International Association IAGC of Geophysical Contractors
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16 December 2019

Committee Secretary
Senate Standing Committees on Environment and Communications
PO Box 6100
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Canberra ACT 2600

Via Electronic Submission: ec.sen@aph.gov.au

RE: The International Association of Geophysical Contractors (IAGC) Submission to the "Impact of seismic testing on fisheries and the marine environment" Australian Senate Inquiry

The International Association of Geophysical Contractors (IAGC) welcomes the opportunity to provide a submission to the Senate Environment and Communications References Committee's Inquiry to "Impact of seismic testing on fisheries and the marine environment".

Executive Summary

- Geophysical survey activities, one kind of which are seismic surveys, occur onshore and offshore. Seismic surveys are essential to the safe discovery, development, and valuation of Australia's subsurface. The marine seismic surveys which are a focus of this Inquiry, create images of the geological structure beneath the ocean floor, using a method that is similar to ultrasound in medicine.

- These surveys are utilized by the military, marine and offshore extractive industries, and academic researchers for a variety of purposes, including: Identification of petroleum and mineral resources; Scientific studies of the earth's geological history; Definition of sites for sequestration of greenhouse gases; Assessment of seabed foundations for offshore construction (i.e. petroleum production platforms and pipelines) and accurate placement of offshore renewable energy infrastructure (i.e. wind turbines); To enhance the prediction and monitoring of earthquakes and tsunamis; Searching for shipwrecks and lost aircraft; as well as many other industry and research purposes.

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- Seismic surveys are temporary and transitory lasting only days or weeks in a single survey area. These surveys are the least intrusive way to explore Australia's subsurface geology and dynamic processes, and reduce the footprint of any future exploration activity.

- 1,480 individual seismic surveys have been undertaken in Australia since 1960. This equates to almost 1.6 million line kilometres (2D Seismic) and 1.43 million square kilometres (3D seismic). More seismic surveying is needed to verify new resources and update historic data.

- Despite this significant activity, there have been no recorded negative impacts on a commercial fishery, nor an impact on the viability of individual species or marine ecosystems. Fisheries in regions that host oil and gas activities continue to be some of the most productive in Australia.

- We have been and continue to be committed to continuing a constructive and genuine dialogue with the fishing industry and other users of the marine environment to address their questions and concerns about our operations.

- The geophysical and exploration industry's long track record of collaboration with the fishing industry is focused on working together to access and use marine resources, and we seek to improve cooperation, communication and consultation where possible.

- The geophysical and exploration industry, like the fisheries industry, works in a comprehensive regulatory environment that considers all relevant science and potential risks to the environment. The geophysical and exploration industry is also required to ensure activities do not impact other marine industries to a greater extent than is necessary in carrying out operations.

- The geophysical and exploration industries are committed to operating in an environmentally responsible manner around the world. This requires thorough attention to the potential impacts on the marine environment, including sounds generated by upstream activity. Mitigation measures for seismic surveys are carefully designed and implemented to address potential site-specific safety and environmental impacts identified during project planning.

- After more than 50 years of worldwide seismic surveys, including in Australian waters, and more than 15 years of extensive peer-reviewed scientific research, there remains no evidence that sound from properly mitigated seismic surveys has had any significant impact on any marine populations. The geophysical and exploration industries continue to invest considerable resources in research and technology to further understand the effects of sound on marine life.

- There is no scientific support for statements that seismic sound kills or injures marine mammals, causes them to beach themselves, or disrupts their behaviour to the extent that it affects the health and well-being of the individuals or the populations of which those individuals are a part.

- There is no evidence to date that sound from seismic activities negatively impacts other marine life populations. This, however, does not mean that our industry plans to discontinue our active search for any and all potentially undetected risks through our support of independent, third-party research, nor does it mean that we will reduce our diligence in monitoring, mitigation and documentation of our activities and their potential environmental effects.

- The preponderance of evidence against the possibility of environmental effects from our activities does, however, mean that irresponsible and unsupported speculations of what “could, might, or may” potentially occur will be subjected to the same high standards of scientific verification and validation that would be expected of our own industry-funded research.

This submission sets out:

I. <u>The Association</u>

Founded in 1971, the International Association of Geophysical Contractors (IAGC) is the global trade association for the geophysical and exploration industry (Industry), the cornerstone of the energy industry. With more than 80 member companies in 50 countries, our membership includes onshore and offshore survey operators and acquisition companies, data and processing providers, exploration and production companies, equipment and software manufacturers, industry suppliers and service providers.

The IAGC focuses on advancing the geophysical and exploration industry's freedom to operate. The IAGC engages governments and stakeholders worldwide on issues central to geophysical operations and exploration access, including prioritizing timely, accessible data acquisition throughout the life of the asset; providing predictability & competition; promoting regulatory & fiscal certainty; and promulgating risk- & science-based regulations.

II. Geophysical & Exploration Industry

The offshore Australian Continental Shelf (ACS) (Figure 1) is an indispensable source of petroleum resource for Australia's energy supply and a lynchpin of Australia's economy. The development of resources on the ACS, such as Ichthys, Prelude, Gorgon, Wheatstone, and

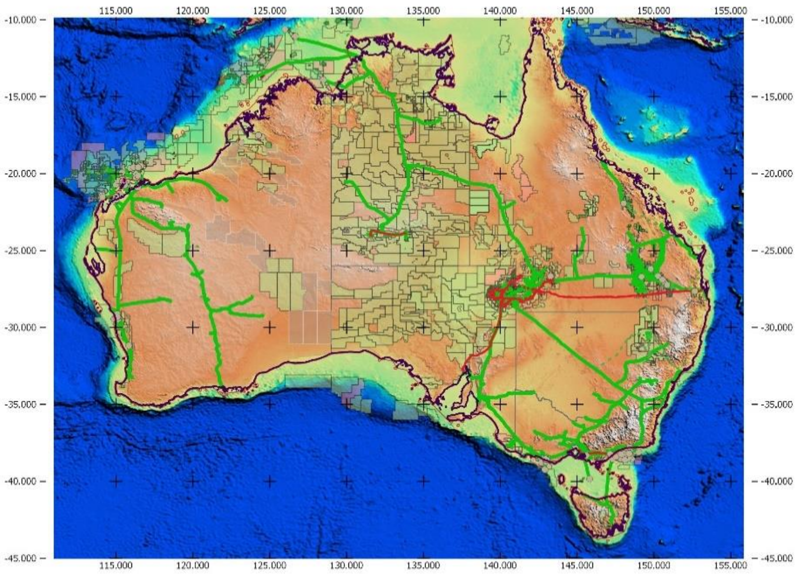

Figure 1 Digital Elevation Map of the Australia. The Australian Continental Shelf is highlighted in light green, Land – orange and oceanic areas in blue. The current Australian petroleum permits and petroleum infrastructure have been added (green – gas pipelines, Red – oil pipelines).

many others, has enabled Australia to become, in 2018, the world's largest exporter of Liquified Natural gas (LNG).

Geophysical survey activities, one kind of which are seismic surveys[1], occur onshore and offshore. Seismic surveys are essential to the safe discovery, development, and valuation of

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[1] Is seismic testing the same as seismic surveying? "Testing" is a neologism created by political activist groups to infer that seismic survey methods are somehow novel, experimental or unknown (and therefore to be feared); this does not accurately depict our survey activities. If you look at the terms "testing" and "surveying," you will find that survey is the most appropriate term. Seismic survey technology has been in use extensively for more than 50 years and can hardly be considered novel or a "test." Rather than testing, our activities are just like any other survey which examines and records the features of an area. Seismic survey activities produce images of the earth's subsurface to construct a map of geological features. One of those

Australia's subsurface. The marine seismic surveys examined by this Inquiry create images of the geological structure beneath the ocean floor, using a method that is similar to ultrasound in medicine. They are utilized by the military, marine, alternative energy, and offshore extractive industries and academic researchers for a variety of purposes, including:

- Identification of petroleum and mineral resources;
- Scientific studies of the earth's geological history;
- Definition of sites for sequestration of greenhouse gases;
- Assessment of seabed foundations for offshore construction (i.e. petroleum production platforms and pipelines) and accurate placement of offshore renewable energy infrastructure (i.e. wind turbines);
- To enhance the prediction and monitoring of earthquakes and tsunamis;
- Searching for shipwrecks and lost aircraft.

The seismic survey process is straightforward. A vessel tows an acoustic source array (usually a set of compressed air chambers) that creates predominantly low-frequency pulses of acoustic energy. The release of compressed air sends sound waves through the water and into rock layers beneath the ocean floor. Hydrophones towed behind the seismic vessel record reflected and refracted sound waves, which constitute the seismic data.

Once collected, the raw seismic data are processed to generate subsurface images. These high-resolution images are then used to identify areas where oil and gas may be present. More than 50 years of experience demonstrates that this method of exploration is the most reliable means for locating possible oil and gas reservoirs.

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benefits of seismic surveying is delineating geological features indicative of possible oil and natural gas resources. This is surveying, not testing.

Seismic surveys help to exclude areas where there are likely no recoverable oil and gas resources. Effectively identifying the most prospective areas in this way reduces unnecessary industrial interaction with the marine environment and the need for drilling.

Seismic surveys are temporary and transitory lasting only days or weeks in a single survey area. These surveys are the least intrusive way to explore Australia's subsurface geology and dynamic processes.

Further development of Australia's resource, in particular on the ACS, cannot safely, effectively, or efficiently occur without geophysical survey activities. Geophysical surveying has been, and continues to be, essential to meet global energy and resource needs because it is the most practical technology available that accurately images the subsurface:

- before a single well is drilled;
- a structure is built;
- to monitor a field during its production; and
- throughout the life of an asset.

The Industry has made significant improvements in seismic survey acquisition efficiency in recent years. Using standard hardware, the Industry now acquires better-quality data more efficiently due to advancements in vessels, survey configurations, acquisition planning and execution practices, as well as data processing.

For some categories of geophysical surveys (i.e. high resolution, or "HRG"), this includes the use of autonomous technologies to conduct surveys without ships. This reduces the environmental impact of surveys, improves safety by requiring fewer people to be on the water and reduces cost to the operator.

Advancements in geophysical technology—including seismic reflection and refraction, gravity, magnetics, and electromagnetics— afford the Industry significant precision in subsurface imaging and provide improved estimates of potential resources. By utilizing these tools and applying increasingly accurate and effective interpretation practices, the Industry can better locate and safely dissect prospective areas for exploration, thus reducing the number of exploration wells required to be drilled.

Seismic and other geophysical surveys (Surveys) have been safely conducted around the world for 50 years. These Surveys are the critical first step to better understanding the resource base of a prospective area. The Surveys provide policy makers and regulators with the information they need to make informed decisions about petroleum development based on the best available data.

Modern Surveys *reduce risk* by increasing the likelihood that exploratory wells will successfully identify a petroleum accumulation and by decreasing the number of wells that need to be drilled in a given area, thereby reducing associated safety and environmental risks as well as the overall environmental footprint of exploration and development. For example, subsurface imaging can predict potentially hazardous over-pressurized zones in a reservoir and thus allow an operator to better design a well to reduce its associated types and levels of risk. As technology advances, the geophysical industry can continue to reduce drilling risk, reduce the environmental footprint of developments and increase production. Seismic survey technology is similar to physician's using ultrasound technology in that both methods use the same principles of sound to generate an image or picture, geophysical experts are actively using and enhancing modern technology to improve evaluations. In addition to these advancements, the Industry is committed to scientific research aimed at better understanding the potential effects of geophysical activities on all forms of marine life and informing the development of best mitigation practices and potential alternative technologies[2]. The technical details of a seismic survey are discussed in Appendix A.

The seismic Survey and source array discussed herein is the best commercially available technology to obtain necessary, accurate sub-surface data. Alternative technologies, such as marine vibroseis, continue to be explored, however this type of technology is not yet

[2] See E&P Sound and Marine Life Joint Industry Programme, www.soundandmarinelife.org

commercialized and has not yet been shown to provide comparable seismic data quality. Moreover, the possible environmental benefits of alternative technologies have not yet been demonstrated.

III. The Body of Science and Research into the Use of Seismic Surveying

Tens of thousands of offshore seismic surveys have occurred throughout the world over the last 50 years using conventional compressed-air arrays. This includes approximately 1,480 seismic surveys on the Australian Continental Shelf alone, consisting of more than 1.6 million linear kilometres of 2D seismic surveys and 1.43 million square kilometres of 3D Seismic surveys. In all that time, and across millions of kilometres, there is no credible evidence that seismic survey sound has had any significant impacts on marine mammals, marine life, or the marine environment. The IAGC compiled the attached Annotated Fish Bibliography (Appendix B) and the Annotated Marine Life Bibliography (Appendix C), providing references to additional citations to those referenced in this section.

To backup this statement, a review of the body of scientific research into the impact of seismic surveying on marine life has been included below with particular focus on:

- Fish and Invertebrates;
- Rock Lobster;
- Zooplankton; and
- Scallops.

A. Fish and Invertebrates

Marine seismic surveys have been conducted since the 1950's, and experience shows that fisheries and seismic activities can and do coexist. There has been no observation of direct physical injury or death to free-ranging fish caused by seismic survey activity. Any impacts to fish from seismic surveys are short-term, localized and have not led to significant impacts on a population scale.

Prior to conducting a seismic survey, operators work cooperatively with local fishing communities and regulatory bodies to minimize interaction with delicate spawning grounds, sensitive times of year and mitigate any potential economic losses to fishers. The geophysical industry works with fishers to define and address potential concerns early in the permitting process.

During seismic surveys, a vessel exclusion zone is maintained around the survey vessel and its towed streamer arrays to avoid interruption of commercial fishing operations, including setting of fishing gear. These exclusion zones are dependent on the type of activity and national and local regulations in the area of operation.

Typical marine seismic surveys are a moving sound source, and any potential effects on fish are inherently local and short-term. Marine seismic vessels move along a survey racetrack in the water creating a line of seismic impulses. The impulse consists of a dominantly low-frequency sound pulse generated by releasing compressed air into the water as the vessel is moving. As the seismic vessel is in motion, each signal is short in duration, local and transient. Fish may react to these pulses by temporarily swimming away from the seismic air source. When fish move away from a survey vessel they often return after the vessel has passed.[3] There is no conclusive evidence, however, showing long-term or permanent displacement of fish. Because the sound output from a seismic survey is immediate and local, there is also no contaminate residue or destruction of habitat.

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[3] Two 1996 papers from Engas et al. are frequently cited as evidence that seismic surveys can contribute to a decline in catch rate. However, these studies relied upon a confined area and densely concentrated surveying, and was not representative of typical seismic survey practices. Additionally, cod are well known to move lower in the water column when exposed to sound – including typical commercial fish finders. While this might reduce catches in midwater trawls, this response could be expected to *increase* catches in bottom trawls. Similarly, Lokkeborg et al. (2012) is often cited as evidence that seismic surveys may affect catches out to 20 kilometers. This, however, is a misinterpretation – catches only temporarily declined within 1-3 km of the survey vessel, while the survey vessel was in the vicinity. The catches did not fully rebound in five days following the conclusion of this study. However, this is likely attributable to the unusually concentrated fishing effort during this study. There is no scientific evidence to suggest long-term changes in fish habitat use or distribution following seismic surveys. For example, Wardle et al. (2001) indicated that several species of fish did not move away from a seismic survey even at close range, and exhibited only a brief startle response. Most importantly, however, a behavioral response (whether an observed behavior or movement away from the sound source) does not necessarily indicate that the response is *biologically significant* and could be reasonably expected to have any bearing on the long-term health, fecundity, or survival of the individual fish or the collective population.

Fish eggs, larvae and fry do not have the ability to move away from a sound source and may be injured in the unlikely event they are within a few meters of the seismic source. The impact of this damage, however, is insignificant on a population scale compared to the high natural mortality rate of eggs, larvae, and fry.

There is no evidence that the normal use of seismic sound can kill or seriously injure fish, despite numerous attempts to induce such effects in controlled studies subjecting fish to more prolonged and closer exposures to a seismic sound source than would occur normally[4]. In one study in which some hearing damage was produced, fish were held in cages in shallow water so that they could not move away from the sound and were exposed to seven direct overhead passes of a seismic sound source in less than three hours[5]. This scenario, of course, would never occur under normal conditions, which only highlights how extremely unlikely injury or hearing loss to fish would be during real seismic surveys performed in the natural environment.

Like marine mammals, fish may respond behaviourally to any detectable stimulus, including seismic sound. The question, as for mammals, is whether the disturbance is substantial and frequent enough to produce biologically significant results. There is no scientific evidence to suggest that this is likely to be the case. Out of more than 200 research papers the IAGC have reviewed on this topic, almost all report no significant response[6] .

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[4] McCauley, R.D. *et al*. 2008. Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef Lagoon, Western Australia: Full report of Curtin University findings. Center for Marine Science and Technology, Curtin University, Perth WA. 92 pp. CMST Report 2008-32. And Popper A.N., J.A. Gross, T.J. Carlson, J. Skalski, J.V. Young, A.D. Hawkins, *et al.* 2016. Effects of Exposure to the Sound from Seismic Airguns on Pallid Sturgeon and Paddlefish. PLoS ONE 11(8):e0159486.

[5] McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am., 113:638-642.

[6] Pena, H., N.O. Handegard, and E. Ona. 2013. Feeding herring schools do not react to seismic air gun surveys. ICES Journal of Marine Science. 70(6):1174–80.
Boeger, W.A., M.R. Pie, A. Ostrenski, and M.F. Cardoso. 2006. The effect of exposure to seismic prospecting on coral reef fishes. Brazilian Journal of Oceanography, 54(4):235-239.
Hassel, A., T. Knutsen, J. Dalen, *et al*. 2004. Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). ICES Journal of Marine Science, 61:1165–1173.
Hastings M.C., and J. Miksis-Olds. 2012 Shipboard Assessment of Hearing Sensitivity of Tropical Fishes Immediately After Exposure to Seismic Air Gun Emissions at Scott Reef. In: Popper A.N., and A. Hawkins, eds. The Effects of Noise on Aquatic Life. Advances in Experimental Medicine and Biology, vol 730. Springer, New York, NY International Whaling Commission (IWC). 2019. Description of the USA Aboriginal Subsistence Hunt: Alaska. Inupiat and Siberian Yupik Subsistence Hunting and Management of Western Arctic Bowhead Whale Stock. https://iwc.int/alaska.

For example, Wardle et al.[7] found that cod, pollack, and hake did not move away from a seismic source only 109 meters away, even though the observed exposure level was 195 dB[8] SPL[9]. The only observed effect was C-start behaviour, which was momentarily observed at the instant of sound exposure. C-start is a reflexive "startle" response in which the fish's body performs a C-shaped movement of its body to produce a very quick, short forward motion rather than the normal S-shaped swimming[10].

Studies exposing animals to abnormally high levels of sound under abnormal conditions are too often interpreted as indicating a possibility of effect from the much lower levels exposures associated with the passage of a seismic vessel under normal conditions. For example, such papers[11], in which the sound source was placed abnormally close to the test

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McCauley, R.D. *et al*. 2008. Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef Lagoon, Western Australia: Full report of Curtin University findings. Center for Marine Science and Technology, Curtin University, Perth WA. 92 pp. CMST Report 2008-32.
Miller, I. and E. Cripps. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. Marine Pollution Bulletin, 77(1-2):63-70.
Sara, G., J.M. Dean, D. D'Amato, G. Buscaino, A. Oliveri, S. Genovese, S. Ferro, G. Buffa, M. Lo Martire, and S. Mazzola. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. Marine Ecology Progress Series 331:243-253.
Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research 21:1005–1027.

[7] Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research 21:1005–1027.

[8] The dB (decibel) is the unit used to measure the intensity of a sound. It is a logarithmic scale, the smallest audible sound (near total silence) is 0 dB. A sound 10 times more powerful is 10 dB. A sound 100 times more powerful than near total silence is 20 dB. A sound 1,000 times more powerful than near total silence is 30 dB.

[9] Sound pressure level (SPL) is a means of characterizing the amplitude of a sound.

[10] Webb, P.W. and D. Weihs. 1983. Fish Biomechanics. Praeger Publishers, New York NY. ISBN 978-0275911003

[11] McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am., 113:638-642.
Aguilar de Soto, N.A., N. Delorme, J. Atkins, S. Howard, J. Williams, and M. Johnson. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports, 3:2831.
Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann, and J.M. Semmens. 2017. Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop *Pecten fumatus*. Proceedings of the National Academy of Sciences of the United States of America 114:e8537-8546.
McCauley R.D., R.D. Day, K.M. Swadling, Q.P. Fitzgibbon, R.A. Watson, and J.M. Semmens. 2017. Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature: Ecology & Evolution, 1(7):195.
Sole, M., M. Lenoir, M. Durfort, M. Lopez-Bejar, A. Lombarte, and M. Andre. 2013. Ultrastructural damage of *Loligo vulgaris* and *Illex coindetii* statocysts after low frequency sound exposure. PLoS One 8(10):e78825.
Sole, M., M. Lenoir, J.M. Fortuna, M. Durfort, M. van der Schaar, and M. Andre. 2016. Evidence of Cnidarians sensitivity to sound after exposure to low frequency noise underwater sources. Scientific Reports, 6:37979.
Sole, M., P. Sigray, M. Lenoir, M. van der Schaar, E. Lalander, and M. Andre. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma, Scientific Reports, 7:45899.
Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from geophysical survey device on behavior of captive rockfish. Canadian Journal of Fisheries and Aquatic Sciences, 49:1343-1356.
Santulli, A., A. Modica, C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. D'Amelio. 1999. Biochemical responses of European sea bass (*Dicentrarchus labrax* L.) to the stress induced by off shore experimental seismic prospecting. Marine Pollution Bulletin, 38:1105-1114.

subjects (in some cases, only a few inches or feet away) and was broadcast continuously for as long as five days or passed directly over caged animals for several consecutive passes within a few hours. In the opinion of IAGC, relying upon these studies to support sweeping conclusions about the alleged effects of seismic surveys on marine life (under normal conditions) is scientifically inappropriate and misleading.

a. Rock Lobster

The IAGC's in-house biologist Dr. Alex Loureiro, Director of Marine Environment & Biology, and Dr. Jerry F. Payne, retired Fisheries and Oceans Canada scientist and present scientist emeritus, completed independent reviews of a paper by Day et al. (2019) reporting potential damage to rock lobsters by seismic air sources[12]. The effect on balancing function was assessed through measurement of turnover rate (or righting) in animals placed ventrum-up ("belly up") in water. The abstract indicated that there was more hair damage in exposed animals than the background damage observed in unexposed animals, with exposed animals displaying slower turnover rates. However, the observed damage was consistent with damage observed in a rock lobster population located close to an active port. This suggests that the damage is a result of *sound exposure*, and not specific to seismic sound. More importantly, the population of lobster in the active shipping area is healthy and thriving. The review further notes that caution is warranted in flow through concern about ecological and fisheries impacts and that the lobster were exposed to very high levels of sound with calculated peak to peak pressures up to 210dB.

b. Zooplankton

Over 50 years of worldwide seismic surveying activities and scientific research indicate that there is a negligible potential for impacts on zooplankton populations. After more than decade of intense scrutiny by hundreds of scientists, there is still no scientific evidence that indicates sound from seismic operations has biologically significant negative impacts on

[12] Day, R.D. et al. (2019). Seismic airguns damage rock lobster mechanosensory organs and impair righting reflex. Proc. R. Soc. B 286:20191424.

marine animal populations. In the Gulf of Mexico, an area of concentrated seismic surveying activity, zooplankton populations are thriving and support a robust marine ecosystem. No population level adverse effects to zooplankton have been identified in any area of seismic surveying operation.

The IAGC remains open to all emerging new scientific information. However, we are troubled with the results of the most recent zooplankton study by McCauley et al. (2017)[13] which suggests but does not prove the conclusion that seismic survey air sources negatively impact zooplankton.

The IAGC sought seven independent anonymous reviews of McCauley et al. (2017) from expert plankton ecologists. Those reviews were provided anonymously, as is the practice for scientific peer review, to prevent ad hominem professional rivalries from developing or at least minimize that kind of non-objective behaviour within the community. The results have been shared with the authors of the McCauley et al. (2017) study as well as with other interested regulatory agencies.

As an initial matter, the results of McCauley et al. (2017) are inconsistent with at least five prior studies that found no effects of seismic sound on zooplankton, except at very close ranges[14]. More recently, Fields et al. (2019)[15] showed no significant increase in mortality to a copepod species at distances of greater than five meters, and no significant behavioural

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[13] McCauley R.D., R.D. Day, K.M. Swadling, Q.P. Fitzgibbon, R.A. Watson, and J.M. Semmens. 2017. Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature: Ecology & Evolution, 1(7):195.

[14] Booman, C. *et al*. 1996. Effekter av luftkanonskyting på egg, larver og yngel. Undersøkelser ved Havforskningsinstituttet og Zoologisk laboratorium [Effects of airgun pulses on eggs, larvae and fry]. Fisken og Havet 1996:3. [Norwegian with English Summary.]
Dalen, J. and G.M. Knutsen. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. *In* Merklinger, H.M., ed. Progress in underwater acoustics. London: Plenum Press, pp. 93-102.
Kostyuchenko, L.P. 1971. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. Hydrobiological Journal, 9(5):45-48.
McCauley, R.D. *et al*. 2008. Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef Lagoon, Western Australia: Full report of Curtin University findings. Center for Marine Science and Technology, Curtin University, Perth WA. 92 pp. CMST Report 2008-32.
Saetre, R. and E. Ona. 1996. Seismiske undersøkelser og skader på fiskeegg og -larver en vurdering av mulige effekter pa bestandsniv. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level]. *Fisken og Havet* 1996:1-17, 1-8. [Norwegian with English summary.]

[15] Fields, D.M., N.O. Handegard, J. Dalen, C. Eichner, K. Malde, O. Karlsen, A.B. Skiftevik, C.M. Durif, and H.I. Browman. 2019. Air gun blasts used in marine seismic surveys have limited effects on mortality, and no sublethal effects on behaviour or gene expression, in the copepod Calanus finmarchicus. ICES Journal of Marine Science. doi:10.1093/icesjms/fsz126.

differences were detected. Mortality rates were assessed at one hour and at seven days post-exposure.

The design and data analysis used in McCauley et al. (2017) also had numerous methodological flaws, as pointed out by the external reviewers. For example, the fish-finder sonar used in the study could not actually detect the size of plankton captured in the nets, causing a mismatch between the net data and the sonar data. The nets were also of the wrong mesh and aperture size and were improperly towed, leading to possible clogging of the cod end of the net and rejection of plankton by the overfilled net. The larger plankton could have evaded the nets or were pushed out when the mesh of the net became clogged. Moreover, some net samples farther from the sound source had more dead plankton in them than nearer samples, suggesting either that other sources of plankton mortality were confused with effects from seismic sound (the paper reports foraging on plankton by fish) or that the modelling of water movement following passage of the seismic vessel was incorrect and that a sample considered to be from the edge of the water mass was actually taken from somewhere nearer to the centre due to the water having drifted between the time the plankton were exposed to sound and the sample was collected (a half hour or longer).

Based on the inconsistent and incomplete sets of data generated by the study, McCauley et al. (2017) attempted to use those flawed data to model a “hole” created in the field of plankton by the seismic source. This “hole” would not be something readily seen or even measured, due to the transitory nature of the particular piece of water that had been ensonified by the seismic source, but it was an attempt by McCauley et al. (2017) to simplify the scope of what they felt their data were telling them. However, the “hole” in the plankton based on the acoustic data may have been an artefact due to modelling error of the water movements at this shallow site and/or possible changes in plankton movement and body orientation that changed their sonar reflectance (e.g., plankton swimming toward the bottom or simply facing down instead of forward can change their reflectance in the fish-finder sonar and make it look like they have “disappeared,” and thus was not a real “hole” in the plankton).

In summary, the McCauley et al. (2017) paper is a deeply flawed exception to a larger body of contrary findings. Indeed, the Australian Institute of Marine Science, with McCauley and some of his co-authors included in the research team, is planning to replicate this study in 2019-2020, with corrections to the methodological errors of the initial study and an increased sample size, along with use of a real, full seismic source. This is the normal, healthy way that science advances our understanding of natural phenomena.

It is also important to consider whether there is any biological significance to the claims made in McCauley et al. (2017), even if the study was not flawed. Zooplankton are neither whales nor fish: their lives are short and they exist in the trillions; living a short life of a few weeks; dying by the millions every day; and wandering at the whims of weather, tides, and the highs and lows of their predators and prey. In light of this context and the claims made by McCauley et al. (2017), Richardson et al. (2017)[16] conducted a modelling study of biological impacts on krill abundance at a large scale. Even if McCauley et al. (2017) was not flawed and its results could be scientifically accepted, Richardson et al. (2017) found that the impacts reported in McCauley et al. (2017) would be biologically insignificant. In short, the results of McCauley et al. (2017), even if eventually confirmed through a properly designed study, do not have “profound implications for ocean health,” and will not “lead to major decreases in the foundation of the ocean’s food webs, potentially resulting in a trophic cascade affecting all levels of the food chain”, as some have claimed.

Against the backdrop of vast ocean currents and highly volatile population growth and decline, the contribution of a seismic survey, like a pencil line across the side of a building, is nearly invisible and ranks far below the more relevant determinants of plankton population

[16] Richarson, A.J., R.J. Matear, and A. Lenton. 2017. Potential impacts on zooplankton of seismic surveys. CSIRO, Australia. 34 pp. 29 June 2017. https://publications.csiro.au/rpr/pub?pid=csiro:EP175084

movements, growth, and abundance. Whether that pencil line is 10 metres wide or 1,000 metres wide in an ocean that is millions of metres wide does not result in a biologically significant consequence, as the Richardson et al. (2017) model shows. For context, the propellers of large shipping vessels, which churn a swath of water many tens of meters wide, do extensive damage to plankton, and there are over 200 times as many large cargo vessels plying our oceans as there are seismic vessels. No evidence of biologically significance impacts from shipping vessels on zooplankton populations has been reported.

The evidence for plankton mortality offered by McCauley et al. (2017) is preliminary and tentative at best, and even if fully validated through a properly designed study would not support a conclusion that seismic surveys cause biologically significant impacts at the population and ecosystem level. Based upon our extensive review of the available literature on this topic, seismic surveys have no meaningful impacts on zooplankton populations.

c. Scallops

Aguilar de Soto et al. 2013[17], a study involving scallop larvae, is often cited by environmental advocacy groups. However, in that experiment, the larvae were exposed to a simulated continuous noise not at all like a seismic sound source at loud volume for up to 90 hours at a distance of nine centimetres (3.5 inches). The actual mechanical displacement of water at such close ranges was measured and found to be consistent with a free field exposure of 195-200 dB, not the 140-160 dB at which the sounds were initially recorded. Exposures at 195-200 dB are something that could only occur for fractions of a second within ten meters or so of the moving array and would therefore likely have no effect on development or survival.

[17] Aguilar de Soto, N.A., N. Delorme, J. Atkins, S. Howard, J. Williams, and M. Johnson. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports, 3:2831.

Przeslawski et al. 2018[18] (Report 2014-041), describes three separate sound exposure studies between 2010-2015 using real seismic surveys in the Gippsland Basin/ Bass Strait scallop beds. The study is the third of its kind to show no short-term evidence of mass mortality or other negative impacts of seismic arrays on scallops. Immediate mass mortality of scallops in response to air source exposure was not observed and overall mortality rates in all three experiments were at the low end of the range of the naturally occurring mortality rate documented in the wild. It is unclear whether the observed physiological impairment would result in heightened chronic mortality in timeframes beyond those examined in the current study.

B. Marine Mammals

The geophysical and exploration industry has demonstrated the ability to operate seismic exploration activities in a manner that protects marine life. Marine seismic exploration is carefully regulated by the federal government and managed by the operator to avoid impacting marine animals. Many decades of world-wide seismic surveying activity and scientific research related chiefly to marine mammals have shown no evidence that sound from seismic activities has resulted in physical or auditory injury to any marine mammal species. Likewise, there is no scientific evidence demonstrating biologically significant adverse impacts on marine mammal populations. Attached, please find an IAGC developed Annotated Bibliography of frequently cited references on Anthropogenic sound and impacts to marine life (Appendix C). Nevertheless, the Industry implements mitigation measures to further reduce the negligible risk of harm to marine mammals.

Not all marine life hears the same frequencies equally well. Much like the differences in hearing between humans and bats or dogs, some marine animals hear well at higher frequencies, and relatively poorly at lower frequencies. Others hear better at lower frequencies. Some studies have shown that marine mammal hearing sensitivity may be

[18] Przeslawski, R., Z. Huang, J. Anderson, A.G. Carroll, M. Edmunds, L. Hurt, and S. Williams. 2018. Multiple field-based methods to assess the potential impacts of seismic surveys on scallops. Marine pollution bulletin, 129(2):750-761.

temporarily affected if exposed to sound at levels encountered very close to an operating seismic sound source. Other studies have found that marine mammals did not react to sounds that would only be realized within a few tens of meters of a typical seismic array.

a. Behavioural Reactions

When assessing the potential effects of sound on marine mammals, it is important to distinguish between observed and directly reported behavioural reactions and overgeneralization or speculation that is not based upon scientifically observed results. For example, the observed data provide evidence of a small change in hormone levels associated with a change in the level of noise associated with a vessel generally[19], but the change in hormone levels is only marginally statistically significant and is not associated with any biologically significant outcome. As another example, the observed data show that beaked whales alter their diving behaviour in response to sonar sound, but the range of observed variation in behaviour remains within the variability seen in normal baseline diving behaviour, leaving the threshold for physiological consequences or risk of stranding unknown[20]. As a final example, masking is suggested as a theoretical risk factor for possible mother-calf separation, but no scientific observations of such an effect are available, with the exception of a single instance in which a sonar was driven deliberately at a group of killer whales, leading to a one-hour “separation” in which the calf was never out of touch with the group and re-joined the group immediately after the chase with the sonar ended[21].

The most recent and best large-scale study of marine mammal behavioural response to seismic survey sound—the Behavioural Response of Humpback Whales to Seismic Sound (“BRAHSS”) study—examined the responses of migrating humpback whales to a realistic full

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[19] Rolland, R.M., S.E. Parks, K.E. Hunt, M. Castellote, P.J. Corkeron, D.P. Nowacek, *et al*. 2012. Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society B: Biological Sciences, 279(1737):2363-2368.

[20] Bernaldo de Quirós, Y., A. Fernandez, R.W. Baird, R.L. Brownell Jr., N. Aguilar de Soto, D. Allen, *et al*. 2019. Advances in research on the impacts of anti-submarine sonar on beaked whales. Proceedings of the Royal Society B, 286(1895):20182533.

[21] Miller, P., R. Antunes, A.C. Alves, P. Wensveen, P. Kvadsheim, L. Kleivane, *et al*. 2011. The 3S experiments: studying the behavioural effects of naval sonar on killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*), and long-finned pilot whales (*Globicephala melas*) in Norwegian waters. Scottish Oceans Inst. Tech. Rept.

seismic survey operation and collected detailed observations of thousands of whales collected by hundreds of observers[22]. The results of the BRAHSS study show that humpback whales displayed the onset of behavioural response beginning at two to three km from the seismic source, with the ultimate response being an average deviation of 200 meters from their initial migratory path, comparable to a driver changing lanes 300 feet prior to passing a slower driver in the next lane. For context, these Australian humpback whales have a total migration of 5,000 to 8,000 km, so going 200 m "out of their way" is well within the amount of meandering they do every day to socialize, undertake foraging bouts along the way, or avoid a shark or killer whale. The BRAHSS study results also show that some animals exhibited no behavioural response when exposed to the seismic survey sound and some animals even approached the sound source. Other animals continued with social activities that attracted or repelled them more strongly than the seismic sound and thus made the effects of the seismic sound difficult to statistically distinguish from other causes of exhibited behaviour.

Similar results to those documented in the BRAHSS study have been documented for grey whales in California and Alaska in the 1980s[23] and for migrating grey whales[24]. These studies observed changes from the line on which marine mammals were traveling when the sound source was within, on average, 1 to 3 km, and the animals were observed to deviate 100 to 500 m from that line as they passed the sound source. Again, it is important to distinguish what has been observed in scientific studies from what is being hypothesized but has not been observed.

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[22] Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017a. Determining the behavioural dose response relationship of marine mammals to air gun noise and source proximity. Journal of Experimental Biology 220:2878-2886.
Dunlop, R.A, M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017b. The behavioural response of migrating humpback whales to a full seismic airgun array. Proceedings of the Royal Society B: Biological sciences, 284(1869):20171901

[23] Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1983. Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Bolt, Beranek and Newman Report No. 5366, prepared for the US Department of the Interior, Minerals Management Service, Anchorage AK, November 1983. MMS Contract No. AA851-CT2-39. 407 pp.

[24] Tyack, P.L. and C.W. Clark. 1998. Quick-look report: Playback of low frequency sound to gray whales migrating past the central California coast. Report submitted to the SURTASS LFA Program, 23 June 1998. 55 pp. Available at http://www.whoi.edu/fileserver.do?id=57468&pt=10&p=40212

b. Biological Significance

The important question when considering the consequences from observed responses to seismic sound sources or other sound sources is to ask whether the observed sound induced reaction by a marine mammal has biological significance. There are widely accepted models for assessing whether disturbance from minor behavioural responses produces a biologically significant consequence, such as the Population Consequences of Disturbance model (NRC 2005)[25] (known as the “PCOD model”). The PCOD model incorporates the relationship between a stimulus, such as sound, and the gamut of possible behavioural outcomes associated with that stimulus. Those behavioural outcomes are evaluated based on their demonstrated consequences for important life functions, such as feeding and breeding. For example, Southall et al. (2019)[26] evaluated the effect on beaked whale foraging associated with observed movements away from a site when sonar is present. As another example, studies of the effects of sound on birds often report the number of eggs laid with or without noise, or the number of fledglings hatched[27]. It is the consequences of the behaviour, not the behaviour itself, that are important. These consequences are expressed as vital rates—i.e., the “actuarial tables” for that population of individuals—for lifespan, lifetime reproductive success, and survival at different life stages. These are the factors that determine the future status of the population.

Ultimately, the metric of the relevant effect is at the level of the population, not whether one can point to a single example of an individual whale having dived longer in the presence of sound or altered the number of vocalizations it produced during a given period of sound exposure. The best indicator of the ultimate impact of scattered incidences of response to an

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[25] National Research Council (NRC). 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. Washington, DC: The National Academies Press.

[26] Southall, B.L., K.J. Benoit-Bird, M.A. Moline, and D. Moretti. 2019. Quantifying deep-sea predator–prey dynamics: Implications of biological heterogeneity for beaked whale conservation. Journal of Applied Ecology, 2019;00:1–10.

[27] Shannon, G., M.F. McKenna, L.M. Angeloni, K.R. Crooks, K.M. Fristrup, *et al*. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews, 91(4):982-1005.
Slabbekoorn, H., R. Dooling, A.N. Popper, and R.R. Fay, eds. 2018. Effects of Anthropogenic Noise on Animals. Springer Handbooks of Auditory Research, Springer New York NY USA. ISBN 978-1-4939-8574-6.

activity like a seismic survey is to examine the long-term record for marine mammals living in areas with even higher levels of seismic survey effort such as the U.S. Gulf of Mexico or the North Sea. That record is one of consistently healthy and often increasing marine mammal populations over decades of exposure to seismic sound.

For example, intensive seismic surveying (hundreds or more seismic surveys) has occurred for decades in the Gulf of Mexico and in the North Sea, but there is no indication that this prolonged period of seismic activity has had any effects on any marine mammal populations (or individual marine mammals) in either area. Likewise, humpback whale populations in Australia and in west and east Africa have increased throughout the well-documented history of seismic surveys in those areas.

It is essential that the potential effects from marine mammal behavioural disturbance due to sound-producing activities, such as seismic surveys, be assessed in terms of the biological significance those effects may or may not have on the marine mammal populations of concern. Models can be used to assess the biological significance of the potential behavioural responses associated with certain levels of sound exposure. Often times, in contrast, anti-energy exploration interests produce no countering facts, evidence, or modelling, and rely instead on unsupported statements about “worst-case” outcomes that could occur but have not been observed. Moreover, the best available information shows that marine mammal populations have thrived and even rapidly recovered from historical depletions (due to whaling) in the presence of repeated seismic survey activities in numerous parts of the world. The best available data and information show that demonstrated behavioural reactions that marine mammals may exhibit in response to seismic survey sound have no biological significance.

IV. The Regulation of Seismic Surveying in (Australian) Commonwealth and State Waters

The geophysical and exploration industries are committed to operating in accordance with the guidelines, regulations and laws of the countries within which they operate. Australia's Commonwealth and state regulatory authorities maintain a world-class regulatory framework. The regulation of Geophysical Surveys in Australia Commonwealth and state waters is clear, robust and transparent.

For any seismic survey activity to commence in Australia's offshore (i.e. on the ACS), the seismic survey operator must first submit relevant risk management plans to NOPSEMA for assessment and acceptance. Submitted plans can include safety cases, offshore project proposals and environment plans.

NOPSEMA's dedicated assessment teams, which comprise highly qualified and experienced industry experts, assess each plan against strict criteria as set out in the Offshore Petroleum Greenhouse Gas Storage Act 2006 (OPGGS Act) and associated regulations.

To be accepted, a plan must clearly demonstrate how a company will undertake a proposed activity to protect the health and safety of offshore workers and the integrity of the well(s) to as low as reasonably practicable (ALARP) whilst reducing environmental impacts to levels that are ALARP and acceptable.

NOPSEMA conducts inspections to monitor a seismic survey operator's implementation and compliance with the accepted risk management plan and compliance with the broader legislative framework.

Among a comparison across countries around the world, Australia is positioned more closely to the restrictive, precautionary and highly regulated end of the spectrum than to countries with fewer regulations where active offshore energy industry activities exist.

V. The Approach taken to Seismic Surveying Internationally

The geophysical and exploration industries are committed to operating in an environmentally responsible manner. This requires thorough attention to the potential impacts on the marine environment, including sounds generated by upstream activity.

Mitigation measures for seismic surveys are carefully designed and implemented to address potential site-specific safety and environmental impacts identified during project planning. After more than 50 years of worldwide seismic surveys and more than 15 years of extensive peer-reviewed scientific research, there remains no evidence that sound from properly mitigated seismic surveys has had any significant impact on any marine populations. This holds true for even the most extensively and regularly surveyed areas such as the U.S. Gulf of Mexico, and in the North Sea. The geophysical and exploration industries continue to invest considerable resources in research and technology to further understand the effects of sound on marine life.

Mitigation measures are implemented to reduce real threats to marine species. The IAGC supports seismic survey mitigation measures that are grounded in the best available science and consistent with existing practices that are proven to be effective and operationally feasible. However, we do not support mitigation measures that have no basis in fact or science or aimed at addressing presumed but unproven effects that have not occurred nor are projected to occur.

As the Industry supports these measures, it also calls upon modelling and regulatory efforts to minimize those potential and actual risks to be fact-based and free of baseless precaution. Introduction of precautionary assumptions, that are not based in scientific information during modelling and regulatory efforts nor identified as precautionary, creates confusion about the level of evidence supporting the decision process relative to the degree of conservative bias applied to extend risk minimization beyond the evidence.

For example, exercising precaution by inserting multiple conservative assumptions within a multivariate model leads to unexpected unreliable results because the precautionary assumptions interact multiplicatively. This means introduction of seemingly small precautions that double or triple the risk avoidance in any given variable can yield results that amount to thousand-fold over-predictions of risk when those multiple small precautions interact. Decision-makers should therefore employ the best objective information available when setting the values of model parameters and then clearly delineate any precaution being applied to the result to avoid confusion about the correlation between the model and real-world outcomes.

The geophysical and exploration industry supports utilizing effective mitigation measures based on corresponding levels of potential risk or significant potential impacts on marine animals. Such an approach helps to ensure that the scope of mitigation measures implemented in the field are appropriate to the level of potential risk and specific to the local population of marine animals.

Stewardship is a priority for the geophysical industry and part of its core values. The seismic industry is committed to conducting its operations in an environmentally responsible manner and utilizes mitigation measures, such as exclusion zones, soft-starts and protected species observers to further reduce any possibility of impacts to marine populations.

Mitigation Measures

In the absence of any regulations or operation-specific monitoring and mitigation requirements, the geophysical and wider upstream petroleum industry recommend implementation of the following measures during marine seismic survey operations:

Implement an exclusion zone for monitoring purposes:

- At least 500 m horizontal radius from centre of source array.

Visually observe the exclusion zone for at least 30 minutes prior to the seismic source being activated:

- Observer(s) should be trained to an acceptable standard.
- Observer(s) may be crew members, other employees, or third-party contractors.
- Observer(s) should have no other duties or distractions while serving observer duties.
- If cetaceans are present within the defined exclusion zone, delay the start of soft start procedure until at least 20 minutes after the last sighting of a cetacean.
- If there are no cetaceans present, initiate soft-start procedure.

Soft-start procedure:

- The first stage will involve activating the smallest volume element in the array.
- Subsequent stages will involve doubling the number of active elements at the start of each stage.
- All stages should be of approximately equal time duration.
- The total duration of the soft-start should be at least 20 minutes, no longer than 40 minutes or as specified in applicable regulatory requirements.
- As there will generally be one stage in which doubling the number of elements is not possible (due to the number of elements in the full array not being, for example, 8, 16 or 32), it is preferable to make this stage the last one of the soft start sequence (as opposed to adjusting the increments of other stages or placing a lower increment early in the soft-start sequence).

Periods of poor visibility and darkness:

- Initiate soft-start procedure as above.
- Consider the use of alternative monitoring technologies, such as Passive Acoustic Monitoring (PAM) prior to initiation of soft-start procedures. In addition to the existing IAGC PAM guidance, the following recommendations are provided.

Monitoring data:

- All cetacean observations, details of monitoring effort and relevant operations are documented electronically and may be made available externally within a reasonable time frame of completing a survey activity for evaluation and study so that the biological value of the observation data can be realized.
- In the absence of any national reporting forms, monitoring data is documented using standardized recording forms, such as those developed as part of a review study supported by the IOGP E&P SML JIP. http://www.iogp.org/sound-and-marine-life/

VI. Conclusion

After more than 50 years of continuous seismic survey sound in many places around the world, including Australia, and after a decade of intense scientific and environmental advocacy group scrutiny, there is still no scientific support for statements that seismic sound kills or injures marine mammals, causes them to beach themselves, or disrupts their behaviour to the extent that it affects the health and well-being of the individuals or the populations of which those individuals are a part. Further, there is no evidence that sound from seismic activities negatively impacts other marine life populations. This, however, does not mean that Industry plans to discontinue our active search for any and all potentially undetected risks through our support of independent, third-party research, nor does it mean that we will reduce our diligence in monitoring, mitigation and documentation of our activities and their potential environmental effects.

The preponderance of evidence against the possibility of environmental effects from our activities does, however, mean that irresponsible and unsupported speculations of what "could, might, or may" potentially occur will be subjected to the same high standards of scientific verification and validation that would be expected of our own industry-funded research.

The IAGC appreciates the opportunity to provide this submission to the Senate Standing Committees on Environment and Communications Inquiry into “Impact of seismic testing on fisheries and the marine environment.”. We welcome the opportunity to further discuss the exploration industry with the Committees or individual members as requested.

○ APPENDIX A - TECHNICAL ASPECTS OF SEISMIC SURVEYS

TECHNICAL ASPECTS OF SEISMIC SURVEYS

A seismic survey uses a source of sound and the corresponding reflections and refractions to image the subsurface. The sound source can be created in several ways, the most common and currently most discussed sources are those that use the release of compressed air. The compressed air is released from four ports in the air chamber to create a spherical air bubble. The sound created by the release of the air is omnidirectional that is spreading equally in all directions. The arrangement of the sound sources in a flat “planar” array enables the individual omnidirectional elements to interact additively in the vertical direction (downward), but not in other directions. The sound is not “shot” or “fired” or “blasted” or “exploded,” which is why the Industry accurately uses the term “seismic source” (though the colloquial and inaccurate “air gun” is still often used). After the compressed air is released, the air bubble rises and vents into the atmosphere. In short, the seismic source draws air from the atmosphere, compresses it, expels it, and returns it to the atmosphere.

The individual air chambers that serve as the sound sources are typically towed in a rectangular arrangement (seismic array) composed of a dozen to over 40 individual sound source elements, spaced about two to three meters apart from each other. This geometrical arrangement allows the sounds produced by each individual element to interact in such a way that the sound traveling toward the seabed is augmented because the purpose of the survey is to acquire subsurface information. At all angles other than directly downward, the sound level is considerably lower. The arrangement of the seismic array elements is also used to reduce the high frequency component of the sound in order to minimize sound in the frequency range most used by marine mammals.

The sound sources themselves are pressurized to about 2,000 psi (pounds per square inch / 13.8 MPa), which is comparable to the pressures found in scuba tanks (2,000 to 3,000 psi / 13.8 -20.6 MPa). In fact, the seismic sources resemble a scuba tank in size and weight, though they hold far less air. The typical amount of air in an individual seismic source ranges from the volume of a coffee cup to that of a two-litre soft drink bottle. The total volume of compressed air expelled during activation of a seismic array is equivalent to the interior of a hotel mini-fridge (a typical medium sized seismic array of 3,465 to 4,620 cubic inches is about 2.5 cubic feet, or 71 litres).

The seismic vessel tows the source arrays at a slow and steady speed, about eight kilometres per hour or 4.5 knots, and releases air to make a sound every six to 20 seconds so that the geological data is sampled every 12 to 25 meters. Usually two source arrays are towed behind the survey vessel and are activated alternately, with the inactive array refilling with compressed air during the intervals between successive air releases.

The survey vessel proceeds straight on a survey trackline or racetrack for hours or even

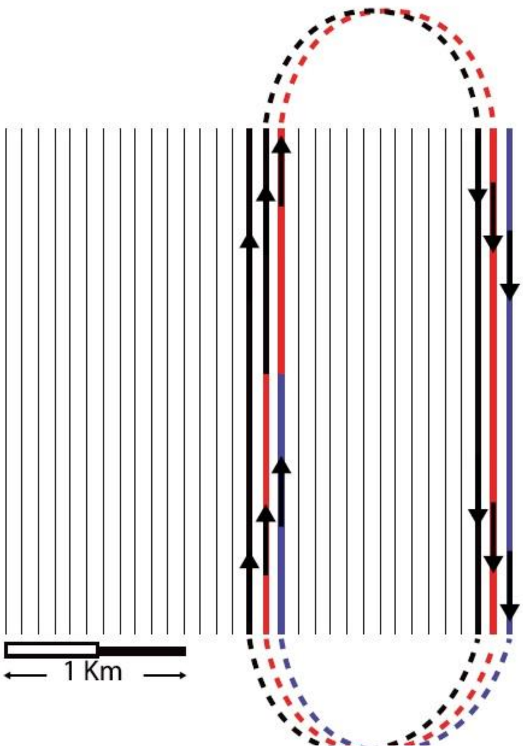

Figure 1 Image taken from "An overview of Marine Seismic Operations_IAG-OGPC_448" Report No.448 April-2011.

before turning and starting a new line at an offset (Figure 1), much like mowing a lawn, or in some cases in a looping shape. A source array will therefore not return to a given locality for 16 to 72 hours or more between passes, depending on the length of the tracks. When the vessel does make a return pass, it will be hundreds to thousands of meters away from the previous trackline, depending on the spacing of the data to be obtained.

Further, the amount of "down time" in a seismic survey has a significant impact on the time-spacing of activation of the source array. Although the ideal economics of a seismic survey would have the source array operating for the duration of the survey, the reality is that equipment needs to be maintained, the ship must turn to start a new survey leg, and there are shutdowns when marine mammals are detected within the legally mandated shutdown range specified in the permits. Some types of survey even require the vessel having to return to port, in order to conduct crew-change, replenishment, refuel and resupply activities – again, meaning the vessel could be away from site for 2-4 days, depending on the distance to the resupply port. Interruptions are common and often prolonged for hours or days. This can result in approximately 35% to 40% "down time" per survey, i.e. when the seismic source is not actually in use.

APPENDIX B - ANNOTATED FISH BIBLIOGRAPHY

ANNOTATED FISH BIBLIOGRAPHY

Robert C. Gisiner, Ph.D.; Director, Marine Environmental Science & Biology, IAGC

Review Articles

Casper, BM. 2006. The hearing abilities of elasmobranch fishes. Ph.D. dissertation, U. of South Florida. http://scholarcommons.usf.edu/etd/2476, 146+pp.

Vastly improves on audiometric data available for this group of fishes, the sharks and rays. Audiograms provided as particle motion (most consistent with anatomy), and sound pressure, including with a dipole source (more biologically realistic – a swimming fish is a dipole source). AEP audiograms were calibrated against behavior for at least one species. A wealth of data on hearing anatomy. Best comprehensive resource on shark and ray hearing.

CEF Consultants Ltd. 2011. Report on a Workshop on Fish Behaviour in Response to Seismic Sound held in Halifax, Nova Scotia, Canada, March 28-31, 2011, Environmental Studies Research Funds Report No. 190, Halifax, 109 p.

Workshop provided study recommendations for assessing behavioral effects on ecological categories of fishes arising from prior workshops. Rather than a review of effects, this workshop focused on methods for future effects assessment and research.

DFO (Canadian Department of Fisheries and Oceans). 2004. Review of Scientific Information on Impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals. DFO Can. Sci. Advis. Sec. Habitat Status Report 2014/002. 15 pp.

This is a summary report without references, but describes a prolonged expert panel literature review leading to the stated conclusions. The review found no documented cases of fish mortality from seismic operations, even when follow boats were used to look for fish kills. Behavioral effects of C-start, moving deeper in the water column, cessation of vocalization and other responses were noted and considered to be of little impact and of short duration, though they left open the possibility of effects on breeding/spawning behavior and potential for longer term effects. Similar results were reported for invertebrates, noting that the field report by Guerra (not specifically cited) seemed anomalous and that lab results suggested potential effects at close ranges of about 5 meters or so. Behavioral effects were described as similar to fish responses and similarly considered generally inconsequentially while acknowledging the potential for exceptions. Effects on eggs and larvae were similarly reviewed as minimally injurious or damaging although there were a number of points about stress and growth/developmental effects (again, without references). Behavioral effects were generally seen as inconsequential against the background of other sources of mortality, with the possible exception of eggs and larvae that were for some reason confined to a limited spatial area for the duration of development and seismic exposure, a highly unlikely set of conditions.

Edds-Walton PL and Finneran JJ. 2006. Evaluation of evidence for altered behavior and auditory deficits in fishes due to human-generated noise sources. Tech. Rpt. 1936, US Navy SPAWAR Systems Center San Diego, San Diego CA 92152-5001. 47+ pp.

This review provides relatively limited information on behavioral effects compared to other more recent reviews by Popper et al 2014 or SoundWaves Consortium 2015, but provides a very thorough review of hearing and non-hearing physiological effects from a variety of laboratory and field studies. The Conclusions section of the review reports no meaningful long term apparent effect on stress hormones or growth from noise. They anticipate the 2 paper by Smith et al 2014 (see below) and Nedwell et al 2013 in the emphasis on weighting TTS effects as a relative metric to auditory threshold and not an absolute value, as well as the relative effects of loudness and duration on magnitude of Threshold Shift and its duration. Like other thoughtful treatments of responses to sound by fish and invertebrates they note the importance of determining the roles of particle displacement relative to sound pressure level, arguing for development of tools and their application to more readily obtain particle motion data as well as sound pressure data. They cite Hastings et al 1996 on the frequency-dependence of particle acceleration, noting that the acceleration associated with a 300 Hz sound will be five times the acceleration required to produce a 60 Hz sound of the same sound pressure level (SPL).

Gausland, I. 2003. Seismic Surveys Impact on Fish and Fisheries. Unpublished report to the Norwegian Oil Industry Association (OLF), dated March 31, 2003. Stavanger, Norway.

Hawkins AD and Popper, AN. 2014. Assessing the impacts of underwater sounds on fishes and other forms of marine life. *Acoustics Today*, Spring 2014; p. 30-41.

This is a general readership review of material covered in Popper et al 2014. As such it provides good reviews of phenomena like particle motion versus sound pressure, plus a review of fish hearing weighting functions and a fairly neutral and thoughtful review of thresholds for behavioral response to sound and their basis.

Hawkins AD, Pembroke A and Popper AN. 2014. Information gaps in understanding the effects of noise on fishes and invertebrates. Rev Fish Biol Fisheries. DOI 10-1007/s11160-014-9369-3.

This can be considered a companion review to Hawkins and Popper 2014 and Popper et al 2014. The challenge is that issues are expressed slightly differently in each document, offering insights or novel perspectives on a topic that is given short treatment in one of the other reviews. While this review states a focus on information gaps it is as much a review of existing information as it is a list of information gaps (which are neatly presented in eleven text boxes for different research areas such as behavior or injurious effects). The list of information gaps is not ranked or expressed in terms of relative impacts on decision processes for risk assessment or resource management; it really is more an academic's wish list, reflecting the particular interests of the authors, and as such will likely be found incomplete and not especially helpful to decision makers planning programs of applied research.

Keevin TM and Hempen GL. 1997. The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts. U.S. Army Corps of Engineers, St. Louis District, St. Louis, MO. 99 pp.

A thorough review of explosions as an example of an impulse sound source and effects on fish and invertebrates, mainly freshwater. One of the best features of this review is the careful examination of mistakes and omissions in experimental methods, data collection and interpretation of the many studies they review. Anyone undertaking similar experiments and measurements will avoid many potential errors simply by learning from the examples in this review.

Popper, AN, Hawkins, Fay RR, Mann DA, Bartol S, Carlson TJ, Coombs S, Ellison WT, Gentry RL, Halvorsen MB, Lokkeborg S, Rogers PH, Southall BL, Zeddies DG, Tavolga WN. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014. Springer Briefs in Oceanography. ASA Press, Springer, NY NY. 76 pp.

A thorough and current review of the literature on fish and sea turtle hearing and effects of sound. As with Southall et al (2007) for marine mammals, behavioral response guidelines are not offered, due to the complexity and confounding variables present in most if not all data sets. Should be compared with The SoundWaves Consortium (AN Hawkins, D Hughes and S Chessman, plus others) report

Understanding the Scale and Impacts of Anthropogenic Noise upon Fish and Invertebrates in the Marine Environment.

SoundWaves Consortium. 2015. Understanding the Scale and Impacts of Anthropogenic Noise on Fish and Invertebrates in the Marine Environment. 126 + pp. Available from http://www.ncl.ac.uk/marine/research/soundwaves/

Possibly more thorough and encyclopedic that Popper et al, 2014. The SoundWaves Consortium includes co-authors who were also involved in the Popper et al 2014 paper, so there is a great deal of overlap in references and how they are used. The SoundWaves Consortium paper tends to offer more details on methodology and instrumentation for making necessary measurements, and may be more thorough in its recommendations for additional research, although both sets of recommendations reflect a strong academic bias, as opposed to applied science or baseline regulatory and resource management data. The SoundWaves Consortium report also includes a section of recommended monitoring and mitigation actions. The SoundWaves Consortium website also includes a number of papers and reports prepared for the UK Government and others: one or two are listed below, but interested readers may find other useful resource materials on the SoundWaves Consortium site.

Walters, C and Martell SJD. 2004. Fisheries Ecology and Management. Princeton University Press. ISBN 978-0-691-11545-0.

A useful textbook on modern fishery modeling concepts and tools.

General References

Aguilar de Soto N, Delorme N, Atkins J, Howard S, Williams J, Johnson M. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports 3, 2831. DOI 10: 1038/srep02831. www.nature.com/scientificreports.

Purports to demonstrate that airgun sound affects development of scallop larvae at levels of 160 dB SPL or lower. But the work has many flaws; an unrealistically long sound, played at much shorter than normal intervals for as much as 90 hours continuous. The sound source used in the experiment was not able to accurately replicate the actual seismic sound and was placed only 9 cm from the test subjects, producing large particle displacement effects of 4-6mm/s velocity, comparable to an SPL of 195 dB SPL. The latter value translates to a distance of a few tens or hundred meters from an actual source, not the hundreds of square kilometers postulated by the authors. Perfect scores for all controls at all stages are also puzzling, since even the best laboratory culture methods typically yield some variation in survival and development. The work needs to be replicated by an independent and expert experimentalist.

Amundsen L and Landrø M. 2011. Marine Seismic Sources VIII: Fish hear a great deal. GeoExPro: Geoscience and Technology Explained, v. 8, n. 3. http://www.geoexpro.com/articles/2011/03/marine-seismic-sources-part-viii-fish-hear-a-great-deal

A brief overview of the physics and biology of fish hearing.

Andersson MH. 2011. Offshore wind farms – ecological effects of noise and habitat alteration on fish. Ph.D. Dissertation, Dept. of Zoology, Stockholm University, Stockholm Sweden.

Playback of piling sound by a speaker, so not true impulse. Fish were free-swimming in a relatively large net enclosure, tens of meters on a side. Cod, with good hearing, reacted by freezing and then swimming around faster than usual, but only for the duration of exposure. Sole, without a swim bladder, also showed increased swimming during exposure. Cod thresholds of response are reported as 156-142 dB SPL peak or 6.5-8.6 x10-4 m/s2 particle acceleration. Sole thresholds are reported as particle acceleration values only 6.5-4.1 x 10^{-4} m/s^2. The author extrapolates these values to real piling sound fields to conclude effects out to tens of km, but playbacks of an impulse sound by a speaker only capable of producing tonal sounds and at much reduced source levels and particle displacements should probably not be extrapolated in this way.

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 Houégnignan L. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. Front Ecol Environ 2011; doi: 10.1890/100124. www.frontiersinecology.org. The Ecological Society of America.

Another study where it is difficult to know what to make of the data because of the way the sound was presented and measured. The reported received level is 157 dB re 1 µPa, so one can presume that the measurement is of pressure, but whether this is averaged, spectrum level, or total energy under the envelope is unclear. Levels up to 175 dB re 1 µPa are also reported but it is not clear if that is a single frequency peak or whether the received levels fluctuated around 157 dB to as high as 175 dB. Thus the actual exposure history as SEL for the two hours of exposure is unknown. The sound source is in air and its properties are not provided. Given the impedence mismatch of water the source would have had to be extremely loud to get as much as 157-175 dB SPL into the water, creating, among other possibilities, the potential for vibratory coupling from the speaker and its mountings into the floor and walls of the tank. Squid do not have swim bladders or air spaces associated with the ears, so the appropriate value to report is actually particle velocity. This is especially true since the containers were so much smaller than the wavelengths of sound in water at those frequencies (4-30 meters). The sound field inside the containers is bound to be complex and should have been measured. What is most probable is that the squid experienced considerable vibratory motion for two hours, leading to the damage observed; damage that could have never occurred in an open water environment where pressure and particle velocity would never be experienced at those levels for that duration.

Australian Petroleum Production and Exploration Association (APPEA) and [five Commercial Fishing and Seafood Industry Associations]. 2015. Memorandum of Agreement (MOU) to establish principles of co-operation, communication, and consultation between APPEA and assigned Commercial Fishing and Seafood Industry representative bodies to assist in improving the interactions between our two industries in their joint access and use of Australia's valuable marine resources. 25 November 2014. 5 pp.

Blaxter JHS, Gray JAB, Denton EJ (1981) Sound and startle responses in herring shoals. J Mar Biol Assoc UK61:851–870.

In this study, following initial startle response, herring exhibited increased swimming and reduced schooling scaled with source loudness.

Boeger WA, Pie MR, Ostrenski A, and Cardoso MF. 2006. The effect of exposure to seismic prospecting on coral reef fishes. Brazilian J Oceanog 54(4)235-239.

Three species of reef fish with swim bladders were exposed to seismic sound. The caged fish and nearby free-swimming fish were monitored by video cameras. The fish were subjected to three different exposure conditions: two passes by an eight element, 635 cubic inch array at 7 meters horizontal displacement, two passes at 0 meters horizontal displacement and the fish at 7.5 meters depth (this would place the fish only 2.5 meters from the array at 5 meters depth!!), and exposure to 50 consecutive impulses from a 2 element array placed 1 meter away from the caged fish. The measured peak SPL of the 8 element array was 196 dB SPL(peak). C-start responses were observed in some but not all of the caged fish and appeared to diminish over time. Caged fish did not swim about or move to the bottom of the cage, but free swimming nearby fish left the field of view of the monitoring cameras, which was interpreted as action to reduce received sound levels. The absence of any injury or pronounced behavioral disturbance at such apparent close proximity to the air sources differs considerably from the majority of other similar studies; results should be interpreted carefully when extrapolating to models of risk.

Bolle LJ, de Jong CAF, Bierman SM, van Beek PJG, van Keeken OA, Wessels PW, van Damme CJG, Winter HV, de Haan D, Dekeling RPA. 2012. Common Sole Larvae Survive High Levels of Pile-Driving Sound in Controlled Exposure Experiments. PLoS One 7(3): e33052. Doi 10:1371/journal.pone.0033052.

This is a well-designed and properly measured sound exposure experiment, although claims that recordings played from a speaker are able to replicate the impulse time amplitude signature should always be treated with skepticism. Exposures up to 206 dB SEL_{cum} did not produce mortality, with single strike SELs of 186 dB and zero to peak pressures of 32 kPa, erroneously reported as 210 dB re $1\mu Pa^2$ in the abstract.

Booman, C, Dalen J, Leivestad H, Levsen A, van der Meeren T, and Toklum, Kjell. 1996. Effekter av luftkanonskyting på egg, larver og yngel. Undersøkelser ved Havforskningsinstituttet og Zoologisk laboratorium [Effects of airgun pulses on eggs, larvae and fry]. *Fisken og Havet* 1996:3. Norwegian with English Summary.

Bureau of Ocean Energy Management (BOEM). 2012. Atlantic OCS Proposed Geological and Geophysical Activities. Final Programmatic Environmental Impact Statement. Gulf of Mexico OCS Region. BOEM Document Number 2014-001.

Casper BM, Popper AN, Matthews F, Carlson TJ, Halvorsen MB (2012) Recovery of Barotrauma Injuries in Chinook Salmon, *Oncorhynchus tshawytscha* from Exposure to Pile Driving Sound. PLoS ONE 7(6): e39593. doi:10.1371/journal.pone.0039593

Juvenile salmon about 100 mm in length and weighing about 10 grams, were exposed to simulated pile driving sound in a specially designed vibratory chamber to replicate far-field plane wave acoustic conditions of a realistic piling strike. A series of 960 piling strikes was played at either a single strike SEL of 187 dB re $1\mu Pa^2$-s or 180 dB re $1\mu Pa^2$-s to produce a cumulative SEL exposure of either 217 or 210 dB $SEL_{cum.}$ Fish exposed to 960 strikes at 187 dB SEL_{ss} (217 dB SEL_{cum}) showed severe barotraumatic injury to the swim bladder, liver and other tissues, while the fish exposed at 210 dB SEL_{cum} had fewer and less severe injuries. The authors concurred with a previous related study by Halvorsen et al (2011) recommending 210 dB SEL_{cum} as the onset threshold for injury, noting that the new value is considerably less conservative (i.e. allowing for considerably higher exposure levels) than prior regulatory standards. The single strike values of 187 or 180 dB SEL should not be misinterpreted, as these are values for impulses of less than a second in duration. It would therefore require single strike values considerably in excess of 210-217 dB SEL_{ss} to reach levels of injurious effects.

Chapman CJ, Hawkins AD. 1969. The importance of sound in fish behaviour in relation to capture by trawls. FAO Fish Rep 62:717–729.

This study found a change in vertical distribution toward the bottom that affected trawl catch rates, dependent on the depth of trawl. This has become a commonly repeated phenomenon for midwater trawl fisheries for gadid fish (cod, haddock, hake, whiting, pollack, etc).

Christian JR, Mathieu A, Thomson DH, White D, Buchanan RA (2003). Effect of Seismic Energy on Snow Crab (*Chionoecetes opilio*) Environmental Research Funds Report No. 144. Calgary: 106 pp.

Conn PB, Johnson DS, Fritz LW, and Fadely BS. 2014. Examining the utility of fishery and survey data to detect prey removal effects on Steller sea lions (Eumetopias jubatus). Can J Fish Aquat Sci 71:1229-1242. Dx.doi.org/10.1139/cjfas-2013-0602. www.nrcresearchpress.com/cjfas 12 April 2014.

A very thorough review of the measures of fishing allocation, fishing effort and fishing success, together with assessments of pros and cons for correlation with fishery dependent environmental trends.

Cudahy E and Ellison WT. 2002. A review of the potential for *in vivo* tissue damage by exposure to underwater sound. White paper report to the US Navy SURTASS LFA Program. 6 pp. Available at http://www.surtass-lfa-eis.com/docs/CudahyEllison2002.pdf

This paper reviews the information on human lung resonance by low frequency sound and the duration/amplitude of sound required to produce damage to the most delicate tissues in the lung, such as capillaries and alveolar walls.

Cushing, D. 1973. The Detection of Fish. Pergamon Press, Oxford UK

This is a solid introductory text on the use of sound to detect fish by the reflected and re-radiated resonant sound from fish swim bladders. The resulting acoustic signatures not only map the density and spatial distribution of the fish school, but also provides information on the likely species, size distribution of individuals and their orientation.

Dalen, J., Dragsund, E., Næss, A., Sand, O., 2007. Effects of seismic surveys on fish, fish catches and sea mammals. Report no: 2007–0512. Det Norske Veritas. AS Veritasveien 1. 1322 Høvik. Norway, 27 pp.

Dalen, J. and G.M. Knutsen. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. In: Merklinger, H.M., ed. Progress in underwater acoustics. London: Plenum Press. Pp. 93-102.

Eaton RC, Lee RKK, Foreman MB (2001) The Mauthner cell and other identified neurons of the brainstem escape network of fish. Prog Neurobiol 63:467–485.

A description of the specialized neurons responsible for C-start reflexive response to loud sound (and other stimuli potentially associated with risk of predation).

Engås A, Løkkeborg S, Soldal AV, and Ona E. 1996a. Comparative fishing trials for cod and haddock using commercial trawl and longline at two different stock levels. J Northw Atl Fish Sci 19: 83-90. http://journal.nafo.int.

Commercial bottom trawl and longline vessels fished 5 out of 7 days before, 5 days during, and 5 days after a seismic survey was conducted in the area. Acoustic surveys of fish populations were also conducted, along with a sampling bottom trawl of different dimensions and mesh size than the commercial trawl. Only before and after data were analysed in this paper; "during" data were omitted but are reported in Engås et al (1996b). Because multiple fishing methods were employed on two species of fish, the matrix of data are somewhat complicated: generally, catches declined, smaller fish were caught after the seismic survey, and the ratio of haddock to cod increased after survey. It is difficult to know what to make of the results given the number of uncontrolled and possibly contributing variables that could have confounded the results, including the unusual prolonged proximity of survey vessels to fishing, and the amount of continuous fishing in one place that may have contributed to reduced catches and smaller size fish being caught as time went by.

Engås A, Løkkeborg S, Ona E, and Soldal AV. 1996b. Effects of seismic shooting on local abundance and catch rates of cod (Gadus morhua) and haddock (Melanogrammus aeglifinus). Can J Fish Aquat Sci 53:2238-2249.

Same study as above but includes during data and more spatial information showing the effects described above tended to be greatest near the seismic survey and less out to the borders of the study area. An independent re-analysis of the data (JRHGeo, unpublished) suggest a different interpretation of declining catches during the before-exposure period suggestive of depletion of stocks within the unusually heavy, concentrated fishing effort within the test area, followed by clearly decreased catches within 1 km of the survey but smooth decline through pre- and during exposure periods, suggesting little to no effect beyond 1 km. In the 5 days following seismic survey there is a rebound of catch at both the < 1 km and 1-3 km ranges, which suggests that there may have indeed been an effect from the seismic sound on catches, but catches recovered immediately afterward, confounded by the ongoing 10-15 days of continuous intensive fishing in the area. The re-analysis suggests that the data may have been confounded by variables other than sound, and that the original clearcut conclusions in Engas et al 1996a,b are perhaps not quite as pronounced as initially stated.

Finneran, J. J. and Schlundt, C. E. (2011a). "Auditory weighting functions and acoustic damage risk criteria for marine mammals," in *Fourth Intergovernmental Conference on the Effects of Sound in the Ocean on Marine Mammals* (Amsterdam, The Netherlands).

Provides the basis for modified M-weighting functions for marine mammals and their relevance to risk criteria based on the dynamic range of the mammalian ear and its vulnerability to damage by loud sound.

Finneran, J. J. and Schlundt, C. E. (2011b). "Subjective loudness level measurements and equal loudness contours in a bottlenose dolphin (*Tursiops truncatus*)," *Journal of the Acoustical Society of America* 130, 3124-3136.

Expands the foundation in scientific data for modified marine mammal M-weighting functions by adding measures of equal perceived loudness to Temporary Threshold Shift data. These same relationships form the basis for human A-weighting curves, as metrics of frequency-specific hearing sensitivity, dynamic range, and risk of injury from loud sound.

Gross JA, Irvine KM, Wilmoth S, Wagner TL, Shields PA and Fox JR . 2013. The Effects of Pulse Pressure from Seismic Water Gun Technology on Northern Pike. *Trans Am Fish Soc* 142: 1335-1346. ISSN: 0002-8487 print / 1548-8659 online DOI: 10.1080/00028487.2013.802252.

The study assessed the probability of mortality of pike (freshwater) when exposed to two pulses at 3, 6 and 9 meters distance from either a 343 cu in water gun or a 120 cu in water gun, both pressurized at 2000 psi. Measures of peak and peak-to-peak pressure are provided, as well as $SEL_{cum.}$ SEL_{cum} was used as the metric for effects in most of the Results and Discussion sections of the paper since SEL seemed to correlate best with levels of injury and mortality. Mortality within 72-168 hours was correlated with SELs in excess of 195 dB. Gas bladder rupture was observed at 199 dB SEL; in 100% of fish at 3-6 meters and 87% of fish at 9 meters. Given the history of water guns producing greater injury and mortality than airguns, these results with two pulses from good sized single guns, indicate that fish would need to be within a few meters of a single airgun or full array to achieve comparable effects.

Guerra A, González AF, and Rocha F. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES CM 2004 / CC:29, ICES Annual Science Conference, 22-25 September 204, Vigo, Spain. 17 pp.

This is a puzzling report of massive damage to huge robust squid attributed to seismic; effects that are typically found in animals of that size only when exposed to explosions generated by several kg of high-explosive (TNT or HBX) at a distance of a few meters. It is hard to know what to make of this phenomenon which seems to have only occurred at this one location, once in 2001 and again in 2003 and involving a total of nine animals. Necropsy results are mixed and it is hard to tell if there were differences between years or locations. Some damage seems unilateral, a different level or type of effect on one side versus the other typical of explosive or collision damage, while other damage seems to be uniform. Until this phenomenon is replicated in a lab or recurs under similar circumstances, it is hard to know what to make of this paradoxical observation. The speculative attribution to seismic survey is based solely on the presence of survey vessel in the vicinity, without records of possible exposure levels or timelines or whether there were alternative potential causal factors.

Halvorsen MB, Casper BM, Woodley CM, Carlson TJ, Popper AN. 2011. Predicting and mitigating hydroacoustic impacts on fish from pile installations. NCHRP Report Research Results Digest 363, Project 25–28, National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID =763.

See Casper et al 2012, above.

Halvorsen MB, Casper BM, Woodley CM, Carlson TJ, Popper AN (2012) Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds. PLoS ONE 7(6): e38968. doi:10.1371/journal.pone.0038968

Results consistent with Casper et al 2012 (see).

Harrington JJ, McAllister J, and Semmens JM. 2010. Assessing the short term impact of seismic surveys on adult commercial scallops (Pecten fumatus) in Bass Strait: Final Report. Tasmanian Aquaculture and Fisheries Institute, U. of Tasmania

Scallops were sampled from control and exposure sites before and after an extensive 2-D seismic survey. No statistical differences were found between control and exposed populations, neither in survival nor body condition. Exposure levels were not recorded. The paper also reviews several prior studies of seismic effects on scallops in Ireland and other sites, all also with no effect. One cited paper found one of three shells split when the scallops were 2 meters from an airgun.

Hassel A, Knutsen T, Dalen J et al. (2004) Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). ICES J Mar Sci 61:1165–1173.

As seen in other studies, C-start and movement near the bottom with increased swimming, presumed to be anti-predator behavior, but the received sound level was not estimated.

Hastings, MC, Popper AN, Finneran JJ, and Lanford PJ. 1996. Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. *J. Acoust. Soc. Am*. 99(3):1759-1766.

A thorough comparison of the operating principles of lateral line hair cells and inner ear hair cells in fish, along with an excellent contrast of particle motion and pressure components of sound.

Hastings MC and Miksis-Olds J. 2007. Shipboard assessment of hearing sensitivity of tropical fishes immediately following exposures to seismic airgun emissions at Scott Reef. Proc. Inst. Acoust., 29(3). 6 pp.

No effects of sound exposure were found in any of the 128 fish of four species tested during the study. Exposure levels reached 190 dB re 1µPa^2-s SEL.

Hastings, M. C. and Popper, A. N. (2005). Effects of Sound on Fish. (Contract No. 43A0139, Task Order 1). 2600 V Street Sacramento, CA 9581: California Department of Transportation. Prepared by P. C. Jones & Stokes.

This report was prepared as part of a risk assessment for the driving of very large pilings for repairs and updates to the San Francisco-Oakland Bay Bridge following the Loma Prieta earthquake damage in 1989. The review includes information about lateral line sensitivities as well as inner ear sensitivities, providing a contrast in the functioning of the two noise and vibration sensing systems in fish.

Hawkins AD, Hughes H, and Cheesman S. 2015. Criteria and Metrics for Assessing the Effects of Underwater Sound on Fish and Invertebrates. The SoundWaves Consortium. 53 pp. Available at http://www.ncl.ac.uk/marine/research/soundwaves/

A useful guide to the terminology and methods used in underwater sound measurement, a complicated topic that can give even a moderately expert reader troubles.

Higgins SM. 2014. Declaration; State of New Jersey, Dept of Environmental Protection vs National Science Foundation, et al. United States Federal District Court, District of New Jersey. Case 3:14-cv-04249-PGS-LHG, Document 6-7, filed 07/07/14, pageID 1520-1527

Contains a comparison of annual commercial and recreational fishery catches for years and months in which seismic surveys were conducted off the New Jersey coast, relative to the same months in other years, between 1990-2004. No discernable differences were found between periods with seismic survey and without. (Fishery statistical data from NMFS 2014, http://www.st.nmfs.noaa.gov/).

Jørgensen, R, Olsen KK, Falk-Petersen, I-B, and Kanapthippilai P. 2005. Investigations of potential effects of low frequency sonar signals on survival, development and behaviour of fish larvae and juveniles. The Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø, Norway. 51 pp.

See Shelly, K., 2011.

Landrø M, Amundsen L, and Barker D. 2011. High-frequency signals from air-gun arrays. Geophysics 76(4): Q19-Q27.

The interest for fish is not so much the origins of high frequency output but the explanation of interactions of initial pressure pulse (shock wave) and subsequent bubble oscillations of the released air interacting with the surrounding water.

Løkkeborg S, Soldal AV (1993) The influence of seismic exploration with airguns on cod (*Gadus morhua*) behavior and catch rates. ICES Mar Sci Symp 196:62–67.

Results similar to Engås et al (1996)

Løkkeborg S, Ona E, Vold A, and Salthaug A. 2012. Effects of sounds from seismic air guns on fish behaviour and catch rates. In A.N. Popper and A. Hawkins (eds.), *The Effects of Noise on Aquatic Life*, Advances in Experimental Medicine and Biology 730, DOI 10.1007/978-1-4419-7311-5_95, pp. 415-419. Springer, NY NY.

This paper provides a good review of prior behavioral studies. They also report recent data from what is arguably the most realistic and thorough study to date; monitoring of two fisheries (gillnet and longline) for four species of fish; a halibut, two gadids (pollack and haddock) and a seabass (Sebastes marinus), along with acoustic (HF sonar) surveys of the fish populations. Gillnet catches of halibut and seabass increased during and after survey, possibly due to increased swimming activity, while longline catches of halibut and pollack decreased. Acoustic surveys revealed decreases in pollack abundance, but not other species, consistent with prior study by Engås et al (1996a,b).

Lovell JM, Findlay MM, Moate RM, and Yan HY. 2005. The hearing abilities of the prawn Palaemon serratus. Comp Biochem Physiol, Part A, 140:89-100.

The authors used ABR techniques to establish responsiveness to sounds between 100 and 3000 Hz. There was no testing at frequencies below 100 Hz. Thresholds were determined to be around 100-120 dB SPL re 1 microPascal, although the mechanics of the statocyst organ are presumed to be responsive to particle motion, not pressure.

McCauley RD, Kent CS, Archer M. 2008. Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef Lagoon, Western Australia: Full report of Curtin University findings. Center for Marine Science and Technology, Curtin University, Perth WA. 92 pp. CMST Report 2008-32.

An extensive research effort involving a real seismic survey over a thoroughly monitored reef lagoon. Caged snapper and damselfish were exposed to seismic passes as close as 45-74 meters with 1% loss of hearing hair cells, later fully recovered. Behavioral reaction was observed at 155-165 dB SPL sound exposure levels but avoidance only occurred out to 200 meters on either side of survey. There was no effect on normal fish sound choruses. A single sonar survey after a seismic pass presented a reduction in zooplankton backscatter out to 500 m from the survey line. This unprecedented result was not replicated and deserves follow-up study: did the zooplankton move away, go to the bottom, or change orientation in a way that reduced sonar backscatter?

McCauley RD and Gavrilov A. 2010. Underwater noise monitoring Western Tasmania, T48P Seismic Survey and biological sources, Feb-Jun 2008. Centre for Marine Science and Technology (CMST), Curtin University, Perth, Western Australia.

During monitoring of sound propagation from a seismic survey the authors were able to detect chorusing fishes at varying distances and locations. Due to the variation in the chorusing behavior and movement of the source over time it was not possible to statistically determine if chorusing was affected by the seismic sound.

McCauley RD, Fewtrell J and Popper AN. 2003. High intensity anthropogenic sound damages fish ears. J Acoust Soc Am 113(1):638-642 DOI: 10.1121/1.1527962

The authors were able to produce considerable unrecovered damage to the sensory structures of a typical fish ear (pink snapper) after seven close passes (5-15 meters) by a towed 20 cubic inch seismic air source in the span of four hours. Although no cumulative Sound Exposure Level (SEL) or peak pressure or particle velocity measures were reported, the graphical display of the passes indicates multiple exposures over short periods of time at levels in excess of 180 dB SPL $rms_{0.95}$. The fish were caged and the authors noted that their movements indicated that they likely would have fled if they could have, which would have prevented the artificially high levels of exposure found in this experimental design.

Miller I. and Cripps E. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. Mar Pol Bull. Elsevier Press. http://dx.doi.org/10.1016/j.marpolbul.2013.10.031

No change in abundance or species composition was found in a natural reef community of resident reef fishes (emphasis on damselfishes) and mobile demersal fishes (emphasis on snappers of the Family Lutjanidae). Multiple passes by a full working seismic array were separated by about 6 hours between pass. Minimum stand-off distances from the reef were 400 meters on the outside and 800 meters inside the reef lagoon. Estimated exposures were generally around 187 dB SEL with some

exposures as high as 200 dB SEL. Instantaneous peak or average SPL or particle velocity/acceleration were not measured.

Moir HM, Jackson JC, and Windmill JFC. 2013. Extremely high frequency sensitivity in a 'simple' ear. Biology Letters, doi: 10.1098/rsbl.2013.0241. http://rsbl.royalsocietypublishing.org/content/9/4/20130241

Performance and mechanisms of moth detection of high frequency sound from bats and conspecifics.

Mooney TA, Hanlon, RT, Christensen-Dalsgaard J, Madsen PT, Ketten DR, Nachtigall PE. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure. J Exp Biol 213: 3748-3759.

A methodologically strong use of auditory evoked potential methods to obtain an audiogram for the common Atlantic market squid, *Loligo pealeii*. Similar auditory anatomy is found in many species of squid and octopus and suggests that cephalopod molluscs hearing capabilities comparable to those of fish without swim bladders.

National Research Council (NRC). 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. National Academy Press, Washington DC. www.nap.edu.

This NRC report lays out a framework for estimating population consequences from behavioral disturbance by sound, and by extension, any source of behavioral perturbation, individually or cumulatively. While developed for marine mammals, the principles of the Population Consequences of Acoustic Disturbance (PCAD) model are appropriate to any biological population.

Nedelec SL, Radford AN, Simpson SD, Nedelec B, Lecchini D and Mills SC. 2014. Anthropogenic noise playback impairs embryonic development and increases mortality in a marine invertebrate. Nature Communications: SCIENTIFIC REPORTS | 4 : 5891 | DOI: 10.1038/srep05891. www.nature.com/scientificreports/

This is a flawed work product consistent with the work coming out of the very prolific Radford laboratory, which has produced a huge number of papers, all of them finding some sort of adverse effect on fish or invertebrates from anthropogenic noise playbacks. In this case the playback sound is a recording of small boat motor noise. There are a lot of problems with the paper, not the least of which is that although they claim that received pressure and particle velocity measurements were made, the values are not reported. Exposures consisted of one one-minute recording of a vessel pass and four minutes of recorded background noise for 12 continuous hours each day for the five day larval development period. Results were highly variable, with many exposure samples having higher survival than the paired control, but the overall trend was greater mortality in the exposed samples. It is hard to understand the basis for the rather strong assertion of effect in the title of the paper and the purely speculative discussions of possible causes and consequences, given the flaws in the methodology and the inconsistency and weak effects reported in the Results.

Nedwell JR, Turnpenny AWH, Lovell J, Parvin SJ, Workman R, Spinks JAL, and Howell D. 2007. A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise. Subacoustech Report No. 534R1231. Produced for the U.K. Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. 74+pp.

Neo YY, Seitz J, Kastelein RA, Winter HV, ten Cate C, and Slabbekoorn H. 2014. Temporal structure of sound affects behavioural recovery from noise impact in European seabass. Bio Con 178: 65-73. Journal homepage: www.elsevier.com/ locate/biocon

A laboratory experiment examining the effect of amplitude modulation and signal intermittency on behavior. Results were consistent with other similar studies, with C-start responses and increased, “agitated” swimming, along with movement up away from the bottom that resulted in reduced schooling. Their data suggest a longer time for recovery from exposures to intermittent versus continuous sound and speculate that perhaps uncertainty or anxiety about exposure resuming may have played a role, although the intervals between intermittent signals were quite short: this makes it hard to understand how anticipation of resumption might have gone on for so long when the actual intervals the fish had experienced were very much shorter. Stress was discussed but no measurements were made. Fish were held in relatively small net enclosures (2m x 1.6m) which may have influenced results compared to open water response.

Norwegian Oil and Gas Association. 2013. Norwegian Oil and Gas recommended guidelines for Coexistence with the fishing sector when conducting seismic surveys. No. 136, 2013.03.04. 14 pp. https://www.norskoljeoggass.no/en/Publica/Guidelines/

Establishes guidelines for good communication and minimizing impacts of each industry on the other, both in planning and conducting seismic surveys.

Norwegian Petroleum Directorate. 2014. Guide: Implementation of seismic surveys on the Norwegian Continental Shelf. Fiskeri-Og Kystdepartementet and Olje-Og Energidepartementet. 24 pp. http://www.npd.no/global/engelsk/5-rules-and-regulations/guidelines/guidelines-seismic-surveys.pdf

Parker RWR and Tyedmers PH. 2014. Fuel consumption of global fishing fleets: current understanding and knowledge gaps. Fish and Fisheries, 4 July 2014. DOI: 10.1111/faf.12087.

A review of the role of fuel costs in the economics of many of the largest modern fisheries, including limits to practical ranges from port, time at sea, and cost of catch per unit effort.

Parry GD and Gason A. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research 79 (2006): 272-284.

A statistical comparison of changes in commercial catch rates (Catch Per Unit Effort, CPUE) coincident with seismic survey effort. No correlation was found in a two way analysis of variance, although the authors do note that most survey effort was in deep water away from the shallow water fishery, and that one survey in shallow water was in an area of low lobster abundance.

Payne , J. F. 2004. Potential Effect of Seismic Surveys on Fish Eggs, Larvae and Zooplankton. Canadian Science Advisory Secretariat (CSAS/CSSC), Fisheries and Oceans Canada. ISSN 1499-3848. Available at http://www.dfo-mpo.gc.ca/csas/. 16 pp.

Payne, J. F., Coady, J. and White, D. 2009.Potential Effects of Seismic Airgun Discharges on Monkfish Eggs (*Lophius americanus*) and Larvae. Environmental Studies Research Funds Report No.170. July 2009. Science Branch, Fisheries and Oceans Canada, PO Box 5667, St. John’s, NL A1C 5X1, Canada. 32+ pp.

Pearson WH, Skalski JR, Malme CI (1992) Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). Can J Fish Aquat Sci 49:1343–1356.

A field experiment with five Sebastes species, locally called “rockfish” in California (rockfish is a common name applied to very different species of fish in other parts of the world). The test group composition varied from day to day depending on the number and species that were captured by hook and line at least a day preceding the test and then allowed to acclimate to the shallower environment of the test site. The planned design of 20 fish per trial was modified somewhat due to constraints of what species the researchers were able to catch for testing prior to the test. A change in the mix of species in the test enclosure had to be made after one species showed a tendency to eat the smaller individuals of other species or individuals died during the acclimation phase prior to testing. The enclosure was octagonal and 4.6 m across in 3.6m of water. The fish came from deeper water and don't usually occur at such shallow depths except as juveniles. The source was a 100 cu inch air sources pressurized to 4500 psi and producing a source level of 223 dB (presumably peak pressure): this was a slightly higher source level for that air volume compared to normal 2000 psi pressurization. The source was moved closer over the course of trials from a distance of over 200 meters to a nearest approach of 21 m, which produced a received level of over 200 dB (peak pressure?) at the nearest approach. Perhaps due to the artificiality of the environment and natural behavioral variations between species, the data varied considerably. Vermillion and olive rockfish that normally hover near the bottom reacted at about 187 dB SPL_{peak} by either rising in the water or settling even deeper and becoming still. Blue and black rockfish that typically hover further off the bottom either dropped to the bottom (black rockfish) or milled in tighter schools (blue rockfish). Olive and black rockfish showed high tolerance of the sound and did not startle until receiving levels of 200 dB SPL_{peak} or higher. Based on the variance they saw the authors speculated that onsets of behavioral response might occur as low as 161-162 dB SPL_{peak} by regression from the observed responses. The results illustrate the complexity of response threshold and response behavior even among closely related species. The use of a simplified convention of simply reporting "dB" is a bit surprising, given that one of the co-authors, Malme, tends to be very specific about such things usually. From reading the text it appears that the presented values were measured peak pressures and are so described in this review.

Peña H, Handegard NO, and Ona E. 2013. Feeding herring schools do not react to seismic air gun surveys. ICES J Marine Science, doi:10.1093/icesjms/fst079. 7 pp. http://icesjms.oxfordjournals.org/

A full 3-D seismic survey array was used to assess responses of herring monitored by an omnidirectional fisheries sonar. The source vessel approached the fish school from a distance of 26 km to a close approach at 2 km without any effect on the swimming and schooling behavior of the fish.

Popper AN. 2005. A review of hearing by sturgeon and lamprey. A Report submitted to the U.S. Army Corps of Engineers, Portland District. August 2005. 23 pp.

Despite the title the paper is a review that reports that there are limited to no data on lamprey and sturgeon hearing. Based on anatomy and phylogeny Popper offers that the lamprey, the most primitive true vertebrate alive today, may have limited or no hearing ability or hearing-mediated behavior, while the sturgeon probably offers hearing abilities similar to other fish: best hearing between 100 and 1000 Hz with some hearing ability below 100 Hz. Popper also offers a review of fish hearing anatomy and the hearing abilities of various fish, including the cyprinid specialist the goldfish, as a surrogate for another Columbia River fish, the topminnow.

Popper AN, Salmon M, Horch KW. 2001. Acoustic detection and communication by decapod crustaceans. J Comp Physiol, 187:83-89.

Popper AN, Smith ME, Cott PA, Hanna BW, MacGillivray AO, Austin ME and Mann DA. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. J Acoust Soc Am 117:3958-3971.

This is one of the few, if not the only, paper to report exposure conditions in SPL (peak and $rms_{0.9}$), SEL, particle velocity (dB re 1nm/sec peak and rms over 1 second), and intensity (as a product of pressure and particle velocity re 0.676 x 10^{-18} W/m^2, the intensity of a 1µPa plane wave). The three tested species were two hearing generalists with swimbladders, northern pike and lake whitefish, and a hearing specialist cyprinid fish, the chub: the species were chosen for their local food importance (pike and whitefish) and being native to the MacKenzie River delta. The test conditions were somewhat constrained (fish held in small mesh or wire containers) so that the fish could be tested immediately by Auditory Brainstem Response ABR hearing assessment methods after exposure. ABR methods are assumed to slightly underestimate thresholds produced by behavioral methods, but have the advantage of being quick and providing multiple replicates. The source was an eight element array of 70 to 150 cubic inch sources arranged in an equally spaced 2x4 matrix of 2.6m by 1.2 m and totaling 730 cubic inches. The array was placed vertically and broadside to the fish to simulate a direct overhead pass at a distance of 13-17 m. The system was pressurized to 1900 psi but triggered manually, which led to some slight variations in individual exposures. Due to the experimental constraints listed above the data may thus be somewhat limited in predicting the actual onset of TTS in wild free-swimming fish exposed to other arrays, but still offers a tremendously useful benchmark on a phenomenon, onset of temporary hearing impairment, that is of importance in assessing the spectrum of effects thresholds from mortality to onset of minor behavioral disturbance. Whitefish and juvenile pike did not show any TTS after exposure to five seismic playback of about 209 dB SPL_{peak} or 180 dB SEL, and 139 db SVL re 1nm/s (it is not possible to determine which physical property was responsible for any TTS observed in any of the tests). Adult pike under similar exposure conditions showed a TTS of about 20 dB at 400 Hz, which was recovered within 18 hours. Chub, also under similar exposure levels, showed slightly higher levels of TTS, about 25 dB at 200 Hz and 35 dB at 400 Hz, similar for 5 playbacks or 20 playbacks, and fully recovered within 18 hours. Fish were sacrificed to collect hearing tissues and no obvious damage to swim bladders or other tissues were seen during dissection, the data from microscopic examination of the ears were reported in Song et al (2008).

Sarà G, Dean JM, D'Amato D, Buscaino G, Oliveri A, Genovese S, Ferro S, Buffa G, Lo Martire M, and Mazzola S. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. Mar Ecol Prog Ser 331:243-253. www.int-res.com

An interesting observational study of the behavioral responses of tuna confined in a large pen when receiving sound from the opportunistic passage of various vessels. But as the authors note "The results reported here raise many more questions than they have answered." While spectral sound pressure levels are presented for low frequencies around 50 – 100 Hz up to 20 kHz at different ranges from the three vessel types considered, the actual exposure levels associated with observed response were not recorded, or at least not provided. The response consisted largely of departures from the organized circling of enclosure walls typically exhibited by tunas, sharks and other large wide-ranging fishes when held in captivity. The fish switched to disorganized and usually faster swimming or formation of tighter schools of different shapes, together with changes upward or downward from the mid-water column level of baseline swimming (tuna and similar open ocean predators are usually found at shallow depths, but in deep water and show great variation in the depth zone occupied in the wild). The observed behaviors are all comparable to the data reported for other fish: changes in depth upward or downward, faster 'more agitated' swimming or unusual slow milling or motionless schooling. Details of the responses differed for the different vessel types: large car ferry, hydrofoil and small motor vessel. Speculations about the cessation of schooling or school shapes the fish assumed during noise exposure, about the health and fitness consequences of the observed response, and about the consequences for fisheries are all unsupported by data and contain quite a bit of anthropomorphic bias about the sensory abilities and motivations of the fish. The overall value of the observations are therefore quite limited and should be clearly differentiated from the many speculative conclusions offered by the authors.

Saetre, R. and Ona, E. 1996. Seismiske undersøkelser og skader på fiskeegg og -larver en vurdering av mulige effekter pa bestandsniv. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level]. *Fisken og Havet* 1996:1-17, 1-8. (in Norwegian with English summary).

Shelley, K. 2011. Reanalysis of "Investigation of the Potential Effects of Low Frequency Sonar Signals on Survival, Development, and Behavior [sic] of Fish Larvae and Juveniles" by Jørgensen et al …. Memorandum in support of the decisional record for the Biological Opinion on the US Navy 2010-2015 Keyport Range Complex Extension (FWS #13410-2009-F-0082). Memorandum for the Decisional Record, 31 May 2011. US Fish and Wildlife Service, Lacey WA. 4 pp.

Independent expert review of Jørgensen et al 2005, found the Jørgensen paper inconclusive on lethal and injurious effects to juvenile herring due to a failure to replicate injurious effects observed in one trial condition at the highest exposure levels of 189 dB SPL for 20 successive 1 second duration sonar pulses at 1.5 kHz frequency, every 5 seconds. The sound source was not a full operational sonar with a source level of 220-230 dB SPL, but a laboratory source capable of a maximum 200 dB SPL placed 3 m from the test subjects (the actual sonar would have had to be about 100 meters away from the subjects to obtain similar exposures).

Simpson SD, Purser J and Radford AN. 2014. Anthropogenic noise compromises antipredator behaviour in European eels. Global Change Biology doi: 10.1111/gcb.12685. John Wiley & Sons.

Glass stage eels exposed to simulated ship noise from a speaker underneath the bottom of the tank were twice as slow to respond to visual cues of a simulated predator and more than twice as quickly caught by a dipnet, mimicking predator pursuit. Opercular beat rate was observed to increase during noise exposure, taken to indicate a heightened state of activation, although this invites the question as to why the subjects were not more inclined to react instead of less reactive. Various reasons are hypothesized for the observed result but were not tested. There are some of the usual problems with lab playback experiments; the playback source is much closer than the actual source (ships), the playback signal only partially resembles the frequency/amplitude structure of the original signal, and particle velocity could not be measured (one wonders if this was due to ground-transmitted vibration from pumps and other machinery in the lab). Although the playback was intended to replicated the RMS sound pressure level of the original signal, either the frequency response of the speaker or other factors led to a signal that is as much as 10 dB louder in the frequency range audible to the fish (below 2 kHz) and correspondingly lower at higher frequency so that the overall rms amplitudes are equal but the frequency specific amplitudes are very different. One wonders why threshold of response tests weren't done, why stress hormones or other measures of allostatic load weren't measured, and why different sound levels or different frequency band pass filters applied to test what it was about the "masking" vessel sounds that might have led to differential response to "predator" cues that were largely or entirely visual or particle displacement (net chase), but not acoustic. The paper was reviewed and published in less than two months: this might be interpreted as either a triumph for the timeliness of electronic publishing or a cautionary note for more thorough review and higher editorial standards for scientific publications.

Simpson SD, Radford AN, Tickle EJ, Meekan MG, and Jeffs AG. 2011. Adaptive avoidance of reef noise. Proceedings of the Library of Science, One (PLOSOne) v6(2):e16625 doi:10.1371/journal.pone.0016625.

This is not really a paper about effects of anthropogenic noise directly, but uses apparent differential response to reef noise to suggest that changes in anthropogenic noise could interfere with sound-mediated approach or avoidance of the reef habitat at night. The authors examined differences in the catches of seven broad taxonomic groups of larval or adult invertebrate zooplankters to suggest that pelagic and night emerging taxa avoided playbacks of reef noise (fish choruses, snapping shrimp etc) while reef settling larvae approached the noise. They offer speculative rationales for the differences in behavior. They also speculate about the mechanism by which these tiny organisms were able to achieve directed movements in an environment with a lot of dynamic water motion that had to be overcome. The data are more than ten years old, but apparently the current surge of interest in anthropogenic underwater sound made the data publishable if linked to anthropogenic noise and its (adverse) effects.

Skalski JR, Pearson WH, Malme CI (1992) Effects of sound from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). Can J Fish Aquat Sci 49:1357–1365.

A well-designed and clever experiment in which commercial hook and line sets were conducted during exposures of 180-190 dB SPL by towing a seismic source over a fish aggregation and then circling the fishing vessel at a set distance of about 160 meters. During controls air bubbles were passed through a line to simulate the surface expression of an airgun pulse but without the sound so the fishermen could not readily tell when the sound source was on or off. Catches during exposure trials were considerably lower, as much as 80% for some trials, but most interesting was the expression of reduction in catch in terms of dollar value of catch for a set amount of effort, with the reduction being approximately 50% in cash value of fish landed during noise exposure. Fish moved deeper in the water column but the hypothesized primary cause of catch reduction was reduced feeding during exposure. No dispersal was observed from the seamount habitats being fished, but the authors speculated that other rocky habitats where these species aggregate such as shale slopes might have seen more dispersal. Many design aspects of this experiment were based on the results of Pearson et al (1992) in the same general habitat area with similar species aggregations over rocky habitat.

Slotte A, Kansen K, Dalen J, Ona E (2004) Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fish Res 67:143–150.

The species being acoustically surveyed, blue whiting (Micromesistius poutassou), moved deeper in the water column near active seismic survey activity, similar to findings of Skalski et al (1992). These results have sometimes been misinterpreted as stating that the fish moved away from the site, into deeper waters, when actually the fish stayed in place but sank closer to the bottom, a commonly observed response to sound assumed to be a defense against midwater predators.

Smith ME, Kane AS, Hastings ME, and Popper AN. 2014. Physiological Effects of Noise on Fishes. ICBEN 6pp.

The authors review several studies of damaging effects of noise: the CALTRANS study of pile driving noise effects on fish; the McCauley and Popper study of Australian snapper exposed to multiple airgun passes; and an unpublished study by Smith (2003) to determine asymptotic levels of TTS produced by white noise in the goldfish. The latter study revealed a linear relationship between loudness of exposure and amount of TTS induced for sound of equal durations (LINTS). Smith et al provide a graphic representation of the LINTS scale for mammals, birds and fish (based on the goldfish data). The LINTS formula enables the user to predict that within each major taxon more sensitive species will be more prone to TTS than less sensitive species and that the threshold shift will be greatest where the individual's baseline threshold is lowest, thus reinforcing an apparent consistency of hearing system mechanics and functional processes across all vertebrates.

Smith, M. E., Kane, A. S., and Popper, A. N. (2003). Relationship between acoustical stress and hearing sensitivity in fishes. Abstracts of the 26th Annual Midwinter Research Meeting of the Association for Research in Otolaryngology, Daytona Beach, FL, 164.

This is a short abstract of an unpublished assessment of stress hormone fluctuations correlated with sound exposure at different levels within the range of hearing of the test species.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of Northern Canadian freshwater fishes following exposure to seismic air gun sounds. J. Acoust. Soc. Am. 124(2):1360-1366.

No damage was found to any of the ears of the test fish from Popper et al (2005), despite findings of Temporary Threshold Shift in two cases where peak pressure exceeded 205-209 dB re 1µPa SPL (peak) or 176-180 dB re 1 µPa^2-s single impulse (shot) SEL.

Stanley JA, Radford CA, Jeffs AG (2011) Behavioural Response Thresholds in New Zealand Crab Megalopae to Ambient Underwater Sound. PLoS ONE 6(12): e28572. doi:10.1371/journal.pone.0028572

Tripp E. 2014. How much fuel did it take to catch that fish? Marine Science Today, August 13, 2014. http://marinesciencetoday.com/2014/08/13/how-much-did-it-take-to-catch-that-fish/#ixzz3CJPph3Qo.

A short popular science treatment of the scholarly article by Parker and Tyedmers (2014).

United States Navy. 2013. Atlantic Fleet Training and Testing Final Environmental Impact Statement / Overseas Environmental Impact Statement. Available online at http://aftteis.com/DocumentsandReferences/AFTTDocuments/FinalEISOEIS.aspx

Vermeij MJA, Marhaver KL, Huijbers CM, Nagelkerken I, and Simpson SD. 2010. Coral larvae move toward reef sounds. PLoS ONE 5(5): e10660. doi:10.1371/ journal.pone.0010660.

An interesting study with huge implications. Coral larvae are small and lack most of the sophisticated features of fish, cephalopod or arthropod larvae: they have no central nervous system, no ears and no obvious sound sensing structures (e.g. hair cells), and they have very limited swimming abilities. And yet the findings of this paper suggest that the free-floating coral larvae can orient toward the sound of surf crashing on a reef and actively move toward the reef to find suitable sites to settle and become sessile adult corals. Details of how the coral larvae are able to detect the sound, orient to it and get to the reef remain to be determined.

Walters, C and Maguire, J (1996). "Lessons for stock assessment from the northern cod collapse". Reviews in Fish Biology and Fisheries 6: 125–137. doi:10.1007/bf00182340.

One of the most information-rich fishery stock assessment models, illustrating the magnitude of effects like overfishing or changes in available prey species that are required to produce losses in commercial harvest and failure to recover.

Wardle CS, Carter TJ, Urquhart GG, Johnstone ADF, Ziolkowski AM, Hampson G, Mackie D (2001) Effects of seismic air guns on marine fish. Cont Shelf Res 21:1005–1027.

A study of free swimming cod, pollack and hake on a reef, using a fixed seismic source. C-start but no movement away from the source was observed at exposure levels up to 195 dB SPL at a distance of 109 meters. The authors speculate on possible reasons for the lack of response, including site fidelity to the unique reef environment at which the study was performed.

APPENDIX C - ANNOTATED MARINE LIFE BIBLIOGRAPHY

ANTHROPOGENIC SOUND AND IMPACTS TO MARINE LIFE:

An Annotated Bibliography of Selected & Frequently Cited References

IAGC, together with the oil and gas industry, funds independent research to further our understanding of the effects of seismic surveys on marine life. This is helping to remove uncertainties about the possible effects of seismic surveys. Some of this research, in addition to other frequently cited references regarding the effects of sound on marine life, is reviewed in the attached annotated bibliography.

More than four decades of worldwide seismic surveying and scientific research indicate that the risk of direct physical injury to marine life is extremely low, and currently there is no scientific evidence demonstrating biologically significant negative impacts to marine life. As BOEM stated in its August 22, 2014 *Science Note*, "To date, there has been no documented scientific evidence of noise from air guns used in geological and geophysical (G&G) seismic activities adversely affecting marine animal populations or coastal communities. This technology has been used for more than 30 years around the world. It is still used in U.S. waters off of the Gulf of Mexico with no known detrimental impact to marine animal populations or to commercial fishing.".

There has been no observation of direct physical injury or death to free-ranging fish caused by seismic survey activity, and there is no conclusive evidence showing long-term or permanent displacement of fish. Any impacts to fish from seismic surveys are short-term, localized and are not expected to lead to significant impacts on a population scale or to commercial and recreational fishing activities.

The seismic sound source is engineered to direct its energy downward, rather than laterally. For any energy that is transmitted laterally, the signal strength decreases rapidly and would not cause injury to marine mammals. Research indicates that in-water sounds received at 110-90 dB SPL are comparable to a whisper or soft speech, even if it travels hundreds or thousands of kilometers in water. In some areas, such as the busy ports of the Atlantic coast, ambient sound in the frequencies produced by seismic sources may be as high as 110-120 dB due to ship noise, thereby masking any additional contribution from distant seismic surveys. What evidence there is of potential behavioral disturbance from seismic operations suggests minor and transitory effects, such as temporarily leaving the survey area, and these effects have not been linked to negative biologically significant impacts on populations.

More information on our commitment to science can be found at www.soundandmarinelife.org.

ANTHROPOGENIC SOUND AND IMPACTS TO MARINE LIFE:

An Annotated Bibliography of Selected & Frequently Cited References

Aguilar de Soto N, Delorme N, Atkins J, Howard S, Williams J, Johnson M. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports 3, 2831. DOI 10: 1038/srep02831. www.nature.com/scientificreports.

Purports to demonstrate that airgun sound affects development of scallop larvae at levels of 160 dB SPL or lower. But the work has many flaws; an unrealistically long sound, played at much shorter than normal intervals for as much as 90 hours continuous. The sound source used in the experiment was not able to accurately replicate the actual seismic sound and was placed only 9 cm from the test subjects, producing large particle displacement effects of 4-6mm/s velocity, comparable to an SPL of 195 dB SPL. The latter value translates to a distance of a few hundred meters from an actual source, not the hundreds of square kilometers postulated by the authors. The best laboratory culture methods typically yield some variation in survival and development, but this study reported perfect scores for all controls at all stages. The work needs to be replicated by an independent and expert experimentalist.

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 Houégnignan L. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. Front Ecol Environ 2011; doi: 10.1890/100124. www.frontiersinecology.org. The Ecological Society of America.

Another study where it is difficult to know what to make of the data because of the way the sound was presented and measured. The reported received level is 157 dB re 1 μPa, so one can presume that the measurement is of pressure, but whether this is averaged, spectrum level, total energy under the envelope is unclear. Levels up to 175 dB re 1 μPa are also reported but it is not clear if that is a single frequency peak or whether the received levels fluctuated around 157 dB to as high as 175 dB. Thus the actual exposure history as SEL for the two hours of exposure is unknown. The sound source is in air and its properties are not provided. Given the impedence mismatch of water the source would have had to be extremely loud to get as much as 157-175 dB SPL into the water. Squid do not have swim bladders or air spaces associated with the ears, so the appropriate value to report is actually particle velocity. This is especially true since the containers were so much smaller than the wavelengths of sound in water at those frequencies (4-30 meters). The sound field inside the containers is bound to be complex and should have been measured. What is most probable is that the squid experienced considerable vibratory motion for two hours, leading to the damage observed; damage that could have never occurred in an open water environment where pressure and particle velocity would never be experienced at those levels for that duration.

Bartol, S.M. and Bartol, I.K. 2011. Hearing Capabilities of Loggerhead Sea Turtles (Caretta caretta) throughout Ontogeny: An Integrative Approach involving Behavioral and Electrophysiological Techniques. Final Report, JIP Grant No.22 07-14. Available online at http://www.soundandmarinelife.org/research-categories/physical-and-physiological-effects-and-hearing/hearingcapabilities-of-loggerhead-sea-turtles-throughout-ontogeny.aspx

Bolle LJ, de Jong CAF, Bierman SM, van Beek PJG, van Keeken OA, Wessels PW, van Damme CJG, Winter HV, de Haan D, Dekeling RPA. 2012. Common Sole Larvae Survive High Levels of Pile-Driving Sound in Controlled Exposure Experiments. PLoS One 7(3): e33052. Doi 10:1371/journal.pone.0033052.

This is a well-designed and properly measured sound exposure experiment, although claims that recordings played from a speaker are able to replicate the impulse time amplitude signature should always be treated with skepticism. Exposures up to 206 dB SEL_{cum} did not produce mortality, with single strike SELs of 186 dB and zero to peak pressures of 32 kPa, erroneously reported as 210 dB re $1\mu Pa_2$ in the abstract.

Booman, C., Dalen, J., Leivestad, H, Levsen, A., van der Meeren, T. and Toklum, K. 1996. Effects from airgun shooting on eggs, larvae, and fry. Experiments at the Institute of Marine Research and Zoological Laboratorium, University of Bergen. (In Norwegian. English summary and figure legends). Fisken og havet No. 3. 83 pp. as reviewed in: Dalen, J, Dragsund E, Næss A, and Sand O. 2007. Effects of seismic surveys on fish, fish catches and sea mammals. Report for the Cooperation group – Fishery Industry and Petroleum Industry, Report No. 2007-0512. Available at https://www.norskoljeoggass.no/PageFiles/6574/Effects%20of%20seismic%20surveys%20on%20fish,%20fish%20catches%20and%20sea%20mammals.pdf?epslanguage=no

Observed effects on eggs and larvae only extended 1 to 5 meters from a full seismic array, suggesting that powerful particle motion effects were responsible for damaging the microscopic eggs and larvae. The net effect would be a pencil line damage zone in the wake of the array that would conceivably account for some tiny fraction of 1% of pelagic eggs and larvae distributed in the larger region of interest. Considering that more than 99% of eggs and larvae typically never make it to adulthood, this is an inconsequential effect compared to predation, disease and many other natural density-dependent or density independent causes of mortality.

Castellote, M., Clark, C.W., and Lammers, M.O. 2012. Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. Biological Conservation 147: 115–122.

The authors make a slim statistical case that calls were altered by the presence of shipping noise and in one case a seismic survey. Measured and modeled acoustic data in the Straits of Gibraltar, a very unusual acoustic environment, were extrapolated as a more general case to predict effects of seismic on fin and other related whales generally. This speculation should be supported with data. Inferences of whale displacement by sound were from reductions in numbers of vocalizations, not actual observed movement or changes in distribution.

Engås A, Løkkeborg S, Soldal AV, and Ona E. 1996a. Comparative fishing trials for cod and haddock using commercial trawl and longline at two different stock levels. J Northw Atl Fish Sci 19: 83-90. http://journal.nafo.int.

Commercial bottom trawl and longline vessels fished 7 days before, 5 days during, and 5 days after a seismic survey was conducted in the area. Acoustic surveys of fish populations were also conducted, along with a sampling bottom trawl of different dimensions and mesh size than the commercial trawl. Only before and after data were analysed in this paper; "during" data were omitted but are reported in Engås et al (1996b). Because multiple fishing methods were employed on two species of fish, the matrix of data are somewhat complicated: generally, catches declined, smaller fish were caught after the seismic survey, and the ratio of haddock to cod increased after survey. It is difficult to know what to make of the results given the number of uncontrolled and possibly contributing variables that could have confounded the results, including the unusual prolonged proximity of survey vessels to fishing, and the amount of continuous fishing in one place that may have contributed to reduced catches and smaller size fish being caught over time.

Engås A, Løkkeborg S, Ona E, and Soldal AV. 1996b. Effects of seismic shooting on local abundance and catch rates of cod (Gadus morhua) and haddock (Melanogrammus aeglifinus). Can J Fish Aquat Sci 53:2238-2249.

Same study as above but includes data during the survey and more spatial information showing the effects described above tended to be greatest near the seismic survey and less out to the borders of the study area. An independent re-analysis of the data (JRHGeo, unpublished) suggest a different interpretation of declining catches during the before-exposure period suggestive of depletion of stocks within the unusually heavy, concentrated fishing effort within the test area, followed by clearly decreased catches within 1 km of the survey but smooth decline through pre- and during exposure periods, suggesting little to no effect beyond 1 km. In the 5 days following seismic survey there is a rebound of catch at both the < 1 km and 1-3 km ranges, which suggests that there may have indeed been an effect from the seismic sound on catches, but catches recovered immediately afterward, confounded by the ongoing 10-15 days of continuous intensive fishing in the area. The re-analysis suggests that the data may have been confounded by variables other than sound, and that the original clearcut conclusions in Engas et al 1996a,b are perhaps not quite as pronounced as initially stated.

Finneran J.J., Schlundt C.E., Branstetter, B.K., Trickey, J.S., Bowman, V., and Jenkins, K. (2013). Temporary threshold shift (TTS) in odontocetes in response to multiple air gun impulses. Final Report for JIP Project 2.1.1., 51 pp. Available online at http://www.soundandmarinelifejip.org/index.php?doc=docmeta&id=3695

Finneran J.J., Schlundt C.E., Branstetter, B.K., Trickey, J.S., Bowman, V., and Jenkins, K. (in review). Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. Submitted to J. Acoust. Soc. Am. Gross JA, Irvine KM, Wilmoth S, Wagner TL, Shields PA and Fox JR . 2013. The Effects of Pulse Pressure from Seismic Water Gun Technology on Northern Pike. *Trans Am Fish Soc* 142: 1335-1346. ISSN: 0002-8487 print / 1548-8659 online DOI: 10.1080/00028487.2013.802252.

The study assessed the probability of mortality of pike (freshwater) when exposed to two pulses at 3, 6 and 9 meters distance from either a 343 cu in water gun or a 120 cu in water gun, both pressurized at 2000 psi. Measures of peak and peak to peak pressure were made as well as $SEL_{cum.}$ SEL_{cum} was used as the metric for effects in most of the results and discussion since it seemed to correlate best with levels of injury and mortality. Mortality within 72-168 hours was correlated with SELs in excess of 195 dB. Gas bladder rupture was observed at 199 dB SEL; 100% of fish at 3-6 meters and 87% of fish at 9 meters. Given the history of water guns producing greater injury and mortality than airguns, these results with two pulses from good sized single guns, indicate that fish would need to be within a few meters of a single airgun or full array to achieve comparable effects.

Harrington JJ, McAllister J, and Semmens JM. 2010. Assessing the short term impact of seismic surveys on adult commercial scallops (Pecten fumatus) in Bass Strait: Final Report. Tasmanian Aquaculture and Fisheries Institute, U. of Tasmania

Scallops were sampled from control and exposure sites before and after an extensive 2-D seismic survey. No statistical differences were found between control and exposed populations, neither in survival nor body condition. Exposure levels were not recorded. The paper also reviews several prior studies of seismic effects on scallops in Ireland and other sites, all also with no effect. One cited paper reported that one of three scallops experienced a split in its shell at distance of 2 meters from an airgun.

Higgins SM. 2014. Declaration; State of New Jersey, Dept of Environmental Protection vs National Science Foundation, et al. United States Federal District Court, District of New Jersey. Case 3:14-cv-04249-PGS-LHG, Document 6-7, filed 07/07/14, pageID 1520-1527

Contains a comparison of annual commercial and recreational fishery catches for years and months in which seismic surveys were conducted off the New Jersey coast, relative to the same months in other years, between 1990-2004. No discernable differences were found between periods with seismic survey and without. (Fishery statistical data from NMFS 2014, http://www.st.nmfs.noaa.gov/).

Lavender, A.L., Bartol, S.M., and Bartol, I.K. (2014). Ontogenetic investigation of underwater hearing capabilities in loggerhead sea turtles (*Caretta caretta)* using a dual testing approach. J. Exp. Biol., 2014, 217(14):2580-2589.

Løkkeborg S, Ona E, Vold A, and Salthaug A. 2012. Effects of sounds from seismic air guns on fish behaviour and catch rates. In A.N. Popper and A. Hawkins (eds.), *The Effects of Noise on Aquatic Life*, Advances in Experimental Medicine and Biology 730, DOI 10.1007/978-1-4419-7311-5_95, pp. 415-419.Springer, NY NY.

This paper provides a good review of prior behavioral studies. They also report recent data from what is arguably the most realistic and thorough study to date; monitoring of two fisheries (gillnet and longline) for four species of fish; a halibut, two gadids (pollack and haddock) and a seabass (Sebastes marinus), along with acoustic (HF sonar) surveys of the fish populations. Gillnet catches of halibut and seabass increased during and after survey, possibly due to increased swimming activity, while longline catches of halibut and pollack decreased. Acoustic surveys revealed decreases in pollack abundance, but not other species, consistent with prior study by Engås et al (1996a,b).

McCauley RD, Kent CS, Archer M. 2008. Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef Lagoon, Western Australia: Full report of Curtin University findings. Center for Marine Science and Technology, Curtin University, Perth WA. 92 pp. CMST Report 2008-32.

An extensive research effort involving a real seismic survey over a thoroughly monitored reef lagoon. Caged snapper and damselfish were exposed to seismic passes as close as 45-74 meters with 1% loss of hearing hair cells, later fully recovered. Behavioral reaction was observed at 155-165 dB SPL sound exposure levels but avoidance only occurred out to 200 meters on either side of survey. There was no effect on normal fish sound choruses.

McCauley RD, Fewtrell J and Popper AN. 2003. High intensity anthropogenic sound damages fish ears. J Acoust Soc Am 113(1):638-642 DOI: 10.1121/1.1527962

The authors were able to produce considerable unrecovered damage to the sensory structures of a typical fish ear (Pink snapper) after seven close passes (5-15 meters) by a towed 20 cubic inch seismic air source in the span of four hours. Although no cumulative Sound Exposure Level (SEL) or peak pressure or particle velocity measures were reported, the graphical display of the passes indicates multiple exposures over short periods of time at levels in excess of 180 dB SPL $rms_{0.95}$. The fish were caged and the authors noted that their movements indicated that the fish would have moved away from the sound source if possible, thus preventing the artificially high levels of exposure experienced.

Miller I. and Cripps E. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. Mar Pol Bull. Elsevier Press. http://dx.doi.org/10.1016/j.marpolbul.2013.10.031

No change in abundance or species composition was found in a natural reef community of resident reef fishes (emphasis on damselfishes) and mobile demersal fishes (emphasis on snappers of the Family Lutjanidae). Multiple passes by a full working seismic array were separated by about 6 hours between pass. Minimum stand-off distances from the reef were 400 meters on the outside and 800 meters inside the reef lagoon. Estimated exposures were generally around 187 dB SEL with some exposures as high as 200 dB SEL. Instantaneous peak or average SPL or particle velocity/acceleration were not measured.

Moein, S. E., Musick, J. A., Keinath, J. A., Barnard, D. E., Lenhardt, M. L. & George, R. 1995. Evaluation of seismic sources for repelling sea turtles from hopper dredges. In *Sea Turtle Research Program: Summary Report*. (Ed. Hales, L. Z.) pp 90-93. Technical Report CERC-95.

National Research Council (NRC). 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. National Academy Press, Washington DC. www.nap.edu.

This NRC report lays out a framework for estimating long term, cumulative population consequences from behavioral disturbance by sound, and by extension, any source of behavioral perturbation, individually or cumulatively. While developed for marine mammals, the principles of the Population Consequences of Acoustic Disturbance (PCAD) model are appropriate to any biological population.

Parry GD and Gason A. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research 79 (2006): 272-284.

A statistical comparison of changes in commercial catch rates (Catch Per Unit Effort, CPUE) coincident with seismic survey effort. No correlation was found in a two way analysis of variance, although the authors do note that most survey effort was in deep water away from the shallow water fishery, and that one survey in shallow water was in an area of low lobster abundance.

Peña H, Handegard NO, and Ona E. 2013. Feeding herring schools do not react to seismic air gun surveys. ICES J Marine Science, doi:10.1093/icesjms/fst079. 7 pp. http://icesjms.oxfordjournals.org/

A full 3-D seismic survey array was used to assess responses of herring monitored by an omnidirectional fisheries sonar. The source vessel approached the fish school from a distance of 26 km to a close approach at 2 km without any effect on the swimming and schooling behavior of the fish.

Popper AN, Smith ME, Cott PA, Hanna BW, MacGillivray AO, Austin ME and Mann DA. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. J Acoust Soc Am 117:3958-3971.

Whitefish and juvenile pike did not show any TTS after exposure to five seismic playbacks of about 209 dB SPL_{peak} or 180 dB SEL, and particle displacements of 139 db SVL re 1nm/s (it is not possible to determine which physical property was responsible for any TTS observed in any of the tests). Adult pike under similar exposure conditions showed a TTS of about 20 dB at 400 Hz, which was recovered within 18 hours. Chub, also under similar exposure levels, showed slightly higher levels of TTS, about 25 dB at 200 Hz and 35 dB at 400 Hz, similar for 5 playbacks or 20 playbacks, and fully recovered within 18 hours. Chub are members of a hearing specialist family of freshwater fishes with no marine species.

Santulli A, Modica A, Messina C, Ceffa L, Curatolo A, Rivas G, Fabi G, D'Amelio V. 1999. Biochemical Responses of European Sea Bass (Dicentrarchus labrax L.) to the Stress Induced by Off Shore Experimental Seismic Prospecting. *Marine Pollution Bulletin*, Volume 38, Issue 12, December 1999, Pages 1105-1114.

This study involved exposure of caged fish to very close and very prolonged seismic air source in order to obtain physiological responses typical of stress. The fish returned to baseline levels within 72 hours, with no injury and no apparent lasting effect, despite the unusually high and prolonged sound exposures.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of Northern Canadian freshwater fishes following exposure to seismic air gun sounds**. J. Acoust. Soc. Am.** 124(2):1360-1366.

No damage was found to any of the ears of the test fish from Popper et al (2005), despite findings of Temporary Threshold Shift in two cases where peak pressure exceeded 205-209 dB re 1μPa SPL (peak) or 176-180 dB re 1μPa_2-s single impulse (shot) SEL.

United States Navy. 2013. Atlantic Fleet Training and Testing Final Environmental Impact Statement /Overseas Environmental Impact Statement. Available online at http://aftteis.com/DocumentsandReferences/AFTTDocuments/FinalEISOEIS.aspx

Wardle CS, Carter TJ, Urquhart GG, Johnstone ADF, Ziolkowski AM, Hampson G, Mackie D (2001) Effects of seismic air guns on marine fish. Cont Shelf Res 21:1005–1027.

A study of free swimming cod, pollack and hake on a reef, using a fixed seismic source. C-start but no movement away from the source was observed at exposure levels up to 195 dB SPL at a distance of 109 meters. The authors speculate on possible reasons for the lack of response, including site fidelity to the unique reef environment at which the study was performed.