National Park Service
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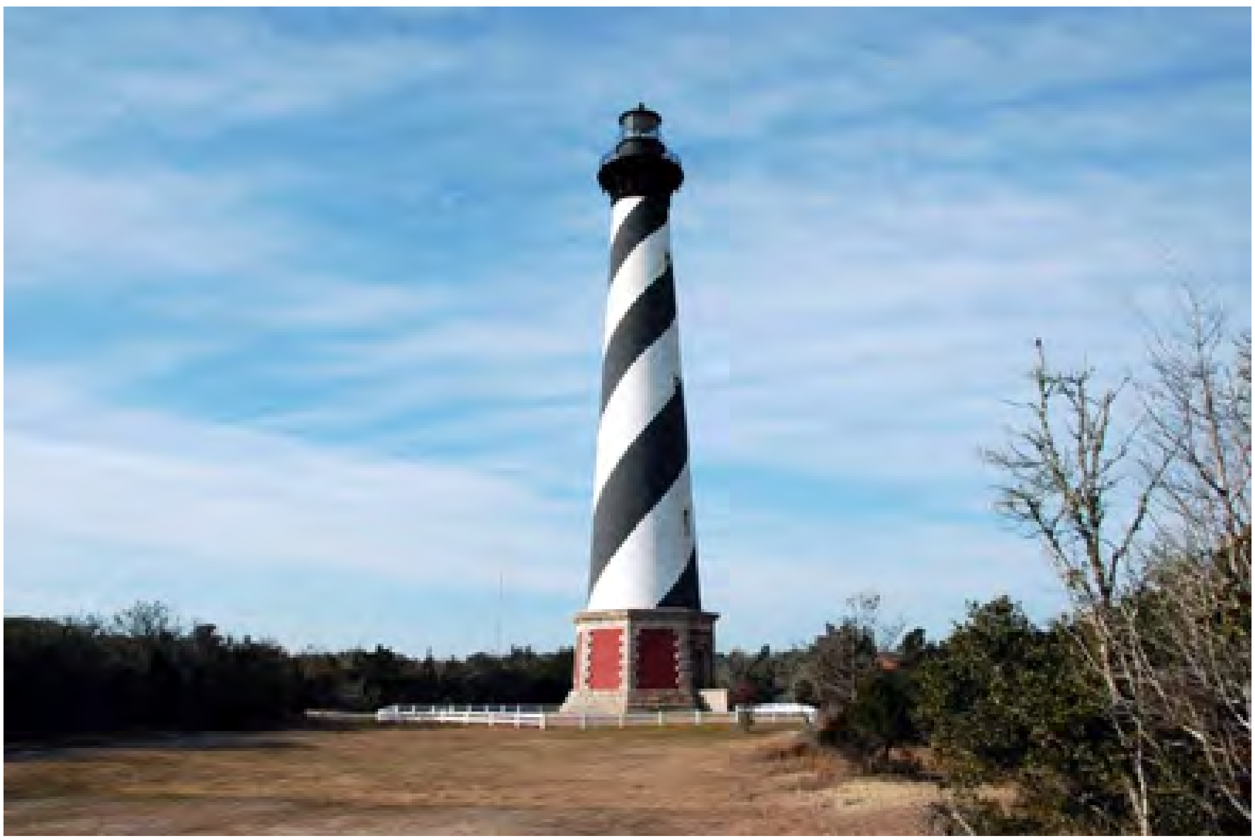
Natural Resource Stewardship and Science

Cape Hatteras National Seashore

Acoustical Monitoring 2008 and 2011

Natural Resource Report NPS/NRSS/NRR—2014/871



ON THE COVER
Cape Hatteras National Seashore, taken in 2008
Photograph courtesy Volpe Center

Cape Hatteras National Seashore

Acoustical Monitoring 2008 and 2011

Natural Resource Report NPS/NRSS/NRR—2014/871

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13. ABSTRACT (Maximum 200 words)
During the summer of 2008(May) and winter of 2011 (September-November) baseline acoustical data were collected at Cape Hatteras National Seashore at three sites deployed for approximately 30 days each. The baseline data collected during these periods will help park managers and planners estimate the effects of future noise impacts and will help to inform future park planning objectives such as creating soundscape management plans, as well as the development of an Air Tour Management Plan (ATMP), which provides for the regulation of commercial air tours. The sound sources of concern at Cape Hatteras include developments near park boundaries, air tours, commercial and private aircraft activities, and requests for special use permits for noisy activities. This document summarizes the results of the noise measurement study.

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Table of Contents

Page

Figures

Figures (continued)

Page

Tables

Executive Summary

During September to November of 2011, two acoustical monitoring systems were deployed by National Park Service (NPS) personnel in Cape Hatteras National Seashore (CAHA). The purpose of this monitoring effort was to characterize existing sound levels and estimate natural ambient sound levels in these areas, as well as identify audible sound sources in support of the potential development of an air tour management plan (ATMP). This report provides a summary of results of these measurements, representing CAHA's winter season. This report also includes measurement data collected during May and June of 2008, representative of the summer season.

In determining the current conditions of an acoustical environment, the National Park Service (NPS) examines how often sound pressure levels exceed certain decibel values that relate to human health and speech. The NPS uses these values for making comparisons; they should not be construed as thresholds of impact. Table 1 and Table 2 report the percent of time that measured levels were above four sound level values at each of the measurement locations in dBA and dBT. The first value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis, et. al., 2008). The second value is based on the World Health Organization's recommendation that noise levels inside bedrooms remain below 45 dBA (Berglund, et. al., 1999). The third value, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (Environmental Protection Agency, 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m (3 ft). Hikers and visitors in the park would likely be conducting such conversations.

Table 1. Percent Time Above Metrics (dBA).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
Summer season (2008)									
CAHA001	Bodie Island Boneyard	87.9	11.0	2.1	0.2	98.5	25.7	2.6	0.1
CAHA002	Cape Point	99.9	46.3	3.6	0.3	100.0	90.6	30.6	0.1
CALO001	Portsmouth Island	90.4	24.2	2.0	0.2	100.0	50.3	1.2	0.1
Winter season (2011)									
CAHA001	Bodie Island Boneyard	99.5	48.2	8.7	0.7	100.0	92.0	30.4	0.1
CAHA003	Oregon Inlet Campground	100.0	99.9	51.7	0.5	100.0	99.9	58.7	0.1

Table 2. Percent Time Above Metrics (truncated spectra – dBT).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
Summer season (2008)									
CAHA001	Bodie Island Boneyard	74.5	6.0	0.7	0.1	65.3	3.8	0.1	0.0
CAHA002	Cape Point	99.6	39.1	1.6	0.2	100.0	73.9	3.3	0.0
CALO001	Portsmouth Island	78.5	13.1	0.8	0.1	99.2	18.1	0.1	0.0
Winter season (2011)									
CAHA001	Bodie Island Boneyard	65.5	4.6	1.0	0.2	43.3	2.2	0.2	0.0
CAHA003	Oregon Inlet Campground	100.0	93.5	6.8	0.1	100.0	92.4	15.8	0.0

Table 3 and Table 4 summarize the daytime and nighttime* acoustical observer log data (off-site listening and *in situ* logging combined) which provide an indication of the amount of time that certain sources are present at each site. The *in situ* logging is performed during visits to the site itself; off-site listening is performed in the office using audio files that were collected at each site.

Table 3. Daytime acoustical observer log data (*in situ* and off-site listening combined).

Site ID	Site Name	% Time Audible: Daytime (7 am to 7 pm)			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
Summer season (2008)					
CAHA001	Bodie Island Boneyard	5.7	5.0	56.8	32.5
CAHA002	Cape Point	6.7	0.8	7.5	85.0
CALO001	Portsmouth Island	5.5	4.4	12.3	77.9
Winter season (2011)					
CAHA001	Bodie Island Boneyard	8.6	6.6	45.6	39.3
CAHA003	Oregon Inlet Campground	2.3	0.7	25.9	71.2

Table 4. Nighttime acoustical observer log data (off-site listening).

Site ID	Site Name	% Time Audible: Nighttime (7 pm to 7 am)			
		Fixed-Wing Aircraft and Helicopters	Aircraft Sounds	Other Human Sounds	Natural Sounds
Winter season (2011)					
CAHA001	Bodie Island Boneyard	0.0	5.9	22.8	72.3
CAHA003	Oregon Inlet Campground	0.0	2.0	9.5	88.5

* Nighttime acoustical observer logs are not available for the 2010 summer season.

Acknowledgments

The authors of this report wish to express their sincere gratitude to all who helped make this a successful study. The Federal Aviation Administration (FAA), Western-Pacific Regional Office, and National Park Service (NPS), Natural Sounds Office, proved invaluable coordination and support. We would also like to thank Meghan Carfioli and Sarah Strickland (Cape Hatteras National Seashore) for their assistance during site selection and deployment.

List of Terms

Acoustical Environment
The actual physical sound resources, regardless of audibility, at a particular location.

Amplitude
The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility
The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

dBA
A-weighted decibel. A-Weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

dBT
Truncated decibel. A measure of sound energy in the range of frequencies where transportation noise is most often focused (20 - 1250 Hz). Transportation is often a major contributor of low frequency sound, but this range does not correspond to a specific vehicle or type of transportation.

Decibel
A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: 20*(Log$_{10}$(sound level/reference sound level)). 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

Frequency
The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency)
By convention, an average, healthy, young person is said to hear frequencies from approximately 20 Hz to 20000 Hz.

Hertz
A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound
Any sound that is attributable to a human source.

L_{eq}
Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

L_x
A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period.

Masking
The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Noise-Free Interval
The period of time between noise events (not silence).

Noise
Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Off-site Listening
The systematic identification of sound sources using digital recordings previously collected in the field.

1. Introduction

An important part of the National Park Service (NPS) mission is to preserve and/or restore the natural resources of the parks, including the natural soundscapes associated with units of the national park system. The collection of ambient sound level data provides valuable information about a park's acoustical conditions for use in developing acoustic resource management plans.

Ambient data are also required to establish a baseline from which noise impacts can be assessed. The National Parks Air Tour Management Act of 2000 provides for the regulation of commercial air tour operations over units of the national park system through air tour management plans (ATMPs). The objective of the ATMPs is to develop acceptable and effective measures to mitigate or prevent significant adverse impacts, if any, of commercial air tour operations upon the natural and cultural resources of and visitor experiences in national park units as well as tribal lands (those included in or abutting a national park).

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the Federal Aviation Administration (FAA), Western-Pacific Region (AWP) and NPS, Natural Sounds and Night Skies Division (NSNSD) in the development of ATMPs.

Ambient data were collected at Cape Hatteras National Seashore (NS) during May and June 2008 to represent the summer season and September to November of 2011 to represent the winter season. An overview map of the areas managed by Cape Hatteras NS is shown in Figure 1. The purpose of this report is to provide a summary of the results of these measurements that will be used to represent the summer and winter seasons at Cape Hatteras NS.

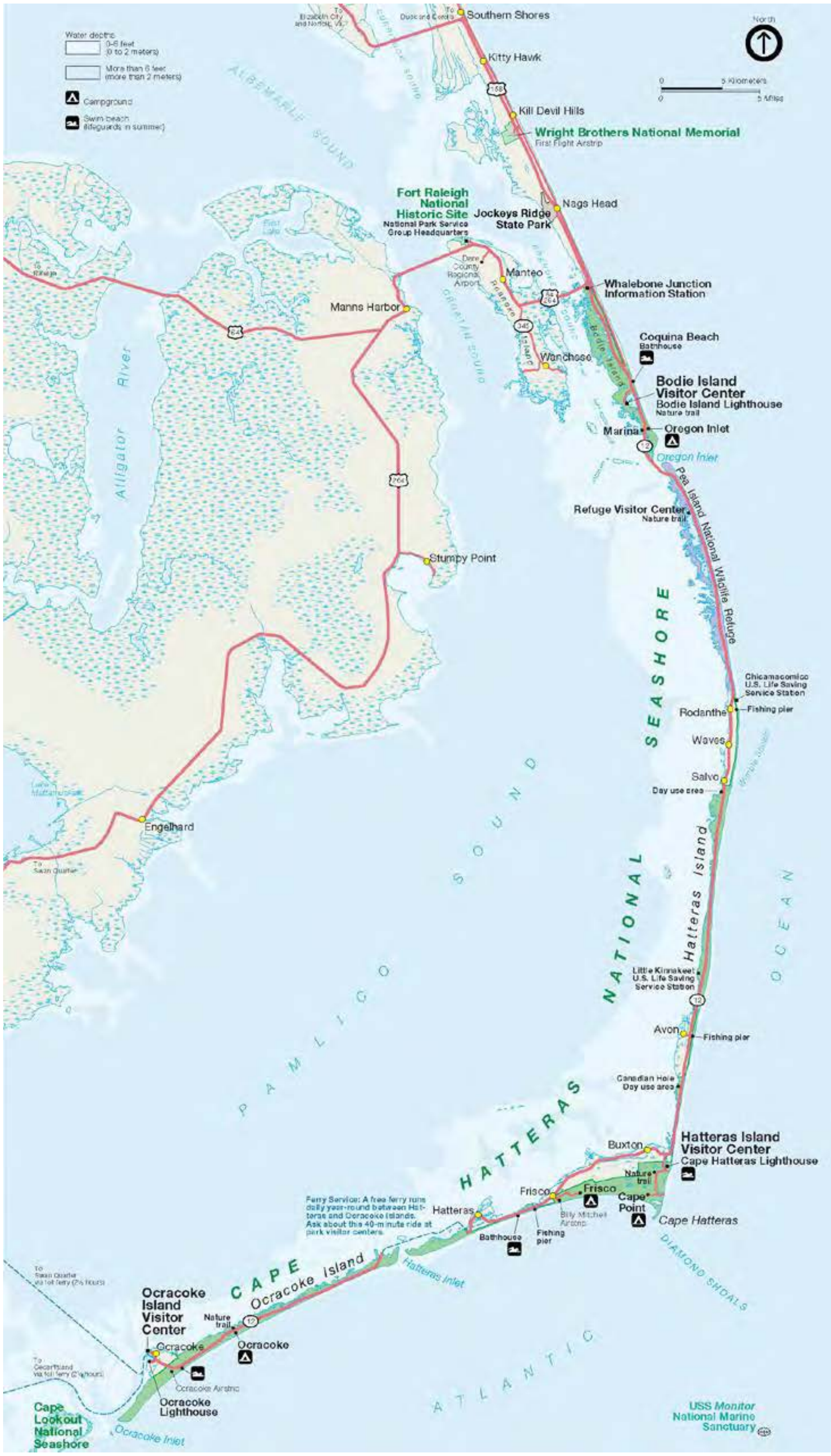

Figure 1. Map of Cape Hatteras National Seashore (National Park Service 2014).

2. Study Area

Two acoustical monitoring systems were deployed at Cape Hatteras National Seashore during September to November of 2011 to represent the winter season, while three systems were deployed at Cape Hatteras and Cape Lookout National Seashores during May to June of 2008 to represent the summer season.[2] These sites were selected based on discussion between Volpe, NSNSD, and CAHA personnel and are shown in Table 4. In 2011, a road overwash at Oregon inlet made points south inaccessible; therefore, CAHA002 and CALO001 could not be replicated.

Table 5. Summary of measurement sites selected for Cape Hatteras and Cape Lookout.

Site ID	Site Name	# Days of Data	NLCD[3] Classification	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
Summer season (2008)					
CAHA001	Bodie Island Boneyard	28 days	Emergent Herbaceous Wetlands	35.82550° 75.56966°	0.6 m (2 ft)
CAHA002	Cape Point	28 days	Shrub/Scrub	35.23439° 75.54999°	1.8 m (6 ft)
CALO001	Portsmouth Island	27 days	Barren Land	35.05145° 76.05454°	0.6 m (2 ft)
Winter season (2011)					
CAHA001[4]	Bodie Island Boneyard	34 days	Emergent Herbaceous Wetlands	35.82531° 76.56968°	1 m (3 ft)
CAHA003[5]	Oregon Inlet Campground	34 days	Barren Land	35.80307° 75.54476°	2 m (7 ft)

[2] Ambient data were not collected during the winter season at Cape Lookout NS. Summer season ambient data collected at Cape Lookout NS are presented herein, as the summer season baseline ambient maps for Cape Hatteras utilize this data.

[3] With the goal of potentially facilitating future data transferability between parks, all baseline acoustical data collected for the ATMP program have been organized/classified in accordance with the National Land Cover Database (NLCD). Developed by the U.S. Geological Survey (USGS), the NLCD is the only nationally consistent land cover data set in existence and is comprised of twenty-one NLCD subclass categories for the entire U.S. (Homer, C.C., et.al., 2004).

[4] Original measurement data files (log sheets, etc.) for the Boneyard site in 2011 ID this site as CAHA002. The site was renamed CAHA001for consistency between seasons.

[5] Original measurement data files (log sheets, etc.) for the Oregon Inlet Campground site in 2011 ID this site as CAHA001. The site was renamed CAHA003 for consistency between seasons.

3. Methods

3.1 Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed for continuous acoustical monitoring over both monitoring periods at Cape Hatteras. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and one-third octave-band data, and exports these data to a portable storage device (thumb drive). These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards (American National Standards Institute 1990).

In addition to the Larson Davis SLM, each acoustical sampling station consisted of:

- Microphone with environmental shroud
- Preamplifier
- Multiple 12V NiMH rechargeable battery packs
- Anemometer
- MP3 recorder
- Meteorological data logger
- Photo voltaic panels

Each acoustical sampling station collected:

- Sound level data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings
- one-third octave-band data every second ranging from 12.5 Hz – 20,000 Hz
- Meteorological data

3.2 Source Identification/Observer Logging

In characterizing natural and non-natural acoustic conditions in a park, knowledge of the intensity, duration, and distribution of the sound sources is essential. Thus, during sound-level data collection, FAA and NPS have agreed that periods of observer logging "*in situ*" (i.e., on site and in real-time) and/or off-site using high-quality digital recordings will be conducted in order to discern the type, timing, and duration of different sound sources. *In situ* observer logging takes full advantage of human binaural hearing capabilities, allows identification of sound source origin, simultaneous sound sources, and directionality, and closely matches the experience of park visitors. Off-site audio playback observer logging allows for sampling periodically throughout the entire measurement period (e.g., 10 seconds every 2 minutes) and repeated playback of the recordings (e.g. when the sound is difficult to identify). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment.

3.3 Calculation of Sound Level Descriptors

All sound-level data were analyzed in terms of the following metrics (also refer to the List of Terms section for definitions):

- L_{Aeq}: The equivalent sound level determined by the logarithmic average of sound levels of a specific time period;
- L_{50}: A statistical descriptor describing the sound level exceeded 50 percent of a specific time period (i.e., the median); and
- L_{90}: A statistical descriptor describing the sound level exceeded 90 percent of a specific time period.

Each descriptor is computed from the broadband A-weighted sound level and the 33 un-weighted one-third octave-band sound levels (12.5 to 20,000 Hz) which define the un-weighted sound level spectrum. The process of computing descriptors using the un-weighted one-third octave-band spectrum is virtually identical to the process for computing the broadband A-weighted sound level descriptors. Specifically, the un-weighted sound level descriptor is computed individually for each one-third octave-band. This method of constructing the sound level spectrum means the reported spectrum is not an actual measured one-third octave-band spectrum associated with a particular measurement sample, but a composite spectrum using the computed descriptor for each one-third octave-band.

3.4 Definitions of Ambient

The following four types of “ambient” characterizations are generally used and considered sufficient by the FAA and NPS in environmental analyses related to transportation noise (Fleming, et. al., 1999), (Fleming, et. al., 1998), (Plotkin, 2002).

- *Existing Ambient:* The composite, all-inclusive sound associated with a given environment, excluding only the analysis system’s electrical noise (i.e., aircraft-related sounds are included);
- *Existing Ambient Without Source of Interest:* The composite, all-inclusive sound associated with a given environment, excluding the analysis system’s electrical noise and the sound source of interest, in this case, commercial air tour aircraft;
- *Existing Ambient Without All Aircraft (for use in assessing cumulative impacts):* The composite, all-inclusive sound associated with a given environment, excluding the analysis system’s electrical noise and the sounds produced by the sound source of interest, in this case, all types of aircraft (i.e., commercial air tours, commercial jets, general aviation aircraft, military aircraft, and agricultural operations);[6] and
- *Natural Ambient:* The natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excluding all human and mechanical sounds.

[6] The definition of Existing Ambient Without All Aircraft used in this report is consistent with FAA’s historical approach for cumulative impact analysis.

If one considers the three sound level descriptors and the four types of ambient characterizations above, twelve ambient descriptors could potentially be computed as shown in Table 5.

Table 6. Matrix of twelve potential ambient descriptors.

Metric	Ambient Type			
	Existing	Existing Without Air Tours	Existing Without All Aircraft	Natural
L_{Aeq}	1	4	7	10
L_{50}	2	5	8	11
L_{90}	3	6	9	12

From the above twelve potential ambient descriptors, only the first three can be readily computed. The computation of ambient types other than Existing Ambient is more challenging because different sound sources often overlap in both frequency and amplitude; there is currently no practical method to separate out acoustic energy of different sound sources (i.e., human-caused sounds imbedded with natural sounds). The two ambient descriptors agreed upon for use in ATMP analyses are:

- L_{50}, Existing Ambient Without Source of Interest – Descriptor 5 from the table above; and
- L_{50}, Natural Ambient (L_{Nat}) – Descriptor 11 from the table above.

3.5 Calculation of Ambient

Using the data in the acoustical observer logs, different characterizations of ambient can be estimated from the sound level data. This method was developed throughdetailed data analyses conducted by the Volpe Center, working closely with the NPS, comparing several approaches of estimating of the Natural Ambient and is comprised of the following steps: (Rapoza et. al., 2008)

1) From the short-term *in situ* and off-site logging, determine the percent time human-caused sounds are audible.

2) Sort, high-to-low, the A-weighted level data, derived from the short term, one-second, one-third octave-band data (regardless of acoustical state), and remove the loudest percentage (determined from the percent time audible of human-caused sounds in the short-term observer logs) of sound-level data. For example, if from Step 1 above, it is determined that at a particular site, the percent time audible of all human-caused sounds is 40 percent, then the loudest 40 percent of the A-weighted level data is removed. The L_{50} computed from the remaining data is the estimated A-weighted natural ambient. This L_{50}, computed from the remaining data, can be mathematically expressed as an L_x of the entire dataset as follows (%TA is the percent of time human-caused sounds are audible in the short-term observer logs):

$$L_x, \text{ where } x = 50 + \frac{\%TA}{2}$$

For example, if non-natural sounds are audible for 40% of the time, L_0 to L_{40} corresponds to the loudest (generally non-natural) sounds, and L_{40} to L_{100} corresponds to the quietest (generally natural) sounds. The median of L_{40} to L_{100} data is L_{70}. Therefore, the A-weighted decibel value at L_{70}, the sound level exceeded 70 percent of the time, would be used for the entire dataset to characterize the natural ambient sound level.

3) The associated one-third octave-band un-weighted spectrum from 12.5 to 20,000 Hz is constructed similarly, except the L_{50} is computed from the remaining data for each one-third octave-band, mentioned earlier. It is not an actual measured one-third octave-band spectrum associated with a particular measurement sample, but rather a composite spectrum derived from the L_x for each one-third octave-band.

This method for estimating the natural ambient is conceptually straightforward – as percent time audible approaches 0 percent, the L_x approaches L_{50}; as it approaches 100 percent, the L_x approaches L_{100}. A concern with this approach is that sporadic, loud natural sounds, such as thunder, could be removed from the data before calculating natural ambient sound levels, and the resulting calculated natural ambient sound levels could be an under-estimate of natural ambient sound levels. Although this is a valid concern, such events are rare relative to the entire measurement period (>25 days). Therefore, removing these data should not likely have a significant impact on calculations of natural ambient sound levels. This method also eliminates the possibility of having an estimated natural ambient level that exceeds the existing ambient level.

Based on the concept of the above method, the computation of the other ambient types (Existing Without Air Tours, and Existing Ambient Without All Aircraft) is a similar process.

4. Results

This section summarizes the results of the study. Included are an overall summary of the final ambient sound levels for each measurement site, time analysis, temporal trends, and the acoustical observer data logged at each measurement site.

4.1 Summary Results

The following figures and tables are presented to show overall site-to-site comparisons:

- Figure 2 presents a plot of the overall daytime[7] L_{50} sound level computed for each site (a few points of interest outside the parks are also shown for comparison purposes only). The figure also shows a dark line above and below each plotting symbol, which indicate the 95% confidence interval on the results;[8]
- Table 6 presents a tabular summary of the daytime and nighttime and computed ambients;
- Table 7 and Table 8 contain ambient spectrum data for the winter and summer seasons respectively; and
- Figure 4 and Figure 5 present the associated spectral data for these ambient maps.

[7] FAA and NPS have agreed that impact assessment will be conducted using ambient sound levels during the time that the air tour operations occur – typically daytime hours. Daytime (as used in this report) will refer to the time period 7 am to 7 pm; nighttime will refer to the time period 7 pm to 7 am. For Cape Hatteras ATMP analysis, only daytime data (measured during the time period of 7 am to 7 pm) will be used.

[8] The confidence interval is a measure of how certain one is of the value shown. The length of each of the dark lines indicate the day-to-day variability of the measurement for a particular site - the longer the line, the larger the day-to-day variability.

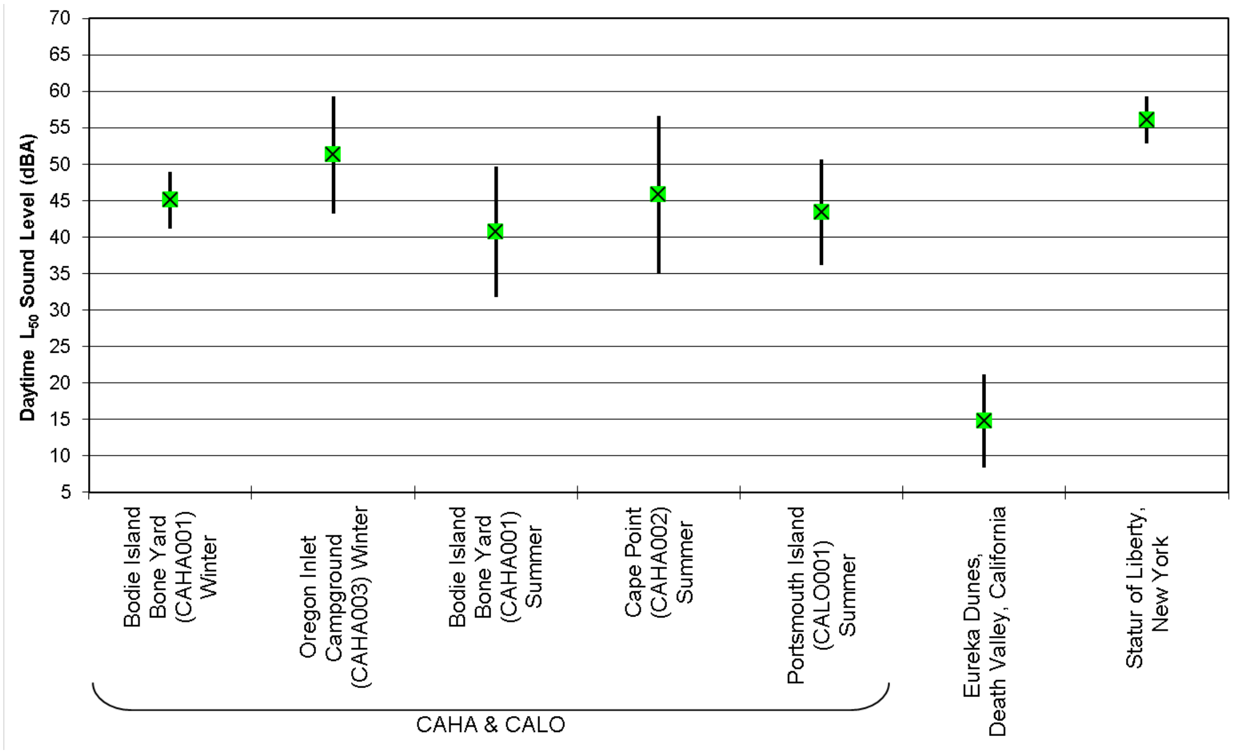

Figure 2. Comparison of overall daytime L_{50} sound levels.

Table 7. Summary of measured ambient sound level data. [9]

Site ID	Site Name	Total # Days	Existing Ambient						Existing Ambient Without Air Tours (Daytime Data 7 am to 7 pm)	Existing Ambient Without All Aircraft (Daytime Data 7 am to 7 pm)	Natural Ambient (Daytime Data 7 am to 7 pm)
			Daytime Data Only: 7 am to 7 pm			Nighttime Data Only: 7 pm to 7 am					
			L_{Aeq} (dBA)	L_{50} (dBA)	L_{90} (dBA)	L_{Aeq} (dBA)	L_{50} (dBA)	L_{90} (dBA)	L_{50} (dBA)	L_{50} (dBA)	L_{50} (dBA)
Summer season (2008)											
CAHA001	Bodie Island Boneyard	28	48.1	40.5	33.8	48.7	42.6	32.6	40.0	39.7	35.1
CAHA002	Cape Point	28	47.6	40.5	31.9	52.1	47.8	38.7	39.7	39.4	38.5
CALO001	Portsmouth Island	27	45.4	39.6	30.6	49.6	45.1	39.6	39.0	38.6	37.3
Winter season (2011)											
CAHA001	Bodie Island Boneyard	25	49.2	43.6	40.4	51.2	50.3	45.3	43.3	43.0	41.4
CAHA003	Oregon Inlet Campground	71	53.0	51.3	49.0	53.0	51.7	43.4	51.3	51.3	50.7

[9] As stated earlier, two ambient maps were agreed upon for use in ATMP analyses: the Existing Ambient Without Air Tours (L_{50}) and the Natural Ambient (L_{50}).

Table 8. Summary of measured, daytime (7 am to 7 pm), ambient sound level spectral data, Existing Ambient Without Air Tours L_{50}.[10]

Frequency (Hz)	Summer season (2008)			Winter season (2011)	
	CAHA001	CAHA002	CALO001	CAHA001	CAHA003
12.5	50.4	60.9	59.4	44.2	64.0
16	48.9	58.3	56.3	44.5	62.1
20	47.2	55.4	53.0	44.2	60.1
25	46.2	53.1	50.4	44.7	58.4
31	45.4	50.6	48.0	45.8	56.7
40	45.1	48.4	46.9	44.9	55.2
50	43.7	46.7	45.3	43.8	54.1
63	43.5	45.8	43.5	43.1	53.1
80	42.2	44.7	42.9	42.2	52.9
100	39.2	42.6	41.8	38.8	52.3
125	34.7	40.9	39.3	34.0	50.0
160	30.4	38.2	36.0	30.2	46.8
200	28.8	35.5	31.8	28.7	43.8
250	28.3	32.9	28.5	29.5	43.3
315	29.0	30.9	28.4	29.9	44.4
400	30.4	29.7	30.0	30.8	43.8
500	31.3	29.0	30.7	31.1	42.5
630	31.2	29.0	29.9	29.8	41.5
800	30.3	28.3	27.2	27.2	41.7
1000	28.3	27.4	25.4	24.3	41.5
1250	26.1	26.2	24.7	21.9	40.9
1600	23.7	24.6	23.6	19.5	39.9
2000	21.8	23.1	22.3	17.3	38.8
2500	22.1	21.7	21.6	16.8	37.5
3150	21.8	19.7	21.9	17.5	35.6
4000	21.1	17.6	20.6	19.3	33.0
5000	19.5	16.8	19.9	18.8	30.3
6300	16.1	12.9	16.3	28.7	27.0
8000	16.0	11.4	15.4	37.6	22.6
10000	15.4	10.5	15.0	27.6	17.4
12500	14.0	9.7	12.1	22.5	12.2
16000	10.2	8.7	8.1	21.7	8.0
20000	11.4	9.3	10.4	11.4	6.7

[10] As discussed in Section 3.5, the spectral data associated with the L_{50} exceedence level is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

Table 9. Summary of measured, daytime (7 am to 7 pm), ambient sound level spectral data, Natural Ambient L_{50}.[11]

Frequency (Hz)	Summer season (2008)			Winter season (2011)	
	CAHA001	CAHA002	CALO001	CAHA001	CAHA003
12.5	45.7	60.3	57.9	41.3	62.3
16	44.6	57.7	54.8	42.1	60.4
20	44.0	54.8	51.2	42.2	58.6
25	43.4	52.6	49.3	43	57.3
31	43.2	49.9	47.4	44.2	55.4
40	42.5	47.8	46.2	43.2	54.2
50	41.4	46.2	44.7	42.1	53.3
63	41.0	45.5	43.1	40.2	52.4
80	39.4	44.3	42.7	39.6	52.2
100	36.2	42.3	41.6	35.8	51.5
125	32.1	40.7	39.0	31.5	49.4
160	28.1	38.0	35.7	27.9	46.2
200	26.5	35.5	31.5	27.2	43.2
250	26.2	32.7	28.2	27.6	42.7
315	27.1	30.6	28.1	28.6	43.9
400	28.6	29.5	29.7	29.6	43.3
500	29.8	28.7	30.3	30	41.9
630	29.4	28.5	29.5	28.5	41
800	28.1	27.5	26.8	25.9	41.1
1000	26.1	26.6	25.0	22.6	40.8
1250	24.0	25.8	24.2	20.1	40.1
1600	21.4	24.3	23.1	17.6	39.1
2000	19.1	22.7	21.8	15.4	37.9
2500	18.4	21.2	20.9	13.9	36.6
3150	16.9	19.1	20.6	13.2	34.9
4000	16.3	17.3	19.8	15.3	32.2
5000	15.8	16.0	19.1	14.4	29.3
6300	12.8	12.3	15.8	25.5	26.2
8000	13.2	11.1	14.8	34.2	21.9
10000	12.8	10.1	14.4	24.3	16.6
12500	11.2	9.3	11.4	19.9	11.5
16000	7.3	8.4	7.6	18.9	7.5
20000	9.8	9.1	10.2	8.6	5.8

[11] As discussed in Section 3.5, the spectral data associated with the L_{50} exceedence level is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

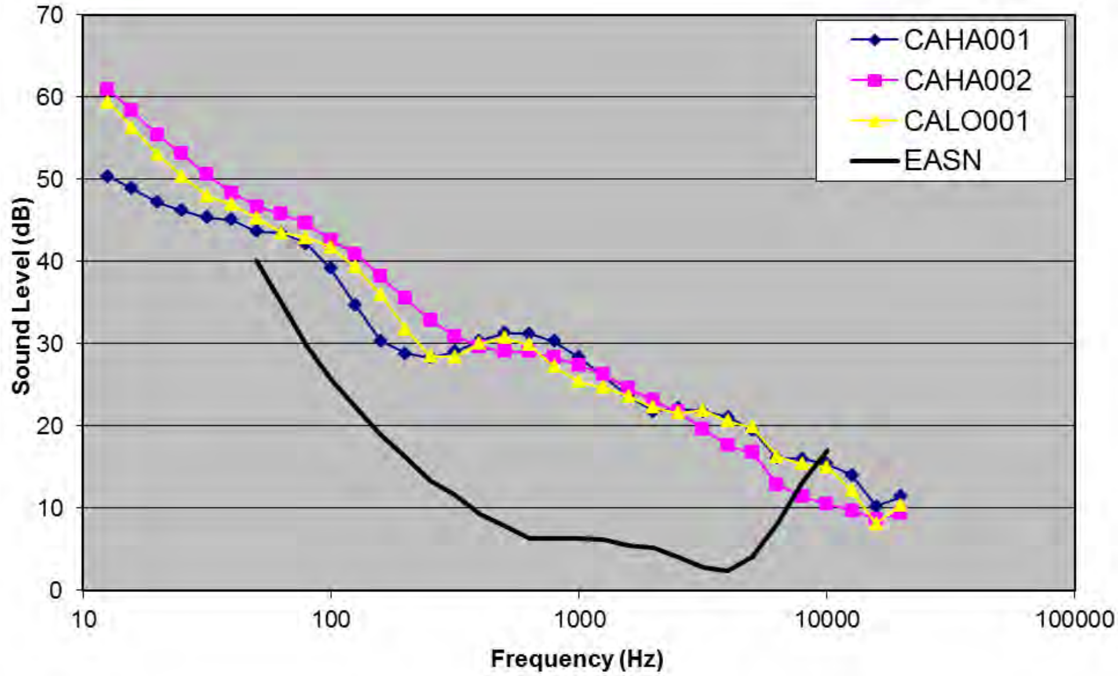

Figure 3. Spectral data for the existing Ambient Without Air Tours (L_{50}), summer season (2008).[11]

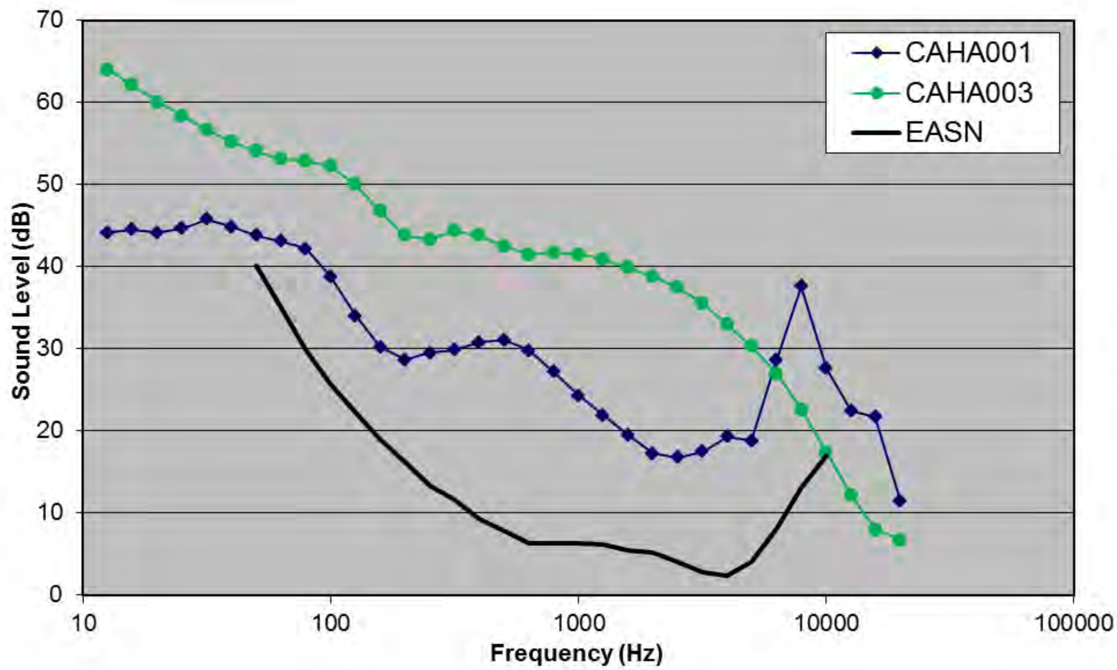

Figure 4. Spectral data for the existing Ambient Without Air Tours (L_{50}), winter season (2011). [12]

[12] Also shown in each figure is the Equivalent Auditory System Noise (EASN), which represents the threshold of human hearing for use in modeling audibility using one-third octave-band data.

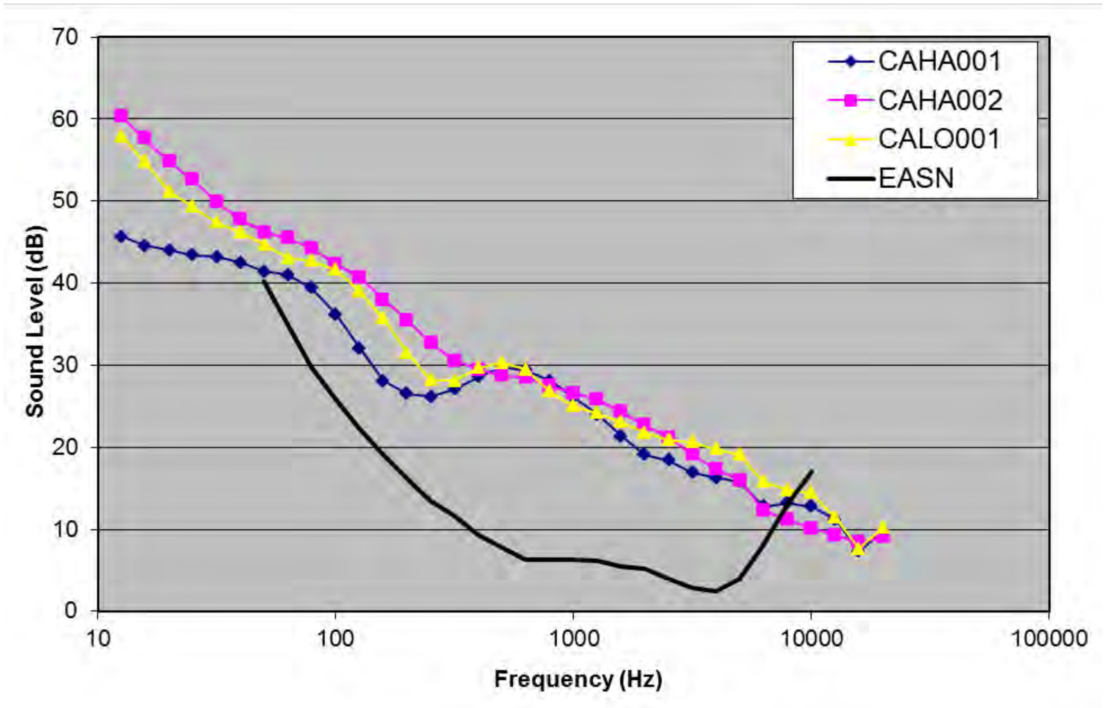

Figure 5. Spectral data for the Natural Ambient (L_{50}) summer season (2008). [13]

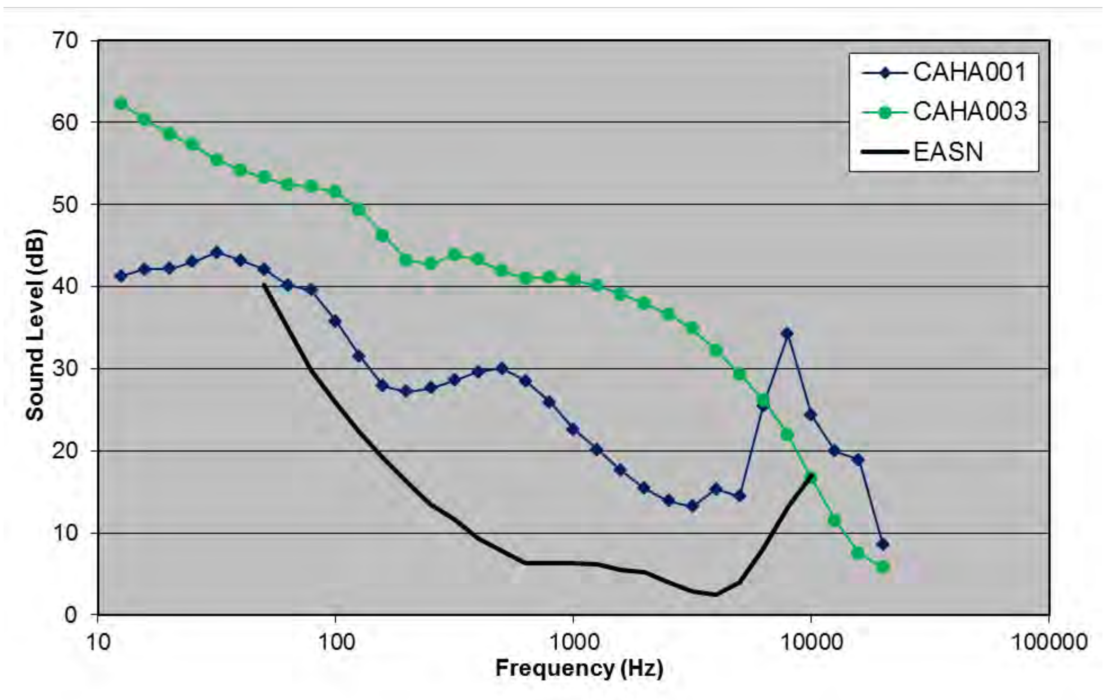

Figure 6. Spectral data for the Natural Ambient (L_{50}) winter season (2011).[12]

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[13] Also shown in each figure is the Equivalent Auditory System Noise (EASN), which represents the threshold of human hearing for use in modeling audibility using one-third octave-band data.

4.2 Time Above Results

The Time Above metric indicates the amount of time that the sound level exceeds specified decibel values. In determining the current conditions of an acoustical environment, the NPS examines how often sound pressure levels exceed certain decibel values that relate to human health and speech. The NPS uses these values for making comparisons, but they should not be construed as thresholds of impact. Table 9 and Table 10 report the percent of time that measured levels were above four decibels values at each of the Cape Hatteras measurement locations. The first decibel value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis, et. al., 2008). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund, et. al., 1999). The third value, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (Environmental Protection Agency, 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m (3 ft). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 10. Percent Time Above Metrics (dBA).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
Summer season (2008)									
CAHA001	Bodie Island Boneyard	87.9	11.0	2.1	0.2	98.5	25.7	2.6	0.1
CAHA002	Cape Point	99.9	46.3	3.6	0.3	100.0	90.6	30.6	0.1
CALO001	Portsmouth Island	90.4	24.2	2.0	0.2	100.0	50.3	1.2	0.1
Winter season (2011)									
CAHA001	Bodie Island Boneyard	99.5	48.2	8.7	0.7	100.0	92.0	30.4	0.1
CAHA003	Oregon Inlet Campground	100.0	99.9	51.7	0.5	100.0	99.9	58.7	0.1

Table 11. Percent Time Above Metrics (truncated spectra – dBT).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
Summer season (2008)									
CAHA001	Bodie Island Boneyard	74.5	6.0	0.7	0.1	65.3	3.8	0.1	0.0
CAHA002	Cape Point	99.6	39.1	1.6	0.2	100.0	73.9	3.3	0.0
CALO001	Portsmouth Island	78.5	13.1	0.8	0.1	99.2	18.1	0.1	0.0
Winter season (2011)									
CAHA001	Bodie Island Boneyard	65.5	4.6	1.0	0.2	43.3	2.2	0.2	0.0
CAHA003	Oregon Inlet Campground	100.0	93.5	6.8	0.1	100.0	92.4	15.8	0.0

4.3 Temporal Trends

This section discusses the daily and diurnal trends of the data. Daily trends are shown on a 24-hour basis. Figure 8 presents the daily median Existing Ambient (i.e., the L_{50} with all sounds included). For the purpose of assessing daily trends in the data, sound level descriptors are computed for each individual hour; then the median from the 24 hours each day is determined. Dips and increases in daily sound levels are usually an indication of passing inclement weather and localized events. This data is useful in visually identifying potential anomalies in the data. Data anomalies would then be further examined from data recorded by the sound level meter and/or recorded audio samples.

Diurnal trends are shown on an hourly basis. Sites with a strong daytime diurnal pattern typically indicate the presence of human activity largely influencing the sound levels at those sites. Sites with a nighttime pattern typically indicate the presence of insect activity. Sites with little discernible pattern, e.g., somewhat constant across all hours, typically indicates a constant sound source. Examples of constant sound sources include nearby brook or river. This data is also useful in visually identifying potential anomalies in the data.

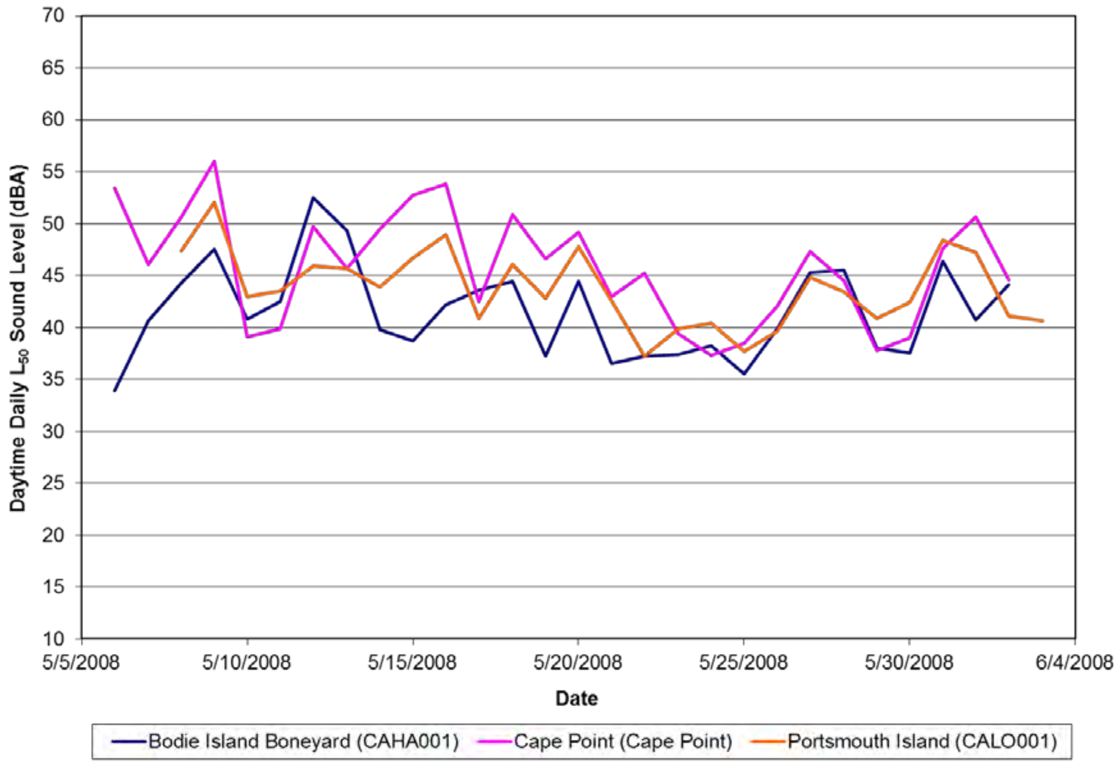

Figure 7. Comparison of daily L_{50} sound levels, summer season (2008).

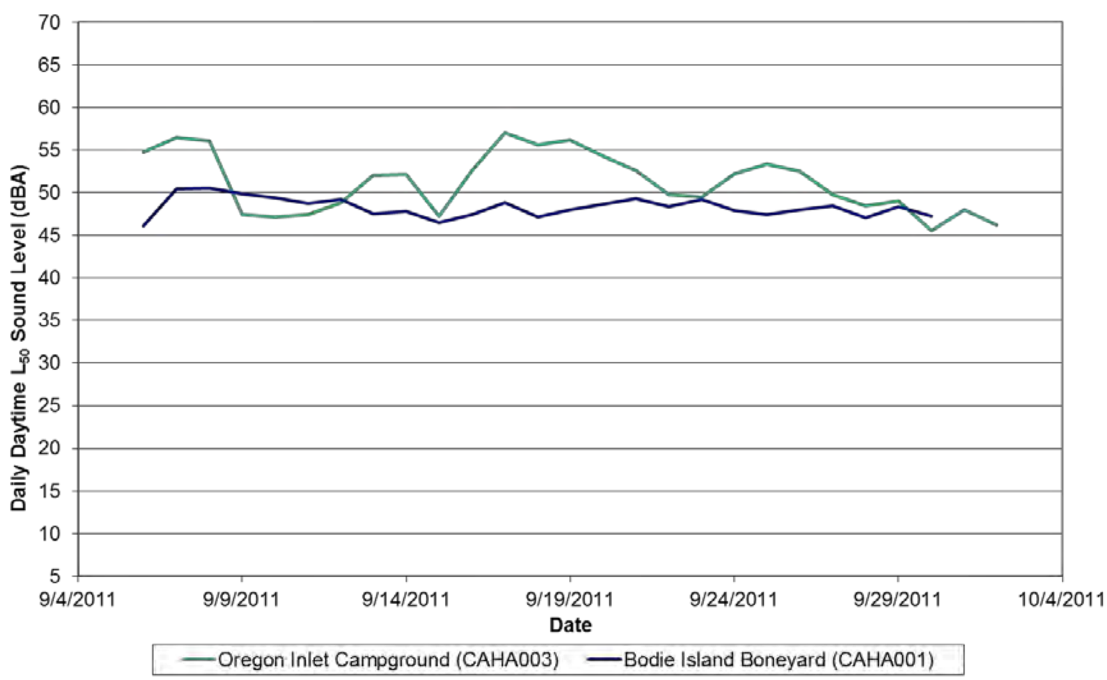

Figure 8. Comparison of daily L_{50} sound levels, winter season (2011).

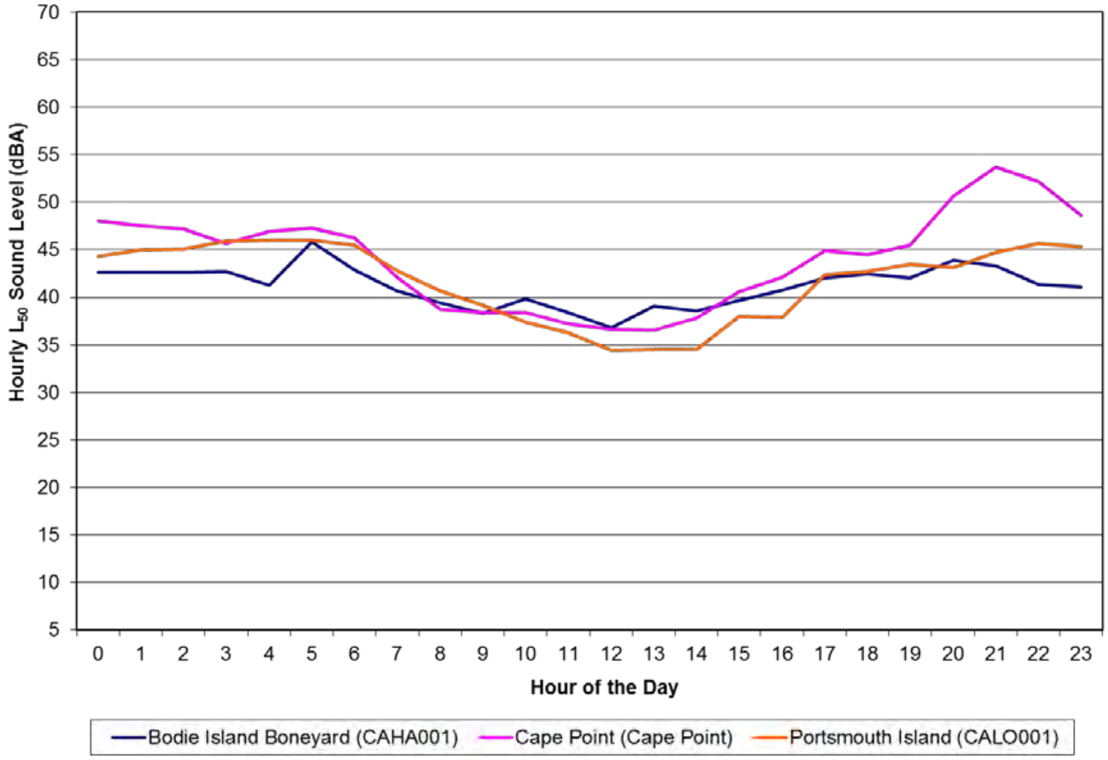

Figure 9. Comparison of hourly L_{50} sound levels, summer season (2008).

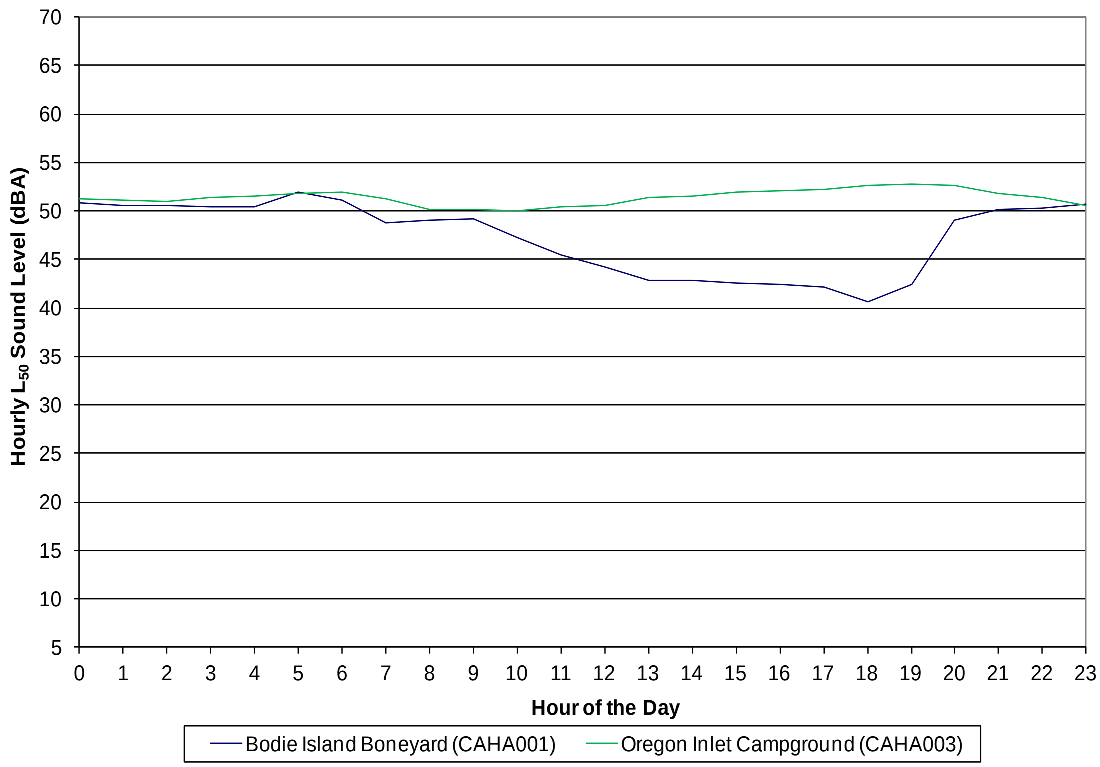

Figure 10. Comparison of hourly L_{50} sound levels, winter season (2011).

4.4 Acoustical Observer Log Results

Table 11 summarizes the combined listening results determined from both *in situ* and off-site sound source logs. This table provides an indication of the amount of time that certain sources are present at each site. *In situ* logging occurs on-site; an observer logs the source, time and duration of audible sounds. Typically a limited amount of *in situ* logging data is available due to measurement logistics. Off-site listening results are from a post-measurement review of the continuous audio files that were collected at each site. Continuous audio files were collected for the entire measurement and this allows a greater ability to listen and log sound sources for several days and any time period. Table 12 summarizes the nighttime off-site listening results for the winter measurements (nighttime off-site listening was not performed for the summer season data).

Table 12. Daytime acoustical observer log data (*in situ* and off-site listening combined).

Site ID	Site Name	% Time Audible: Daytime (7 am to 7 pm)			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
Summer season (2008)					
CAHA001	Bodie Island Boneyard	5.7	5.0	56.8	32.5
CAHA002	Cape Point	6.7	0.8	7.5	85.0
CALO001	Portsmouth Island	5.5	4.4	12.3	77.9
Winter season (2011)					
CAHA001	Bodie Island Boneyard	8.6	6.6	45.6	39.3
CAHA003	Oregon Inlet Campground	2.3	0.7	25.9	71.2

Table 13. Nighttime acoustical observer log data (off-site listening).

Site ID	Site Name	% Time Audible: Nighttime (7 pm to 7 am)			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
Winter season (2011)					
CAHA001	Bodie Island Boneyard	0.0	5.9	22.8	72.3
CAHA003	Oregon Inlet Campground	0.0	2.0	9.5	88.5

5. Ambient Mapping

Using the ambient data measured at each site, a comprehensive grid of ambient sound levels throughout the park (i.e., an ambient “map”) is developed. Ambient maps are useful to: (1) graphically characterize the ambient environment throughout an entire study area; and (2) to establish baseline, or background values in computer modeling. For ATMPs, the FAA’s Integrated Noise Model (INM)[14] will be used to model air tour aircraft activities and compute various noise-related descriptors (e.g., percentage of time aircraft sounds are above the ambient) and generate the sound-level contours that will be used in the assessment of potential noise impacts due to air tour operations.

The development of ambient maps is accomplished using Geographic Information System (GIS). In GIS, the following actions are performed:

- Define the input “objects”:
  - Define the park boundary in Universal Transverse Mercator (UTM)[15] coordinates to set the initial grid area boundary.[16]
  - Divide the park into a regular grid of points at a desired spacing using a Digital Elevation Model (DEM), which is a digital representation of a topographic surface typically used in GIS applications. Each point is assigned an elevation value and UTM coordinates from the DEM. Note: For Cape Hatteras, a grid spacing of 100 ft (30.5 m) was used.
  - Define the acoustical zone boundaries in UTM coordinates.
  - Define the location of each measurement site.
- Assign a “measured” ambient sound level (and its associated one-third octave-band, un-weighted spectrum), computed in Section 3.5, to each to each grid point within an acoustical zone.

For development of all ambient maps, except for Natural Ambient, three additional steps are performed:

[14] For ATMPs, the FAA and NPS have agreed to use the INM. The INM is a computer program used by over 700 organizations in over 50 countries to assess changes in noise impact. Requirements for INM use are defined in FAA Order 1050.1E, Environmental Impacts: Policies and Procedures, and Federal Aviation Regulations (FAR) Part 150, Airport Noise Compatibility Planning. In accordance with the results of the Federal Interagency Committee on Aviation Noise (FICAN) review (“Findings and Recommendations on Tools for Modeling Aircraft Noise in National Parks”), INM Version 6.2 is the best-practice modeling methodology currently available for evaluating aircraft noise in national parks and will be the model used for ATMP development.
[15] The UTM system provides coordinates on a worldwide flat grid for easy manipulation in GIS applications.
[16] Because the ATMP Act applies to all commercial air tour operations within the ½-mile outside the boundary of a national park, the park boundary included a ½-mile buffer.

- Define the location of localized noise sources, primarily vehicles on roads, but may also include brooks, waterfalls, and river rapids. The closest distance to each source is calculated and assigned to each grid point.
- Assign an ambient sound level (and its associated one-third octave-band, un-weighted spectrum) for each roadway to each grid point using the drop-off rates determined by computer modeling discussed in Section 5.2.
- Compute a combined measured and roadway ambient (and spectra). This is performed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition.

The resultant ambient maps are presented in Section 5.3.

5.1 Assignment of Measured Ambient Data to Acoustical Zones

Because it is neither economically nor expeditiously feasible to manually collect noise data under all possible conditions throughout an entire park, areas of like vegetation, topography, elevation, and climate were grouped into "acoustical zones," with the assumption that similar wildlife, physical processes, and other sources of natural sounds occur in similar areas with similar attributes. The primary goal of the site selection process was to identify the minimum number of field-measurement sites, which would allow for characterization of the baseline ambient sound levels throughout the entire park by assigning measured data stratified to these acoustical zones. The following considerations are used in the determination of acoustical zones:

- Vegetation/Land Cover: Sound propagates differently over different types of ground cover and through different types of vegetation. For example, sound propagates more freely over barren environments as compared with grasslands, and less freely through forest type environments. In addition, vegetation is typically dependent upon time-of-year, with foliage being sparser in the winter than other times in the year. Land cover can also affect wildlife activity.
- Climate Conditions: Climate conditions (temperature, humidity, precipitation, wind speed, wind direction, etc.) can also affect ambient sound levels. For example, higher elevation areas typically exhibit higher wind speeds resulting in higher ambient sound levels. Climate is also dependent upon daily and seasonal variations, which can affect ambient sound levels. For example, under conditions of a temperature inversion (temperature increasing with increasing height as in winter and at sundown), sound waves may be heard over larger distances; and winds tend to increase later in the day, and, as such, may be expected to contribute to higher ambient noise levels in the afternoon as compared with the morning.
- Park Resources/Management Zones: Park resources contribute, not only, to the multitude of sounds produced in certain areas of the park, but also to the serenity of other areas in the park. The way in which a park manages its resources can affect how potential impacts may be later assessed. It may also help identify where greater resource protection may be needed.

Based on the above considerations, Figure 11 presents the acoustical zones that were developed and the location of the measurement sites for CAHA. The ATMP Act applies to all commercial air tour operations within the ½-mile outside the boundary of a national park. Table 13 presents which measurement site data were applied to each acoustical zone during each season based on best available data and geographical proximity.

Figure 11. Acoustical zones and measurement sites for Cape Hatteras NS.

Table 14. Assignment of ambient data to acoustical zones.

Acoustical Zone	Site ID	Site Name
Summer season (2008)		
Wetlands Evergreen Forest Developed	CAHA001	Bodie Island Boneyard
Shrubland	CAHA002	Cape Point
Barren/Dunes Open Water	CALO001	Portsmouth Island
Winter season (2011)		
Wetlands Evergreen Forest Developed	CAHA001	Bodie Island Boneyard
Barren/Dunes Open Water Shrubland	CAHA003	Oregon Inlet Campground

5.2 Ambient Mapping of Localized Sound Sources

The contributing effect of localized noise sources, primarily vehicles on roads, but may also include brooks, waterfalls, and river rapids, are typically modeled and combined with the measured sound levels to develop a composite, baseline, ambient "map" of a park for all ambient maps, except natural ambient (see Table 14). The combined (measured plus roadway, for example) ambient are computed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition. Roadway sound sources were modeled using the Federal Highway Administration's Traffic Noise Model® (TNM) where the estimated drop-off rate, reflecting a continuous decrease in sound level as a function of increasing distance from each sound source, was computed (Lee, 2004). For a non-time-varying source, such as roadway noise, the TNM-computed L_{Aeq} sound level parameters may be conservatively assumed to be equivalent to the L_{50} and L_{90} and, thus, used interchangeably as the "roadway" ambient.

Table 15. Composite ambient maps.

Metric	Ambient Type			
	Existing	**Existing Without Sound Source of Interest**	**Existing Without All Aircraft**	**Natural**
L_{50}	Measured + Localized Noise Source(s)	Measured + Localized Noise Source(s)	Measured + Localized Noise Source(s)	Measured

In the vicinity of and within Cape Hatteras, there were a number of roadways. The following general assumptions were made in the modeling:

- Roadway Traffic Volumes – Annual traffic volume on each roadway was determined using data collected by the North Carolina Department of Transportation (NCDOT) specifically, the NCDOT Urban Area AADT Traffic Maps (North Carolina Department of Transportation 2013). Where data are available for multiple years, the corresponding study year was chosen. The traffic volume for an average day during the peak winter month (November) and summer month (July) were obtained by using monthly visitation data obtained from the NPS Public Use Statistics Office website (National Park Service 2013) to apportion the NCDOT annual traffic. Hourly volume is estimated by dividing the month's volume by the number of days in the month (30 and 31 respectively) and by 12 hours per day, which assumes the majority of daytime traffic occurs between 7 am and 7 pm – typical commute hours.

- Roadway Traffic Mix and Speeds –The traffic mix and speeds on a given roadway were based on a number of sources: (1) federal fleet characterization data (Federal Highway Administration 2012); (2) National Park Service 2004 Traffic Data Report (Federal Highway Administration 2005); (3) state regulations on speed limits (North Carolina General Assembly 2013); and (4) observations by field personnel during site visits. In some cases, a specific speed limit was determined using Google Maps using the "street view" to view an actual speed limit sign. When multiple speed limit signs showed varying speeds over a single road segment, an average. In some specific cases, notations from the Volpe field notes en route to measurement site locations were used to determine speed limits over various segments. An average speed of 35 mph was assumed as the default within the park when another more specific speed limit could not be determined.
- Ground Impedance – An effective flow resistivity of 1000 cgs/rayls was used for Cape Hatteras.

Table 16. Estimated hourly roadway traffic volume and speed.

Roadway			Estimated hourly volume				
#	Name	Average Speed (mph)	Autos	Medium Trucks	Heavy Trucks	Buses	Motor-cycles
Summer season (2008)							
1	NC 12 (Atlantic Dr to Oregon Inlet)	55	812	1	2	26	22
2	NC 12 (Oregon Inlet to Hwy 64)	55	916	1	2	29	25
3	S Old Oregon Inlet Rd (Count at Whalebone Junction)	35	447	1	1	14	12
4	NC 12 (North of Bodie Island)	55	674	1	1	22	19
5	Hwy 64 (West of SR12 to 345)	55	3,057	106	61	18	63
6	Hwy 158 (North of Hwy 64)	55	4,076	141	82	24	84
7	NC 12 (Rodanthe, Campground Rd to Atlantic Dr)	55	1,036	36	21	6	21
8	NC 12/Irvin Garrish Hwy (Ocracoke to Hatteras Inlet)	55	815	28	16	5	17
9	NC 12 (Coast Guard Rd to Park Drive)	55	1,698	59	34	10	35
10	NC 12 (Park Dr to Campground Rd)	55	1,223	42	24	7	25
11	NC 345 (Old Warf Rd to Hwy 64)	55	1,291	45	26	8	27
12	NC 345 (Hwy 64 to Sir Walter Reigh St)	55	3,227	112	65	19	67
13	NC 345 (Manteo, Sir Walter Reigh St to Fort Raliegh N High School)	55	1,240	43	25	7	26
14	NC 345 (Fort Raleigh N High School to Hwy 64)	55	272	9	5	2	6
Winter season (2011)							
1	NC 12 (Atlantic Dr to Oregon Inlet)	55	196	0	0	6	5
2	NC 12 (Oregon Inlet to Hwy 64)	55	231	0	1	7	6
3	S Old Oregon Inlet Rd (Count at Whalebone Junction)	35	118	0	0	4	3
4	NC 12 (North of Bodie Island)	55	231	0	1	7	6
5	Hwy 64 (West of SR12 to 345)	55	643	22	13	4	13
6	Hwy 158 (North of Hwy 64)	55	1,457	50	29	9	30
7	NC 12 (Rodanthe, Campground Rd to Atlantic Dr)	55	219	8	4	1	5
8	NC 12/Irvin Garrish Hwy (Ocracoke to Hatteras Inlet)	55	163	6	3	1	3
9	NC 12 (Coast Guard Rd to Park Drive)	55	382	13	8	2	8
10	NC 12 (Park Dr to Campground Rd)	55	287	10	6	2	6
11	NC 345 (Old Warf Rd to Hwy 64)	55	287	10	6	2	6
12	NC 345 (Hwy 64 to Sir Walter Reigh St)	55	771	27	15	5	16
13	NC 345 (Manteo, Sir Walter Reigh St to Fort Raliegh N High School)	55	274	10	6	2	6
14	NC 345 (Fort Raleigh N High School to Hwy 64)	55	77	3	2	0	2

5.3 Final Ambient Maps

The two ambient maps agreed upon for use in ATMP analyses are:

- Existing Ambient Without Air Tours (i.e., the Source of Interest); and
- Natural Ambient.

Figure 12 through Figure 15 present the ambient maps for the winter and summer seasons.[17]

[17] Summer season baseline ambient maps for Cape Hatteras utilize data collected at Cape Lookout NS.

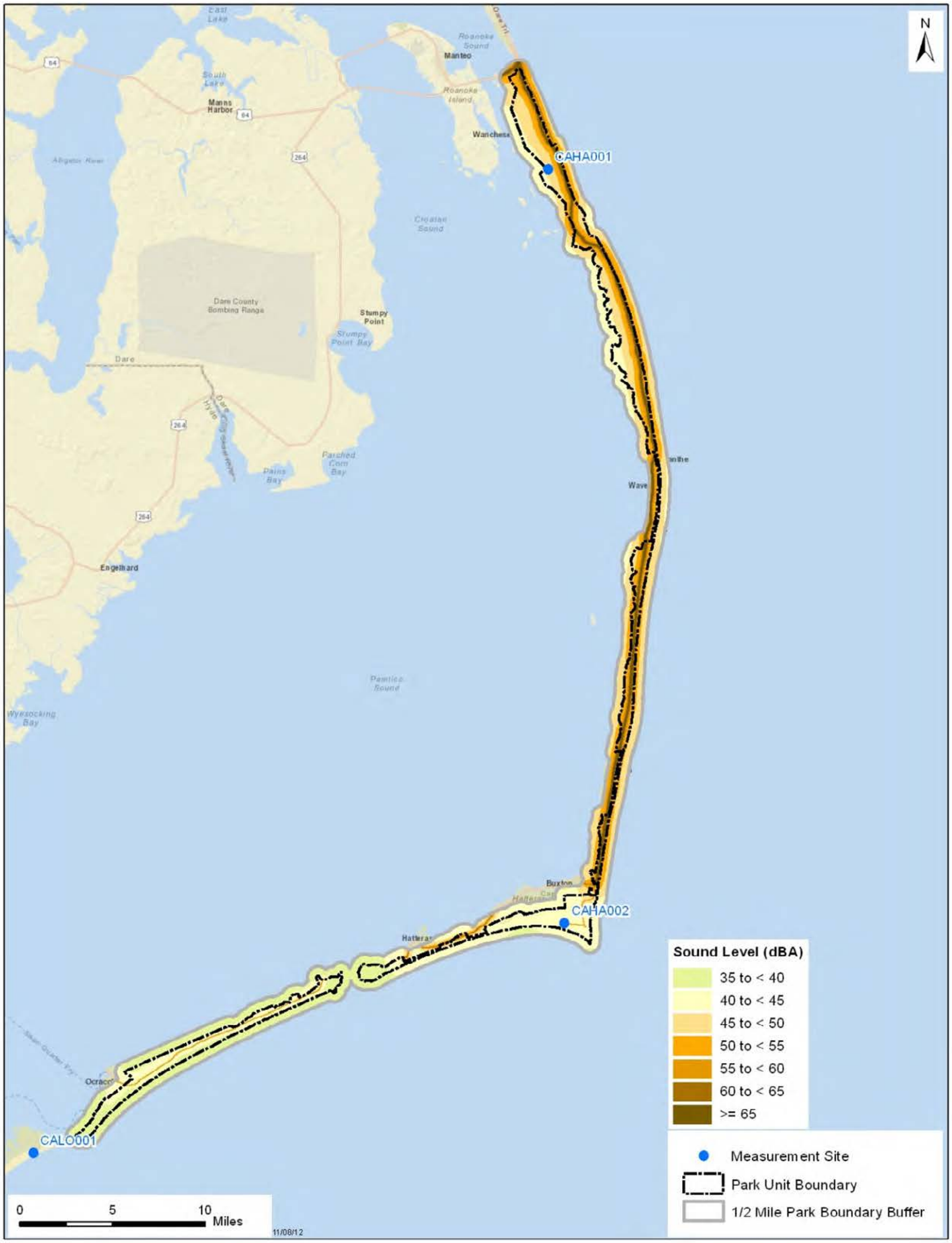

Figure 12. Baseline ambient map; Existing Ambient Without Air Tours (L_{50}), summer season (2008).

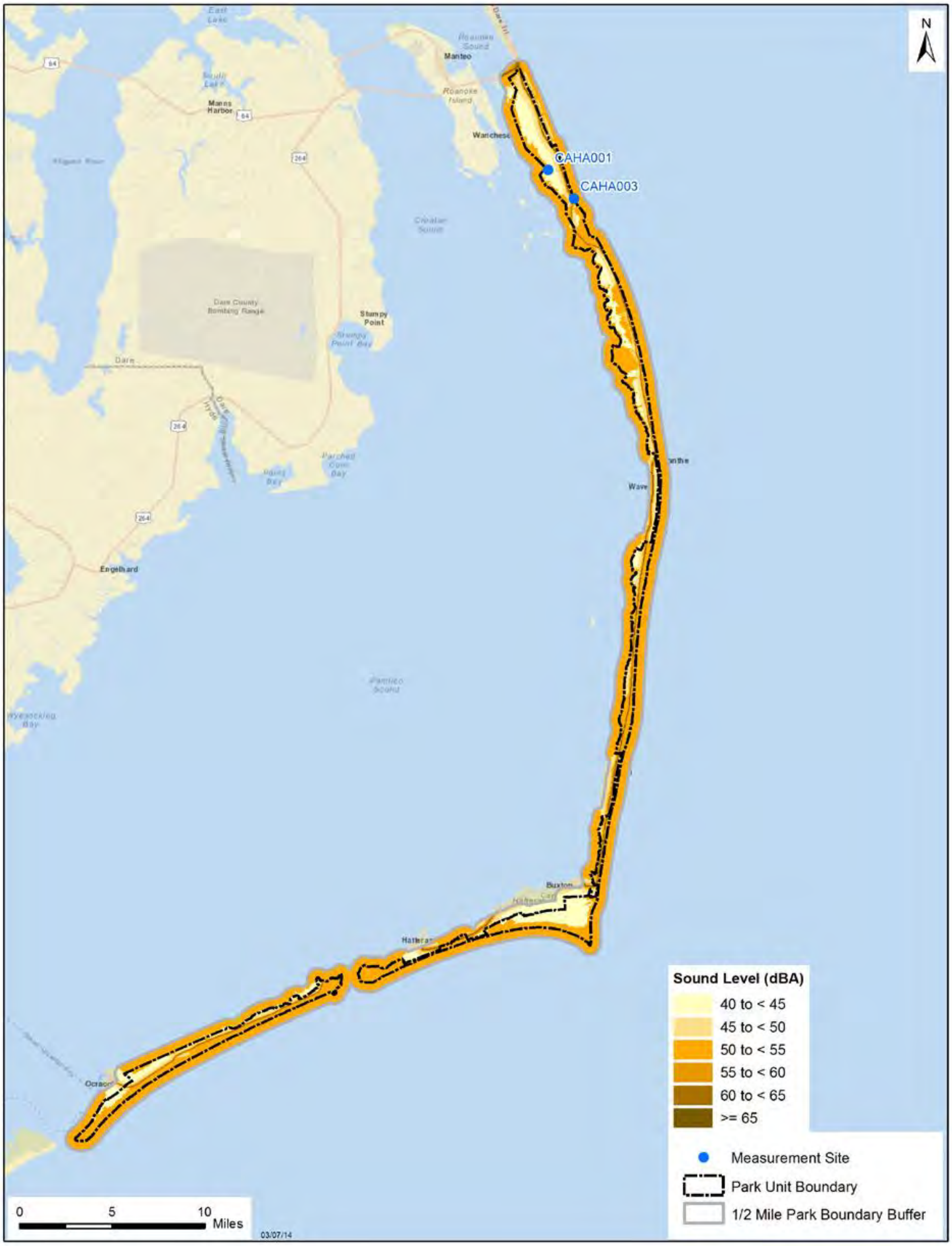

Figure 13. Baseline ambient map; Existing Ambient Without Air Tours (L_{50}), winter season (2011).

Figure 14. Baseline ambient map; Natural Ambient (L_{50}), summer season (2008).

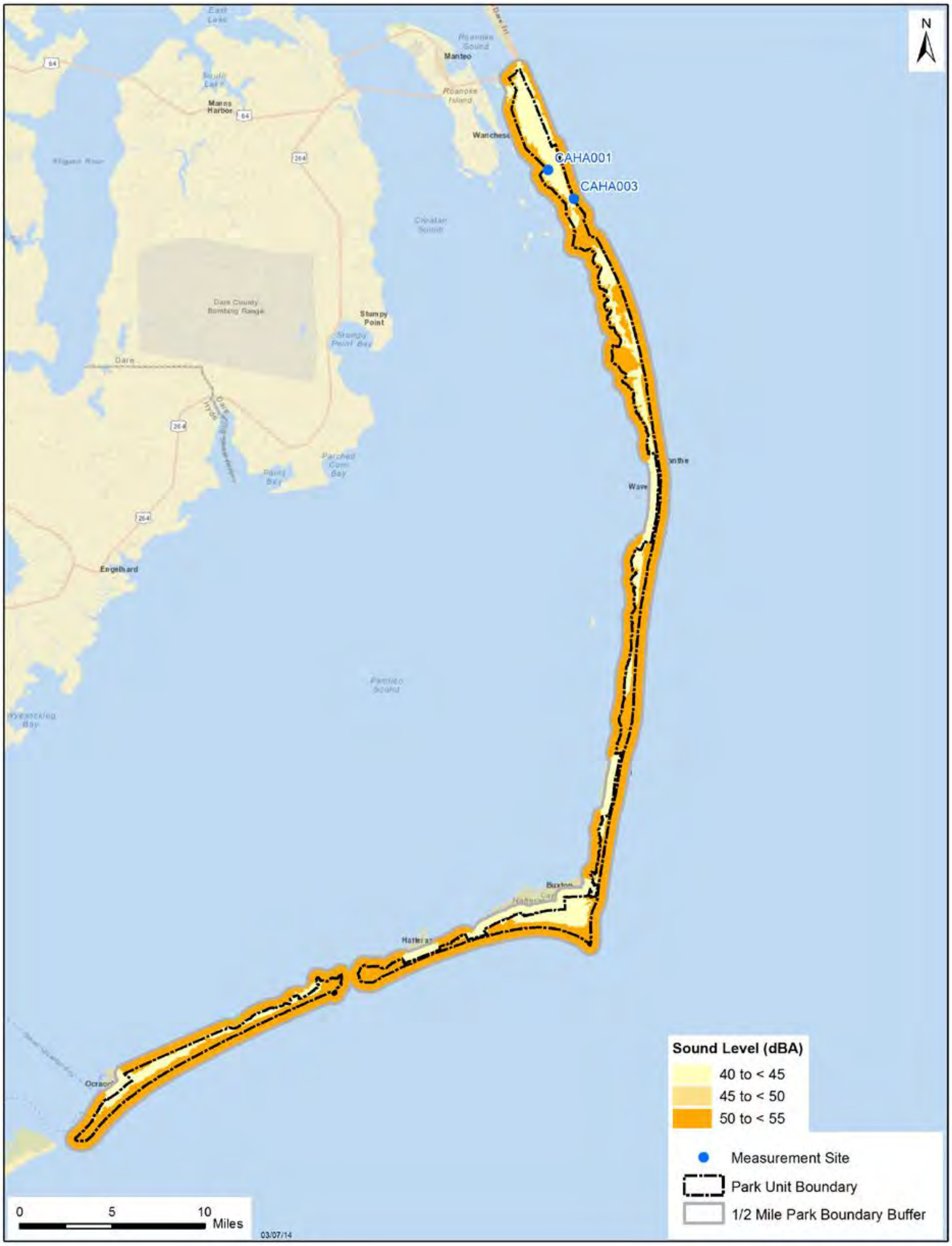

Figure 15. Baseline ambient map; Natural Ambient (L_{50}), winter season (2011).

6. Data for Individual Sites

This section provides more detailed information for each individual site. For each site, the following are included:

- Figure 16, Figure 26, Figure 31, Figure 37: A photograph of the measurement site and a brief discussion of preliminary observations;
- Figure 17, Figure 18, Figure 27, Figure 32, Figure 38: A pie chart presenting a comparison of types of sound sources that were audible during observer logging;
- Figure 19, Figure 20, Figure 28, Figure 33, Figure 39: A graphic presenting distribution plots of the number of 1-second samples of each sound pressure level measured during daytime and nighttime hours, and daytime/nighttime combined;
- Figure 21, Figure 22, Figure 29, Figure 34, Figure 40: A graphic presenting the daily sound levels using three hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to Terminology for definitions), as well as average daily wind speeds over the entire measurement period;
- Figure 23, Figure 24, Figure 30, Figure 35, Figure 41: A graphic presenting the hourly sound levels using three hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to Terminology for definitions), as well as average hourly wind speeds over the entire measurement period; and
- Figure 25, Figure 36: A graphic presenting the dB levels for each of 33 one-third octave-band frequencies over the day and night periods using three hourly A-weighted metrics (L_{10}, L_{50}, and L_{90}). The L_{10} exceedance level represents the dB exceeded 10 percent of the time and 90 percent of the measurements are quieter than the L_{10}. Refer to Terminology for definitions of L_{50} and L_{90}. The grayed area represents sound levels outside of the typical range of human hearing.

6.1 Site CAHA001 – Bodie Island Boneyard

Figure 16. Photographs of Site CAHA001, summer season 2008 (top) and winter season 2011 (bottom).

The CAHA001 Bodie Island Boneyard site was located in a marshy area on the “sound side” (Roanoke Sound) of Bodie Island. The measurement system collected data from May 6, 2008 to June 2, 2008 to represent the summer season and September 6, 2011 to September 30, 2011 to represent the winter season.[18] The area near the measurement system was comprised of wetlands and salt marshes. There was a wide variety of sound sources in the area including insects, crickets, birds, wind through reeds and brush, military aircraft, boats, automobile traffic and general aviation. The measurement location was approximately 500 ft. from the Sound and 0.7 miles from Highway NC-12.

Figure 17 and Figure 18 summarize on-site observations and off-site review of recorded audio data for daytime and nighttime hours (nighttime observer data are unavailable for the summer 2008). During summer, aircraft were audible during 11% of daytime hours. During winter, aircraft were audible 15% of daytime hours and 6% of nighttime hours. During summer, other human sounds (vehicles and boats) were audible 56% of daytime hours. During winter, other human sounds were audile 46% of daytime hours during and 22% of nighttime hours. During summer, noise-free time periods accounted for 33% of daytime hours. During winter, noise-free time periods accounted for 39% of daytime hours and 72% of nighttime hours. The natural sound sources were fairly consistent from season to season during the daytime and consisted of wind, surf, and birds. Natural sounds increased during the night time period as insect activity increased and vehicular and motor activities diminished.

The overall median daytime sound level for this site was 40.5 dBA during summer and 43.6 dBA during winter; winter levels were higher due to increases in both human and insect activity. The nighttime median sound level for this site was 42.6 dBA during summer and 50.3 dBA during winter. Spectral analysis and audio review of the night time winter measurements indicate louder insect activity during September (winter) than during May/June (summer).

The daily median sound levels (L_{50}) during summer ranged between 35 dBA and 52 dBA and had high variability due to stormy conditions during the monitored period. Loud daily sound levels occurred on May 12, 20th and June 1st, 2008 and were related to inclement weather including heavy storms. The date of May 12th, 2008 was very windy and loud, May 20th and June 1st experienced thunder during the 1900 hour which also is apparent in the hourly sound level results. The winter daily L_{50} levels ranged between 45 dBA and 50 dBA and were much more consistent from day to day than the summer levels.

Hourly median sound levels during varied from 37 to 46 dBA during summer and 40 to 52 dBA during winter. Louder hourly sound levels during both seasons occurred in the morning and evening due to insect activity, which was louder during the winter.

[18] Original measurement data files (logsheets, etc.) for the Boneyard site in 2011 ID this site as CAHA002. The site renamed CAHA001 for consistency between seasons.

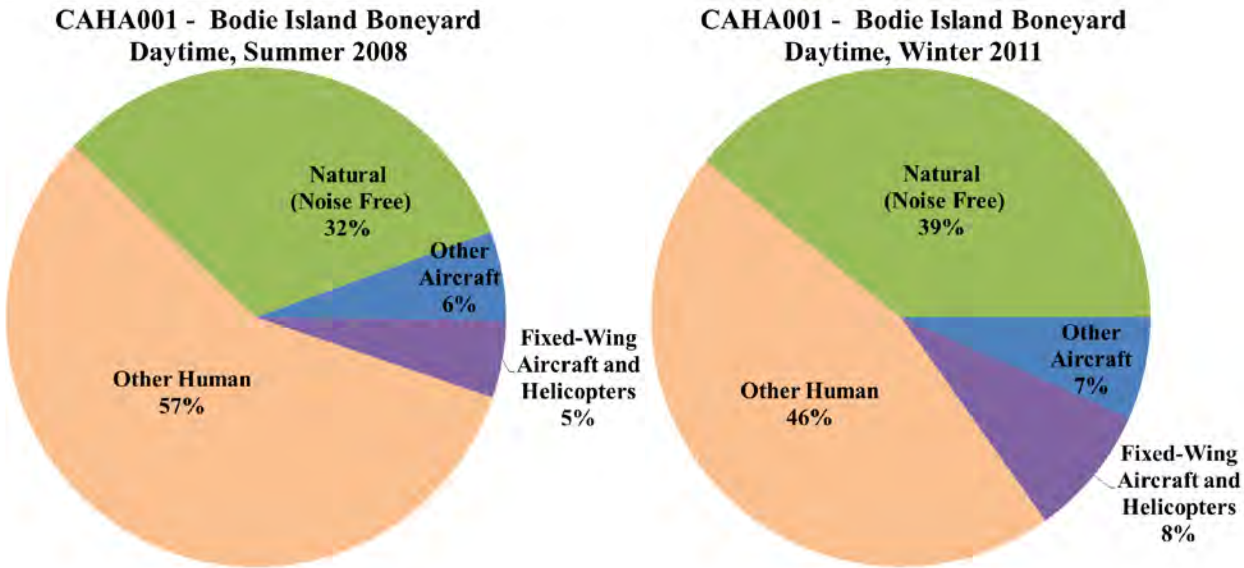

Figure 17. Distribution of <u>daytime</u> sound sources audible (*in situ* and off-site listening combined) for CAHA001, summer season (2008) (top) and winter season (2011) (bottom).

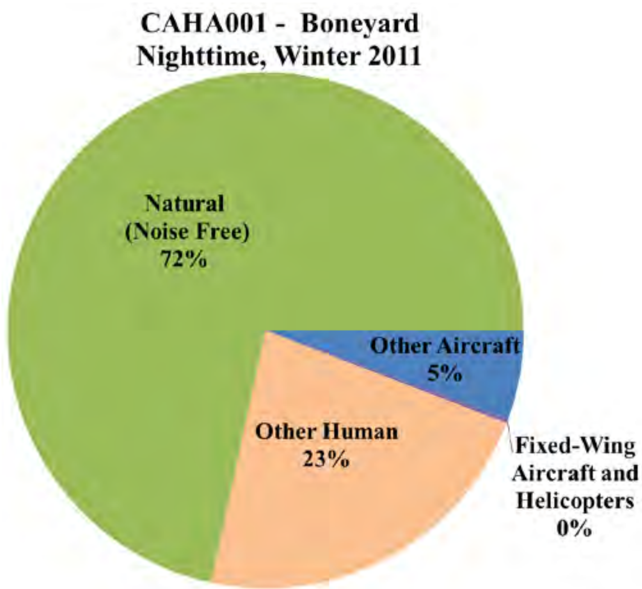

Figure 18. Distribution of <u>nighttime</u> sound sources audible (off-site listening) for CAHA001, winter season (2011) (summer season results unavailable).

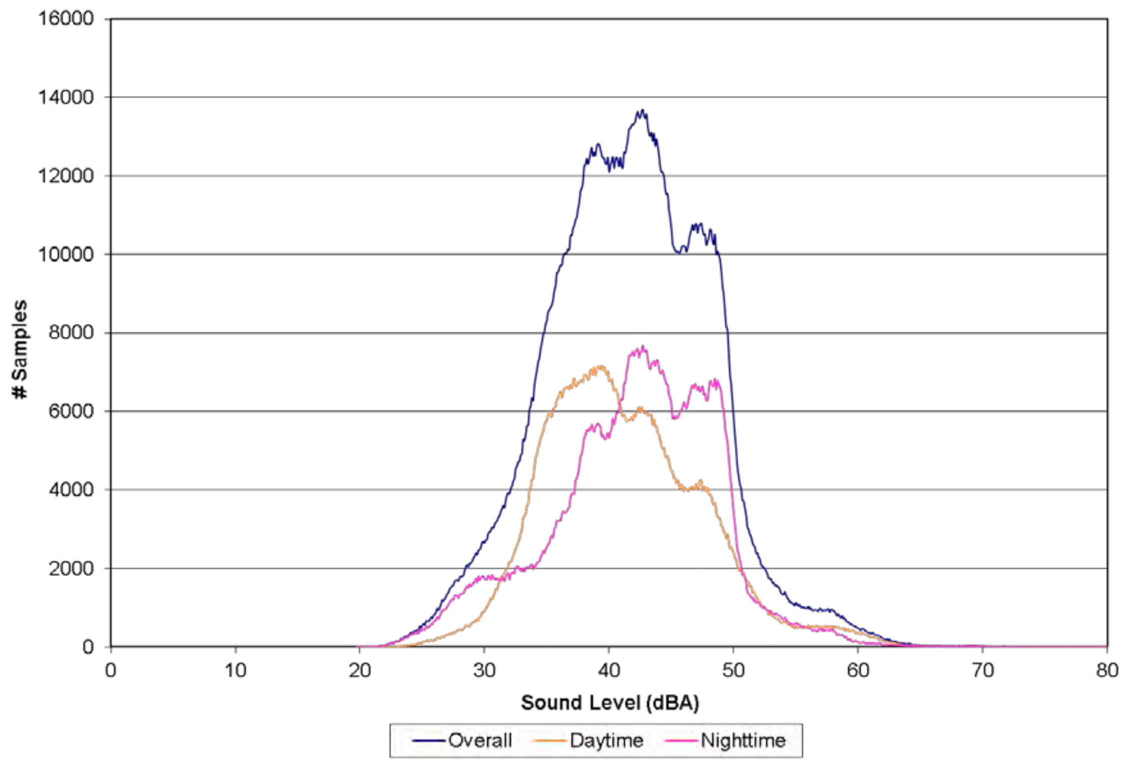

Figure 19. Distribution of sound level data for CAHA001, summer season (2008).

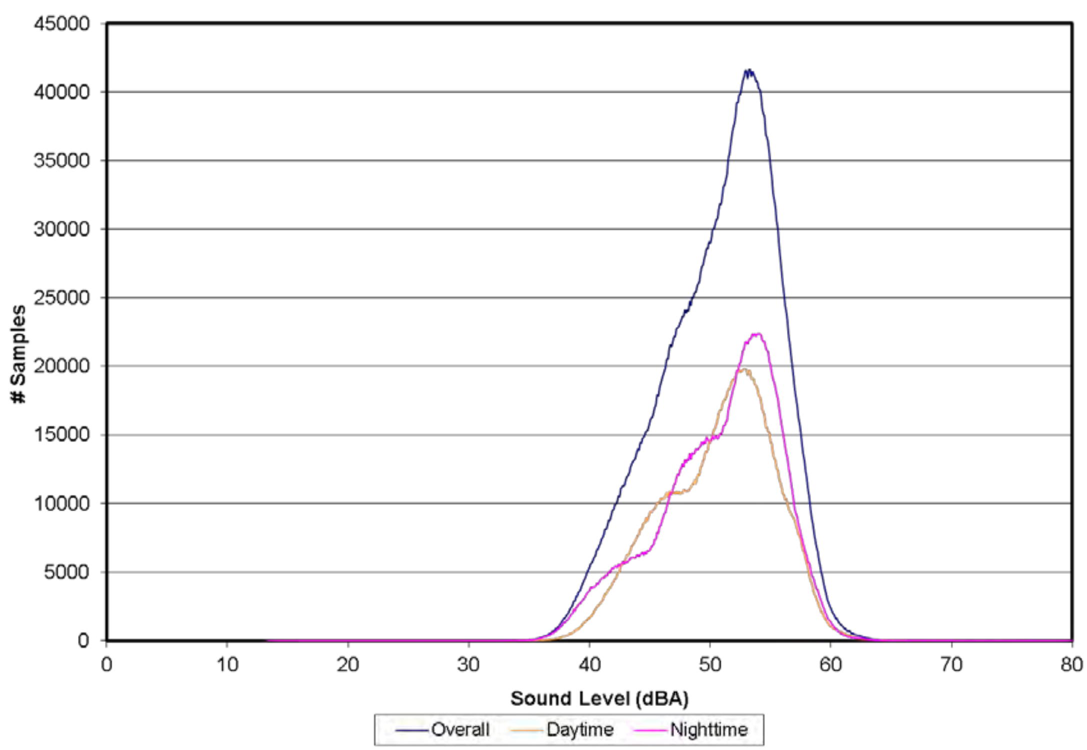

Figure 20. Distribution of sound level data for CAHA001, winter season (2011).

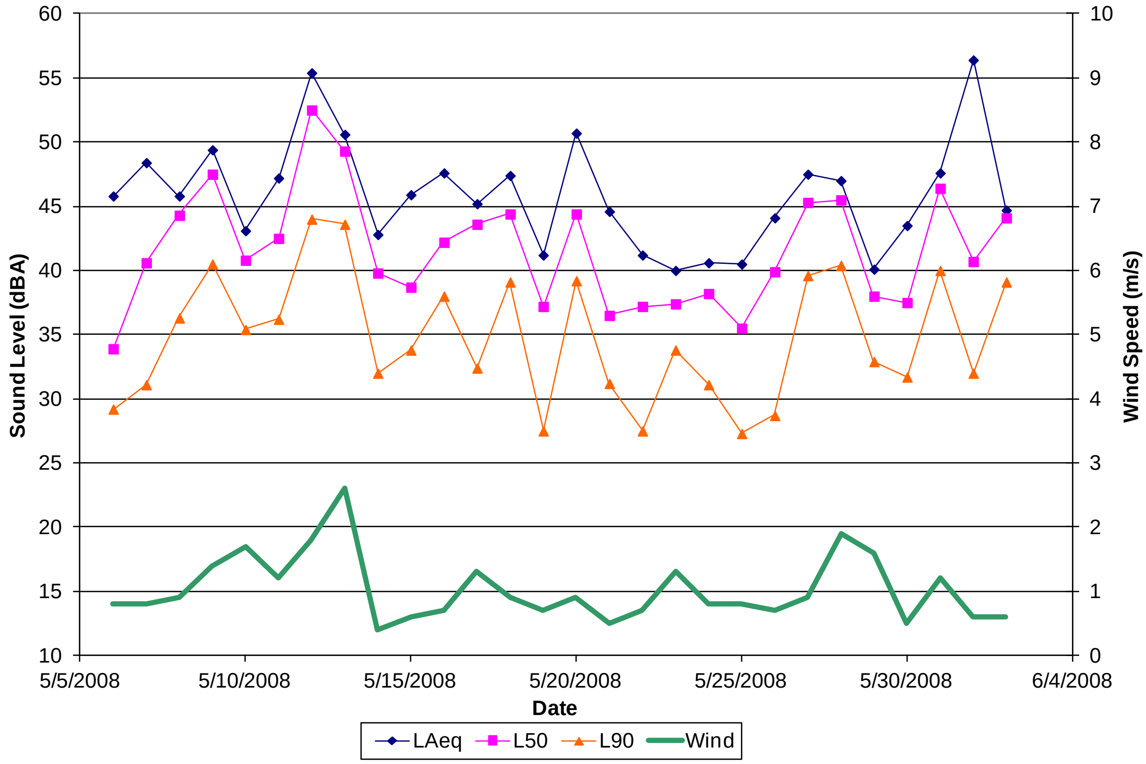

Figure 21. Daily sound levels and wind speeds for site CAHA001, summer season (2008).

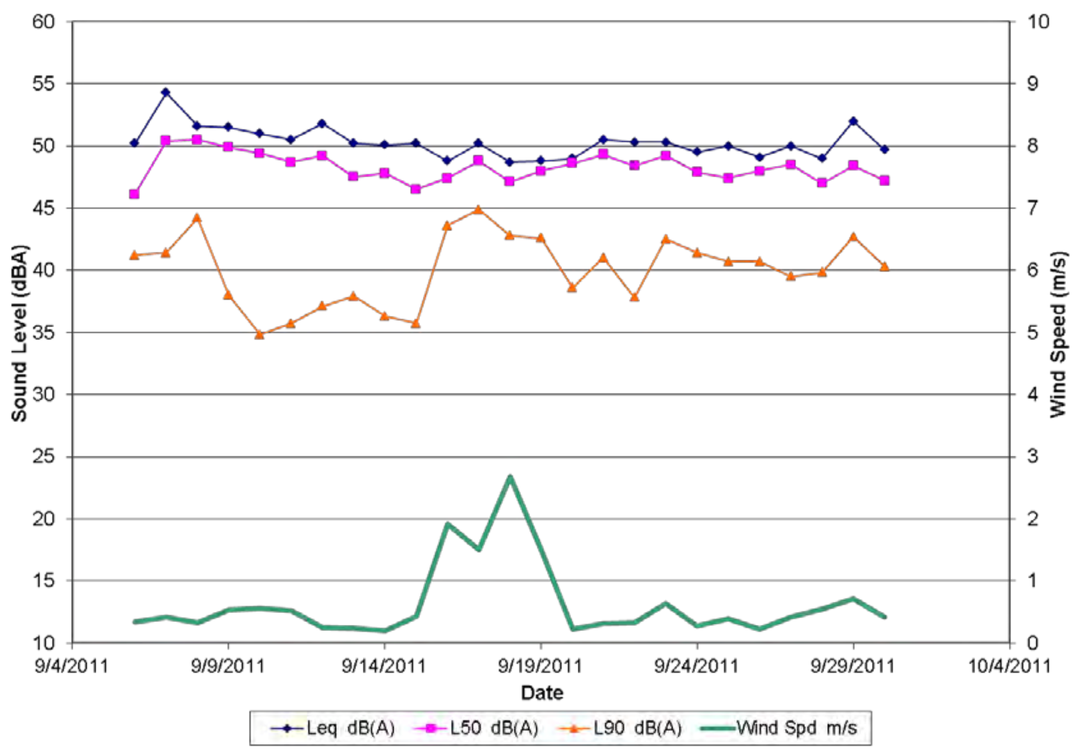

Figure 22. Daily sound levels and wind speeds for site CAHA001, winter season (2011).

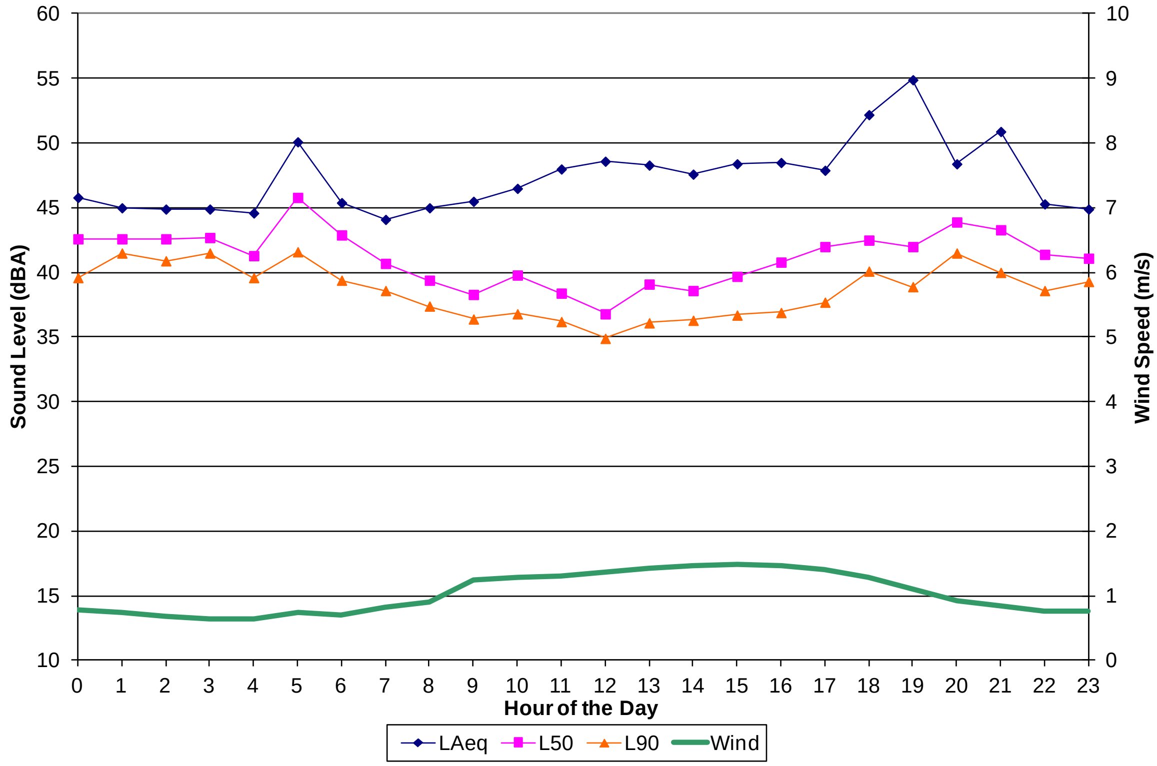

Figure 23. Hourly sound levels and wind speeds for site CAHA001, summer season (2008).

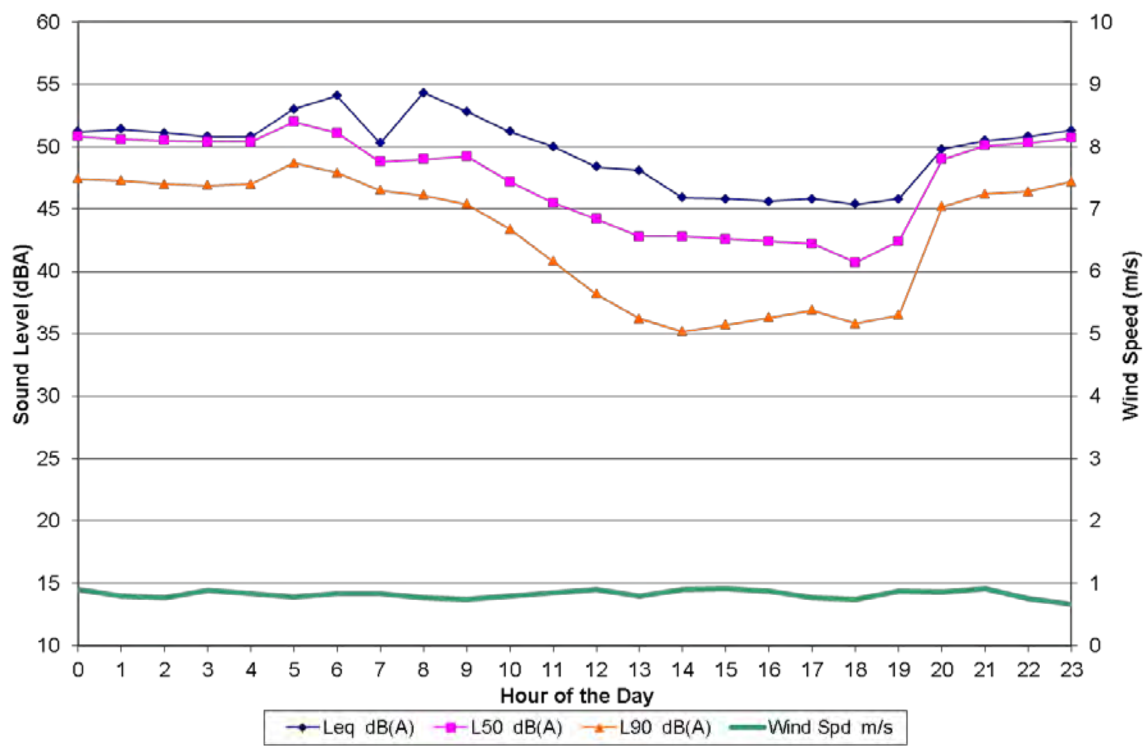

Figure 24. Hourly sound levels and wind speeds for site CAHA001, winter season (2011).

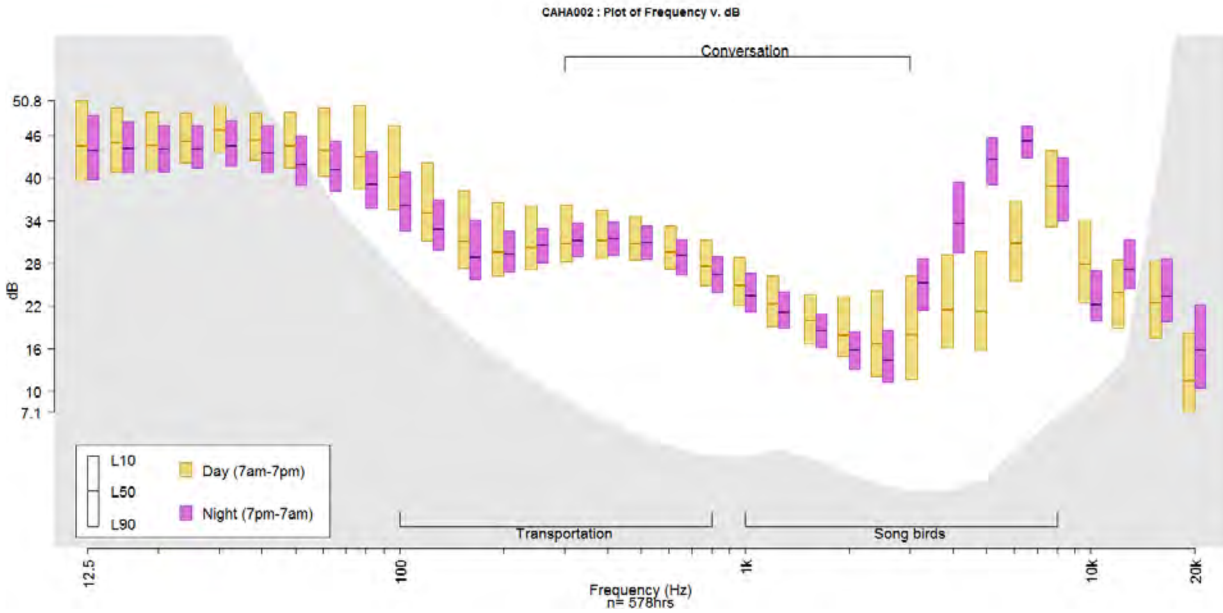

Figure 25. Sound spectrum for site CAHA001, winter season (2011).

6.2 Site CAHA002 – Cape Point

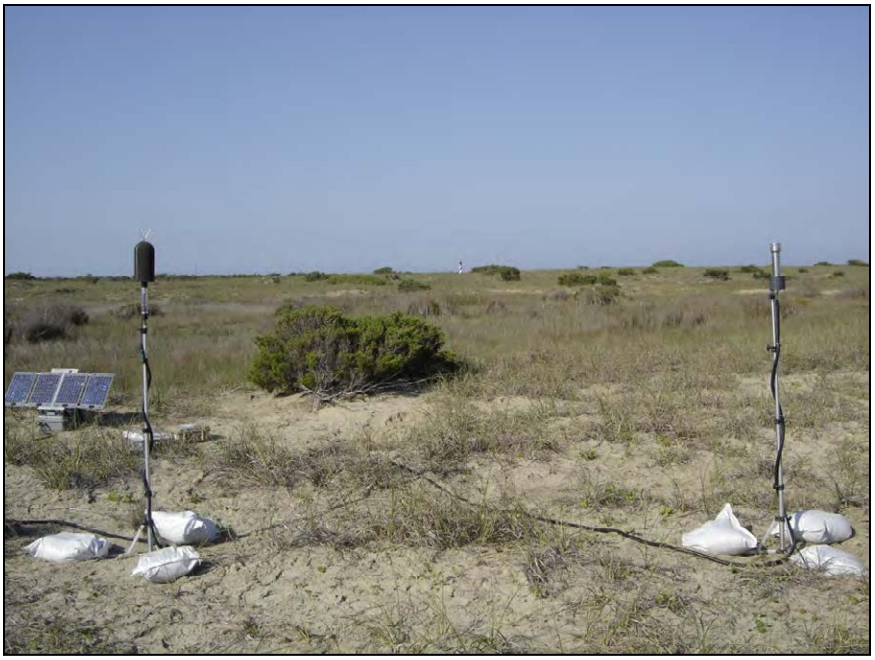

Figure 26. Photograph of Site CAHA002 summer season (2008).

The CAHA002, Cape Point site was located in a strip of land between the beach and the Cape Point campground. Sand dunes on either side of this ribbon of land created a shielded area with a wide variety of birds, insects, frogs and mammals in the area. The site was in close proximity to the beach (approximately 0.2 miles to the shoreline) but the dunes provided some shielding from wind and surf. The measurement system collected data from May 6, 2008 to June 2, 2008 to represent the summer season. Winter measurements were not conducted at this location as the site was inaccessible due to hurricane damage.

On-site observations and off-site review of recorded audio data concluded that aircraft were audible 8% of daytime hours (7 am to 7 pm); total human-related sounds (aircraft and distant vehicles) were relatively low at this site (15% of daytime hours). As such, noise-free sound conditions (i.e., natural only) were more prevalent (85% of the day). Surf and wind were the dominant natural sources at this site, followed by frogs, birds and insects.

The overall median daytime sound level during the summer was 40.5 dBA. Daily (twenty-four hour) median sound levels ranged from 37 to 56 dBA. Increased daily sound levels occurred on May 9, 12, and 20 due to heavy storms with increased wind and some thunder, as well as loud frog activity in the evening hours. The elevated sound levels in the evening can be seen in the distributions and hourly median sound levels, specifically during the 9 to 11 pm time period.

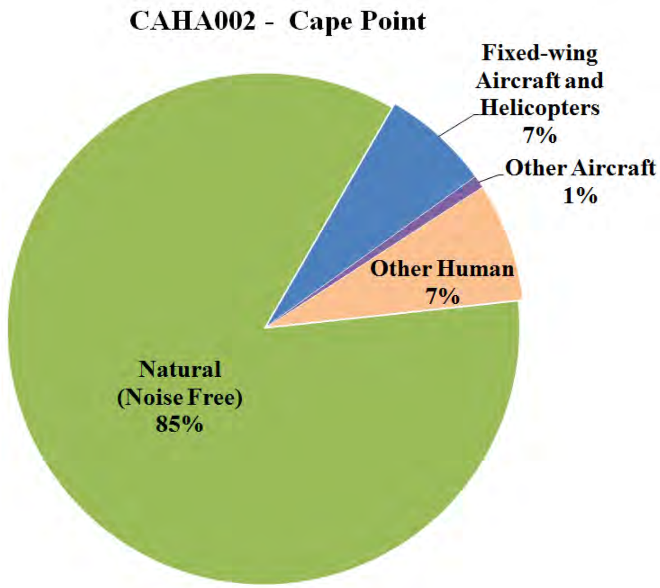

Figure 27. Distribution of sound sources audible (*in situ* and off-site listening combined) for CAHA002, summer season (2008).

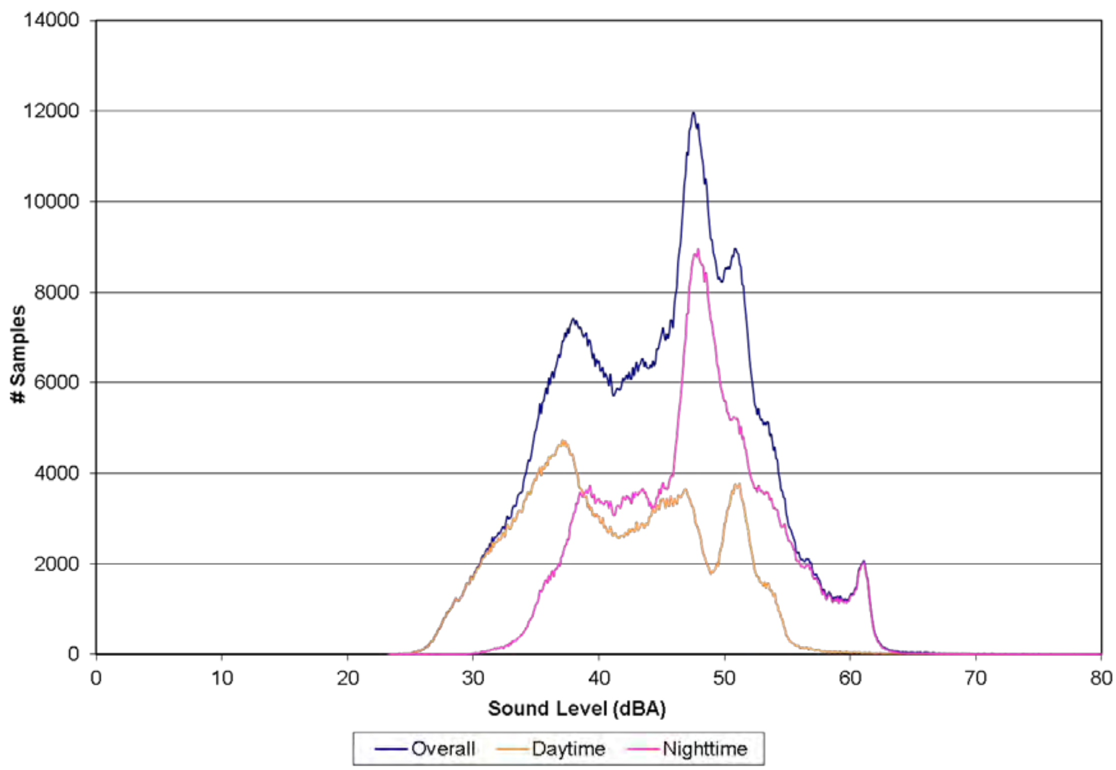

Figure 28. Distribution of sound level data for CAHA002, summer season (2008).

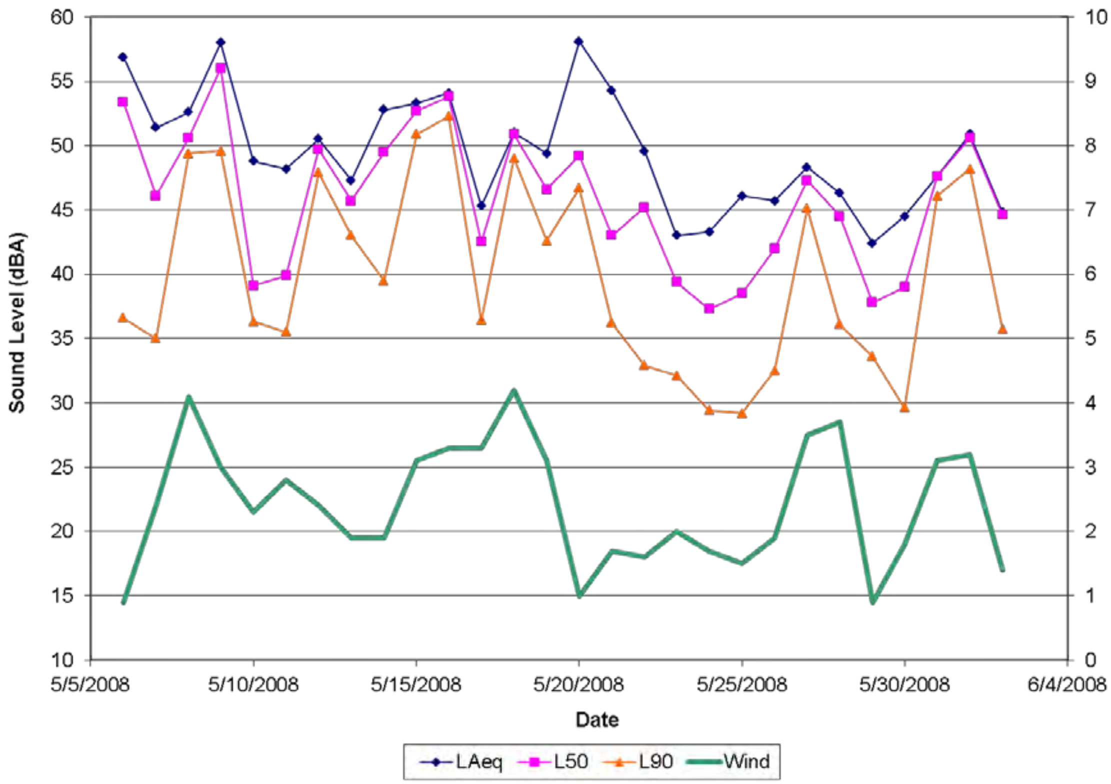

Figure 29. Daily sound levels and wind speeds for site CAHA002, summer season (2008).

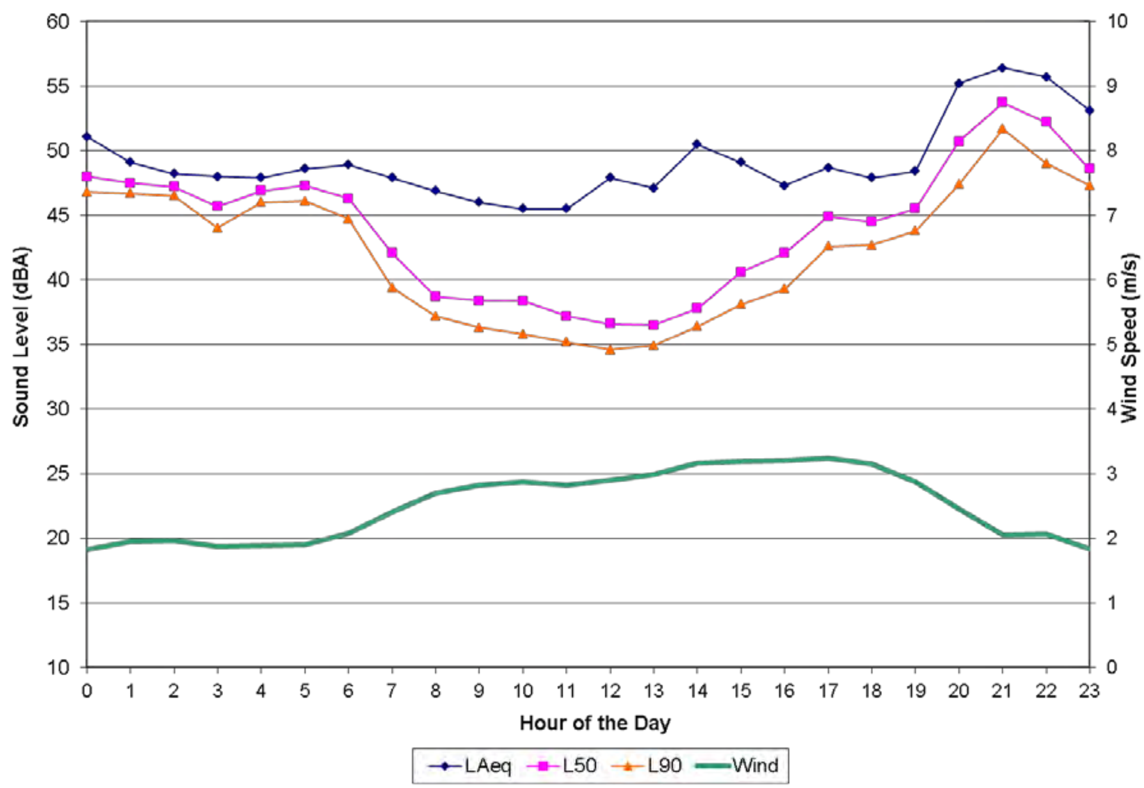

Figure 30. Hourly sound levels and wind speeds for site CAHA002, summer season (2008).

6.3 Site CAHA003 – Oregon Inlet Campground

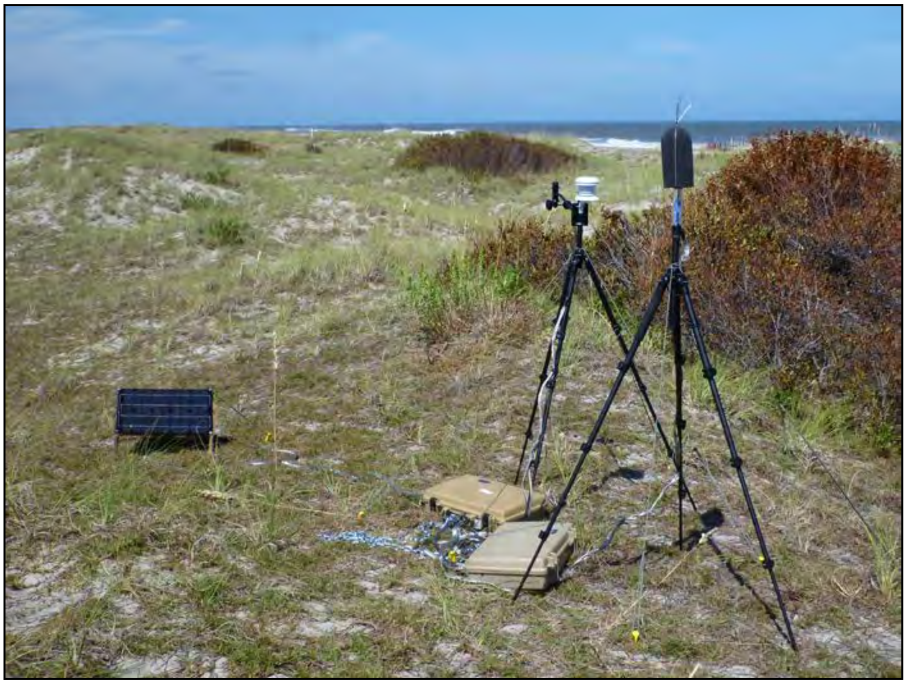

Figure 31. Photograph of Site CAHA003 winter season (2011).

The CAHA003 Oregon Inlet Campground site was located 150 meters north of Oregon inlet campground, between NC 12 and the beach, approximately 500 ft. from highway NC 12. The vegetation near the measurement system consisted of coastal grasses, scrub and undulating terrain of the sand dunes. The site's proximity to both the beach and highway subjected it to regular noise from vehicles, surf and wind related sounds. Additional sources of sound included motor sounds, birds, and insects. The measurement system collected data from September 6, 2011 to November 16, 2011 to represent the winter season (this location was not monitored during the summer season).[19]

Figure 32 summarizes on-site observations and off-site review of recorded audio data for daytime and nighttime hours during the winter season. Aircraft were audible for 3% of daytime and 2% of nighttime hours. Other human sounds (vehicles and other motor sounds) were audible 26% of the daytime and 9% of nighttime hours. Noise free time periods where natural sounds (wind, surf, birds) were audible occurred during 71% of the daytime hours and 89% of nighttime hours.

The overall median sound level (L_{50}) for this site was 51.3 dBA during daytime and 51.7 dBA during nighttime. The similarity of these two results points to the constant sources of sound at this location that set the background conditions (wind and surf). The daily and hourly L_{50} sound levels ranged between 45 dBA and 57 dBA (the loudest condition measured in CAHA) and are primarily due to the

[19] Original measurement data files (logsheets, etc.) for the Oregon Inlet Campground site in 2011 ID this site as CAHA001. The site was renamed CAHA003 for consistency between seasons.

turbulent wind and surf conditions at this site. Figure 35 shows that hourly sound levels at this site do not vary, again indicating the constant background sources.

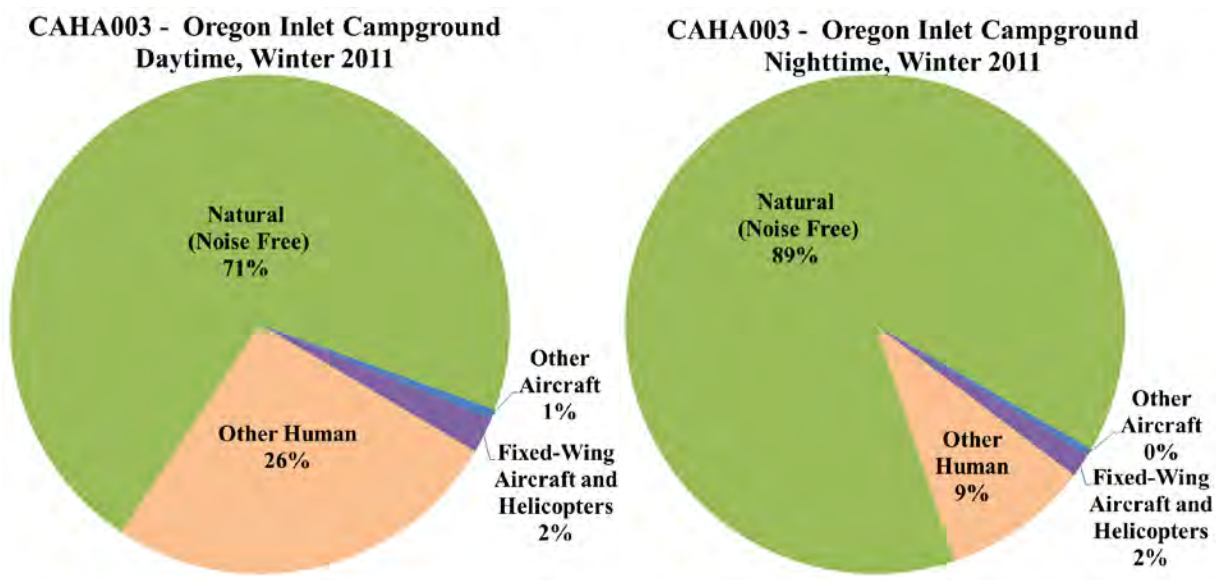

Figure 32. Distribution of sound sources audible (*in situ* and off-site listening combined) during daytime (top) and nighttime (bottom) hours for CAHA003, winter season (2011).

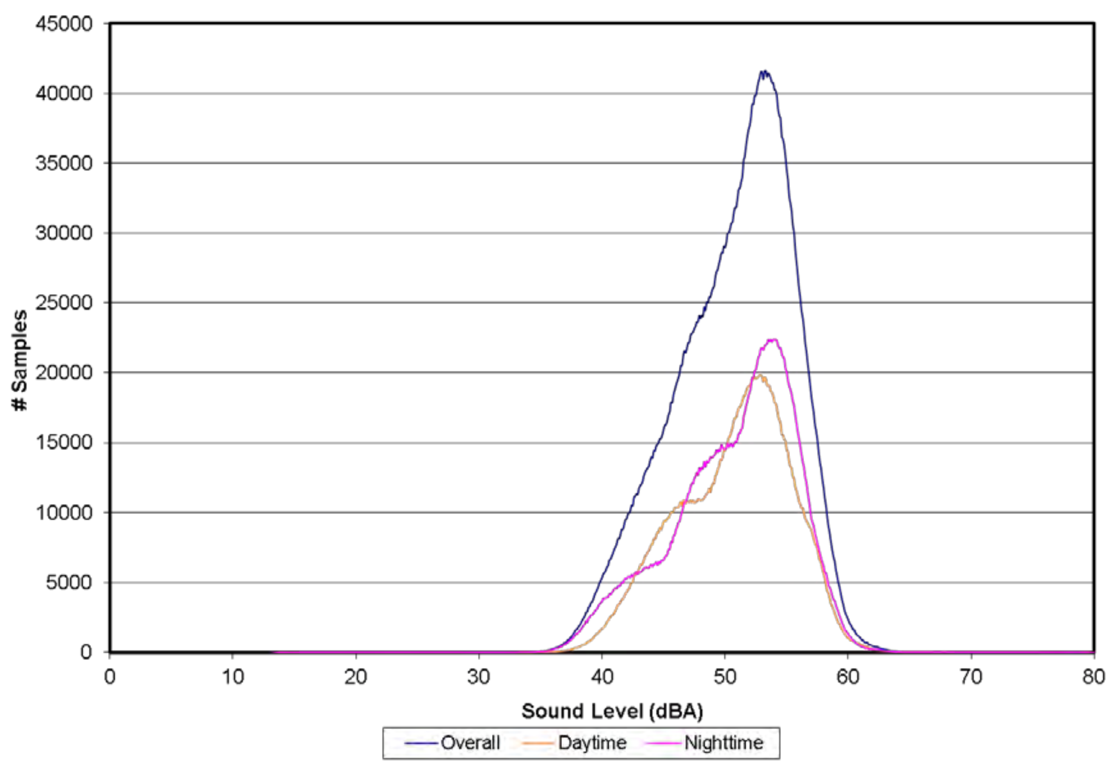

Figure 33. Distribution of sound level data for site CAHA003, winter season (2011).

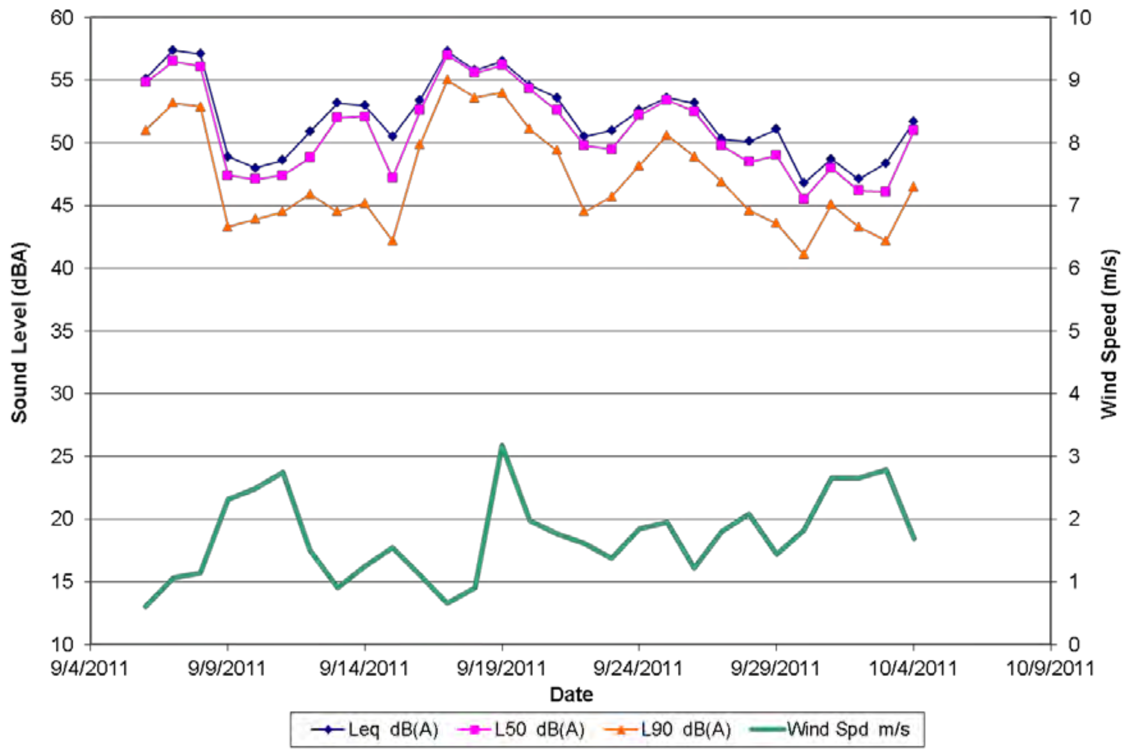

Figure 34. Daily sound levels and wind speeds for site CAHA003, winter season (2011).

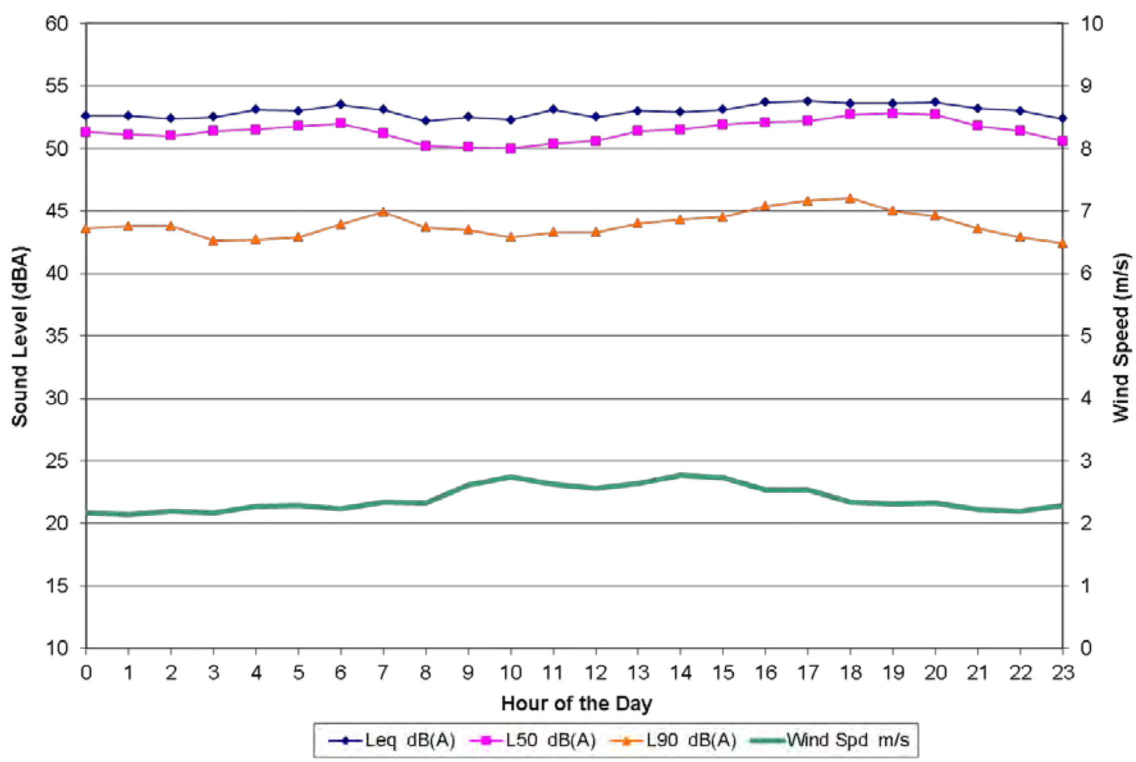

Figure 35. Hourly sound levels and wind speeds for site CAHA003, winter season (2011).

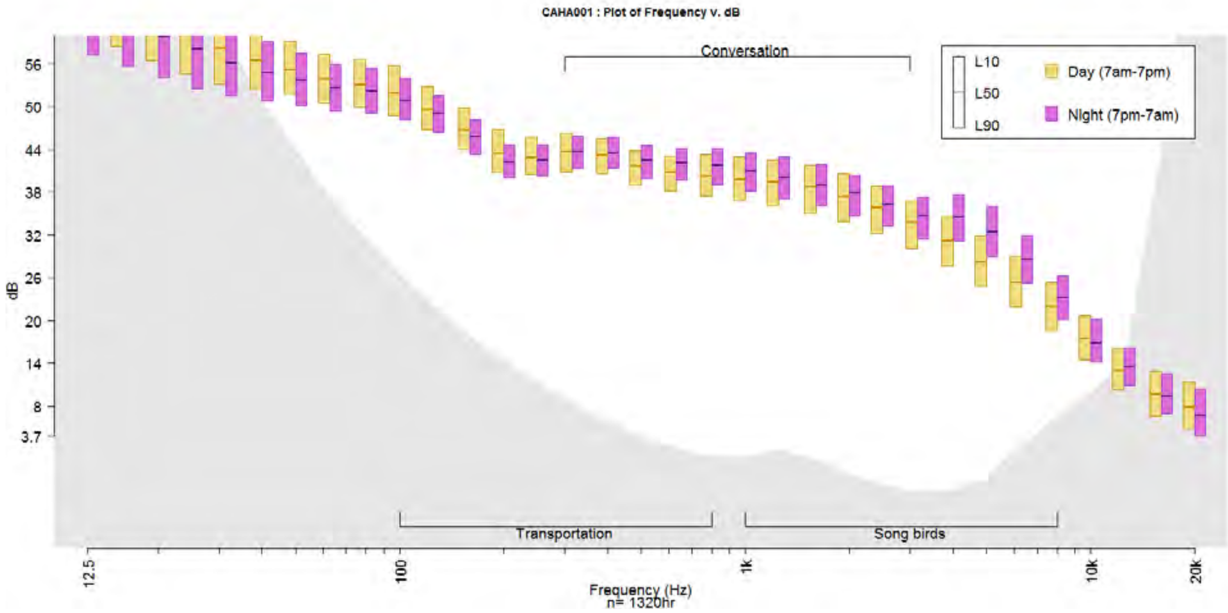

Figure 36. Sound spectrum for CAHA003, winter season (2011).

6.4 Site CALO001 – Portsmouth Island

Figure 37. Photograph of site CALO001, summer season (2008).

The CALO001 site in Cape Lookout was located on Portsmouth Island near the beach (approximately 0.2 miles to the shoreline). There sound sources in the area included insects, birds, wind, surf, visitors, aircraft, and off-road vehicles (ORV's). Data were collected from May 8th to June 3rd, 2008 to represent the summer season. Winter season measurements have not been conducted at this location.

The overall median daytime sound level during the summer was 39.6 dBA. Daily (twenty-four hour) median sound levels ranged from 37 to 53 dBA. Increased daily sound levels occurred on May 11 and 20 due to heavy storms with rain, thunder, and high winds. The sound level distributions and hourly median sound levels ranged from 34 to 46 dBA. A review of elevated nighttime sound levels around 10 pm showed they were due to thunder on May 11 and 20. The night time sound levels were generally higher than during the day and this was due to insect activity during the evening hours.

On-site observations and off-site review of recorded audio data concluded that aircraft were audible 10% of daytime hours (7 am to 7 pm); total human-related sounds (aircraft, boats, visitors, ORV's, and other vehicles) were relatively low at this site (22% of daytime hours). As such, noise-free sound conditions (i.e., natural only) were more prevalent (78% of the day). The majority of the human sounds were due to aircraft, watercraft and vehicular (ORV's, jeeps, and other automobiles) sounds. Additionally, sounds of what appeared to be military ordinance concussions were also heard during observations on May 21. The natural sounds of surf, birds and insects were prevalent at this location.

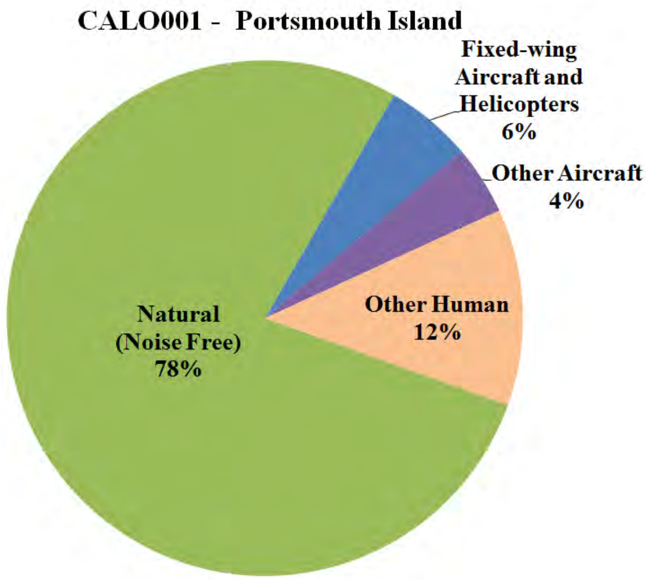

Figure 38. Distribution of sound sources audible (*in situ* and off-site listening combined) for CALO001, summer season (2008).

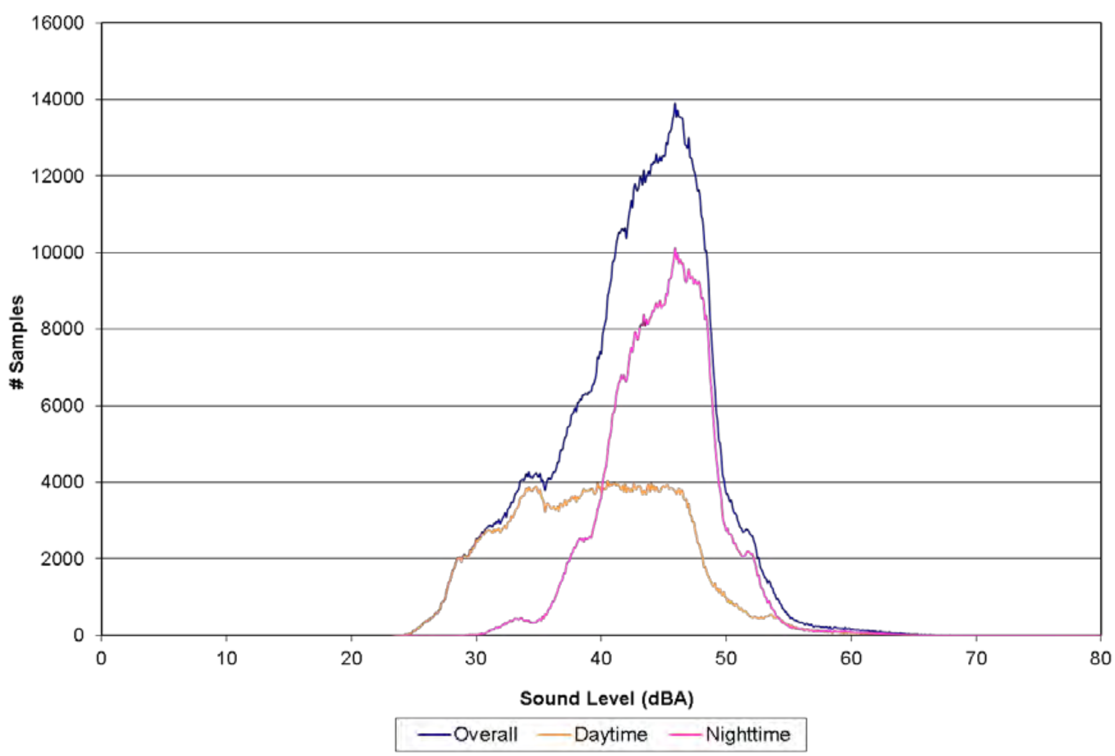

Figure 39. Distribution of sound level data for site CALO001, summer season (2008).

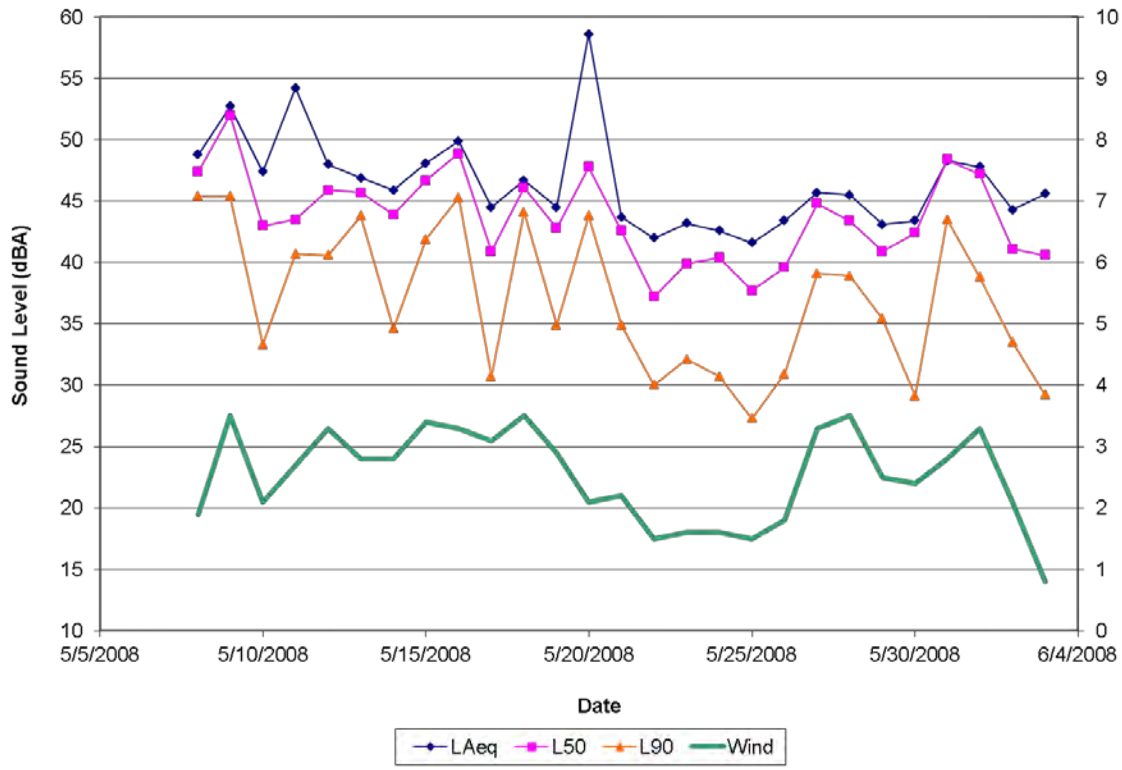

Figure 40. Daily sound levels and wind speeds for site CALO001, summer season (2008).

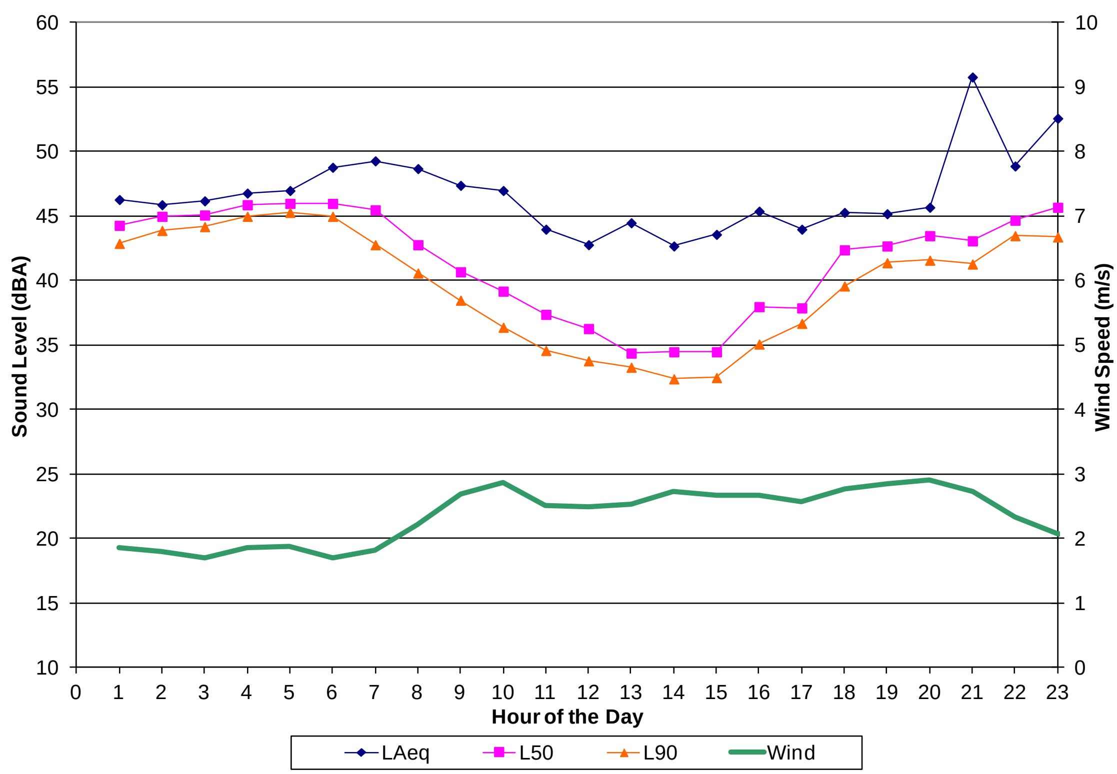

Figure 41. Hourly sound levels and wind speeds for site CALO001, summer season (2008).

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