Developments in bioacoustics monitoring for management of marine mammal presence in shipping lanes

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Abstract

Research assessing Marine Mammal (MM) health and prospects for enhancing the care of individuals in professional facilities has significantly escalated during the past decades. Although subjects like comfortable housing, sufficient opportunities for social and engaging enhancement, and superior medical treatment have garnered attention from management and researchers, there is a deficiency in defined acoustic parameters for assessing the welfare of these creatures. MM depend on bioacoustic (BA) emission and perception for orientation and interaction. Numerous countries have established regulations regarding artificially generated sounds in seas, primarily informed by studies with controlled and trained creatures, owing to the possible adverse effects of unregulated noise on MM. A definitive standard of excellence for the BA well-being tracking of marine creatures in medical facilities has yet to be developed. Measuring MM auditory perception and vocalization can provide a comprehensive understanding of MM health by facilitating the early identification of anthropogenic sounds, analyzing the BA activity of the livestock, and examining the characteristics of their calls. This review introduces and discusses the method of tracking cetacean BA social assistance through emotional hearing assessments and Auditory Evoked Possibilities (AEPs), inactive acoustic tracking devices like the Welfare Acoustic Monitoring Systems (WAMS), and proposes the application of novel methods for leveraging vocal health indicators as possibilities for incorporation into MM welfare strategies.

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Introduction

Over the past decade, studies on the welfare of animals under medical supervision in zoological institutions have surged significantly (Martelli and Krishnasamy, 2023). Although the health of farm animals has historically been a concern for legislators and agriculturalists, investigators, animal care specialists, and the general public have embraced comprehensive examinations of the well-being of species at zoological institutions (Zhou *et al.,* 2025). Ethical considerations, including the necessity for animals to be liberated from extended fear and suffering and to operate effectively utilizing their innate capacities, have driven the development of numerous welfare systems that are currently implemented (Kerfouf *et al.,* 2023). The Five Areas, widely recognized as the prevailing welfare structure, elaborated on the initial Five Rights and offered an organized method to assess the welfare of human-managed creatures (Ramachandran and Naik, 2024). The domains are continually revised by advancements in welfare studies, notably the transition from an exclusive emphasis on negative emotions to incorporating good experiences in wellbeing assessment (Gulland *et al.,* 2022; Sánchez-Ancajima *et al.,* 2022). The areas presently encompass diet, physical surroundings, wellness, behavioural interactions, and emotional states, combining the effects of human relationships (Klamkam *et al.,* 2022).

The well-being of Marine Mammals (MM), particularly cetaceans, has garnered attention in recent research aimed at developing metrics to assess and enhance the welfare of dolphins in medical supervision (Coria-Avila *et al.,* 2022; Anand *et al.,* 2024). The Cetaceans Welfare Evaluation formulated welfare criteria grounded in the four guidelines for optimal nutrition, suitable habitat, robust health, and behavioral adaptations (Mthembu and Dlamini, 2024). The 36 metrics included in C-Well did not encompass the soundscape or acoustic activity beyond dolphins' echolocation capabilities in intricate settings (Ge *et al.,* 2023). Although a setting promoting echolocation is crucial for odontocetes' optimal habitation, the acoustically appropriate setting (i.e., relatively low environmental noise levels) was overlooked (Escobedo *et al.,* 2024). Bioacoustic (BA) welfare—defined as a suitable acoustic surroundings and the capacity to exhibit natural sound-related behaviors, such as communication—has been overlooked in other evaluations of MM social security, despite the significance of the MM's inherent abilities concerning sound generation and processing, which undoubtedly affect welfare (Karimov *et al.,* 2024; Ansari and Parmar, 2024).

Although the significance of BA wellbeing was addressed, a new analysis of cetacean auditory wellbeing has revitalized the discourse on integrating auditory data into assessing cetacean species' welfare (Leitner, Mangler and Rinderle-Ma, 2011, Ziwei and Han, 2023). This review amplifies the previous call by concentrating on implementing sound welfare tracking, particularly within the MM Program (MMP) (Zantis *et al.,* 2021). It summarizes recent advances in instruments for the BA monitoring of whales in healthcare and delineates suggested subsequent phases for further progress in this domain (Karimov and Bobur, 2024).

Related Works

Auditory weighting algorithms are mathematical constructs employed to accentuate harmonics of heightened sensitivity for human beings and other creatures while diminishing the significance of frequencies with reduced sensitivity. The weighting algorithm accurately modifies the unweighted Sound Pressure Levels (SPLs) observed by the person listening according to their hearing threshold (audiogram) across the frequency spectrum (Nair and Rathi, 2023). The magnitude of both top and bottom harmonics is diminished to variable extents based on the person listening. The A-weighting is a type of equal volume curve, akin to a hearing graph or audiogram, designed to represent the corresponding loudness of airborne sounds as experienced by the ears of humans. It is frequently employed to evaluate the effects of ambient noise. The utilization of weighting factors has been recognized as a crucial instrument in evaluating noise effects on people, and their application has been broadened to include MM. Generalized hearing-weighted algorithms have been established for several operational hearing categories for MM, depending on the audiograms of representative MM. Weighting functions are employed to calculate weighted Sound Exposed Levels (SEL), which can be utilized to evaluate the likelihood of transient or Persistent Threshold Shifts (PTS) across various MM functional hearing groups (Winship and Jones, 2023).

After applying an auditory weighted model to predict the probable perceived magnitude of a signal at a particular frequency or frequency range, it is essential to ascertain whether the signal is likely to be discovered. Natural and manmade sounds can obscure messages that would be distinctly perceptible in tranquil environments (Kapoor and Gupta, 2023). Metrics like the critical proportion have been employed to assess the identification of vocalizations amidst masking noise. It is essential to ascertain the signal-to-noise rates and utilize data from scientific assessments of the auditory capabilities of captive MM to evaluate the hearing of both biological and anthropogenic environmental noises. There is a lack of research offering a definitive regulated approach for assessing the ability to be identified of real-world noises for MM.

Notwithstanding the advancement of MM weighting operations, several contemporary environmental evaluations continue to utilize unused wideband loudness as a standard metric for assessing the BA effects of industry noise on aquatic creatures. Unweighted wideband levels fail to consider a creature's frequency-dependent auditory capabilities and inaccurately depict the noise levels experienced by the living thing. Audiogram information is not accessible for all species, but general frequency-weighting algorithms can roughly represent the varied auditory capabilities of MM groupings.

Materials and Methods

Data Acquisition

- *Passive BA Information*

The three hydrophones captured BA information throughout 30 to 40 days from March to November 2022. The times were aligned with a public holiday in New South Wales. An instrumental fault caused the hydrophone to lose 2 hours of information (06:00 to 09:00 EST). Except for this issue, statistics were constantly collected throughout the study duration for each recording. All recordings were configured for sampling at 46 kHz with the highest gain calibrated setting, yielding a successful recording range of 25 Hz to 28 kHz. The monitors were designed to monitor and document the immediate temperatures every 10 seconds.

This investigation excludes examining the vessel BA information collected during the following set of records. Still, BA information from the subsequent installation of the recorders was utilized for transmitting loss modeling computations due to the unavailability of data from the first installation. In the second installation, the recording was configured to record data continuously for 30 minutes every hour. The recording device was configured to sample at 45 kHz using the highest gain calibrating option, and it documented the instantaneous temperatures every hour.

- *Patrol Vessel Trajectories*

Throughout the installation of the recording devices, the New South Wales (NSW), a 6.7-meter Rigid-Hulled Inflatable Kayak (RHIK) equipped with twin Yamaha 4-stroke motors, executed three elliptical maneuvers at a small velocity of 13 km/h at lengths roughly 250, 600, and 1200 meters around the recording devices. Time-stamped GPS coordinates were supplied for these paths and utilized in loss during transmission modeling.

Periodic Global Positioning System (GPS) time stamps were not recorded during the installation. Throughout the second installation, the reconnaissance Watonga (a 6.2-meter boat equipped with twin motors) executed two semi-concentric sections at an average 22 km/h speed, covering lengths between 250 and 1200 meters around the recording device.

Timestamped GPS coordinates were supplied for these tracks and utilized in loss during transmission modeling. The in-situ circumstances, including temperatures and sound speed profile, were consistent across the first and subsequent installations, and the environmental factors (i.e., bathymetry and seabed characteristics) were unchanged. The results were deemed suitable for modeling transmission loss at the location and understanding the data gathered during the first phase of installation.

Data Analysis

After extracting BA records from each found recording device, the resultant records were carefully examined utilizing the BA program Raven Pro 2.0. Using the spectrogram in Raven Pro 2.0, recordings were analyzed for vessel noise from 0 to 12 kHz with a 3-minute viewing opening, a Fast Fourier Transform (FFT) of 4k points at 55% overlap, luminance set to 45, and contrast set to 72. Every location had a comprehensive visual and auditory assessment over its entire recorded duration, encompassing the few days during which the microphones were set up and retrieved; only partial hours were omitted from the study.

The occurrence of distinct vascular events and their lengths of time were quantified utilizing the Raven Pro selecting tool. A distinct vessel event was characterized by a distinct auditory signature lasting from seconds to days. The auditory fingerprints of vessels are disrupted by reduced or absent vessel noise intervals when the ship changes gears or the motor is deactivated. If the duration of reduced or absent vessel noise exceeded 5 minutes, the two occurrences were categorized as distinct vessel occurrences; if the duration was shorter than 3 minutes, the occurrence was regarded as a singular, discrete vessel incident. When two distinct BA signals were detected simultaneously, they were classified as two distinct vessel occurrences due to variations in their frequency ranges.

Upon identifying a vessel profile, a choice box was created around the incident to facilitate duration calculation. To minimize the analysis of remote, huge boats, BA signatures indicative of such vessels, characterized by tones below 550 Hz and devoid of broadband power, were omitted from consideration.

Distinct vessel occurrences were categorized based on their distances upon selection. Vessels were classified into three different types according to the strength of their sound signals. 1) Closest Point of Algorithm (CPA), the juncture at which a vessel neared and traversed the hydrophone sufficiently to generate a Doppler impact; 2) Transportation level A (TA), wherein a vessel did not demonstrate a CPA (resulting in the nonexistence of a Doppler impact) and was consequently considered remote, yet still emitted broadband power; and 3) Transit levels B (TB), where a the ship was discernible above 500 Hz but sufficiently distant to lack in keeping broadband colors. CPAs and TAs were additionally classified into CPA with a movement (CPA + M) and TAs without a movement (TA + M), where movements denoted alterations in vessel conduct, such as gear changing or idling, during the event's period. Movements in Raven Pro are represented as variations in the strength or duration of the tones produced by the vessel engine, observable for CPAs and TAs, but too subtle for definitive detection for TB transmissions. The unique auditory patterns were classified as a different element in the study, as maneuvering ships (e.g., vessels anchoring, shifting gears, or turning down engines) within the MPAs were presumed to be more prone to show extractive activities than passing vessels. Extractive activities like boating are prohibited; however, passage across the MPA is permitted. Classifying CPAs and TAs as moving or non-maneuvering ships facilitated distinct evaluations of vessels potentially involved in illicit activities versus those merely traveling through the MPA. The general number of these groups and all identified vessels was displayed and analyzed for trends using R programming.

Acoustic Behavior Surveillance

Recent applications of BA welfare-monitoring technologies in terrestrial creatures, especially livestock, have surged significantly. BA tracking of utterances and other sounds, including coughing, has been effectively applied and demonstrated to serve as valuable welfare biomarkers that can mitigate disease transmission in herds. Ultrasound vocalization monitoring in research rats (Rattus norvegicus) has been employed to assess favorable social attachment and anxiety occurrences. Technological improvements have facilitated the proliferation of automated processes, enhancing the maintainability of these networks. Studies indicated a 56.5% increase in detection rate when employing automated surveillance equipment for chicken distress cries compared to manual inspections. A substantial body of research exists regarding the correlation between vocal actions and inappropriate behaviors linked to distress, strain, aversion, violence, and prejudice across various species; however, the application of vocal indicators for welfare tracking has, to the best of our knowledge, not been employed for MM in medical treatment beyond livestock situations.

Numerous investigations have discovered alterations in the auditory actions of odontocetes that correlate with variations in their health. For instance, research was the first to document a whistle produced by a distressed dolphin, potentially to solicit assistance from another species. Likewise, research noted a continuous whistle production from wild bottlenose dolphins that could not sustain buoyancy in the water column. The generation of whistles was linked to altruistic behavior by similar species that assisted the ailing MM at its lowest point. In times of anxiety, dolphins issued trademark whistles more often and with increased strength; also, other research indicated that a sick female dolphin generated an elevated quantity of repetitive whistle outputs. Capture-release incidents, which represent a possibly stressful setting, have been linked to a substantial rise in both the whistle frequency and the amount of whistle looping in whales. Research indicated that out-of-water medical interventions were connected to a notable increase in whistle frequency in whales, which corresponded with elevated blood cortisol concentrations. The movement and arrival of a different species correlated with a remarkable and extended decline in vocalization rates, indicating that changes in BA production hold significance. These results present a persuasive case that the whistle-blowing activity of whales offers insights into welfare-related occurrences, including discomfort and disease.

Notwithstanding the welfare advantages of sound surveillance for odontocetes in managed-care settings, the application of such devices has been minimal. Researchers have achieved significant advancements by implementing a 'Welfare BA Surveillance System (WASS)' that functions continuously with a fixed hydrophone array. This system employs modules, including the recording device, whistle and moan detection device, WASS, and alarm component, to establish a real-time alert monitoring system for atypical whistle behavior in a pod of bottlenose whales. The sound input is evaluated in real time to determine, locate, and quantify the whistles a specific group of whales produces. Upon exceeding a user-defined limit for the whistling rate within a set time frame, an email alert is generated, containing the whistle count, a screenshot of the spectroscopy, and a radar screen with placement details, which is promptly dispatched to a specified recipient's email address. A creature care cadmium, night watch personnel, curator, or study can obtain immediate, comprehensive email notifications when whistle rates exceed an unhealthy threshold. Unusually elevated whistle rates in MM have been documented in various circumstances pertinent to wildlife treatment and administration, including sadness and dolphin work.

Acoustic Biomarkers of Well-being

Although the whistle rate is the most extensively recorded vocal indicator of unhappiness in bottlenose whales, specific findings indicate that the sound qualities of MM utterances convey indicators of well-being and health. The latest developments in audio analysis tools enable feature analyses to yield more profound insights into MM communication networks. For instance, goats exhibited distinct fundamental harmonic and modulation frequencies of calls in positively valenced circumstances as opposed to adverse situations. The latest studies revealed that a model effectively differentiated between hens infected with perfringens and healthy ones based on the characteristics of their screams. Research likewise identified that five vocal characteristics were markedly distinct between the utterances of bison infants with illness and those without. The researchers propose that BA characteristics function as a non-invasive diagnostic instrument for the early detection of tuberculosis in bison infants.

Welfare Surveillance Metric

In light of these recent achievements, MM utterances convey information regarding their well-being and health through their characteristics. Initial research indicates the presence of BA indicators that can define the health status of dolphins based on their whistles. Early disease identification is crucial for enhanced results and decreased healthcare expenses. BA records of MM sounds, accompanied by a documented health state (e.g., retrieval from water, transportation, medical facilities, strandings, rehabilitation facilities, etc.), are invaluable for this research's future advancement, implementation, and extrapolation. In managing MM, learning individuals to produce vocalizations (e.g., signature whistles by bottlenose dolphins) and documenting the characteristics of these whistles along with health status will facilitate the creation of a library of instances to train machine learning designs for enhanced health status forecasts. Trainers can "capture" a provided trademark whistle by boosting its spontaneous generation and associating it with a hand gesture or other prejudiced stimuli. The instructors instruct the dolphin to emit the whistle upon receiving the command, and the sound can be documented for examination.

Contemporary BA Surveillance Protocols in Zoos and Aquaria

One of the primary advantages of BA tracking is its capacity to gather data on MM at periods when human interaction is infeasible, hazardous, or challenging (e.g., shadows, late hours, high-density MM housing, undersea). Although the cost for gear and trained professionals for passive sound monitoring devices remains elevated, one should consider the possible savings linked to early detection of disease or incidents and the decreases in healthcare and caregiver costs that result. The research describes the existing procedures for BA well-being assessment. These instruments are relevant for implementation in other reputable establishments:

- Annual sound level records and further measures when significant alterations occur in the surroundings (e.g., modifications to filtering systems, proximate construction activities, etc.) to avert and alleviate possible hearing loss.
- Periodic auditory assessments are administered to the population.
- Implementation of an underwater sound surveillance system. This method can be employed for sound level assessments in the WASS of MM BA behaviour.
- Creating a vocal database for each MM across various settings (e.g., good and bad polarity) and health states (i.e., healthy and pathological) for neural network applications in behaviors and medical tracking.

Conclusion

There is growing evidence of the effects of anthropogenic noise exposure on MM auditory impairment, behavioral alterations, compromised interaction, and diminished foraging efficacy. Comprehensive welfare-monitoring techniques for MM in managed facilities have not consistently integrated BA tracking into their guidelines. The research presents evidence that technical improvements have rendered available applied methods for BA welfare tracking. Institutions capable of investing in such endeavors via sound level audio files, regular hearing assessments, the setting up of a submerged BA-monitoring structure, and the creation of a vocal inventory will enhance their capacity to care for the MM they serve and further the comprehension of the effects of sound on MM well-being and health both in clinical environments and in nature.

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