NOISE REPORT – NLR 2015-02

Impact of Vessel Noise at Wattle Grove

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Summary

This report investigates the noise emitted by a vessel used for servicing marine farms. The vessel, Ronja Huon, is a relatively new vessel and its operations in the Huon River and D'entrecasteaux Channel has resulted in a number of complaints regarding the noise emitted by the vessel.

Aspects of the noise from the vessel have been identified and it can be concluded that the main component of the noise is a significant tonal peak at 45 Hz. The energy in this peak dominates the noise and is almost totally responsible for the resulting A-weighted noise level at any distance from the vessel.

The noise from the vessel also contains many smaller tonal peaks that are within a series of harmonics based on a fundamental of 7.5 Hz.

The results are consistent with the vessel complying with the 74 dB(A) at 25 metre limit in Regulation 8(1) of the *Environmental and Pollution Control (Miscellaneous Noise) Regulations 2014*.

Introduction

The Ronja Huon is a new vessel that is currently under contract to Huon Aquaculture to provide support for marine farming activities in the lower Huon River, Channel and eastern side of Bruny Island.

The vessel started operation at the beginning of 2015. Unfortunately, it was setup for 60Hz shore-power which is generally not available in Australia. Consequently it was necessary to keep the on-board generators running when the vessel was in port for both routine restocking and extended maintenance and operational adjustments. This situation has been rectified and shore-power for the vessel is now available at Port Huon.

Complaints have been received by several agencies regarding noise from the vessel. These complaints relate to the operation of ship's generators in Port Huon, the transit of the vessel in front of residences on the riverbanks of the Huon River or the operation of the vessel at leases near the mouth of the Huon River as heard from areas such as Roaring Beach (Surveyors Bay) and Lunawanna (Bruny Island).

These complaints represent a considerable range of source to receiver distances, from some hundreds of metres for Port Huon residents hearing the vessel at the Port Huon pier to well over 10 km for on-lease noise reaching Lunawanna.

This report provides details and interpretation of acoustic measurements made of the vessel noise in the Huon River and D'entrecasteaux Channel areas.

Vessel Details

The Ronja Huon is described as a Well Boat. It has three 1000 tonne water holds and has a gross weight of 3566 tonnes. Its home port is Aalesund, Norway, and it sails under the Norwegian flag.

The vessel is owned by Sølvtrans, with web address Sølvtrans.NO, who has a fleet of these wellboats which are mainly employed on log-term contracts in Norway, Scotland, Canada, Chile and Australia.

The vessel is 76 metres long and the height of the engine exhaust stack above the water level has been estimated to be about 15 metres. The main propulsion utilises power from a pair of 2MW diesel-electric generators, which are believed to provide electricity for all other services.

The main noise sources on the vessel are expected to include the main engine exhausts, engine and pump noise radiated through the hull, and noise from deck-based equipment.

Vessel Movements

It has been possible to follow the general movements of the vessel using data provided by AIS (Automatic Identification System) via web-based providers. The intention has been to use this data to indicate typical courses, locations and speeds in relation to measurement locations.

Some measurements had been made before AIS locations were collected. This relates to noise measurements at Wattle Grove and Port Huon. Some vessel positions can be inferred from variations in the measured noise levels, such as the time of closest approach to the Wattle Grove site and times of arrival and departure at Port Huon.

At Port Huon it appears that the vessel is located on the western side of the pier at Lat -43.159540, Lon 146.975600 or 498016mE, 5221468mN.

Measurement Locations

This investigation into noise from Ronja Huon is based on measurements and audio recordings made at five main locations. The choice of these locations has been based, in part, on direct complaints regarding disturbance from vessel noise. The locations are not intended to provide a definitive evaluation of the noise leading to complaints but rather provide useful measurements of vessel noise from different distances and different directions. At the same time, the ambient noise conditions will vary significantly. All sites are close to the coastline and thus will be influenced by noise from wave action.

Site	Latitude	Longitude	Easting	Northing
Port Huon	-43.165903	146.973021	497807mE	5221760mN
Wattle Grove	-43.177975	146.987671	498998mE	5219421mN
Nebraska Beach	-43.071338	147.349393	528445mE	5231203mN
Roaring Beach	-43.289859	147.091789	507447mE	5206992mN
Lunawanna	-43.349140	147.225343	518263mE	5200288mN

Survey details are included in **Appendix A**.

Equipment

Measurements were made with Acoustic Research Laboratories Ngara noise loggers. These units measure both A and C frequency weighted noise levels at a rate of 10 measurements per second. The loggers also capture a high quality audio recording in one-hour segments. Typically the memory capacity will provide for about 8 days of operation.

Many environmental noise limits are specified as A-weighted values. This particular frequency weighting is intended to adjust the measurements to align to the frequency response of the human ear. However, it appears to underestimate the response to low-frequency sounds.

C-weighting is an alternative frequency weighting which includes significantly more low-frequency sound that A-weighting and has been used to advantage to identify noise from the Ronja Huon.

The loggers were calibrated with a Bruel and Kjaer Type 4231 field calibrator before and after deployment.

Results from Port Huon and Wattle Grove

Noise loggers were deployed at both Port Huon and Wattle Grove from 05 to 11 February 2015 and then followed by a second deployment from 12 to 20 February 2015. Graphical noise level results for the deployments are provided in **Appendix B**.

During the two deployments the Ronja Huon docked at Port Huon once arriving at about 5:30 pm on 10 February and departing at about 10:00 pm the same day.

Although it is conventional to use A-weighting results, much better clarity of noise from the vessel is provided using C-weighted levels. In addition, noise loggers record at a rate of 10 measurements per second which are then grouped into more convenient time segments, typically 5-minutes. This provides a statistical distribution of the noise during each 5-minute period. This scheme has the advantage that particular components of the noise can be separated out for investigation. The vessel noise is fairly constant and will thus control the lower part of the statistical distribution of the noise. Short, high-level sources of noise, such as passing cars and bird calls, can be very significant contributors to the average noise level and will tend to mask the constant, lower-level contributors. It is possible to exclude the short-term elevated noise by choosing a statistic, such as the L_{90}, which is the noise level exceeded for 90% of the time.

Figure 1 shows the variation of the L_{90}, C-weighted sound pressure level for a 12 hour period starting at midday on 10/02/2015. The noise level at the Port Huon monitoring site increases as the vessel arrives, between 5:00 and 6:00 pm, and there is a similar increase when the vessel leaves at 10:00 pm. Between these times the noise level is fairly constant at 60 dB(C), indicating that the boat noise is dominant during the intervening period.

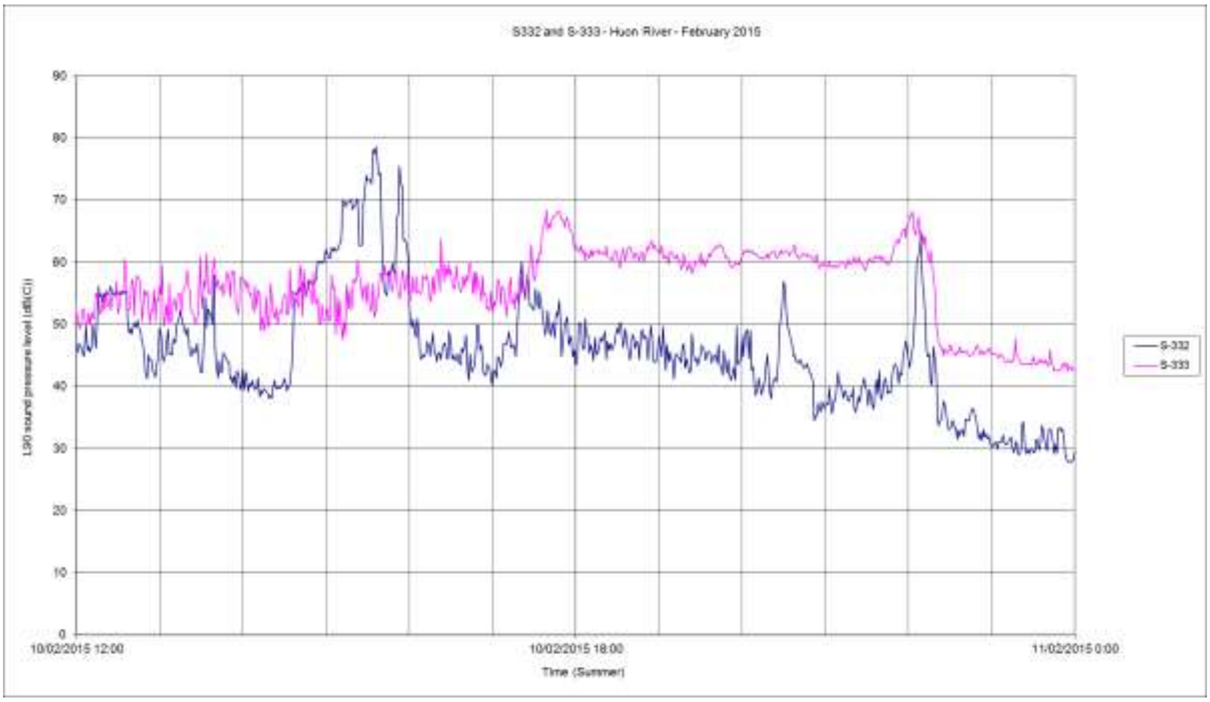

Figure 1. Time plot of the L_{90}, C-weighted sound pressure level at S-332 (Wattle Grove, blue) and S-333 (Port Huon, magenta)

The delineation of the noise from the vessel is quite obvious at the Port Huon monitoring site, due to the increase in noise level at arrival and departure and due to the constant noise level whilst the vessel is at the dock.

The increase in noise as the vessel passes the Wattle Grove site can be identified in relation to the variation in noise level at Port Huon. The increase during arrival is not as obvious as during departure, primarily due to the level of the background noise. It can be seen from figure 1 that the noise level at the Wattle Grove site was about 40 dB(C) before the approach of the Ronja Huon and had reduced to about 30 dB(C) after departure.

The vessel noise measured at Wattle Grove produced a level of about 60 dB(C) on arrival and 63 dB(C) on departure. The departure peak is more obvious due to the reduced background noise.

The A-weighted sound pressure levels recorded at the two sites are presented in **Figure 2** for the corresponding time period as figure 1. The clarity provided by figure 1 is not present in figure 2 but it is possible to extract some useful information by relying on the timing provided in figure 1.

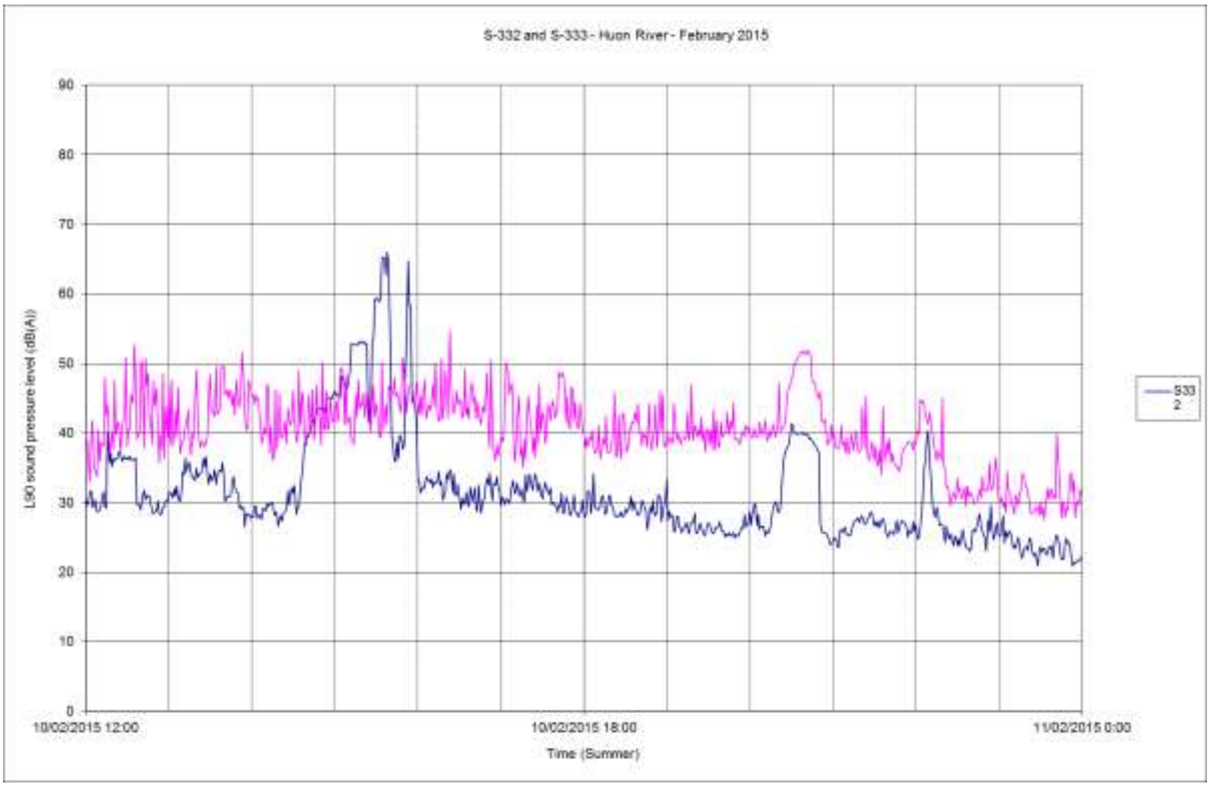

Figure 2. Time plot of the L_{90}, A-weighted sound pressure level at S-332 (Wattle Grove, blue) and S-333 (Port Huon, magenta) for the same period as figure 1

The noise level at Port Huon appears to be fairly constant at about 40 dB(A) whilst the vessel was in port, apart from a 30 minute period at about 8:30pm when there is a significant increase at both measurement sites, followed by a reduction of several dB(A) at Port Huon towards the end of the time in port. There was a reduction of about 6 dB(A) in the noise level at the Port Huon site when the vessel departed.

At the Wattle Grove site the noise level was about 27 dB(A) before the vessel departed and reached a maximum of about 40 dB(A) as the vessel passed, then dropped to about 24 dB(A). It can be seen from figures 1 and 2 that the best signal to noise ratio to measure the properties of the sound from the Ronja Huon is during its pass-by of the Wattle Grove site.

The exact path of the vessel as it passed Wattle Grove on 10 February 2015 is not known but trajectories derived from AIS data indicate that the vessel tended to follow a similar path past Wattle Grove, which would be expected for a vessel of this size. The distance from the measurement site to the point of closest approach, as shown in **Figure 3**, is about 825 metres. Errors propagated to noise level determinations resulting from an error in the separation distance will, however, be minimal.

The attenuation of sound intensity with distance is generally dominated by divergence but for distances over about 500 metres the influence of air absorption becomes important. Air absorption is frequency dependent with attenuation increasing with frequency. It is necessary to take air absorption into account as the frequency spectrum measured at 825 metres will have been modified from the emitted spectrum. Since the emission spectrum is not known, it can be determined from the received spectrum and the theoretical air absorption.

Figure 3. Closest approach to the Wattle Grove measuring site, based on several vessel trajectories. The yellow line is 825 metres long.

One-third octave spectra of the noise at the Wattle Grove site have been determined for a series of short time periods, between 1 and 2 minutes each, whilst the vessel was moving past. The timing of the spectra relative to the passage of the vessel is shown in **Figure 4**. Spectrum 4 was centred on the time of peak noise and has corresponding broad-band levels of 70 dB(lin), 67 dB(C) and 43 dB(A). One additional spectrum, spectrum 9, was measured about 50 minutes after the time of closest approach. The levels derived from spectrum 4 are expected to be slightly lower than the peak levels indicated in figure 4 because the spectrum has been averaged over a greater period that the levels indicated in the figure.

Only spectra 3, 4 and 9 will be considered at this stage. There is a peak immediately before the time period for spectrum 3. This peak, which is more obvious in the A-weighted trace than the C-weighted trace, is due to a passing car.

One-third octave spectra 3, 4 and 9 are shown in **Figure 5** and the same spectra, but A-weighted, are shown in **Figure 6**. In general, spectrum 9 can be regarded as indicating the ambient background conditions, i.e. the general acoustic conditions in the absence of the vessel.

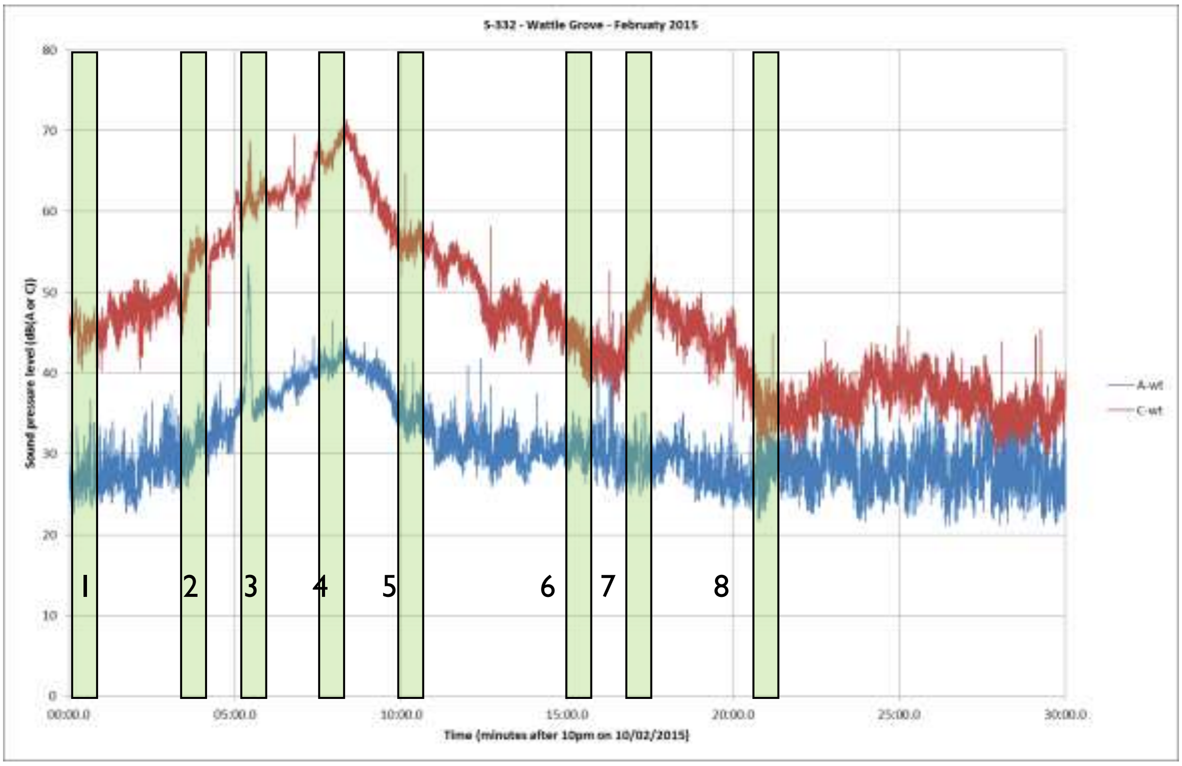

Figure 4. Sound pressure level at the Wattle Grove measuring site, both A and C weighted. Frequency spectra have been measured at the eight indicated periods and 50 minutes after the time of the peak noise level.

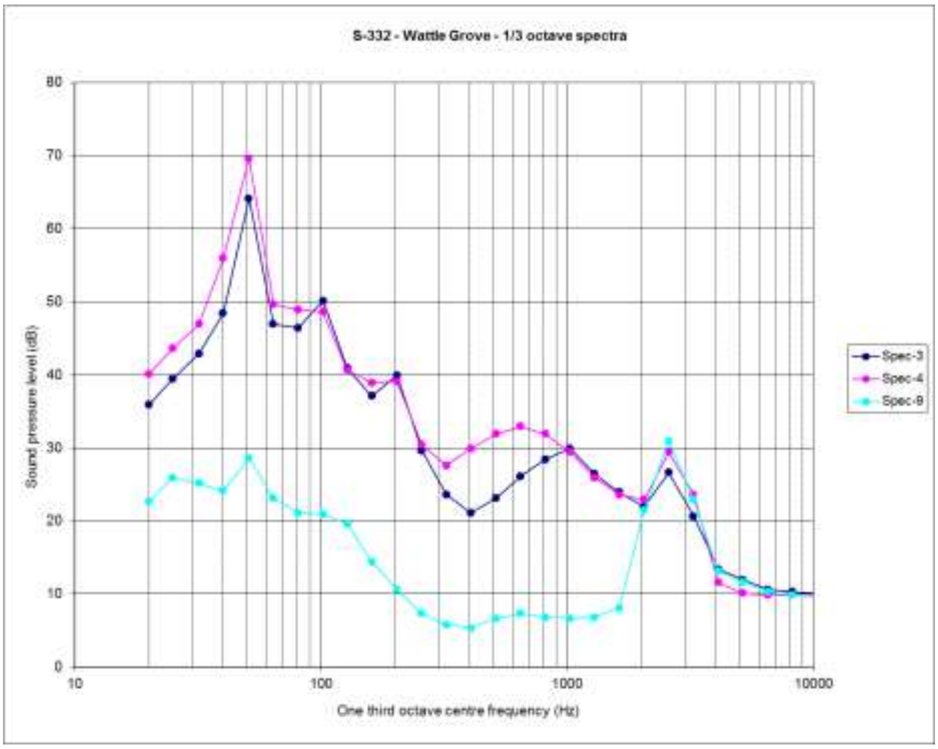

Figure 5. One-third octave spectra 3, 4, and 9

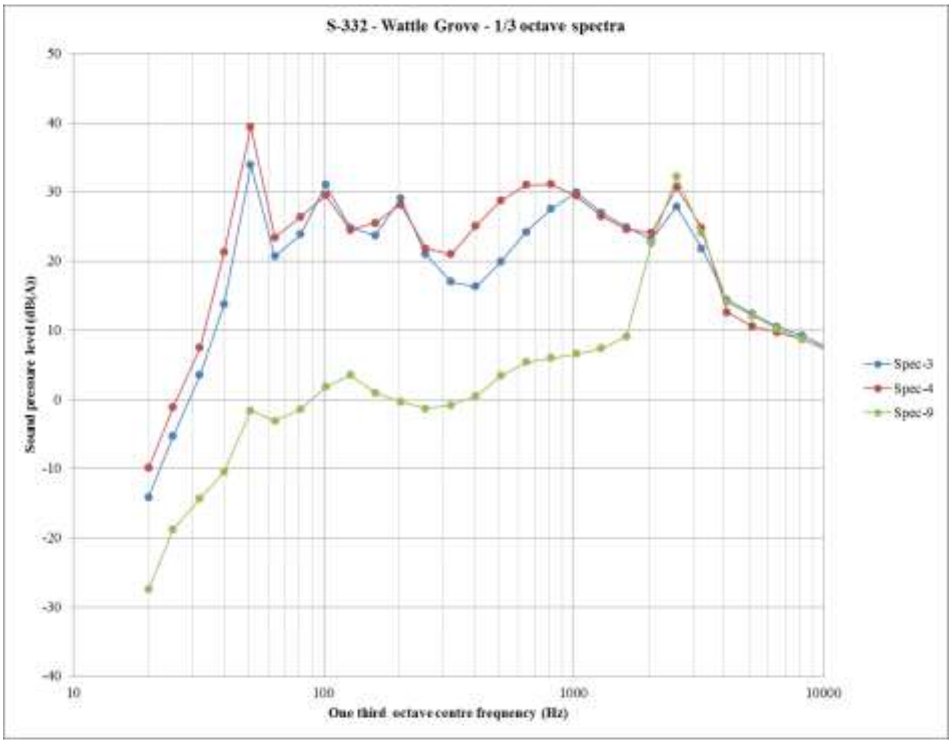

Figure 6. A-weighted one-third octave spectra 3, 4 and 9

The main peak in the 50 Hz band is very apparent for spectra 3 and 4, extending about 20 dB(A) above the neighbouring bands. In addition, the 100 Hz and 200 Hz bands are elevated, which would be consistent with harmonics of the energy in the 50 Hz band. There is a broad peak from about 400 Hz to 2 kHz but this is not identical for spectra 3 and 4.

In general, the background one-third octave levels indicated by spectrum 9 are more than 15 to 30 dB below the levels when the vessel is at closest approach. However, the 2 kHz to 4 kHz bands are significantly elevated in all spectra and it is highly likely that this relates to noise from nearby insects. Clearly this band of energy is not due to the vessel and has to be removed from the levels in spectrum 4 to determine the contribution from the vessel. There is a hint of the main tonal peak of the vessel noise in the 50 Hz one-third octave band but no other evidence of a contribution of vessel noise in spectrum 9.

The method for removing the insect noise peak from spectrum 4 could have some influence on the final sound power determination, particularly for an A-weighted value. However, the main interest will ultimately be on long-range propagation and so this part of the emission spectrum will be of minimal importance. The 1.6 kHz band (23.6 dB) is clearly dominated by vessel noise but the next band at 2.0 kHz (22.9 dB) is clearly dominated by insect noise. It is considered that a reduction of the levels in the bands from 2.0 to 5.0 kHz down to 10 dB would give an acceptable approximation for the vessel spectrum. The resultant change is 0.4 dB(A) which indicates that the insect noise has minimal influence on the A-weighted noise level. It is likely that the energy at higher frequency bands (5 kHz and above) is also unrelated to the vessel.

Some additional clarification can be extracted from similar data measured at the Port Huon measurement site. At 10 pm when the vessel departed the port, the noise level dropped from about 66 dB(C) by about 20 dB to about 46 dB(C). This does not provide as much signal to noise ratio as provided in the Wattle Grove measurements but the reduced separation provides a little less high-frequency attenuation. One-third octave spectra with both the vessel present and absent are shown in **Figure 7**. As expected, the otherwise ambient noise was greater at the Port Huon site. There is no indication of insect noise and there is an indication of an increase in sound level due to the vessel up to about 4kHz.

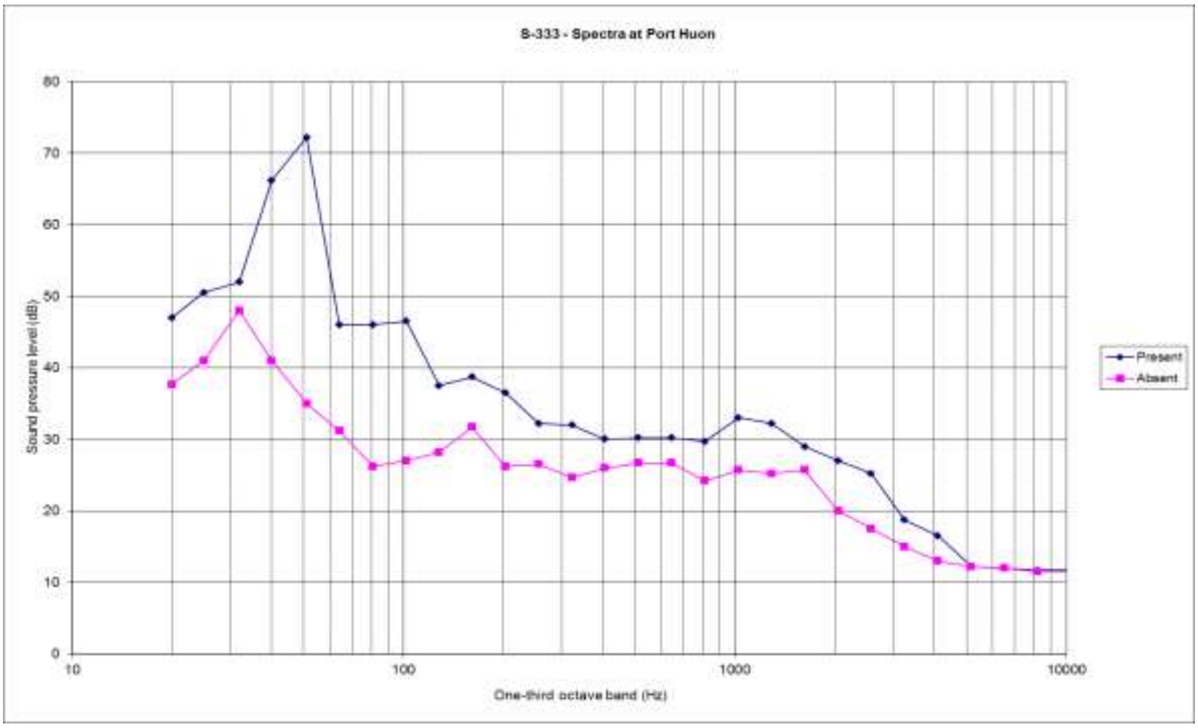

Figure 7. One-third octave spectra with and without the vessel as measured at the Port Huon site

High-resolution spectra, corresponding to spectra 3, 4 and 9 discussed earlier, are provided in **Figure 8**. These spectra show that the vessel noise includes many tonal peaks with a dominant peak at 45 Hz. Other strong peaks are harmonics of the 45 Hz at 90 Hz and 180 Hz. There are many other tonal peaks that align to a regular spacing of 7.5 Hz that extend from 22.5 Hz up to about 300 Hz and possibly higher.

The main 45 Hz peak for spectrum 4 has a level of 69 dB and has sufficient energy to completely dominate the corresponding 50Hz one-third octave band level.

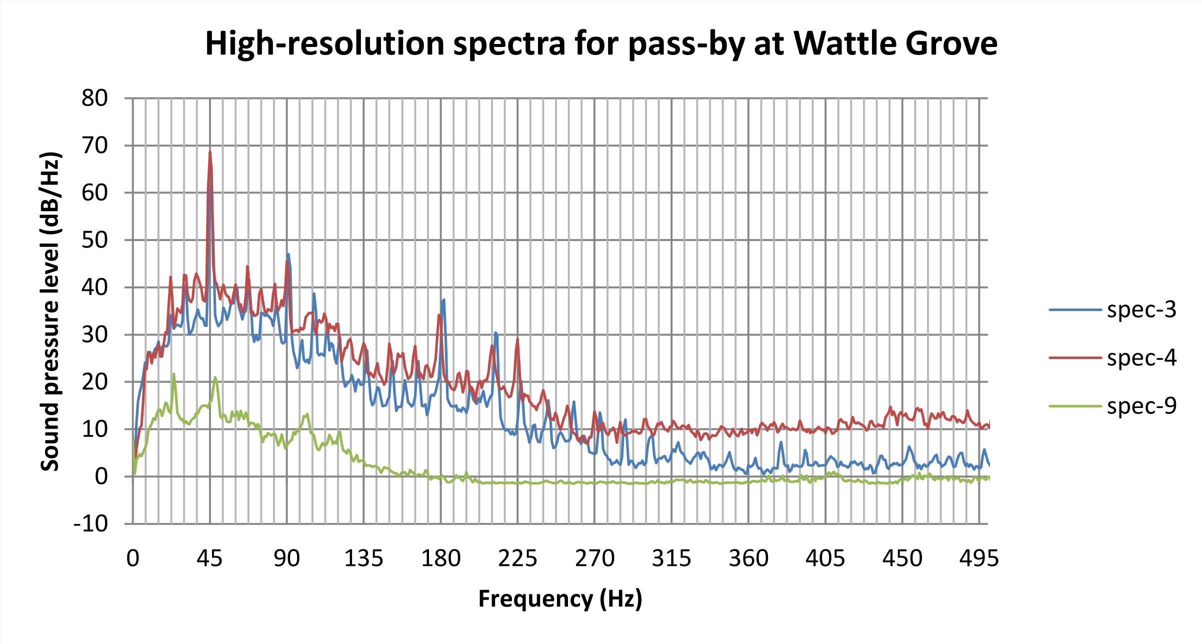

Figure 8. High-resolution spectra corresponding to the one-third octave spectra shown in figure 6 The vertical gridlines are spaced every 7.5 Hz.

To provide some additional clarity regarding the propagation and direction of emission, a vessel position mid-way between the Port Huon and Wattle Grove measurement sites has been identified, as shown in **Figure 9**. This position is 1350 metres from the two measurement sites and 1040 metres from the point of closest approach to Wattle Grove.

From other measurements it is believed that the vessel was travelling at about 4.3 metres per second and, at this speed, would have taken 242 seconds (4 min 2 sec) to move from the mid-point to the position of closest approach to Wattle Grove. **Figure 10** is a plot of the level of the 45 Hz peak as the vessel moves down the Huon River. The time axis is relative to the peak at Wattle Grove which is assumed to indicate the time of closest approach to the Wattle Grove measurement site. At 242 seconds before the time of closest approach the respective noise levels at Port Huon and Wattle Grove were 66 and 57 dB. This difference of 9 dB is not expected, nor is the behaviour of the levels as the vessel continues down river. In particular, it is expected that after the closest approach to Wattle Grove, the level at Port Huon will always be lower than the level at Wattle Grove – which is clearly not the case.

There are several possible causes of these unexpected observations, including directional noise from the vessel, meteorological influences and topographic screening. There are also some other indications of unexplained influences for long distance propagation.

Figure 9. The position labelled 'mid-point' is equidistant for the Port Huon and Wattle Grove measurement sites

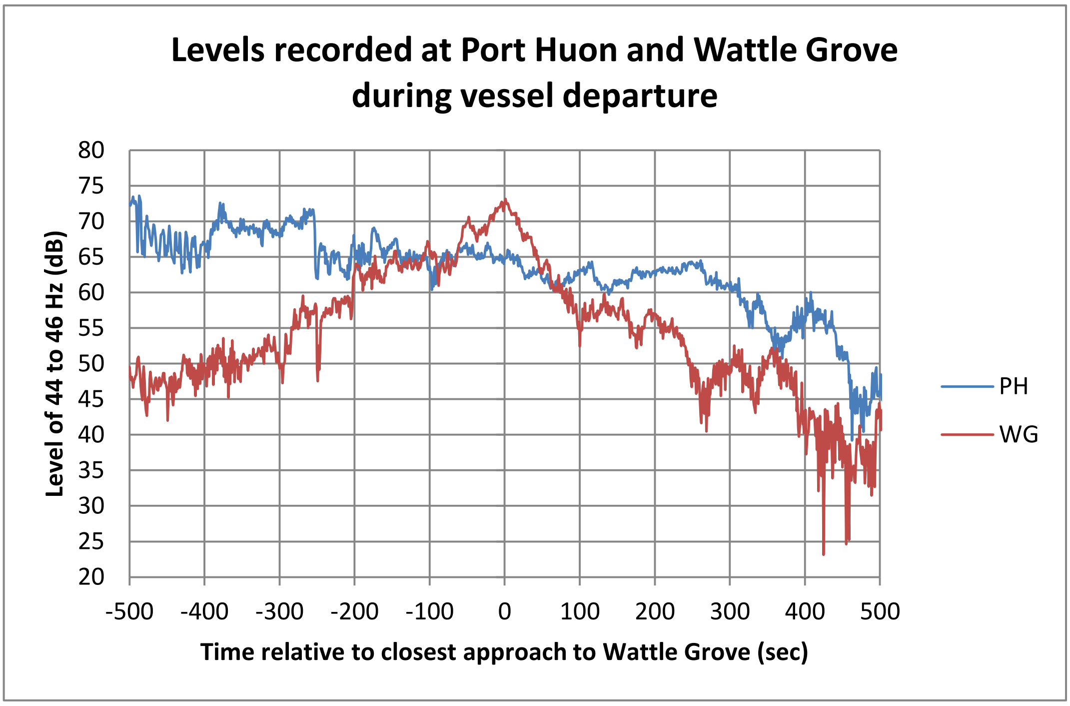

Figure 10. Level of the 45 Hz peak as measured from Port Huon (PH, blue) and Wattle Grove (WG, red) The vessel was mid-way between the monitoring sites at -242 seconds.

It has not been possible to resolve all the differences between the Port Huon, Wattle Grove and the mid-point results but it is clear that the vessel noise is dominated by the main tonal peak at 45 Hz that reports to the 50 Hz one-third octave band. At the time of closest approach to Wattle Grove this peak represents an unweighted noise level of 69 dB. The corresponding C and A-weighted levels are 70 dB(C) and 42 dB(A) respectively.

Variation in the Frequency Spectrum

There is a variation in the fine detail of the frequency spectrum in the vicinity of the main 45 Hz tonal peak. The variation with time of the spectral shape has been reviewed by spectral analysis at 1 Hz resolution, although it appears that the variations occur well below this resolution. The variation for the 44 to 48 Hz bands are shown in **Figure 11** and it can be seen that 45 and 46 Hz are the maximum components before the 530 second peak but that 44 and 45 Hz are the maximum components after the 530 second peak.

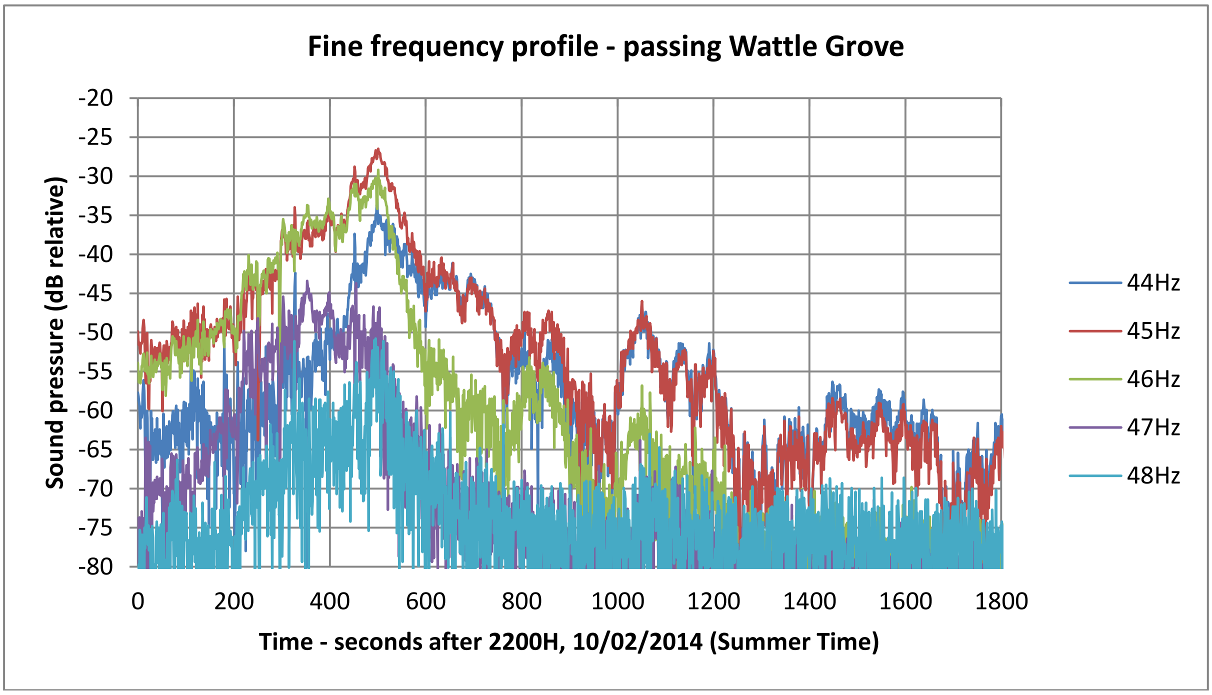

Figure 11. Fine frequency profiles as the vessel passes Wattle Grove

This indicates a variation in the frequency of the main energy peak consistent with Doppler shift, i.e. the pitch is slightly elevated as the vessel approaches the recorder and then drops as the vessel passes and travels away. This variation in frequency has been estimated from the amplitude of the 44, 45 and 46 Hz levels and the result of this frequency determination has been plotted in **Figure 12.** It can be seen from the figure that there is an initial rise in frequency to about 45.6 Hz followed by a fall through a point of inflection at about 530 seconds to a minimum at about 700 seconds. There is a then a rise to about 45.0 Hz at about 820 seconds followed by a drop to about 44.5 Hz.

The interpretation is an initial rise in frequency due to the vessel accelerating from rest at the Port Huon pier, reaching a steady speed at about 200 seconds on the Figure 12 time axis, and then there is a classic Doppler profile as the vessel moves past the recording site. The local peak at about 820 seconds on Figure 12 is due to the bend in the vessel's path around Bullock and Brabazon Points.

The approach frequency is 45.60 Hz and the depart frequency is 44.45 Hz. Assuming the speed of sound is 340 m/s, the variation in frequency is consistent with a Doppler variation from a source travelling at 4.3 m/s (8.4 knots).

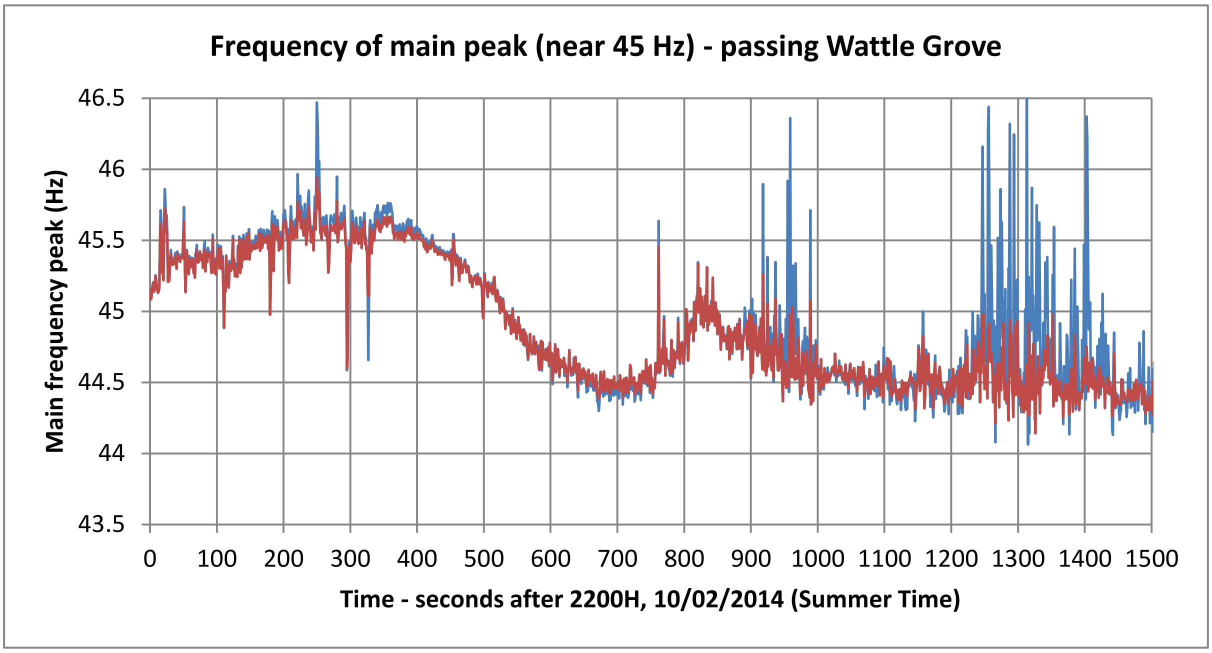

Figure 12. Variation in frequency of the main ~45 Hz spectral peak measured at Wattle Grove as the vessel departs from Port Huon.

Other Measurement Sites

In addition to the Wattle Grove site, several other measurement sites have been utilised to provide a range of vessel to receiver distances. Descriptions of the other sites are provided below together with measured spectra of vessel noise. There are 15 spectra taken at a range of distances from the vessel.

Nebraska Beach

The vessel passed the Nebraska Beach measurement site during the period 1pm to 3pm on 31/03/2015. There is a lease on the outside of Bruny Island and the vessel accesses this lease about once a week. This measurement site, towards the southern end of Nebraska Beach, was chosen due to the relatively simple waterway and the access to a suitable measurement site. There have not been any representations regarding the vessel from residents in the upper sections of the D'entrecasteaux Channel. The course of the vessel between Tinderbox and the Nebraska site is fairly constrained and it is expected that the vessel will always pass at a similar distance from the shore. The distance to closest approach has been estimated at about 1150 m.

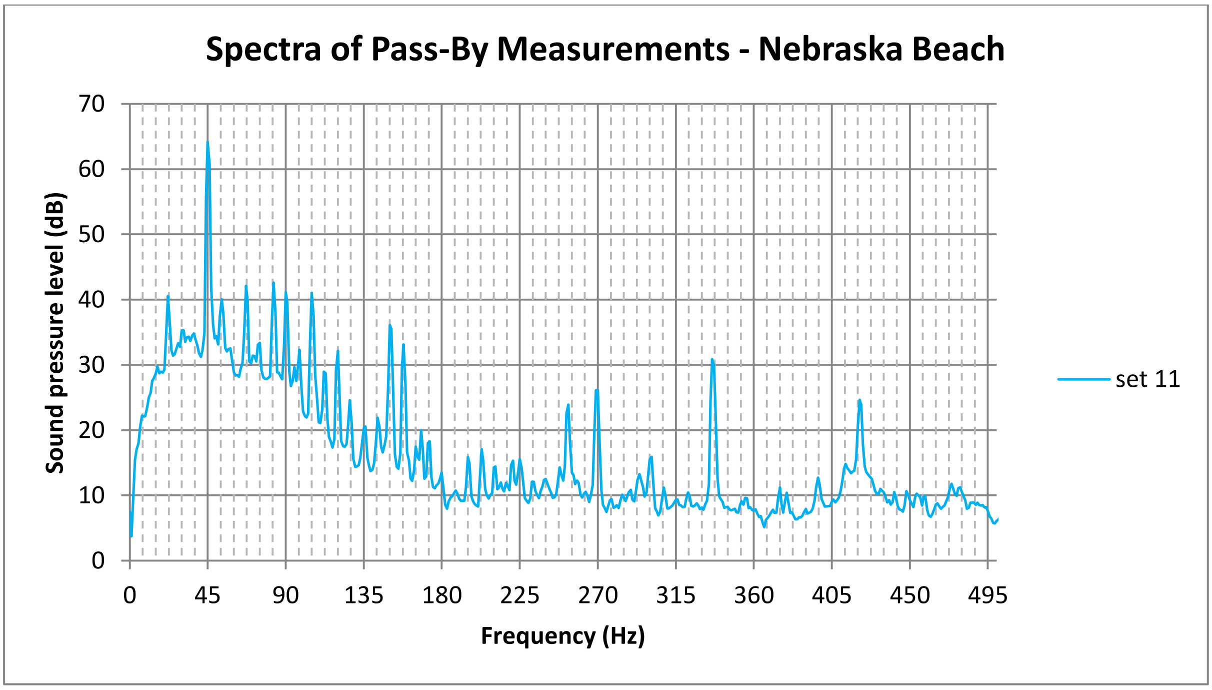

Figure 13. Vessel spectrum at Nebraska Beach

Roaring Beach

The vessel spends a significant proportion of time at the mouth of the Huon River servicing leases between Roaring Beach and Huon Island and SSE of Roaring Beach. The site was chosen as a result of complaints.

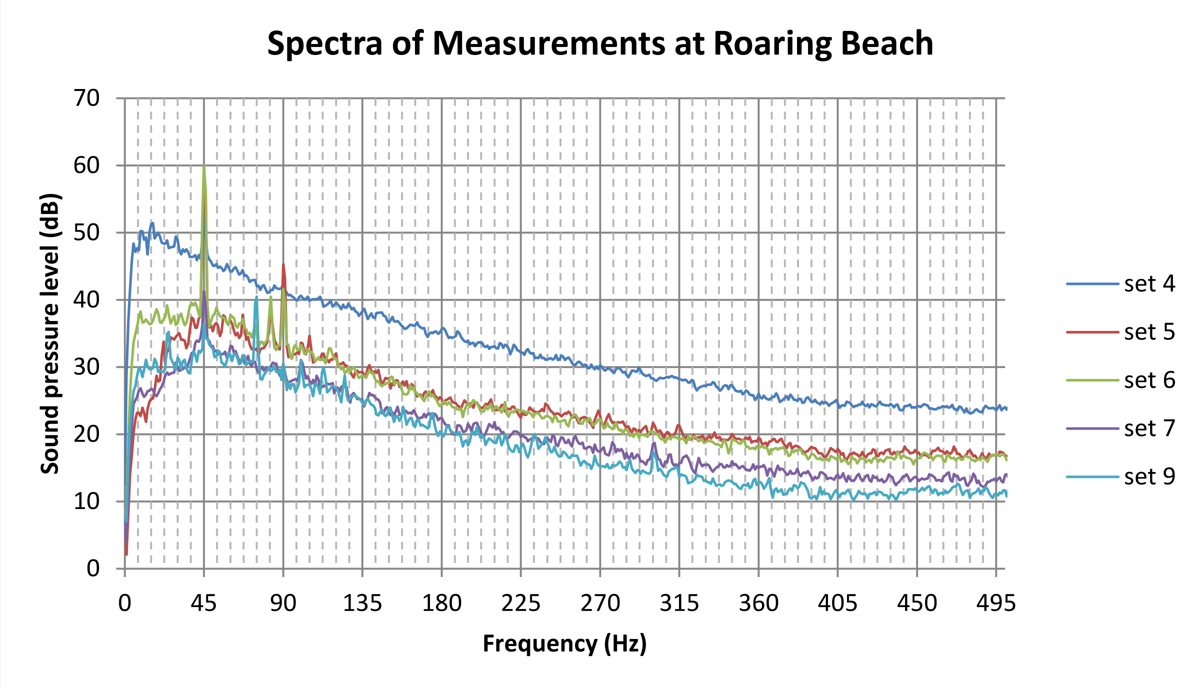

Figure 14. Vessel spectra measured at Roaring Beach

<u>Lunawanna</u>

To the south-east of the Roaring Beach leases are several lease areas at Zuidpool. The Lunawanna site was chosen as a result of complaints. At the time of the first complaint, the vessel was tracked by AIS to be about 11 km WNW of Lunawanna and it was considered surprising that the vessel could be heard consistently at such a distance.

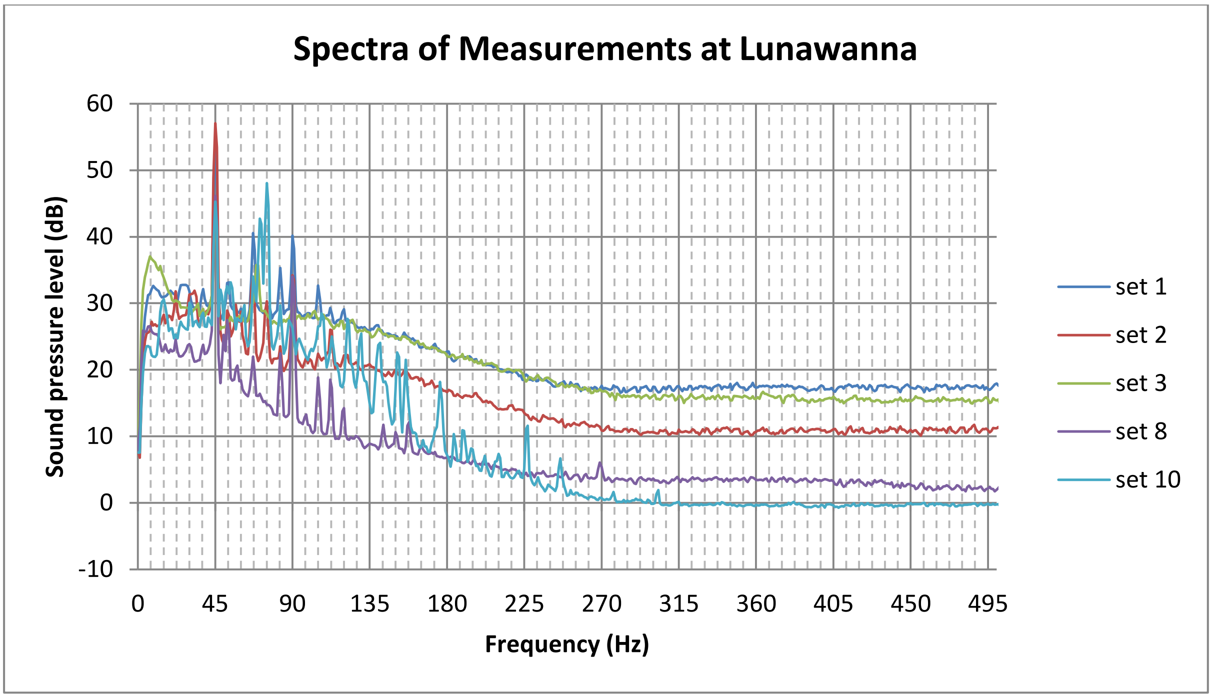

Figure 15. Vessel spectra measured at Lunawanna

<u>Petcheys Bay</u>

Various complaints regarding noise have been received from the Petcheys Bay area regarding various aspects of marine farming. Currently the nearby leases are not actively used but boat noise is still leading to complaints. A recent monitoring exercise has provided an opportunity to measure the Ronja Huon as the vessel passes on its way from Port Huon to lease areas at the mouth of the Huon River. The vessel's position was near Petcheys Bay at 7am on 10/06/2015. Characteristic tonal harmonic pattern typical of the vessel was detected between 0640H and 0655H on 10/06/2015.

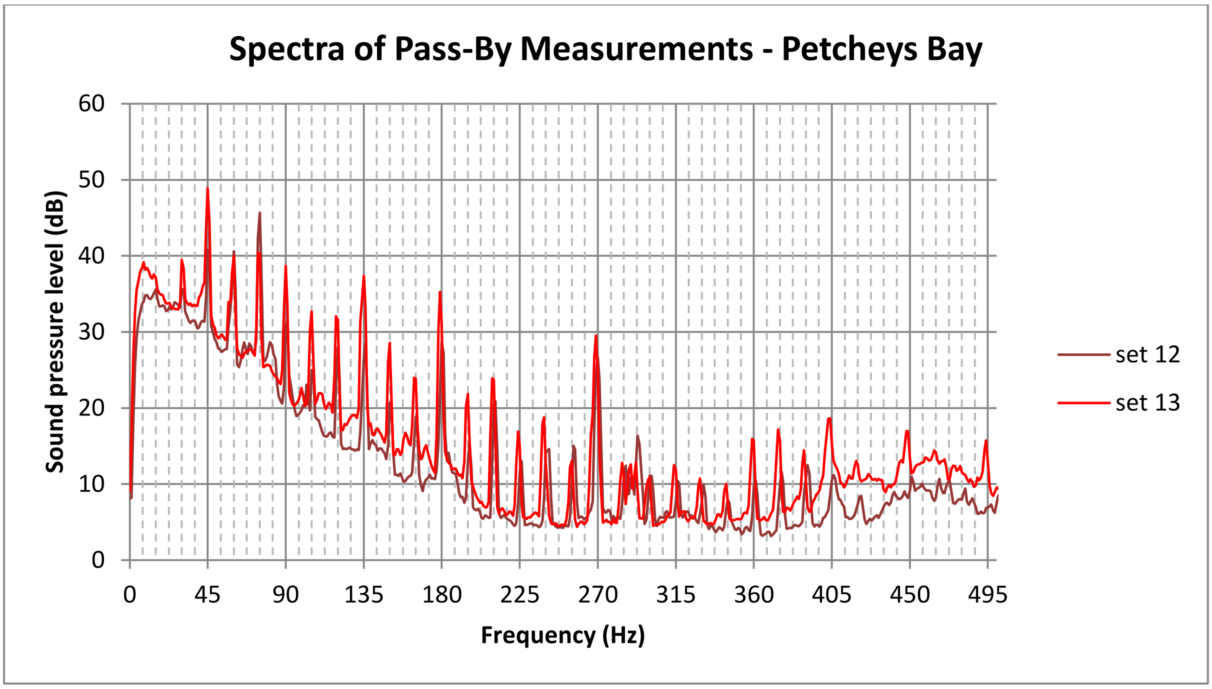

Figure 16. Vessel spectra measured at Petcheys Bay

Deep Bay

AIS records indicate that the vessel was travelling to the SE as it passed Petcheys Bay on 10/06/2015. However, no acoustic signals were detected at Deep Bay consistent with the Ronja Huon in the hours after the Petcheys Bay detection. It is interesting that noise from the vessel was not detected, given that the vessel would have been in a direct line of sight at about 6 km distance under fairly sheltered conditions.

Wattle Grove

There are two measured spectra provided for Wattle Grove, the first corresponds to the vessel heading into Port Huon and the second is for the vessel after departing the port.

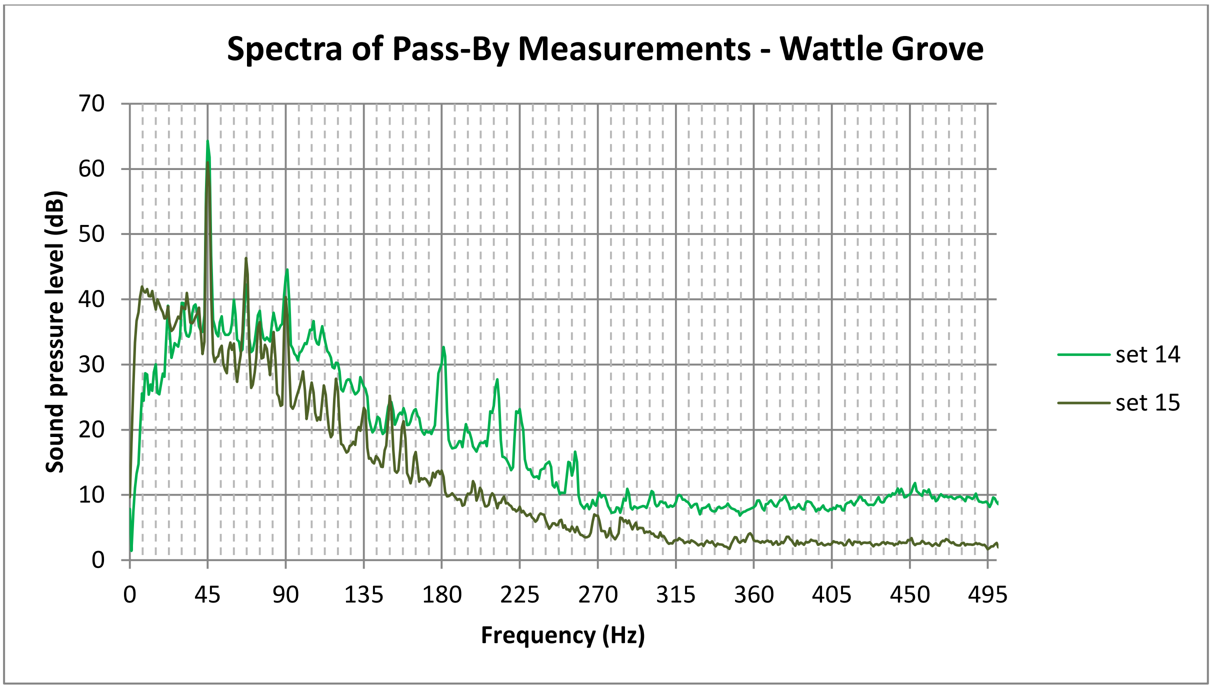

Figure 17. Vessel spectra measured at Wattle Grove

Discussion

The previous results show that aspects of the noise from the Ronja Huon can be detected at distances of many kilometres. This is most consistently achieved from the detection of the tonal peak at 45 Hz but there are also contributions from the extensive harmonic series of tones based on 7.5 Hz. Several significant variations in the harmonic series are noted, such as the Petcheys Bay results that have every second harmonic completely missing, whereas most other spectra include some peaks at 7.5 Hz separation.

The 45 Hz peak can be used as the prime measure of vessel noise. Most of the acoustic energy is in the peak and, even though it is at a pitch that is attenuated significantly by the human ear, it dominates the A-weighted level. Minor adjustments can be included, depending on distance.

The level of the 45 Hz peak for each spectrum has been plotted against the estimated distance to the vessel on **Figure 18** below. The green triangle on the figure indicates the level measured by Pitt and Sherry corresponding to 67 dB(A) at a reference distance of 25 metres. This indicates that the vessel complies with the 74 dB(A) limit specified in Regulation 8(1) of the *Environmental and Pollution Control (Miscellaneous Noise) Regulations 2014* and that the noise from the vessel reaching Wattle Grove is not unreasonable with respect to the Regulation requirements.

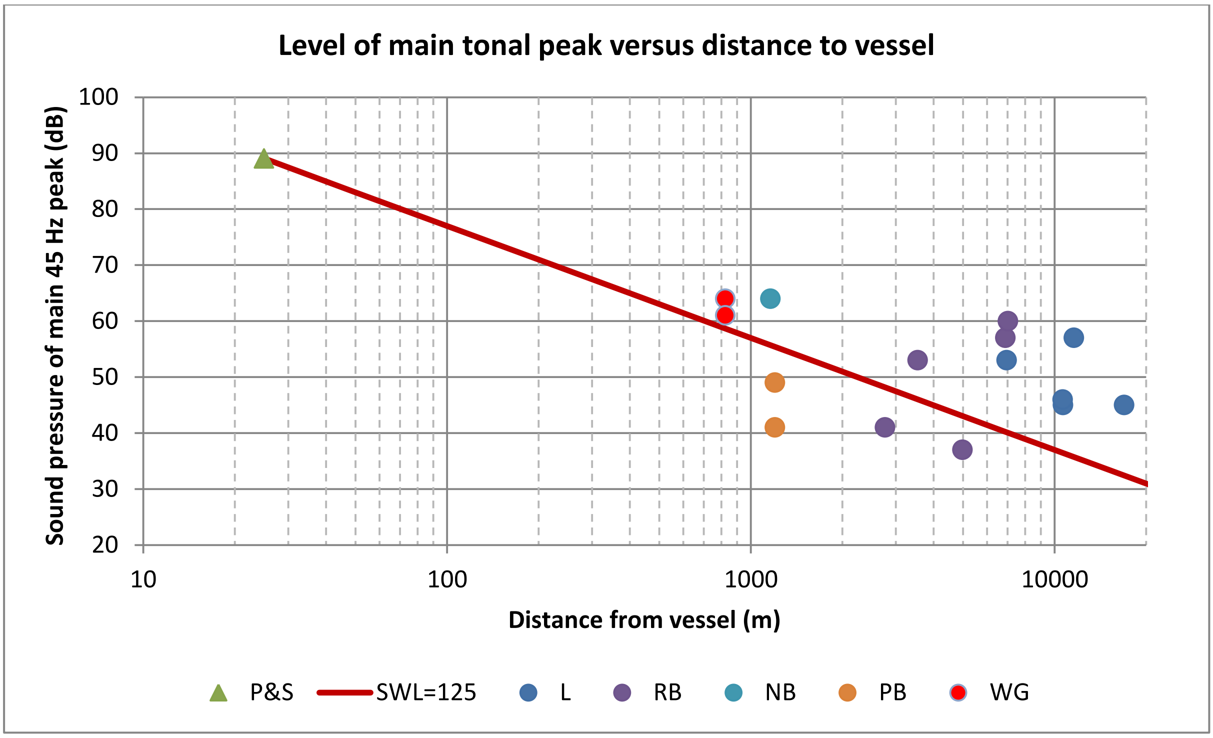

Figure 18 – Summary of results for the 45 Hz peak as a function of distance from the vessel. The straight line is the classic drop of 6 dB per doubling in distance and the green triangle point relates to a reference measurement at 25 metres. (L=Lunawanna, RB=Roaring Beach, NB=Nebraska Beach, PB=Port Huon and WG=Wattle Grove)

The results presented in figure 18 suggest there is a consistent elevation of vessel noise at Lunawanna but that the results at the other sites are reasonably consistent with the straight line representing a sound power of 125 dB and a drop of 6 dB per doubling in distance.

Since the noise from the vessel is dominated by a single tone, the propagation will be influenced significantly by reflection of sound at the sea-surface. A discussion of this effect has been included in **Appendix C**.

Appendix A – Measurement survey details

Data Set	Location	Comment	Start	Finish
S-332	Port Huon		1400h 05/02/2015	0900h 11/02/2015
S-333	Wattle Grove	With S-332	1400h 05/02/2015	1000h 11/02/2015
S-334	Port Huon		1500h 12/02/2015	0800h 20/02/2015
S-335	Wattle Grove	With S-334	1500h 12/02/2015	0800h 20/02/2015
S-339	Dennes Point		1300h 31/03/2015	0600h 08/04/2015
S-340	Lunawanna	Only 4 hr	1200h 13/04/2015	1500h 08/04/2015
S-341	Roaring Beach		1600h 01/05/2015	1200h 08/05/2015
S-342	Lunawanna		1200h 04/05/2015	1200h 11/05/2015
S-343	Roaring Beach		1200h 08/05/2015	0400h 16/05/2015
S-344	Lunawanna		1200h 11/05/2015	0400h 19/05/2015
S-347	Petcheys Bay		1100h 05/06/2015	0300h 13/06/2015
S-348	Deep Bay		1200h 05/06/2015	0400h 13/06/2015

Appendix B – Plots of complete data sets for Wattle Grave and Port Huon

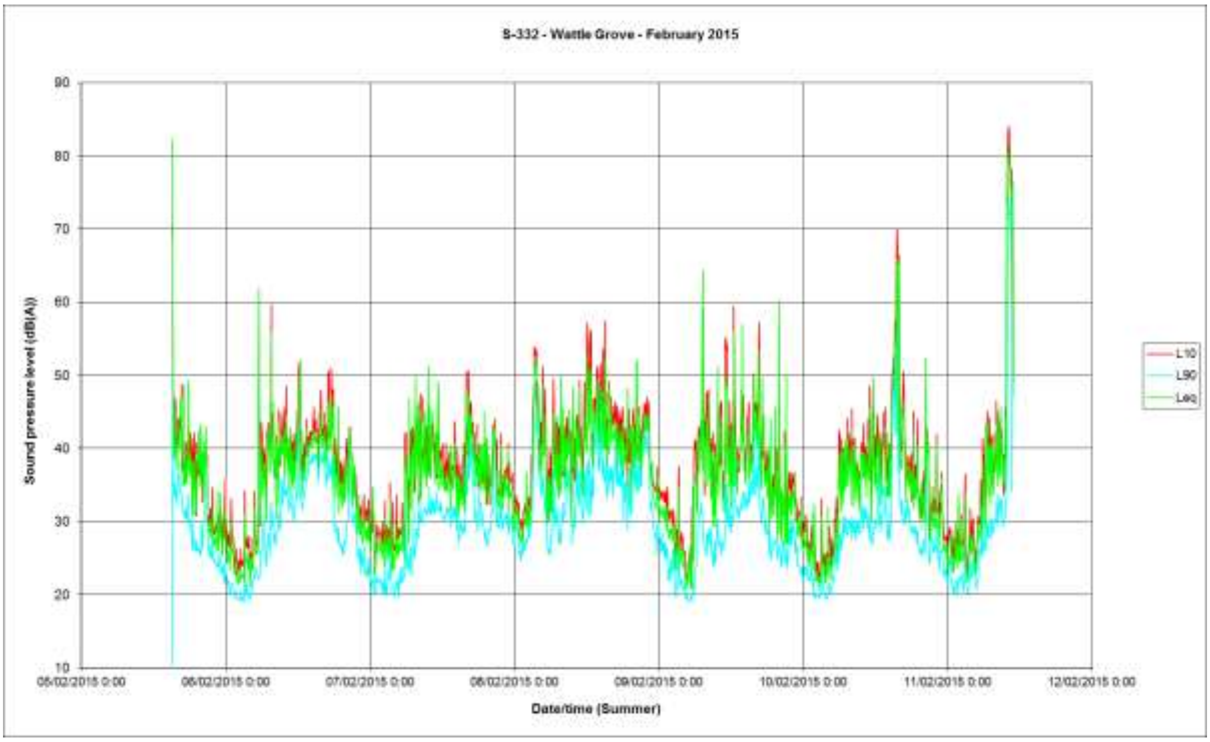

Figure B1 – Noise levels for 05 – 12 February 2015 at Wattle Grove

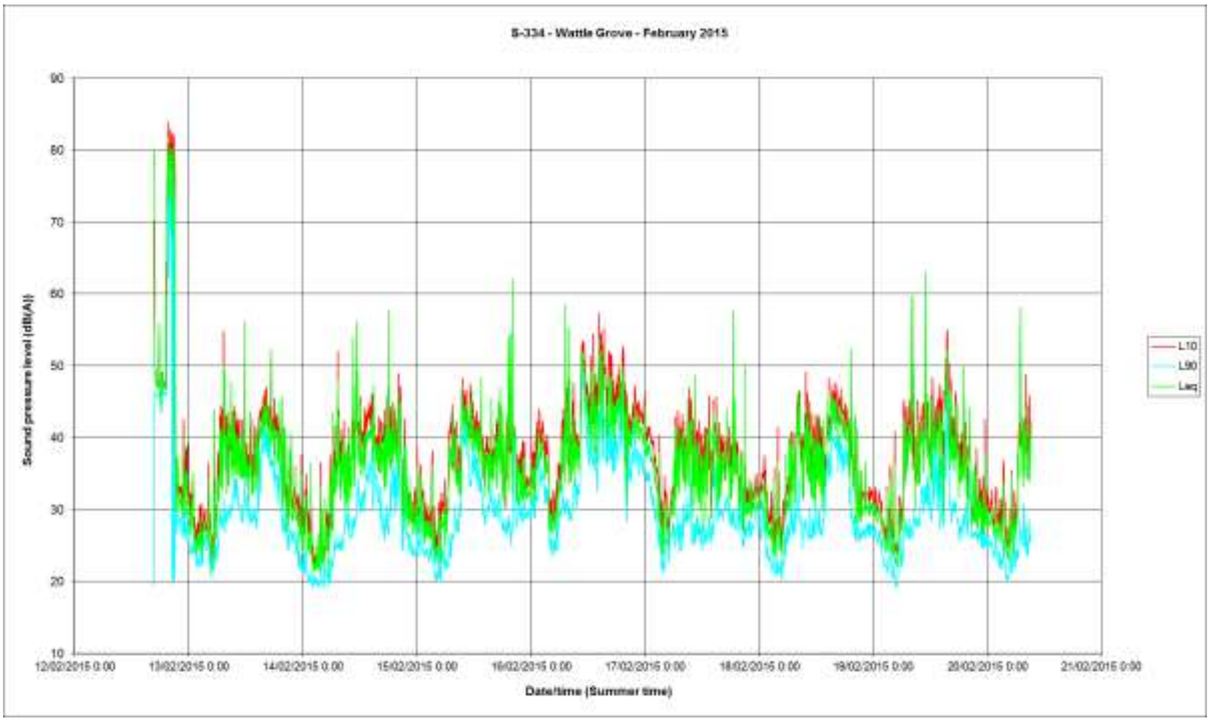

Figure B2 – Noise levels for 12 – 20 January 2015 at Wattle Grove

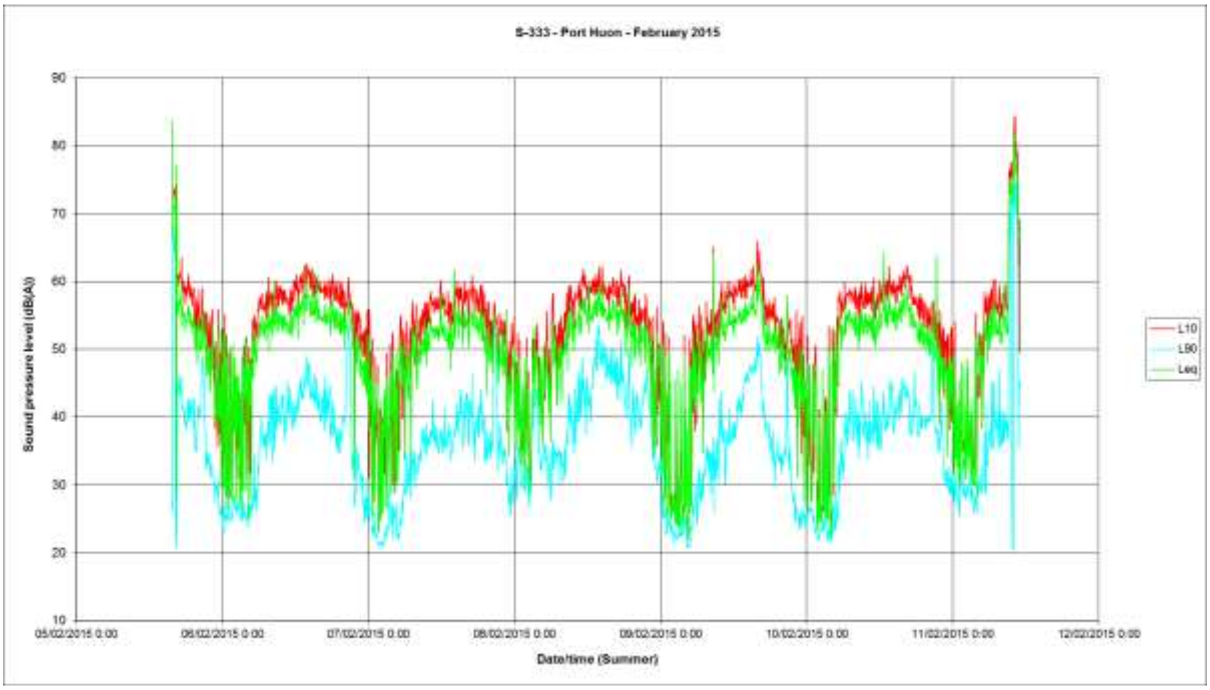

Figure B3 – Noise levels for 05 to 12 February 2015 at Port Huon

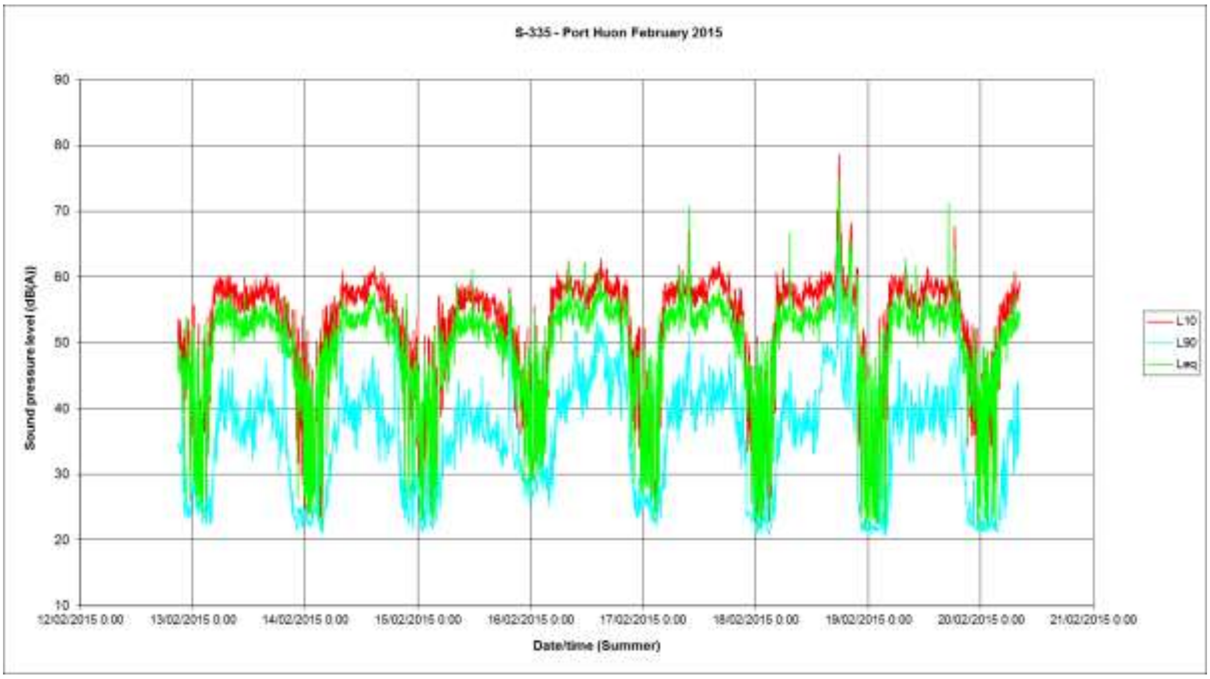

Figure B4 – Noise levels for 12 to 21 February 2015 at Port Huon

Appendix C – Enhancement from sea surface reflection

Sound emitted from the vessel may reach a measurement site by several paths. Of particular interest here is the interaction between the sound that propagates along the direct line of sight and sound that reflects off the water surface. The two pathways will result in two signals arriving at the receiver but with a slight time delay between the signals.

Because the sound from the vessel is dominated by a single tone, the addition of the two signals has some very specific properties. If the time delay between the signals is negligible, then the two signals will exhibit coherent addition which results in an increase in sound level of 6 dB. Two random signals of equal amplitude will combine incoherently to produce a resultant sound that is normally 3 dB greater that one of the signals. The increase of 6 dB only occurs when the direct and the reflected signals are in phase and this tends to be the case at low frequencies or for long propagation distances. It can also occur when the difference between the direct and reflected signal paths is an integral number of wavelengths. When the difference in the path lengths places the signals completely out of phase, the two signals will cancel.

The graph below shows the expected enhancement due to reflection at the sea surface of the sound from the vessel observed at Wattle Grove when the vessel is 825 metres away at its point of closest approach. It can be seen that the 45 Hz emission will have virtually the full 6 dB enhancement but harmonics near 170 Hz could be completely lost.

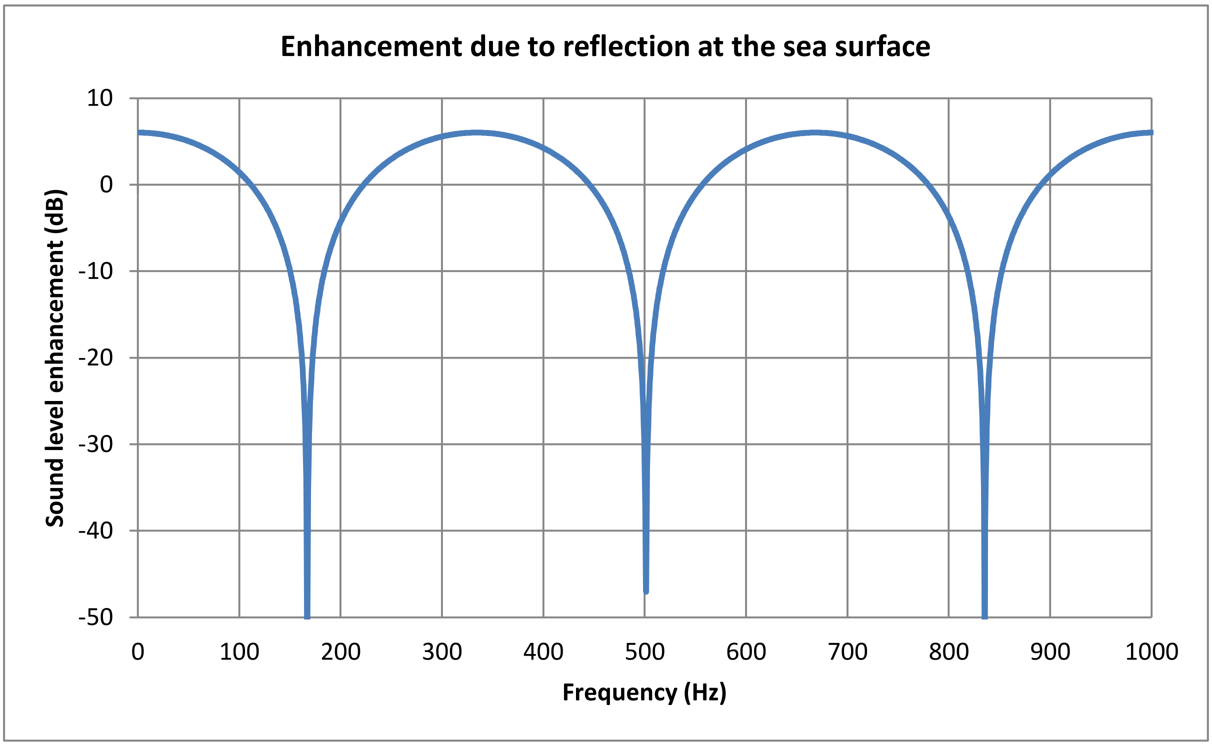

Figure C1 – Enhancement at Wattle Grove due to reflection by the sea surface

The figure shows that there is a comb filter produced by the interference where the reductions are equally spaced along the frequency axis.

The same effect produces a change in signal strength as the distance between the source and the receiving position change. The figure below shows the expected variation for a 45 Hz source 15 metres above the water surface and a receiver 28 metres above the water surface, corresponding to the geometry of the Ronja Huon and Wattle Grove.

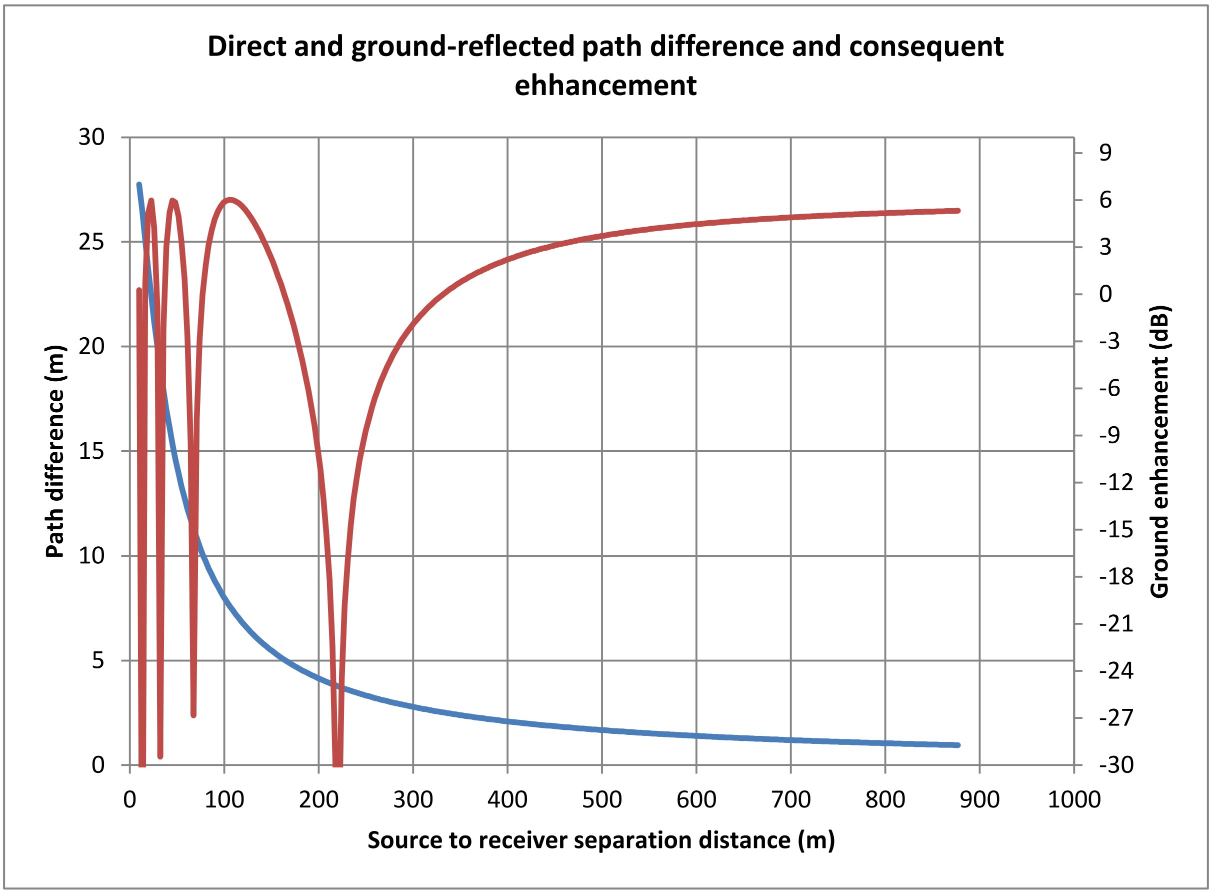

Figure C2 – Enhancement at 45 Hz as a function of source – receiver separation (for a given lateral separation, the difference in direct and reflected path is shown in blue and the corresponding enhancement is shown in red)

Note that for a frequency of 45 Hz there is no destructive interference for separation distances beyond about 300 metres. All measurements in this investigation were made at distances of 400 metres or greater from the vessel and so there will generally be a ground enhancement of 6 dB inherent in all measurements at 45 Hz. Both enhancement and destructive interference can be expected at frequencies above about 100Hz.