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Minimizing noise in fiberglass aquaculture tanks: Noise reduction potential of various retrofits

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Abstract

Equipment used in intensive aquaculture systems, such as pumps and blowers can produce underwater sound levels and frequencies within the range of fish hearing. The impacts of underwater noise on fish are not well known, but limited research suggests that subjecting fish to noise could result in impairment of the auditory system, reduced growth rates, and increased stress. Consequently, reducing sound in fish tanks could result in advantages for cultured species and increased productivity for the aquaculture industry. The objective of this study was to evaluate the noise reduction potential of various retrofits to fiberglass fish culture tanks. The following structural changes were applied to tanks to reduce underwater noise: (1) inlet piping was suspended to avoid contact with the tank, (2) effluent piping was disconnected from a common drain line, (3) effluent piping was insulated beneath tanks, and (4) tanks were elevated on cement blocks and seated on insulated padding. Four combinations of the aforementioned structural changes were evaluated in duplicate and two tanks were left unchanged as controls. Control tanks had sound levels of 120.6 dB re 1 μPa. Each retrofit contributed to a reduction of underwater sound. As structural changes were combined, a cumulative reduction in sound level was observed. Tanks designed with a combination of retrofits had sound levels of 108.6 dB re 1 μPa, a four-fold reduction in sound pressure level. Sound frequency spectra indicated that the greatest sound reductions occurred between 2 and 100 Hz and demonstrated that nearby pumps and blowers created tonal frequencies that were transmitted into the tanks. The tank modifications used during this study were simple and inexpensive and could be applied to existing systems or considered when designing aquaculture facilities.

Keywords: Noise reduction; Noise; Sound; Aquaculture; Fish hearing

1. Introduction

Equipment such as aerators, pumps, blowers, filtration systems, and harvesting equipment that are required for intensive aquaculture production can increase noise in aquaculture systems, especially within recirculating systems that utilize these mechanical components (Bart et al., 2001; Timmons et al., 2001).

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Cascading flows associated with recirculating systems could also increase noise. Concerns have been raised that existing sound levels in the environment and in aquaculture facilities could negatively impact aquatic organisms (Richardson et al., 1995; Popper, 2003). Possible effects include impairment of the auditory system, increased stress, and reduced growth rates.

Noise can negatively affect fish hearing (Popper and Clarke, 1976; Scholik and Yan, 2002; Smith et al., 2004). Temporary hearing loss and stress responses occurred in goldfish, *Carassius auratus*, following exposure to white noise with a bandwidth of 0.1–10 kHz and average sound pressure levels (SPL) of 160–170 dB re 1 μPa (Smith et al., 2004). Simulated boat engine noise (0.3–4.0 kHz, 142 dB re 1 μPa) caused elevated auditory thresholds in the fathead minnow, *Pimephales promelas* (Scholik and Yan, 2002). Note: Due to the differences in density and speed of sound of air and water, sound levels must be referenced differently for the two media. In referencing underwater sound, an arbitrary reference value, 1 microPascal (re 1 μPa), is typically used and in air 20 μPa is typically used (Hawkins and Myrberg, 1983; Popper, 2003). Thus the following equation is used to convert pressure to decibels: $dB = 20 \log_{10}(p \text{ sound}/p \text{ reference})$, where p is the pressure.

Few studies have investigated the effects of noise on growth and reproduction, especially in regard to aquaculture species. Banner and Hyatt (1973) observed lower egg viability and reduced growth rates for longnose killifish, *Fundulus similis*, and the sheepshead minnow, *Cyprinodon variegates*, when sound levels within small aquarium tanks were approximately 20 dB higher than levels in the control tanks. Growth and reproductive rates of brown shrimp, *Crangon crangon*, were reduced when ambient SPL's were 30–40 dB higher than SPL's common to the natural habitat of the brown shrimp (Lagardère, 1982).

Teleost fishes are separated into two non-taxonomic groups based on hearing sensitivity: hearing specialists and hearing generalists (Popper, 2003). Hearing specialists such as channel catfish (*Ictalurus punctatus*) and goldfish have bony connections (Weberian ossicles) or other structures that bridge the swim bladder with the inner ear, enabling these species to detect higher frequency sounds (Amoser and Ladich, 2003; Popper et al., 2003). Hearing specialists can detect sounds to over 3 kHz; with best sensitivity between 300–1000 Hz and most hearing specialists can detect sound pressure levels as low as 50–75 dB re 1 μPa and in the frequency range of 100–2000 Hz (Popper et al., 2003). The majority of fish species are hearing generalists. Hearing generalists lack specialized connections between the swim bladder and the inner ear and are therefore only able to detect low frequency sounds. Hearing generalists typically can only detect frequencies below 500–1000 Hz and are not as sensitive to sound pressure levels as hearing specialists (Popper et al., 2003).

Sound levels and frequencies recorded in commercial-scale aquaculture systems are within the hearing range of fish, including the less sensitive hearing generalists and range from 125 to 135 dB re 1 μPa at 25–1000 Hz, and from 100 to 115 dB re 1 μPa at 1–2 kHz (Bart et al., 2001). In a comparison of sound levels within recirculating systems with fiberglass tanks, concrete raceways, and earthen ponds; recirculating fiberglass tanks had the highest SPL's with maximum SPL's of 153 dB re 1 μPa (Bart et al., 2001). Sound pressure levels as high as 160 dB re 1 μPa have also been reported in aquaculture settings (Clark et al., 1996).

In natural aquatic environments, fish exposed to sounds that are significantly above ambient levels can move away from the sound source. However, fish in aquaculture settings are typically confined to individual culture tanks where avoidance of less than optimal sound is not possible. We theorize that reducing sound in tanks, particularly within recirculating systems, could benefit cultured species and potentially enhance productivity for the aquaculture industry. The objective of this study was to evaluate the noise reduction potential of various retrofits to fiberglass fish culture tanks. Retrofit designs focused on buffering sound and eliminating sound transmission pathways to tanks, which are proven techniques to reduce noise (Berendt et al., 1998).

2. Methods

Ten round fiberglass tanks (1.5 m inside diameter $\times$ 0.8 m deep) within a flow-through facility were used to examine the noise reduction potential of structural changes. Three avenues for possible sound transmission into the tanks were identified: (1) PVC inlet piping, (2) effluent piping, and (3) the gravel substrate under the tanks. Potential solutions for noise reduction include avoiding direct contact between vibrating units and other structural surfaces and applying noise dampening materials made of rubber or neoprene between vibrating surfaces (Berendt et al., 1998). Three tank structural modifications were developed and evaluated based on the possible avenues of sound transmission. Modification 1: inlet pipes, initially supported with a PVC fitting connected to the top of the tank wall, were elevated and supported from

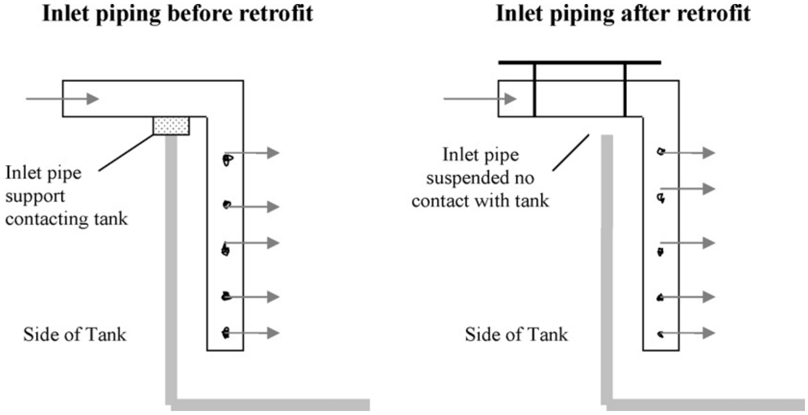

Fig. 1. Modification 1, suspend inlet. Inlet piping designs before and after the retrofits (arrows indicate flow direction).

above to eliminate direct contact with the tank walls (suspend inlet; Fig. 1). Modification 2a: effluent piping, initially connected to a central wastewater drain line fed by six tanks, was disconnected from the drain line so that water spilled into the pipe without direct contact (disconnect effluent; Fig. 2). The intent of this modification was to prevent sound from traveling a reverse path from the wastewater drain back into the tanks. Modification 2b: effluent piping connected to the bottom center drain beneath the tanks and contacting the gravel floor was covered with black foam insulation (typically used in air conditioning and refrigeration applications) for some retrofit combinations (insulate effluent; Fig. 2). Modification 3: culture tanks, originally seated on a gravel floor, were elevated on cement blocks and seated on neoprene isolation padding (Neopad, Isolation Technology, Inc., Massapequa, NY), to buffer sound transmission through the gravel floor (elevate/neopad; Fig. 3). Four retrofit designs consisting of combinations of modifications 1–3 were used to evaluate sound reduction (Table 1). Two tanks were used for each retrofit design and two tanks were left unchanged as controls.

Sound characteristics were measured using two methods. First, broadband sound level measurements were made using a calibrated hydrophone (HTI-94-SSQ, High Tech, Inc., Gulfport, MS) connected to a voltmeter. The hydrophone sensitivity was −170.1 dB re 1 V/μPa with a frequency response of 2 Hz to 30 kHz. The hydrophone was positioned midway between the sidewall and the center of each tank at depths of 38 cm (middle of the water column) and 66 cm (about 10 cm from the bottom of the tank). Water depth during normal operation was 76 cm. Raw voltage values were mathematically converted to broadband sound pressure levels, also known as root-mean-squared (RMS) levels, using the following equation:

$$\text{SPL (dB re 1}\,\mu\text{Pa RMS)} = 20\log_{10}\left(\left(\frac{X \times 10^3}{\text{HCV}}\right) \times 10^6\right)$$

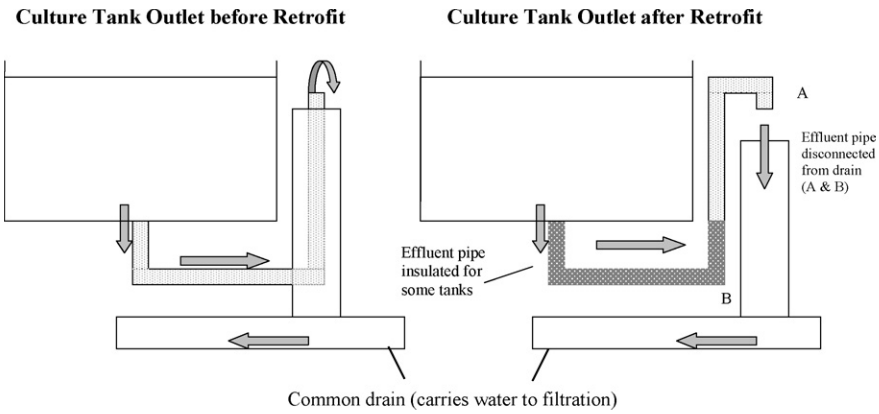

Fig. 2. Modifications 2a and 2b, Disconnect effluent and insulate effluent. Effluent piping designs before and after the retrofit.

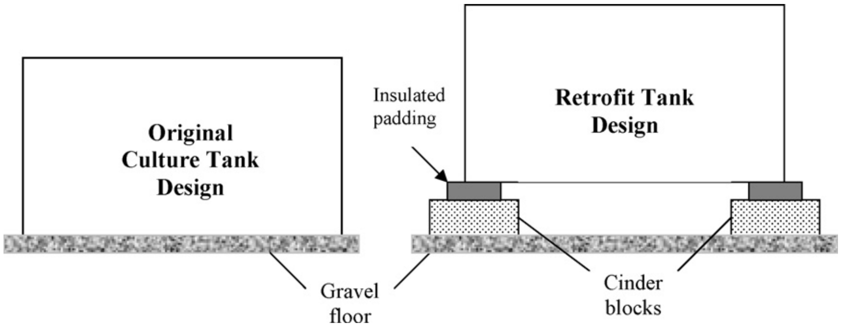

Fig. 3. Modification 3, elevate/neopad. Culture tank support designs before and after the retrofit.

where X is the voltmeter rms reading in mV and HCV = 3126 V/μPa (hydrophone calibration value). Broadband sound pressure levels represent the average amplitude of a complex waveform that consists of many frequencies.

Second, sound recordings were collected using the calibrated hydrophone connected to a low-pass filter (Model 91149A, Precision Filters, Inc., Ithaca, NY), a pre-amplifier (Model FP-11, Shure Inc., Niles, IL), and an analog-to-digital converter and data logger (Model USB-9215, National Instruments, Austin, TX) connected to a lap top computer installed with NI-DAQmx Base Software using a Labview 7.1 application (National Instruments, Austin, TX). Sound spectra were generated from the data collected with this equipment.

In most machines, vibrational energy from specific moving parts is transmitted through the machine structure causing other parts and surfaces to vibrate and radiate sound. For example, pipe vibration is often caused by motor driven pumps (Berendt et al., 1998). The majority of noise created by such sources usually exists as pure tones associated with the rotational speed of the pumps or motors (Cudina and Sterzaj, 1988; Berendt et al., 1998). A separate test was conducted to determine if nearby mechanical equipment contributed to sound within the tanks. A single recording was initiated and then an oxygen saturator pump and a carbon dioxide blower were sequentially turned off. Sound spectra were then analyzed to determine if tonal frequencies varied with unit operation.

3. Results and discussion

The structural changes evaluated during the study contributed to substantial noise reduction. The unmodified control tanks had the highest sound level, 120.6 dB re 1 μPa. SUSPEND INLET tanks had a mean sound level of 116.0 dB re 1 μPa; a reduction of 4.6 dB from the sound levels in the control tanks (Table 1). Since the decibel scale is logarithmic, a 6 dB decrease represents a 50% reduction in sound level and a 20 dB decrease represents a 90% reduction in sound level. Therefore, the 4.6 dB reduction resulting from inlet piping modifications is a considerable decrease. Mean sound pressure levels expressed as microPascals (μPa) illustrate the magnitude of the sound reduction. Mean sound pressure decreased from 1.1×10^6 μPa in the control tanks to 6.3×10^5 μPa in the suspend inlet tanks (Table 1).

As structural changes were combined, a cumulative sound reduction was observed. For example, tanks with suspend inlet and disconnect effluent had a mean sound level of 112.3 dB re 1 μPa compared to suspend inlet only tanks that had a mean sound level of 116.0 dB re 1 μPa (Table 1). Eliminating contact between the effluent piping and the common wastewater drain resulted in an additional 3.7 dB decrease. The

Table 1
Modifications made, broadband sound levels (dB re 1 μPa), and mean sound pressures for each retrofit design

Retrofit design	Suspend inlet	Disconnect effluent	Insulate effluent	Elevate/ neopad	Mean broadband dB re 1 μPa	Mean sound pressure (μPa)
Control					120.6	1.1×10^6
1	√				116.0	6.3×10^5
1, 2a	√	√			112.3	4.1×10^5
1, 2b, 3	√		√	√	108.6	2.7×10^5
1, 2a, 2b, 3	√	√	√	√	108.6	2.7×10^5

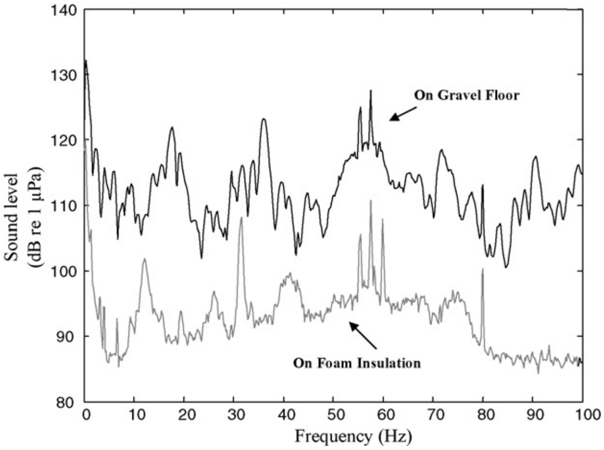

Fig. 4. Sound spectrum comparison of a water filled bucket seated directly on a gravel floor vs. a water filled bucket with foam insulation between the bucket and the gravel floor.

cumulative sound reduction of the suspend inlet and disconnect effluent modifications was 8.3 dB. Mean sound pressure decreased from 1.1×10^6 μPa in the control tanks to 4.1×10^5 μPa in tanks with suspend inlet and disconnect effluent modifications.

Additional sound reduction was observed when effluent piping was insulated and tanks were elevated on cement blocks and seated on neoprene padding. The sound level measured within tanks having the suspend inlet, insulate effluent, and elevate/neopad modifications was 108.6 dB re 1 μPa, which represents and additional sound level reduction of 3.7 dB and a cumulative sound level reduction of 12.0 dB, approximately a four-fold decrease in sound pressure (Table 1). insulate effluent and elevate/ neopad modifications were both newly introduced for these tanks, therefore, the reduction in sound level could have resulted from one or both of these modifications. We speculate that the majority of the sound reduction for these tanks can be attributed to the elevate/neopad modification. A preliminary test showed that placing a piece of foam insulation beneath a 120 L water-filled bucket seated on a gravel floor reduced in-water sound by as much as 20 dB across the frequency spectrum compared to sound levels recorded when the water-filled bucket was seated directly on the gravel floor (Fig. 4). Tanks modified with elevate/neopad used sections of neoprene insulation with a surface area of 200 cm^2 between the tank and each cinder block. Using larger sections of neoprene insulation or cutting a circular piece of insulation to fit beneath the entire tank might have further reduced noise. Noise dampening materials dissipate the vibrational energy in the form of frictional heat that is generated by the flexing and bending of particles of the dampening material (Berendt et al., 1998). Therefore, the use of sound buffering materials beneath tanks should be considered, especially with tanks that are seated on metal or concrete platforms that could be more conducive to sound transmission than gravel.

Tanks that incorporated all structural changes: suspend inlet, disconnect effluent, insulate effluent, and elevate/neopad, also had a sound level of 108.6 dB re 1 μPa, a cumulative sound level reduction of 12.0 dB. Although additional sound reduction was not observed for these tanks, our findings clearly show that combinations of modifications caused cumulative decreases in underwater sound. The modifications to the culture tanks affected sound transmission pathways and substantially reduced noise within the tanks. Suspend inlet, disconnect effluent, and elevate/neopad and/or insulate effluent modifications each decreased sound levels. Sound pressure levels (μPa) were reduced by 41, 62, and 75% compared to the control tank values, as each modification was introduced (Fig. 5).

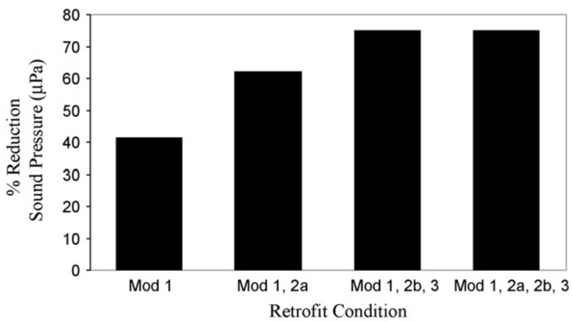

Fig. 5. Percent sound pressure reduction for all retrofit modifications compared to sound pressure for the control tanks.

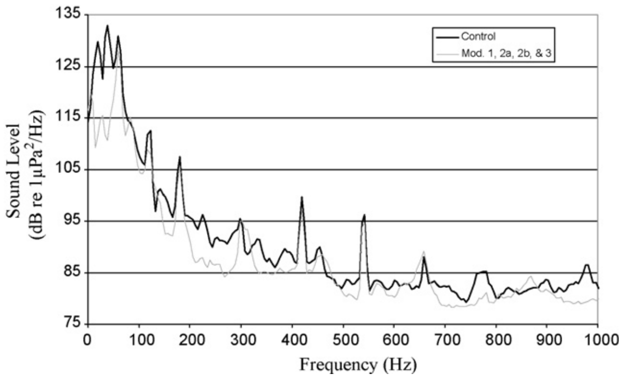

Fig. 6. Sound spectrum comparison for control tanks and the retrofit design with Modifications 1, 2a, 2b, and 3 (suspend inlet, disconnect effluent, insulate effluent, and elevate/neopad). This retrofit design utilized combinations of modifications that most effectively reduced sound.

Sound spectrum data for all conditions showed that the highest sound levels, 105–130 dB re 1 $\mu Pa^2/Hz$, occurred at low frequencies (2–100 Hz). Sound levels declined steadily between 100–500 Hz and stabilized between 75–85 dB re 1 $\mu Pa^2/Hz$ at 500–1000 Hz (Fig. 6). The largest mean sound reduction, 10–15 dB, occurred between 2 and 100 Hz (Fig. 6). Sound spectrum data also indicated that combined structural changes resulted in cumulative sound reductions and the largest sound decreases.

Sound recordings confirmed that mechanical equipment operating close to fish culture tanks could transmit sound into the control tanks. After sound recordings were initiated, a carbon dioxide blower and an oxygen saturator pump were turned off. A 29 Hz tonal frequency produced by a carbon dioxide blower and a 59 Hz frequency produced by an oxygen saturator pump disappeared from the sound spectrum after each unit was turned off (Fig. 7). The disappearance of the 29 and 59 Hz signals confirmed that these frequencies were being transmitted into the tanks when the equipment was operating. A potential method to reduce sound is to control sound at the source (Berendt et al., 1998). Although methods to abate sounds originating from the oxygen saturator pump and carbon dioxide blower were not evaluated in this study, several sound buffering techniques could be utilized to diminish sound radiating from mechanical equipment. Underwater sound reduction in tanks could be achieved by setting large pumps and blowers on resilient mounts, such as neoprene padding or air mounts, to prevent transmission of vibrations through the supporting base and thus reduce

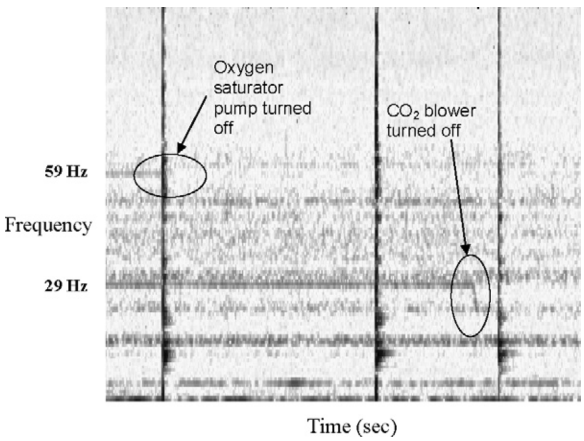

Fig. 7. Sound spectrogram indicating transmission of oxygen saturator pump and carbon dioxide blower frequencies into a culture tank. *Note*: The dark horizontal bars indicate intense tonal frequencies. The dark vertical bars are transient sounds that were intentionally created to denote events in time during the test.

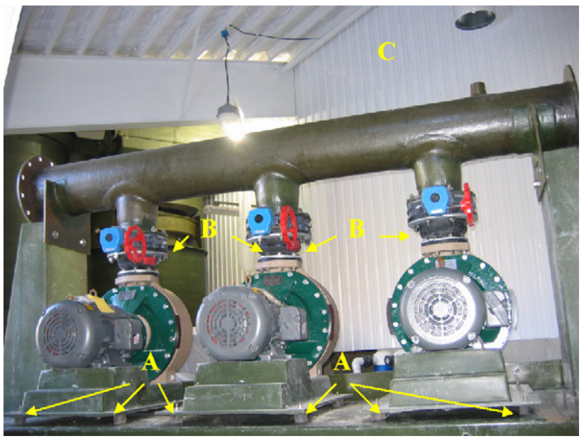

Fig. 8. A custom pump stand fabricated by Marine Biotech Inc. (Beverly, MA) installed at the USDA ARS, NCWMAC (Franklin, ME) illustrates (A) resilient pump mounts to reduce transmission of motor vibration noise, (B) rubber vibration isolation couplings on both the pump inlet & outlet piping, and (C) locating the water treatment pumps and equipment in a room separate from the fish culture tanks.

the potential for radiation of noise into adjacent areas. Additionally, pumps and blowers could be partially enclosed or could be isolated from the tanks in separate rooms. Soundproofing walls and enclosures are commercially available. Engineers at the Freshwater Institute considered the findings of this study when designing recirculating aquaculture systems at the USDA ARS National Cold Water Marine Aquaculture Center (NCWMAC) in Franklin, ME. A custom pump stand (Marine Biotech Inc., Beverly, MA) with resilient pump mounts and rubber vibration isolation couplings on the pump inlet and outlet piping was installed in a separate water treatment room (Fig. 8).

This study demonstrated that sound levels within fish culture tanks could be substantially reduced using structural changes designed to eliminate sound transmission pathways. Eliminating contact between PVC inlet and effluent piping and the tanks effectively decreased the underwater sound levels within the tanks, indicating that PVC piping is a common sound transmission pathway to culture tanks. Other sound control techniques, not demonstrated in this study, can be utilized to reduce sound transmission through PVC pipe. Rubber fittings and couplings can be used on PVC pipe runs to dampen sound and specialized noise suppressors are available that can be installed within pipe runs or at pump outlets. In addition to PVC pipe, other sound transmission pathways could exist at aquaculture facilities. Anything directly contacting the culture tank walls could transmit sound into the tanks such as steel supports, walkways and stairways around and across tanks, and electrical conduit. The tank modifications and considerations used during this study were simple and inexpensive and could easily be incorporated into existing culture systems. However, sound reducing options should also be considered during the planning and design phase for aquaculture facilities. Although limited data exists regarding the effects of sound on fish in aquaculture facilities, taking steps to reduce sound within systems could reduce stress levels, enhance growth rates, and increase survival of aquaculture species, and could ultimately increase profitability.

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