Biological Conservation 187 (2015) 27–33

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Traffic noise masks acoustic signals of freshwater stream fish

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ARTICLE INFO

Article history:
Received 20 January 2015
Received in revised form 30 March 2015
Accepted 5 April 2015

Keywords:
Blacktail Shiner
Noise pollution
Bioacoustics
Acoustic propagation

ABSTRACT

In order for an acoustic signal to be an effective source of communication, the signal must be successfully detected and interpreted by the intended receiver. One potential barrier to acoustic communication is background noise. Lotic systems contain a wide variety of habitats including riffles, shoals and waterfalls that can become quite noisy. The increasing prevalence of road and train crossings over small streams, and increased boat traffic in navigable rivers and lentic systems also presents potential anthropogenic noise sources with which vocal fishes did not evolve. The present study investigates the relationship between vocalizations and the natural soundscape of a common fish of the Southeastern United States, the Blacktail Shiner (*Cyprinella venusta*), and the potential effects anthropogenic noise from bridge crossings may have on the soundscape and acoustic communication in this species. Results revealed a particularly close association of a quiet window in the natural soundscape of *C. venusta* and dominant frequencies of the courtship vocalization of *C. venusta*. Results also indicated that *C. venusta*'s acoustic signals propagate short distances, following predictions based on the calculated cutoff frequency of the streams they inhabit, and were masked by noise generated from bridge crossings. Our calculations suggest that road traffic noise propagates to an extent that virtually entire watersheds are impacted by this noise pollution, especially in urban areas.

1. Introduction

Because sound has the capacity to carry information, can be used intermittently, and does not require a line of sight, it is used extensively by animals as a mode of information transfer. Sound production has been documented in over 800 species of fishes representing 109 families within the infraclass Teleostei (Kasumyan, 2008). Despite the fact that a large number of fishes likely utilize sound for communication, numerous factors concerning the properties of the projected sound, hearing abilities of the receiver, constraints imposed by the physical environment, and ambient noise levels of the environment must fit together properly in order for acoustic communication to be effective. Ambient noise from both biotic and abiotic (wind, rainfall, turbulence) sources can decrease the signal-to-noise ratio of signals, or make temporal information more difficult to extract (Wysocki and Ladich, 2005). Studies on terrestrial species have shown that these environmental noise sources can act as strong selective pressures in the evolution of signal structure (Waser and Waser, 1977; Wiley and Richards, 1982; Jouventin et al., 1999; Narins et al., 2004).

Unlike natural biotic and abiotic noise sources, the relatively recent development and rapid expansion of human activities such as urbanization, shipping, motorized recreational activities, drilling, and seismic explorations (Myrberg, 1990; Popper, 2003) do not provide the time necessary for the evolution of acoustic signals. Efforts have been made to determine the effect of anthropogenic noise on marine mammals (Southall et al., 2007; Hastings, 2008), and primarily marine fishes (Codarin et al., 2009; Ladich, 2013; Radford et al., 2014; Voellmy et al., 2014a,b). Elevated noise levels have been shown to reduce egg survival, reproduction and growth rates in fishes (Banner and Hyatt, 1973) and shrimp (Lagardère, 1982). Studies have also shown that anthropogenic noises can affect fish hearing or behaviors (Fernandes et al., 2000; Vabø et al., 2002; Handegard et al., 2003), which can potentially have detrimental effects on fitness. Amoser et al. (2004) found, for example, that noise from powerboats racing on an alpine lake was loud enough to be detected by otophysine fishes (fishes possessing a hearing specialization; see Popper and Fay, 2010) at up to 400 m away. Vasconcelos et al. (2007) found that the noise from ferry boats in the Tagus River estuary (Portugal) caused significant hearing threshold shifts in the Lusitanian toadfish (*Halobatrachus didactylus*), and that females ability to detect male signals would be significantly diminished under ship noise.

Despite efforts that have been made in other habitats, we are currently unaware of any study that has looked at potential anthropogenic noise sources in small freshwater streams, and how these noise sources may impact the ability of small, vocal

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http://dx.doi.org/10.1016/j.biocon.2015.04.004
0006-3207/

fishes to communicate acoustically. While several studies have examined signal propagation with regard to the ambient environment in shallow water systems, these studies have not included the effects of anthropogenic noise (Fine and Lenhardt, 1983; Ghahramani et al., 2014; Locascio and Mann, 2011; Lugli and Fine, 2007). Because small freshwater systems are home to a disproportionately large percentage of the imperiled fishes of the southeastern United States, an initiative must be taken to better characterize anthropogenic noise transmitted into these systems. The current study was aimed at describing the interaction between the natural soundscape and acoustic repertoire of the Blacktail Shiner (*Cyprinella venusta*) in east Alabama. We also examined the effect that bridge traffic, one particular anthropogenic noise source common in low order streams, may have on the natural soundscape and the ability of *C. venusta* to communicate acoustically. The results provide a better understanding of how a common source of anthropogenic noise may affect the acoustic soundscape of small freshwater streams and rivers.

2. Materials and methods

2.1. Natural ambient noise measurements

All natural ambient noise measurements were made on 12 May 2011 between 1300 and 1600 h. A large shoal on Little Uchee Creek (Lee Co., AL, U.S.A., 32° N, −85° W), which is a tributary of the Chattahoochee River, was chosen to describe the natural soundscape of *C. venusta*. Water temperature was 27.2 °C. This location was chosen because it offered a wide variety of suitable spawning habitats for *C. venusta* and during the reproductive summer months, the water is periodically shallow and clear enough to allow a researcher to locate the exact locations of nests by watching the fish behave from the bank. Nine active nest sites were identified by observation from exposed bedrock using polarized sunglasses. Nest sites were typically found at the confluence of an area of high flow and a pool. However, spawning aggregations were also observed directly within rapidly flowing chutes.

A hydrophone (Hi-Tech HTI-96-MIN, sensitivity −164.4 re 1 V/μPa, frequency response: 0.002–30 kHz) and digital recorder (Marantz PMD 661, sampling rate 44.1 kHz) were used to record 1 min of ambient noise in each of the 9 sites. In sites with substantial flow, an effort was made to place the hydrophone in a low flow area adjacent to the flow to reduce hydrodynamic noises. Sounds were imported into Raven 1.4 (Cornell University, Ithaca, NY), where three, 1 s segments were randomly selected from the recording made at each site. Two power spectra of each segment were then calculated using the power spectrum function of Raven (Hamming window, 50% time overlap, FFT length: 2048 samples, analysis bandwidth: 21.5 Hz; FFT length: 512 samples, analysis bandwidth: 86.1 Hz). Two separate power spectra, each with a unique analysis bandwidth had to be produced for natural ambient noise and anthropogenic noise sources so that SNR's could be calculated between *C. venusta* acoustic signals and noise. When calculating SNR's, it is necessary to analyze all sounds to be included in the analysis at the same frequency resolution. The analysis bandwidths of 21.5 and 86.1 Hz result from the typical duration of growls and knocks, respectively. For each analysis bandwidth, the three power spectra from each nest site were exported into Microsoft Excel where they were averaged to produce a single power spectrum for each of the 10 nest sites. Kendall's concordance test was used to determine whether spectrum shape (using the spectrum curve with analysis bandwidth of 21.5 Hz) of natural ambient noise between 21.5 and 1999.5 Hz was significantly different across active nesting sites (Lugli and Fine, 2003). No difference was observed in the shape of curves from different nesting sites, and so power spectra from all sites were averaged to generate a single, composite power spectrum for natural ambient noise. Spectrum levels were calibrated to represent absolute levels using the sensitivity of the hydrophone and a GW GOS-6xxG dual trace Oscilloscope, and by taking into consideration the gain applied to the signal by the Marantz and when importing sounds into Raven.

The frequency range of major spectral components (such as bandwidth of the quiet window found in the natural field recordings) of natural and anthropogenic sounds were defined as the range of frequencies within 3 dB of the peak frequency of the average power spectrum. This is standard for determining general tuning properties of sounds (Bennet-Clark, 1999), and has been used in a similar context by Lugli (2010).

2.2. Anthropogenic noise source measurements and propagation

Source levels and propagation of semi-trailer trucks crossing streams were measured at 6 road crossings, all located within Lee County and Macon County, Alabama (Table 1). Recordings were made between 3 and 14 March 2010. Water temperatures were not recorded. All crossings were beam bridges supported by a piling at the junction of each bridge segment. For all recordings, the hydrophone was placed approximately 8 cm off the substrate. This depth was chosen because the substrate was mostly sand and gravel, and potential nests in this type of habitat are usually close to the substrate. The hydrophone was mounted to the end of a 17.7 cm PVC pipe, which was secured between two submerged sandbags and positioned in such a way that the sandbags were downstream of the hydrophone. Water depth and flow velocity were not recorded, however water depth never exceeded approximately 84 cm (the maximum depth at which the hydrophone apparatus could be set up with without the researcher having to submerge their head).

At each road crossing, one hydrophone was fixed 1 m upstream or downstream of the bridge's edge (direction was determined by accessibility), while a second hydrophone was moved different distances away from the first hydrophone in the direction opposite the bridge. Both hydrophones recorded simultaneously onto separate channels of the Marantz digital recorder. Prior to going into the field, gain on each channel of the Marantz was made equal by recording a tone of known amplitude with the same hydrophone successively on each channel, and adjusting gains on each channel until the level was the same on both channels. Distances separating the hydrophones varied between 2 and 16 m for each site (Table 1), and depended on the locations of suitable (not flowing rapidly) and accessible (shallow enough to set hydrophone up on substrate) habitat. Because of hydrophone cable length constraints, recordings with both hydrophones simultaneously were not possible beyond 16 m. However, at three of the six sites, recordings were made with a single hydrophone at several distances up to 82 m. Recording was performed for several minutes at each distance, and the time at which semi-trailer trucks passed was noted. Care was taken to ensure that at least 3 trucks passed over, and that at least one 10 s period with no traffic occurred during the recording period at each distance.

Table 1
Recording sites and hydrophone distances from the source of anthropogenic noise.

Location	Total bridge length (m)	County	Hydrophone separation (m)
I-85 at Choctafaula Cr.	62.5	Lee	2, 4, 12, 16
I-85 at Hodnett Cr.	92.5	Macon	2, 4, 13, 40, 80
I-85 at tributary to Choctafaula Cr.	72.5	Macon	2, 4, 6, 12, 16, 36
I-85 at Uphapee Cr.	200.1	Macon	2, 4, 6, 9, 12, 14, 23, 49, 82
I-85 at Cubahatchee Cr.	129.2	Macon	2, 4, 6, 12, 16
C.R. 40 at Calebee Cr.	152.8	Macon	4, 7.5, 15