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## Best available science? Are NOAA Fisheries marine mammal noise exposure guidelines up to date?

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### Abstract

NOAA Fisheries employs a set of in-water noise exposure guidelines that establish regulatory thresholds for ocean actions that impact marine mammals. These are established based on two impact criteria: Level A – a physiological impact including “Permanent Threshold Shift” (PTS), and/or tissue damage, and/or mortality, and Level B – a behavioral impact or disruption. Recently the Level A exposure thresholds were reconciled to the frequency-dependent hearing sensitivities of five classes of marine mammals based on work done more than a decade ago (Southall et al. 2007). Since that time much more work has been published on behavioral impacts of various noise exposures, and consideration of more variables such as frequency-dependent noise propagation characteristics, cumulative, concurrent, and continuous exposures, and noise impacts on marine soundscapes have entered into the discussion – but have not been incorporated into the NOAA Fisheries guidelines.

Some of these variables will be highlighted, suggesting that it may be time to reevaluate the thresholds for Level B exposures.



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## A little history

In 1972 the Marine Mammal Protection Act (MMPA) was signed into law. Aimed most particularly at regulating activities that caused damage or mortality to marine mammals in the course of marine industrial activities (including whaling itself), with the objective of promoting the restoration of whale stocks, and protecting marine mammals that were increasingly becoming entangled up in the growing industrialization of the ocean. But noise was not given much regulatory consideration until the first high-profile noise-associated stranding in 2000.<sup>1</sup> The profile of this event was elevated because it occurred during the hearings and public comment period for the US Navy-proposed Surveillance Towed Array Sensor System – Low Frequency Active (SURTASS\_LFA).<sup>2</sup> But even while these high-profile cases were in play, there was still many questions about whether sound had negative impacts on marine mammals.<sup>3</sup> Prior work on the impacts of marine mammals evaluated injury only in the context of secondary effects of noise disturbance of behaviors,<sup>4</sup> and even as late as 2003 there had been little direct evidence of acoustic trauma in marine mammals.<sup>5</sup>

Acoustical disturbance was first regulated under the MMPA in 1981 – mostly associated with “takes” from oil and gas exploration,<sup>6</sup> which at the time often used dynamite as the excitation source – so the regulation was more about impulse damage than “noise” per se.

Perhaps one of the more ambiguous statutory terms used in the regulation is the word “take.” The MMPA defined a “take” as “to harass, hunt, capture, or kill or attempt to harass, hunt, capture or kill any marine mammal”<sup>7</sup> which likely folded out of the original driving incentive of the Act in response to high marine mammal mortality associated with purse seine operations, and of course the intentional takes of commercial whaling. The term is ambiguated by the word “harass,” which was not statutorily defined until 1994, “...but in practice the term was interpreted to mean any documented change in distribution or behavior caused by human activity.”<sup>8</sup>

There was also a lot of equivocation about the relative value of “takes” between commercial takes for zoos and aquariums, takes for scientific research, and takes by subsistence hunters. There was also the unintentional - or “incidental” takes for navy exercises and offshore oil and gas operations for which “Incidental Harassment Authorizations” were devised.

Distinguishing the severity of the takes began flavoring the 1981 amendments of the Act, but the actual statutory definitions of “Level A” and “Level B” takes didn’t show up until 1994, when the term “harassment” was statutorily defined under these distinctions.<sup>9</sup> A “Level A” take is pretty clearly defined as “any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild.” The acoustical exposure threshold for this can be determined by way of inferring (through auditory threshold testing) how loud a sound exposure would need to be to cause a permanent hearing threshold shift. I say “inferred” because empirically determining the threshold of hearing damage on a marine mammal would be unethical and immoral.

## Determining regulatory thresholds

In the early stages of the “Level A Take” definition there was a bit of “push and pull” but was finally settled by the National Marine Fisheries Service (NMFS) as a “do not exceed” threshold below which physical injury would not occur. In cetaceans this was 180dB re: 1μPa (ref. <sup>10</sup>) (in pinnipeds this was 190dB).<sup>11</sup>

Level B exposure is defined as “any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns, including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering, to a point where such behavioral patterns are abandoned or significantly altered.”<sup>12</sup> But defining what constitutes “disruption” is itself fraught with threshold vagaries – given that behavior is always contextual, and the weight of the biological significance of the

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disruption hinges on a human value scale. How biologically significant is it when Bowhead whales change their vocalization rates in response to airgun CSEL<sub>10-min</sub> of 80-85dB re: 1μPa<sup>2</sup>-s (ref.<sup>13</sup>) – well below the Level B threshold?<sup>14</sup> How biologically significant is it when a sea lion risks exposure to loud, (above Level A) intentionally harassing signals to predate on fish pens in a behavioral relationship known as “the dinner bell effect?”<sup>15</sup>

## Regulatory Metrics

Regulations work best when they are unambiguous. Regulators are not fond of nuance. Dichotomous decisions of Yes/No, Go/No-Go are their stock and trade. It was for this reason that until just recently the marine mammal exposure guidelines were really simple:

Noise exposure above 180dB = Level A exposure

Noise exposure above 160dB = Level B exposure (for impulsive sounds)

Noise exposure above 120dB = Level B exposure (for continuous sounds)

But it was clear that these regulatory thresholds were actually too simple. When dolphins were riding the bow waves of seismic survey vessels – frolicking in a Level A noise field, it was apparent that the regulatory thresholds did not reflect common field conditions. This was addressed in what became known as “Southhall 2007”<sup>16</sup> which eventually informed the current NOAA Fisheries noise exposure guidelines.<sup>17</sup> These guidelines more accurately reflected the noise exposure criteria relative to the hearing ranges of a range of marine mammal species; Low Frequency Cetaceans, Mid Frequency Cetaceans, High Frequency Cetaceans, Sirenians (dugongs and manatees), Phocids (seals), Otariid (eared seals) and other non-phocid marine carnivores such as otters.<sup>18</sup>

While this new standard more accurately reflected the frequency-defined hearing ranges of the exposed animals, it did not accurately address the complexity of the noise exposures in terms of sound qualities, nor in terms of the complexity of the sound environments in which the exposures would typically occur. The regulatory thresholds have been derived through a synthesis of marine mammal auditory threshold testing. These thresholds have been established using sinusoidal signals or sinusoidal-derived band-limited ‘pink’ noise.<sup>19</sup> While these signals do lend consistency to audiometric testing, they do not necessarily reflect the characteristic signals being introduced into the sea. They may even poorly reflect actual marine mammal thresholds because the ocean – and all of the noise from natural activities and actions in the sea, are inherently sinusoidal.

## Actual sound exposures

Increasingly complex signals are being used in the sea for underwater communication and equipment control. These communication signals include characteristically rapid rise-times either in set frequencies such as square waves or other high “crest factor”<sup>20</sup> signals which are non-sinusoidal – which, unlike sinusoids, can be rough or “screechy,” and more disturbing<sup>21</sup> than equal energy-level sinusoidal signals. They can also be more damaging.<sup>22</sup> Signal characteristics that would have behavioral and physiological damage impacts are not accurately reflected in the definitions for Level A and Level B thresholds.

Additionally, sounds presented in the typical Environmental Impact Statements (EIS) are presented as single sources of sound, and while there is some consideration for cumulative impacts,<sup>23</sup> the accumulation period “resets” after 24 hours, so the metric only reflects accumulated noise exposure and does not address the impacts of a habitat completely transformed by continuous, or ongoing noise. Given that typical seismic airgun surveys run around the clock for weeks to months at a time, and have an acoustical reach of hundreds to thousands of kilometers, the activity is likely to have much greater behavioral impact than is reflected in accumulating and dumping of a noise exposure index every 24 hours.

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Furthermore, operations such as seismic survey, or underwater extraction industry operations typically have a lot of different, but simultaneous sound sources. Seismic surveys may include seafloor profiling with multi-beam or side-scan sonars. It was, in fact the seafloor profiling sonars (Multi-Beam Echo Sounders) that were estimated to be the cause of a mass-stranding incident in Madagascar in 2008,<sup>24</sup> not the seismic surveys.

Underwater extraction industries such as seafloor processing for hydrocarbon extraction, or seafloor mining operations will necessarily have multiple sound sources - with equipment, along with acoustical communications for status monitoring, and remote and autonomous control of the equipment. These concurrently-operating compliments of equipment can create a very complex soundscape. And even if the specific pieces of equipment don't in-and-of-themselves exceed regulatory thresholds, they may nonetheless create acoustically-hostile soundscapes likely to have behavioral and metabolic impacts on marine animals.<sup>25</sup> So far there are no qualitative metrics for compromised soundscapes, but modeling for concurrent sound exposures is possible, and in this context, many concurrent sounds would constitute "continuous sound," thereby qualifying the soundscape as a whole under the Level B continuous sound criteria of 120dB.<sup>26</sup>

This is particularly the case for a proposed set of seismic surveys in the Mid-Atlantic,<sup>27</sup> wherein three separate geophysical surveys will be occurring simultaneously in close proximity. Incidental Harassment Authorizations have been released by NOAA Fisheries for these surveys which have not taken the 'concurrent noise exposures' into account.

Additionally, while sound sources in the near-field may be considered "impulsive sounds," and thus regulated under "Level B" criteria for impulse sounds, due to reverberation and multi-path echoes, louder sounds which have a long reach should be considered as "continuous sound sources" in the far field and thus be regulated under the Level B continuous sound criteria of 120dB.

### **Recommendations:**

1. NOAA sound exposure metric should be updated to reflect sound quality (accommodating for signal characteristics) as well as amplitude.
2. "Soundscapes" need qualitative and quantitative definitions, and then incorporated into the regulatory framework.
3. Exposure metrics needs to accommodate for concurrent sound source exposures.
4. The threshold for what constitutes "continuous sound" needs to be more clearly defined, particularly in terms of loud sound sources in the far field subject to reverberation and multi-path echoes.

### **References:**

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  - <sup>3</sup> Hofman, Robert J., (2003). *Marine Sound Pollution: Does It Merit Concern?* Marine Tech. Soc'y Journal 61
  - <sup>4</sup> Richardson, W. John, Charles R. Green, Jr., Charles I, Malme, Denis H. Thompson (1995) *Marine Mammals and Noise* Academic Press.
  - <sup>5</sup> National Research Council (2003) *Ocean Noise and Marine Mammals* p. 89 National Academies Press
  - <sup>6</sup> McCarthy, Elena, Flora Lichtman (2007) *The Origin and Evolution of Ocean Noise Regulation under the Marine Mammal Protection Act* Ocean and Coastal Law Journal v. 13
  - <sup>7</sup> 16 U.S.C. § 1362(13) (Supp. 1972).
  - <sup>8</sup> McCarthy and Lichtman (2007) Ocean and Coastal Law Journal v. 13
  - <sup>9</sup> 16 U.S.C. § 1362 (18)(A)(ii) (1994).
  - <sup>10</sup> Hereinafter all absolute sound pressure levels will be referenced to 1µPa.
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- <sup>11</sup> National Marine Fisheries Service (NMFS). (1995). *Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California: Notice of issuance of an incidental harassment authorization*. Federal Register, 60(200, 17 October), 53753-53760.
- <sup>12</sup> 16 U.S.C. § 1362 (18)(B)(ii) (1994).
- <sup>13</sup> Cumulative Sound Exposure Level over 10 minutes re  $1\mu\text{Pa}^2$  per second
- <sup>14</sup> Blackwell SB, Nations CS, McDonald TL, Thode AM, Mathias D, Kim KH, et al. (2015) *Effects of Airgun Sounds on Bowhead Whale Calling Rates: Evidence for Two Behavioral Thresholds*. PLoS ONE 10(6):
- <sup>15</sup> David John St. Aubin, Joseph R. Geraci, Valerie J. Lounsbury (1996) *Rescue, Rehabilitation, and Release of Marine Mammals: An Analysis of Current Views and Practices : Proceedings of a Workshop Held in Des Plaines, Illinois, 3-5 December 1991* NMFS
- <sup>16</sup> Brandon L. Southall, Ann E. Bowles, William T. Ellison, James J. Finneran, Roger L. Gentry, Charles R. Greene Jr., David Kastak, Darlene R. Ketten, James H. Miller, Paul E. Nachtigall, W. John Richardson, Jeanette A. Thomas, & Peter L. Tyack (2007) *Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations* Aquatic Mammals Volume 33, Number 4
- <sup>17</sup> NOAA Technical Memorandum NMFS-OPR-59 (2018) *2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0) Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts*
- <sup>18</sup> Ibid.
- <sup>19</sup> Band limited “Pink Noise” is typically derived from Fourier Transfer derived Gaussian noise constructed from sine waves without any coherent time-domain component.
- <sup>20</sup> Crest factor is the ratio of peak to RMS value of a signal. Pure sinusoidal waves have a crest factor of .707; pure “square waves have a crest factor of 1; repetitive impulse sounds have a crest factor greater than 1.
- <sup>21</sup> Sukhbinder Kumar, Helen M. Forster, Peter Bailey, Timothy D. Griffiths (2008) *Mapping unpleasantness of sounds to their auditory representation* J. Acoust. Soc. Am. 124: 6
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- <sup>23</sup> NOAA Technical Memorandum NMFS-OPR-59 (2018) Appendix D.III *Modeling Cumulative Sound Exposure Levels*
- <sup>24</sup> Southall, B.L., Rowles, T., Gulland, F., Baird, R.W., and Jepson R.T. (2103) *Final report of the independent scientific review panel investigating potential contributing factors to a 2008 mass stranding of melon headed whales (Peponocephala electra) in Antsohihy, Madagascar.*
- <sup>25</sup> Rolland, R. M., Parks, S. E., Hunt, K. E., Castellote, M., Corkeron, P. J., Nowacek, D. P., . . . Kraus, S. D. (2012). *Evidence that ship noise increases stress in right whales*. Proceedings of the Royal Society B-Biological Sciences, 279(1737), 2363-2368.
- <sup>26</sup> “Continuous sounds are those whose sound pressure level remains above that of the ambient sound, with negligibly small fluctuations in level” (NIOSH, 1998; ANSI, 2005).
- <sup>27</sup> <https://www.boem.gov/Atlantic-G-G-PEIS/>
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