National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
Natural Sounds and Night Skies Division

Everglades and Dry Tortugas National Parks
Noise Source Measurement Summary Report

August 2011 (Final Revision with Park Comments)

Background Information
Per the National Park Service Organic Act and Chapter 8 of NPS Management Policies 2006, the fundamental purpose of all national park units includes providing for the enjoyment of park resources such as the soundscape. In section 4.9 of the Management Policies, superintendents are directed to monitor noise caused by mechanical devices. In section 8.2.2, park managers are directed to identify levels and sounds that may hinder visitor enjoyment and specifically, to monitor mechanical noise that adversely affect opportunities to enjoy park soundscapes.

In line with the aforementioned policies, Everglades National Park (EVER) staff requested assistance from the Natural Sounds Program (NSP) for collection of noise source data to help inform potential noise source impact assessments. Specifically, the NSP was asked by EVER staff to assist in making measurements of noise from typical motorboats in Florida Bay, airboats in Shark River Slough, small RV generators at Flamingo campground, and large power generators at Fort Jefferson. The information was expected to provide information needed to support planning efforts, and in some cases, potential mitigation measures.

This summary report contains an analysis of the recorded noise source data and operational parameters to help assist EVER and NSP staff in understanding the acoustical data and relevant management actions. The report provides tables of measured noise source data and site descriptions.

Data & Metrics
At the airboat and watercraft measurement sites, medium duration sound pressure level (SPL) measurements were made, along with digital audio recordings and meteorological data. At the RV generator and large generator set measurement sites, only short term sound pressure level (SPL) measurements were made. In all cases, microphone measurements were made according to ANSI S1.4 Type 1, IEC 61672 Class 1 requirements, using one-third octave spectral data and overall A-weighted sound levels. Because it helps sound level measurements better match human hearing sensitivity, A-weighting has been widely adopted for environmental noise measurement, and is prevalent in many sound level meters and measurement standards. C-weighting is typically used for louder sounds, such as jet aircraft and exhausts.

The logarithmic dB scale can be difficult to interpret, and the functional effect of a seemingly small change in SPL can be greater than anticipated. When noise interferes with hearing natural sounds, the noise is said to *mask* the natural sounds, and this affects the extent of the listening area. For example, if the ambient SPL is 30 dB, and transportation noise raises the ambient to 33 dB (a 3 dB increase), the auditory horizon for humans (and many animals) would decrease, reducing the listening area by half (50%). Increasing the ambient SPL an additional 3 dB (to 36 dB) would reduce the listening area by half again, to 25% of the initial area.

Although changes in SPL do not always proportionately translate to changes in perceived loudness, there are some rules of thumb. At a minimum, each 10 dB increase in SPL generally causes a doubling of human perceived loudness (Crocker, 1997, p. 1481). To help in understanding the magnitude of sound levels, Table 1 presents some typical park sounds and other common sound sources with their corresponding A-weighted decibel (dBA) values.

Table 1. Sound pressure level examples

Park Sound Sources	Common Sound Sources	dBA
Volcano crater (HALE)	Human breathing at 3m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5m (ZION)	Residential area at night	40
Conversation at 5m (WHMI)	Busy restaurant	60
Snowcoach at 30m (YELL)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2m	100
Military jet at 100m AGL(YUCH)	Train horn at 1m	120

Table 2 summarizes sound pressure levels that relate to human health and speech, as documented in the scientific literature. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper, 2007, p. 5). To help interpret the acoustical data collected within the park, and to better understand the implications of the data, it may be helpful to consider sound pressure levels in relation to the functional effects listed in Table 2.

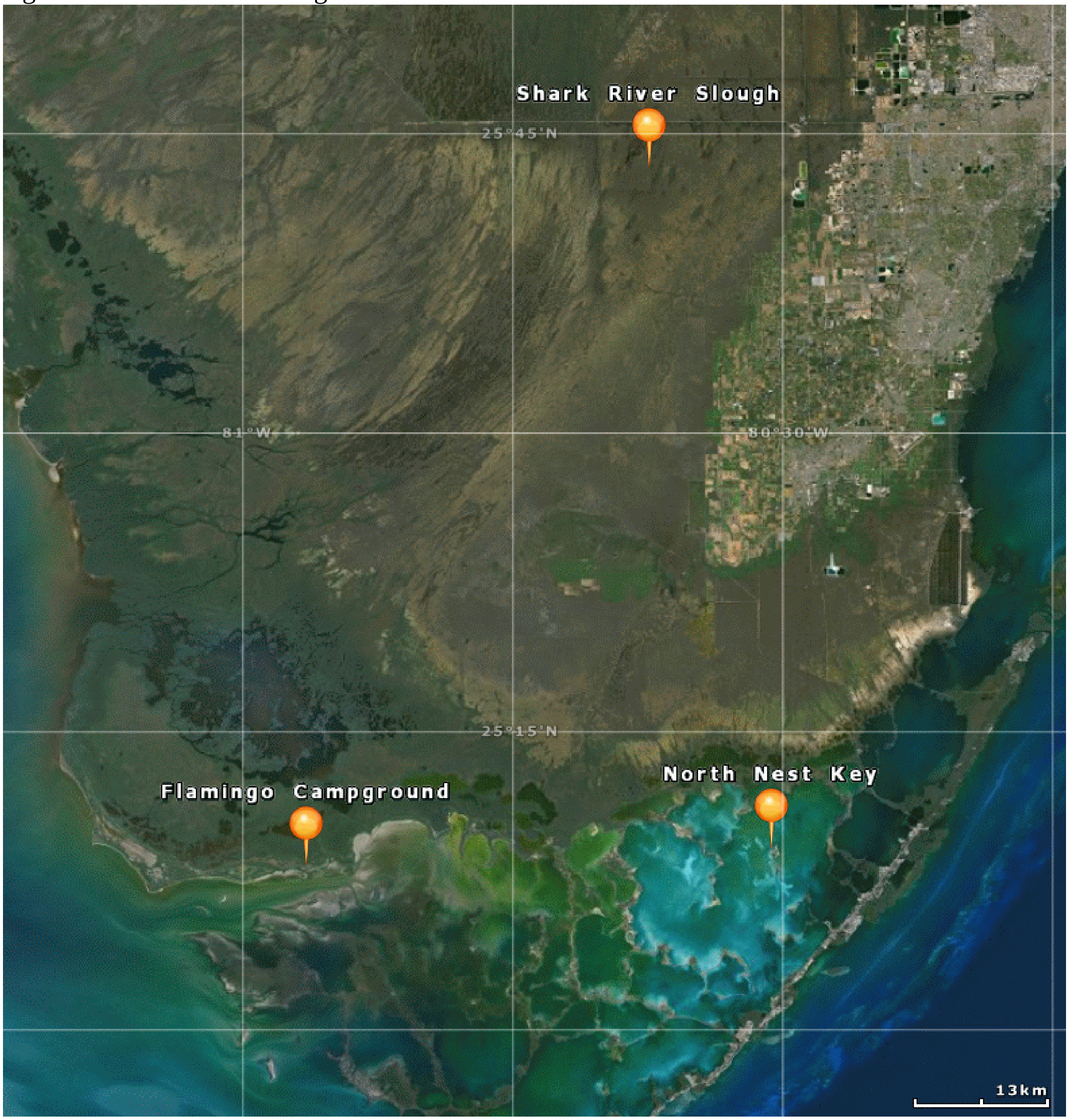
Table 2. Effects of sound pressure levels on humans

SPL (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela, 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency, 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency, 1974)

Site Descriptions

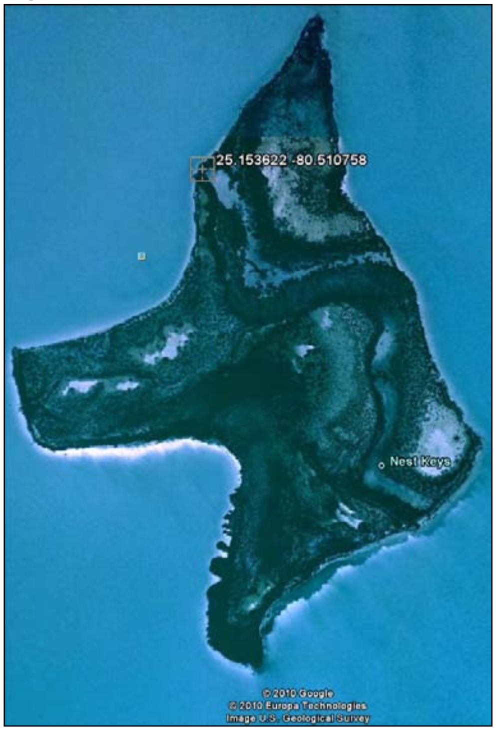
Site visits to EVER and DRTO locations were made on April 19-22, 2008. Prior to the site visit, EVER staff personnel were contacted in order to select sites and discuss desired noise source data. This report contains data from the following selected sites: North Nest Key, Shark River Slough, Flamingo Campground, and Fort Jefferson. All sites other than Fort Jefferson are shown in Figure 1 below. Descriptions follow of the measurement sites and the noise sources that were measured at those sites.

Figure 1 – Locations of Everglades measurement sites



At North Nest Key, sound level measurement equipment was set up at a NW island point. The location was an inland site at the northern extent of the bay and shoreline where camping is permitted. The measurement site was selected to capture general Florida Bay boat noise levels at a quiet shoreline location similar to the noise levels that might be experienced at this campground and nearby keys. Because most keys in Florida Bay are closed to landing, more consistent boat traffic was expected to occur close to this designated accessible shoreline. In Figure 2 below, the measurement site is indicated by the square marker with crosshairs and GPS coordinates.

Figure 2. Left—an aerial view of the entire island. Right—the bay and accessible shoreline



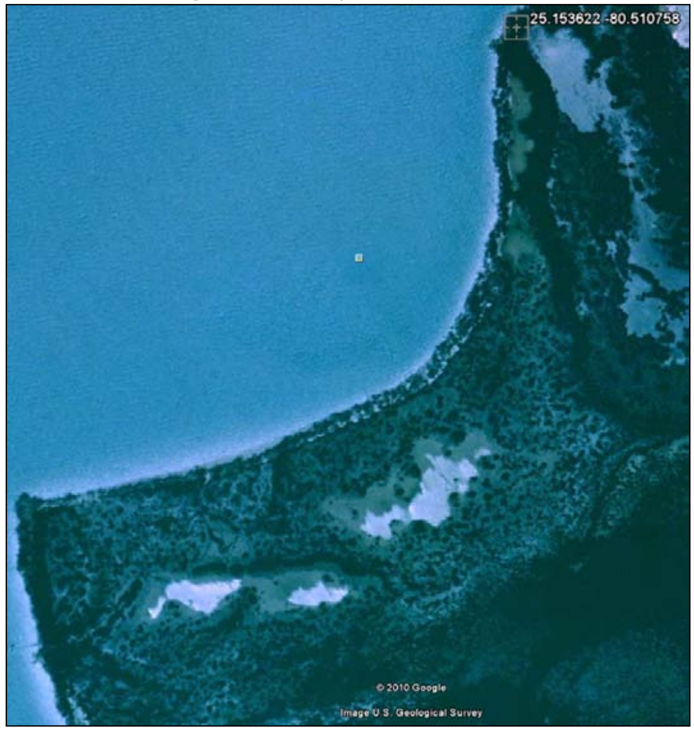
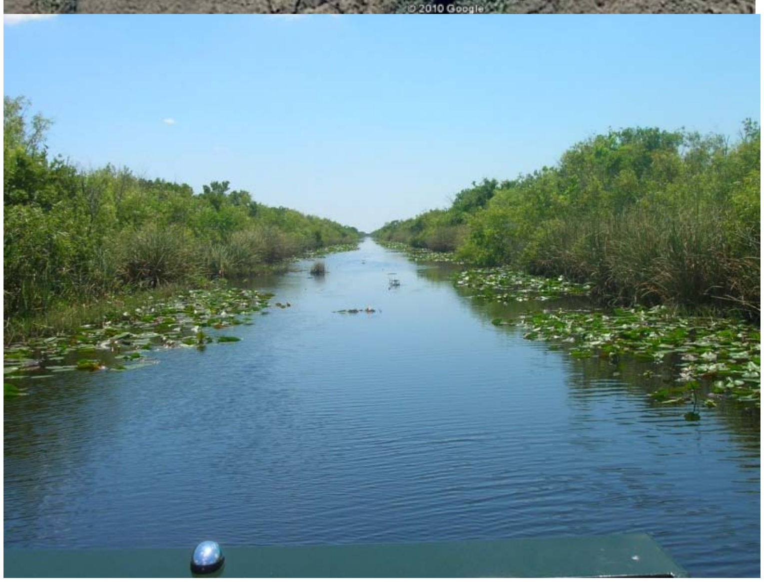


Figure 3 below shows the measurement set up and general vegetation at the North Nest Key site. A small clearing was located close to the shore, with minimum obstructing vegetation between the microphone and the North Nest Key bay. The specific location was chosen due to its proximity to the bay entrance and former regulation buoys with no-wake signage. The location was also chosen because public access would be difficult, and therefore, equipment security would be increased.

Figure 3. Boat noise measurement setup at North Nest Key site

At the Shark River Slough site, sound level measurement equipment was set up along the Blue Shanty Canal, approximately 135 m south of a major intersection where five other canals come together to cross at a single point. The location was a few meters inland on the west side of the canal. The measurement site was selected to capture general airboat noise levels as they pass by the equipment. In Figure 4 below, the measurement site is indicated in the top image by the square marker with crosshairs and GPS coordinates; the canal adjacent to the site is shown in the lower image. The leading edge of the airboat can be seen at the very bottom of the lower image.

Figure 4 Top—an aerial view of the Blue Shanty canal. Bottom—the canal adjacent to the site



At the Flamingo Campground, sound level measurement equipment was set up in the T loop in order to measure recreational vehicle (RV) power generator noise levels. The location was at the east side of a dump station close to the first restroom between sites 17 and 18. The measurement site and time was chosen to capture RV power generator operating while the camper waste water was emptied. In Figure 5 below, the measurement site is located immediately north of the restroom structure and is indicated by the square marker with crosshairs and GPS coordinates. Eco Pond can be seen in the upper right hand corner of the aerial photo.

Figure 5. RV generator measurement location at Flamingo campground

At Fort Jefferson in Dry Tortugas National Park (DRTO), sound level measurement equipment was set up at various locations inside and outside of the fort. The outside locations included positions along the outside moat, nearby beach, and campground. The inside locations included the generator room and the fort courtyard adjacent to the generator room.

The exterior wall and windows (gun casemates) for the Fort Jefferson generator room is shown below in Figure 6. The left photo shows two of three generator exhaust pipes protruding at the top of three gun casemate openings. Those openings also contain a duct opening with louvers. The right photo shows the exhaust pipes from the perspective of the large open walkway above.

Figure 6. Exterior wall for Fort Jefferson generator room

Figure 7 below shows a close-up of the exterior wall and the generator room.

Figure 7. Left—exterior wall from Fort Jefferson moat. Right—interior of generator room

Figure 8 shows four exterior measurement locations. Moving counter clockwise from the top left, the first photo shows the moat wall location directly in front of the generator exhausts. The second lower left photo shows the beach location 50 m from the generator exhausts. The third lower right photo shows the beach location 100 m from the generator exhausts. The top right photo shows the campground location, 92 m from the generator exhausts between campsites #2 and #3.

Figure 8. Exterior measurement locations for Fort Jefferson generators

Noise Measurements

Sound level measurements at EVER and DRTO locations were made by Mr. Randy Stanley on April 19-22, 2008. Recordings were made at a 1.5 m (5 ft) height in accordance with measurement standards and in line with typical listener ear height. Based on careful onsite sound level meter observations, site notes, site photos, and follow-up inspection of the acoustic data, it was possible to identify the measurement events, times, levels, and in some cases, associated spectral data which best characterize the noise sources recorded during the measurement.

North Nest Key

At North Nest Key, a medium-term duration measurement was made on April 19-21, 2008. The North Nest Key boat noise measurement was not intended to capture qualified noise source data and related parameters needed for modeling, such as boat type, model, horsepower, specific throttle, and distance; rather, it was intended to capture general Florida Bay boat noise levels at a shoreline near significant boat traffic and the acoustic effect of site-specific boat operational rules. Therefore, the measured boat noise levels will represent the conditions at the particular measurement site, and those noise levels can be expected to vary with boat motor size, throttle position, motor load (dependent on a combination of variables including boat weight, hull draft, pre-plane attitude/trim, time-variant planing hull drag, wave height/spacing, etc.), meteorological conditions, boat orientation, and distance from the measurement position.

At one time, regulation buoys with no-wake signage were located at the northwest bay on North Nest Key, requiring boats to idle into the bay in order to achieve a no-wake zone. The buoys were located 75-100 yards from shore. Although the buoys were believed blown away by a hurricane or other significant wind storm, boat operators traditionally follow these expected operational rules when approaching the shore. This has a significant impact on noise levels because boats with operating motors usually generate the lowest noise levels when at the neutral or low idle condition. Conversely, boats motors can generally be expected to create the highest noise levels before they throttle down to idle condition (arrival) or after they throttle up from idle and load increases as they work to achieve plane and leave the area (departure). The actual throttle condition is unknown but will change at the point where boats vary their throttle position to comply with the no-wake zone rule.

As a result, sound level extraction focused primarily on gathering the data most relevant to supporting potential management action, i.e. capturing maximum pass-by levels and in particular, the change in noise level as Florida Bay boats throttle up/down to achieve a no-wake zone. The process of sound level extraction included visual inspection of the one-third octave spectral data, listening-based source detection, and level quality assessment. The process also included searches for time varying patterns due to wave chop and changes in engine harmonic structure (orders) due to engine throttle changes. In some cases, the engine harmonics (orders) and spectral levels mimic that of other vehicles such as propeller aircraft and thus make it difficult to positively identify without listening verification.

In many respects, gauging event level quality and choosing specific spectral data (levels and time) are multivariate tasks and the most difficult parts of the process. Recorded boat sound levels can be influenced by a number of events, some which are directly related to operation of the noise source and some which are not. Noise sources which are related to operation of Florida Bay boats include outboard engine noise (case radiated and exhaust header/pipe), propeller noise, and boat wave sound. Related boat wave sound can include the effect of waves slapping the boat hull or the splash that occurs when a pre-plane or on-plane boat hull splits and pushes water rapidly to either side. Sounds which are unrelated or not directly related to the operation of a measured boat may include other boats, beach activity (voices, music), aircraft, birds, insects, wind, and waves striking the shore. In order to ensure the reported sound levels are due to a specific noise source, it is important to identify contributing sound sources and to ensure that the identified levels are not unduly influenced by unrelated sources. Such inspection is typically accomplished by a selected combination of listening, considering multiple noise sources vs. time-variant operating conditions, inspecting changing spectral patterns, observing level increases above the apparent ambient, and calculating level differences over time. The apparent ambient is the estimated sound level due to the combination of all other sound sources other than the measured boat.

To adequately account for throttle position and associated operating conditions, the times of level observations must be carefully chosen. In the case of boat arrivals, sufficient time must be allowed for the boat to drop from plane, for the engine speed in revolutions per minute (RPM) to drop to a nominal idle level, and for unrelated wave action to subside. For boat departures, sufficient time must exist for the engine RPM to reach a nominal high throttle level as the boat works to approach plane. The time choices are also accomplished by listening and observing changing spectral levels, including prominent boat engine harmonics (orders).

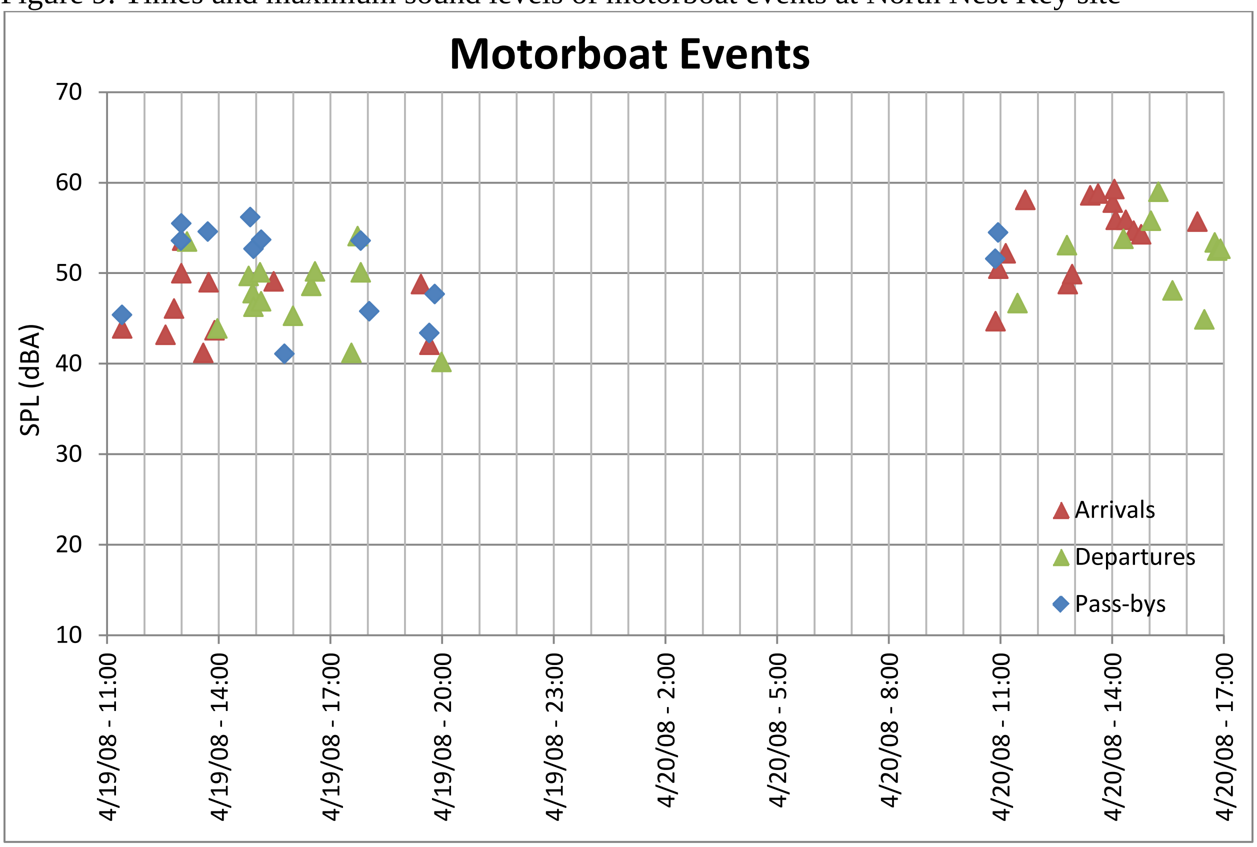
Tables with site descriptions and measurement results are provided below. Table 3 offers site coordinates, estimated distance to noise sources, and a general site description. It should be noted that the provided GPS coordinates are approximate; GPS location accuracy is limited by the capabilities of the utilized GPS device.

Table 3. Location and description of North Nest Key measurement site

GPS		Estimated Distance (m)	Site Description	L_{max} Range (dBA)
Lat	Long			
25.153622	80.510758	50 - 500	Coastal salt marsh; grass, small shrubs and trees	40 - 59

The times and maximum sound levels of recorded motorboat events at the North Nest Key measurement site are shown in Figure 9 below. Boat arrivals, departures, and pass-bys were limited to daytime hours and mainly occurred between 11:00 AM and 8:00 PM. The loudest recorded events mostly occurred during the early afternoon of Sunday, April 20, 2008. In the late night hours of April 20 and during daytime hours of April 21, 2008, strong wave action and associated sound made further motorboat sound level extraction impossible.

Figure 9. Times and maximum sound levels of motorboat events at North Nest Key site



The distribution of North Nest Key boat noise levels is shown in Table 4 below. The number of arrivals and departures were events which were judged to meet minimum quality levels. As described above, minimum quality means that throttle condition is acceptable and that the identified levels are not unduly influenced by unrelated sources. At least a dozen pass-bys, arrivals, and departures did not meet these quality levels and were excluded. In addition, because the analysis focused on arrivals and departures, not all boat pass-bys were analyzed for maximum pass-by level. In general, Table 4 will reflect the maximum A-weighted sound level (L_{max} in dBA) recorded just before reduction in throttle (for arrivals) or just after increase in throttle (for departures). In Table 4, P_{90} refers to the 90th percentile L_{max}, or the value below which 90 percent of the L_{max} observations are found. Similarly, P_{10} refers to the 10th percentile L_{max}, or the level below which 10 percent of the L_{max} values may be found. The P_{90} is analogous in concept to the L_{10} (level exceeded 10% of the time); while the P_{10} is analogous to the L_{90} (level exceeded 90% of the time).

Table 4. Distributions of maximum North Nest Key boat sound levels by event type

Event Description	Number	Highest L_{max} (dBA)	P_{90} L_{max} (dBA)	Median L_{max} (dBA)	P_{10} L_{max} (dBA)	Lowest L_{max} (dBA)
Pass-bys	14	56	55	53	44	41
Arrivals	26	59	58	50	43	41
Departures	24	59	54	50	44	40
Total	50	59	58	50	44	40

Table 5 shows the maximum sound levels and associated octave band spectral levels for an average North Nest Key boat. The spectral levels and maximum sound levels are calculated as an energy average of all the events listed in Table 4. Therefore, all of the sound pressure values are squared and then averaged. The symbol Δ (dBA) refers to the average change in A-weighted decibels that occurs just after a reduction in throttle (for arrivals) or just after an increase in throttle (for departures). Similarly, the symbol Δ (dBC) refers to the average change in C-weighted decibels. While differences in level ranged from 4 to 23 dB, the typical change was well over 10 dB. Note that spectral data was not gathered during analysis of pass-by sound levels, and due to the relatively continuous throttle found during most pass-by events, there are no calculated level differences for pass-by events.

Table 5. Maximum sound levels of average North Nest Key boat by event type

Event Description	Number	Octave Band Levels (dB)									L_{max} (dBA)	Δ (dBA)	L_{max} (dBC)	Δ (dBC)
		31.5	63	125	250	500	1000	2000	4000	8000				
Pass-bys	14	-	-	-	-	-	-	-	-	-	53	-	62	-
Arrivals	26	49	54	62	58	51	47	39	30	24	54	13	64	11
Departures	24	47	51	56	56	50	44	36	27	23	52	13	60	9
Total	50	48	53	60	57	51	46	37	29	24	53	13	63	10

An examination of Table 5 reveals that the A-weighted sound levels are typically dominated by spectral contributions between roughly 125 - 1000 Hz and most especially in the 250 Hz and 500 Hz octave bands. When looking at A-weighted decibels (dBA), there is an average 13 dB change when boats arrive and decrease throttle or when boats depart and increase their throttle setting. Consequently, park managers may expect that for equivalent boat distances, a no-wake zone will result in an average A-weighted level decrease of 13 dB. This is an approximate one-third change in loudness. Such a drop could be expected to produce an approximate 4.5x increase in alerting distance and a 20.5x increase in listening area at affected locations. To help put a 13 dB reduction into context, a doubling of noise source distance will usually produce a minimum 6 dB decrease, along with the expected 2.0x increase in alerting distance and a 4.0x increase in listening area. Therefore, while increasing noise source distance has a substantial benefit in terms of noise reduction, limiting engine speed can produce an even greater benefit.

The maximum sound levels and associated octave spectral levels shown in Table 5 for an average North Nest Key boat are displayed in greater detail in Figure 10 below. This includes one-third octave data in unweighted form, as is common for presentation of octave or one-third octave data. While for an arriving boat, the unweighted spectral contribution in the 125 Hz octave band is relatively high, it is nevertheless less significant when adjusted by the A-weighting curve than the contributions from the 250 Hz and 500 Hz bands.

Figure 10. Spectral levels of average North Nest Key boat by event type

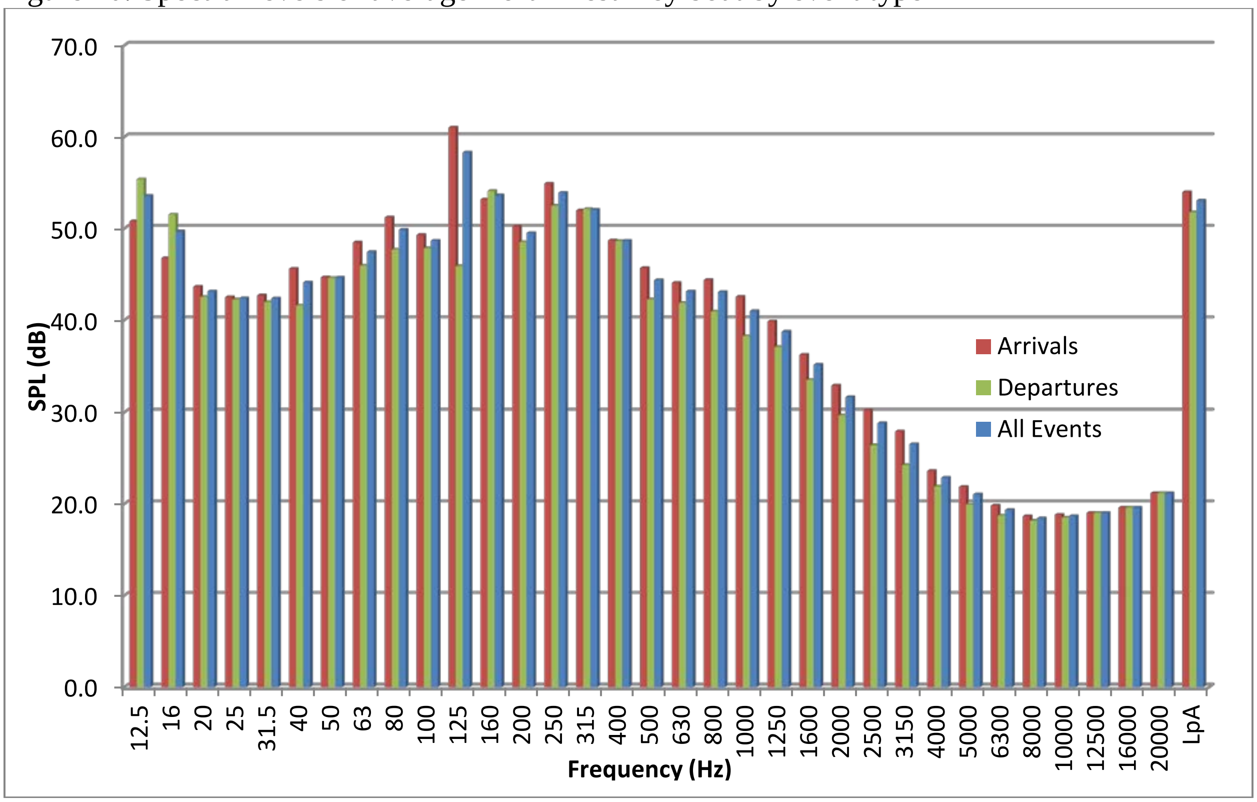
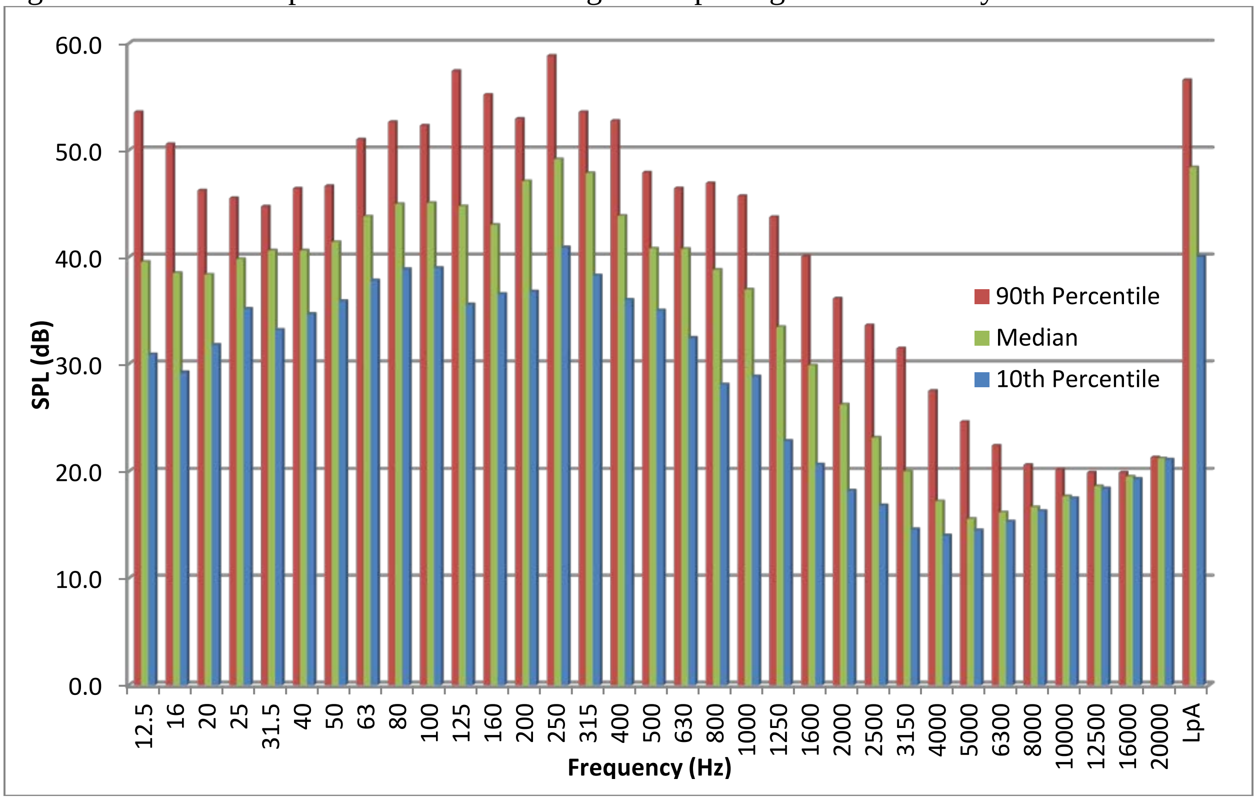


Figure 11 below shows the 90th percentile, 10th percentile, and median spectral levels for all boats arriving and departing at North Nest Key. This plot is intended to show how the loudest 10% of boats differ from the median and the quietest 10% of boats measured at this location. However, like maximum spectral levels, percentile spectral levels do not accurately reflect the complex frequency relationships of operating noise sources and therefore represent spectral events that probably never occurred. Consequently, the total calculated level (LpA) at the right hand edge of the plot deviates from the actual percentile levels in Table 3 by roughly 2 - 4 dB. In both Figure 10 and Figure 11, it should be noted that the spectral levels in the lowest and highest spectral bands are likely influenced by wind noise and sound level meter noise floor, respectively.

Figure 11. Percentile spectral levels of arriving and departing North Nest Key boats



Shark River Slough

At Shark River Slough, a medium-term duration measurement was made on April 19-21, 2008. Like the North Nest Key boat noise measurement, the Shark River Slough measurement was not intended to capture qualified noise source data and related parameters useful for modeling, such as airboat type, model, horsepower, and specific throttle; however, it was intended to capture general airboat source levels within the Shark River Slough and the effect of site-specific airboat operation. Therefore, the measured airboat noise levels will represent the conditions of airboat use at the chosen measurement site. As with other motorized vehicles, measured airboat noise levels can be expected to vary with engine size, muffler, throttle/rudder position, propeller speed, wind speed/direction, boat/propeller orientation, and distance from the measurement position.

Airboats with operating motors typically generate the lowest noise levels when at the lowest throttle condition. As throttle and propeller speed increase, the relative contribution of exhaust noise for an appropriately muffled engine will decrease, and the total noise level will be dominated by propeller noise. Airboat noise levels can generally be expected to increase with engine throttle and propeller speed. The actual throttle condition during these measurements is unknown but will vary with site conditions and operator control, i.e. desired to accelerate or maintain a minimum planing speed.

Similar to the process for North Nest Key boat sound level extraction described above, the process of airboat sound level extraction included visual inspection of the one-third octave spectral data and listening-based analysis of operating condition. Assessment of operating condition was important in order to ensure that the throttle condition is acceptable and representative of normal use. It was not difficult to differentiate airboat sound levels from other noise sources, but due to a nearby intersection of canals, it was difficult to ensure a local airboat pass-by under normal operating conditions without listening.

Due to the relatively high sound levels for airboats, it was not challenging to ensure that the identified levels were not significantly influenced by unrelated sources. However, to adequately account for throttle position and associated operating conditions, the times of level observations had to be carefully chosen. Maximum pass-by levels were chosen according to throttle position and airboat location. The time choices were also accomplished by listening and observing changing spectral levels.

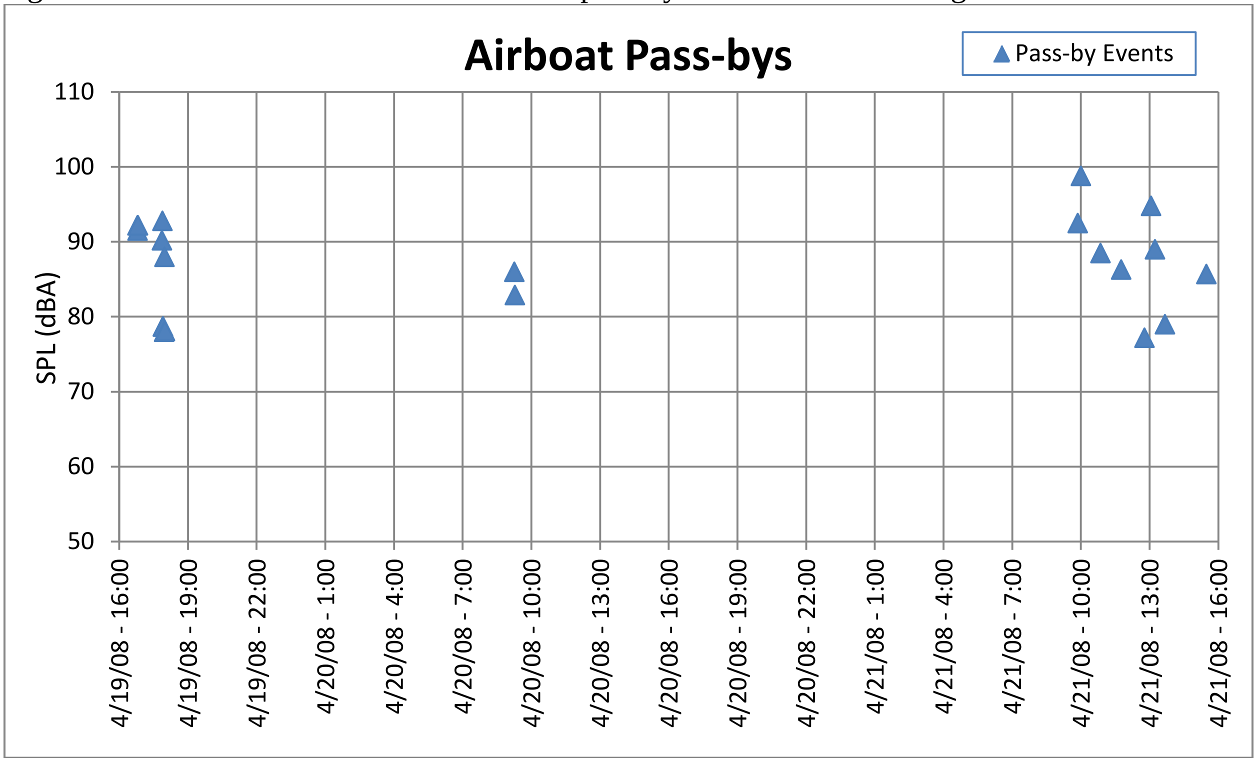
Tables with site descriptions and measurement results are provided below. Table 6 offers site coordinates, estimated distance to noise sources, and a general site description. It should be noted that the provided GPS coordinates are approximate; GPS location accuracy is limited by the capabilities of the utilized GPS device.

Table 6. Location and description of Shark River Slough (Blue Shanty canal) measurement site

GPS		Approximate Distance (m)	Site Description	L_{max} Range (dBA)
Lat	Long			
25.72289	80.62414	7 m	Sawgrass, swamp fern, and hardwood hammock species	77 - 99

The times and sound levels of the airboat pass-by events at the Blue Shanty canal measurement site are shown in Figure 12 below. The events were limited to daytime hours and frequently occurred in a cluster of 2 – 5 hours. The loudest recorded airboat events were due to fast pass-bys that occurred around 10:00 AM and 1:00 PM on Monday, April 21, 2008.

Figure 12. Times and sound levels of airboat pass-bys at Shark River Slough site



The distribution of Shark River Slough (south Blue Shanty canal) airboat noise levels is shown in Table 7 below. The number of pass-bys reflects events that were deemed to meet minimum throttle levels representative of normal use. Several pass-bys had to be excluded. Table 7 gives the maximum A-weighted sound level (L_{max} in dBA) and C-weighted sound level (L_{max} in dBC) recorded during the event, since A-weighted levels are most common in airboat regulations, although C-weighting is intended for application to levels above 85 dB, such as may be found with nearby airboat pass-bys. Because C-weighting is typically used for these louder sounds, it was felt more important to include this data for airboats than for North Nest Key boats, for example. In Table 7, P_{90} refers to the 90th percentile L_{max}, and P_{10} refers to the 10th percentile L_{max}, as explained on page 6.

Table 7. Distributions of maximum Shark River Slough airboat sound levels by pass-by speed

Event Description	Number	Highest L_{max} (dBA)	P_{90} L_{max} (dBA)	Median L_{max} (dBA)	P_{10} L_{max} (dBA)	Lowest L_{max} (dBA)
Fast Pass-by	2	99	-	-	-	95
Slow Pass-by	19	93	92	86	78	77
All Pass-bys	21	99	93	88	78	77
Event Description	Number	Highest L_{max} (dBC)	P_{90} L_{max} (dBC)	Median L_{max} (dBC)	P_{10} L_{max} (dBC)	Lowest L_{max} (dBC)
Fast Pass-by	2	109	-	-	-	107
Slow Pass-by	19	106	104	99	92	91
All Pass-bys	21	109	106	101	92	91

Table 8 shows the maximum sound levels and associated octave band spectral levels for an average Shark River Slough (south Blue Shanty Canal) airboat. The spectral levels and maximum sound levels are calculated as an energy average of all the events listed in Table 7. Consequently, if the average result were multiplied (repeated) by the total number of events, the combined sound exposure level would be roughly equivalent to that experienced during the actual measurement. It should be noted that the time of L_{max} in dBA did not always correspond with the time of L_{max} in dBC. Therefore, the moment of maximum pass-by level and the associated spectrum were identified separately for A-weighted and C-weighted levels. However, for purposes of Table 8, the associated octave band spectral levels are taken from the times of L_{max} in dBA. It is believed that these spectra would be better suited for possible modeling and general impact assessment at larger distances.

Table 8. Maximum sound levels of average Shark River Slough airboat by pass-by speed

Pass-by Description	Number	Octave Band Levels (dB)									L_{max} (dBA)	L_{max} (dBC)
		31.5	63	125	250	500	1000	2000	4000	8000		
Fast	2	81	99	107	98	92	91	87	85	82	97	108
Slow	19	88	96	98	89	85	82	78	74	73	89	100
All	21	88	96	100	91	86	84	80	77	75	91	102

Assessment of Table 8 reveals that the A-weighted sound levels are dominated by spectral contributions in the 125 - 2000 Hz octave bands. During the listening and sound level extraction process, it was noted that most airboats moving through the measurement site were engaged in bird watching. Many airboats slowed down and cut engines in the vicinity of the measurement site. In some cases, a large bird could be heard flapping and departing as an airboat approached. Therefore, with the exception of the two very fast airboat pass-bys, most airboats were most likely not producing the maximum possible sound levels. However, there was a level decrease of 8 - 9 dB between the average maximum pass-by level of the fast and slow moving airboats. This is an approximate one-half change in loudness. A 9 dB reduction could result in a 2.75x increase in alerting distance and a 7.5x increase in listening area at affected locations. If airboats are required to lower their speed to a lower throttle pre-plane speed sufficient to achieve this maximum level decrease, the aforementioned benefits could be expected.

The maximum sound levels and associated spectral levels shown in Table 8 for an average Shark River Slough (south Blue Shanty canal) airboat are displayed in greater detail in Figure 13 below. This includes one-third octave data in unweighted form, as is common for presentation of octave or one-third octave data. For a fast airboat pass-by, the unweighted spectral contribution in the 125 Hz octave band is relatively high and remains significant even when adjusted by the A-weighting curve.

Figure 13. Spectral levels of average Shark River Slough airboat by pass-by speed

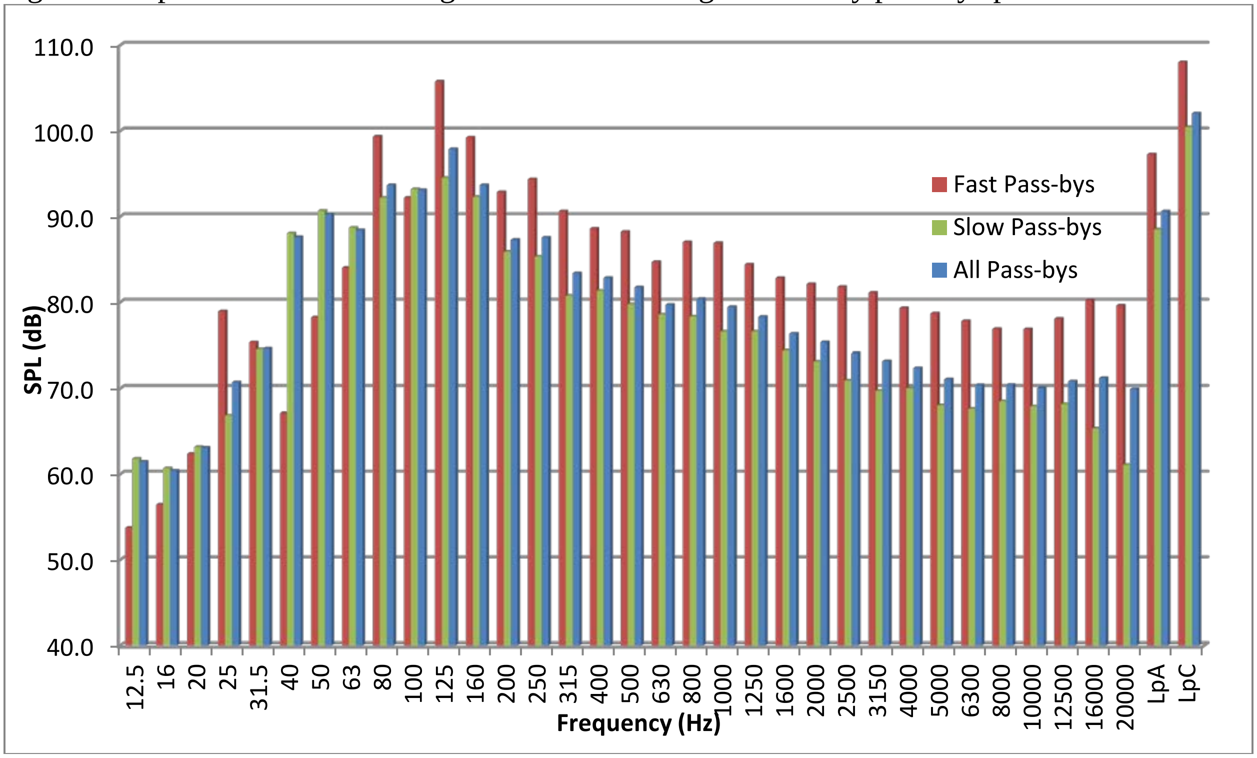
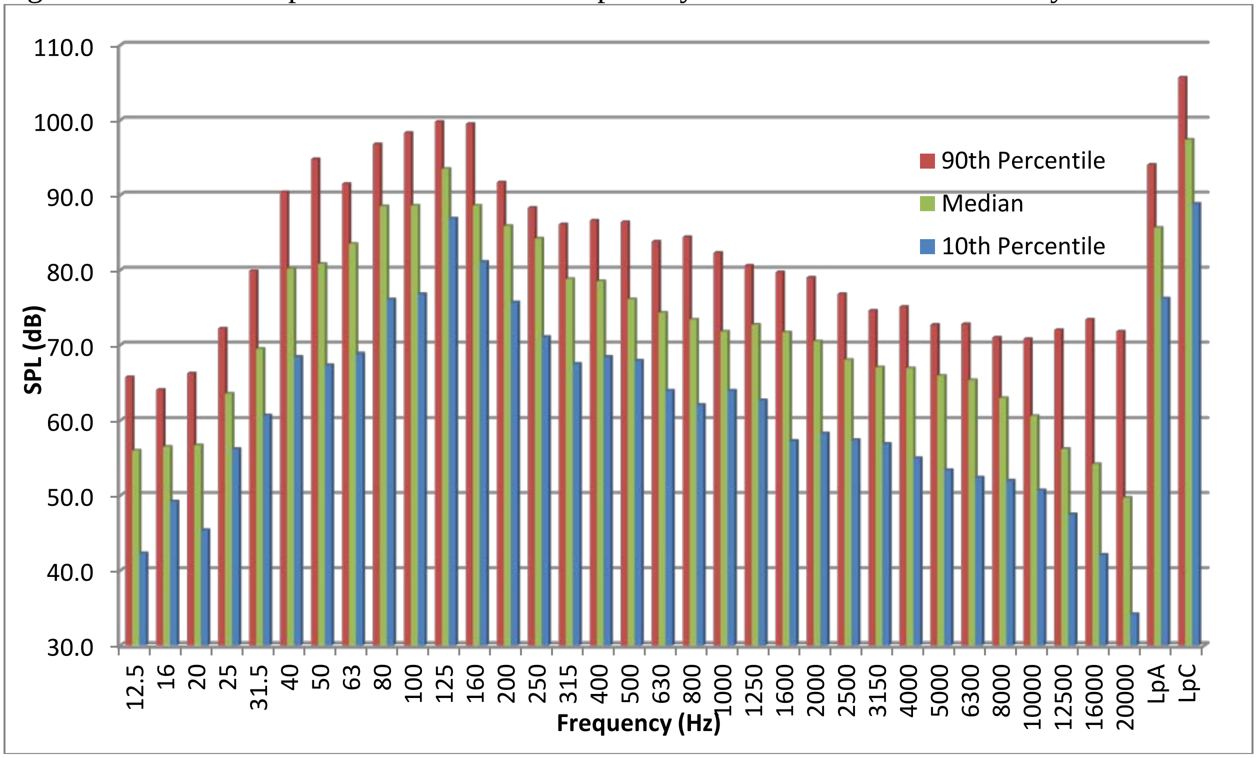


Figure 14 below shows the 90th percentile, 10th percentile, and median spectral levels for all pass-by events at Shark River Slough. However, as explained above with North Nest Key motorboat events, percentile spectral levels do not accurately reflect the complex frequency relationships of operating noise sources and therefore represent spectral events that probably never occurred. Consequently, the total calculated levels (LpA and LpC) at the right hand edge of the plot deviate from the actual percentile levels in Table 7 by approximately 2 - 4 dB.

Figure 14. Percentile spectral levels of airboat pass-bys at Shark River Blue Shanty canal



<u>Flamingo Campground</u>

At Flamingo campground, a short-term measurement was made on Sunday, April 20, 2008. The measurement was intended to capture the noise levels of one or more RV power generators. On that Sunday morning, there were very few RVs present. None of the RVs were using their generators until one pulled up to the dump station to empty waste water before leaving. Because it was considered important to capture the sound levels from an operating RV generator, an attempt was made to capture the noise levels produced by its operating generator.

RV power generator noise measurements were made at specific angles and distances. Distances were determined using a laser rangefinder. As with other noise sources, generator measurements were made at a 1.5 m (5 ft) height, with the microphone oriented at the appropriate angle toward the noise source for flat frequency response. Different angles were chosen in order to capture some spatial variation in generator noise, as well as to avoid potential reflections that might influence the measurement levels. RV power generator noise can be expected to vary according to engine size, muffler, engine speed, and electrical load. However, since generator load does not vary rapidly and engine speed in revolutions per minute (RPM) is often controlled, RV power generators typically operate at relatively constant speeds.

Table 9 shows the time-average sound levels and associated octave band spectral levels for the RV generator measured at the Flamingo campground on April 20, 2008. The generator was a standard model on a Georgie Boy RV. It was believed to be a Cummins Onan or Kohler unit, between 4 - 6 kW in size. Measurements were made for at least 60 second durations; however, analyzed segments were somewhat shorter depending on judged ambient influence. For purposes of noise modeling and general impact assessment at greater distances, it is believed that the 10 m location is closest to typical measurement standard distance and its associated levels best suited for use as generator noise source spectra.

Table 9. Time-average sound levels for an RV generator at the Flamingo campground

Noise Source	Distance (m)	Octave Band Levels (dB)									L_{Aeq} (dBA)	L_{Ceq} (dBC)
		31.5	63	125	250	500	1000	2000	4000	8000		
RV Generator	5	77	73	68	63	62	59	56	48	47	64	78
	10	74	66	60	59	58	51	47	42	40	58	73
	20	68	64	56	55	50	45	42	38	36	52	68

The time-average sound levels and associated spectral levels shown in Table 9 for the measured RV generator at Flamingo campground are displayed in greater detail in Figure 15 below. Examination of Table 9 indicates that at distances of 10 m and greater, the A-weighted sound levels are dominated by spectral contributions in the 250 - 2000 Hz octave bands. One can conclude from comparison with Table 2 thresholds that noise levels from a single RV generator levels can disrupt normal conversation at close distances of 5 m, and that if any part of a group were to move within 20 m of this noise source, speech from an interpretive talk could be difficult for those participants to hear. The total levels and potential for speech interference would increase with the number of operating RV generators in the campground. For equivalent conditions including distance and source levels, each doubling of sources will produce a 3 dB increase in the total sound level. For 2 sources, one can expect a +3 dB increase; for 32 sources, one can expect levels up to +15 dB higher than a single source. For the T loop in the Flamingo campground, 32 RVs would be the approximate number of vehicles when half full.

Figure 15. Time-average sound levels for an RV generator by distance

Fort Jefferson

At Fort Jefferson, short-term measurements were made on Monday, April 21, 2008. The measurements were made at several locations in order to better understand the magnitude of noise levels produced by the three onsite power generator sets (gensets) and the effect of potential mitigation measures. During the site visit, only two of the three gensets were operated. The decision of which genset to operate was made by onsite maintenance personnel according to noise considerations, functionality, genset warm-up times, and site power needs.

Fort Jefferson genset noise measurements were made at various angles and distances, both inside and outside of the fort. Outside distances were determined using a laser rangefinder. As with RV power generators, larger genset noise levels can be expected to vary according to engine size, muffler, engine/fan speed, and electrical load. Genset noise levels can fluctuate with load conditions, even when engine speed in RPM does not change considerably. Fort Jefferson operates three Multiquip (MQ Power) Model KD100 packaged diesel gensets rated at 80 kW continuous power. It is believed that the gensets utilize Volvo TAD520GE or similar engines.

Table 10 shows the time-average sound levels and associated octave band spectral levels for generator #1 at various exterior locations. Measurements were made for at least 120 second durations; however, analyzed segments were somewhat shorter depending on judged ambient influence. For purposes of noise modeling and general impact assessment at greater distances, it will be necessary to use closer near field measurements, room reverberation calculations, and estimates of expected contributions from engine exhaust, radiator fan, and case radiated noise.

Table 10. Time-average sound levels at exterior locations due to Fort Jefferson generator #1

Location	Time	Dist (m)	Octave Band Levels (dB)									L_{Aeq} (dBA)
			31.5	63	125	250	500	1000	2000	4000	8000	
on moat, inline w/ exhaust	12:09	26	54	74	60	59	64	60	57	51	42	65
on moat, 45° from wall	12:12	36	50	77	56	56	56	56	52	46	39	60
on beach, 40° from wall	12:16	50	47	72	53	54	56	50	47	39	32	56
on beach, 40° from wall	12:28	100	51	67	47	41	46	45	44	42	38	51
in campground, near site #3	13:14	92	53	67	50	41	45	41	37	31	27	46

The time-average sound levels and associated spectral levels shown in Table 10 are displayed in greater detail in Figure 16 below. Examination of Figure 16 reveals a relatively strong 60 Hz tone, as could be expected from a four pole genset operating at 1800 RPM. Because the tone is low in frequency, its rate of attenuation will be lower with distance than other generator sound sources. This may indicate the need for a different muffler design with better attenuation at 60 Hz. However, the large adjustment of A-weighting significantly reduces its contribution to the overall A-weighted level. When close to the fort, the spectral contributions above 400 Hz are stronger and more audible than the 60 Hz tone. The spectral components above 400 Hz are most likely due to a combination of radiator fan and case-radiated engine noise.

Figure 16. Time-average sound levels of Fort Jefferson generator #1 at exterior locations

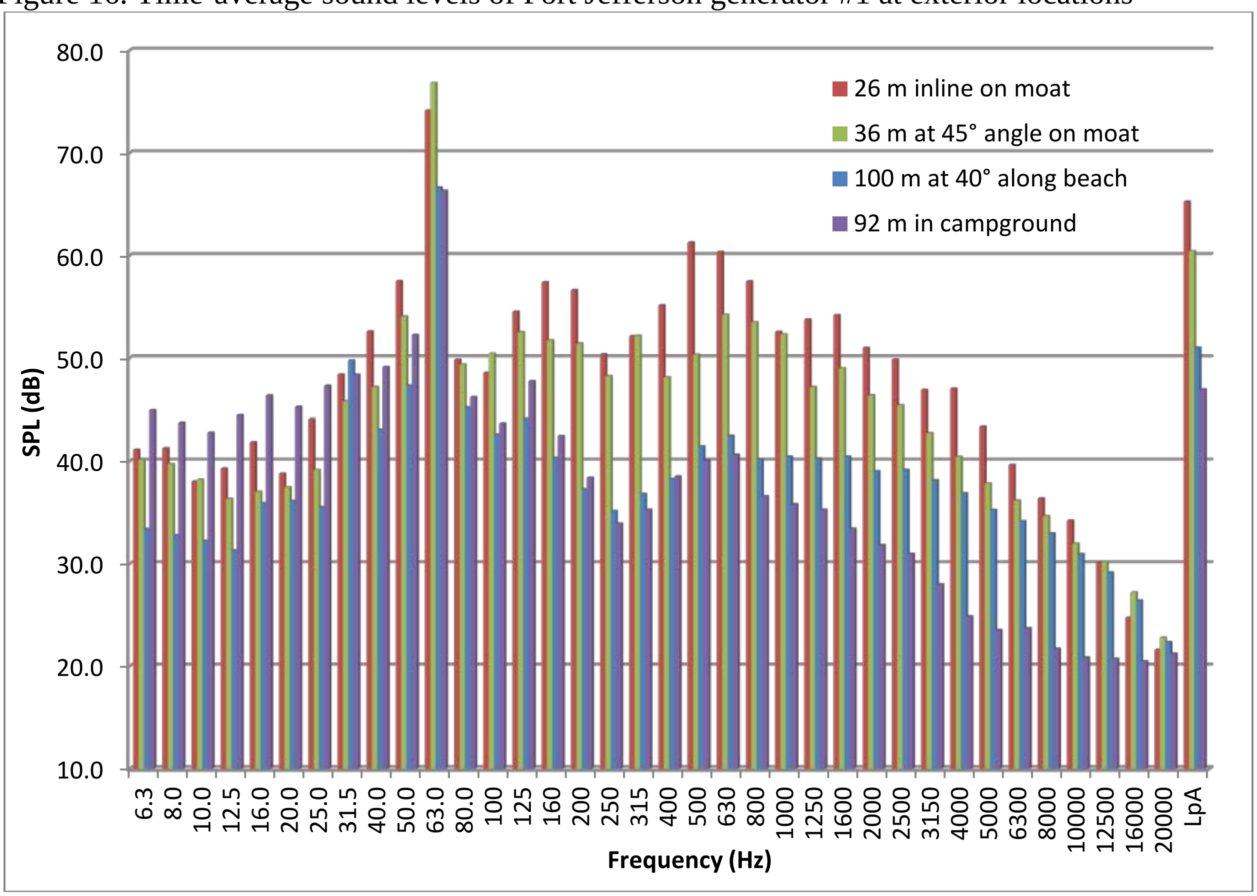


Table 11 shows the time-average sound levels and associated octave band spectral levels for generator #3 at various exterior locations. Generator #3 was chosen by onsite personnel for the reasons described above. As with generator #1, measurements were made for minimum 120 second durations and analyzed segments were for shorter periods. Unfortunately, due to sound level meter key bounce or other failure, there was insufficient measurement duration at the 50 m distance to assess generator #3 sound levels at that distance. Measurements were not made in the campground because they were redundant or ambient conditions did not permit measurement.

Table 11. Time-average sound levels at exterior locations due to Fort Jefferson generator #3

Location	Time	Dist (m)	Octave Band Levels (dB)									L_{Aeq} (dBA)
			31.5	63	125	250	500	1000	2000	4000	8000	
on moat, inline w/ exhaust	11:25	25	56	79	64	64	69	66	61	55	45	70
on moat, 45° from wall	11:52	35	51	77	58	59	60	61	55	50	41	64
on beach, 40° from wall	11:54	50	-	-	-	-	-	-	-	-	-	-
on beach, 40° from wall	11:59	100	47	66	49	46	48	46	44	41	34	52

Comparison with Table 2 thresholds shows that exterior noise levels from the Fort Jefferson gensets are of concern for speech intelligibility and interpretive activities. The generator levels can be expected to disrupt normal conversation on the moat walkway, as well as any interpretive talks. Even at distances of up to 100 m along the beach, if any part of a group were to move too far from the speaking interpreter, speech from that talk could be difficult for those participants to hear. While the generator noise level in the campground was lower, the level nevertheless exceeded World Health Organization's recommendation for maximum noise levels inside bedrooms and was higher than the threshold determined to increase blood pressure and heart rate in sleeping humans as described in the Data and Metrics section above. Therefore, whether or not campers are awakened, it is reasonable to conclude that existing genset noise levels may cause some undesirable stress for Fort Jefferson campers.

Inspection of Tables 10 and 11 also shows that generator #3 produced sound levels 4-6 dB higher than generator #1 at moat measurement locations. The reason for this could not be confirmed, but onsite speculation included radiator fan noise increase due to airflow restriction from the louvers. For unknown reasons, it appeared that the louvers for one genset did not open as far as the others. Also, occasional rattle was heard from one of the louvers.

As with generator #1, the spectral levels for generator #3 are displayed in greater detail in Figure 17 below. Examination of Figure 17 reveals the same prominent tone at 60 Hz, but also strong contributions above 400 Hz. These contributions are even stronger than those for generator #1 and are similarly believed due to a combination of radiator fan and case-radiated engine noise. It is possible that differences in louver opening are contributing to the differences in level.

Figure 17. Time-average sound levels of Fort Jefferson generator #3 at exterior locations

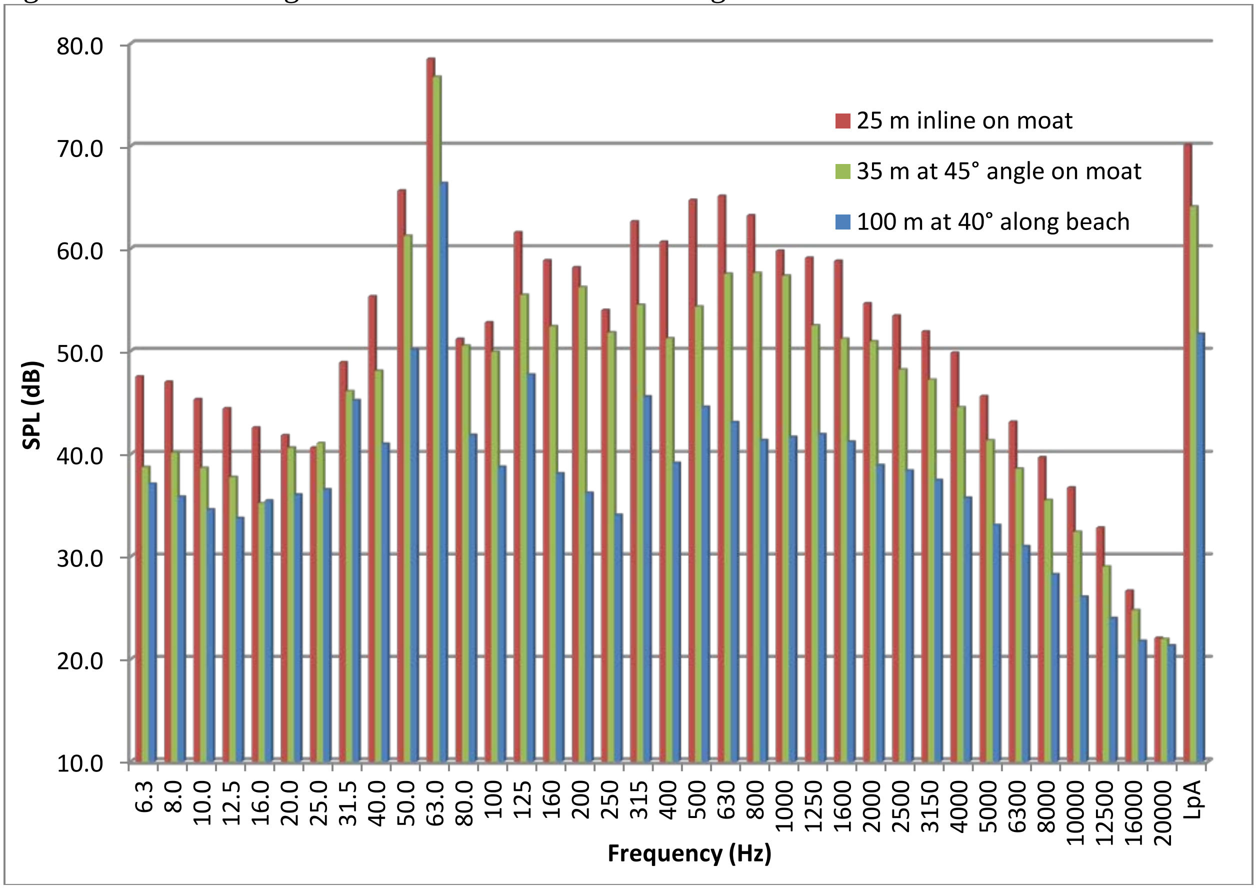


Table 12 provides the time-average sound levels and associated octave band spectral levels for generator #1 at various interior (courtyard) locations. The measured levels in the vicinity of the courtyard walkway exceeded the threshold in Table 2 for disruption of interpretive talks. Measurements of generator #3 were not made at courtyard locations because it was believed the acoustic paths would not be substantially different for the two generators, and therefore the measurement would be redundant.

Table 12. Time-average sound levels at interior locations due to Fort Jefferson generator #1

Location	Time	Dist (ft)	Octave Band Levels (dB)									L_{Aeq} (dBA)
			31.5	63	125	250	500	1000	2000	4000	8000	
entry, from sliding door	13:54	8	67	87	73	79	76	72	70	62	54	78
courtyard, from wall	14:00	15	56	71	54	57	54	52	46	36	30	57
courtyard, from wall	14:03	30	50	67	53	52	47	45	43	34	30	51

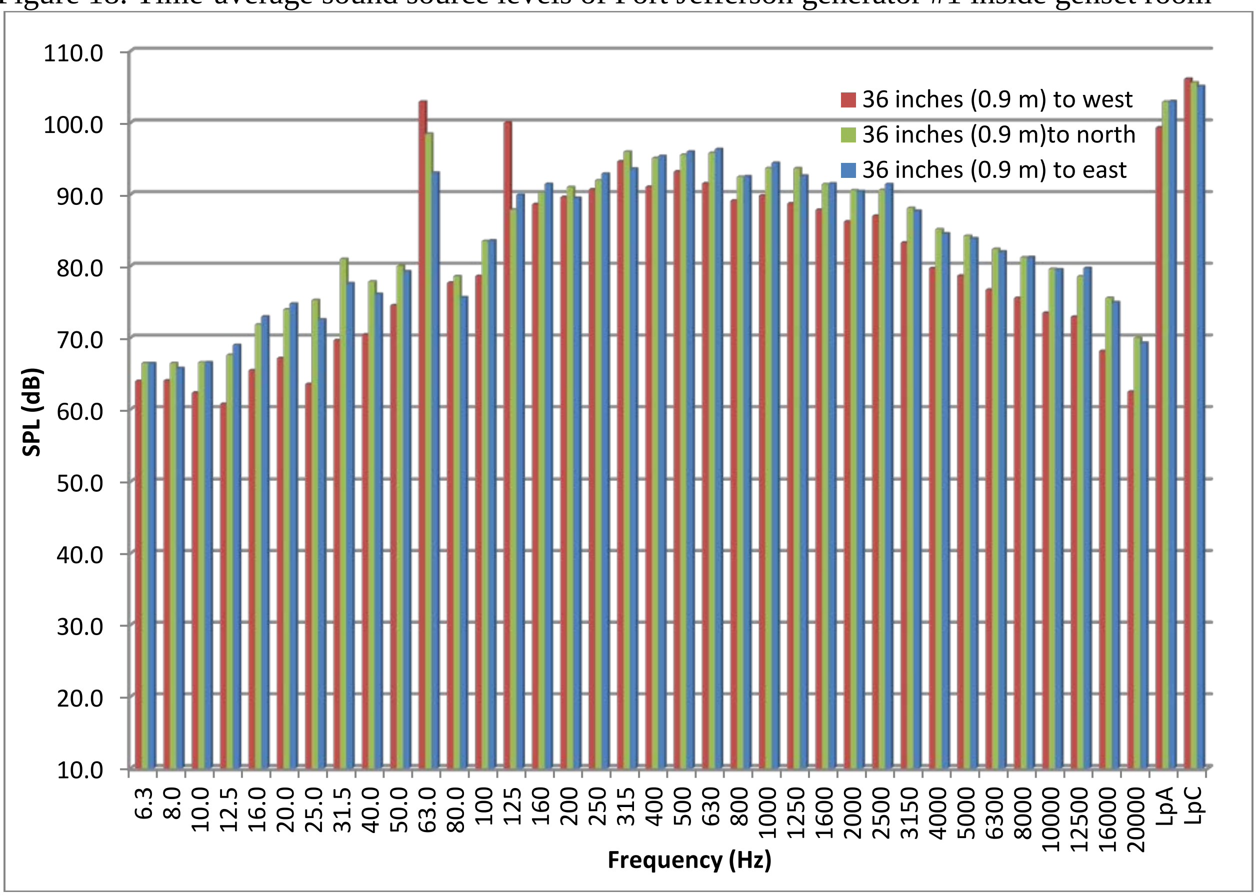
Table 13 lists the time-average sound source levels and associated octave band spectral levels for generator #1 inside the generator room. Measurements were made at the three exposed sides of the generator block (case) and at the end of the room. With the enclosure panels removed, the measured sound level in most of the room exceeds 85 dBA, which is the action level defined in 29 CFR 1910.95. This applies even if NPS employees may not necessarily spend long periods in the generator room. More specifically, when employees are subjected to an 8-hour time weighted average sound level of 85 dBA (action level) or higher, 29 CFR 1910.95 requires employers to administer a hearing conservation program. If employee noise exposures equal or exceed an 8-hour time weighted average of 90 dBA, 29 CFR 1910.95 requires feasible administrative and/or engineering controls to reduce worker noise exposure to below those levels. Measurements of generator #3 were not made inside the generator room because it was believed the acoustic paths would not be substantially different for the two generators, and therefore the measurement would be redundant.

Table 13. Time-average sound source levels of Fort Jefferson generator #1 inside genset room

Location	Time	Dist (m)	Octave Band Levels (dB)									L_{Aeq} (dBA)	L_{Ceq} (dBC)
			31.5	63	125	250	500	1000	2000	4000	8000		
on west side of case	14:13	0.9	74	103	100	97	97	94	92	86	80	99	106
on north end of case	14:16	0.9	83	99	93	98	100	98	96	91	86	103	106
on east side of case	14:19	0.9	81	93	94	97	101	98	96	90	86	103	105
west end of room	14:22	15	72	82	74	85	82	81	76	70	64	85	89

The time-average sound levels and associated spectral levels inside the generator room are displayed in greater detail in Figure 18 below. Figure 18 contains the same strong tone at 60 Hz seen in the previous spectral plots but also includes a 120 Hz tone measured at one location. However, both are considerably less significant when compared to the relative contribution of spectral components above 400 Hz. Consequently, noise control efforts such as returning the enclosure walls would probably be effective for reducing these components and the overall level.

Figure 18. Time-average sound source levels of Fort Jefferson generator #1 inside genset room



Mitigation of Large Power Generator Sets

Generator set acoustic sources typically include engine exhaust noise, case-radiated engine noise (particularly with diesel engines), cooling fan noise, and to a lesser extent, alternator/induction noise. In part because case-radiated and cooling fan noise are so significant for large generators and resulting indoor levels often exceed OSHA regulatory limits for hearing loss prevention, generator sets are often placed in noise attenuating enclosures to limit the amount of radiated sound. However, even standard enclosures can be expected to significantly reduce radiated genset sound. According to a Cummins news feature document, standard enclosures typically reduce radiated noise by a minimum of 10 dBA (Aaberg, 2007, p. 9).

Fan noise is dependent on several related parameters, including the fan design, size, speed, airflow (volume per second), and static pressure. If not appropriately selected, louvers installed inline with a cooling fan can cause excessive airflow restriction and static pressure that could reduce fan performance and simultaneously increase noise levels. This may be especially true of air actuated louvers, if actuation pressure is excessive.

During the site visit on April 21, 2008, inspection of the generator setup was made, and pictures were taken. The pictures show that side panels were removed from the generators, reportedly to help improve genset cooling. Four fans were observed to be operating: two wall fans, the generator fan, and a large portable room fan directed toward an exposed generator engine.

At the time of the visit, the east wall fan near the courtyard entry was blowing air into the room, while the west fan by a shop room was blowing air out of the room. The genset fan was blowing heated air out into the moat area and appeared to be moving the greatest air volume. In fact, even though the west wall fan was blowing air out of the room, the net effect of the genset fan was to suck the air back into the room via the opening above the door. One can conclude that the resulting airflow of the west fan by the shop room was at least partly ineffective, producing circular airflow above and around the door, and potentially worsening room temperatures by forcing higher, potentially hotter air to come into the room from above the door. The gensets require a steady supply of incoming cool air, and since the genset radiator fans are set up by default to blow heated air out of the room (into the moat area), all other fans should be set up to assist. It was therefore suggested during the site visit and remains recommended that all wall fans be set up to blow cool air into the generator room.

In general, most of the Fort Jefferson genset cooling is expected to come from cooling airflow across the radiator, and to a lesser extent, cooling airflow across the engine case. Optimum cooling should be guaranteed by ensuring that genset radiator airflow (and coolant flow) is not compromised. It is believed that unless radiator airflow is otherwise compromised by louvers, small inlet/exhaust duct area, or other restrictions, removing side panels from the standard enclosure should ideally not produce a large improvement in genset cooling. Furthermore, assuming that the end panel at the north (generator) side of the genset is completely open, airflow across an otherwise enclosed engine case may be equal or greater than the airflow produced by a portable room fan across an open generator enclosure. Unless engineers at the genset manufacturer (MQ Power or perhaps Volvo) advise otherwise, it is believed that the genset should not require a portable room fan and side panels can remain on the enclosure. However, a sufficient supply of cool room air is nevertheless required, and the end panel at the north (generator) side of the genset may need to remain open to ensure good radiator airflow.

In summary, the following steps are recommended to ensure adequate Fort Jefferson genset cooling and to reduce genset noise at exterior locations, including the moat wall, beach, and campground. In addition, if sound absorbing material can be added to the interior of partially enclosed gensets (side panels in place) and one interior wall, the aforementioned treatments can also be expected to produce simultaneous level decreases at interior locations, including the generator room, fort courtyard, and nearby residences for park staff.

- Consult with genset manufacturer (MQ Power) for minimum cooling requirements, e.g. airflow (in cfm or other measure), intake air temperature, static pressure, duct size, etc.
- Unless MQ Power engineers advise otherwise, genset enclosure side panels should ideally be installed
- Compare known or estimated static pressure drop of existing louvers and radiator discharge duct size to above requirements
- If indicated, replace existing louvers with a different design that achieves outside weather protection needs and produces less static pressure drop and/or rattling noise
- Replace radiator discharge (outlet air) duct with a sound trap or sound attenuating S duct lined with suitable sound absorbing material (Aaberg, 2007, pp. 10-11), in accordance with manufacturer-recommended cooling requirements
- Line at least 30% of the existing genset enclosure interior with sound absorbing material
- Construct a cool air intake with a sound trap or sound attenuating S duct; if this is not possible and the north (generator) end panel must remain open, consider constructing a solid baffle with sound absorbing material inline and facing the genset or applying sound absorbing material to a large area of the facing wall
- Ensure that other than the required openings for the air intake and radiator discharge (outlet air) duct, there are no major exposed openings in the enclosure; seal all penetrations
- Ensure that a steady supply of cool generator room air is available
- Monitor genset radiator coolant/oil temperature vs. room air temperature before and after completion of sound mitigation work

Minimum recommended thickness for duct liners is 1.5-2 inches, while minimum thickness for enclosure lining is 4-6 inches. For a given material, a greater thickness will generally result in better low frequency performance. If possible, sound absorbing materials should be applied to the interior of opaque genset enclosure areas such as the ceiling, side panel supports, base, and radiator end wall. Suitable sound absorbing material may include fiberglass, mineral wool, or other oil resistant and flame retardant products (Aaberg, 2007, pp. 10). Fiberglass may be covered in a resin coating/ mat facing or encapsulated in a thin (acoustically transparent) Mylar film if required for cleanability and mildew resistance.

If the aforementioned genset mitigation measures can be implemented for all operating generators, then it is expected that the health and speech criteria in Table 2 will be met for most exterior and interior (courtyard) locations. However, reduction of genset noise to levels below the threshold for blood pressure and heart rate increase in sleeping humans will require additional measures. If the genset cooling system cannot reasonably accommodate basic requirements outlined above for a standard or noise attenuating enclosure, then at the discretion of the park, it should be considered whether the gensets should be replaced with a new system that is more energy efficient, reduces noise, and is compatible with standard enclosures and existing onsite temperatures.

Additional measures for reducing existing genset noise below threshold for blood pressure and heart rate increase may include installation of a battery-based energy storage system such as is used in hybrid generator systems at several Alaska parks to store excess generated power when continuous genset operation is not required (Propane Council, 2006, 2007). This could allow the genset to be turned off during sensitive times such as overnight hours when generator requirements may be lower. Another option may be propane fuel cells such as have been installed at Kenai Fjords (Propane Council, 2006). As with Denali National Park maintenance staff, who consulted with Federal Energy Management Program (U.S. DOE) staff and benefited from a technical assistance grant, Everglades and Dry Tortugas National Park staff could contact FEMP staff for similar ideas on how to reduce noise pollution, air pollutants, and ground contamination risks (U.S. DOE FEMP, 2003).

Conclusion

Motorboat, airboat, and generator noise levels were measured under the specific conditions described above. Measurement sites and noise sources were selected in conjunction with onsite personnel to provide best guidance toward planning efforts and potential management decisions anticipated at that time. The provided data are based on described conditions and all information available to the NPS Natural Sounds Program office at the time of this report.

Inspection of the data in the tables and figures above shows that noise levels from the measured sources vary widely according to source, operating condition, and distance, among other factors. Airboats are clearly the loudest noise sources measured during the 2008 visit, and therefore, their use needs to be considered carefully, especially in sensitive areas. Even when operated at a low throttle condition, airboat noise levels are quite significant. However, at the measurement locations, most of the other measured average or typical maximum levels were higher than the threshold in Table 2 for disruption of interpretive activities, and all were higher than the nighttime thresholds.

It should be noted that while increasing noise source distance has a substantial benefit in terms of noise reduction (minimum 6 dB decrease in noise for every each doubling of distance), limiting engine speed can also produce a substantial benefit in those cases where this is possible and the noise source cannot be moved or prevented from operating in a certain area. In other words, creation of motorboat no-wake zones or airboat speed limits that greatly reduce engine speed can produce large decreases in the noise levels that can be generated by those sources in sensitive areas. For RV generators, engine speed cannot be adjusted, but levels will go up rapidly with the number of generators operating in the campground. Therefore, the ideal situation is to eliminate the necessity of RV generators by providing plug-in AC power. When RV generator use is required, however, regulating time of generator operation is an effective way to ensure that noise impacts are minimized during sensitive hours.

Mitigation of Fort Jefferson generator noise is strongly recommended to improve visitor enjoyment, reduce noise impacts along the beach and nearby campground, ensure interpretive activities can continue uninterrupted, and to help reduce hearing loss risk for NPS employees that must enter the generator room.

Addendum

Since the original June 2010 draft of this report, Everglades National Park has made multiple substantive issues to address some of the issues mentioned in this report. In order to reduce RV generator noise in the Flamingo campground, the park has installed electric hook-ups at 41 campsites, the majority of T-Loop. According to the park, the electric hook-ups are very popular for convenience, comfort, noise and air quality, and improved visitor experiences. For more info, see press release: http://www.nps.gov/ever/parknews/everprflamingocampsites010711.htm In order to reduce motorboat noise in Florida bay, the park implemented a 9400 acre pole/troll and paddle zone (no combustion engine use) in a popular shallow water area near Flamingo, called Snake Bight. For more info, see: http://www.nps.gov/ever/poleandtroll.htm Key objectives for the project were a strong connection to natural sounds (wildlife viewing, paddling opportunities, wilderness values).

Note: This is a summary report designed to assist park staff in understanding noise source measurements, associated operating conditions, and potential mitigation measures. Noise sources produce sound levels that vary considerably, depending on parameters such their size, type, construction, mounting, power, operating condition, and many other factors. The sound levels presented here are not intended to be comprehensive or inclusive of all park motorboat, airboat, and generator noise sources, but rather ones with similar operating conditions and other relevant site parameters.

Due to the complexity of noise sources and associated parameters, onsite sound level measurements are often required when such data is not published or otherwise available. If there are any questions or concerns about the information in this document, please contact the Natural Sounds Program. Thank you for your interest in NPS noise measurements.

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