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ACOUSTICAL ECOLOGY. NOISE AND VIBRATION

Sonar Inter-Ping Noise Field Characterization During Cetacean Behavioral Response Studies off Southern California[1]

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Abstract—The potential negative effects of sound, particularly active sonar, on marine mammals has received considerable attention in the past decade. Numerous behavioral response studies are ongoing around the world to examine such direct exposures. However, detailed aspects of the acoustic field (beyond simply exposure level) in the vicinity of sonar operations both during real operations and experimental exposures have not been regularly measured. For instance, while exposures are typically repeated and intermittent, there is likely a gradual decay of the intense sonar ping due to reverberation that has not been well described. However, it is expected that the sound field between successive sonar pings would exceed natural ambient noise within the sonar frequency band if there were no sonar activity. Such elevated sound field between the pings may provide cues to nearby marine mammals on source distances, thus influencing potential behavioral response. Therefore, a good understanding of the noise field in these contexts is important to address marine mammal behavioral response to MFAS exposure. Here we investigate characteristics of the sound field during a behavioral response study off California using drifting acoustic recording buoys. Acoustic data were collected before, during, and after playbacks of simulated mid-frequency active sonar (MFAS). An incremental computational method was developed to quantify the inter-ping sound field during MFAS transmissions. Additionally, comparisons were made between inter-ping sound field and natural background in three distinctive frequency bands: low-frequency (<3 kHz), MFA-frequency (3–4.5 kHz), and high-frequency (>4.5 kHz) bands. Results indicate significantly elevated sound pressure levels (SPLs) in the inter-ping interval of the MFA-frequency band compared to natural background levels before and after playbacks. No difference was observed between inter-ping SPLs and natural background levels in the low- and high-frequency bands. In addition, the duration of elevated inter-ping sound field depends on the MFAS source distance. At a distance of 900–1300 m from the source, inter-ping sound field at the exposure frequency is observed to remain 5 dB above natural background levels for approximately 15 s, or 65%, of the entire inter-ping interval. However, at a distance of 2000 m, the 5 dB elevation of the inter-ping SPLs lasted for just 7 s, or 30% of the inter-ping interval. The prolonged elevation of sound field beyond the brief sonar ping at such large distances is most likely due to volume reverberation of the marine environment, although multipath propagation may also contribute to this.

Keywords: underwater noise, sonar, marine mammal, behavioral response, reverberation

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INTRODUCTION

How military sonar may negatively affect marine mammals (primarily cetaceans which include whales and dolphins) has been a subject of significant research, conservation, and regulatory interest for the past several decades. Numerous cetacean mass stranding events resulting in mortality have been associated with naval exercises involving mid-frequency (1–10 kHz) active sonar (MFAS) operations [1–5]. Although a definitive mechanism of the mass stranding is unknown, some researchers have found gas emboli in stranded animals [6, 7]. Additional analyses based on acoustic propagation modeling and animal locations suggest that these outcomes may not result directly simply from high levels of sound exposure, but that the animals' behavioral response to the MFAS exposure may play a more indirect, but important mediating role in the stranding [4, 5, 8]. Different types and magnitudes of behavioral responses may be expected to occur depending on the interaction of received sound level and a variety of sound exposure conditions [9]. Consequently, considerable efforts are being devoted to reveal the potential behavioral responses of marine mammals to MFAS exposure [10]. Nevertheless, con-

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sidering the more complex nature of contextual variables that appear to drive response probability beyond the simple received sound level considered in many earlier studies, more comprehensive quantification of sound exposure is clearly needed.

The acoustic field in the vicinity of sonar operations is likely to experience a gradual decay of the high sound pressure levels (SPLs) after the termination of the ping due to reverberation. Therefore, it is expected that the sound field between successive sonar pings (e.g., during the inter-ping interval) would exceed natural ambient noise within the sonar frequency band if there were no sonar activity. Such elevated sound field reverberation characteristics, and the information it may convey about proximity and/or relative orientation of source and receiver, thus has the potential to affect the probability of marine mammal behavioral responses to MFAS beyond the initial direct-path exposure. Where these frequencies overlap, they may also mask biological signals that are important to the life functions of marine mammals [11]. In order to provide a thorough assessment of behavioral response and acoustic masking potential in an environment influenced by MFAS, it is important to understand the reverberant field. However, among the large and growing number of studies being conducted on noise impacts to marine life over the past decades, few investigations have characterizing the reverberant field from anthropogenic noises [12, 13] or explicitly addressed concerns of reverberant field on marine mammal behavioral responses and acoustic masking [11]. Specifically, no research that the authors are aware of addresses the potential of acoustic masking from tonal sources, and only occasionally tonal masking is discussed in relation to noise impacts to marine mammals (e.g., Richardson et al. [14] and Au and Hastings [15]).

To address some of these information gaps and quantify relevant sound field characteristics resulting from intense anthropogenic transient tonal noises such as military sonar, we measured and analyzed the soundscape in the vicinity of a conducted during a subset of experimental sonar experiments involving controlled exposure experiments (CEEs) with simulated MFAS (described in Southall et al. [10]). The objectives of this study are to (1) use a quantitative method to analyze a simulated MFAS inter-ping sound field levels; (2) compare the inter-ping sound field among different frequency bands; (3) compare the inter-ping sound field between the time of simulated MFA playbacks and that of pre- and post-playbacks; (4) investigate the relationship between the inter-ping sound level and the distance of MFAS source; and (5) investigate the inter-ping sound field decay at different distances from the source.

MATERIALS AND METHODS

Passive Acoustic Data Collection

An interdisciplinary research program, referred to as the Southern California Behavioral Response Studies (SOCAL-BRS), has been conducted off southern California, USA since 2010, in order to understand marine mammal behavioral responses to military MFAS [10]. The study archival acoustic tags (e.g., DTAGs which are digital tags that attached to target animal by suction cups to track its movement and position, as well as to record sound [16]) to conduct controlled CEEs from animals exposed to simulated Navy MFAS pings [10, 17]. The simulated MFAS source used in the SOCAL-BRS was composed of a triad of upsweep and constant frequency tones projected from a 10-element vertical line array transducer. The transmitted ping had an initial 0.5 s linear frequency-modulated upsweep from 3.5–3.6 kHz, followed by a 0.5 s constant frequency tone at 3.75 kHz, then a 0.1 s silent period, and finally a 0.5 s constant frequency tone at 4.05 kHz. The total duration of the MFAS ping was 1.6 s, with a repetition rate of every 25 s from the onset of one ping to the onset of the next. Sound transmission was initiated at a broadband source level of 160 dB (RMS) re 1 μPa @ 1 m and ramp up at a 3 dB per ping to a maximum source level of 210 dB re 1 μPa @ 1 m.

During the SOCAL-BRS experiments in 2013 and 2014 seasons, passive acoustic recordings were made from drifting acoustic spar buoys deployed in the vicinity of the study sites. The drifting acoustic buoys were equipped with a HTI-96 hydrophone (nominal sensitivity of –180 dB re 1 V/μPa, with precise calibrated sensitivity used for each unique hydrophone). The hydrophone is attached to a pre-amplifier with a 20 dB gain, thus making the recording unit with a flat nominal sensitivity of –160 dB re 1 V/μPa (±3 dB) between 16 and 30000 Hz. The hydrophone was lowered to a depth of either 30 or 100 m below the surface, depending on the cable lengths of the drifting buoys being deployed. Acoustic data were recorded on high-density SD cards using an SM2M marine recorder (Wildlife Acoustics, Inc., Maynard, MA) housed in the instrument case of the drifting buoy. The sampling rate was set at either 50 kHz (for most of the 2013 season) or 80 kHz (for some 2013 and all 2014 seasons) on the SM2M recorder. To reduce noise generated from wave actions and cable strumming, a 3/16"-diameter bungee cord was use to link the buoy and the sensor, thus relieving the strain on the cable.

Deployments of the acoustic buoys were opportunistic within the SOCAL-BRS experiment, during periods when a DTAG was attached to the target animal and just prior to simulated MFAS CEEs or silent control sequences (see Southalll et al. [10] for a detailed description of SOCAL-BRS experiment design). The drifting buoys were either deployed from the source vessel R/V *Truth*, or from a dedicated pas-