Interpretation of Biological Activity Using an Acoustic Backscatter Sensor (ABS)

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INTERPRETATION OF BIOLOGICAL ACTIVITY USING AN
ACOUSTIC BACKSCATTER SENSOR (ABS)
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Introduction

The use of acoustic techniques has become a reliable method for collecting data related to hydrodynamics, sediment concentration, and bathymetry in the marine environment (Thorne & Bell, 2009; Thorne & Hanes, 2002). Using transducers of varying frequencies, measurements are often read as the strength of a returned signal to the transducer when reflected from a sediment particle or the seafloor. Prior to acoustics, other methods were used to sample the water column including water point-sampling, optical methods, and nuclear methods (Hamilton, Shi, & Zhang, 1998). Limitations of these methods include disturbance to the environment and lower resolution profiles (Hamilton, Shi, & Zhang, 1998). Acoustics have been used for over two decades and are now the preferred method of data collection. In the past few years, the potential for acoustics to measure interactions between local hydrodynamics, sediment concentration, and the seabed has become more clear (Thorne & Bell, 2009).

Benefits of using acoustics include the ability of the instruments to collect data of high temporal and spatial resolution without disturbing the environment, and to simultaneously take various measurements of hydrodynamics, sediment concentration, and bathymetry while using the “location of bottom” as a reference point (Thorne & Bell, 2009; Thorne, Agrawal, & Cacchione, 2007; Hamilton, Shi, & Zhang, 1998). Acoustics aid in the description of complex processes, such as the suspension of sand particles exposed to local hydrodynamic forces above a rippled bed (Cacchione, et al., 2008). Acoustic data can be applied to several aspects of the marine environment such as marine chemistry, biology, geology, and ecology.

The acoustic data collected in this study was part of a larger, grant-funded project that focused on sediment transport and settlement preference on two offshore hardbottoms following beach renourishment along the heavily developed coast in northeastern South Carolina. Acoustic
data collection was used in the larger project to describe changes in sediment concentrations offshore of Myrtle Beach, SC on the inner-shelf of Long Bay, SC (Wren et al., 2010). During certain time periods, data collected by the Acoustic Backscatter Sensor (ABS) do not appear to be correlated with wave or current data (Wren et al., 2010). Additionally, during these times the ABS indicates that there are larger particles suspended in the middle of the water column (Wren et al., 2010); however, there are no strong currents or waves to suspend sediment. These anomalies occur during fall and spring months (Wren et al., 2010). Without a driving force for sediment re-suspension, the cause of the acoustic return in the middle of the water column is unknown. The purpose of this study is to determine if the acoustic data can help identify unusual concentrations of large particles in the middle of the water column as possible biological interference.

The analysis of the anomalies found in the acoustic data from Long Bay, SC will extend beyond the analysis that has been published thus far. If the suspension is indeed biological, acoustics will provide another option for biological data collection. This analysis not only will attempt to explain the acoustic anomaly, but it will also lead to additional uses of acoustic instruments. Since this type of analysis has never been completed, it may help fill gaps noted in previous research and further expand conclusions already presented. Though the information may be site-specific, like much other research, it will serve as a guideline for other acoustic analyses.

Background

The use of multi-frequency acoustic instruments, such as the ABS, was invented to directly measure profiles of suspended sediment concentration and particle size. Through these measurements, the ABS can infer precise concentration profiles throughout the bottom boundary
layer to the seafloor (Cacchione, et al., 2008). The ABS is based on the principles of measuring the intensity of backscatter, or the intensity of the sound reflected back from particles in the water column. The ABS emits sound waves of high frequency (0.5-5 MHz) into the lower water column from typically 1-2 meters above the seabed (Thorne & Hanes, 2002). The emitted pulse moves toward the seabed, and the backscatter signal provides information on the number of particles. The intensity of the returning acoustic signal to the transducers is transformed into suspended sediment concentration, which depends on the concentration, composition, size, and shape of the suspended particles as well as the attenuation properties of the water column (Betteridge K., Williams, Thorne, & Bell, 2003). In addition, the size of the particle detected by the acoustic instrument depends on the wavelength of the acoustic signal, which is a function of the acoustic frequency. The ABS typically has three acoustic transducers, all of which emit varying frequencies of 1.0, 2.0, and 4.0 MHz. Lower frequency transducers will detect larger particles while higher frequency transducers will detect smaller particles, providing a range in grain size distribution. This is based on Equation 1, which relates the speed of sound in water (c = 1500 m/s) to the frequency (f) of the acoustic signal (1.0, 2.0 or 4.0 MHz) in order to determine the wavelength (L) of the returning sound wave. Wavelength of the sound wave corresponds to the diameter of a particle which the transducer of a specific frequency will be sensitive to following:

\[ L = \frac{c}{f} \]  

(1)

The calibration required for the attenuation and backscattering properties of the ABS is based on a variation of sphere scattering (Thorne & Hanes, 2002; Thorne & Meral, 2008; Betteridge, Thorne & Cooke, 2008). Particle size and concentration can be determined by the incorporation of different scattering characteristics through the formulation of backscattering and
attenuation properties. (Thorne & Meral, 2008). The form function applied to sediments cannot be applied to biology because of the varying scattering properties. Therefore, the corrected voltage was used for comparison. The range corrected voltage considers attenuation and absorption differences, as well as changes in salinity and density of the water column. Barans et al. (1997) estimated sizes of biological organisms that could be a source of interference based on the equivalent spherical radius.

Most commonly, the ABS has been used to determine mean sediment concentration profiles (Betteridge, Williams, Thorne, & Bell, 2003; Thorne & Hardcastle, 1997; Thorne, Agrawal, & Cacchione, 2007; Thorne & Hanes, 2002; Thorne & Meral, 2008; Cacchione, et al., 2008; Betteridge, Thorne & Cooke, 2008). This acoustic instrument carries a fine spatial and temporal resolution, which can provide accurate data within meters of the seabed. In addition, the ability of acoustics to take co-existing measurements will be useful to help explain complex processes of hydrodynamics and how they may influence benthic composition. The accuracy of the ABS to measure suspended sediment concentration was confirmed when acoustic data from a triple frequency ABS was compared to in-situ samples (Thorne & Hardcastle, 1997). Suspended sediment concentration at 1 cm above the bed was compared to the ABS model and was considered a good estimate of true concentration, supporting the accuracy of the ABS (Cacchione, et al., 2008). Therefore, it can be concluded that the use of acoustics provides accurate data of complex processes in the water column with high spatial and temporal resolution. The ABS appears to be very successful at providing accurate data when deployed over seabeaks of nominally homogenous and non-cohesive sediments (Thorne & Hanes, 2002). Acoustic backscatter techniques can also be applied to cohesive sediments, but may not prove as accurate as other methods.
Even though acoustics have served as an innovative way to collect data on hydrodynamics, sediment concentration, and bathymetry, there are still are limitations to the instruments. One limitation to the use of acoustics in oceanography includes the effects of temperature on the speed of sound, which is used in calculations of wave length (Hamilton, Shi, & Zhang, 1998). The speed of sound is directly related to the density and elasticity of the water mass. Temperature and salinity determine the density, thus being essential measurements when using acoustics. One study confirmed that bubbles and biological material can contaminate the backscatter signal and be a source of interference (Thorne & Hanes, 2002). Additionally, the use of measuring biological activity is limited because the ABS can only detect biological particles that can effectively reflect sound, which limits the possibilities to organisms with shells or a spot of metal within the particle.

Although the ABS has not been used for biological measurements and has mainly been used to examine thresholds of sediment movement and the concentration of suspended sediment, multiple studies have employed the use of acoustics to make inferences about possible biology in the water column (Weeks, et al., 1995; Yahel, R., Yahel, G., & Genin, 2002; Barans et al., 1997). In one study, acoustic data provided from a long-lasting phytoplankton bloom was used to determine how the biological, chemical, and physical data affected the phytoplankton distribution and how the zooplankton distribution responded (Weeks, et al., 1995). Acoustics were the most reliable method for observing these phenomena on many different scales. The Mean Volume Backscatter Strength (MVBS) found a pattern with high backscatter in the upper 75 m of the water column (Weeks, et al., 1995). Between 75 and 160 m, the backscatter was lower and patchy and became higher again at depths greater than 160 m. Micronekton of at least 10 mm would produce the most backscatter at 150 kHz; however, most were small copepods
which are unlikely to be contributing to backscatter (Weeks, et al., 1995). Acoustic variability noted between two sites affected by the bloom was due to differences in numbers and composition of micronekton, supporting the presence of possible biological interference. (Weeks, et al., 1995).

Another study was completed near five fringing reefs in the northern Gulf of Aqaba, at the Red Sea, where suspended sand concentration (SSAC) was measured using acoustics (Yahel, R., Yahel, G., & Genin, 2002). Acoustic measurement exhibited a much higher SSAC during the day than at night. Waves, currents, and wind did not significantly contribute to the resuspension of sediment in this region and rarely exceeded the threshold for sediment transport, except during large storm events (Yahel, R., Yahel, G., & Genin, 2002). Therefore, the resuspension must have some other explanation. In this study, bioturbation by a few fish species caused resuspension of sediment. Fish would disturb the seafloor searching for benthic invertebrates, causing resuspension (Yahel, R., Yahel, G., & Genin, 2002). Video imaging supported this behavior and helped explain the pattern noted in acoustic return, with higher return during the day when feeding would occur (Yahel, R., Yahel, G., & Genin, 2002). Acoustics were once thought to be limited to sediment, but it is now known that acoustics have the ability to detect other particles in the water column.

**Methods**

2.1 **Study Site**

The study site is located on the inner continental shelf of Long Bay, South Carolina offshore of a heavily developed beach locally known as the Grand Strand (Figure 1). The Grand Strand is composed of 54 km of shoreline that stretches from Cape Fear to Cape Romain, with
Figure 1. This is a map of the study site, Long Bay, South Carolina. The sampling was done off the coast of Myrtle Beach.

very few tidal inlets (Wren et al., 2010). Long Bay is composed mostly of hardbottom substrate and is not exposed to high fluvial input of new sediment. Therefore, the inner continental shelf is an area that is sediment starved and only has a thin, discontinuous layer of sand covering the

Figure 2. Map of inshore and offshore sites (black dots) where Area 3 is inshore and Area 11 is offshore.
hardbottom. Although this area has very little sediment deposition, the hardbottom substrate serves as critical habitat to several species close to shore (Wren et al., 2010). Furthermore, this suggests the possibility of high biological productivity close to shore.

The inshore study site is located 850 meters offshore of Myrtle Beach on the hardbottom substrate, which is also a highly productive marine hardbottom habitat (Figure 2). The offshore site is located approximately 2.5 kilometers offshore of Myrtle Beach; however, the acoustic data presented here is only from the inshore site (Wren et al., 2010). Nine deployments from June 2008 to December 2009 collected information using three acoustic instruments at the inshore site. Deployment length varied depending on season and storm activity ranging from approximately three to eight weeks (Wren et al., 2010). The instruments at the inshore site included a 1200 kHz RD Instruments Acoustic Doppler Current Profiler (ADCP), an upward-looking 1500 kHz Nortek Acoustic Wave and Current profiler (AWAC), and an Acoustic Backscatter Sensor (ABS). The ADCP, AWAC and ABS were located approximately 1.3 meters above the seabed to collect measurements in the bottom boundary layer. The ABS provided suspended sediment concentration and grain size for all nine deployments.

Biological data collected over 19 months via vertical tile arrays may aid in the identification of species possibly causing interference. Stacks of tiles at varying heights were placed 5 m upstream and downstream from the frames holding the acoustic instruments at both the inner and outer sites. Each tile served as a settlement substrate for benthic organisms and the various heights and textures (between the top and bottom of a single tile) leads to information of settlement preference and recruitment of many different benthic species (Wren et al., 2010). Vertical tile arrays were attached to the frame that holds the acoustic instruments at each location, allowing for direct comparison between hydrodynamic conditions and settlement. The
tiles were at varying heights throughout the water column to obtain a range of settlement of about 90 cm (Wren et al., 2010). After collection of the tiles, the species were identified in order to qualitatively report the number of taxonomic groups that may have been present in the water column during data collection (Wren et al., 2010).

2.2 ABS Data Analyses

Each of the nine deployments was reviewed for acoustic anomalies. Further analysis was determined by comparing the plots of bottom orbital velocity and suspended sediment concentration. If suspension was present with little to no bottom orbital velocity, a force other than increased wind or current speed was causing suspension. The plots of suspended sediment concentration represented the average suspension measured by all three transducers. The varying frequencies emitted from each transducer on the ABS allowed size data to be inferred about suspended particles. Lower frequency transducers detect larger particles while higher frequency transducers detect smaller particles. The dates in which acoustic anomalies were detected were then plotted using MatLab, a program that allows you to manipulate raw data and customize plots for further analysis.

2.3 MatLab Analysis

MatLab was used to modify the suspended sediment concentration data as well as grain size to only include the dates where the anomaly was present. MatLab allows additional analysis of the anomaly such as identifying the time of day in which the anomaly was present. MatLab also makes patterns of acoustic backscatter clearer by allowing one to manipulate the scale to be the same range for all deployments for more accurate comparison. Plots from the same two-day period were created for both 2008 and 2009 for comparison between years. The time of year that the anomaly occurred was an essential component of the research as well because of changes in storm activity and the possibility of increased biological activity during the spring and fall due to
possible phytoplankton blooms. During the winter, storms are more prevalent and therefore accompanied by increased winds, currents, and sediment transport. MatLab was also used to plot physical parameters such as wind speed and direction, current speed and direction, wave height, wave period and tidal changes collected at the study site during Deployments 3 and 9. The time series of each parameter was plotted in order to determine potential relationships between the ABS data and possible biological activity with tidal range and frequency, current flow, temperature, wave and wind velocities.

Additionally, a Fast Fourier Transform (FFT) was also done on each physical parameter using MatLab. The FFT is used to transform a function of time into a function of frequency. Periodic functions, such as sine and cosine, are able to approach infinity with a longer period. The waveforms are broken into the smaller components of sine or cosine functions, which lead to values of frequency. The FFT was completed for the corrected voltage at 1 MHz in order to determine if the 12 hour pattern of possible biological activity coincided with a physical aspect of the environment. The peak of each graph was identified to see if its occurrence was also on a daily cycle, possibly contributing to the pattern. Each graph can also be analyzed for coherence with another physical parameter. The FFT identifies coherence more accurately than using a time series and may expose a relationship not noticed prior. The Welch’s method (pwelch) was used to perform the FFT, which is a power spectral density function that splits the data into eight sections of equal length with 50% overlap. The window size for this method was based on a log function with a base of two. The default settings were applied, using cycles per hour as the input for sampling frequency.
2.4 Biological Interference

The profiles created in MatLab were used in conjunction with the biological data collected by the vertical tile arrays to classify possible biological interference. The tiles placed at various heights in the water column corresponded to the height in the ABS data where large suspended particles were found without the presence of strong currents. In addition, only certain biology reflects sound, limiting the species that could be the cause of acoustic return. The physical parameters and sediment concentration data was collected at the inner site but biological data was collected from both the outer and inner sites. The SC Department of Natural Resources provided data on the percent cover values of each broad taxonomic group that settled on the vertical tile arrays during ABS data collection. The top and bottom of the tile was analyzed for percent cover. Histograms of percent cover were created for the inner and outer site for the top and bottom of each tile. Since there was such a large variation in the data, an average of the North and South stacks was taken and used for the histograms for each site. The histogram included biological data from only 2009 to support Deployment 9. Percent cover for the two months prior to Deployment 9 were also included to note variability between months. The dates for tile retrieval from Deployment 9 included August 18, October 1, and December 17. The ABS only detected organic particles that could effectively reflect sound, which limited the possibilities to organisms with shells or a spot of metal within the particle. Interpretation of the biological data, physical parameters, and the presence or absence of coherence led to the determination of whether the acoustic return was in fact due to biology, and what organism it could be.
Results

Sediment Concentration

According to MatLab plots of suspended sediment concentration and wave bottom orbital velocities, the greatest acoustic anomalies were noted in Deployment 3 during October and November of 2008 and Deployment 9 during October and November of 2009 (Figures 3 and 4). Both deployments displayed a distinct pattern of increased backscatter signal during times of low bottom orbital velocities, which is the driving mechanism that re-suspend sediment from the seafloor into the bottom boundary layer. Therefore, these time periods from each deployment were chosen to analyze for possible biological activity.

The strong patterns in high backscatter appeared to be in the middle of the water column approximately 0.2 to 1.2 meters above the seafloor. The acoustic return in the middle of the water column differs greatly from the sediment suspension resulting from a strong wave or storm event, where sediment concentration increases with depth. Moreover, the voltage measured in the middle of the water column during these times was even stronger than the voltage data collected during times of sediment re-suspension, particularly in the 1 MHz transducer (Figures 5 and 6).

During periods of increased bottom orbital velocity, the backscatter is strongest immediately above the seafloor and dissipates above 0.2 meters, while the unidentified signal does not appear until approximately 0.2 meters above the bed and extends upward for about a meter. The second week of November 2008 showed the strongest pattern and indicated that the anomaly was present throughout the night into early morning. Higher suspended sediment concentrations corresponded with an increase in bottom orbital velocity during October 12th and 25th of 2008. However, the backscatter signal during these days occurred immediately above the seafloor,
suggesting sediment resuspension due to increased bottom orbital velocities. The days where increased backscatter is present in the middle of the water column did not correspond to an increase in bottom orbital velocity.

November 8 through 21 exhibited the greatest signal of return in the middle of the water column during Deployment 3 (Figure 7). On November 8 and 9 of 2008, the pattern was strong and lasted approximately 12 hours every 24 hours (Figure 8). The activity appeared to be from 7:00 P.M. to 7:00 A.M. This similar pattern was noted throughout the deployment. The three transducers all showed an increase in the backscatter signal but the ABS software algorithm determined that the most dominant sediment size based on the suspended sediment concentration from all three transducers was about 0.6 mm. The patterns noted in Deployment 9 were slightly

Figure 3. Suspended sediment concentration and grain size during Deployment 3 is depicted as a pattern and is most visible during the first two weeks of November.
Figure 4. Suspended sediment concentration and grain size during Deployment 9 is depicted as a pattern and is most visible during the first week of November. The overall pattern appears to be in a wave shape.

Figure 5. Voltage during Deployment 3

Figure 6. Voltage during Deployment 9
stronger than those seen during Deployment 3. The position of the backscatter signal during Deployment 9 varied slightly in the water column, with the highest position during the first week of November. Sediment suspension occurring near the seabed around October 24, 26, 28 and

Figure 7. The pattern of “suspended sediment” in the middle of the water column is most clear as a daily pattern during November 7-21.

Figure 8. Typical pattern of increased voltage and grain size anomaly for all deployments which appeared to be present between 7:00 PM and 7:00 AM (local time) each day.
November 12, 13 also corresponded with an increase in bottom orbital velocity. A clear pattern of diel signal was noted during the first ten days of November 2009 (Figure 9). On November 8th and 9th of 2009, the pattern was strong and lasted approximately 12 hours every 24 hours. The activity also appeared to be from 7:00 P.M. to 7:00 A.M., indicating night activity (Figure 10). This similar pattern was noted throughout the deployment. The three transducers all showed an increase in the backscatter signal but the ABS software algorithm determined that the most dominant sediment size based on the suspended sediment concentration from all three transducers was about 0.6 mm. The 1 MHz transducer, which exhibited the strongest signal, is most sensitive to particles that are 1.5 mm. During both Deployments 3 and 9, the pattern was most visible in the grain size plot but was still present in the sediment concentration plot. The pattern also diminished during storm events. When waves suspended sediments at the site, the increased backscatter signal was due to resuspension of sediment particles.

Sunrise and sunset data from the U.S. Naval Observatory records were compared to the time when the signal was present, and the diel migration pattern appeared to follow these times closely. During Deployment 3, the sunrise ranged from 6:11 AM to 6:53 AM (local time) and sunset ranged from 5:58 PM to 6:09 PM (local time). During Deployment 9, there was less variation due to a shorter deployment, with the sun rise ranging from 6:26 AM to 6:48 AM (local time) and sun set ranging from 5:33PM to 5:12 PM (local time). In the figures illustrating the day night cycle (Figure 8) the sun rise was 6:41 AM and the sun set was 5:17 PM (local time) for November 8 and 6:42 AM and 5:16 PM (local time), respectively for November 9. It is clear that the signal is present at 7 PM but not during the previous burst at 5 PM, occurring during or prior to sunset. The signal then disappears when the 7 AM burst begins, following sunrise. Therefore,
it can be inferred that the migratory patterns exhibited in the acoustic signal exhibit a diel migration that is driven by photosensitivity.

Figure 9. The first ten days of November 2009 most strongly depicted the acoustic pattern during

Figure 10. During November 8th and 9th of 2009, the pattern was strong and also appeared to be between 7:00 PM and 7:00 AM (local time).
Using AquaScat Toolkit, the position and strength of the signal in the water column during every two hour sampling period was identified. November 8th was used as a comparison between 2008 and 2009 to identify differences in the phenomena (Figure 11 A-D, Figure 12 A-D). During both of the deployments, the signal is strongest during the first half of the day, during the morning hours. The signal is averaged over 600 profiles during the two hour sampling period. The signal appeared to move vertically up and back down during those hours during both deployments but is more visible during Deployment 9.
Figure 11. This figure represents the signal that appeared during November 8, 2008, including frequency and position in the water column at (A) 7 PM (B) 11 PM (C) 3 AM (D) 9 AM.
Physical Parameters

The physical parameters collected during both deployments included wave height, wave period, wind direction, wind speed, current direction, and current speed. Pressure data was also available for Deployment 9. During 2008, the wind speed typically fluctuated between approximately 3 m/s and 7 m/s; however, some higher peaks were noted throughout the
deployment (Figure 13). The highest wind speed was approximately 14 m/s and occurred on October 12, 2008. Other peaks of wind speeds near 13 m/s were recorded on November 4 and October 25, where the winds appeared to change direction starting with winds from the north, then northeast, southwest and then from the north. Biological activity was not present during increased wind speeds or several changes in wind direction. The wind direction during this deployment varied, but typically blew from the north (Figure 14). The winds began to blow from the north on November 5 and then the direction changed from the northwest, to southwest, back to northwest and then to north. November 15-17 experienced winds that were blowing from the southwest and then changed directions from the northwest to west to north.

Wave heights at the study site varied between approximately 0.2 meters and 1.9 meters, recorded on October 29 and October 25, respectively (Figure 15). Other peaks of increased wave height were noted between October 8 and 13 with waves up to 1.4 meters, November 3 and 6 with waves up to 1.1 meters, and November 12-16 with waves up to 1.3 meters. Increased wave energy corresponded to no biological activity. The highest wave height of 1.9 meters...
corresponded with a storm event bringing increased wind speed and almost no acoustic return. During the period of increasing wave height from November 13-16, the acoustic signal becomes weaker as the peak wave height of 1.3 meters on November 16 occurs.

The wave period ranged from between 4 and 10 seconds throughout the deployment (Figure 16). The longest period recorded was approximately 14.5 seconds and occurred on October 22. On October 31, the wave period dropped from approximately 14 seconds to a little over 2 seconds immediately following.

The current speed documented during this deployment mostly remained between 0.02 m/s and 0.12 m/s (Figure 17). However, there were a few peaks of increased current speed throughout the deployment. The highest peak occurred on October 30 and reached a current speed of 0.38 m/s. This peak appeared to be only a single measurement. Other peaks were

![Figure 14](image1.png)

Figure 14. Wind direction changed greatly throughout the deployment, but mostly remained from the north.
Figure 15. Wave height reached a maximum on October 25 of approximately 1.9 meters. Other peaks occurred between October 8 and 13, November 3 and 6, and November 12-16.

Figure 16. The wave period also fluctuated greatly throughout the deployment with the longest period being approximately 14.5 seconds and occurred in October 22. The majority of the wave periods were between 4 and 10 seconds.

Figure 17. The current speed mostly remained between 0.02 m/s and 0.12 m/s. The highest recorded current speed was approximately 0.38 m/s on October 30.
noted on November 12 of 0.34 m/s and November 25 of 0.3 m/s. Current direction fluctuated greatly throughout the deployment and appeared to generally move toward the north (Figure 18).

During 2009, the wind speed varied greatly (Figure 19). The highest wind speed recorded was approximately 23 m/s and occurred around October 29, blowing from a direction of 20 degrees northeast, to east, to southwest, to north, to northwest. A pattern of overall lower wind speed was present during November 3-10 and a pattern of overall higher wind speed was present during November 11-14. Increased wind speed and changes in wind direction corresponded with weak acoustic return in the middle of the water column. On November 11, strong backscatter was present with strong winds but the signal was located immediately above the seabed, as a result of resuspension of sediment. The direction of the winds during this time changed from 40 degrees northeast to 160 degrees southeast. The wind direction during Deployment 9 commonly blew from the north (Figure 20).

Wave heights at the study site varied between approximately 0.2 meters and 1.25 meters, recorded on October 6 and November 13, respectively (Figure 21). Wave height displayed four short peaks around October 24, 26, 28, and 30. A period of overall greater wave height was noted during November 10-13, while a period of smaller wave heights followed this peak from November 14-15. Greater wave heights correspond with weak acoustic signal in the middle of the water column, or strong signal near the seabed. The period of smaller wave heights coincided with strong acoustic return in the middle of the water column.

On November 14, the longest wave period was measured around 15 seconds. Other peaks occurred on October 31, with peaks between 11 and 12 seconds. Another set of peaks occurred around November 4-5. The majority of the data appeared to fluctuate around a period of 6-8
Figure 18. The current direction fluctuated greatly throughout the deployment, but mostly remained toward the north.

Figure 19. Wind speeds during Deployment 9 reached a maximum on October 29th with 23 m/s. Another peak of wind speed occurred during November 11-14, following a pattern of lower wind speed from November 3-10.

Figure 20. Wind direction fluctuated throughout the deployment, but mostly remained from the north.
seconds (Figure 22). The pressure exhibited a semi-diurnal tidal cycle with a slight diurnal inequality, with the highest tidal range during the week of November 1-8 (Figure 23).

Current speed during Deployment 9 mostly remained between 0.05 and 0.07 m/s (Figure 24). However, one large peak occurred around November 12, reaching a current speed of approximately 0.47 m/s. The second tallest peak in current speed occurred around October 30, reaching a speed of approximately 0.23 m/s. The current direction during this deployment was typically from the southwest or northeast (Figure 25). Current direction changed much more frequently than the direction of the wind, due to the tidal cycle.

The time series data of the physical parameters that were correlated the most with the corrected voltage were plotted together in order to determine the changes in physical parameters that lead to changes in acoustic signal for both deployments (Figure 26, 27). The signal disappeared during Deployment 3 when the physical forcing parameters became more energetic. Wind speeds were between 10-15 cm/s blowing from the northeast to northwest. Wave heights were from 1.0 - 1.4 m and the wave period was about 5 seconds. Current speeds were between 0.15 and 0.35 cm/s toward the southwest. During Deployment 9, there was an overall higher wind speed than during Deployment 3 however, the signal still disappears when the wind speed exceeds 12 cm/s, blowing from the northeast to northwest. Wave heights exceeded 1 meter and

![Figure 21](image-url)
wave periods were between 4 and 8 seconds during the periods where the signal disappeared. Current speeds did not appear to have as much of an effect on the presence of the signal. Even when current speeds increased, the signal remained.

**Biological Interference**

The tiles collected were analyzed by DNR for percent cover. The most common taxonomic groups that were attached to the tiles during the deployment were identified as well. Following the August 18 retrieval, the percent cover on the top of the tiles at the inner site was highest for polychaetes, with 34.87% cover (Figure 28). On the bottom of the tiles at the inner site, polychaetes also had the highest percent cover with 30.32% (Figure 29). On the top of the tiles at the outer site, polychaetes had the highest percent cover with barnacles behind, with 30.74% and 18.9%, respectively (Figure 30). The bottom of the tiles at the outer site had the highest percent cover with barnacles, and polychaetes close behind, with 37.46% and 21.04%, respectively (Figure 31). The retrieval on October 1, 2009 revealed that at the inner site, on the tops of the tiles that barnacles had the highest percent cover with 56.34%. Polychaetes and hydroids also had a high percent cover with 53.42% polychaetes and 48.13% hydroids (Figure 28). The bottom of the tiles at the inner site revealed the highest percent cover of barnacles, with 59.46%. Hydroids and polychaetes followed with 43.44% hydroids and 41.51% polychaetes

![Figure 22. The wave period also fluctuated greatly throughout the deployment with the longest period being approximately 15 seconds and occurred on November 14. The majority of the wave periods were between 6 and 8 seconds. Other peaks were centered on October 31 and around November 4-5.](image)
Figure 23. The pressure graph for Deployment 9 resembles a mixed tidal cycle, with the strongest tidal difference between high tide and low tide occurring during the week of November 1-8.

Figure 24. The current speed mostly remained between 0.05 m/s and 0.07 m/s. The highest recorded current speed was approximately 0.47 m/s on November 12.

Figure 25. Current direction fluctuated much more than wind direction but was mostly recorded as southwest or northeast.
Figure 26 a-d. Physical parameters of Deployment Three and corresponding corrected voltage where (a) range corrected voltage at 1 MHz, (b) wave height, (c) wind speed, and (d) current speed.

Figure 27 a-e. Physical parameters of Deployment Nine and corresponding corrected voltage where (a) range corrected voltage at 1 MHz, (b) pressure, (c) wave height, (d) wind speed, and (e) current speed.
Figure 28. This figure displays the percent cover of broad taxonomic groups on the top of the tiles at the inner site.

Figure 29. This figure displays the percent cover of broad taxonomic groups on the bottom of the tiles at the inner site.
Figure 30. This figure displays the percent cover of broad taxonomic groups on the top of the tiles at the outer site.

Figure 31. This figure displays the percent cover of broad taxonomic groups on the bottom of the tiles at the outer site.
Barnacles and polychaetes had the highest percent cover on the top of the tiles at the outer site, with 65.48% and 45.52%, respectively (Figure 30). On the bottom of the tiles at the outer site, barnacles had the greatest percent cover with 51.15% (Figure 31).

The retrieval on December 17th was from tiles that were deployed on October 22, the time at which Deployment 9 began. Therefore, these tiles represented the type of epi-benthic organisms present in the water column. On the top of the tiles at the inner site, the highest percent cover of 53.64% was due to barnacles (Figure 28). The bottom of the tiles at the inner site was also dominated by barnacles with a 49.95% cover (Figure 29). At the outer site, the top of the tiles had the highest percent cover of barnacles, with 83.88% and amphipods close behind with 66.7% (Figure 30). The bottom of the tiles at the outer site was also mostly covered by barnacles, with 83.27% cover and amphipods with 62.08% cover (Figure 31). Therefore, it appears that polychaetes and barnacles dominate the greatest surface area of settlement during this period of the year.

Other categories of organisms that were found on the tiles include bivalves, solitary ascidians, colonial ascidians, and bryozoans. A miscellaneous category was also included. The percent cover of these organisms was usually in trace amounts and had variable settlement behavior. From the August 18th retrieval, the top of the tiles at the inner site included 13.73% barnacles, 0.05% amphipods, 6.82% hydroids, 0.12% bivalves, 0% solitary ascidians, 0.44% bryozoans, 0% other, and 0% colonial ascidians (Figure 28). The bottom of the tiles at the inner site included 17.64% barnacles, 0% amphipods, 7.21% hydroids, 0.16% bivalves, 0.11% solitary ascidians, 0.44% bryozoans, 0% other, and 0% colonial ascidians (Figure 29). At the outer site, the top of the tiles had 0% amphipods, 3.76% hydroids, 0.41% bivalves, 0% solitary ascidians, 0.21% bryozoans, 0% other, and 0.05% colonial ascidians (Figure 30). The bottom of the tiles at
the outer site contained 0.05% amphipods, 4.40% hydroids, 0.05% bivalves, 0% solitary ascidians, 0% bryozoans, 0% other, and 1.86% colonial ascidians (Figure 31). The October 1st retrieval included a species cover of 0.07% amphipods, 1.01% bivalves, 0.30% solitary ascidians, 0.8% bryozoans, 0.06% other, and 0% colonial ascidians on the top of the tile at the inner site (Figure 28). On the bottom of the tile at the inner site, 0.19% amphipods, 0.06% bivalves, 3.19% solitary ascidians, 0.18% bryozoans, 0% other, and 0% colonial ascidians was present (Figure 29). At the outer site, the top of the tile included 0.22% polychaetes, 1.29% amphipods, 0.65% hydroids, 0.41% bivalves, 0% solitary ascidians, 0.44% bryozoans, 0% other, and 0% colonial ascidians (Figure 30). The bottom of the tile at the outer site contained 20.74% polychaetes, 0.83% amphipods, 12.21% hydroids, 0.31% bivalves, 1.02% solitary ascidians, 0.83% bryozoans, 0% other, and 2.16% colonial ascidians (Figure 31). The December 17th retrieval included a species cover of 17.55% polychaetes, 7.95% amphipods, 13.75% hydroids, 15.67% bivalves, 5.91% solitary ascidians, 0.96% bryozoans, 0.19% other, and 0% colonial ascidians on the top of the tile at the inner site (Figure 28). At the inner site, the bottom of the tile included 15.98% polychaetes, 2.05% amphipods, 7.07% hydroids, 19.89% bivalves, 3.53% solitary ascidians, 1.16% bryozoans, 0.2% other, and 0% colonial ascidians (Figure 29). The top of the tile at the outer site contained 0.22% polychaetes, 1.29% hydroids, 0.65% bivalves, 0.05% solitary ascidians, 0.11% bryozoans, 0.05% other, and 0.16% colonial ascidians (Figure 30). On the bottom of the tile at the outer site, 0.16% polychaetes, 0.49% hydroids, 0.05% bivalves, 0.05% solitary ascidians, 0.11% bryozoans, 0% other, and 13.79% colonial ascidians was present (Figure 31).
Data analysis

The times series data from the pressure as well as the 1 MHz voltage from each deployment was transformed into a frequency spectrum using MatLab. The pressure data exhibited and confirmed that the tides are influenced by a semi-diurnal tidal cycle (Figure 32). The voltage data from Deployment 3 had the largest peak at 0.04 which corresponds to a daily cycle. Two smaller peaks around 0.08 and 0.127 corresponded to a semi-diurnal cycle and one of approximately eight hours, respectively (Figure 33). The peaks suggesting the daily and eight hour cycle are fairly small and this system was dominated by the largest peak frequency corresponding to 24 hours. During Deployment 9, the largest peak was at 0.04 which also corresponds to a daily cycle (Figure 34). The peak noted at 0.04 hours during Deployment 9 is about twice the strength of that seen during Deployment 3. The two smaller peaks that were present in Deployment 3 were also present in Deployment 9 corresponding to the same frequencies.

![Figure 32. Frequency Spectra of pressure that supports that the tides are semi-diurnal at the study site.](image)

![Figure 33. Frequency Spectra of Deployment 3 shows the largest peak around 0.04, supporting a daily cycle.](image)
Figure 34. Frequency Spectra of Deployment 9 shows a much stronger peak at 0.04, supporting a stronger cycle of 24 hours.

Discussion

Based on the analysis of the physical parameters, the phenomena witnessed in November 2008 and 2009 did not appear to be a result of the changes in currents, tides, waves, or wind. When the acoustic anomaly was present, the corresponding physical parameters exhibited calm conditions. The pattern would disappear when physical parameters were enhanced, therefore suggesting the sustained effects on a mobile organism. Current speed did not appear to have as much of an impact on the presence of the signal as the other physical parameters, which suggests that this phenomena may not be as dependent on currents. However, when wave height and wind speed increased and wave period decreased, the presence of the anomaly vanished. The changing intensity of these physical parameters was due to frontal passages when winds increased in intensity. Therefore, the threshold for sediment resuspension is surpassed during these times. During the times when the pattern disappears and physical parameters are enhanced, much of the signal, if present, is within the bottom 30 cm of the seafloor. The acoustic return is due to sediment resuspension from the increase in physical forcing in the bottom boundary layer. In general, Deployment 9 was exposed to a slightly higher level of wave energy then Deployment 3, but the pattern still remained, as wave orbital velocities were not high enough to continually
re-suspend sediments from the seabed. The enhancement of physical forcing in both deployments caused the signal to disappear.

Pressure data was available for Deployment 9 and water height fluctuations primarily driven by tidal influence were also measured, and considered as a possible influence of the acoustic signal. The Fast Fourier Transform (FFT) performed in MatLab on the variable of pressure provided a dominant frequency signal corresponding to a period of about 12.5 hours corresponding to a semi-diurnal tidal cycle. The FFT performed on Deployment 3 and 9 also identified the dominant cycles within the deployment. The identification of the dominant frequency corresponds to a period that is most often experienced during that deployment. During Deployment 3, the dominant frequency corresponded to a period of about 24 hours. Two other dominant frequencies corresponded to a period of about 12.5 hours and 8 hours. The frequency spectrum corresponding to 12.5 hours was the smallest of the three. During Deployment 9, the dominant frequency also corresponded to a period of approximately 24 hours.

The dominant frequency in both deployments corresponded to a daily 24 cycle. This cycle corresponds to the possible 24 diel migration pattern that is noted in the acoustic data. The pattern is present for 12 hours (from after sunset to sunrise) every 24 hours and is supported by the Fourier Transform Analysis as the dominant frequency in both deployments. The semi-diurnal tidal cycle that is dominant in this region is not responsible for this phenomenon. If the dominant frequency in both deployments was one that corresponded to a period of 12.5 hours, it would be acceptable to assume this is a tidally driven event. However, the dominant frequency corresponds to a period that is of 24 hours in both deployments, suggesting that the source of this acoustic anomaly is not driven by tides, or any other physical parameters. The absence of a
A strong correlation between the acoustic anomaly and a physical parameter strongly suggests biological activity.

Several previous studies have identified organisms thought to contribute to biological activity measured with acoustics. Barans et al. (1997) researched the vertical distribution of zooplankton and other small particles suspended in the water column in North Edisto Inlet of South Carolina. Using a Tracor Acoustical Profiling System (TAPS), possible patterns of relationships of distribution with diel, tidal, lunar and seasonal cycles were identified. Using a similar acoustical application of an equivalent spherical radius (ESR) as in this study, Barans et al. (1997) described the patterns for varying sizes. Barans et al. (1997) found that organisms that were of smaller size, corresponding to 0.13 mm ESR, were most abundant in the water column and were strongly influenced by tidal cycle. These particles were found in deeper parts of the water column but also extended upward, even up to the surface, depending on ebb and flood tides. Organisms that corresponded to the 0.79 mm ESR were of similar size to those particles that were detected by the 1 MHz detector on the ABS used in our study (Barans et al., 1997). This size range included zooplankton as well as crustacean larvae with varying body shapes, which were strongly influenced by both tidal and diel signal. During the night, the copepods of genus Labidocera and Calliariassa were most prominent (Barans et al., 1997). During June the strongest signal was detected, where a moderate concentration was present throughout the water column during darkness and distinct layers were created during the day. The bottom 1-1.5 meters was not measured during the September-October deployment, where the zooplankton were found in a narrower distribution at night and in deeper locations during the day (Barans et al., 1997). The planktonic fish larvae and small pelagic fish that represent the 5.0 mm ESR exhibited the largest spatial and temporal distribution at night (Barans et al., 1997). The spatial distribution of
organisms of a 5.0 mm ESR was similar to those of 0.79 mm ESR and extending even closer to the surface. Barans et. al (1997) suggested that each specific distribution based on tidal and diel signal could represent a specific behavioral response of a different species or group of species. Zooplankton exhibited a specific response of density distribution based on the tidal and diel cycle. More specifically, the daily diel vertical pattern was clear in the ESR category of 0.79 mm, representing the 1MHz transducer on the ABS (Barans et al., 1997). The acoustic return of zooplankton was noted higher in the water column than the resuspension of sediments, which corresponds with the data in my analysis. The resuspension of sediment was within the bottom 30 cm of the seafloor while the acoustic return from biological interference was between 20 and 120 cm above the bed, which exhibits similarities to the ABS data in my analysis.

Barans et. al (1997) mentions the possibility of larval crustaceans causing the acoustic interference and Sato and Jumars (2008) have a strong argument for the emergence of a specific crustacean, *N. americana*. Sato and Jumars (2008) researched the vertical distribution patterns of *N. americana* in an estuary in Maine using a TAPS from October to November, and July to August. Field sampling with a 1 mm netting on a pyramidal trap and night plankton tows accompanied this acoustic data. Previous studies identified *N. americana* as the primary emergent species that exhibits nocturnal behavior throughout much of the year, but is much stronger in the summer than the fall (Sato and Jumars, 2008). The spectral analysis performed on the data (FFT) show a strong 24 hour cycle during the summer at 256 kHz and 420 kHz. During the fall, at 7 meters above the bed, the spectral analysis identified three frequencies that corresponded to periods of 24.74, 12.31 and 6.17 hours, therefore suggesting that the behavior of *N. americana* is simultaneously influenced by all of the dominant periods (Sato and Jumars, 2008). The timing of the emergence has been correlated with current speed near the bottom,
where some organisms will avoid emergence during periods of increased current speed. It appears that there is a threshold of physical parameters that when met, prevent emergence (Sato and Jumars, 2008), which is very similar to this ABS data from the study in Long Bay, especially with regard to wind speed and wave height. When the wind speed increased and wave height surpassed about 1 meter, the acoustic signal was not present. It is possible that the threshold was met to prevent emergence of the species contributing to the acoustic anomaly. Sato and Jumars (2008) suggest that other possible organisms that could produce biological interference are crangonids, the predator of the mysid shrimp, or fish larvae. However, Sato and Jumars (2008) note that fish larvae are the most abundant in the late winter and early spring and they are more likely to produce spikes in the acoustic data, rather than a consistent pattern. The dormant behavior of the mysid shrimp on or in the bottom sediments during the day supports the possibility that mysids could be causing the acoustic anomaly (Sato and Jumars, 2008). Unlike my analysis, Sato and Jumars (2008) found that the mesozooplankton organisms respond stronger to tidal influence than diel influence in both summer and fall, but stronger tidal currents are present in the estuary than in the coastal ocean.

Corey (1988) also found distributions of *N. americana* to be higher in the summer and fall, as well as at night. Paired Bongo nets were used to collect plankton within 5 meters of the bottom extending to the surface in the Bay of Fundy. *N. americana* was the most abundant mesoplankton species collected during the tow and the distributional patterns depended on the stage of maturity the organism had met (Corey, 1988). This species is known to inhabit coastal and estuarine waters of depths less than 250 meters, extending from southern Newfoundland to northern Florida (Corey, 1988). Offshore movement of *N. americana* during the late summer and fall can influence the distribution patterns as well. In addition, this species is identified as one
that exhibits regular diurnal vertical migration, being more abundant in the surface at night
(Corey, 1988).

Jumars (2007) completed a study on habitat coupling of mysids in temperate latitudes and
supports the strong diel migration of this family. The emergence of mysids occurs during the
night from on or within the bottom substrate or sediments, with hardbottoms being a desirable
habitat (Jumars, 2007). The pattern of emergence can vary widely, according to Jumars (2007),
with several factors such as timing, seasonality, tidal and daily influences. Mysids have two
advantageous features that allow them to be successful vertical migrators, including statocysts
that allow for vertical orientation as well as sensitivity to pressure changes for identifying depth
(Jumars, 2007). Mysids are also known to exhibit schooling behaviors where they may exhibit
planar aggregations that are stacked within the water column, varying by gender and age
(Jumars, 2007). In addition, Jumars (2007) found that the first set of migrators tend to be more
organized than the following groups. The most common migrating species were *N. americana,*
*Erythrops erythrophthalmal*, and *Americamysis bigelowi*. However, in South Carolina, Jumars
(2007) identified *N. americana* as being present yearlong in shallow ocean waters.

Harding (2001) suggests that the composition of zooplankton can be affected not only by
biological or oceanographic factors individually, but as a combined mechanism as well. In my
analysis, the physical parameters did not appear to be as essential to the acoustic anomaly and
was most likely driven by a biological parameter. Harding (2001) also found that the specific
behavioral response of the species can attribute more to the diel pattern than physical changes
within the environment. The study completed by Harding (2001) correlated seasonal changes
with changes in the zooplankton community, based on various reproductive and life history
stages. The maximum abundance of total zooplankton occurred during mid to late summer. The
dominant taxa that were found later in the year, near the time of our deployments, were bivalve veligers, calanoid copepod nauplii and calanoid copepod adults (Harding, 2001). However, the two most abundant nocturnal species were calanoid copepod adults and decapod zoea (Harding, 2001). In addition, calanoid copepod adults exhibited stronger aggregation than other taxa. Bivalve veliger abundance was highest from July to September (Harding, 2001). Harding (2001) found that the tidal influence significantly affected the distribution of the majority of the species present. In an estuary, the tidal currents in tidal channels can be much larger than offshore in open waters where they are less than 5 cm/s. However, the influence of tidal stage, independently, is not greater than a seasonal or diel pattern of migration (Harding, 2001).

Hart and Allanson (1976) studied the diel vertical migration of three species in the calanoid copepod classification, all within the genus *Pseudodiaptomus*. Sampling took place in a subtropical lake in southern Africa, where the benthic and pelagic populations were both sampled. The distribution of calanoids was compared to abiotic and biotic factors, similar to my analysis, and no correlation was found. Light sensitivity was identified as being an age-related factor that may influence distribution (Hart and Allanson, 1976). The adult populations were most sensitive to changes in lunar conditions and younger populations were identified as the first migrators. In addition, innate rhythmic behavior among the copepods was also suggested to influence the migrational patterns between genders (Hart and Allanson, 1976). Hart and Allanson (1976) suggest that the rate of change of light intensity triggers the migration as a set stimulus in the environment. This stimulus causes the copepods to become more active swimmers in contrast to their otherwise stationary behavior near the bottom or within the sediments (Hart and Allanson, 1976).
A more specific approach was taken by Twining et al. (2000), who studied the possibility of homing behavior in a coral reef mysid, *M. gracile*. Twining et al. (2000), noted that this species began to disperse in the evening and arrived back in the early morning, similar to what was noted in my analysis. In addition, *M. gracile* would return back to the same benthic site for several days. Twining et al. (2000) suggested that *M. gracile* participate in homing behavior because individuals of similar size, color, and reproductive level were found in the same site and when aggregations were removed from sites, no mysids would return the next day. The nocturnal dispersal pattern of the mysids is predicted to be several meters. Twining et al. (2000) identified that 77% of the mysids that were present on a given day returned the following day. The return rate could be an underestimate due to the possibility of not catching all individuals the second day or longevity of the radioactive tracer used to track the individuals. However, it is clear that homing behavior does not provide a perfect return rate, which identifies homing behavior as not very precise. This behavior is specific to the *M. gracile*, the only known demersal zooplankton known to exhibit homing (Twining et al., 2000).

Many of the conclusions that Barans et al. (1997) presented were based on the combined effects of diel and tidal influence on the distribution of zooplankton and other particles in the water column. My analysis of the study in Long Bay presented only a dominant frequency of 24 hours in Deployment 3 and 9, thus not supporting the presence of a strong tidal influence on the acoustic signals. Since the tidal influence is semi-diurnal in this region, the dominant frequency would need to be 12.5 hours if the tidal cycle had a strong effect on the presence of the signal. However, since the strongest frequency corresponds to a 24 hour period, the diel influence is the only proposition from Barans et al. (1997) that is supported by my analysis. The study that Sato and Jumars (2008) completed suggested the emergence of *N. americana* to be a dominant,
nocturnal emergent species. However, the driving mechanism behind the emergence of this organism was linked to tides rather than diel influence (Sato and Jumars, 2008). In my analysis, the diel influence is much stronger than the tidal influence. In addition, *N. americana* arrives in late April and stays in the bottom meter or two above the seabed until late May or June for emergence (Sato and Jumars, 2008). The pattern noted during Deployment 3 and 9 occurred during October and November. The summer deployments in my analysis did not exhibit a strong enough pattern to investigate, if any. On the other hand, Corey’s (1988) research found that *N. americana* participates in diurnal vertical migration as well as offshore movement during late summer and fall. The site in which the acoustic data was collected was considered an inshore site, 850 meters from shore. It is possible that by November, *N. americana* has moved more offshore and therefore would not affect the acoustic data. Jumars (2007) noted that the mysids often aggregate in planar assemblages which can be supported by the profiles created in Toolkit showing the movement in the water column throughout the night. There are several different sets of pings in these profiles which may correspond to the planar aggregations of mysids. The biological information provided by the recruitment data noted the significant increase in bivalve cover corresponded with the deployment when the acoustic anomaly was present. From the data in my analysis, it could be suggested that the increased proportion of bivalves could be related to the acoustic pattern. However, according to Harding (2001), bivalves are most abundant from July to September. The strongest acoustic patterns were noted in late October and November, which decrease the likelihood that bivalves are contributing to this phenomenon. Bivalves are not likely to be the cause of the acoustic signal because they are a sessile organism and therefore not able to move within the water column. The pattern noted in the acoustic data must be from a mobile organism with the ability to move to the same position every 12 hours. Harding (2001)
also attributed nocturnal activity in the decapod zoea and calanoid copepod adults. However, since her study took place in a river, the differences in salinity between the study sites could influence the species present. Hart and Allanson (1976) noted that the activity noted among *Pseudodiaptomus* was low during the daylight, peaked at dusk and then slowly declined throughout the night back to day time levels. In my analysis, it appeared that the activity was fairly consistent throughout the night and had an immediate peak and drop off around 7 PM and 7 AM, respectively. Since Hart and Allanson (1976) completed their study in Africa, it is possible that a different species of *Pseudodiaptomus* is contributing to the anomaly. However, the study also noted no clear seasonal variation in the patterns of distribution whereas October and November exhibited the strongest distributions of any other month (Hart and Allanson, 1976). Another possibility introduced by Twining et al. (2000) was due to the homing behavior of the coral reef mysid, *M. gracile*. Even though the behavior is not precise, the time for dispersal and appearance closely corresponds to the time where the acoustic pattern was present. The size range of *M. gracile* is between 1.5 and 6 mm, larger than the suspected grain size for the 1 MHz transducer of the ABS (Twining et al., 2000). However, the spatial resolution of the ABS may not be accurate and in fact, the instrument could be reflecting signal of particles this size. The spatial distribution of *M. gracile* does not extend into Long Bay, South Carolina (Harding, 2000). However, it is possible that a different species of mysid may also exhibit homing behavior over the hard bottom region at my study site that has yet to be studied in depth.

Based on the previous studies that have been completed, it is likely that the cause of biological interference in Long Bay, South Carolina was a type of mesoplankton. Since there were no plankton tows completed at the time of data collection, it is very difficult to determine the species that caused this behavior. However, it appears that several mysid species have
exhibited similar diel nocturnal migration in other locations. The species may vary based on the environmental parameters of the habitat. Since the acoustic anomaly is not determined by physical parameters, the cause of the signal is most likely due to diel migration patterns. Further research is needed in order to identify the species that exhibits this pattern in November.

**Conclusion**

There was not enough data collected during Deployment 3 and 9 to determine the identity of the species that caused the acoustic anomaly. If a plankton tow was completed, it is more likely that an individual species could be correlated with this signal. For future research, I would suggest that a plankton tow accompany the acoustic instruments during the deployment. Day and night plankton tows would be useful in determining the dominant migrator in October and November. Since the acoustic signal was the strongest during mid-October through November, I would suggest centering the deployment on those months. Physical parameter data can be collected using the acoustic instruments, similar to this study. If the species causing the acoustic anomaly is identified, the specific environmental conditions triggering the migration can be identified as well. Since the ABS does not have the capability of identifying the size of the organism with great accuracy, the range of possible sizes may be much larger than what is suggested using the equivalent spherical radius (ESR). The focus of the study should be on organisms that are an estimated size of 1.5 mm and are mobile. Future studies should be repeated in Long Bay near the same location in order to capture the phenomena that occurred in November 2008 and 2009. The environmental parameters as well as the distance from shore may influence the phenomena and should therefore be kept consistent with the future study. A grant is currently being developed to investigate this acoustic anomaly further to study the activity in the water column in greater detail noted in this study.
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