**Sound Production Intensity and its Correlation to Mass in Cetaceans**

By Blake Pack

**Introduction**

A sound wave is measured by its frequency (Hz) and its intensity/amplitude (dB), with frequency representing the number of wave cycles per a given time or distance. Intensity of sound is measured in decibels(dB) and is the loudness aspect of sound that we hear. The ranges of sound production and perception differ across species. Different intensities and frequencies can be used for different reasons due to how sound travels with respect to the intensity and frequency1.

**Figure 1 Sound Wave Visualization**

A picture containing table

Description automatically generated

Sound is a form of energy and depending upon the frequencies and intensities can travel different lengths and through different things. Lower frequency sounds travel through obstructions and further than those of higher frequencies due to them being able to penetrate obstructions without colliding as frequently with said obstruction. Higher intensity sounds also travel further than less intense sounds due to the fact that energy and amplitude in sound decrease the further from the source you travel, thus by increasing the amount of energy put in to create the sound at the start the longer it will take for the energy to diminish1. Understanding the types of sounds, calls, intensities, and frequencies is very important in understanding an animal’s behavior and purpose of the sounds.

Many of the loudest sound producing organisms are also very large in terms of mass, with many of the loudest sounds coming from some of our largest creatures. The blue whale’s estimated range topping out at 188dB, the sperm whale’s maximum is estimated to be 230dB, and an elephant’s maximum is estimated to be 117dB. To help put that in perspective here are a few sound intensity benchmarks that are well known, a rock concert is around 145dB loud, a lawn mower is around 100dB, and a space shuttle launch from the minimum safe distance is 170dB2.

In this paper I will analyze the intensity of communicatory calls in several Whale (cetacean) families for the purpose of seeing if a whale’s mass and its intensity of sounds produced have a correlation. For the purposes of this paper intensity(dB) will be the only sound component analyzed and I will focus on calls responsible for communication between whales. In whales there are two main types of calls, the communicatory calls which include the whistles and moans, and then the clicking sounds responsible for navigation. The clicking sounds are generally high frequency and lower intensity while the whistles are lower frequency and higher intensity. The original hypothesis of this paper is that a cetacean’s mass and its ability to produce high intensity sounds is positively correlated in both averages and maximums.

**Materials and Methods**

**Data used and Gathering Methods**

The data collection was broken down into two major parts. Cetacean sounds were collected and analyzed for intensity in a semi-random form following a set of criteria. And the other part being the collection of known maximum sound production ranges, which were collected from other articles and research papers. The major database pulled from for audio clips was the “Watkins Marine Mammal Sound Database”, making up 78 of the 96 calls analyzed3. This database has call types listed, the audio is available for download, has sounds organized by species, has the sound clips cut into one call, and has ample metadata for each audio clip. Other audio analysis was done on species not available on Watkins Database. These sound clips were mainly found in other marine sound databases, Wikipedia’s cetacean audio library, and through YouTube audio clips.

Each audio clip chosen for analysis was listened to for clarity first, then for call type, and then narrowed for length. The clips analyzed ranged from less than a second in length to over eighteen seconds. Whistles were the main call type chosen for analysis as they are generally the most intense communicatory call. Eight audio clips maximum per species was set to give enough room for an accurate average but not so many that it would limit time spent on analysis and gathering data on other species. Data on sixteen cetacean species was gathered under this method and ninety-six calls were analyzed in total. For the known sound production maximums, they were gathered mainly through other research articles as posted in the data and cited below Figure 2. If a maximum could not be found then the species was left out of the known maximums correlation test, only nine were included total in this correlation.

**Analyses of Data**

The sounds chosen randomly were analyzed using a computer app called Decibel X and by using youlean’s online analysis tools4,5. Through the analysis in these apps the average decibel of a given audio clip and the maximum decibel reached throughout the clip was recorded. The maximums of each call for a species were averaged and the average of each clip was also averaged for each species. All three of these averages were graphed against the average masses of each species. Pearson correlation tests were then conducted on these averages against the averaged masses and another test was done on the known maximum against the average masses, both at the 95% confidence interval. All species average adult masses were gathered from ecological archives6 and all statistical tests and graphs were done in R-coding7.

**Results**

The Pearson product moment correlation between the average dB of each recording and mass was 0.157. The Pearson correlation between the average of the average dB per species and the average mass was 0.223. The Pearson correlation between the average maximums and average masses was 0.227. Lastly, the Pearson correlation between known maximums and mass was 0.425. In Figure 2D the Sperm Whale and Sei whale was added to the data set as their known maximums were available but sound clips with proper analysis was not possible13,14.

****

Figure 2A shows the results from the sound analysis with the average intensity in decibels for every sound analyzed against the average masses of each species. Figure 2B shows the average of the average sounds for each species graphed against the average mass of the species. Figure 2C shows the Average of the Maximum sounds analyzed for each species graphed against their average masses. Lastly Figure 2D is the Estimated Maximum Intensity Sounds possible to be produced against their Average Masses8–14.

**Discussion**

Based on the correlations calculated there is a positive correlation between a cetacean species average mass and its ability to produce more intense sounds, so the original hypothesis was correct. In terms of the mechanism behind this, one possible explanation is that the larger the animal the larger the vocal producing muscles which allow for more intense sounds to be produced. However, the loudest maximum sound in the data and the loudest animal on earth is the sperm whale and it is in a completely different family of whales from the other heavier baleen whales. The calls sperm whales use is also very different not just in terms of intensity but in the terms of the actual type of call and how it is made15. Sperm whales use a complicated system of naval cavities and air sacs to push air through a lip like structure to create incredibly intense clicking sounds that travel hundreds of miles15. This is very different to the calls in the other larger baleen whales, who use a larynx, laryngeal air sacs, and vocal cords for their sound production16.

Another possibility exists in the fact that a majority of the most intense calls between the whales are communicatory calls used in courting and mating. These are generally made up of elaborate displays with several very loud whistles and moans. In many species the louder and more complicated the mating song is the more likely they are to mate, making sexual selection a possible explanation as to why these intense sounds show up so often. However, yet again there is a large difference found in sperm whales. The sperm whale uses a series of very low or very high frequency sounds that are very intense and thought to be used for echolocation and communication. Either way these intense sounds are showing up consistently in heavier cetaceans no matter the mechanism of production or purpose of the sound.

In terms of explanations as to why these intense sounds show up time and time again in increasingly large cetaceans, several possible theories exist. Firstly, sound travels faster and further in ocean water, light is also far less useful due to its limited penetration in water making sound even more valuable for long distance communication and echolocation. Many of these cetacean species live in pods and travel both long distances each year for food sources or for mating. Being able to communicate across these distances and attract mates between pods is necessary for some and can be seen as advantageous for these types of groups. This explanation along with the sexual selection for them and the increasing size of the vocal cords are just some explanations and it is likely to be a combination of all of them to differing degrees.

The only conclusion that can be drawn is that intense sound production has showed up several times, being produced in different ways, while still being shown to be correlated to mass in cetaceans. And I believe this backs up the hypothesis that mass and sound production is connected across cetacean families.

**Possible Roots of Error/Biases**

There are several possible roots of error throughout this experiment that will be explained for transparency. Different recording equipment and recording environments were not accounted for nor were they standardized within the databases and this could lead to some error in the correlations. There were also few known maximums for the analyzed species and of them the larger animals were more represented. This is part of a larger problem, that being that research surrounding sound production in cetaceans is much more focused on the larger whales. The fact that data was more readily available around larger whales could lead to drawing conclusion based on their overrepresentation in terms of their sound production. The largest problem that could lead to bias or errors was in the smaller sample size of species and their selection. Several species were selected based upon their available data and the sample size could be made much larger. Also, a phylogenetic regression was not implemented and should’ve been to add further clarity on the actual correlation of mass to sound intensity.

1. Sound Waves. https://www.mediacollege.com/audio/01/sound-waves.html.

2. How many of the top 10 loudest noises have you been exposed to? https://www.ishn.com/articles/105610-how-many-of-the-top-10-loudest-noises-have-you-been-exposed-to.

3. Watkins Marine Mammal Sound Database. https://cis.whoi.edu/science/B/whalesounds/index.cfm.

4. Decibel X: Pro dBA Noise Meter. https://skypaw.com/decibel10.html.

5. Free Online Loudness and Sound Meter by Youlean. *Youlean* https://youlean.co/online-loudness-meter/.

6. Ecological Archives E088-096. http://esapubs.org/archive/ecol/E088/096/.

7. R: The R Project for Statistical Computing. https://www.r-project.org/.

8. Knowlton, C. Fin Whale. *Discovery of Sound in the Sea* https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/fin-whale/ (2017).

9. admin. Gray Whale Vocalizations. *Ocean Conservation Research* https://ocr.org/sounds/gray-whale/.

10. Parks, S. E., Johnson, M., Nowacek, D. & Tyack, P. L. Individual right whales call louder in increased environmental noise. *Biol. Lett.* **7**, 33–35 (2011).

11. Chen, J., Pack, A. A., Au, W. W. L. & Stimpert, A. K. Measurements of humpback whale song sound levels received by a calf in association with a singer. *J. Acoust. Soc. Am.* **140**, 4010 (2016).

12. Knowlton, C. Risso’s Dolphin. *Discovery of Sound in the Sea* https://dosits.org/galleries/audio-gallery/marine-mammals/toothed-whales/rissos-dolphin/ (2017).

13. Knowlton, C. Sei Whale. *Discovery of Sound in the Sea* https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/sei-whale/ (2017).

14. Sperm Whales Are So Loud They Could Potentially ‘Vibrate’ You to Death. *Roaring Earth* https://roaring.earth/sperm-whales-can-vibrate-humans-to-death/ (2018).

15. PBS - The Voyage of the Odyssey - Track the Voyage - Papua New Guinea. https://www.pbs.org/odyssey/odyssey/20010809\_log\_transcript.html.

16. Knowlton, C. How do marine mammals produce sounds? *Discovery of Sound in the Sea* https://dosits.org/animals/sound-production/how-do-marine-mammals-produce-sounds/ (2017).