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Acoustic characterization of seahorse tank environments in public aquaria: A citizen science project

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ABSTRACT

Professional aquarists from nine U.S. public aquaria participated in a citizen science project to characterize ambient noise in marine ornamental aquaria containing seahorses (*Hippocampus* spp.). Participants collected data on tank design specifications and acoustic recordings from the middle of the water column of each tank surveyed. Ambient noise in aquaria was very variable, ranging in total RMS power from 116.3 to 142.9 dB SPL (re: 1 μPa), with a mean total RMS power of 126.1 ± 0.8 dB. Among tank design specifications: wall material, bottom habitat type, and their interaction had significant effects on total RMS power. Glass tanks were significantly louder than acrylic and concrete tanks, but not fiberglass tanks. Bare bottom tanks were significantly louder than tanks with a plenum or gravel bottom. In the context of literature documenting effects of noise on hearing, acoustic communication, and stress, the exposure to loud ambient noise may be deleterious to aquarium fishes in several ways; thus, system soundproofing techniques are offered. This project demonstrated the utility of citizen science to gather a data set across a large geographic area on a feasible budget, while providing opportunities for professional aquarists to understand the acoustic environment of their systems and appreciate the utility of research to improve animal management.

1. Introduction

In optimizing health, growth, and reproduction of fishes in aquaria, aquarists and culturists are often faced with balancing system design and husbandry parameters that can adversely affect one another. For example, a high rate of water flow might facilitate filtration, but may adversely affect delicate fry (Opstad et al., 1998). A high protein feed may accelerate growth but may also increase biological load on the filtration system and adversely affect water quality (Tidwell et al., 1996). The precarious balance that must be struck may be particularly difficult to optimize when some strategies adversely affect the organism in ways that the aquarist or culturist is unaware.

The acoustic sense of fishes is a sensory modality that may be overlooked in aquarium husbandry and aquaculture. The earliest evolved and most general role of the fish ear is to gain information about the environment through its acoustic signature (Popper and Fay, 1999; Fay, 2011). Some fishes have taken further advantage of the acoustic sense by evolving sound production mechanisms for intraspecific communication (Zelick et al., 1999; Ladich and Fine, 2006; Ladich and Bass, 2011; Luczkovich et al., 2011). In an aquarium or aquaculture environment, loud ambient noise emanating from life support equipment may mask biologically relevant sounds (Wysocki and Ladich, 2005; Stummer and Ladich, 2008; Gutscher et al., 2011), may induce hearing loss (Smith et al., 2004), or may trigger a physiological stress response with subsequent adverse consequences for health (Balm, 1997), growth (Gregory and Wood, 1999), and reproduction (Billard et al., 1981).

Exposure to aquarium/aquaculture noise affects the hearing ability of fishes. Stummer and Ladich (2008) and Gutscher et al. (2011) documented hearing threshold shifts by 15–28 deciBels (dB) in *Carassius auratus* (historically characterized as a hearing specialist) and up to 9 dB in *Lepomis gibbosus* (historically characterized as a hearing generalist) when hearing signals over the ambient noise of aquaria with various filtration regimes. Ambient noise spectra of aquaria operating with external filters, with outflows placed above the water surface, provoked the highest threshold shifts.

A few studies have shown that aquatic organisms demonstrate chronic stress responses in loud aquaria. Banner and Hyatt (1973) exposed eggs and fry of *Cyprinodon variegatus* to noise from a submersible water pump and airstones, emitting a broadband sound ranging from 20 to 1100 Hz, with spectrum level sound pressure levels (SPLs) ranging from 78 to 118 dB with reference to 1 micropascal (re: 1 μPa). Tested against controls in quieter tanks, they discovered greater mortality of eggs and fry in noisy

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tanks. Lagardère (1982) exposed brown shrimp (*Crangon crangon*) to noise generated by aquarium air pumps placed adjacent to culture tanks, emitting a broadband sound ranging from 5 to 1000 Hz, with spectrum level SPLs ranging from 59 to 116 dB. Tested against controls in soundproofed tanks, animals in louder tanks demonstrated slower growth, less food consumption, reduced reproduction (fewer females carrying eggs), and higher mortality due to higher rates of cannibalism and higher incidence of disease. Anderson et al. (2011) demonstrated increased plasma cortisol concentrations, heterophilia and higher heterophil:lymphocyte ratios, and increased loss of weight and body condition among lined seahorses (*Hippocampus erectus*) housed in tanks for one month with average total RMS power SPLs of 123.3 ± 1.0 dB at mid-water column, compared to controls in tanks with average total RMS power SPLs of 110.6 ± 0.58 dB at mid-water column. In contrast, Wysocki et al. (2007) detected no stress response or increased mortality among rainbow trout (*Oncorhynchus mykiss*) exposed to sound at total RMS power SPLs of 150 dB.

Given the effects of chronic noise exposure on fish hearing, behavior, and physiology, it is important to understand whether or not ambient noise in aquarium/aquaculture conditions is loud enough to induce such deleterious effects. Davidson et al. (2007) characterized the acoustic environment of round fiberlass tanks (1.5 m ID $\times$ 0.8 m depth) in an aquaculture facility and reported highest spectrum-level SPLs ranging from 105 to 130 dB below 100 Hz. Craven et al. (2009) surveyed ambient noise at an aquaculture facility consisting of relatively large (2800–62,000 L) broodstock and juvenile rearing tanks seated on a concrete floor. Mean peak spectrum level SPLs ranged from 105 to 117 dB, with peak frequencies consistently at 187.5 Hz. Some of the SPLs reported in these studies clearly fall into a range known to induce temporary hearing threshold shifts (e.g., Popper and Clarke, 1976; Wysocki and Ladich, 2005; Gutscher et al., 2011) and stress (Banner and Hyatt, 1973; Lagardère, 1982; Anderson et al., 2011).

This study characterizes the range of ambient noise among public aquaria containing seahorses (*Hippocampus* spp., Family Syngnathidae), as it pertains to a larger set of studies on acoustic considerations on the behavior and physiology of the lined seahorse (*H. erectus*) in aquarium/aquaculture environments (Anderson, 2009; Anderson et al., 2011; Anderson and Mann, 2011). This survey offers data on an assortment of smaller tanks more likely to be in use among aquarists and culturists of ornamental fishes. It also includes summarized data on materials used for tanks and stands. Ambient noise profiles are characterized, and relationships between tank design specifications and ambient noise levels are explored and presented.

Seahorses, like most fish, are probably best characterized as hearing generalists in accordance with the traditional scheme, based on their reduced sensitivity in comparison to fishes historically characterized as hearing specialists, their low frequency range of sensitivity, and the lack of bony or gaseous vesicular connections to the swimbladder (Anderson and Mann, 2011). As such, it is likely that these fishes are probably detecting and processing both the particle motion and pressure components of sound, though the relative contributions of each to these biological functions probably vary with respect to distance from sound source, frequency, and sound pressure level.

This study reports only on sound pressure fields in seahorse aquaria due to technological and logistical constraints faced by all fish bioacousticians. The importance of particle motion to fish hearing has long been recognized (e.g., Fay and Popper, 1975; Popper and Fay, 1993); yet, the vast majority of studies on hearing in fishes, as well as characterizations of ambient noise in fish environments, have been characterized exclusively in terms of sound pressure. This is because of a dearth of, and need for, specialized, commercially available equipment to accurately characterize particle motion fields (e.g., geophone, laser vibrometer; see Mann, 2006). Limited options for geophones have only recently become available and have begun to contribute to our understanding of particle motion fields in underwater environments (Lugli and Fine, 2007), as well as detection and processing in fishes (Casper and Mann, 2006, 2007; Horodysky et al., 2008; Wysocki et al., 2009; Anderson and Mann, 2011). Still, the technology available as of this writing lacks the ability to record particle motion fields in three orthogonal axes simultaneously and to integrate three channels of simultaneous vector recordings into one output representing magnitude. Nonetheless, though fishes historically characterized as hearing generalists are detecting and processing particle motion via direct stimulation of the inner ear; it is equally likely that at least some species of generalists are also detecting and processing sound pressure via conversion of pressure oscillations to particle motion re-radiated by the swimbladder, even without the benefit of connecting bony or gaseous vesicular structures that improve transduction to the inner ear (Cahn et al., 1969; Sand and Enger, 1973; Wysocki et al., 2009), and even in generalist species where the swimbladder is far removed from the inner ear (e.g., *Anguilla anguilla*, Jerkø et al., 1989). This study thus operates on the assumption that seahorses may also be detecting and processing sound pressure; thus, characterization of tanks in terms of sound pressure may still play a role in a seahorse's umwelt, and suggestions for reducing unnecessary ambient sound pressure may still be of value to seahorse health and welfare (Anderson et al., 2011).

This study was conducted using the concept of citizen science; i.e., engaging non-research scientist stakeholders in the gathering of scientific information. Citizen science has worked well in numerous formats (e.g., Cohn, 2008; Bonney et al., 2009) to (1) advance scientific knowledge, enabling the gathering of data on a larger geographic scale than is possible in more traditional scientific research, and (2) to increase public awareness of and participation in science.

2. Materials and methods

2.1. Aquarium data collection

Professional aquarists were recruited to participate in the study via solicitation on an email list-serv targeted to the audience. Respondents were personally contacted by the author (either by email, phone, or both) to arrange participation. Participants were shipped The Seahorse Sound Survey kit. Per the principles of Bonney et al. (2009), the self-contained data collection kit was designed to ensure the collection and submission of accurate data, and included (1) clear data collection protocols, (2) simple and logical data forms, and (3) communication support for participants to understand how to follow the protocols and submit their information. The kit contained a simple but complete instruction manual, a questionnaire, an HTI-96 min pressure-sensitive hydrophone (High Tech Instruments, Inc., Gulfport, MS; sensitivity, −165 dB re: 1 V/μPa; bandwidth, 2–30,000 Hz), a NOMAD Jukebox 3 digital audio recording device (Creative Labs, Inc., Milpitas, CA), a digital camera, headphones, and measuring tape. The questionnaire requested data on tank specifications (volume, dimensions, tank wall and stand materials, substrate type). In addition to completing the questionnaire, participating aquarists were asked to take acoustic recordings of tanks at times of day when visitors were absent (i.e., before opening or after closing of the facility). One 1 min recording was requested for each tank, with the hydrophone positioned in the middle of the water column. During recording, the hydrophone was connected to the 9-volt battery amplifier, and to the NOMAD Jukebox 3. Aquarists were asked to hold the NOMAD Jukebox 3 and excess cord still during recording, not to allow recording equipment to come in contact with any other solid