Environmental noise impact of a major transport corridor on a barramundi fish farm

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ABSTRACT

The environmental noise impact of a proposed major transport corridor on a barramundi fish farm was assessed following concerns about the potential impacts on the barramundi. As part of the assessment, a study into fish hearing and the impacts of noise on fish was conducted. The ambient noise environments within the fish tanks and building enclosure were measured before construction of the transport corridor to establish the existing conditions. The existing environment was found to be relatively noisy and audible to the barramundi, with measured underwater noise levels of 130 to 135 dB re 1 μPa between 10 Hz and 4 kHz. Low frequency noise (<400 Hz) due to water pumps, aeration equipment and other mechanical plant dominated the fish tank environments. Impacts of the transport corridor were identified as negligible because the noisy existing environment masks the predicted traffic noise levels. This paper gives an overview of the assessment process and presents some of the outcomes.

INTRODUCTION

AECOM was engaged to assess the environmental noise impact of a proposed major road and rail transport corridor on a barramundi fish farm in Australia. The assessment considered both the construction and operation of the proposed road and rail corridor. The transport corridor passes the fish farm at a minimum distance of approximately 110 m from the centre of the proposed alignment plan. A major interchange is located at a distance of approximately 600 m from the fish farm. Road traffic accelerating from this interchange onto the transport corridor passes the fish farm at a minimum distance of approximately 80 m from the fish farm. The minimum distance between the rail line and the fish is about 100 m. Speed limits of 110 km/hr apply to both road and rail traffic. Daily traffic volumes are predicted to be in the order of 90,000 vehicles per day. A maximum of 26 trains will pass the fish farm on a daily basis.

The barramundi fish farm has a number of 200 m^3 fibreglass fish tanks located within a building enclosure in which barramundi are grown to marketable size over an 8 month process. To start the growing process, fingerlings about 30 mm in size are purchased, and breeding of barramundi is thus not conducted at the fish farm. Aeration and temperature control of the tank water is achieved using eight aeration blowers. These aeration blowers are located within the building enclosure and contribute significantly to the existing in-air ambient noise environment. Other plant includes water pumps, filtration equipment, electrical motors for filter drums, and a refrigeration unit located external to the building enclosure. Some of the water pumps are rigidly connected to the tank structures, causing significant tank wall vibrations, radiating underwater noise into the fish tanks. The building enclosure is not air-conditioned, apart from the aeration air escaping from the fish tank water. Most of the doors within the facades of the fish farm are open during the day and closed at night. Our assessment therefore assumed that these doors were open.

A study into fish hearing was conducted to estimate the absolute hearing threshold and frequency range of best hearing for barramundi. The available literature on behavioural and physiological impacts of environmental noise on fish, including stress response, startle reactions, and permanent and temporary threshold shifts (PTS and TTS), was investigated to predict how much noise exposure causes an impact. The findings of this study are summarised here.

In-air and underwater noise measurements were conducted at the fish farm to establish the existing ambient noise conditions within the building enclosure and fish tanks. In-air and underwater noise levels are both reported in dB re 1 μPa to avoid confusion. To convert in-air levels to a level re 20 μPa one simply deducts 26 dB. Vibration measurements were conducted on the fish tank walls, and on various pieces of mechanical plant to establish their noise signature. It is noted that the impact of ground-borne vibrations was predicted to be negligible due to the existing high-level ground and tank wall vibration environments.

Modelling the transmission loss that occurs along the sound propagation path between the transport corridor and the underwater environment of the fish tanks is a complex task. To obtain a reasonable prediction of traffic-induced underwater noise levels within the fish tanks, the following transmission loss mechanisms were included in our assessment: (1) geometric spreading loss between the transport corridor and building enclosure (2) transmission loss across the building facade (3) absorption within the reverberant building enclosure (4) transmission loss across the air-water interface due to large impedance mis-match between air and water (5) absorption within the reverberant fish tanks. The predicted underwater noise levels are compared with the existing ambient underwater noise environment within the fish tanks to assess the likely impact of traffic noise.

The aim of this paper is to give an overview of the adopted assessment methodology, and present the measured ambient noise environment within the fish tanks since limited data is available on this topic.

AMBIENT NOISE ENVIRONMENT IN AQUACULTURE SYSTEMS

Bart et al. (2001) conducted an underwater ambient noise survey for aquaculture systems, including enclosed recirculating raceways, fibreglass and concrete culture tanks, and outdoor open ponds. Low frequency noise below 400 Hz dominated the ambient noise environment in all systems measured. Low frequency noise sources included water flow, pumps and machinery vibrations transmitted to the tank walls. Mid to high frequency noise was generated mostly by electrical motors, oscillating and collapsing air bubbles, aeration, and water pump action. In the mid frequency region between 1 to 2 kHz, sound pressure levels ranged from 100 to 115 dB re 1 µPa. In the low frequency region from 25 Hz to 1 kHz, sound pressure levels ranged from 125 to 135 dB re 1 µPa. Fibreglass tanks, which are used at the barramundi fish farm, were found to be noisier than concrete tanks.

Davidson et al. (2009) noted that sound pressure levels within fibreglass culture tanks vary depending on location within the tanks. The loudest areas were closest to the side walls and the bottom of the tank, and the quietest locations were near the top and centre. This is especially true at low frequencies where standing wave patterns will form within the tank causing alternating regions of high and low sound pressure.

Davidson et al. (2007) evaluated the noise reduction potential of various retrofits to fibreglass fish culture tanks. Noise and vibration treatments applied to the tanks included suspending inlet piping to avoid contact with the tank, disconnecting effluent piping from a common drain line, insulating effluent piping beneath tanks, and elevating the tanks on cement block and seating them on rubber padding. Sound pressure levels of 121 dB re 1 µPa were recorded within the unmodified tanks. Tanks that incorporated all treatments had sound pressure levels of 109 dB re 1 µPa. The majority of the 12 dB reduction occurred below 100 Hz.

FISH AND SOUND

Sound production

Fish live in an environment in which vision is not the primary sense because light does not penetrate far beneath the surface of oceans and lakes (Popper et al. 2003). As such, fish have become reliant upon sound because it can propagate rapidly over great distances and is not attenuated as quickly as other signals such as light or chemicals.

Fish use sounds for a wide variety of behavioural reasons such as communication, reproduction, feeding, protection of territory, and defence (Hastings et al. 2005). Most sounds produced by fishes occur in the lower frequency range below 1 kHz. Research data suggests that the temporal pattern of the fish sounds is more important for communication than the frequency content (Hastings et al. 2005).

The majority of sounds produced by fish occur during reproductive activities such as courtship and spawning. It is usually the male that produces sound to try to spawn with a receptive female. Some species form large groups during the spawning season that vocalise for many hours each evening. Other species build nests from which the male will produce courtship calls to attract potential mates. It is noted that breeding of barramundi does not occur at the fish farm.

Hearing

The hearing sensitivity of fish generally varies with frequency (Popper and Fay 1993). Audiograms are therefore used to represent the sensitivity to sounds of different frequencies. An audiogram of a fish species relates the absolute threshold of hearing (dB re 1µPa) within a quiet environment to frequency, and shows the frequency bandwidth over which species can hear. A fish is most sensitive to sounds at frequencies where its absolute hearing threshold is lowest.

Fish species are often divided into hearing generalists and specialists based on the anatomy of their auditory organs (Popper et al. 2003). Hearing specialist species have evolved mechanisms to increase the amount of auditory information transmitted to the inner ear (Popper et al. 2003, 2000, 1993). These specialisations involve some coupling between the inner ear and a gas-filled structure (or bulla) that translates pressure of the sound wave to displacement information that the inner ear can detect. Fish species without any specialisations to the auditory system are considered hearing generalists (Popper et al. 2003). Hearing generalists tend to have less sensitive hearing than hearing specialists, and generally do not hear frequencies much above about 800 Hz, with peak sensitivities around 300 to 500 Hz (Fay 1988). Hearing specialists can hear higher frequencies than hearing generalists.

The grouping of fish into hearing generalists and specialists may serve as a general guideline for determining the hearing sensitivity of a fish species but does not replace audiograms, which describe the hearing sensitivity of a species more accurately. Most fish species, including barramundi, have not yet been classified as hearing generalists or specialists. Audiograms have only been measured for a very small number of species and an audiogram for barramundi is not available. However, Barramundi have a swimbladder and a gas-filled chamber in the otic region (McDougall et al. 2004). This suggests that barramundi are most likely classified as hearing specialists (Fuiman et al. 2004), and that they have relatively sensitive hearing. Audiograms for a number of hearing specialists thought to have similar hearing to barramundi are shown in Figure 1 (Nedwell et al. 2004).

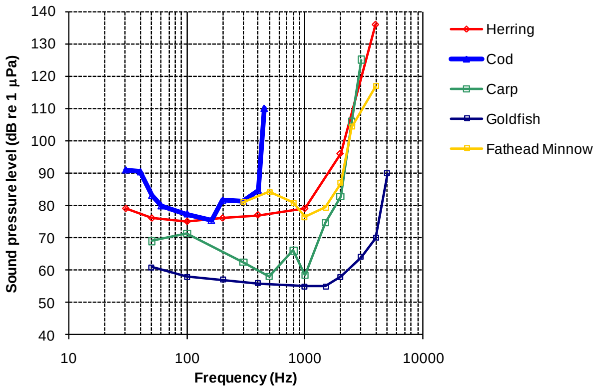

Figure 1 Audiograms of a number of hearing specialist species (Nedwell et al. 2004) illustrating the absolute threshold of hearing at different frequencies.

Based on the audiograms in Figure 1, barramundi are expected to have greatest hearing sensitivity at mid-frequencies between 100 Hz and 1 kHz, with hearing thresholds as low as 60 to 70 dB re 1 µPa.

Behavioural and physiological impacts of noise

Intensive aquaculture production often utilises equipment that increases noise levels in fish culture tanks (Bart et al. 2001). Continuous exposure to elevated noise levels could negatively impact on cultured species. Possible effects include behavioural responses, such as startle reactions and increased activity, and physiological responses, such as impairment of the auditory system, increased stress, and reduced growth rates (Wysocki et al. 2007). Most discussions of physiological effects of noise on fishes have centred on the auditory system, as this system is likely to be most sensitive to acoustic stimuli. When the auditory system is exposed to a high level of sound for a specific duration, the sensory hair cells begin to fatigue and do not immediately return to their normal shape (NRC 2005). This causes a reduction in the fish's hearing sensitivity, or an increase in hearing threshold. If the noise exposure is below some critical sound energy level (SEL), the hair cells will eventually return to their normal shape. This effect is called a temporary threshold shift (TTS) as the hearing loss is temporary. If the noise exposure exceeds the critical energy level, the hair cells become permanently damaged and the effect is called permanent threshold shift (PTS).

Wysocki et al. (2007) investigated the effects of aquaculture production noise on hearing, growth, and disease resistance of rainbow trout. Rainbow trout were cultured for eight months in fibreglass tanks and exposed to one of three broadband sound treatments common to aquaculture systems (Bart et al. 2001) of 115, 130 or 150 dB re 1 µPa, with most energy below 400 Hz. No significant differences in hearing thresholds were observed from exposure to increased ambient sound levels. Growth rate and mortality also were not affected significantly by increased noise exposure. This indicated that the rainbow trout were not negatively impacted by noise levels common to aquaculture systems.

Davidson et al. (2009) evaluated the long term effects of aquaculture production noise on the growth, condition factor, feed conversion efficiency, and survival of cultured rainbow trout. Rainbow trout were cultured in fibreglass tanks and exposed to two sound treatments. One group was exposed to levels of 117 dB re 1 µPa representing levels lower than usually recorded in aquaculture systems. The other group was exposed to levels of 149 dB re 1 µPa representing levels close to the upper limit commonly encountered in aquaculture systems. The introduced sounds had most energy in the low frequency range below 400 Hz which is typical for aquaculture systems (Bart et al. 2001). After five months of exposure, no significant differences were identified between treatments for mean weight, length, specific growth rates, condition factor, feed conversion or survival.

Smith et al. (2003) examined the short and long term effects of increased ambient sound on the stress and hearing of goldfish. Goldfish are hearing specialists and have increased hearing abilities due to specialised structures in their auditory organ. Goldfish were reared in a control tank under quiet conditions with levels of 110 to 125 dB re 1 µPa, and in a test tank under noisy conditions with levels of 160 to 170 dB re 1 µPa (white noise). Alterations in physiological stress were assessed by measuring plasma cortisol and glucose levels which are stress indicators. It was found that noise exposure did not produce long-term physiological stress responses, but a transient spike in stress levels was observed within 10 minutes of exposure. Significant hearing threshold shifts were measured after only 10 minutes of noise exposure, with shifts increasing linearly up to approximately 28 dB over a 24 hour exposure period. Further exposure did not increase threshold shifts. The study concluded that hearing specialist fish species may be susceptible to noise-induced stress and hearing loss for high levels of noise exposure.

Wysocki et al. (2006) investigated the influence of ship noise on stress levels of three fish species. Two hearing specialists, the common carp and the gudgeon, and one hearing generalist, the European perch, were exposed to recorded ship noise with levels of 153 dB re 1 µPa and most energy below 2 kHz. Stress levels were determined by measuring cortisol secretion levels after noise exposure. All three species responded with increased cortisol secretion, and no apparent difference was observed between the hearing specialists and generalist. Unexpectedly, no elevations were observed when exposed to Gaussian noise of similar levels as the ship noise. This indicates that the character and frequency content of the noise need to be considered rather than just the overall level when assessing stress effects.

Numerous other studies have been conducted to assess the impact of impulsive noise sources such as piling, blasting, air guns, and sonar (e.g. Doksæter et al. 2009; Song et al. 2008; Popper et al. 2007; Vagle 2006; Nedwell et al. 2006; Popper et al. 2005; Hassel et al. 2004; McCauley et al. 2003; Engås et al. 1996; Hastings et al. 1996; Yelverton et al. 1975). These sources typically produce high underwater source levels and the studies mostly investigate the noise exposures that cause physiological damage to the auditory system, such as TTS or PTS. The noise levels within the fish tanks likely to be produced by the transport corridor are very much lower. For example, air guns produce underwater source levels of 250 to 255 dB re 1 µPa at 1 m, and may be detectable above ambient ocean noise conditions at great distances.

EXISTING CONDITIONS

Ambient noise environment in fish tanks

Underwater ambient noise measurements were conducted within the fish tanks using a B&K Hydrophone Type 8104 and a B&K Charge Amplifier Type 2635. Measurements were taken in all three types of fibreglass tanks at a depth of approximately 0.3 m and a distance of 0.1 m from the tank walls. Measurements could not be taken at greater depths as the barramundi were swimming into the hydrophone at these depths causing spurious transients in the signal.

Ambient overall noise levels of 130 to 135 dB re 1 µPa were measured within the fish tanks between 10 Hz and 4 kHz. Figure 2 illustrates the one-third octave band ambient noise levels measured within two tanks. The ambient underwater noise environment was dominated by low frequency noise below 400 Hz, with some energy at higher frequencies due to bubble noise from the aeration system. The low frequency noise was caused by water flow and pump vibrations transmitted to the tank walls via pipework and direct mounting of the water pumps to the tank structure. This was confirmed by measuring tank wall vibrations which contained strong tonal components at 50 and 100 Hz related to the running speeds of the pumps and blowers. The measured levels are within the typical range of ambient noise levels measured in the survey of aquaculture systems conducted by Bart et al. (2001).

The one-third octave band ambient noise levels measured within the fish tanks are compared to the absolute hearing thresholds of a number of hearing specialists in Figure 2. One-third octave bands are used in the comparison as it is typically assumed that effective masking bands are one-third octave wide (Richardson et al. 1995). The comparison shows that the absolute hearing thresholds of these species are lower than the ambient one-third octave band noise levels within the fish tanks. This indicates that the ambient noise within the tanks is most likely audible to the barramundi, and that they are currently exposed to significant amounts of audible noise. Any additional traffic noise within the fish tanks due to the transport corridor will be masked by the ambient noise unless it is of a higher level.

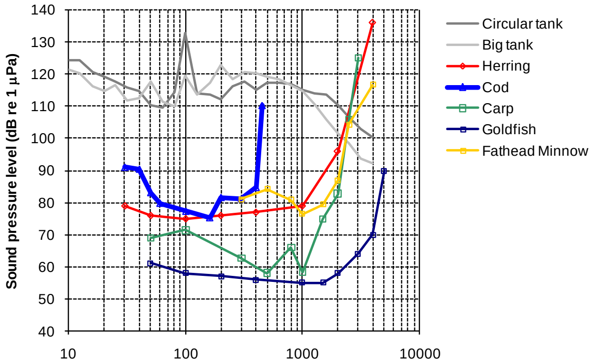

Figure 2 Ambient one-third octave band noise levels measured within fish tanks compared with absolute hearing thresholds of some hearing specialist fish species.

Ambient noise environment in building enclosure

In-air ambient noise measurements were conducted within the building enclosure using a B&K Type 2250 sound level meter. Ambient noise levels (L_{eq}) of around 104 dB re 1 µPa were measured adjacent the fish tanks. The ambient noise environment within the building enclosure was dominated by the aeration blowers, water pumps, a refrigeration unit located directly outside the facade of the fish farm, and other mechanical plant.

NOISE PREDICTIONS

Maximum sound power levels for trucks and trains

The impact of traffic noise on the barramundi is assessed based on maximum noise level events (L_{max}) from the transport corridor. This noise descriptor is used instead because maximum noise events could potentially cause behavioural disturbance or stress responses when resulting in underwater levels that are significantly louder than the measured ambient noise environment of 121 to 135 dB re 1 µPa within the fish tanks.

For road traffic, maximum noise events will be dominated by trucks accelerating onto the transport corridor from a nearby interchange. Noise levels within the fish tanks were calculated assuming a typical maximum sound power level L_w of 116 dB re $1{\cdot}10^{-12}$ W for accelerating trucks.

For rail traffic, typical maximum noise levels for freight train pass-bys were measured on the Adelaide to Darwin rail line at the now closed Moloney Road rail crossing at Virginia. Based on the train pass-by noise measurements, maximum noise levels within the fish farm were calculated assuming a sound power level of 136 dB re $1{\cdot}10^{-12}$ W for a freight train pass-by.

Sound pressure levels outside building enclosure

Maximum sound intensity levels outside the building enclosure $L_{I,o}$ due to truck and train pass-bys were calculated assuming hemi-spherical spreading, such that (Bies & Hansen 2003)

$$L_{I,o} = L_w + 10\log_{10}\frac{1}{2\pi r^2},$$

with the sound intensity level calculated re $1{\cdot}10^{-12}$ W/m^2, and r the minimum distance between the fish farm and the road or rail line. This distance is approximately 80 m for the road and 100 m for the rail line. For this distance, maximum sound intensity levels outside the building enclosure of around 70 dB re $1{\cdot}10^{-12}$ W/m^2 are predicted for accelerating trucks, and 88 dB re $1{\cdot}10^{-12}$ W/m^2 for freight train pass-bys.

Sound pressure levels inside building enclosure

Sound pressure levels inside the building enclosure were predicted by first calculating the total sound power transmitted into the building enclosure. For a single building element, the transmitted sound power $L_{w,i}$ is given by

$$L_{w,i} = L_{I,o} + 10\log_{10} A - TL,$$

with A the area of the considered building element in m^2, TL the transmission loss of the building element, and $L_{I,o}$ the impinging external sound intensity level calculated in the previous section.

Most of the doors within the facades of the fish farm are open for the majority of time during the day but are closed at night. Our assessment therefore assumed that these doors were open (TL = 0). The building facades and roof are constructed from 76.2 mm thick polystyrene sandwich panels. These panels are comprised of 0.6 mm thick steel facings with 75 mm thick polystyrene foam plastic cores. Figure 3 illustrates the transmission loss of the sandwich panels used to calculate traffic noise ingress via the facades and roof.

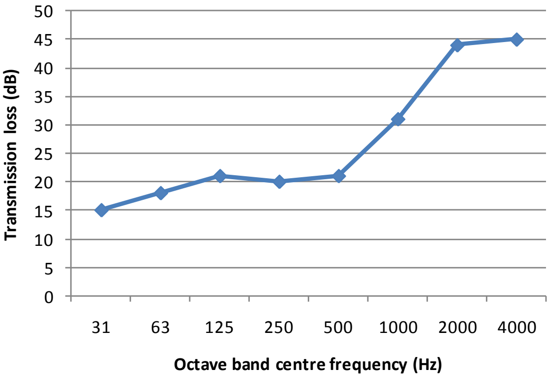

Figure 3 Typical transmission loss of a 76.2 mm thick polystyrene sandwich panel.

The building enclosure is expected to act as a reverberant chamber resulting in a diffuse sound filed, since the concrete floor, sandwich panel facades and roof, and air-water interface of the fish tanks are all highly reflective. Reverberant chamber theory (Bies & Hansen 2003) was therefore used to predict the internal sound pressure levels impinging on the fish tank water. Given the traffic noise sound power $L_{w,i}$ transmitted into the building enclosure, the internal sound pressure level $L_{p,i}$ re 20 µPa is calculated as

$$L_{p,i} = L_{w,i} + 10\log_{10}\frac{4}{R_c},$$

with R_c the room constant for the building enclosure (Bies & Hansen 2003), which is calculated based on the absorption coefficients of the concrete floor, sandwich panel facades and roof, and air-water interface.

For accelerating trucks, maximum noise levels of approximately 92 dB re 1 µPa were predicted within the building enclosure. Maximum noise levels of approximately 110 dB re 1 µPa are predicted for train pass-bys. Figure 4 compares the predicted octave band traffic noise levels (maximum) with the measured ambient noise environment adjacent the fish tanks.

The predicted maximum train pass-by level exceeds the ambient noise level of 104 dB re 1 µPa measured adjacent the fish tanks. Train pass-bys are thus predicted to be audible above the in-air ambient noise environment within the building enclosure.

For accelerating trucks, the predicted maximum noise levels are lower than the measured ambient noise level in all octave bands. Truck acceleration noise is therefore expected to be masked by the existing noise environment. As such, it was concluded that road traffic noise is unlikely to have a significant impact on the barramundi within the fish farm tanks, and is not considered in any further predictions.

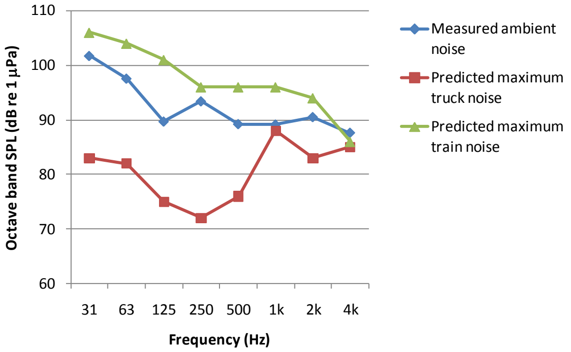

Figure 4 Predicted maximum traffic noise levels within building enclosure compared with the measured ambient noise environment.

Noise energy transmission at air-water interface

The effective sound power impinging on the air-water interface due to the reverberant sound field within the building enclosure is given by (Bies & Hansen 2003)

$$L_{w,air} = L_{p,i} + 10\log_{10} A - 6,$$

with A the area of the air-water interface approximately equal to 60 m^2 for the fish tanks, and $L_{p,i}$ the reverberant sound pressure level re 20 µPa within the building enclosure, which was calculated in the previous section.

Most of the acoustic energy impinging at the air-water interface will not actually transmit into the fish tank water. This is because at the air-water interface, the majority of acoustic energy is reflected back into the building enclosure due to the relatively large difference between the acoustic impedance of water and air. For incident angles smaller than about 75°, sound is totally reflected (Ross 1987). Of the acoustic energy impinging at normal incidence of 90° to the water surface, approximately 30 dB is reflected back into the building enclosure (Ross 1987). The sound power level L_w transmitted into the fish tanks was therefore predicted as

$$L_w = L_{w,air} - 30.$$

The above assumptions are expected to be conservative because they do not take into account that energy impinging at incident angles smaller than about 75°, which occurs assuming a diffuse field, is perfectly reflected back into the building enclosure.

Sound pressure levels inside fish tanks

Sound pressure levels within the fish tanks were calculated using water-filled reverberant chamber as described by Jones & Hoefs (1996). The reason for this is that the fibreglass tank walls and bottom are expected to be highly reflective, and the water-air interface acts as a near-perfect reflector of sound (Ross 1987). The reverberant sound pressure level L_p within the fish tanks was predicted as

$$L_p = L_w + 10\log_{10}\frac{4}{R_c} + 61.7$$

with L_w the traffic sound power transmitted into the water, and R_c the room constant for the fish tank. For a water-filled reverberant chamber, the room constant is given by (Jones & Hoefs 1996)

$$R_c = \frac{0.0373V}{T_{60} - 0.0373V/A}$$

with V the volume of water, A the combined area of the tank walls, bottom and air-water interface, and T_{60} the reverberation time within the fish tank. The fish tanks contain approximately 200 m^3 of water and have a total surface area of 230 m^2. Reverberation times in the order of T_{60} = 0.1 s are predicted for the fish tanks based on reverberation times measured within another hard-walled tank of a similar volume located at the DSTO, South Australia (Jones & Hoefs 1996).

Based on the above assumptions, maximum sound pressure levels of 113 dB re 1 µPa are predicted within the fish tanks due to a train pass-by. Figure 5 compares the predicted octave band levels with the measured ambient noise environment of 130 to 135 dB re 1 µPa within the fish tanks.

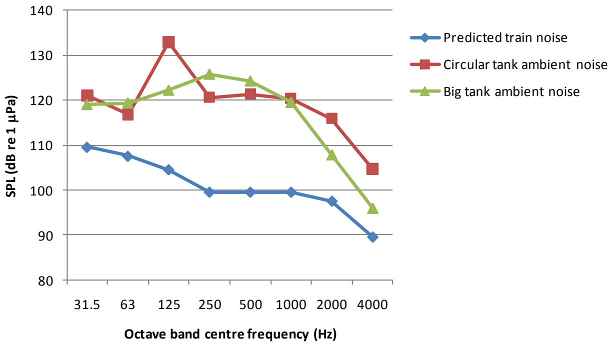

Figure 5 Predicted maximum traffic noise levels within fish tanks compared with the measured ambient noise environment.

The predicted maximum sound pressure levels within the fish tank are lower than the measured ambient noise environment across all octave bands. The noisy existing conditions within the fish tanks, caused by aeration blowers and water pumps, are therefore expected to mask any traffic noise transmitted into the fish tanks. Maximum noise emissions from the transport corridor are thus predicted to be inaudible above the existing environment, and the impact of the transport corridor on the barramundi is likely to be negligible.

CONCLUSION

The environmental noise impact of a proposed major transport corridor on a barramundi fish farm was assessed following concerns about the potential impacts on the barramundi. A study into fish hearing and the impacts of noise on fish was conducted to establish noise exposure levels that may cause significant behavioural or physiological impacts. The ambient noise environments within the fish tanks and building enclosure were measured before construction of the transport corridor to establish the existing conditions. The existing environment was found to be relatively noisy with measured underwater noise levels of 130 to 135 dB re 1 µPa between

10 Hz and 4 kHz. Low frequency noise (<400 Hz) due to water pumps, aeration equipment and other mechanical plant dominated the fish tank environments. The existing high noise environment within the fish tanks will mask the predicted maximum traffic noise levels. Noise impacts of the transport corridor on the barramundi are therefore likely to be negligible.

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