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BRIEF COMMUNICATION

The roar of the lionfishes *Pterois volitans* and *Pterois miles*

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Through the analysis of acoustic recordings of captive *Pterois* spp., this study has confirmed anecdotal evidence that *Pterois* spp. are soniferous. This report of sound production in *Pterois* spp. provides the foundation for future research into their specific acoustic capabilities including sound production mechanisms, the role of social behaviour and applied techniques for controlling and monitoring invasive *Pterois* spp. in the tropical and temperate western Atlantic Ocean.

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Sound allows aquatic organisms to communicate and explore their environment more efficiently than other modes of communication (*e.g.* visual and chemical signals) because it travels much faster and further. Consequently, acoustic signalling has evolved as a dominant mode of communication in aquatic ecosystems. For more than a century, sounds produced by fishes have been the subject of research (Dufossé, 1874*a, b*). Sound production mechanisms in fishes have also been studied for many years (Fish *et al.*, 1952). Fishes produce sounds for a variety of reasons including courtship and spawning, aggression, hunting and as a response to threatening situations (Ladich, 1997). Given this history and their relationship to soniferous fishes, the goal of this preliminary study was to confirm anecdotal observations of sound production in lionfishes *Pterois volitans* (L. 1758) and *Pterois miles* (Bennett 1828). The objective was to gain a rudimentary understanding of their acoustic capabilities by characterizing a small range of vocalizations produced by captive *Pterois* spp. This note is not exhaustive. It does not fully characterize *Pterois* spp. vocalizations nor does it describe *Pterois* spp. sound production characteristics *in situ*. Rather, it is intended as a basis for future research on *Pterois* spp. sound-production mechanisms, contexts

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and triggers, as well as for applications to bolster control and management activities of invasive *Pterois* spp. in the temperate and tropical western Atlantic Ocean.

This study was conducted in an enclosed and isolated 2500 l outdoor concrete seawater tank at the National Oceanic and Atmospheric Administration (NOAA) Laboratory in Beaufort, North Carolina. The 5.3 m long, 2.2 m wide and 0.7 m deep tank had 0.3 m thick walls and was buried 0.5 m in the ground. This tank was chosen because the earthen backing minimized ambient noise levels and tank reverberation, which were measured prior to the trial.

The soundscape was continuously recorded for 5 days at 96 kHz using a SoundTrap recording device (www.oceaninstruments.co.nz). To begin the study, a single *Pterois* spp. 15 cm total length (L_T) was haphazardly selected from a group of 15 individuals (mean \pm s.d. $L_T = 17.4 \pm 4.1$ cm) and was allowed to acclimate in the concrete tank for 24 h. After acclimation, the fish was nominally and intermittently agitated for 60 min by being stalked and netted. Four additional *Pterois* spp. were haphazardly selected from the same group of individuals and were allowed to acclimate in the tank for 48 h. Three of the four fish were similar in size to the original fish (mean \pm s.d. $L_T = 15.33 \pm 0.57$ cm), while the other was notably larger (32 cm L_T). The same methods of agitating were used again with all five fish in the tank and ambient light (34° 43' N) was used throughout the experiment.

Minimal effort was put into stalking and netting the *Pterois* spp. to minimize overall stress. Multiple *Pterois* spp. were used and were agitated to simply maximize the likelihood of stimulating vocalizations and to elicit a greater range of vocalization characteristics. The fishes were stalked and netted using a 30 cm² landing net that was slowly (<0.25 m s⁻¹) and haphazardly moved around the tank. Netting took place when a fish became cornered. No effort was put into purposefully cornering fishes for netting nor were fishes immediately chased after unsuccessful netting attempts in an attempt to re-net the fishes. Once cornered and netted, the *Pterois* spp. was slowly raised and held at the surface of the water for <5 s and then slowly lowered and released. The fishes were never fully exposed during netting. An attempt was made to keep track of the fishes that were netted so they were not netted more than once. It is unknown, however, whether all fishes were netted at least once or more than once since the fishes were not tagged.

Audio recordings were analysed in Raven Pro 1.4 (<http://www.birds.cornell.edu/brp/raven/Raven14UsersManual.pdf>) and MATLAB (www.uk.mathworks.com) software. The recordings taken during agitation were processed first as it was suspected they were most likely to include vocalizations. Once isolated, each vocalization was analysed for duration, average and peak frequencies and bandwidth. All frequency analyses were made with an 8192 point Hamming window, which, with 96 kHz sampling frequency, gives a frequency resolution of c. 11 Hz and a time resolution of c. 0.08 s. Using the full range of these vocalization variables, a detector was created in the extensible bioacoustics analysis programme (XBAT; <https://forge.cornell.edu/sf/projects/xbat/>) in MATLAB to locate additional vocalizations in the remaining 118 h of recordings. The detector was designed to favour false positives over false negatives to provide high confidence that it captured a majority of vocalizations.

Pterois spp. produced two distinct call types and vocalized across a range of durations, frequencies and bandwidths during the continuous 5 day study. The most common call, described as a repetitive pulse call, consisted of one to four distinct pulses, or knocks, with occasional occurrences of up to eight pulses (Fig. 1). A hum call was

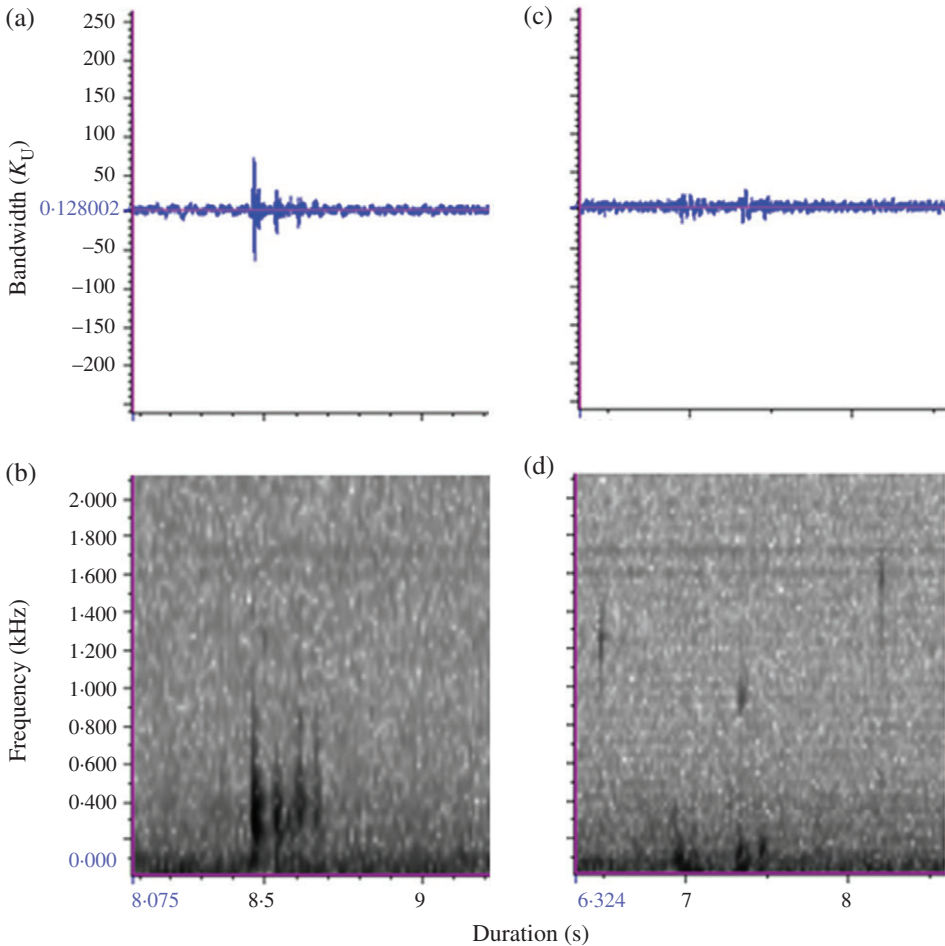


FIG. 1. (a, c) Waveforms and (b, d) spectrograms of two repetitive pulse calls produced by a single *Pterois* spp. (a) A high frequency call with a duration of 0.242 s, a bandwidth of *c.* 852 Hz and (b) a peak frequency of 862 Hz. (c) A low frequency call with a duration of 0.624 s, a bandwidth of *c.* 305 Hz and (d) a peak frequency of 315 Hz.

also identified, which contained continuous energy at relatively low frequencies and was punctuated by intermittent pulses (Fig. 2). Repetitive pulse calls were recorded throughout the entire study, while hum calls were only recorded when all five fish were being agitated.

A range of repetitive pulse-call vocalizations were recorded when a single *Pterois* spp. was in the tank. While the vocalizations share similarities in their pattern of pulses, there was apparent variation in their duration, frequency, number of pulses and bandwidth. Owing to the preliminary nature of this study, the variation in call characteristics was unquantified as to not be misleading. Repetitive pulse calls ranged in duration from 0.24 to 0.624 s and their frequency structure was relatively broad with calls centred between *c.* 180 and 900 Hz and bandwidths of *c.* 180 and 900 Hz. High-frequency calls generally consisted of more rapid pulses and a shorter duration, whereas low-frequency

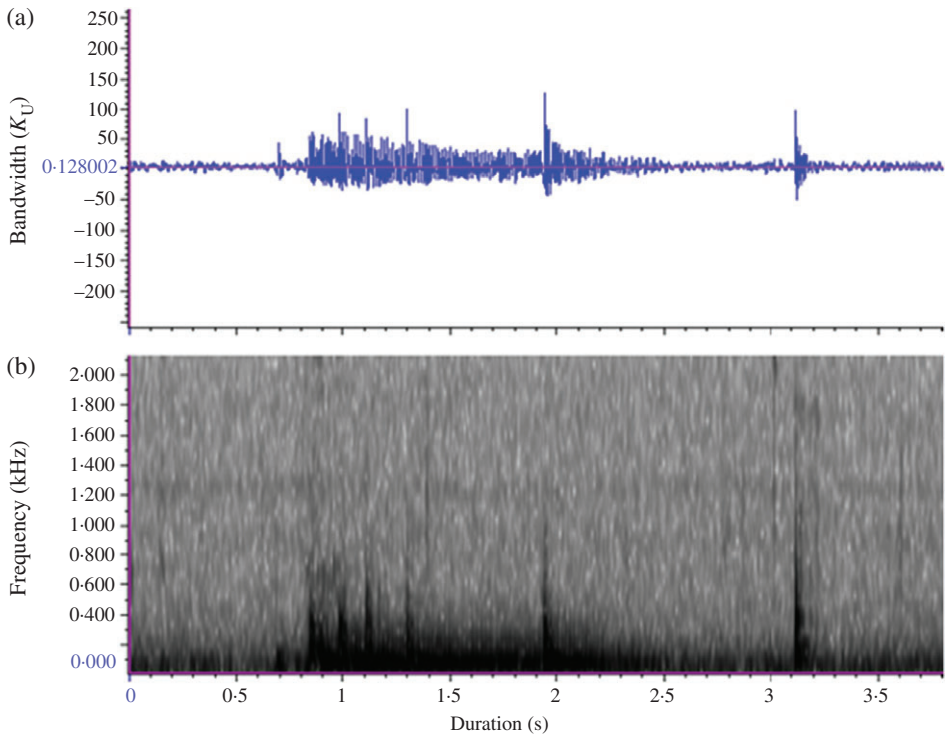


FIG. 2. (a) Waveform and (b) spectrogram of the hum call recorded with multiple *Pterois* spp. in the tank. This particular call had (a) a duration of 1.7 s, a bandwidth of c. 1180 Hz and (b) a peak frequency of 1191 Hz.

calls consisted of less rapid pulses and a longer duration. High-frequency vocalizations were never closely followed by a low-frequency vocalization and *vice versa*. The variation in frequency and span of time between each set of pulses suggests that each set is a single distinct vocalization.

The same range of repetitive pulse-call vocalizations were recorded when multiple fishes were in the tank. The variation seen in the pulse pattern did not, however, always coincide with changes in frequency (*i.e.* both frequency ranges were seen in varying pulse patterns) and it was common for multiple pulses at varying frequencies to occur only seconds apart. These vocalizations deviated from the previously recognized patterns as the low frequency vocalizations consisted of more rapid knocks and a shorter duration than the high frequency vocalizations. The sudden variation of frequency and call pattern within a single period of time suggests that multiple fishes vocalized concurrently (Fig. 3).

Repetitive pulse-call vocalization variables recorded during periods of agitation differed from those when fishes were not being agitated. The repetitive pulse calls produced when the single fish was not being agitated were typically less rapid and were a lower frequency than when it was being agitated. Similarly, the non-agitated calls recorded when multiple fishes were in the tank were typically more rapid and had a higher frequency than the non-agitated calls produced by the single fish. A representative vocalization of a non-agitated repetitive pulse call produced by the single fish

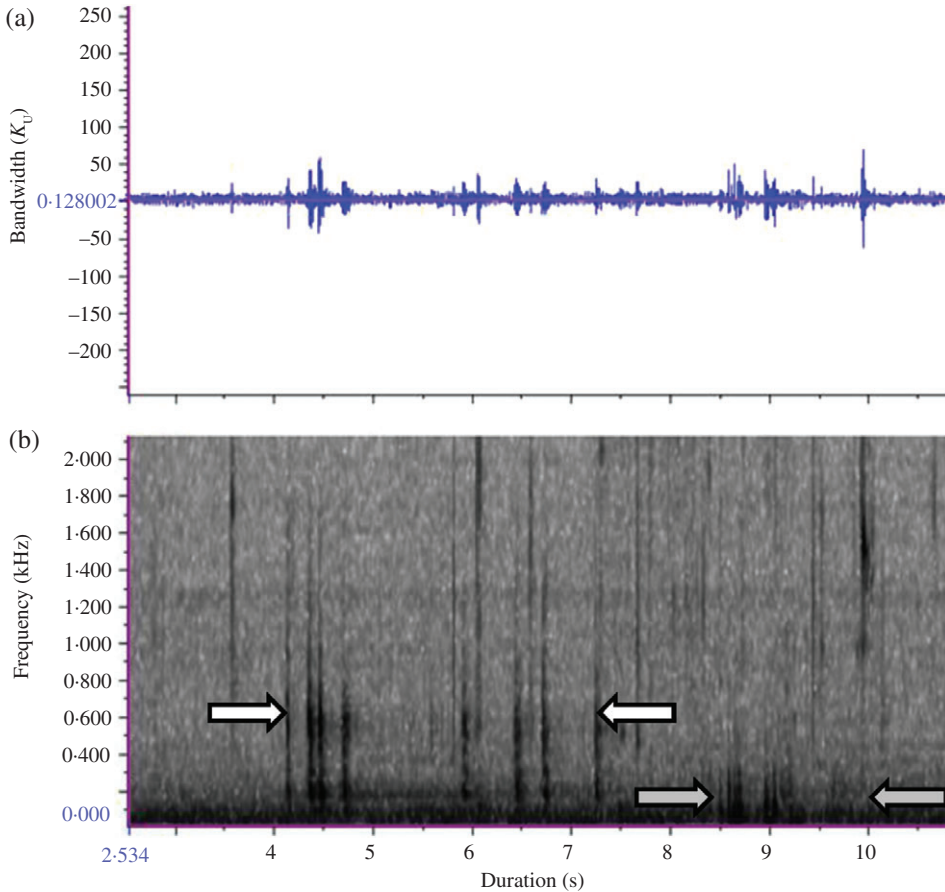


FIG. 3. (a) Waveform and (b) spectrogram of two concurrent repetitive pulse calls recorded with multiple *Pterois* spp. in the tank. The higher frequency call had (a) a duration of 3.2 s, a bandwidth of c. 1204 Hz and (b) a peak frequency of 1214 Hz ($\Rightarrow \Leftarrow$), while the low frequency call had (a) a duration of 1.1 s, a bandwidth of c. 402 Hz and (b) a peak frequency of 411 Hz ($\Rightarrow \Leftarrow$). The relatively large difference in the spectral content of these two calls suggests they were produced by different fish.

had a duration of 4.5 s, a peak frequency of 187 Hz and a bandwidth of c. 170 Hz. A representative agitated call produced by the same fish had a duration of 0.242 s, a peak frequency of 862 Hz and a bandwidth of c. 850 Hz.

The low frequency hum call recorded when all *Pterois* spp. were being agitated was similar to the repetitive pulse-call pattern, but the pulses were much more rapid. The hum comprised a series of rapid pulses, rather than one continuous tone and was followed by a chain of shorter hums and then one to four distinct pulses. While the hum created a very distinct sound, it appeared to be the same pattern of pulses just repeated at a more rapid rate.

Stress has been known to increase the rate (more often and faster) and frequency of fish vocalizations (Orchinik *et al.*, 2002; Ramage-Healey & Bass, 2004, 2005). *Pterois* spp. vocalizations produced during periods of agitation were typically more rapid and

of higher frequency than those produced when the fishes were not being agitated. Additionally, the pulse rate and average frequency produced when the five fishes were not being agitated was more rapid and higher than when the single fish was being agitated. These differences in rates and frequencies suggest stress, from direct agitation or crowding, may alter *Pterois* spp. sound production. Additional trials are needed to quantify the variation in these call characteristics so they can be compared statistically.

The role of sonic muscles in sound production is well documented within the Scorpaeniforme order (Miyagawa & Takemura, 1986; Pusey *et al.*, 2004), including the Scorpaenidae family (Kasumyan, 2008). Sonic muscles around the swimbladder contract and relax to cause pressure and volume changes within the swimbladder (Kasumyan, 2008). These oscillations cause the swimbladder to pulsate producing a drum-like acoustic signal (Kasumyan, 2008). The intrinsic sonic muscles of rockfishes *Sebastes* spp. originate from and are inserted into the swimbladder wall at both ends (Nichols, 2005). This orientation is relatively rare, but appears to be consistent throughout the scorpaenids (Nichols, 2005) including *Pterois* spp. (Cerino, 2010). *Sebastes* spp. commonly create short, low frequency three to four repetitive pulses (Nichols, 2005), which are very similar to the vocalizations identified in this study. Although this study did not attempt to describe *Pterois* spp. sound production mechanisms, the similarities between the swimbladder musculature and the vocalizations of other scorpaenids, particularly *Sebastes* spp., suggest *Pterois* spp. may produce sound in a similar fashion. Further research is needed to describe *Pterois* spp. sound production anatomy and physiology.

Sound is a critical component of fish social behaviour and sound production has been well documented throughout the Scorpaenidae family (Kasumyan, 2008). Little is known about invasive *P. volitans* or *P. miles* social behaviour, but there is evidence to suggest they may display similar behaviours as the zebra lionfish *Dendrochirus zebra* (Cuvier 1829). Rizzari & Lönnstedt (2014) found that *D. zebra* participate in cooperative hunting and Lönnstedt & McCormick (2013) suggest this also occurs in *P. volitans* and *P. miles*. Moyer & Zaiser (1981) report a variety of additional social behaviours in *D. zebra* including social organization and aggregation, which they attributed in part to size (*i.e.* evidence of dominant behaviours). Jud & Layman (2012) suggest *Pterois* spp. may be displaying similar social organization behaviours in the Atlantic Ocean. Not limited to Scorpaenids, Stout (1975) reported larger satinfin shiner *Cyprinella analostana* Girard 1859 produce a 'rapid series of knocks' as an aggressive and dominant behaviour. It is unknown whether or, if so, how sound plays a role in the social behaviour of *Pterois* spp. The rapid increase in the rate and frequency, the change in pulse pattern of the repetitive pulse calls and the existence of the low frequency hum recorded when multiple fishes were in the tank, especially one noticeably larger fish, suggests that it may. Further research is needed to identify and describe size, sex, context and behaviour specific vocalizations.

Passive acoustic monitoring of fish sounds has been used in a variety of applications. Širović *et al.* (2009) described methodology for using *Sebastes* spp. sounds for monitoring populations and Mann *et al.* (2009) and Parsons *et al.* (2009) described methodology for using sounds to locate and monitor spawning aggregation sites. Invasive *Pterois* spp. are highly abundant and broadly distributed throughout the temperate and tropical western Atlantic Ocean. If applicable, the development of passive acoustic techniques for monitoring *Pterois* spp. populations could greatly reduce monitoring costs and increase the size of the monitored area.

Several biological (*e.g.* sterilization), physical (*e.g.* barriers) and chemical (*e.g.* rotenone) methods are commonly used to control invasive species. Owing to their broad distribution in the Atlantic, these traditional methods are ineffective at controlling invasive *Pterois* spp. The most effective method for controlling populations has been through direct removals by divers and as by-catch in the commercial lobster fishery. *Pterois* spp. are known to aggregate in high densities (*i.e.* they are often found in large patches along large reef tracts) and to form groups prior to spawning (Fishelson, 1975). If *Pterois* spp. use sounds for aggregation, it is conceivable that these vocalizations could be used in conjunction with other removal methods to increase removal efficiency. Research is needed to better understand the role of sound production in *Pterois* spp. social behaviour, particularly for aggregating purposes, as well as passive acoustic techniques for monitoring *Pterois* spp. populations.

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