Are We Mitigating Underwater Noise-Producing Activities Adequately?: A Comparison of Level A and Level B Cetacean Takes

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ABSTRACT

Safety zones and Marine Mammal Observers (MMOs)/Passive Acoustic Monitoring (PAM) or ramp up (soft start) as mitigation measures for underwater noise-producing activities (e.g. seismic surveys, naval sonars) are largely unproven in their effectiveness. Moreover, they are only designed to primarily reduce Level A (injury) "takes" under U.S. law. Here, six Environmental Impact Statements or Reports were examined to determine whether the focus on reducing Level A takes is sufficiently protective and effective by comparing the numbers of Level A with Level B takes (behavioral disturbance). Level A takes from mid-frequency naval sonar were found to comprise only 0.005-0.065% of all predicted Level B takes, and 0.3-4.0% of Level B takes from a seismic survey. Thus, the focus on preventing near field, injurious Level A exposures seems out of proportion to the number of animals affected. Given new research showing dramatic behavioral responses at received levels as low as 89 dB (DeRuiter *et al.*, 2013), the current U.S. threshold of 160 dB for Level B cetacean takes may not be precautionary enough. If lower thresholds for Level B takes are adopted, Level B takes will make up even smaller percentages of Level A takes, and impact radii will extend out to tens to hundreds of kilometers. MMOs and PAM are of limited usefulness even in small safety zones of 500m, but beyond 1km, their effectiveness will be even more questionable. Spatio-temporal mitigation (time-area closures) and quieting alternative technologies, such as Marine Vibroseis, in contrast to safety zones and ramp up, can dramatically lower both Level A and B takes. Time-area closures are less effective when range-limited, year-round resident populations are involved or when projects can't easily be moved, such as with most seismic surveys. Marine Vibroseis, which exposes only 1-15% of animals to higher noise levels compared with airguns, presents a better option in these cases. Only in these ways, can noise producers minimize their small numbers "takes" of cetaceans required by U.S. law.

KEYWORDS

noise, conservation, management procedure, monitoring, acoustics, regulations, cetaceans

INTRODUCTION

A growing literature on the impacts of anthropogenic noise on marine animals (e.g. Hildebrand, 2005; Popper and Hastings, 2009; Richardson *et al.*, 1995; Weilgart, 2007; Wright, 2014; Wright and Highfill, 2007) leaves little doubt that anthropogenic noise should be considered a substantial stressor on marine life, degrading the marine environment in ways that can affect individuals as well as populations (Claridge, 2013) and ecosystems. Currently, the primary mitigation tools for noise-producing activities such as naval exercises involving sonar, seismic surveys, explosions, and pile driving include planning to conduct activities in areas and during seasons when fewest sensitive cetaceans are present (spatio-temporal mitigation or time-area closures), using safety zones and Marine Mammal Observers (MMOs) or PAM (Passive Acoustic Monitoring) operators to shut down or power down when animals are sighted or heard near the sound source(s), ramp ups or soft starts to increase the sound source(s) gradually (Nowacek *et al*., 2013), and sometimes deploying Acoustic Harassment or Deterrent Devices to theoretically scare away animals before an explosion or pile driving, for instance. Another approach is to quiet the noise at the source or to attenuate it near the source using sound-damping technologies, as was highlighted at the 2013 Quieting Technologies for Reducing Noise During Seismic Surveying and Pile Driving Workshop (CSA Ocean Sciences Inc., 2014) and in the recent review by Simmonds *et al.* (2014). This mitigation tool is likely to be effective, as we have some idea which characteristics of noise make it more harmful (high peak pressure, high rise time, long duration, long duty cycle, frequency overlap with species in the area, omni-directionality, etc.). Few would also argue against the effectiveness of spatial-temporal mitigation, provided that the abundance and distribution, spatially and temporally, of sensitive animals is indeed well-known (Dolman *et al*., 2011; Nowacek *et al*., 2013). Marine Protected Areas managed for noise have also been proposed as a potentially effective mitigation tool (Dolman, 2007; Weilgart, 2006).

However, the effectiveness of the other mitigation tools is less well proven, if at all, and these have been criticised for their inadequacy (Dolman *et al.*, 2009; Parsons *et al.*, 2008; Parsons *et al.* 2009; Weir and Dolman, 2007). Under U.S. law, the number of "takes" represents the number of animals or incidents of disturbance, harassment, or killing that are anticipated to occur. These takes can be of a Level A (injury) or a Level B (behavioral disturbance). In the past, the U.S. adopted 180 dB as the threshold for Level A injury for cetaceans, and 160 dB for disturbance. More recently, the U.S. Navy uses the dual criteria of cSEL (cumulative sound exposure level), a metric which includes the duration of exposure, and peak pressure. M-weighting, a way to correct the sound level measurement for different frequency-dependent hearing among marine mammals, is also applied to thresholds as this takes into account the difference in frequency sensitivity between groups of cetaceans (low frequency, LF; mid-frequency, MF; or high frequency, HF, cetaceans).

However, such weighting cannot be reliably applied to Level B thresholds or behavioral responses, as animals often react strongly to sounds outside the frequencies of their greatest sensitivity (e.g. Cook *et al.*, 2006; Melcón *et al.*, 2012; Miller *et al.*, 2012, Pirotta *et al.*, 2012; Stone and Tasker, 2006). New thresholds for injury (Level A) are currently under review by the U.S. regulatory agency, the National Marine Fisheries Service (NMFS). The purpose of the safety zone is to reduce Level A (injury) takes which have traditionally been assumed to occur near the sound source, whereas Level B takes have been considered to occur at greater distances from the source. The concept of Level A takes only occurring in the near field may need to be re-examined in light of new information. For instance, beaked whales (Family Ziphiidae) showed severe hemorrhaging in vital organs and even death at sea or through strandings from naval exercises using mid-frequency sonar (Fernandez *et al.*, 2005) at received levels (perhaps 150-160 dB—Hildebrand, 2005) corresponding to distances well beyond traditional safety zones of 500 or 1,000m. Moreover, harbor porpoises (*Phocoena phocoena*) can exhibit TTS (temporary threshold shift) or temporary hearing impairment at levels as low as 124 dB (Kastelein *et al.*, 2012), which would also be experienced far beyond safety zones, at distances of many kilometers. Considerable effort is expended in sighting or listening for whales in the safety zone, and in shutting or powering down noise sources, so it is appropriate that this measure be examined for effectiveness in a way that would actually have enough statistical power to detect impacts and whether they are being meaningfully reduced through mitigation measures.

New thresholds for behavioral disturbance, beyond the 160 dB level, have not been determined yet, due to the variable nature of behavioral responses to noise with context, age, sex, species, etc. (Ellison *et al*., 2011). However, recent research casts doubt on the appropriateness of the 160 dB level. For instance, beaked whales dramatically responded to mid-frequency naval sonar at received levels of 89-127 dB re 1µPa (DeRuiter *et al.*, 2013). Blue whales (*Balaenoptera musculus)* also changed their calling behavior after being exposed to mid-frequency naval sonar of mostly around 110-120 dB rms, but also as low as 80 dB, (Melcón *et al*., 2012).

This paper will examine whether the focus on reducing Level A takes through the safety zone is sufficiently protective and effective by comparing Level A takes with Level B takes. The use of alternative areas and under which circumstances these could reduce takes will also briefly be discussed. It is important to understand how dramatically potential takes increase with distance from the sound source, when lower received levels are being considered as damaging or disturbing. As such, tables have been included to illustrate this effect. Finally, potential takes were compared from an alternative, quieter technology to seismic airguns, known as Marine Vibroseis, to illustrate the mitigation effectiveness of quieter sources.

METHODS

Efforts were focussed on six environmental impact reports (EIR), assessments (EA), or statements (EIS), namely the California State Lands Commission EIR for the Central Coastal California Seismic Imaging Project, also known as the Diablo Canyon Project (CSLC, 2012), the CSLC Mitigated Negative Declaration Low Energy Offshore Geophysical Permit Program Update (CSLC, 2013), the U.S. Navy's Atlantic Fleet Training and Testing EIS (DON, 2013a), their Hawaii-Southern California Training and Testing EIS (DON, 2013b), their Atlantic Fleet Active Sonar Training EIS (DON, 2008), and the EA of Marine Vibroseis (LGL and MAI, 2011). Thus, seismic surveys, other lower energy geophysical sound sources (multibeam echosounder, sidescan sonar, subbottom profiler, and boomer), and naval sonars were the sound sources represented here. Tables in these various documents were used and adapted to simplify the analysis by accepting the data and assumptions behind the tables for the purposes of this paper. Cetacean species densities from the various EIS/EIRs were used, where mentioned, and from the website http://cetsound.noaa.gov/cda.html. Various representative species found off California were chosen from the different cetacean groups: low frequency (LF), mid-frequency (MF), and high-frequency (HF) specialists, and averaged densities for each group and overall were used. The numbers of animals in the area corresponding to the given impact radii in Tables 6,7, and 8 are only meant as an example for illustration purposes, and should not be given much weight, as animals are almost never evenly spread over a given area in nature, and because densities were randomly chosen. These densities were meant to be credible, but not necessarily accurate, complete, or detailed for species, area, time of year, etc.

RESULTS

Level A vs. Level B Takes

In the seismic survey EIR, it becomes obvious fairly quickly that Level A takes usually form only a small fraction (0.3-4.0%) of Level B takes (Table 1). In Table 1, these percentages (Level A/Level B) may be artificially low, as in this EIR, Level A takes include assumed avoidance because of ramp up. To eliminate the assumed effect of ramp up, percentages would be higher by an order of magnitude for all species except for harbor porpoises, where they would be two orders of magnitude higher. Even so, excluding harbor porpoises, percentages would range from 3-40%, with an average of 20%. Similarly, when comparing Level A with Level B takes for multibeam echosounders and sidescan sonars (Table 2), Level A takes are usually only 18% (multibeam echosounders) or 35% (sidescan sonars) of Level B takes, if one excludes the outlier of common dolphins (*Delphinus delphis*), where Level A and B takes are identical.

In the case of naval sonar, the differences in Level A and B takes become more dramatic. Presently, under U.S. law, only Permanent Threshold Shift (PTS) or permanent hearing impairment is considered a Level A take, since TTS, despite also representing an injury, is considered by the U.S. regulators (controversially) to be recoverable over minutes, hours, or days, depending on severity. Thus, when comparing Level A with Level B takes due to naval sonar training and testing in the Atlantic (Table 3), the contrast is stark, as there are no expected Level A takes, except for harbor porpoises, whereas Level B takes number generally in the thousands and even tens of thousands, excluding harbor porpoises (mean of 6,124; range 60-28,764). If one compares just the less severe TTS takes with Level B takes, the percentages range from 1.1 to 93.9% (mean of 42%). As mentioned, harbor porpoises are the only species expected to suffer Level A takes, yet these make up only 0.005% of the predicted Level B takes. Similarly, looking at overall Level A and B takes for naval sonar in the Atlantic (Table 4), Level A takes comprise only around 0.0065% of Level B takes. In all these cases, Level B takes are based on 160 dB thresholds which may be inappropriately high. If this threshold is lowered, Level A takes will become an even smaller portion of Level B takes.

Alternative Areas

EISs are required to examine alternative areas as a way of mitigating impacts. While it could be argued that project proponents generally only present alternative areas that are convenient to their goals, rather than an exhaustive list of all practicable possibilities, EISs show how acoustic exposures can be reduced by modifying the location of impactful activities (Table 4). Even though the reduction is modest (18% in Level A and 22% in Level B takes between Alternatives 1 and 3), 19 fewer Level A takes and 367,767 fewer Level B takes cannot be dismissed. In the seismic project, the alternative area represents a 33-96% reduction in Level A takes (though numbers are small), but only a 9-19% reduction in Level B takes (Table 5). Still, 314 fewer Level B takes is an improvement.

Takes Relative to Horizontal Distance from Source

In general, Sound Pressure Level (SPL) falls off with increasing distance from the source due to spherical or cylindrical spreading of the sound energy over area. This drop in SPL with distance is not linear, but exponential. Thus, very close to the sound source, the SPL falls rapidly, but further away, the loss is much slower. For example, for a subbottom profiler, for SPL to drop from 160 dB to 140 dB, you must travel away from the sound source from a radius of 36 m to a radius of 607 m, yet from 140 dB to 120 dB, for the same loss of 20 dB, the radius increases from 607m to suddenly 6.7km (Table 6). In this way, the number of high-frequency specialist cetaceans potentially impacted can rise from less than one at 140 dB, to 61 at 120 dB. Even more dramatically, for a boomer, the distance from the sound source at which the SPL drops to 160 dB is a radius of 50m, to 140 dB it is 2.3km, and to 120 dB, 28.1km (Table 7). This corresponds to less than one potentially impacted high frequency cetacean at 160 dB, 7 at 140 dB, and 1,045 animals, over two orders of magnitude higher, at 120 dB. Finally, with mid-frequency naval sonar, less than one low frequency cetacean is potentially impacted at levels up to 162 dB SPL at a 8.7km radius from the source, but this increases to 187 cetaceans at 120 dB and at 172.6km (Table 8). For mid-frequency and high frequency cetaceans, there is less than one animal ensonified at SPLs of up to 180 dB and at 858m, but 25,735 cetaceans at an SPL of 120 dB and at 172.6km.

When comparing the subbottom profiler or boomer to the much louder mid-frequency naval sonar, the potential impact radius of the former is only 32-50m at 160 dB compared with over 9km to perhaps almost 40km for the sonar. At 180 dB, it is less than 20m compared with 850m for the sonar.

Table 1. Level A and B takes for the Central Coastal California Seismic Imaging Project (Diablo Canyon). Probabilistic Disturbance is based on a percentage of the minimum population estimate. The Level A takes include assumed avoidance because of ramp up. Without ramp up, numbers would be 100x higher for harbor porpoises and 10x higher for all other species. (Adapted from CSLC, 2012, Tables 4.4-14 & 4.4-15).

Species	Injury SEL (Level A)	Probabilistic Disturbance (Level B)	% Level A/B
Fin whale (*Balaenoptera physalus*)	2.5	77.6	3.22
Humpback whale (*Megaptera novaeangliae)*	1.2	36.5	3.29
Blue whale (*Balaenoptera musculus)*	0.9	38.3	2.35
Minke whale *(Balaenopter acutorostrata)*	0.1	2.5	4.0
Common dolphin *(Delphinus delphis)*	14.8	1,047.1	1.41
Long-beaked common dolphin(*Delphinus capensis)*	0.5	32.2	1.55
Small beaked whale (Ziphiidae)	<0.1	50.9	-
Harbor porpoise *(Phocoena phocoena)*	22.8	1,438.6	1.58
Dall's porpoise *(Phocoenoides dalli)*	0.9	270.4	0.33
Pacific white-sided dolphin *(Lagenorhynchus obliquidens)*	1.6	111.0	1.44
Risso's dolphin (*Grampus griseus)*	0.7	47.8	1.46
Northern right whale dolphin *(Lissodelphis borealis)*	0.6	44.3	1.35
Bottlenose dolphin *(Tursiops truncatus)*	<0.1	19.8	-
Sperm whale (*Physeter macrocephalus)*	<0.1	0.8	-

Table 2. Summary of Estimated Level A Take (180 dB rms) and Estimated Level B Take (160 dB rms) without Mitigation by Equipment Type. (Adapted from CSLC, 2013, Tables 3-47 & 3-49).

Species	Multibeam Echosounder (Level A)	Multibeam Echosounder (Level B)	Sidescan Sonar (Level A)	Sidescan Sonar (Level B)	Multibeam % Level A/B	Sidescan % Min. A/B
Bottlenose dolphin (coastal)	0.42	2.22	2.18	6.16	18.9	35.4
Common dolphin	1.08	1.08	5.56	5.56	100	100
Northern right whale dolphin	0.13	0.69	0.68	1.92	18.8	35.4
Risso's dolphin	0.20	1.07	1.05	2.98	18.7	35.2
Pacific white-sided dolphin	0.26	1.38	1.36	3.85	18.8	35.3
Long-beaked common dolphin	0.06	0.34	0.33	0.94	17.6	35.1
Harbor porpoise	1.82	9.92	10.12	27.31	18.3	37.1

Table 3. Predicted Impacts per Year from Annually Recurring Sonar and Other Active Acoustic Training Activities for Alternative 2, Atlantic Fleet Training and Testing. Total number of impacts and not necessarily the number of individuals impacted. An animal could be predicted to receive more than one acoustic impact over the course of a year. (Adapted from DON, 2013a, Table 3.4-16).

Species	Behavioral Reaction	TTS	PTS	TTS/Behavior (%)
Atlantic spotted dolphin (*Stenella frontalis)*	12,562	7,447	0	59.3
Atlantic white-sided dolphin *(Lagenorhynchus acutus)*	7,776	2,164	0	27.8
Bottlenose dolphin	16,488	11,760	0	71.3
Clymene dolphin *(Stenella clymene)*	1,302	695	0	53.3
Common dolphin	28,764	16,913	0	58.8
False killer whale *(Pseudorca crassidens)*	60	37	0	61.7
Fraser's dolphin *(Lagenodelphis hosei)*	98	57	0	58.2
Killer whale (*Orcinus orca)*	921	486	0	52.8
Melon-headed whale *(Peponocephala electra)*	767	590	0	76.9
Pantropical spotted dolphin *(Stenella attenuate)*	3,916	3,679	0	93.9
Pilot whale *(Globicephala* spp.)	10,343	4,370	0	42.3
Pygmy killer whale (*Feresa attenuata)*	67	50	0	74.6
Risso's dolphin	14,693	7,614	0	51.8
Rough-toothed dolphin *(Steno bredanensis)*	70	50	0	71.4
Spinner dolphin *(Stenella longirostris)*	1,799	786	0	43.7
Striped dolphin *(Stenella coeruleoalba)*	12,208	6,784	0	55.6
White-beaked dolphin *(Lagenorhynchus albirostris)*	1,335	302	0	22.6
Sperm whale	1,101	584	0	53.0
Blainville's beaked whale *(Mesoplodon densirostris)*	4,595	107	0	2.3
Cuvier's beaked whale (*Ziphius cavirostris)*	5,943	139	0	2.3
Gervais' beaked whale *(Mesoplodon europaeus)*	4,526	130	0	2.9
Northern bottlenose whale *(Hyperoodon ampullatus)*	11,946	132	0	1.1
Sowerby's beaked whale *(Mesoplodon bidens)*	2,617	43	0	1.6
True's beaked whale *(Mesoplodon mirus)*	3,068	41	0	1.3
Harbor porpoise	1,964,774	78,250	99	4.0 PTS/Behavior=0.005

Table 4. Summary of acoustic exposure estimates by alternative in Atlantic Fleet Active Sonar Training (Adapted from DON, 2008, Table 4-29).

Alternative Areas	Level A	Level B	A/B %
Alternative 1	87	1,334,912	0.0065
Alternative 2	90	1,371,209	0.0066
Alternative 3	106	1,702,679	0.0062
No Action Alternative	124	1,911,195	0.0065

Table 5. Modelled harbor porpoise take counts with alternative areas for the Central Coastal California Seismic Imaging Project (Diablo Canyon). (Adapted from CSLC, 2012, Table 5.3-5).

Take Estimates	Proposed Project	Alternative	% Reduction
Level A (injury SEL)	23-52	1-3	96-94
Level A (NMFS Minimum)	3-8	2-4	33-50
Level B (Probabilistic minimum)	1,438-3,256	1,303-2,950	9
Level B (NMFS Minimum)	734-1,662	596-1,348	19

Table 6. Subbottom Profiler - horizontal distances from the source (m) in the Low Energy Offshore Geophysical Permit Program-- 180 dB re 1 µPa SPL (Sound Pressure Level) is the threshold for injury; 160 dB re 1 µPa SPL for behavioral modification). Cetacean densities used: LF average: 0.002 animals/km^2; MF average: 0.119 animals/km^2; HF average: 0.430 animals/km^2; overall average: 0.184 animals/km^2 (Adapted from CSLC, 2013, Table 3-37).

	No weighting		M-weighted					
SPL Threshold	R_{max}	No. of Animals in corresp. area	LF		MF		HF	
			R_{max}	No. of Animals in corresp. area	R_{max}	No. of Animals in corresp. area	R_{max}	No. of Animals in corresp. area
190	<20	-	<20	-	<20	-	<20	-
180	<20	-	<20	-	<20	-	<20	-
160	36	<1	32	<1	36	<1	36	<1
140	607	<1	240	<1	607	<1	607	<1
120	6,699	1	6,151	<1	6,699	17	6,699	61

Table 7. Boomer - horizontal distances from the source (m). Cetacean densities used: LF average: 0.002 animals/km^2; MF average: 0.119 animals/km^2; HF average: 0.430 animals/km^2; overall average: 0.184 animals/km^2 (Adapted from CSLC, 2013, Table 3-38).

	No weighting		M-weighted					
			LF		MF		HF	
SPL Threshold	R_{max}	No. of Animals in corresp. area	R_{max}	No. of Animals in corresp. area	R_{max}	No. of Animals in corresp. area	R_{max}	No. of Animals in corresp. area
190	<20	-	<20	-	<20	-	<20	-
180	<20	-	<20	-	<20	-	<20	-
160	50	<1	45	<1	45	<1	45	<1
140	2,329	3	2,329	<1	2,228	2	2,224	7
120	28,110	457	28,110	5	27,820	289	27,818	1,045

Table 8. Range to received sound pressure level in 6-dB increments for low-frequency, mid-frequency, and high-frequency cetaceans for SQS-53 anti-submarine warfare hull mounted sonar in Hawaii - Southern California training and testing activities. Cetacean densities used: LF average: 0.002 animals/km^2; MF, HF average: 0.275 animals/km^2 (Adapted from DON, 2013b, Tables 3.4-13 & 3.4-14).

Received Level in 6-dB Increments	LF Cetaceans Approximate Distance (m)	No. of Animals in corresp. area	MF and HF Cetaceans Approximate Distance (m)	No. of Animals in corresp. area
120 <= SPL <126	172,558 – 162,925	187-167	172,592 – 162,933	25,735-22,935
126 <= SPL <132	162,925 – 117,783	167-87	162,933 – 124,867	22,935-13,470
132 <= SPL <138	117,783 – 108,733	87-74	124,867 – 108,742	13,470-10,216
138 <= SPL <144	108,733 – 77,850	74-38	108,742 – 78,433	10,216-5,315
144 <= SPL <150	77,850 – 58,400	38-21	78,433 – 58,650	5,315-2,972
150 <= SPL <156	58,400 – 53,942	21-18	58,650 – 53,950	2,972-2,515
156 <= SPL <162	53,942 – 8,733	18-1	53,950 – 8,925	2,515-69
162 <= SPL <168	8,733 – 4,308	<1	8,925 – 4,375	69-17
168 <= SPL <174	4,308 – 1,950	<1	4,375 – 1,992	17-3
174 <= SPL <180	1,950 – 850	<1	1,992 – 858	3-1
180 <= SPL <186	850 – 400	<1	858 – 408	<1
186 <= SPL <192	400 – 200	<1	408 – 200	<1
192 <= SPL <198	200 – 100	<1	200 – 100	<1

Exposures from Marine Vibroseis vs. Airguns

As can be seen from the previous paragraph, lower source levels can reduce the radius of potential impact dramatically. Marine Vibroseis is considered to be at least 30 dB quieter at the source, in terms of peak pressure, compared with airguns. Correspondingly, the potential impact radii would be several orders of magnitude smaller, and the numbers of cetaceans exposed only a fraction of those ensonified by airguns (Table 9). At 180 dB, only from 1-15% of animals would be exposed to Marine Vibroseis relative to airguns, depending on the species. At 160 dB, it would be only 2-10% of the animals.

DISCUSSION

It is undoubtedly important to do all we can to prevent very loud, near field exposures of animals to sound sources. However, the effectiveness of MMOs to sight whales in poor visibility conditions such as higher wind speed, fog, or at night has been called into question (e.g. Barlow and Gisiner, 2006). PAM is also dependent on the cetaceans vocalizing, being heard, localized, and correctly identified to species. Even if all individuals were detected within a 500m safety zone, a great deal of effort is expended on only small numbers of animals (Level A takes) rather than the vast majority that are potentially affected far beyond the safety zone. These animals may also be experiencing TTS, physiological stress, and even death in the case of beaked whales, in addition to or as a result of behavioral disruption, at lower exposure levels than what NMFS considers injury, which is only PTS. Using the U.S. Navy's own numbers, we have seen that Level A takes from mid-frequency naval sonar comprise only 0.005-0.065% of all predicted Level B takes, despite the high (160 dB) NMFS threshold for Level B takes. Given new research showing dramatic behavioral responses at received levels as low as 89 dB (DeRuiter et al., 2013), 160 dB may not be precautionary enough. If lower thresholds for Level B takes are adopted, Level B takes will make up even smaller percentages of Level A takes. MMOs and PAM are of limited usefulness even in small safety zones of 500m, but beyond 1 km, their effectiveness will be even more questionable.

For multibeam echosounders and sidescan sonars, Level A takes were 18% and 35%, respectively, those of Level B takes generally. The sound sources modelled in this program tended to be quite a bit quieter than naval sonars. The assumptions behind Level A takes were different in the seismic survey (CSLC, 2012) compared to those of the U.S. Navy take calculations in that avoidance due to ramp up was assumed in the seismic survey. In general, the assumptions behind the effectiveness of ramp up include: 1) animals would swim away from the sound source once they notice the sound getting louder; 2) animals would know in which direction to swim to escape the increasing noise levels, despite sometimes confusing sound fields such as convergence zones where sound can get louder with increasing distance from the source; 3) animals would not initially come in to investigate the (quieter) sound source only to then be exposed to very loud levels when it may be too late to escape or they may be too panicked to know where to swim; 4) animals would be able to swim away fast enough to escape injury; and 4) animals would not have important reasons to stay in an area, such as food, forcing them to put up with high noise levels. While there have been some indications that during ramp ups some individuals may occasionally move away in some instances, the evidence is far from conclusive. If ramp ups were very effective, there would presumably never need to be any shutdowns or power downs, which is not the case.

While PTS should be considered a serious injury, there is good evidence to support the claim that TTS is also injury, despite the fact that, over the short term, recovery seems to be complete within minutes, hours, or days. Firstly, TTS over time, sometimes only minutes to hours, can result in PTS. Secondly, research on terrestrial animals indicates that TTS can cause permanent auditory nerve damage (Kujawa and Liebermann, 2009) and other hearing deficits later in life. And finally, species that are as dependent on sound as cetaceans will likely suffer compromised capabilities (foraging, mating, predator avoidance, etc.) while experiencing TTS, which could affect their fitness. This is why countries such as Germany consider TTS injury, in contrast to the U.S.

As can be seen from the takes in alternative areas, spatial mitigation can lower the numbers of exposures or numbers of animals exposed. It is considered the most effective mitigation tool, provided there is good knowledge about the abundance and distribution of sensitive species (Nowacek et al., 2013). Spatio-temporal mitigation can sharply reduce all takes, Level A and B, whereas safety zones are only potentially useful in lowering Level A takes. However, time-area closures are less effective when range-limited, year-round resident populations are involved, such as harbor porpoises off California (Table 5), and when projects can't easily be moved, such as with most seismic surveys. In these cases, source-based mitigation or quieting technologies are more appropriate. Marine Vibroseis, in addition to

Table 9. Estimated numbers of representative cetacean species, in MV (Marine Vibroseis) as percentage of airgun, potentially exposed to sounds with received levels ≥160 dB re 1 μPa RMS and ≥180 dB re 1 μPa RMS (M-weighted) during otherwise-comparable airgun-based or MV-based seismic surveys in the northern Gulf of Mexico. The MV source was assumed to produce signals 5 sec in duration and with a roll-off rate (above 100 Hz) of 30 dB per octave (Adapted from LGL and MAI, 2011, Table 6-2).

	Number Exposed to ≥180 dB re 1 μPa RMS (MV as % of Airgun)	Number Exposed to ≥160 dB re 1 μPa RMS (MV as % of Airgun)
Deep Site:		
Bottlenose dolphin	8.8	2.2
Bryde's whale *(Balaenoptera edeni)*	15.2	8.8
Sperm whale	2.3	1.9
Shallow Site:		
Bottlenose dolphin	7.8	10.7
Bryde's whale	3.8	10.7
Sperm whale	1.0	5.6

using lower peak pressures and having no harmful sharp rise times like airguns, has the potential to eliminate broadcasting frequencies over 150 Hz which are not used by the oil and gas industry (CSA Ocean Sciences Inc., 2014; Weilgart, 2012). This would presumably greatly mitigate impacts on especially high frequency specialists like harbor porpoises, and also some beaked whales. Marine Vibroseis exposes only 1-15% of animals to 160 dB or 180 dB compared with airguns (LGL and MAI, 2011).

Lower source levels have a large effect on the number of takes, especially Level B takes and particularly if thresholds below 160 dB are used. The potential radii of impact become huge--tens to hundreds of kilometers--at received levels under 160 dB, but especially 120 dB and below. Safety zone mitigation by PAM, and especially MMOs, becomes extremely difficult, if not nearly impossible, at ranges further than 1-2 km. Under U.S. law, noise producers can only "take" small numbers of cetaceans, which will be challenging if lower behavioral thresholds are adopted, as seems appropriate.

CONCLUSION

The focus on preventing near field, injurious Level A exposures seems out of proportion to the number of animals affected. The safety zone, along with its attendant MMOs and PAM, is unproven in its effectiveness, as are measures such as ramp up. Moreover, exposures beyond the range of the safety zone make up the vast majority of potential impacts. Thus, more emphasis should be given to mitigation measures, such as time-area closures and quieter technological alternatives that are much more likely to be effective and can reduce both Level A and Level B exposures at great distances from the sound source. Only in these ways, can noise producers minimize their small numbers takes of cetaceans required under U.S. law.

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