Boat traffic in Bocas Del Toro, Panama associated with selection for lower and louder toadfish (*Amphichthys cryptocentrus)* calls.

Emma K. Gagne
University of Vermont. Department of Biology. 109 Carrigan Drive Burlington, VT 05405.

I. ABSTRACT

The toadfish is an important acoustic contributor to the local marine soundscape of Bocas del Toro. Toadfish emit mating calls to attract females to their burrows to spawn. Given that male toadfish calling behavior determines their reproductive success, boat traffic is expected to affect their acoustic behavior. This study evaluates the effects of boat traffic on toadfish call acoustic structure by comparing two sites within the Archipelago of Bocas del Toro, Panama that vary in boat traffic. The study finds the potential presence of three acoustic toadfish species that varied in call contour. One of the acoustic species, called here as 'flat species' was found in both study sites. Overall, this 'flat species' call was significantly shorter in duration, lower in frequency, and higher in amplitude in the site with high boat traffic than in the site with low boat traffic. The results suggest that noise associated with boat traffic may be selecting for lower and louder signals in noisy habitats. Given the importance of toadfish as health indicators of marine communities these results are important as they indicate how humans are changing their calls and interactions.

II. INTRODUCTION

A. Background

Male toadfish (family Batrachoididae) are an indicator species of many marine communities in North and Central America (O. Campana et al., 2003). They use acoustic communication to attract females to their burrows to spawn, and is therefore critical to their reproductive success. Their mating calls consist of low frequency "grunts" and "boops" which convey information about the male's guarding quality to females (Staaterman et al., 2017). The grunts have been examined, and appear to be used in intrasexual competition (Salas et al., 2018). Therefore, it is important both grunts and boops to be heard at a distance as to attract and outcompete other males in their vicinity (Robertson, 1983). In previous studies, toadfish calling behavior is described to increase with higher water temperatures, and can vary given the day length and tidal amplitude differences (Maruska, 2009).

B. Purpose and Scope

Through this study, I hope to compare the call structures of the Bocon toadfish, *Amphichthys cryptocentrus,* in the Archipelago of Bocas del Toro, Panama. I am asking questions about toadfish's plasticity in call frequency and time variables regarding boat traffic. A previous study by CURE students in 2018 found the calling activity of toadfish in the Archipelago varied between sites that share similarity in structure but differ on daily boat traffic patterns. In Almirante, boat traffic is scheduled and consistent between 6am-6pm. In Sharkhole, boat traffic is not permitted. One of the studies found overall patterns in which toadfish appeared to lower their frequency and signal energy during high boat traffic time. However, these patterns could be due to different toadfish species using the same spatial space. To address this limitation of potentially seeing the difference due to species' specific call structures, I will classify 'acoustic' toadfish species based on the contour of the boop and extract acoustic information during the times of the day at which calling activity is higher: dawn, midday, dusk.

I expect the toadfish call acoustic structure will vary throughout the day. I also hypothesize that if boat noise is the major driver of toadfish call structure, the above patterns should be detected in both the described acoustic species. My prediction is that toadfish calls will be emitted at lower frequency and with higher power values when boat activity is higher, regardless of 'acoustic' species.

C. Significance

This study will provide relevant information about fish responses to boat sounds, a primary source of anthropogenic noise in Bocas del Toro. Toadfish are necessary in marine communities to signify the health of the ecosystem. They can indicate to researchers what kinds of chemicals are present, and how an accumulation of those chemicals can impact other fish. This study will help us to understand how humans are changing the calls and interactions of toadfish, and give insight as to what management steps can be taken to preserve them as a health indicator and critical part of marine communities.

III. MATERIALS AND METHODS

A. Study site

The study took place at the Archipelago of Bocas del Toro, Panama. This is a significant geological area, where the islands were separated from the mainland due to sea level rise. Coral reefs, mangroves, and seagrass habitats compose integral parts of the marine environment there; coral reefs and seagrass meadows are important environmental indicators of water quality (Guzman, M. H., et al. 2005).

B. Recordings

Passive acoustic recordings were taken with RUDAR-mk (RUDAR-mK2 (Sampling rate up to 96kHz -169dB re:1V/uPa) from Cetacean Research Technology (www.cetaceanresearch.com). The recorder was programmed to continuously record the soundscape in segments of 30 minutes at a sampling rate of 48 kHz from March 28 to April 7, 2018. Recorders were deployed in two sites Almirante (9.289N, -82.332W) and Sharkhole (9.184N, 82.176W) at about 12 meters in depth and with coral reef substrate. The main differences between these sites is based on boat traffic. In Almirante, taxi-boats travel daily from mainland to the main island in the Archipelago between 6 a.m. and 6 p.m. In contrast, Sharkhole is relatively deprived of boat traffic with occasional tour and fishing boats passing by.

C. Fish call data

Toadfish calls with good signal-to-noise ratio were selected from dawn (2am-4am), midday (11am-1pm), and dusk (7pm-9pm) to analyze their frequency and temporal characteristics. These time periods were based on Maze (2018) analysis of toadfish activity in these two study sites, representing times of high (dawn, dusk) and low (midday) calling activity. These times also represent times of low (dawn, dusk) and high (midday) boat traffic. The analyses were done in Raven 1.5 (2016; Cornell Lab of Ornithology) with a Fast Fourier Transform size of 4,000 points, an overlap of 50%, and a 4096-sample Hann window. Toadfish mating calls consist of two parts boops and grunts (Staaterman et al., 2018). For each of these call components (and intergrunts, intergrunt-boops, and interboops) the following standard acoustic variables were extracted from each call: grunt duration, grunt peak frequency, grunt fundamental frequency, grunt maximum amplitude, grunt RMS amplitude, inter-grunt interval, grunt-boop interval, boop duration, boop peak frequency, boop fundamental frequency, boop maximum amplitude, boop RMS amplitude, and inter-boop interval (Staaterman et al., 2018).

D. Statistics

A generalized regression analysis was used to determine the contribution of acoustic species, time of day, and site to the call acoustic structure. An ANOVA test was done to determine if acoustic species found in both low and high boat traffic sites significantly vary in call acoustic structure. The statistical analyses were done using JMP Pro 14.2 (SAS, 2019)

IV. RESULTS

A. Acoustic species

Three acoustic species of toadfish were identified based on contour differences of the boop: flat, flat*, and sine. Species flat was characterized by having a boop with constant contour, species sine by a sinusoidal contour, and species flat* had a deep and mostly constant contour (Fig.1). Species flat was most commonly detected (55%) followed by species sine (25%) and flat* (20%). Only species flat was found in both study sites.

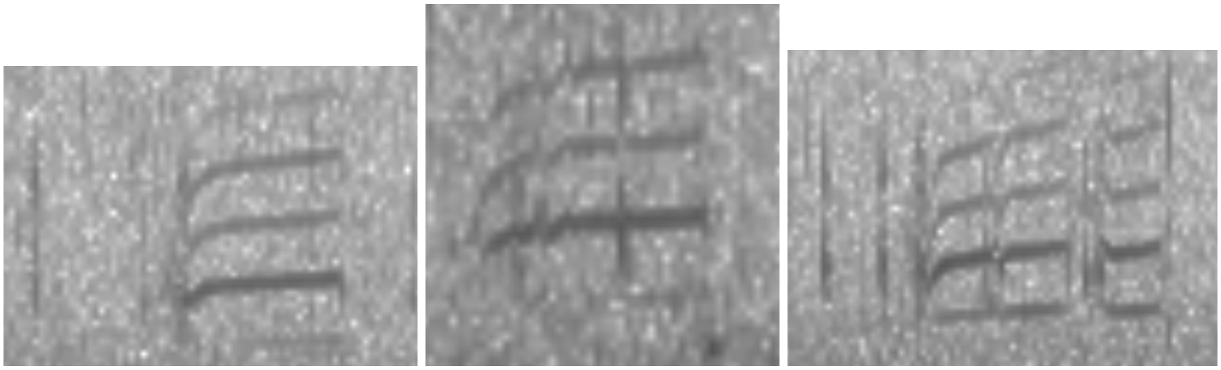

FIG 1. The spectrogram of the three acoustic species are shown. From left to right; species flat, species sine, and species flat*.

B. Factors influencing call acoustic structure

Toadfish call frequency, time, and amplitude characteristics varied in relation to species identity, time of day, and boat traffic level (site). Toadfish call low frequency and peak frequency did not varied significantly among species (p>0.05) but it did vary between sites (LF: F=40.4,df=2, p<0.0001, PK: F=361.2,df=2, p<0.0001) and time of day (F=3.3,df=2, p=0.0367, PK: F=3.3,df=2, p=0.0437p<0.0001). Call high frequency and call duration differences are attributed to site (HF: F=50.3, df=1, p<0.0001, D: F=246.8, df=1, p<0.0001), acoustic species (HF: F=12.4, df=3, p<0.0001, D: F=11.3, df=3, p<0.0001) and time period (HF: F=4.76, df=2, p=0.0086, D: F=5.4, df=2, p=0.0042). Call amplitude differences were also influenced by site (Max. Amp.: F=1710, df=1, p<0.0001, RMS: F=5251, df=1, p<0.0001) and time of day (Max. Amp.: F=10.7, df=2, p<0.0001. RMS: F=108, df=2, p<0.0001) and acoustic species (RMS: F=64, df=2, p<0.0001).

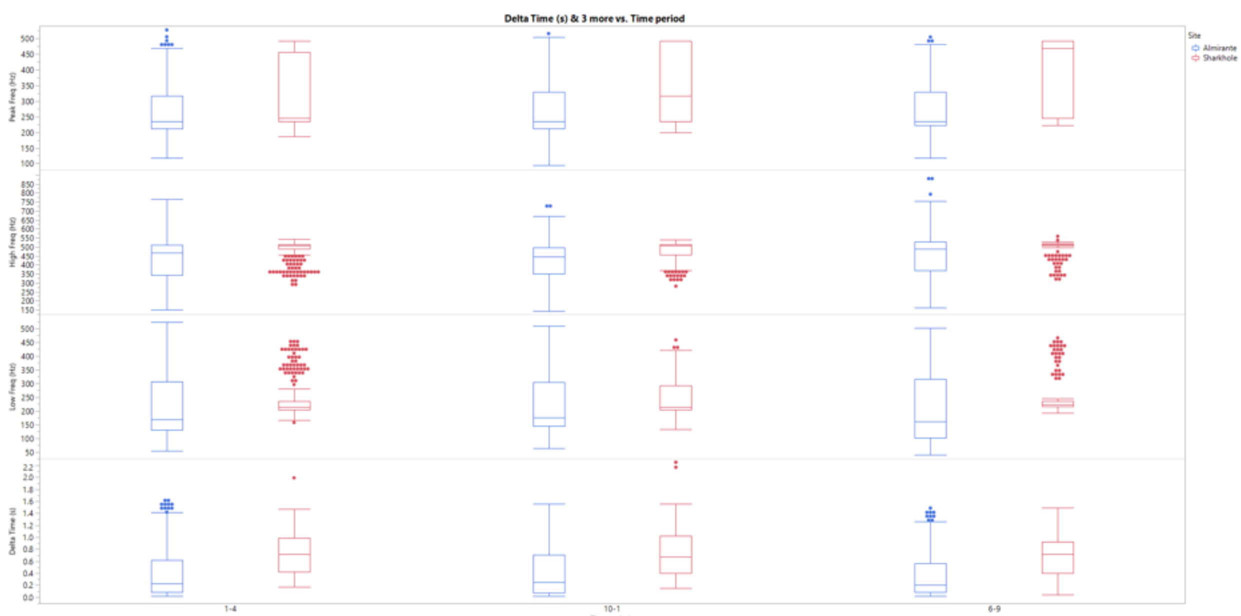

FIG. 2: Box plot comparison of call parameters between Almirante and Sharkhole throughout the day (1 am-4 am, 10 am-1 pm, and 6 pm - 9pm), . Top row shows peak frequency (Hz), second row shows High frequency (Hz), third row shows low frequency (Hz), and the bottom row shows delta time (s).

C. Flat species call acoustic structure

Toadfish flat calls vary significantly in acoustic structure. Calls were lower in frequency in the site with higher boat traffic (Almirante) than in the site with low boat traffic (Sharkhole) (LF:F=49.8, df=1, p<0.0001; HF: F=57, df=1, p<0.0001, PF: F=350.4, df=1, p<0.0001). Calls were also shorter (F=233.1, df=1, p<0.0001) and louder (F=77716, df=1, p<0.0001) in the site with higher boat traffic. Regarding the time of day, in the site with higher boat traffic toadfish call high frequency was significantly lower in the presence of boat traffic (10 a.m. and 1 p.m.) (x2=22.7, df=2, p<0.0001). In contrast, in the site with low boat traffic toadfish call frequency was higher at night (7 to 9 p.m.) (LF: x2=25.7, df=2, p<0.0001, HF: x2=36, df=2, p<0.0001, PF:). No significant differences were found in max amplitude or RMS amplitude with time of day.

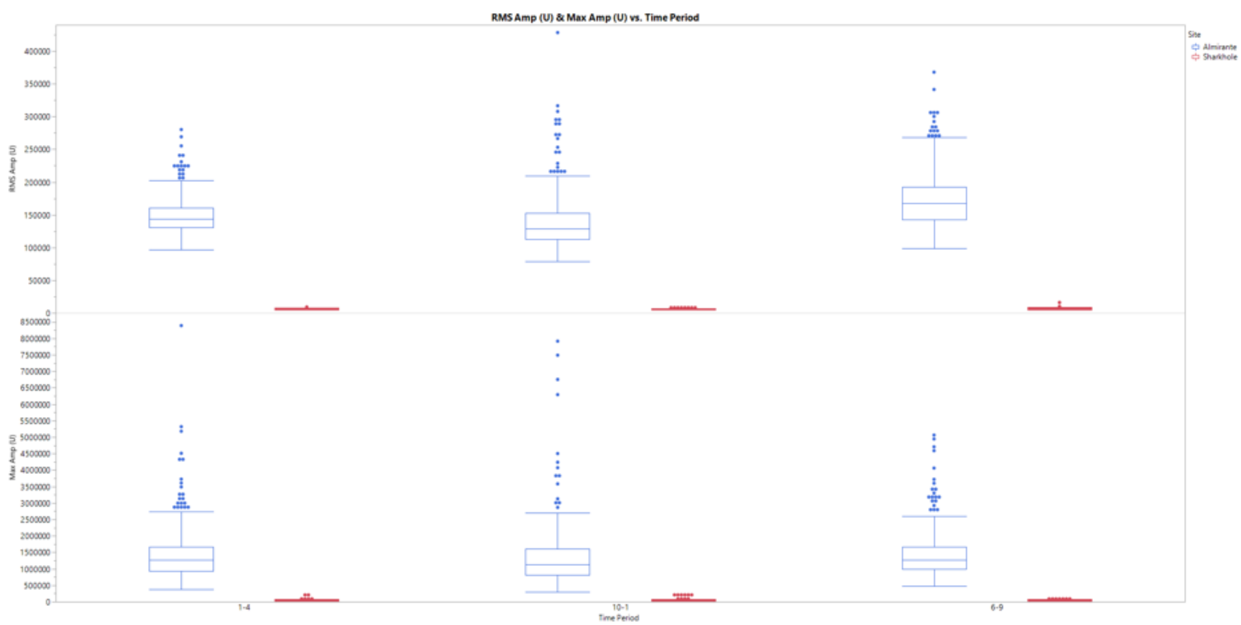

FIG. 3: Box plot comparison of call parameters between Almirante and Sharkhole throughout the day (1 am-4 am, 10 am-1 pm, and 6 pm - 9pm), . Top row shows RMS amplitude and the bottom row shows maximum amplitude.

V. DISCUSSION

In the beginning of the study, our aim was to examine differences in three acoustic toadfish species that all varied in call contour. We examined “flat,” “sine,” and “flat.” Only the ‘flat species,’ however, was found in both study sites. When looking at the time of day, in the site with higher boat traffic toadfish call high frequency was significantly lower in the presence of boat traffic (10 a.m. and 1 p.m.), while the site with low boat traffic toadfish call frequency was higher at night (7 to 9 p.m.); this was expected based on previous studies by my peers. Overall, we find the ‘flat species’ call was significantly shorter in duration, lower in frequency, and higher in amplitude in the site with high boat traffic than in the site with low boat traffic. These results suggest that noisy habitats due to constant boat traffic select for lower and louder toadfish calls.

The “acoustic adaptation hypothesis” states that efficient communication in contexts of mate choice or attraction and territorial defense is predicted to enhance the Darwinian fitness of the individual making the call, despite potentially having adverse costs (Slater, P.J.B, 1983). Most studies on this to date have focused on birdsong and habitat structure (Boncoraglio et al., 2007), however, this study indicates a novel situation with fish and boat traffic. Sound transmission in different habitats suggest that acoustic signal spanning long-distances are likely to be degraded by a number of environmental factors; human noises are no exception (Hansen, P., 1979). Natural selection will favor calls that are able to span those long distances despite degradation from factors. Masking, or threshold change in signal level from neighboring noise (Pollack I, 1975), describes how boat noises can degrade toadfish calls. In the case of the toadfish, we see individuals capable of making lower frequency calls to avoid this. We expect this lower frequency to influence a greater survival rate, according to the acoustic adaptation hypothesis.

In order to create a lower frequency sound, there is likely an associated increase in swim bladder size. In toadfish, they have a swim bladder which is a large pocket of air located in their abdomen; sound is produced through the drumming of the sonic muscle on the swim bladder, causing contraction and expansion at high rates (“How”, 2019). Frogs and roadway traffic noise have been extensively studied; results from these studies show males used higher frequencies to avoid traffic masking, and were therefore, significantly smaller in size closer to the road (Hoskin, C.J., and Miriam, W.G., 2010).

Similarly, because toadfish lower their frequencies to avoid masking from the boats, we could speculate individuals with greater swim bladder size, and therefore greater body size, to be present in boating areas. Future studies could determine if the acoustic adaptation hypothesis holds true here, and describe a novel case of anthropogenic masking in fish. As anthropogenic modification in natural environments continues to increase, species have to adapt quickly in order to survive. Understanding this in toadfish gives insight as to how some communities are changing in response to one human factor; boat traffic and noise. Given the importance of toadfish as health indicators of marine communities these results are important as they indicate how humans are changing their calls and physiology.

REFERENCES

Boncoraglio, Giuseppe, and Nicola Saino. (**2007**). "Habitat Structure and the Evolution of Bird Song: a Meta-Analysis of the Evidence for the Acoustic Adaptation Hypothesis." *Functional Ecology*, vol. **21**, no. 1. doi:10.1111/j.1365-2435.2006.01207.x.

Campana, O., Sarasquete, C., & Blasco, J. (**2003**). "Effect of lead on ALA-D activity, metallothionein levels, and lipid peroxidation in blood, kidney, and liver of the toadfish Halobatrachus didactylus." *Ecotoxicology and Environmental Safety*, ***55***(1), 116-125.

Guzman, M. Hector., et al. (**2005)**. "A Site Description of the CARICOMP Mangrove, Seagrass and Coral Reef Sites in Bocas del Toro, Panama." Caribbean Journal of Science, **41**:3:430-440.

Hansen, Poul. (**1979**). "Vocal Learning: Its Role in Adapting Sound Structures to Long-Distance Propagation, and a Hypothesis on Its Evolution." *Animal Behaviour*, **27**:1270–1271., doi:10.1016/0003-3472(79)90073-3.

Hoskin, Conrad J., and Miriam W. Goosem. (**2010**). "Road Impacts on Abundance, Call Traits, and Body Size of Rainforest Frogs in Northeast Australia." *Ecology and Society*, **15**:3 doi:10.5751/es-03272-150315.

"How Do Fish Produce Sounds?" *Discovery of Sound in the Sea*, 28 Jan. (**2019)**. dosits.org/animals/sound-production/how-do-fish-produce-sounds/.

Maruska, K. P. and A. F. Mensinger. (**2009)**. "Acoustic characteristics and variations in grunt vocalizations in the oyster toadfish Opsanus tau." Environmental Biology of Fishes **84**:325–337.

Pollack, Irwin. (**1975**). "Auditory Informational Masking." *Scitation*, Acoustical Society of America, asa.scitation.org/doi/abs/10.1121/

Robertson, D. Ross., et al. (**1983)**. "Foraging and reproduction of two Caribbean reef toadfishes (Batrachoididae)." Bulletin of Marine Science, **33**:919-927.

Salas, A. K., P. S. Wilson and M. J. Ryan. (**2018)**. "Acoustic communication in the Bocon toadfish (Amphichthys cryptocentrus)." Environmental Biology of Fishes 101:1175–1193.

Slater, P.J.B. (**1983**) The study of communication. Animal Behaviour, Vol. 2 (eds T.R. Halliday & P.J.B. Slater), pp. 9–42. Blackwell Scientific, Oxford.

Staaterman, E., S. J. Brandl, M. Hauer, J. M. Casey, A. J. Gallagher and A. N. Rice. (**2018)**. "Individual voices in a cluttered soundscape: acoustic ecology of the Bocon toadfish, Amphichthys cryptocentrus." Environmental Biology of Fishes **101**:979–995.

Wert, J. C. V. and A. F. Mensinger. (**2019)**. "Seasonal and Daily Patterns of the Mating Calls of the Oyster Toadfish, Opsanus tau." The Biological Bulletin **236**:97–107.