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Acoustic Monitoring of Lunskoye 2006

Lun-A Topsides Installation Summary Report

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Sakhalin Energy Investment Company LTD.

Acoustic Monitoring of Lunskoye 2006 Lun-A Topsides Installation Summary Report

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Acoustic Monitoring of Lunskoe 2006 LUN-A Topsides Installation

Summary Report

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Revision History

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1.0	Initial Draft, released to SEIC for review	Roberto Racca (JASCO) Kate Collins (JASCO)	19/02/2007
1.1	Added executive summary	Roberto Racca (JASCO)	21/02/2007
1.2	Addressed comments by reviewer; added analysis of sound levels over phases	Roberto Racca (JASCO) / Vladimir Nechayuck (SEIC)	22/02/2007
1.3	Addressed comments by reviewer; added some content	Roberto Racca (JASCO) / Lisanne Aerts (LGL)	26/03/2007

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EXECUTIVE SUMMARY

The Pacific Oceanological Institute (POI), Vladivostok, performed underwater acoustic measurements in the Lunskoye offshore region of Sakhalin Island during the installation of the topsides for the LUN-A platform (under construction) in summer 2006. The main objective of the acoustic monitoring was to characterize the sound levels generated by this activity so that the results could later be used in the prediction of the acoustic footprint of a similar operation at the PA-B platform location in the Piltun area, which is situated close to the western gray whale feeding grounds. The monitoring program involved four Autonomous Underwater Acoustic Recorder units deployed along a straight line from the platform site to the W-SW at ranges of 3.2, 5.1, 7.1 and 9.0 km, and yielded data for the period from 21 June to 21 July 2006 with a one-day gap due to maintenance around 5 July. The raw acoustic records were processed by POI and released as datasets that included one-minute averaged sound levels both in broadband form over various frequency ranges and in individual third-octave bands from 5 Hz to 10 kHz.

JASCO Research further analyzed these datasets to generate hourly mean levels (Leq_1hr) for broadband values over the range 20 Hz to 15 kHz, which covered all significant anthropogenic sound while excluding flow (current) noise, and to extract daily statistical properties of the broadband data in the form of the 10^{th}, 50^{th}, 70^{th} and 90^{th} percentile levels. The n^{th} percentile metric represents the dB upper limit value that includes n-percent of the original one-minute sound pressure levels over the duration of a given day. Similarly the third-octave band level data were reduced to hourly mean levels in individual bands to examine the progression of the spectral distribution. These quantities were charted as a function of time through the monitoring period so that changes in intensity and/or spectral features of the received acoustic signal could be compared to the documented sequence of construction tasks. An important aspect of the analysis was to determine, from the progression of the received signal level at the various stations, whether the sound could be realistically assumed to originate at the platform site. This was found to be the case most of the time, which allowed meaningful correlation of measured levels with listed activities at LUN-A through the majority of the work.

The activities monitored included the anchoring of the Castoro 8 (C8) crane barge in position near the LUN-A CGBS, the final floating-in and mooring of the Topside Transport Barge (TTB) between the pillars of the CGBS, the lowering of the topsides onto the base on seismic mounts, the standing off of the C8 and TTB, the retrieval of the mooring anchors, the tow-in, anchoring and connection of a flotel (floating accommodation for work crews) and the initial few days of topsides commissioning work. Captured in the monitoring period, between the topsides deployment and the flotel arrival, were a few days of pipelines related work conducted by the C8. The highest levels encountered during the topsides deployment occurred in the final phase of positioning on 23 June and reached a maximum daily 90^{th} percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). Comparable maximum daily levels were observed on 13 July during the deployment of the flotel, although activities of support vessels operating some distance from the platform may have been the cause of some of the higher readings during this later phase of the construction. To provide an overall assessment of the received sound levels associated with significant phases of the

operation, the 90th percentile received levels were also computed over the duration of complete tasks defined as sets of related activities.

INTRODUCTION

This brief report presents an analysis of noise level measurements performed using bottom mounted acoustic recording stations during installation of the topsides for Sakhalin Energy Investment Company (SEIC)'s LUN-A Concrete Gravity Based Structure (CGBS) platform in the Lunskoe region during the summer of 2006. The operations monitored included the anchoring of the Castoro 8 (C8) crane barge in position near the CGBS, the final floating-in and mooring of the Topside Transport Barge (TTB) between the pillars of the CGBS, the lowering of the topsides onto the base on seismic mounts, the standing off of the C8 and TTB, the retrieval of the mooring anchors, the tow-in, anchoring and connection of a flotel (floating accommodation for work crews) and the initial few days of topsides commissioning work. Captured in the monitoring period, between the topsides deployment and the flotel arrival, were a few days of pipelines related work conducted by the C8. An acoustics team from the Vladivostok based Pacific Oceanological Institute (POI) carried out the field measurements and pre-processed the raw acoustic waveform data. Primary goal of this monitoring operation was to characterize the level and spectral distribution of the underwater sound generated by the installation of the LUN-A platform topsides and associated activities. This information can later be used to predict the acoustic footprint of similar operations at the PA-B platform location in the Piltun area, close to the feeding grounds of the western gray whales. The report provides an overview of the acoustic recording methodology and presents the results of the analysis of sound levels measured during the various phases of the installation period at four ranges from the platform location.

ACOUSTIC MONITORING APPROACH

Sound level was monitored at four location situated along an almost exactly straight line to the W-SW from the LUN-A platform as shown in Figure 1, which also indicates the coordinates of the stations in both UTM and latitude-longitude projection as well as their depth. The ranges of the monitoring stations from the platform were 3.2, 5.1, 7.1 and 9.0 km. It is relevant to note that the range of the third station is very close to the distance between the PA-B platform site in Piltun and the nominal outer edge of the feeding area on the 20m bathymetry line. The acoustic recording devices were Autonomous Underwater Acoustic Recorders (AUARs), bottom deployed hydrophone systems with on-board acoustic signal digitizer and a hard-drive storage media with solid-state (flash) memory buffering. The flash memory buffer allowed the battery life to be extended by only spinning up the hard drive every several hours for data archiving when the buffer was full. The data acquisition was run at 16-bit depth and 30 kHz sample rate, giving a 2 Hz-15 kHz usable acoustic bandwidth. The dynamic range of acoustic levels that could be recorded was greater than 70 dB.

The monitoring stations were put in operation on 20 June 2006 and retrieved on 4 July for servicing, then redeployed on 5 July and operated until 20 to 22 July. Datasets spanning the deployment periods were provided by POI for the purpose of the present study. The datasets consisted of one-minute averaged sound levels in broadband form over various frequency ranges that included [2 Hz-15 kHz], [20 Hz-15 kHz] and [10 Hz-5 kHz], as well as in individual third-octave bands from 5 Hz to 10 kHz.

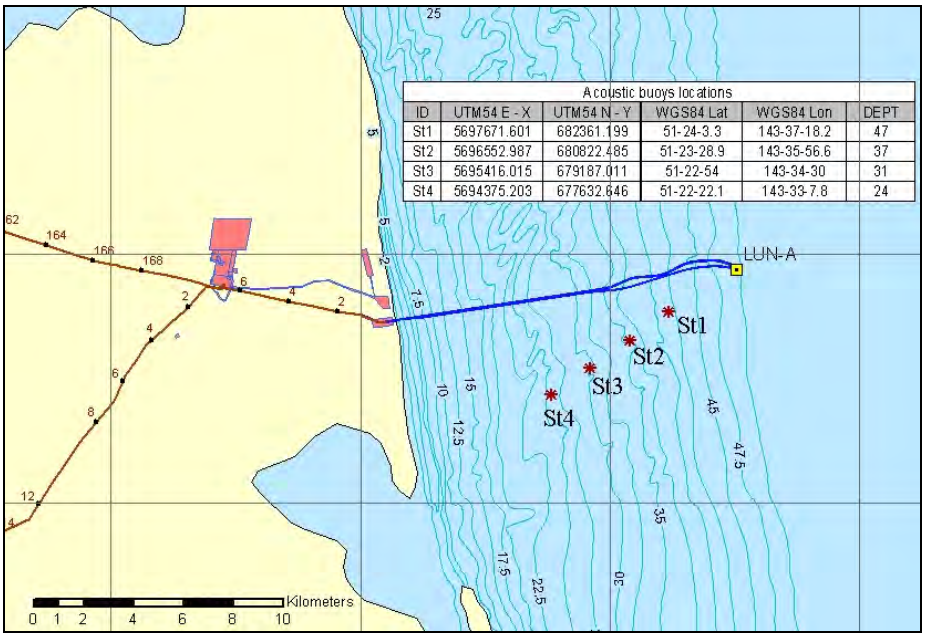

Figure 1: Map of acoustic station locations (red asterisks) and LUN-A platform position.

INSTALLATION ACTIVITIES CHRONOLOGY

The activities taking place in the LUN-A construction field were classified based on information provided by the Topsides Project Group of SEIC. The chronology that can be obtained from this information is generally limited to a daily record of the major installation tasks carried out, without finer scale detail. The time line of the operation as provided is shown in Table 1.

Table 1: Summary of daily activities in the LUN-A construction field.

DATE	ACTIVITY	REMARKS
June 20th	Deployment Of Installation Barge moorings	
June 21st	Test Ballast Systems on the Installation Barge	
June 22nd	Castoro 8 Anchored / Topsides Transport Barge pre-mooring	Installation Preworks Phase Anchor Handling
June 23rd	Lun –A Installation	Mooring Barge between GBS legs Anchor Handling
June 24th	C8 Moved to stand off position	Mooring Barge anchors retrieval Installation Post works

DATE	ACTIVITY	REMARKS
June 25th	Mooring Barge safe location ,	Preparations to tow barge from Field Installation Post works Anchor Handling
June 26th	C8 , Assistance to Pipeline Project Spool deployment	
June 27th	C8 , Assistance to Pipeline Project Spool deployment	
June 28th	C8 , Assistance to Pipeline Project Spool deployment	
June 29th	C8 , Assistance to Pipeline Project Spool deployment	
June 30th	C8 , Assistance to Pipeline Project Spool deployment	
July 01st	C8 , Assistance to Pipeline Project Spool deployment	
July 02nd	Castoro 8 anchor retrieval	
July 03rd	Castoro 8 anchor retrieval	
July 04th	Castoro 8 leaves Lun-A Field	
July 05th	Mashuk Standby	
July 06th	Mashuk Standby	
July 07th	Safe Bristolia Field Entrance	Tow Vessels , Anchor Handling
July 08th	Safe Bristolia In field	
July 09th	Safe Bristolia Stand Off location	
July 10th	Safe Bristolia run Anchors	
July 11th	Safe Bristolia run Anchors	
July 12th	Safe Bristolia Gangway Preparations	
July 13th	Safe Bristolia Gangway Preparations	
July 14th	Gangway Connection made	Platform Preparations to allow large workforce to commence planned Construction
July 15th	Platform Construction Commencement	
July 16th	Platform Construction	
July 17th	Platform Construction	
July 18th	Platform Construction	

DATE	ACTIVITY	REMARKS
July 19th	Platform Construction	
July 20th	Platform Construction	
July 21st	Platform Construction	
July 22nd	Platform Construction	

BROADBAND AND SPECTRAL SOUND LEVEL ANALYSIS

The acoustic levels dataset provided by POI was post-analyzed to generate hourly mean levels (Leq_1hr) for broadband values, and to extract daily statistical properties of the broadband data in the form of the 10th, 50th, 70th and 90th percentile levels. The nth percentile metric was computed as the dB upper limit value that includes n-percent of the original one-minute sound pressure levels over the duration of a given day. The frequency range 20 Hz to 15 kHz was chosen for the analysis of broadband levels as it covered all significant anthropogenic sound while avoiding spurious contribution from flow (current) noise at the lowest frequencies. Figure 2 to Figure 5 below present the time progression of the hourly mean level and the various daily percentile metrics over the available periods of data at the four stations.

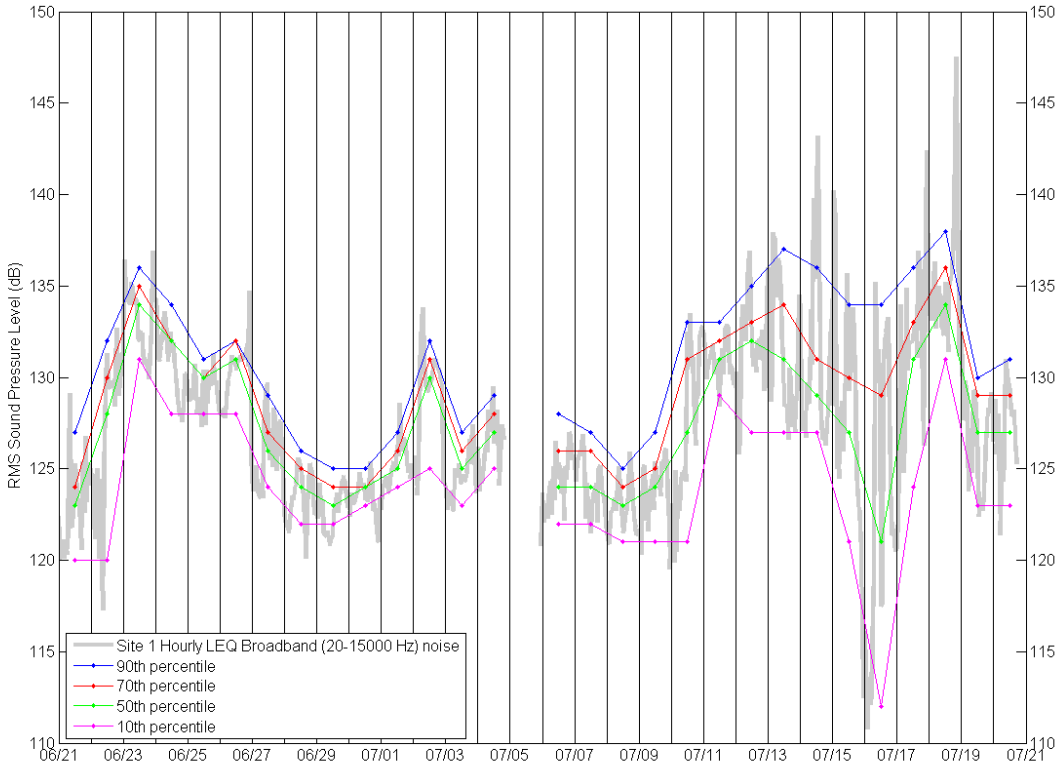

Figure 2: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 1.

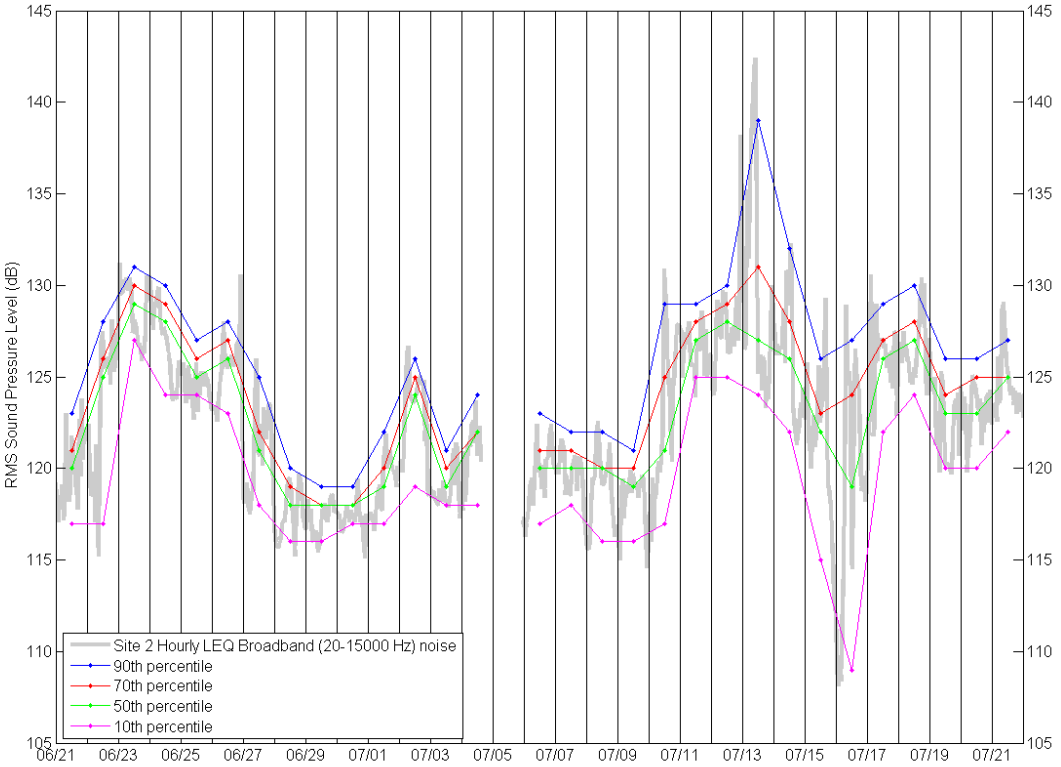

Figure 3: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 2.

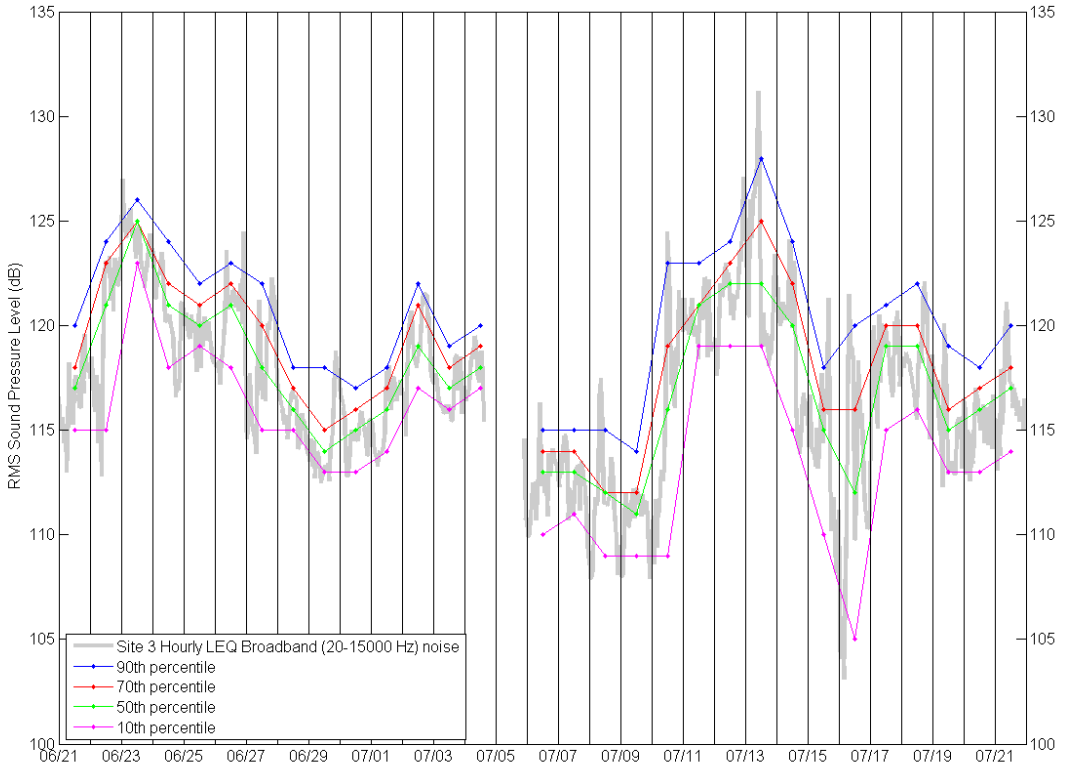

Figure 4: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 3.

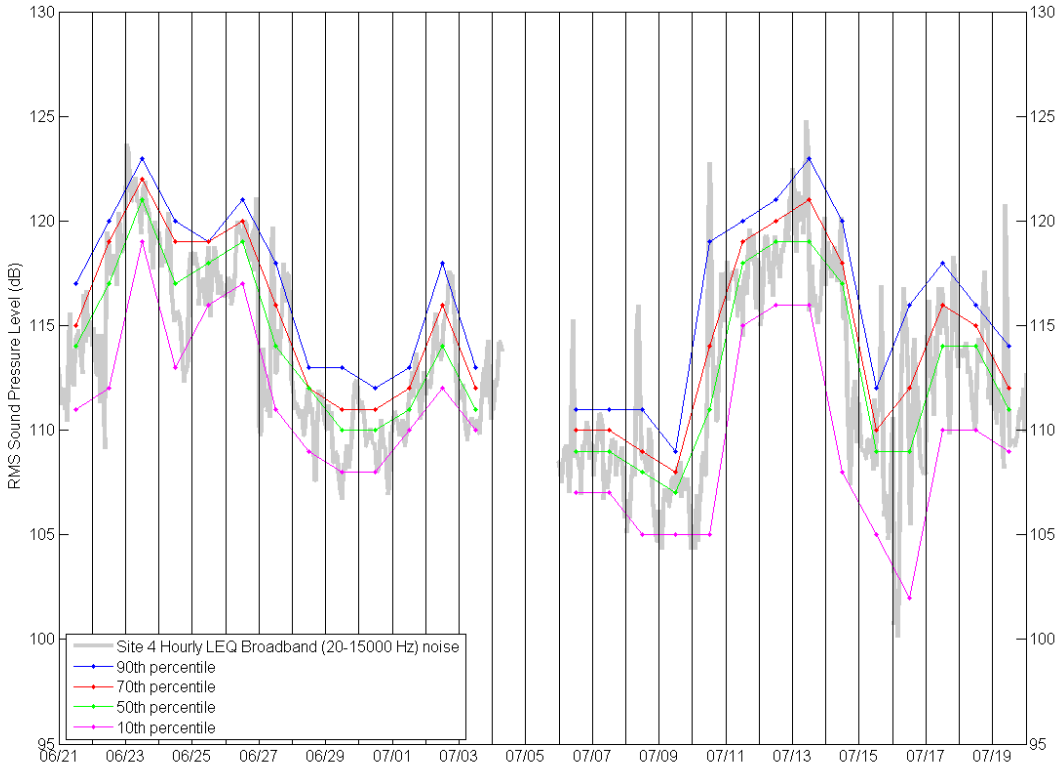

Figure 5: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 4.

Similarly the third-octave band level data from the POI datasets were reduced to hourly mean levels (Leq_1hr) in individual bands to examine the time progression of the spectral distribution. The results are presented in Figure 6 to Figure 9 in the form of sonogram plots.

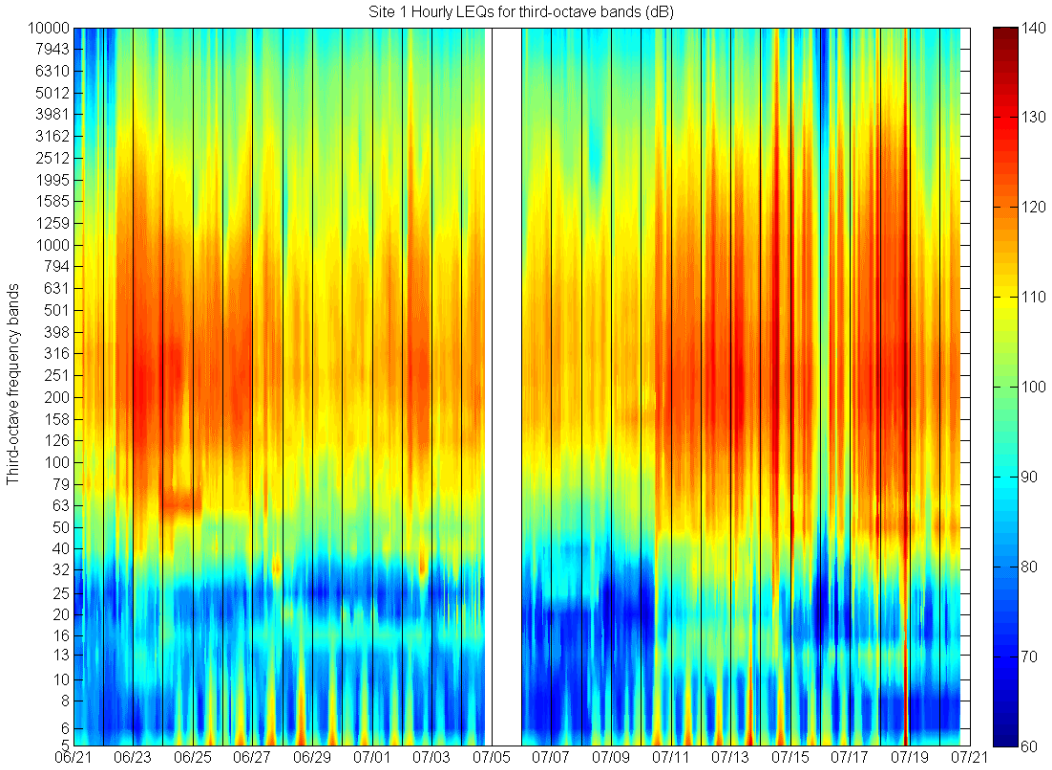

Figure 6: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 1.

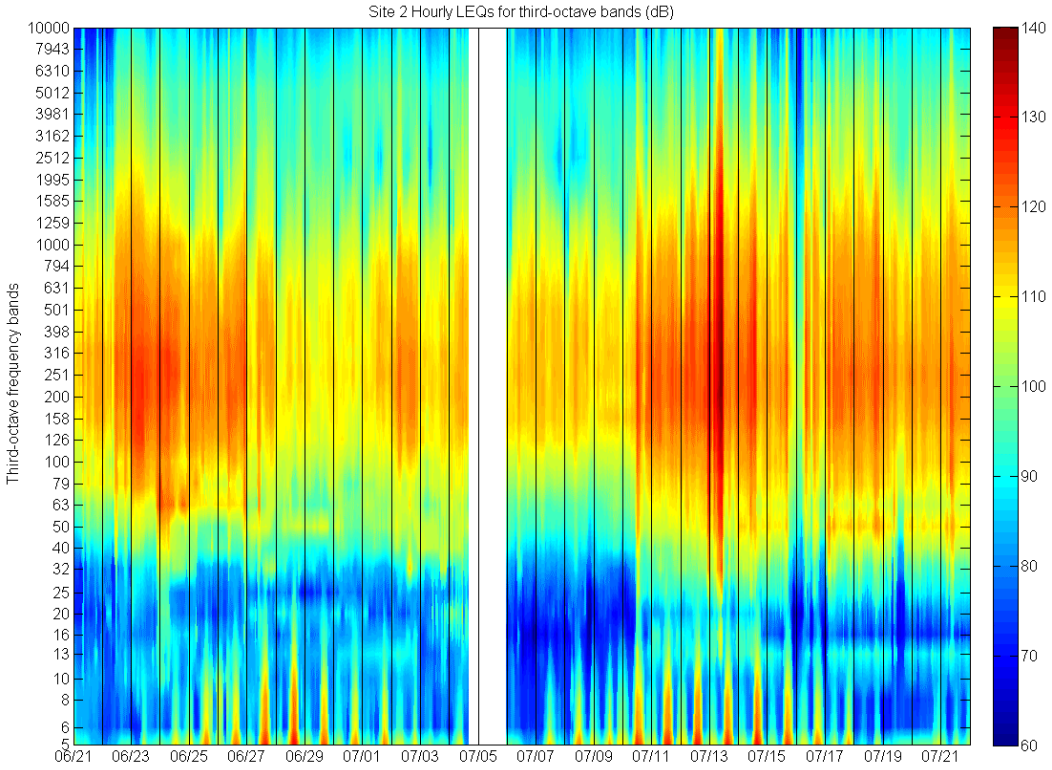

Figure 7: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 2.

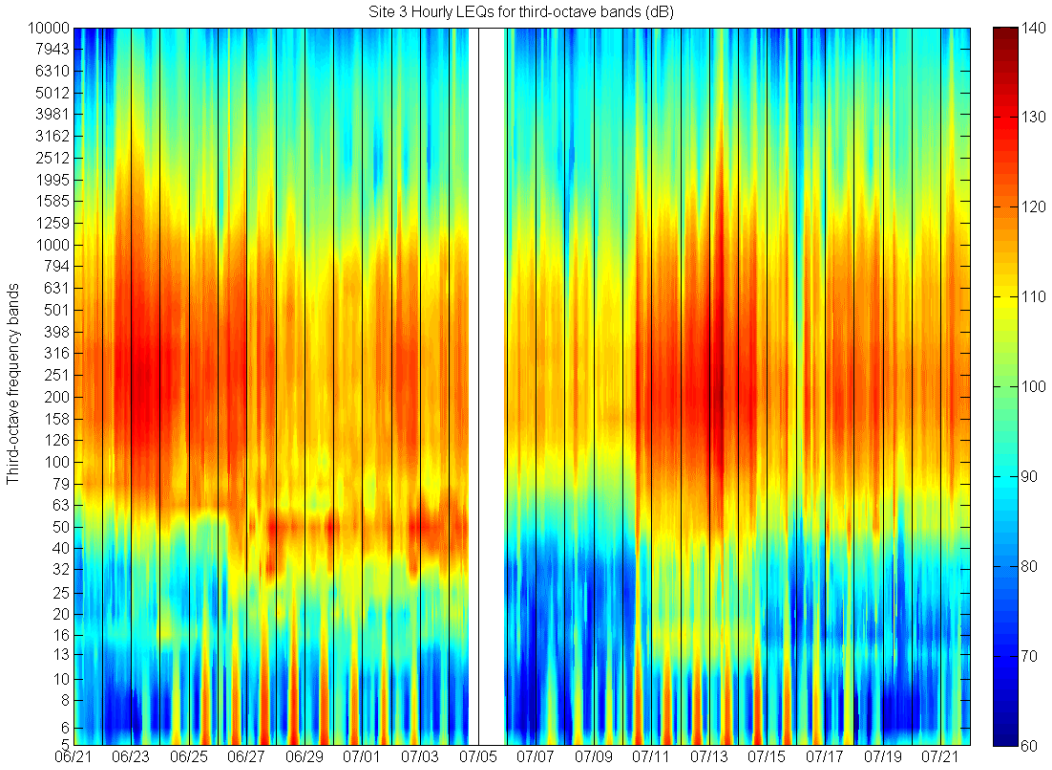

Figure 8: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 3.

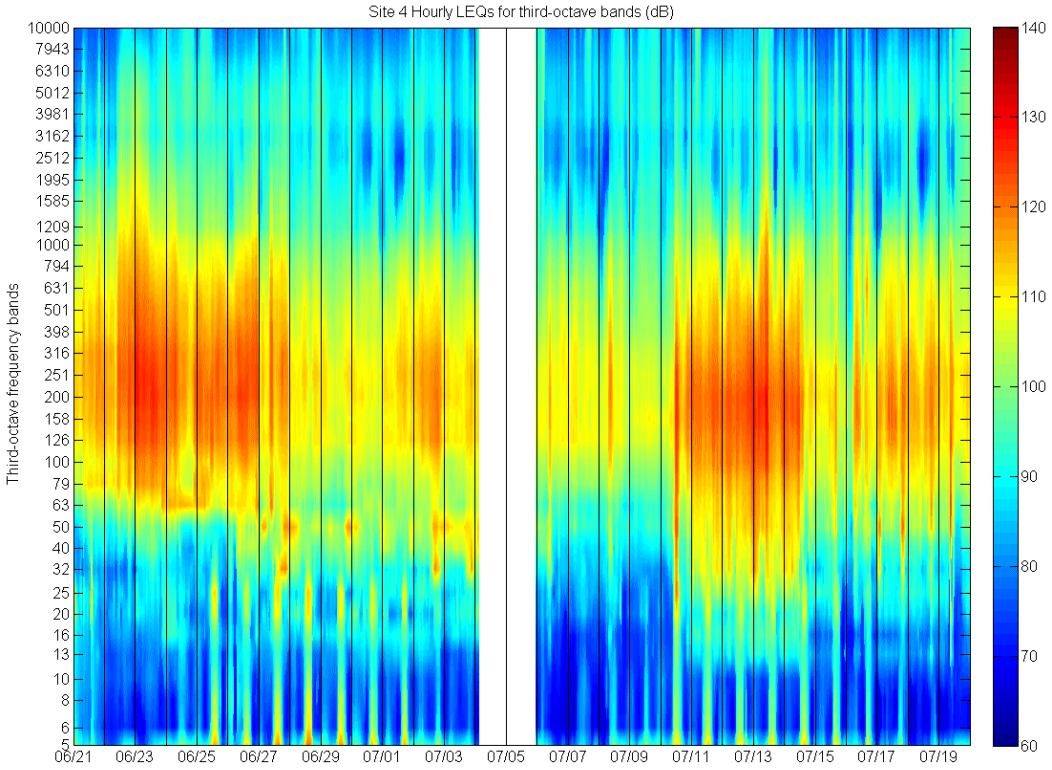

Figure 9: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 4.

CORRELATION OF SOUND LEVELS AND ACTIVITIES

To establish correlations between changes in received acoustic levels and activities taking place at the LUN-A site it is useful to plot the daily 90th percentile levels at the four monitoring stations on a common set of axes, as shown in Figure 10. In this chart the relevant phases of the operation have been put in evidence by background shading. Because the four stations are aligned along a radial from the platform site, variations in sound level due to construction work at that site should show a high degree of correlation in the four analyzed signals with a consistent decrease in overall level from Station 1 to Station 4 due to transmission loss. Any sound intensity changes that occur only at isolated stations, or relative levels that are not consistent with the transmission loss progression, are indicative of some activity taking place at a location other than LUN-A and probably associated with operations unrelated to the topsides installation.

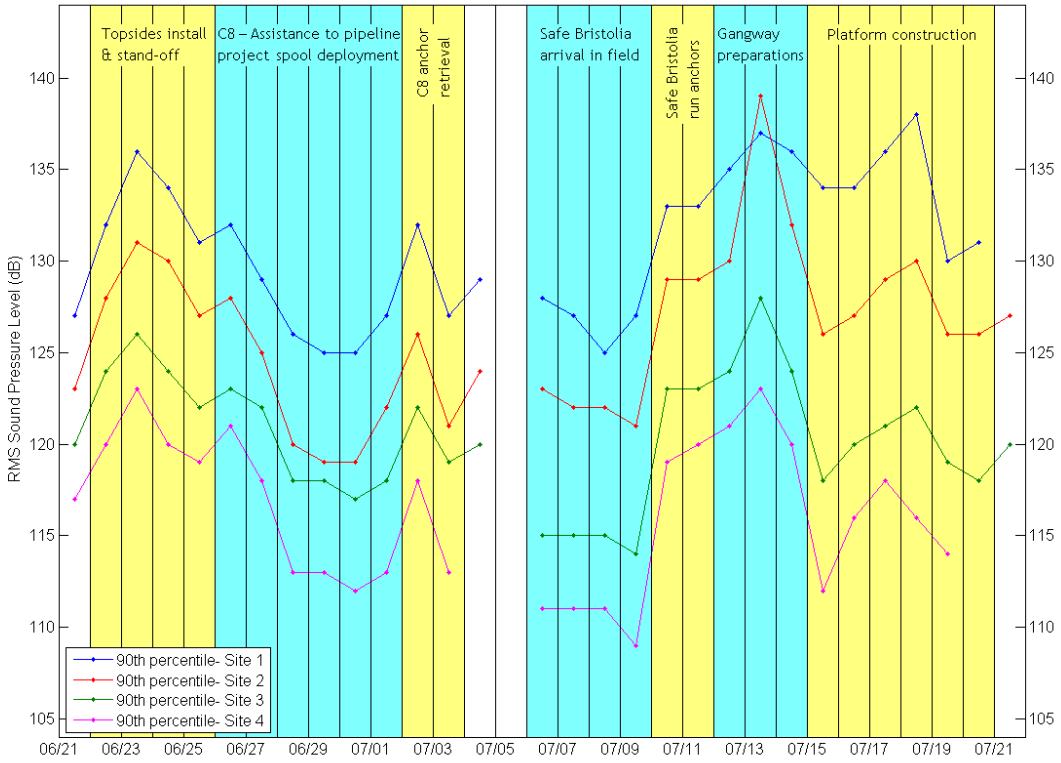

Figure 10: Time progression of daily 90th percentiles of broadband levels from LUN-A topsides installation activities as measured at Stations 1 to 4.

The correlation of the various lines in Figure 10 clearly shows that the majority of the underwater sound being recorded at the four monitoring stations originated at or in the vicinity of the LUN-A platform location. The most notable exceptions took place over the period from 27 June to 4 July, when the daily 90th percentile level at Station 3 appears markedly higher than normal for radial transmission loss in comparison to Stations 2 and 4, for the day of 13 July when the daily 90th percentile level at Station 2 actually surpasses that at Station 1, and between 15 and 18 July when Station 1 exhibits higher than normal levels relative to the others. In the case of the earliest period, the sonogram for Station 3 (Figure 8) shows a prominent signal at a frequency of about 40-50Hz that is only weakly found, if at all, at the other stations; this appears indicative of the presence of a sound source not far from Station 3 during those days. While from a purely temporal standpoint (see Table 1) this period of localized noise might be readily associated with the activities of the C8 barge and attendant anchor handling tug(s) in assistance to the pipeline project spool deployment, the operational information currently available cannot conclusively support this inference – especially given the fact that Station 3 is located several kilometres away from the pipeline route. In the case of the 13 July episode, the sonogram for Station 2 (Figure 7) shows a strong, broadband signal (extending widely across the frequency bands, from 25Hz to 5kHz) lasting a few hours in the early part of the day. The same signal is present fairly prominently over the same time period in the spectrogram for Station 3, identifying a source located not far from either of the two stations (not necessarily collinear with them) but closer to Station 2. According to the available summary no specific activity took place during

that day that could be associated with the locally elevated sound levels; the relatively short duration of the event – a few hours – may point to the transit of one or more vessels being demobilized from the construction area. Finally the operation of a vessel or vessels relatively close to Station 1 over the 15-18 July period, which is observable as occasional strong broadband features in the sonogram in Figure 6, is the cause of the elevated daily 90th percentiles at that station relative to the others.

For all other phases of the acoustic monitoring period the acoustic levels at the four stations appear consistent, on an approximate attenuation scale, with the primary sources of underwater sound being clustered near the LUN-A platform location. This assessment is made without the corroboration of a detailed analysis of the attenuation on a per-frequency basis and comparison with modelled transmission loss curves for the area, which will be performed at a later time as part of the methodology for forecasting acoustic levels from a similar operation to be conducted in summer 2007 at the PA-B platform. For the purpose of the present study it is sufficient that the measured distribution of sound levels on the whole can be realistically attributed to the documented activities at the platform, making a correlation meaningful.

The first significant activity, from a noise standpoint, in the topsides installation operation was the deployment of the TTB moorings. This task, similar in nature to its counterpart for the CGBS installation, involves the dropping of large mooring anchors on a predefined pattern around the platform site and their pre-tensioning by means of tugs. It has the potential for generating short but relatively intense periods of sound emission. This phase of the work ended on the 20th of June and was therefore not captured by full-day acoustic monitoring coverage which only began the following day. Acoustic studies of CGBS installations at LUN-A and PA-B, however, have shown that maximum sound levels from mooring deployment are comparable or lower than levels generated in the subsequent positioning phase; furthermore, the present monitoring did include a later period of mooring anchors deployment for the flotel. It can therefore be said with confidence that sufficient information is available to allow the forecasting of acoustic levels for mooring deployment in the upcoming PA-B topsides operation. The subsequent phase was the anchoring of the C8 in position near the CGBS and the final tow-in, connection and positioning of the TTB – culminating with the installation of the topsides on 23 June. From an acoustic standpoint this progression resulted in increasing levels to a maximum daily 90th percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). The activities over the subsequent two days (24th and 25th), which included removal of the C8 and TTB to stand off positions, retrieval of TTB mooring anchors and other related operations, generated lower daily noise levels than the topsides installation itself; in fact, with the exception of a small rise on 26 June at all stations, the levels dropped steadily over the following days to a minimum daily 90th percentile of 125 dB re µPa at Station 1 and 112 dB re µPa at Station 4 on the 30th. As previously mentioned the levels at Station 3 over this period were higher than would have been expected for a sound distribution centred at LUN-A due to some not better defined local source. Starting on 1 July the levels at all stations again started rising – arguably as a consequence of the onset of removal operations of the C8 from the field – and culminated at a maximum daily 90th percentile of 132 dB re µPa at Station 1 and 118 dB re µPa at Station 4 on 2 July, when retrieval of the C8 anchors took place. Following a maintenance hiatus of about one day in the monitoring around 5 July, the measured levels

remained low (daily 90th percentiles around 127 dB re µPa at Station 1 and 110 dB re µPa at Station 4) as the flotel Safe Bristolia approached the field but rose sharply on 10 July as the anchors for mooring the flotel started being run into position. During the two days of anchors running (10th and 11th) the daily 90th percentiles were 133 dB re µPa at Station 1 and about 120 dB re µPa at Station 4; they subsequently rose further to a maximum of 137 dB re µPa at Station 1 and 123 dB re µPa at Station 4 on 13 July in the course of apparently routine flotel gangway preparations, but possibly due to undocumented support vessel activities. Following a trough in the levels reaching a minimum on 15 July, there is a further surge by a few dB in the daily 90th percentiles culminating on 18 July – with no correlation with a documented construction task. Here as well the activities of support vessels at some distance from LUN-A are the likely source of variation in daily acoustic levels, especially in light of what was said earlier regarding the elevated readings at Station 1 during this period.

ASSESSMENT OF SOUND LEVELS OVER OPERATION PHASES

To provide an overall assessment of the received sound levels associated with significant phases of the operation, 90th percentile levels were also computed over the duration of complete tasks and are shown in Table 2. The starred entries denote periods over which the received sound at a station may have been dominated by a nearby source for at least part of the time.

Table 2: 90th percentile sound levels at each station over the monitored operation phases.

Operation Phase	**90th %ile level at Station 1 (dB re µPa)**	**90th %ile level at Station 2 (dB re µPa)**	**90th %ile level at Station 3 (dB re µPa)**	**90th %ile level at Station 4 (dB re µPa)**
Topsides install & stand-off	135	130	125	122
C8 – assistance to pipeline project spool deployment	131	126	121	119
C8 anchor retrieval	131	125	121*	117
Safe Bristolia arrival in field	127	122	115	111
Safe Bristolia run anchors	133	129	123	119
Gangway preparations	137	134*	126	122
Platform construction	136*	128	120	116

It should be noted that the phases in the table above, which correspond to the shaded background bands in Figure 10, may include more than one of the individual activities identified in Table 1. The phase denoted as "Topsides install & stand-off", for example, includes the mooring of the C8 and TTB, the float-over and lowering of the topsides onto the base, and the standing off of the two barges from the platform site. This logical grouping provides a sound level assessment on a whole-task basis that complements the shorter-term metrics presented earlier.

CONCLUSION

Acoustic level recordings were performed by four autonomous monitoring stations deployed along a straight line to the W-SW from the LUN-A platform at ranges of about 3, 5, 7 and 9km. The monitoring period covered the installation of the topsides on the existing CGBS and subsequent mooring of a flotel in support of platform commissioning activities. With some documented exceptions the underwater sound recorded was found to originate mostly at the platform site, which allowed correlation of measured levels with listed activities from operational records and which will enable the use of these data as a basis to predict the acoustic footprint for similar operations to be conducted at the PA-B platform location in the Piltun area. Both broadband level plots (including hourly averages and daily percentiles) and sonograms in third-octave bands were generated in post-analysis of the recordings. The highest levels encountered during the topsides deployment occurred in the final phase of positioning on 23 June and reached a maximum daily 90^{th} percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). Comparable maximum daily levels were observed on 13 July during the deployment of the flotel, although activities of support vessels operating some distance from the platform may have been the cause of some of the higher readings during this later phase of the construction.

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Authors:

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The Pacific Oceanological Institute (POI), Vladivostok, performed underwater acoustic measurements in the Lunskoye offshore region of Sakhalin Island during the installation of the topsides for the LUN-A platform (under construction) in summer 2006. The main objective of the acoustic monitoring was to characterize the sound levels generated by this activity so that the results could later be used in the prediction of the acoustic footprint of a similar operation at the PA-B platform location in the Piltun area, which is situated close to the western gray whale feeding grounds. The monitoring program involved four Autonomous Underwater Acoustic Recorder units deployed along a straight line from the platform site to the W-SW at ranges of 3.2, 5.1, 7.1 and 9.0 km, and yielded data for the period from 21 June to 21 July 2006 with a one-day gap due to maintenance around 5 July. The raw acoustic records were processed by POI and released as datasets that included one-minute averaged sound levels both in broadband form over various frequency ranges and in individual third-octave bands from 5 Hz to 10 kHz.

JASCO Research further analyzed these datasets to generate hourly mean levels (Leq_1hr) for broadband values over the range 20 Hz to 15 kHz, which covered all significant anthropogenic sound while excluding flow (current) noise, and to extract daily statistical properties of the broadband data in the form of the 10^{th}, 50^{th}, 70^{th} and 90^{th} percentile levels. The n^{th} percentile metric represents the dB upper limit value that includes n-percent of the original one-minute sound pressure levels over the duration of a given day. Similarly the third-octave band level data were reduced to hourly mean levels in individual bands to examine the progression of the spectral distribution. These quantities were charted as a function of time through the monitoring period so that changes in intensity and/or spectral features of the received acoustic signal could be compared to the documented sequence of construction tasks. An important aspect of the analysis was to determine, from the progression of the received signal level at the various stations, whether the sound could be realistically assumed to originate at the platform site. This was found to be the case most of the time, which allowed meaningful correlation of measured levels with listed activities at LUN-A through the majority of the work.

The activities monitored included the anchoring of the Castoro 8 (C8) crane barge in position near the LUN-A CGBS, the final floating-in and mooring of the Topside Transport Barge (TTB) between the pillars of the CGBS, the lowering of the topsides onto the base on seismic mounts, the standing off of the C8 and TTB, the retrieval of the mooring anchors, the tow-in, anchoring and connection of a flotel (floating accommodation for work crews) and the initial few days of topsides commissioning work. Captured in the monitoring period, between the topsides deployment and the flotel arrival, were a few days of pipelines related work conducted by the C8. The highest levels encountered during the topsides deployment occurred in the final phase of positioning on 23 June and reached a maximum daily 90^{th} percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). Comparable maximum daily levels were observed on 13 July during the deployment of the flotel, although activities of support vessels operating some distance from the platform may have been the cause of some of the higher readings during this later phase of the construction. To provide an overall assessment of the received sound levels associated with significant phases of the

operation, the 90th percentile received levels were also computed over the duration of complete tasks defined as sets of related activities.

INTRODUCTION

This brief report presents an analysis of noise level measurements performed using bottom mounted acoustic recording stations during installation of the topsides for Sakhalin Energy Investment Company (SEIC)'s LUN-A Concrete Gravity Based Structure (CGBS) platform in the Lunskoe region during the summer of 2006. The operations monitored included the anchoring of the Castoro 8 (C8) crane barge in position near the CGBS, the final floating-in and mooring of the Topside Transport Barge (TTB) between the pillars of the CGBS, the lowering of the topsides onto the base on seismic mounts, the standing off of the C8 and TTB, the retrieval of the mooring anchors, the tow-in, anchoring and connection of a flotel (floating accommodation for work crews) and the initial few days of topsides commissioning work. Captured in the monitoring period, between the topsides deployment and the flotel arrival, were a few days of pipelines related work conducted by the C8. An acoustics team from the Vladivostok based Pacific Oceanological Institute (POI) carried out the field measurements and pre-processed the raw acoustic waveform data. Primary goal of this monitoring operation was to characterize the level and spectral distribution of the underwater sound generated by the installation of the LUN-A platform topsides and associated activities. This information can later be used to predict the acoustic footprint of similar operations at the PA-B platform location in the Piltun area, close to the feeding grounds of the western gray whales. The report provides an overview of the acoustic recording methodology and presents the results of the analysis of sound levels measured during the various phases of the installation period at four ranges from the platform location.

ACOUSTIC MONITORING APPROACH

Sound level was monitored at four location situated along an almost exactly straight line to the W-SW from the LUN-A platform as shown in Figure 1, which also indicates the coordinates of the stations in both UTM and latitude-longitude projection as well as their depth. The ranges of the monitoring stations from the platform were 3.2, 5.1, 7.1 and 9.0 km. It is relevant to note that the range of the third station is very close to the distance between the PA-B platform site in Piltun and the nominal outer edge of the feeding area on the 20m bathymetry line. The acoustic recording devices were Autonomous Underwater Acoustic Recorders (AUARs), bottom deployed hydrophone systems with on-board acoustic signal digitizer and a hard-drive storage media with solid-state (flash) memory buffering. The flash memory buffer allowed the battery life to be extended by only spinning up the hard drive every several hours for data archiving when the buffer was full. The data acquisition was run at 16-bit depth and 30 kHz sample rate, giving a 2 Hz-15 kHz usable acoustic bandwidth. The dynamic range of acoustic levels that could be recorded was greater than 70 dB.

The monitoring stations were put in operation on 20 June 2006 and retrieved on 4 July for servicing, then redeployed on 5 July and operated until 20 to 22 July. Datasets spanning the deployment periods were provided by POI for the purpose of the present study. The datasets consisted of one-minute averaged sound levels in broadband form over various frequency ranges that included [2 Hz-15 kHz], [20 Hz-15 kHz] and [10 Hz-5 kHz], as well as in individual third-octave bands from 5 Hz to 10 kHz.

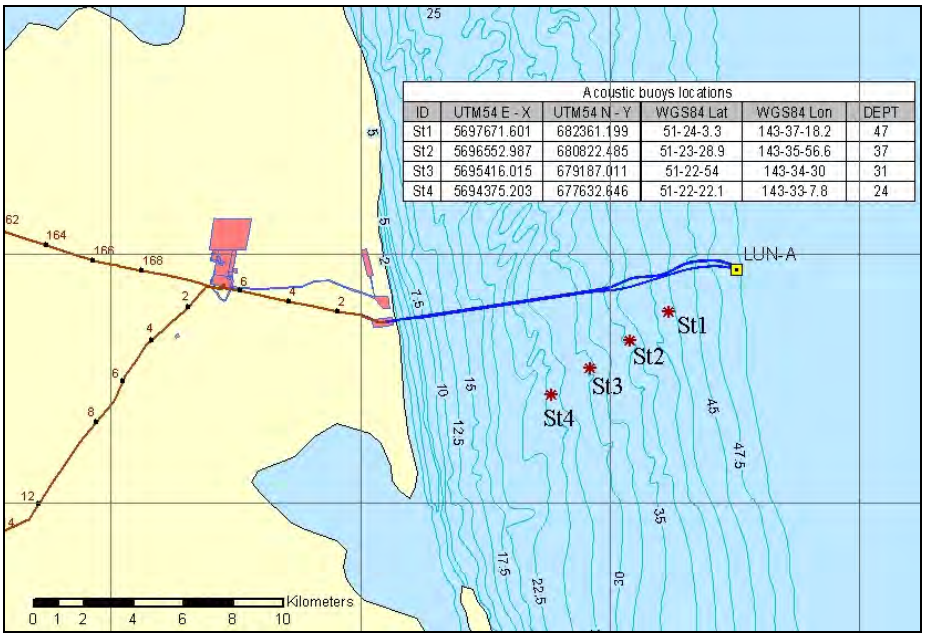

Figure 1: Map of acoustic station locations (red asterisks) and LUN-A platform position.

INSTALLATION ACTIVITIES CHRONOLOGY

The activities taking place in the LUN-A construction field were classified based on information provided by the Topsides Project Group of SEIC. The chronology that can be obtained from this information is generally limited to a daily record of the major installation tasks carried out, without finer scale detail. The time line of the operation as provided is shown in Table 1.

Table 1: Summary of daily activities in the LUN-A construction field.

DATE	ACTIVITY	REMARKS
June 20th	Deployment Of Installation Barge moorings	
June 21st	Test Ballast Systems on the Installation Barge	
June 22nd	Castoro 8 Anchored / Topsides Transport Barge pre-mooring	Installation Preworks Phase Anchor Handling
June 23rd	Lun –A Installation	Mooring Barge between GBS legs Anchor Handling
June 24th	C8 Moved to stand off position	Mooring Barge anchors retrieval Installation Post works

DATE	ACTIVITY	REMARKS
June 25th	Mooring Barge safe location ,	Preparations to tow barge from Field Installation Post works Anchor Handling
June 26th	C8 , Assistance to Pipeline Project Spool deployment	
June 27th	C8 , Assistance to Pipeline Project Spool deployment	
June 28th	C8 , Assistance to Pipeline Project Spool deployment	
June 29th	C8 , Assistance to Pipeline Project Spool deployment	
June 30th	C8 , Assistance to Pipeline Project Spool deployment	
July 01st	C8 , Assistance to Pipeline Project Spool deployment	
July 02nd	Castoro 8 anchor retrieval	
July 03rd	Castoro 8 anchor retrieval	
July 04th	Castoro 8 leaves Lun-A Field	
July 05th	Mashuk Standby	
July 06th	Mashuk Standby	
July 07th	Safe Bristolia Field Entrance	Tow Vessels , Anchor Handling
July 08th	Safe Bristolia In field	
July 09th	Safe Bristolia Stand Off location	
July 10th	Safe Bristolia run Anchors	
July 11th	Safe Bristolia run Anchors	
July 12th	Safe Bristolia Gangway Preparations	
July 13th	Safe Bristolia Gangway Preparations	
July 14th	Gangway Connection made	Platform Preparations to allow large workforce to commence planned Construction
July 15th	Platform Construction Commencement	
July 16th	Platform Construction	
July 17th	Platform Construction	
July 18th	Platform Construction	

DATE	ACTIVITY	REMARKS
July 19th	Platform Construction	
July 20th	Platform Construction	
July 21st	Platform Construction	
July 22nd	Platform Construction	

BROADBAND AND SPECTRAL SOUND LEVEL ANALYSIS

The acoustic levels dataset provided by POI was post-analyzed to generate hourly mean levels (Leq_1hr) for broadband values, and to extract daily statistical properties of the broadband data in the form of the 10th, 50th, 70th and 90th percentile levels. The nth percentile metric was computed as the dB upper limit value that includes n-percent of the original one-minute sound pressure levels over the duration of a given day. The frequency range 20 Hz to 15 kHz was chosen for the analysis of broadband levels as it covered all significant anthropogenic sound while avoiding spurious contribution from flow (current) noise at the lowest frequencies. Figure 2 to Figure 5 below present the time progression of the hourly mean level and the various daily percentile metrics over the available periods of data at the four stations.

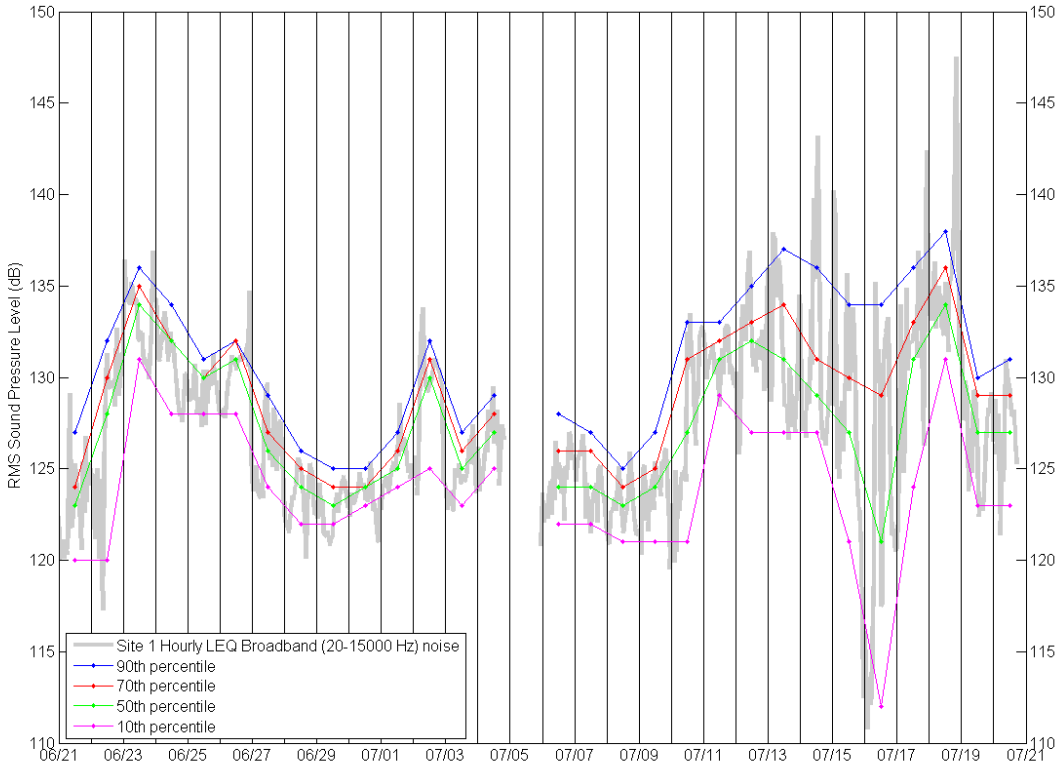

Figure 2: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 1.

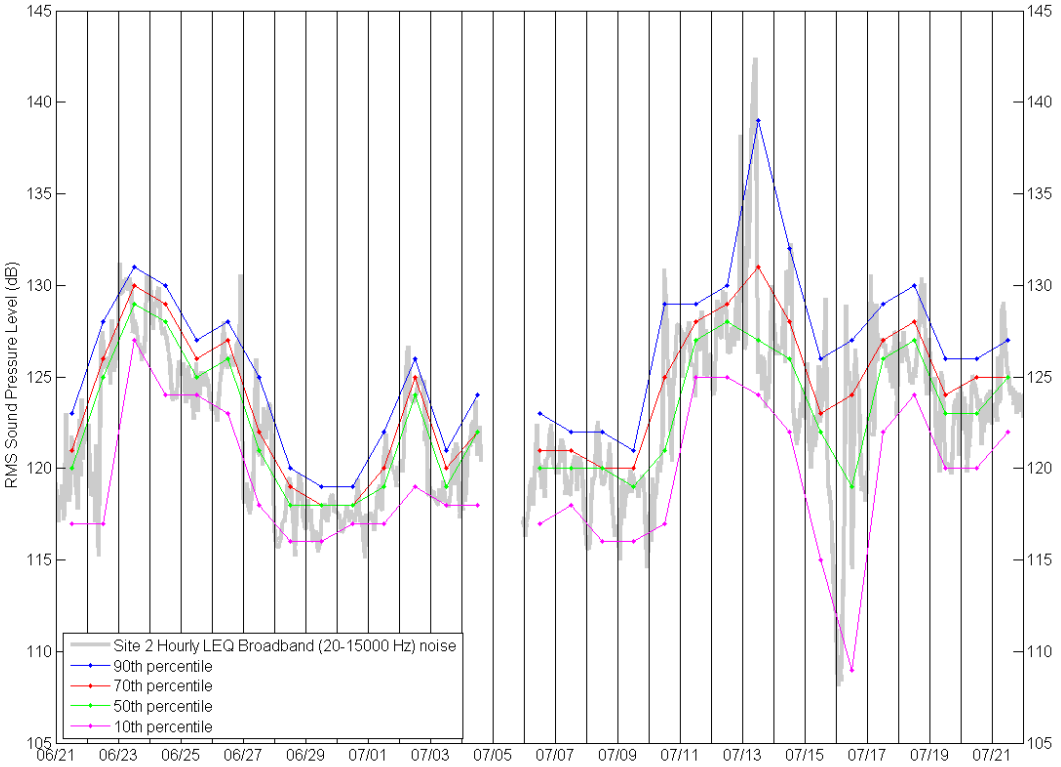

Figure 3: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 2.

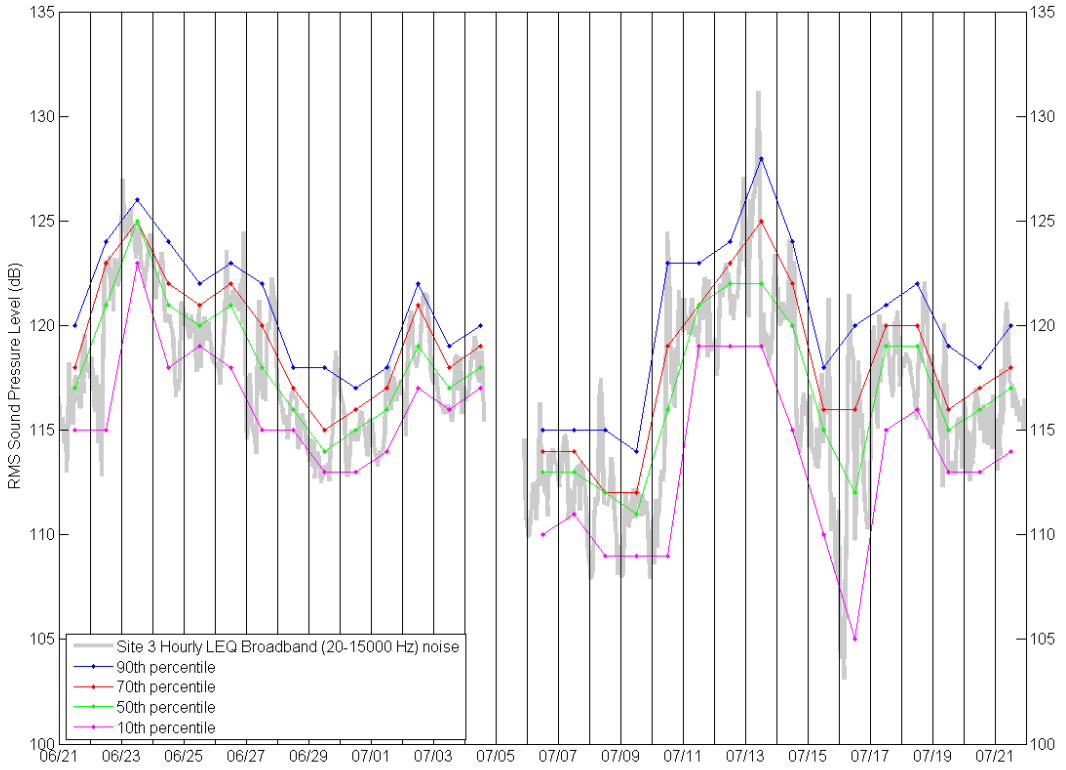

Figure 4: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 3.

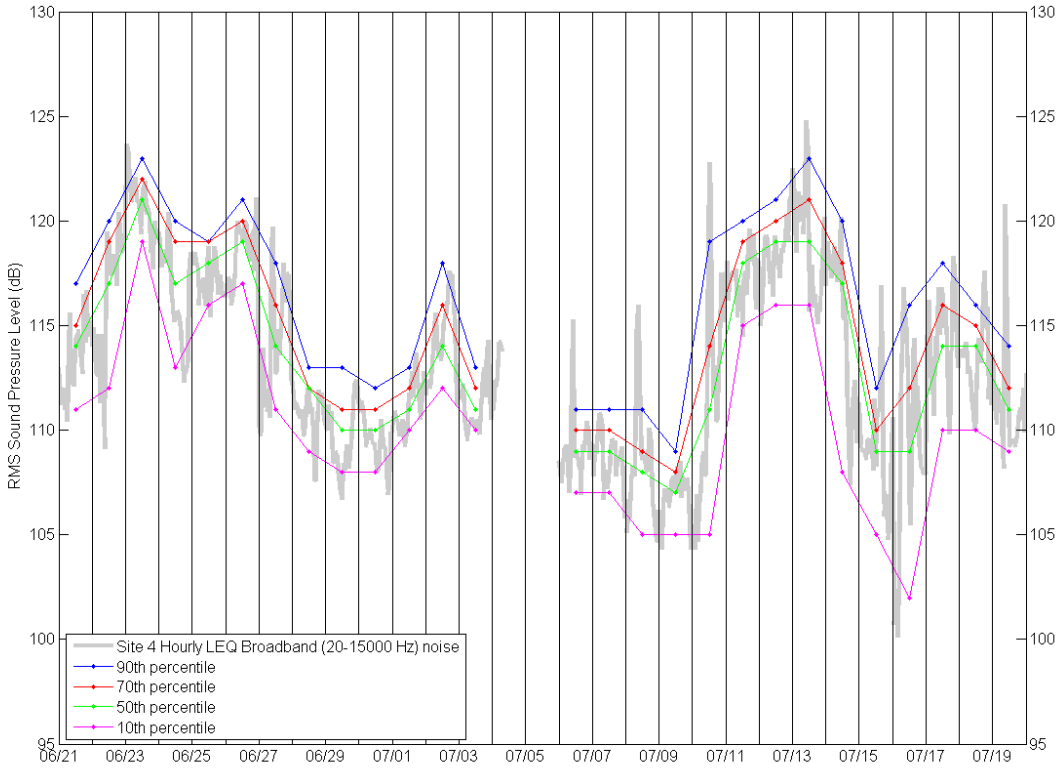

Figure 5: Time progression of hourly averages and daily percentiles of broadband levels from LUN-A topsides installation activities as measured at Station 4.

Similarly the third-octave band level data from the POI datasets were reduced to hourly mean levels (Leq_1hr) in individual bands to examine the time progression of the spectral distribution. The results are presented in Figure 6 to Figure 9 in the form of sonogram plots.

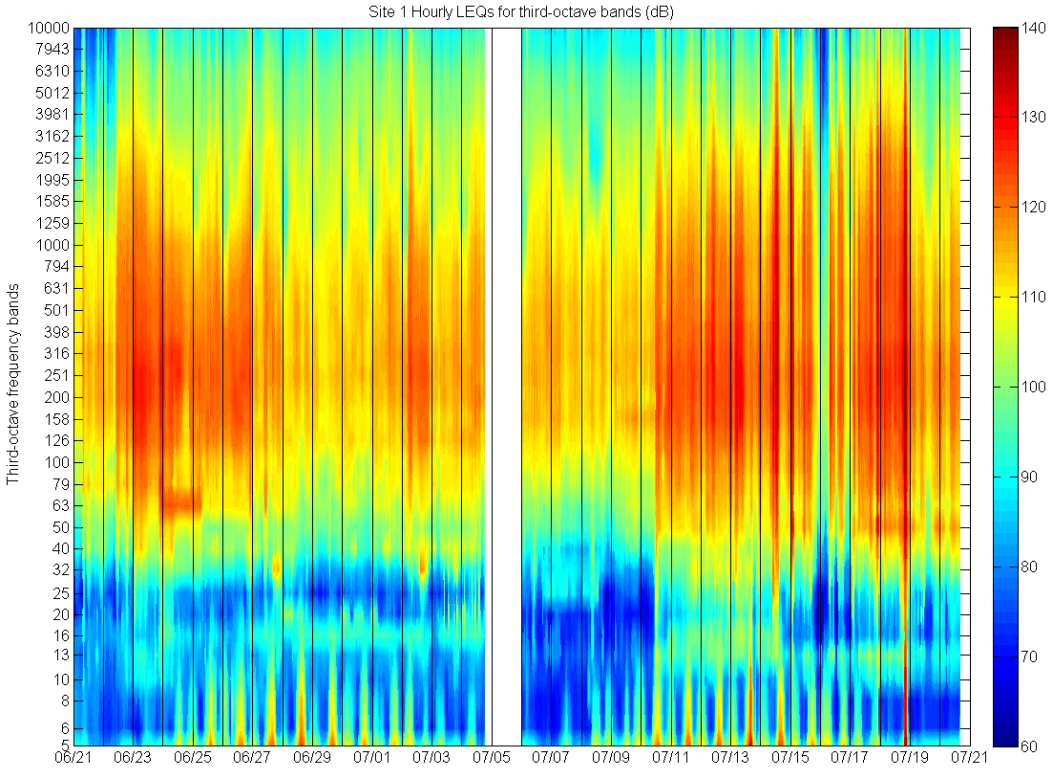

Figure 6: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 1.

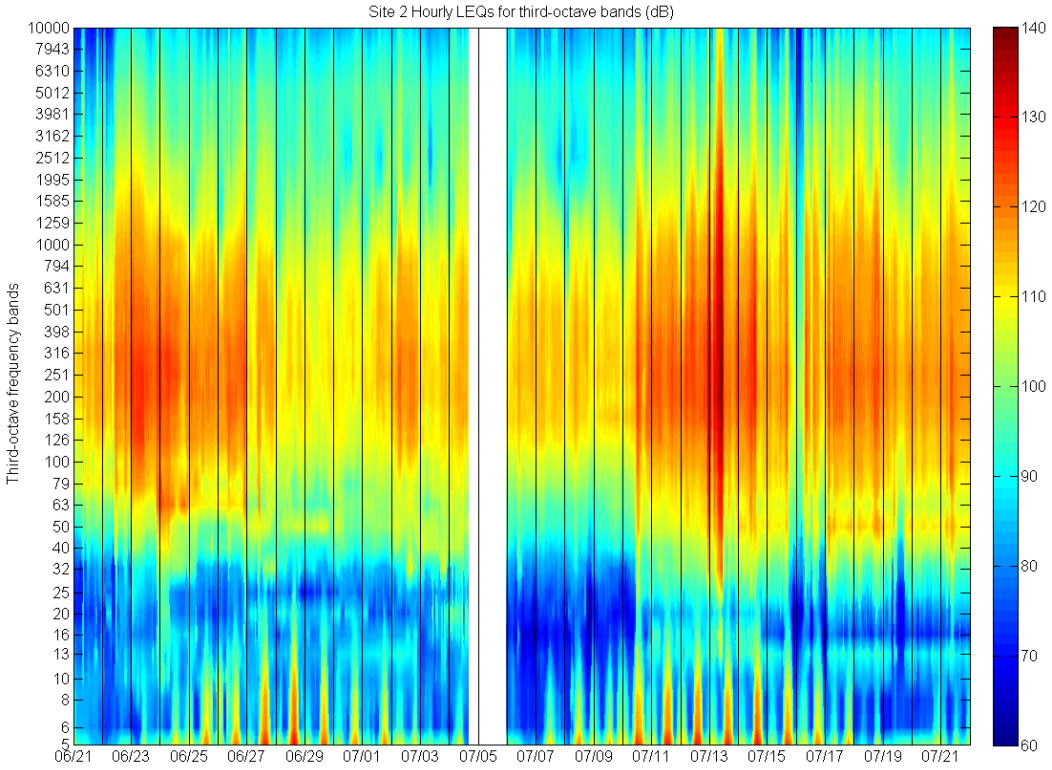

Figure 7: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 2.

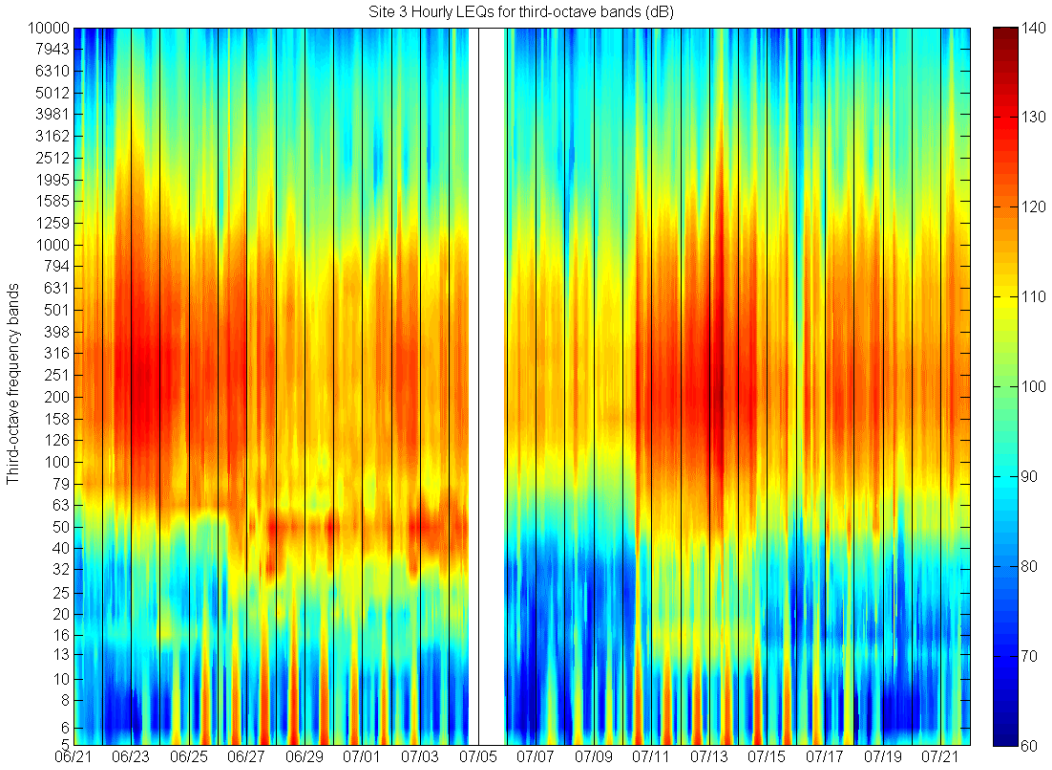

Figure 8: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 3.

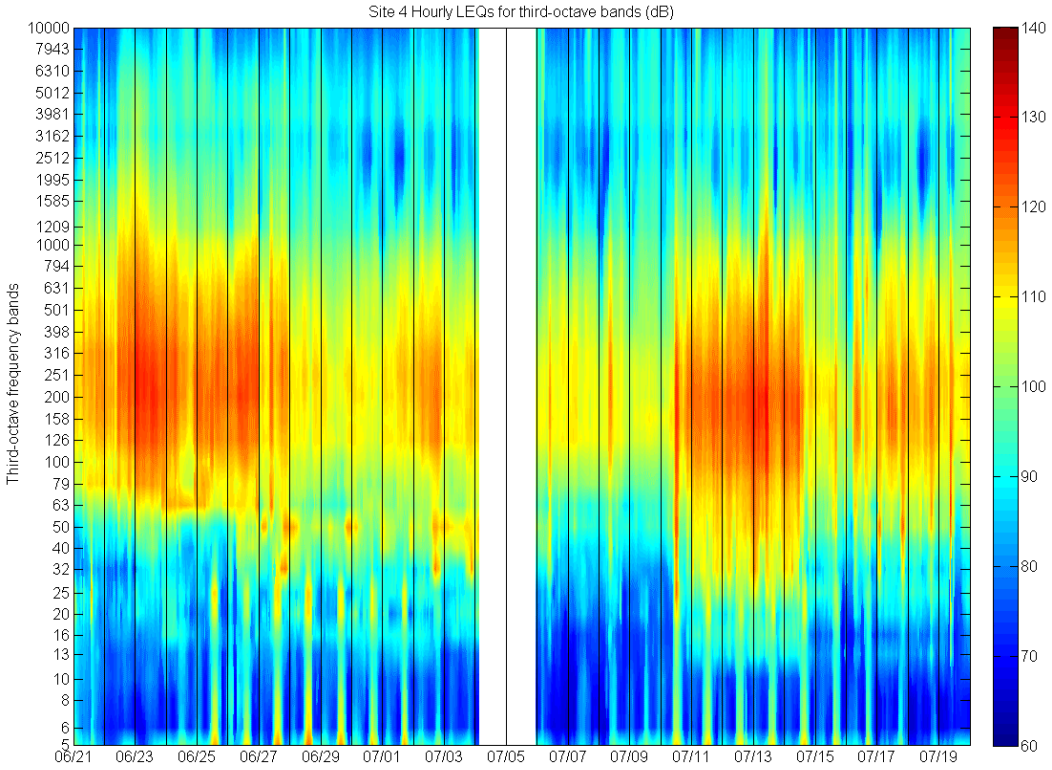

Figure 9: Sonogram plot of hourly average sound levels in third-octave frequency bands from LUN-A topsides installation activities as measured at Station 4.

CORRELATION OF SOUND LEVELS AND ACTIVITIES

To establish correlations between changes in received acoustic levels and activities taking place at the LUN-A site it is useful to plot the daily 90th percentile levels at the four monitoring stations on a common set of axes, as shown in Figure 10. In this chart the relevant phases of the operation have been put in evidence by background shading. Because the four stations are aligned along a radial from the platform site, variations in sound level due to construction work at that site should show a high degree of correlation in the four analyzed signals with a consistent decrease in overall level from Station 1 to Station 4 due to transmission loss. Any sound intensity changes that occur only at isolated stations, or relative levels that are not consistent with the transmission loss progression, are indicative of some activity taking place at a location other than LUN-A and probably associated with operations unrelated to the topsides installation.

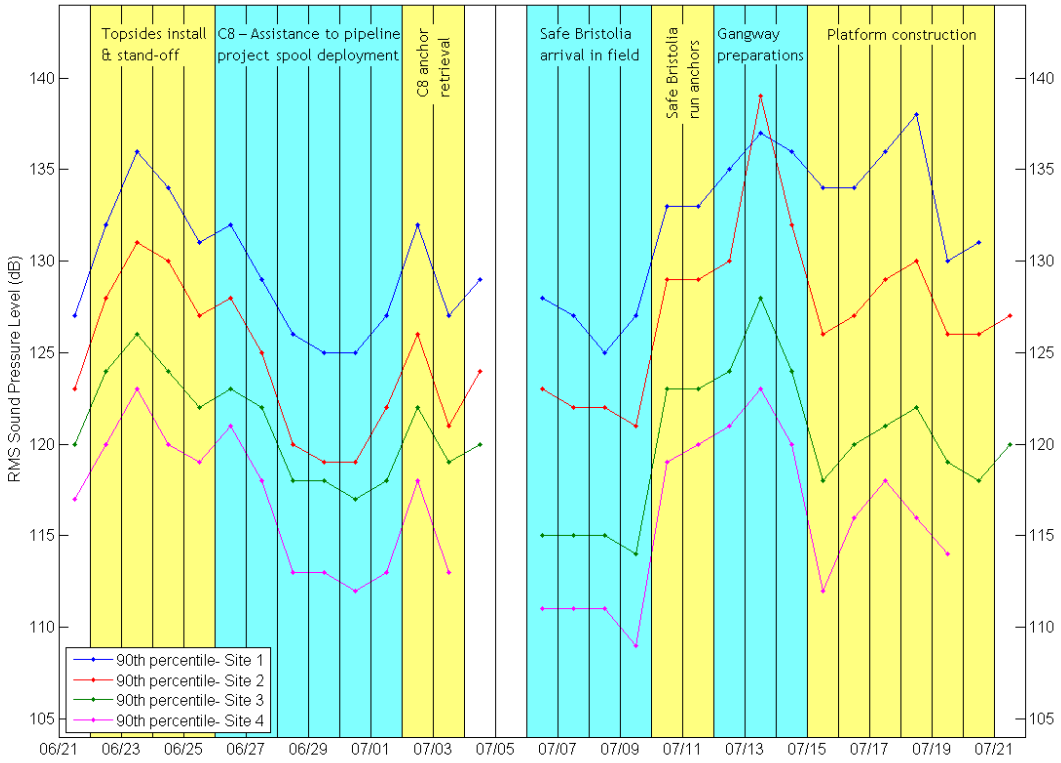

Figure 10: Time progression of daily 90th percentiles of broadband levels from LUN-A topsides installation activities as measured at Stations 1 to 4.

The correlation of the various lines in Figure 10 clearly shows that the majority of the underwater sound being recorded at the four monitoring stations originated at or in the vicinity of the LUN-A platform location. The most notable exceptions took place over the period from 27 June to 4 July, when the daily 90th percentile level at Station 3 appears markedly higher than normal for radial transmission loss in comparison to Stations 2 and 4, for the day of 13 July when the daily 90th percentile level at Station 2 actually surpasses that at Station 1, and between 15 and 18 July when Station 1 exhibits higher than normal levels relative to the others. In the case of the earliest period, the sonogram for Station 3 (Figure 8) shows a prominent signal at a frequency of about 40-50Hz that is only weakly found, if at all, at the other stations; this appears indicative of the presence of a sound source not far from Station 3 during those days. While from a purely temporal standpoint (see Table 1) this period of localized noise might be readily associated with the activities of the C8 barge and attendant anchor handling tug(s) in assistance to the pipeline project spool deployment, the operational information currently available cannot conclusively support this inference – especially given the fact that Station 3 is located several kilometres away from the pipeline route. In the case of the 13 July episode, the sonogram for Station 2 (Figure 7) shows a strong, broadband signal (extending widely across the frequency bands, from 25Hz to 5kHz) lasting a few hours in the early part of the day. The same signal is present fairly prominently over the same time period in the spectrogram for Station 3, identifying a source located not far from either of the two stations (not necessarily collinear with them) but closer to Station 2. According to the available summary no specific activity took place during

that day that could be associated with the locally elevated sound levels; the relatively short duration of the event – a few hours – may point to the transit of one or more vessels being demobilized from the construction area. Finally the operation of a vessel or vessels relatively close to Station 1 over the 15-18 July period, which is observable as occasional strong broadband features in the sonogram in Figure 6, is the cause of the elevated daily 90th percentiles at that station relative to the others.

For all other phases of the acoustic monitoring period the acoustic levels at the four stations appear consistent, on an approximate attenuation scale, with the primary sources of underwater sound being clustered near the LUN-A platform location. This assessment is made without the corroboration of a detailed analysis of the attenuation on a per-frequency basis and comparison with modelled transmission loss curves for the area, which will be performed at a later time as part of the methodology for forecasting acoustic levels from a similar operation to be conducted in summer 2007 at the PA-B platform. For the purpose of the present study it is sufficient that the measured distribution of sound levels on the whole can be realistically attributed to the documented activities at the platform, making a correlation meaningful.

The first significant activity, from a noise standpoint, in the topsides installation operation was the deployment of the TTB moorings. This task, similar in nature to its counterpart for the CGBS installation, involves the dropping of large mooring anchors on a predefined pattern around the platform site and their pre-tensioning by means of tugs. It has the potential for generating short but relatively intense periods of sound emission. This phase of the work ended on the 20th of June and was therefore not captured by full-day acoustic monitoring coverage which only began the following day. Acoustic studies of CGBS installations at LUN-A and PA-B, however, have shown that maximum sound levels from mooring deployment are comparable or lower than levels generated in the subsequent positioning phase; furthermore, the present monitoring did include a later period of mooring anchors deployment for the flotel. It can therefore be said with confidence that sufficient information is available to allow the forecasting of acoustic levels for mooring deployment in the upcoming PA-B topsides operation. The subsequent phase was the anchoring of the C8 in position near the CGBS and the final tow-in, connection and positioning of the TTB – culminating with the installation of the topsides on 23 June. From an acoustic standpoint this progression resulted in increasing levels to a maximum daily 90th percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). The activities over the subsequent two days (24th and 25th), which included removal of the C8 and TTB to stand off positions, retrieval of TTB mooring anchors and other related operations, generated lower daily noise levels than the topsides installation itself; in fact, with the exception of a small rise on 26 June at all stations, the levels dropped steadily over the following days to a minimum daily 90th percentile of 125 dB re µPa at Station 1 and 112 dB re µPa at Station 4 on the 30th. As previously mentioned the levels at Station 3 over this period were higher than would have been expected for a sound distribution centred at LUN-A due to some not better defined local source. Starting on 1 July the levels at all stations again started rising – arguably as a consequence of the onset of removal operations of the C8 from the field – and culminated at a maximum daily 90th percentile of 132 dB re µPa at Station 1 and 118 dB re µPa at Station 4 on 2 July, when retrieval of the C8 anchors took place. Following a maintenance hiatus of about one day in the monitoring around 5 July, the measured levels

remained low (daily 90th percentiles around 127 dB re µPa at Station 1 and 110 dB re µPa at Station 4) as the flotel Safe Bristolia approached the field but rose sharply on 10 July as the anchors for mooring the flotel started being run into position. During the two days of anchors running (10th and 11th) the daily 90th percentiles were 133 dB re µPa at Station 1 and about 120 dB re µPa at Station 4; they subsequently rose further to a maximum of 137 dB re µPa at Station 1 and 123 dB re µPa at Station 4 on 13 July in the course of apparently routine flotel gangway preparations, but possibly due to undocumented support vessel activities. Following a trough in the levels reaching a minimum on 15 July, there is a further surge by a few dB in the daily 90th percentiles culminating on 18 July – with no correlation with a documented construction task. Here as well the activities of support vessels at some distance from LUN-A are the likely source of variation in daily acoustic levels, especially in light of what was said earlier regarding the elevated readings at Station 1 during this period.

ASSESSMENT OF SOUND LEVELS OVER OPERATION PHASES

To provide an overall assessment of the received sound levels associated with significant phases of the operation, 90th percentile levels were also computed over the duration of complete tasks and are shown in Table 2. The starred entries denote periods over which the received sound at a station may have been dominated by a nearby source for at least part of the time.

Table 2: 90th percentile sound levels at each station over the monitored operation phases.

Operation Phase	**90th %ile level at Station 1 (dB re µPa)**	**90th %ile level at Station 2 (dB re µPa)**	**90th %ile level at Station 3 (dB re µPa)**	**90th %ile level at Station 4 (dB re µPa)**
Topsides install & stand-off	135	130	125	122
C8 – assistance to pipeline project spool deployment	131	126	121	119
C8 anchor retrieval	131	125	121*	117
Safe Bristolia arrival in field	127	122	115	111
Safe Bristolia run anchors	133	129	123	119
Gangway preparations	137	134*	126	122
Platform construction	136*	128	120	116

It should be noted that the phases in the table above, which correspond to the shaded background bands in Figure 10, may include more than one of the individual activities identified in Table 1. The phase denoted as "Topsides install & stand-off", for example, includes the mooring of the C8 and TTB, the float-over and lowering of the topsides onto the base, and the standing off of the two barges from the platform site. This logical grouping provides a sound level assessment on a whole-task basis that complements the shorter-term metrics presented earlier.

CONCLUSION

Acoustic level recordings were performed by four autonomous monitoring stations deployed along a straight line to the W-SW from the LUN-A platform at ranges of about 3, 5, 7 and 9km. The monitoring period covered the installation of the topsides on the existing CGBS and subsequent mooring of a flotel in support of platform commissioning activities. With some documented exceptions the underwater sound recorded was found to originate mostly at the platform site, which allowed correlation of measured levels with listed activities from operational records and which will enable the use of these data as a basis to predict the acoustic footprint for similar operations to be conducted at the PA-B platform location in the Piltun area. Both broadband level plots (including hourly averages and daily percentiles) and sonograms in third-octave bands were generated in post-analysis of the recordings. The highest levels encountered during the topsides deployment occurred in the final phase of positioning on 23 June and reached a maximum daily 90^{th} percentile of 136 dB re µPa at Station 1 (about 3km from the platform) and 123 dB re µPa at Station 4 (about 9km from the platform). Comparable maximum daily levels were observed on 13 July during the deployment of the flotel, although activities of support vessels operating some distance from the platform may have been the cause of some of the higher readings during this later phase of the construction.