Temporal and spatial variability in vessel noise on tropical coral reefs

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Temporal and spatial variability in vessel noise on tropical coral reefs

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Coral reef soundscapes are dynamic, demonstrating amplitude and spectral variability across timescales from seconds to seasons. Some of this variability can result from spatiotemporally heterogeneous patterns of human activity. To characterize this variability and the extent to which anthropogenic sound can modify the biological soundscape, seven Hawaiian reefs were equipped with acoustic recorders operating on a 10% duty cycle for 16 months. Spatially, vessel activity was acoustically detected unevenly across reefs; for example, vessels were acoustically present almost every day at a popular snorkeling reef but were rare in a protected area closed to boats, which indicates that exposure of reef fauna to vessel noise will vary by reef. Temporally, vessel activity was most likely to occur during daylight hours, which is consistent with patterns of human activity. This heterogeneity in exposure could have implications for physiology and behavior and underscores the need for long-term acoustic monitoring alongside more targeted studies investigating the potential for effects of noise on aquatic organisms.

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1. INTRODUCTION

Coral reef soundscapes have been shown to vary spatially and temporally and this variability has been linked to differences in the species assemblages present on the reefs (Staaterman *et al.*, 2014; Kaplan *et al.*, 2015). However, patterns of human activity in nearshore marine habitats may also vary among reefs (Kaplan and Mooney, 2015) and accordingly might confound analysis of sounds of biological origin through the introduction of anthropogenic noise. Such differences in exposure of reef organisms to underwater anthropogenic noise could have impacts on animal physiology and behavior but the extent to which these animals might be exposed has yet to be quantified for most habitats, underscoring the need for long-term study. Here, we examine patterns of vessel noise across seven reefs in Maui, Hawaii that were recorded for an approximate 16-month period of time. We show that vessel noise was detected heterogeneously among these reefs in both space and time. In the presence of vessels, ambient soundscapes can be altered in significant ways, with potential implications for the fauna present.

2. METHODS

Seven reefs were selected for study on the west side of Maui, Hawaii, in September 2014 (Fig. 1). Acoustic data were collected at each reef using Ecological Acoustic Recorders (EARs, Lammers et al, 2008) equipped with SQ26-01 hydrophones (Sensor Technology Ltd., Collingwood, ON, Canada) with sensitivities of approximately -193.5 dBV re 1 μPa and configured with 47.5 dB of gain. Recordings were collected at sample rates of 50 kHz on a 10% duty cycle (30 s/300 s) for all reefs except Molokini, where the sample rate was 25 kHz. For all deployments, EARs were affixed to concrete blocks using hose clamps and cable ties and were placed in sand patches adjacent to or within a reef. All EARs except the one at Molokini were deployed in September 2014, refurbished in February/March 2015 and July 2015, and recovered in January 2016. The Molokini EAR was deployed and refurbished on a different schedule (November 2013, June 2014, October 2014, February 2015 and October 2015).

Analyses were carried out in Matlab 8.6 (MathWorks, Natick, MA). Any 30 s sound file that contained clipping was excluded from further analyses. All remaining sound files were corrected for hydrophone sensitivity and resampled to 44 kHz for improved computational efficiency (except for recordings from Molokini, which were not resampled). Root-mean-square (RMS) sound pressure level (dB re 1 μPa) was calculated in two frequency bands – low (100-1000 Hz) and high (1800-20500 Hz; 2000-12000 Hz for Molokini) using four-pole Butterworth bandpass filters.

Anthropogenic noise was marked individually for each reef by visually identifying and aurally confirming such sounds in long-term spectral average plots produced in Triton version 1.91 (Scripps Whale Acoustics Lab, San Diego, CA).

Vessel noise occurrence was stratified by time of day and binned by hour for each reef. Spectrograms were produced using Hamming windows with an FFT size of 500 points and 75% overlap.

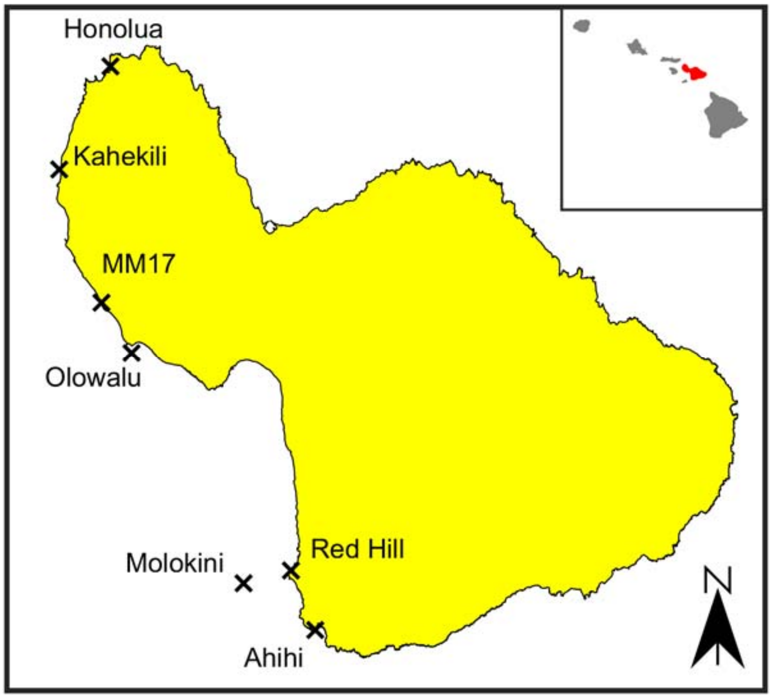

Figure 1. Map of study reefs on the island of Maui, HI.

3. RESULTS

Study reefs varied considerably in terms of the proportion of recordings that contained vessel noise (Fig. 2). Over 80% of recordings from c. 11:00 at Molokini contained vessel noise. The reef with the next most vessel activity was Red Hill, an adjacent reef, followed by MM17 and Olowalu. Only a limited proportion of recordings (i.e., less than 10%) from Ahihi, Honolua, and Kahekili contained vessel noise. In general, vessel noise was highest during daylight hours, which is consistent with typical patterns of human activity, and the number of night detections was only appreciable at MM17.

In addition to differences in the proportion of recordings with vessel noise, differences among reefs were noted in the extent to which sound levels changed in the presence of vessels. Median daytime low-frequency (100-1000 Hz) sound levels were considerably higher at Molokini in the presence of boats than otherwise (Fig. 3a) and the magnitude of the increase when boats were present was greater there than at Ahihi (Fig. 3b), where only limited increases in the presence of boats are evident.

The extent to which the presence of vessels changes the soundscape can be easily visualized in spectrograms. At 08:15 on 7 April 2015, a randomly selected date and time, a high amplitude recording of vessel was present at Molokini (Fig. 4a), which may mask the hearing of aquatic fauna, while no vessel was present at Ahihi (Fig. 4b) where shrimp snaps and low-frequency fish calls can be clearly noted in the spectrogram.

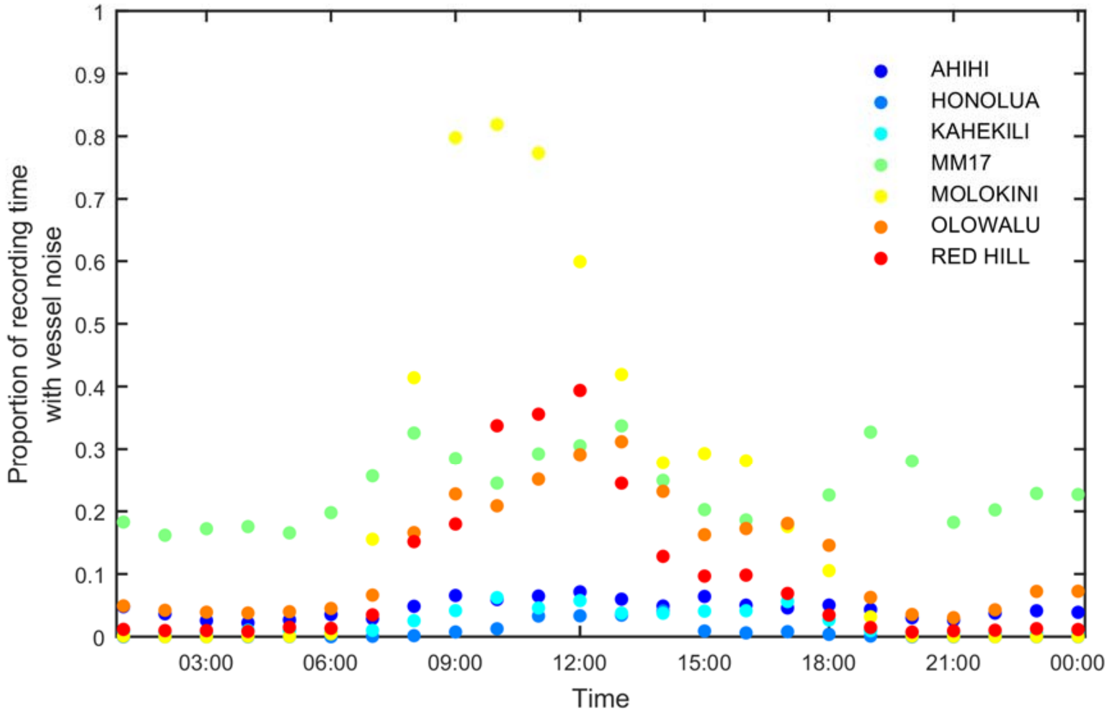

Figure 2. Proportion of recordings that contained vessel noise for each study reef and binned by hour of the day.

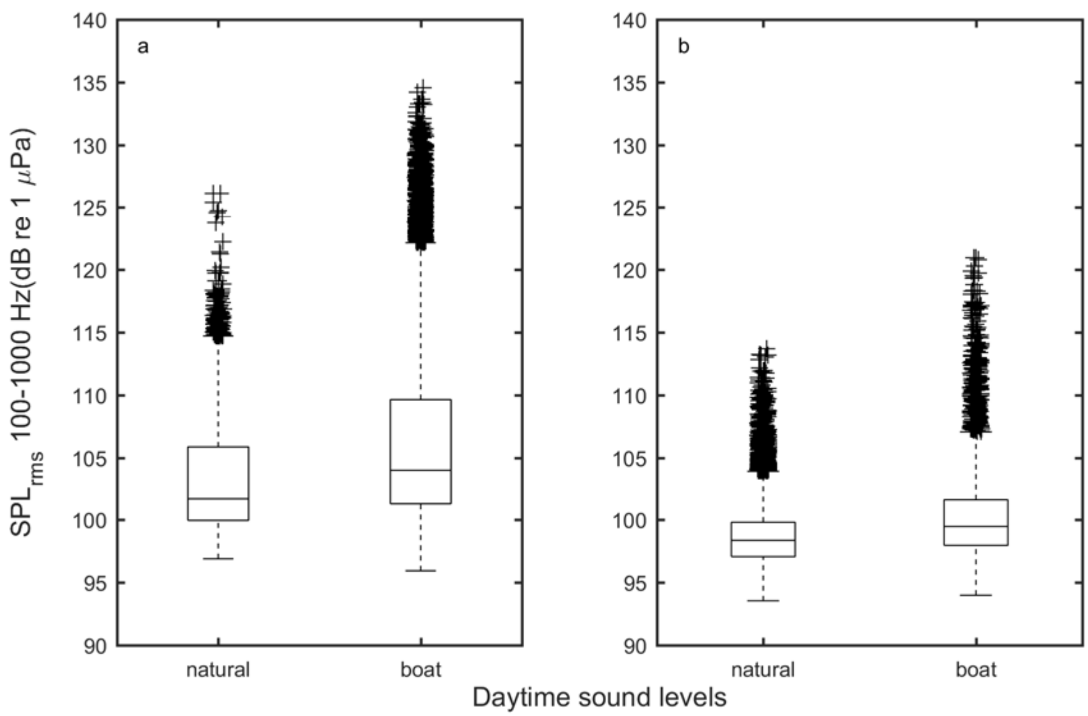

Figure 3. Sound levels at Molokini (a) and Ahihi (b) during the day in the absence (natural) and in the presence of boats (boat).

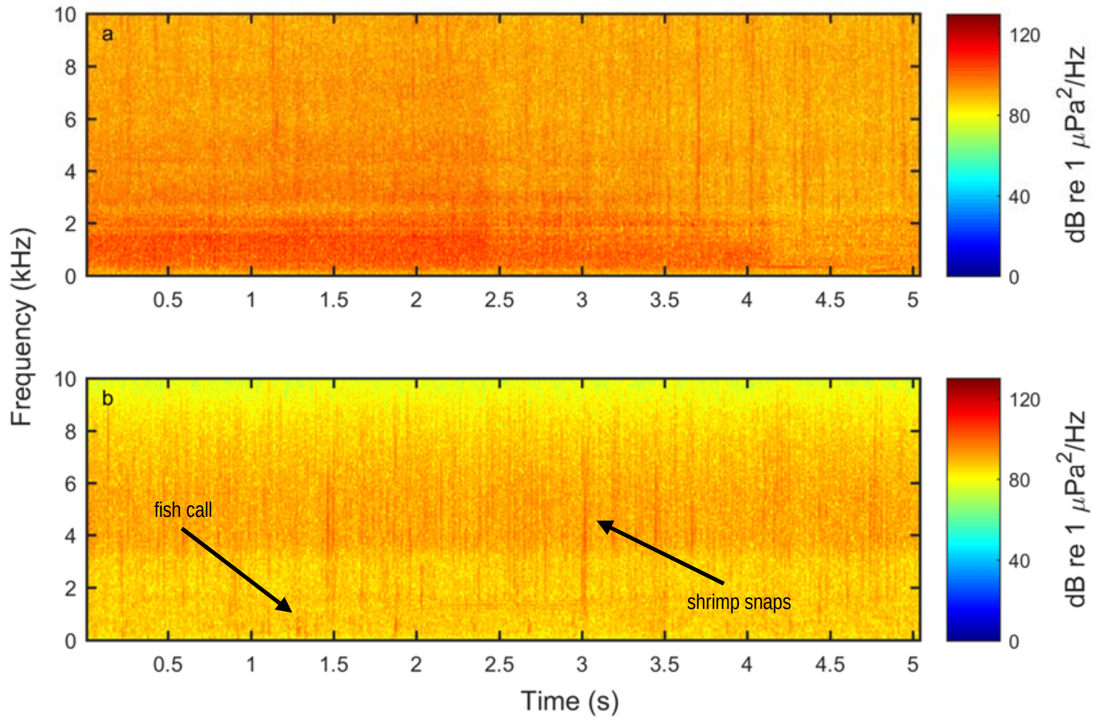

Figure 4. Spectrograms from Molokini (a) and Ahihi (b) on 7 April 2015 at 08:15 showing the presence of a vessel in the former and ambient biological sound production in the latter, with shrimp snaps and fish calls noted on the spectrogram.

4. DISCUSSION

Reefs varied in their exposure to vessel noise, reflective of broader patterns of human activity and local management regimes. For example, vessel noise was detected over 80% of the time at Molokini in the morning as a result of extensive snorkel and dive tourist operators using this reef whereas very little vessel activity was detected at Ahihi, a nearby reef that is closed to vessel entry. The amplitude of vessel noise detected at the various reefs also varied considerably; for example, whereas at many reefs detections may have largely been composed of distant vessels, at Molokini, amplitudes were very high as a result of the fact that vessels were in many cases directly adjacent to the recorder as they transited towards nearby mooring balls during their snorkeling and dive trips.

Detections at night were extremely limited except at MM17, which is a relatively exposed and flat sand patch. Thus, this site could be more prone to receiving low-amplitude continuous vessel noise from tugboats or larger vessels further from shore than adjacent sites.

The heterogeneous exposure among reefs raises questions about the potential effects of noise on the resident fauna. Recent work has shown that antipredator responses might be impaired in the presence of vessel noise (Simpson *et al.*, 2016). Additional work should investigate whether hearing abilities or antipredator behaviors vary as a result of these different noise exposure regimes. Furthermore, the extent to which the behaviors of predators themselves may be affected by vessel noise has yet to be characterized for predator-prey models other than the one studied by Simpson *et al.* (2016)

The extreme prevalence of vessel noise at some of these reefs and the resultant broadband sound level increases raise concern over the potential for masking. Indeed, this vessel noise may reduce the active space of communication for resident fishes, which may be limited even under optimal conditions (e.g. Mann and Lobel, 1997). Conversely, because the majority of sound production by both fishes and invertebrates takes place at crepuscular times, temporal overlap with vessels that are present primarily during the day might be limited.

5. CONCLUSION

Coral reef soundscapes vary in space and time as a result of natural and anthropogenic sound sources. Anthropogenic noise directly attributable to individual vessels can be appreciable on reefs that are popular tourist destinations and limited on reefs closed to vessel entry, but the effects of this noise exposure remain understudied. Experiments are required to further elucidate the extent to which exposure to vessels might affect behavior and vital rates of reef fauna.

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