Metrics for Assessing the Potential Effects of Echo Sounders on Marine Mammals

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Key words: Echo sounder, sonar effect, marine mammals, hydrographic survey

SUMMARY

Marine mammals rely on sound for communication and echolocation. Research has shown that anthropogenic noise can disrupt their signals, leading to behavioral changes, communication disturbances, temporary or permanent hearing damage, and even injuries from exposure to high-intensity sound. From 1963 to 2008, there were more than 16 instances of marine mammals stranding due to military sonar. However, there is limited research focusing on commercial sonar, such as the multibeam echo sounder. Understanding how echo sounder sonar emissions can affect marine mammals is crucial, especially in areas designated as Important Marine Mammal Areas (IMMA). In Malaysia, these areas are inhabited by dolphins, porpoises, and dugongs throughout the country. This paper will investigate the metrics used to assess the potential impact of sonar on marine mammals, specifically focusing on the widely used multibeam echo sounder for bathymetric surveys. This paper will also propose adopting improved survey practices to create new industry standards for hydrographic surveying, especially when mapping Malaysia's waters with MBES, aiming to minimize harm to our remarkable marine life.

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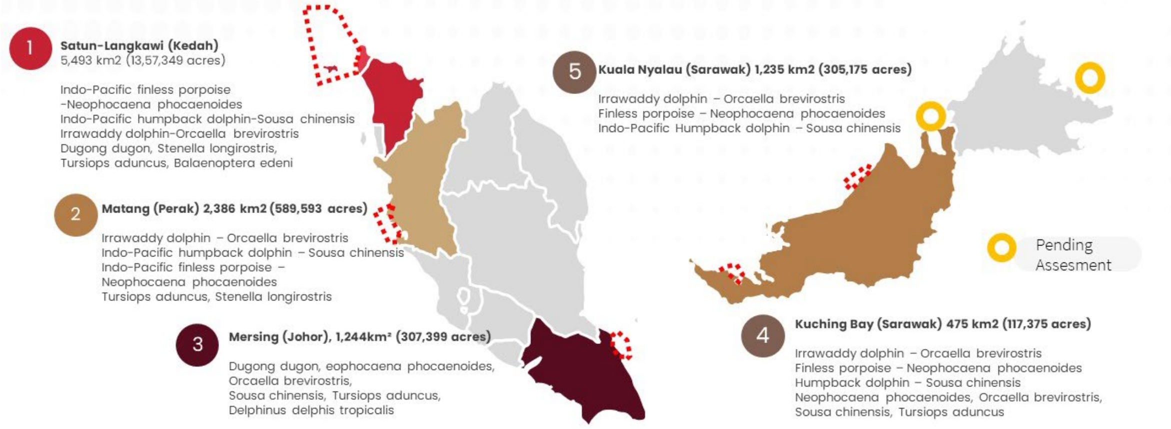
1. INTRODUCTION

Underwater sound travels extremely fast about 1500 m/s at sea water and can be up to thousands of kilometers. In 1991 The Heard island (Australia) feasibility test transmitted 209-220 dB re: 1microPA was detected all over the globe include Canada and Bermuda in the North Atlantic, about 19,820 km away (Munk, Spindel et al. 1994).

Figure 1 *: Stranded Dugong at Tinggi Island, Johor, Malaysia (sources Berita Harian News 21.4.2017)*

Marine mammals like whales, dolphins, dugongs and others rely on sound for communication and echolocation (Erbe, Reichmuth et al. 2016). Research found anthropogenic noise (Jiang, Wang et al. 2018) may interfere their signals include behavioral changes, disruptions in communication (masking), temporary or permanent hearing damage, and even injury due to exposure to high intensity sound (Kates Varghese, Miksis-Olds et al. 2020). Whales experience decompression sickness, a disease that forces nitrogen into gas bubbles in the tissues and is caused by rapid and prolonged surfacing. Although whales were originally thought to be immune to this disease, sonar has been implicated in causing behavioral changes that can lead to decompression sickness.

The purpose of this paper is to understand how echo sounder sonar emissions can impact marine mammals. Understanding these potential impacts and metric of assessment is crucial for designing sound management practices, regulations, and conservation strategies to minimize harm to marine mammal populations while allowing for the continued use of echo sounders in scientific and commercial applications. As Malaysia has begun measuring its waters fully using MBES, this is essential for sound management guidelines in hydrographic surveying especially at areas designated as Important Marine Mammal Areas (IMMA) around the world (MMPATF 2020). In Malaysia, five(5) areas areas are home to dolphins, porpoises and dugong which are located in Langkawi (Kedah), Matang (Perak), Mersing (Johor), Kuala Nyalau (Sarawak) and Kuching Bay (Sarawak) as shown in **Figure 1** (MMPATF 2020).



Source: https://www.marinemammalhabitat.org/imma-eatlas

Figure 2: Important Marine Mammal Areas (IMMA) in Malaysia

Indo-Pacific humpback dolphins (top) and Irrawaddy dolphins (bottom) in the coastal waters of Matang, Perak, Malaysia

Photo: MareCet Research Organization

A dugong herd, including the presence of mother-calf pairs, sighted during aerial surveys around Sibu Island, Johor, Malaysia.

Photo: The MareCet Research Organization

2. POTENTIAL EFFECT OF ECHO SOUNDER ON MARINE MAMMALS

Despite more than 16 stranding events that occurs between year 1963 – 2008 that link to sonar, most of the event were link to military active sonar which operate in low/mid frequency (1-10 kHz) and horizontal focused sonar travel direction (Wikipedia 2023). The sound transmitted which may has potential effects on marine mammals include disruptions in communication, behavioral changes, habitat displacement, and even physical harm due to exposure to high-intensity sound. In addition to military active sonar, seismic airguns are also known for producing very loud sounds that can have a significant impact on marine mammals.

The impact of multibeam echosounder operations on marine mammals however has been less studied compared to military sonars. The effect of sound waves emitted by survey and mapping echo sounders (10 kHz to 500 KHz) remain unclear until 2008 when an independent scientific review panel ISRP concluded that the mass stranding of approximately 100 melon-headed whales in the Loza Lagoon system in Madagascar was was primarily triggered by acoustic stimuli and one of the acoustic signals was from a multi-beam echosounder system (12 kHz) operated by a survey vessel (Southall 2013).

This findings supported by a study by U.S eastern seaboard on beaked whales that changed their behavior upon detecting sounds from a multi-frequency single beam echo sounder (18-200kHz) (ISC 2023).

Cetacean that hear well in the 10-100 kHz range where ambient noise is typically quite low, high-power active sonars operating in this range may in fact be more easily audible and have potential effects over larger areas than lower-frequency systems that have more typically been considered in terms of anthropogenic noise threats. (Southall 2013).

However a recent study at University of New Hampshire about of the effect of mapping echo sounder (12Khz MBES) on the foraging behavior of Cuvier's beaked whales was published in 2020 and found out that there is consistent foraging behavior change during the 2 years test which contra to the research result on Naval mid-frequency active sonar on beaked whales where they stopped echolocation and left the area. (Kates Varghese, Miksis-Olds et al. 2020). Given the ongoing debate, it is advisable to take precautions when addressing this issue

3. ASSESSMENT METRIC

3.1. Frequency Range Overlapping

The overlapping range of frequency can be initial guide to assess the effect of echo sounder on marine mammals. The metrics and methodologies to assess and quantify the potential effects of echo sounders on marine mammals can be first based on their degree of overlapping of the frequency between hearing range of marine mammals and echo sounder.

Marine mammals/cetaceans can categorized into five functional hearing groups which are low frequency (7Hz - 22Khz), mid-frequency (150Hz - 160Khz), high frequency (200Hz - 180Khz), pinnipeds in water (75Hz - 75Khz) and pinnipeds in air (75Hz – 30KHz) as shown in **Table 1** (Southall, Bowles et al. 2007). Meanwhile, echo sounder's frequency ranges about 12kHz to about 500kHz (ISC 2023).

Table 1 *: Marine Functional Hearing Groups and Estimated Functional Hearing Range*

Functional Hearing Group	**Estimated Auditory Bandwidth**	**General Represented (Number Species/Subspecies)**
Low-frequency cetaceans	7 Hz to 22 kHz	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera* (13 species/subspecies) *Dugong dugon*
Mid-frequency cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus,Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcacella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (57 species/subspecies)
High-frequency cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, hocoenoides, Platanista, Inia, Kogia, ipotes,Pontoporia, Cephalorhynchus* (19 species/subspecies)
Pinnipeds in water	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos,Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga, Odobenus*(41 species/subspecies)
Pinnipeds in air	75 Hz to 30 kHz	*Same species as pinnipeds in water (41 species/subspecies)*

Source: Southall et al 2007

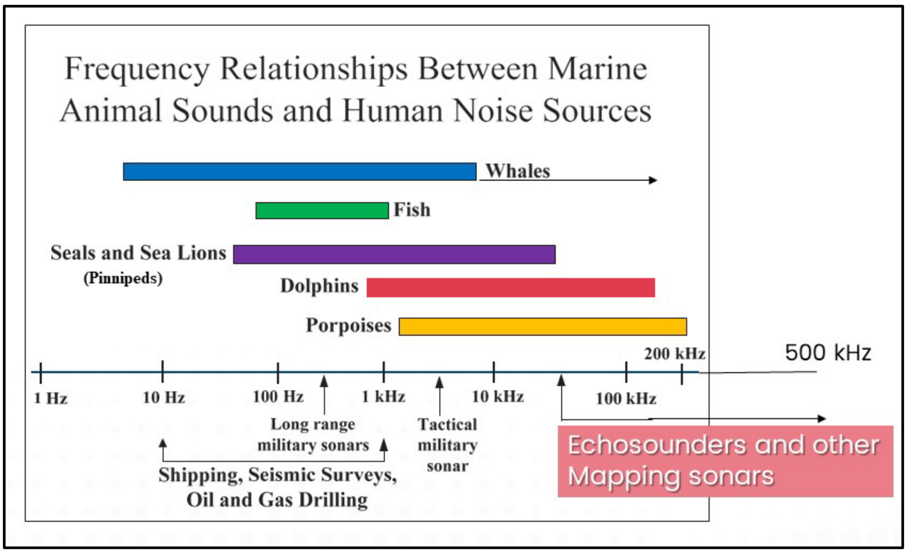


***Figure** 3 Frequency Range of Sounds Generally Produced by Different Marine Animal Groups Shown Relative to Major Human Noise Sources*

Whales like blue whale was from low frequency group which can detect sound generally from few hertz to 10 kHz as shown in **Figure 2**. This proved to be correct when they are highly sensitive to military sonar (1kHz – 10 kHz).

Hydrographic surveyors working at IMMA areas at Malaysia need to be aware of the presence of various cetaceans such as whale, dolphins, porpoises, and dugong at these areas. Surveyor can use appropriate echo sounder model which outside the cetacean's frequency such as Kongsberg EM 2040 (200-400kHz).

3.2. Threshold of Sound Level and Exposure

The assessment not just about frequencies overlapping, what really matters are the specific metric of sound levels threshold and period of exposure determine the scale of impact.

Southall and colleagues studied on how noise affects marine mammal hearing and estimate the threshold of sound pressure level (SPL) and sound exposure level (SEL) from sound events (single or multiple, within a 24-hr period) for injury or behavior changes as shown in **Table 2**. For example, limits of single pulse, 230 dB SPL and 198 dB SEL might cause injury, while 224 dB SPL and 183 dB SEL might cause behavioral changes (Southall, Bowles et al. 2007). This evidence provided in 2000 at Bahamas when a sonar trial using low frequencies between 3–8 kHz and source levels of 223–235 dB led to the stranding of 17 whales (Balcomb and Claridge 2001).

Cetaceans *Low frequency* 7 Hz-22 kHz	 *Mid-frequency* 150 Hz-160 kHz	 *High frequency* 200 Hz–180 kHz	**Pinnipeds** ***in Water*** 75 Hz–75 kHz	**Pinnipeds** ***in air*** 75 Hz–30 kHz
Baleen whales	Most toothed whales, dolphins	Certain toothed whales, porpoises	All species	All species
Single Pulse: 230 dB SPL 198 dB SEL Multiple Pulse: 230 dB SPL 198 dB SEL Non-pulses: 230 dB SPL 215 dB SEL	Single Pulse: 230 dB SPL 198 dB SEL Multiple Pulse: 230 dB SPL 198 dB SEL Non-pulses: 230 dB SPL 215 dB SEL	Single Pulse: 230 dB SPL 198 dB SEL Multiple Pulse: 230 dB SPL 198 dB SEL Non-pulses: 230 dB SPL 215 dB SEL	Single Pulse: 218 dB SPL 186 dB SEL Multiple Pulse: 218 dB SPL 186 dB SEL Non-pulses: 218 dB SPL 203 dB SEL	Single Pulse: 149 dB SPL 144 dB SEL Multiple Pulse: 149 dB SPL 144 dB SEL Non-pulses: 149 dB SPL 144 dB SEL

Table 2 : Criteria for Permanent Injury - estimated values for PTS-onset

Echo sounders emit strongest sonar signals within a meter beneath the transducer and attenuating as moves away from the source. For example like Low frequency attenuating slowly while high frequency attenuating faster.

Figure 4 *Ziphius cavirostris* (BMMS 00-13) Gold Rock beach, Grand Bahama, 19 March 2000. Carcass has been buried and exhumed.

Evidence provid in 2000 at Bahamas when a sonar trial using frequencies between 3–8 kHz and source levels of 223–235 dB led to the stranding of 17 whales (Balcomb and Claridge 2001)

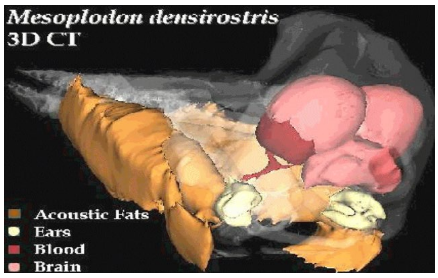


Table 3 *: Criteria and values for TTS-onset (single pulses only) and Disturbance/Behavioural Response (multiple pulses and non-pulses)*

Cetaceans			**Pinnipeds in Water**	**Pinnipeds in Air**
Low frequency 7 Hz-22 kHz	Mid-frequency 150 Hz-160 kHz	High frequency 200 Hz–180 kHz	75 Hz–75 kHz	75 Hz–30 kHz
Baleen whales	Most toothed whales, dolphins	Certain toothed whales, porpoises	All species	All species
Single Pulse: 224 dB SPL 183 dB SEL Multiple Pulse: 120-180 dB SPL Not applicable Non-pulses: 120-160 dB SPL Not applicable	Single Pulse: 224 dB SPL 183 dB SEL Multiple Pulse: 120-180 dB SPL Not applicable Non-pulses: 90-200 dB SPL Not applicable	Single Pulse: 224 dB SPL 183 dB SEL Multiple Pulse: Data unavailable Not applicable Non-pulses: 90-170 dB SPL Not applicable	Single Pulse: 212 dB SPL 171 dB SEL Multiple Pulse: 150-200 dB SPL Not applicable Non-pulses: 100+ dB SPL Not applicable	Single Pulse: 109 dB SPL 100 dB SEL Multiple Pulse: 150-200 dB SPL Not applicable Non-pulses: 100+ dB SPL Not applicable

For depth sounder, taking MBES Kongsberg EM 712 (40-100kHz) for example which is used by survey vessel of National Hydrographic Centre of Malaysia (225-237dB at peak) as an example, assuming attenuation about 10dB/km and considering of Southall's minimum exposure limit "224dB". Theoretical safe distance for marine mammals directly from the source can be calculated as (237db-224db) / 10db = 1.3km. Internationally, the distance of 1km (sea surface) was adopted by Government of Ireland as code of practice (Ireland Department of Environment 2014).

Here are standard set up of for some sonar sources commonly used in the hydrographic industry.

Table 4 *Sonar Sources and the Sonar Propagtion in Water*

Sonar Source	Sound Level	Speed of Sound	Direction of sound
Single Beam Sounders	240 peak @ 1m	0.1 ms	Vertical focused
Sidescan Sonar	240 peak @ 1m	0.2 ms	Vertical focused and fan spread
Multibeam EchoSounders	240 peak @ 1m	0.3 ms	Vertical focused and fan spread

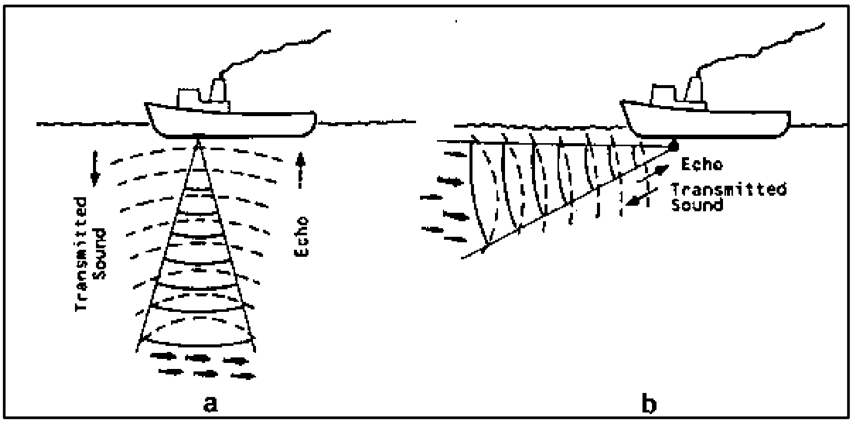


Figure 4 *: Sonar Propagation in water*

Sonar sources have traditionally released sound in a vertical and fan spread pattern like a in **Figure 4**. However, industry demands for broader survey coverage to expedite operations have led to an increase in the angle and height of the sonar sound fan spread like b in **Figure 4**. This poses a potential threat to marine mammals, approaching the capabilities of military sonar, with new advancements in MBES technology.

As precaution measure, before survey commence, it is advised to use a soft start pinging mode and reducing the sound level by 10 or 20 dB during 140º coverage (Kongsberg 2019). Survey line shall start from the coast and move towards deeper waters and not the opposite to prevent marine mammals from being disturbed and swimming toward the shore as recommeded by Department of Environment of Ireland in the Guidance to Manage theRisk to Marine Mammals fromMan-madeSound Sources in Irish Waters (Ireland Department of Environment 2014). The 4.3.4 (ii) in the guideline set a good rule which specify as below:

”Unless information specific to the location and/or plan/project is otherwise available to inform the mitigation process (e.g., specific sound propagation and/or attenuation data) and a distance modification has been agreed with the Regulatory Authority, acoustic surveying using the above equipment shall not commence if marine mammals are detected within a 500m radial distance of the sound source intended for use, i.e., within the Monitored Zone. ”

All states, especially those without guidelines, must adopt measures similar to Ireland's. This is crucial, as recommended by Article 65 of UNCLOS 1982, which provides clear provisions for the protection of marine mammals. The article can be read below:

”Nothing in this Part restricts the right of a coastal State or the competence of an international organization, as appropriate, to prohibit, limit or regulate the exploitation of marine mammals more strictly than provided for in this Part. States shall cooperate with a view to the conservation of marine mammals and in the case of cetaceans shall in particular work through the appropriate international organizations for their conservation, management and study.”

FIG could play a key role in launching a campaign and introducing precaution guidelines to its members involved in hydrographic surveys. It should encourage members to conduct more research on this matter, including actual sonar experiments in areas inhabited by marine mammals, to gain a comprehensive understanding of the subject.

In the last few decades, many methods have been proposed to improve the sonar systems through signal waveform design from the perspectives of Low signal noise ratio (SNR) signals with LFM, FM-CW or other stealth signals, however with low SNR requires a long-time energy accumulation process for target detection, which severely affects the detection efficiency of echo sounder.

Balancing the advantages of echo sounder technology with the protection of marine mammals and ecosystems is a crucial and continuous challenge as we to chart the oceans.

4. CONCLUSION

With the advancement of echo sounders technology, it's vital to minimize their harm to marine mammals. By using best practices and evolving tech to reduce their impact, we can strike a balance that allows us to explore the oceans while safeguarding the remarkable marine life within them.This ultimately reduce harm to marine mammals which are the remarkable marine life in our country.

Echo sounder sonar emissions may not potentially harm marine mammals if proper survey practices are followed as suggested in few example in this paper. This practice can set a new professional guideline for hydrographic surveying especially during the campaign of charting world wide waters using MBES. This paper aims to kickstart further research, and it is eagerly anticipating the results of comprehensive studies on this matter.

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BIOGRAPHICAL NOTES

Ching Yen Sim is a certified hydrographic surveyor (CAT A) and a licensed land surveyor in Malaysia. He hold a master degree in geographical and earth science from University of Glasgow. He is actively practicing with professional surveyor company, Jurukur Mentari Sdn Bhd while pursuing his PhD at the University Teknologi Malaysia. His research focuses on International Maritime Delimitation and his research interest also emphasis on advancing the understanding and implementation of best practices in hydrographic surveys.

Dr. Kelvin Tang Kang Wee, a senior lecturer at the University Teknologi Malaysia, earned his doctorate in Hydrographic Survey from UTM. He is a registered Professional Technologist (P. Tech) under the Malaysia Board of Technologists (MBOT) and a member of the Royal Institution of Surveyors Malaysia (RISM), the Institution of Geospatial and Remote Sensing Malaysia (IGRSM), and the Institute of Electrical and Electronics Engineers (IEEE). His research interest is in marine positioning and seabed topographic modeling using automated imagery-derived approaches.

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