Passive Acoustic Monitoring of Fin Whales (*Balaenoptera physalus)* Near Offshore Wind Farm Areas Off the Coast of New Jersey

By

Britney E. Pepper

Dr. Douglas P. Nowacek (Duke University) & Dr. Aaron N. Rice (Cornell University)

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Executive Summary

Increased interest in renewable energy and newfound technological advances have led to recent development of offshore wind energy in the United States; however, most of what is known about offshore wind farm construction impacts on the maritime environment has been from Europe. Limited research has been conducted on the potential impacts on wildlife in the coastal waters of the United States, specifically on marine mammals. Large baleen whales, such as fin whales, are of particular concern due to limited knowledge about their populations, hearing abilities, and responses to human activities. They are susceptible to acoustic disturbances from the increased underwater anthropogenic noise generated from ocean activities. This study explores the occurrence of fin whales in the vicinity of offshore wind farm areas off the coast of New Jersey to help understand the anthropogenic impacts on fin whale ecology.

Approximately nine months of acoustic data from 2008 were collected by three Marine Autonomous Recording Units (receivers) off the coast of New Jersey that were located in what is now wind energy lease areas. The sound files from the receivers were investigated for the signature 20 Hz pulses that fin whales produce. Machine learning using automated detectors in the program Raven Pro captured data from acoustic events, and visual confirmations of spectrograms were applied in the analysis to determine fin whale presence, in which the date, duration of pulse train, and quantity of pulse trains in each day were recorded. Detector performance was evaluated so as to calculate the precision and recall rates.

Shipping traffic noise could potentially interfere with the receiver's detection range of fin whales. Cargo ships were chosen to be investigated, and Automatic Identification System (AIS) data in 2009 and 2019 were used for traffic comparison. Using ArcGIS Pro, three different buffers with different diameter distances—one-kilometer, three-kilometer, and five-kilometer—were created around the geocode locations where the receivers had been placed. The frequency of cargo ships that traveled through each buffer distance was determined using the Intersect tool in ArcGIS Pro.

Key findings include:

1. Fin whales were found present for 40 days out of the 219 days, with 11 days in August having the highest presence and followed by October and November. They appeared off the coast of New Jersey primarily during the late summer into the middle of fall.
2. A total of 172 pulse trains were detected over the identified 40 days. November was the highest, with 73, followed by October with 36 and August with 22. The number of pulse trains were generally higher from August through December. There was an average of 4.3 pulse trains per day, ranging from one to eighteen on any given day.
3. The durations of pulse trains were measured. The months with the longer pulse trains occurred in August, October, November, and December, which aligned with four of the months having the highest number of pulse trains. The average duration of pulse trains was approximately 25.6 minutes long, and the pulses spanned from half a minute to approximately 337 minutes long.
4. Fin whale calls increased gradually in the morning, reaching the peak at noon, and decreased as the day progressed. These calls happened more frequently from 10 a.m. to 1 p.m., which indicates that the whales may be more active during this time of day.

5. Cargo ship traffic levels were explored using AIS data. The shipping traffic stayed consistent throughout 2009 and 2019. There was a slight increase in traffic between 2009 and 2019. The lengths of cargo ships in 2019 were longer than in 2009, but the upper end of the interquartile range and the median ship length is approximately the same. Chi-squared tests for independence were run between each month and year at each receiver and found that none of the results were statistically significant.
6. Precision and recall rates were calculated for each of the 40 days to evaluate the TD performance. A threshold was set for the TD to minimize inaccurate detections of fin whales; given the threshold of 0.89, the average precision and recall rates were approximately 0.34 and 0.65, respectively.

The presence of fin whales was identified and examined in close proximity to future wind farm development locations off the coast of New Jersey. This study provides a benchmark for the population characteristics of fin whales prior to the construction of wind farms. The times with most presence and greatest quantity of vocalizations were during the late summer to the middle fall and from 10 a.m. to 1 p.m., respectively. The longest duration of pulse trains was found in the same months—August to December—that had multiple pulse trains. AIS data from cargo ships in 2009 and 2019 were analyzed to help provide better understanding of the potential acoustic masking of the recording units. Results from this study give insight to the population of fin whales, and their presence and call patterns can be used for wind farm construction recommendations and other forms of ocean construction that may impact the species while also providing a baseline for future studies.

Acknowledgements

This project was initially designed as an Independent Study that would give me an opportunity to take my initial step into the work of marine mammal bioacoustics. It developed into my Master's Project as I found a passion for ocean acoustics and an opportunity to expand my knowledge to new depths. Whether this project is used by those learning more about our biological world or those progressing in research, I hope my work will be of aid to all who read it and spark curiosity in acoustics similar to how it has for me.

This project was made possible by the Cornell Lab of Ornithology supplying me with the program Raven 2.0 for my acoustical analysis. Many thanks to my advisors, Dr. Douglas P. Nowacek of Duke University and Dr. Aaron N. Rice of Cornell University, for their unwavering support and confidence in my success. I would also like to thank my Coastal Environmental Management cohort for the encouragement that they gave me throughout the two years we spent together. Finally, thank you to my friends and family for always believing in me and giving me the strength to believe in myself.

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I. Introduction

With the combination of increased demand for clean, renewable energy and newfound technological advances, construction of offshore wind farms to generate electricity is becoming a reality. Block Island Wind Farm, the first commercial wind farm in the United States, was constructed off the eastern coast of Rhode Island and became operational in 2016 (Ørsted, n.d.). A pilot project, the Coastal Virginia Offshore Wind, was constructed in 2020 consisting of two wind turbines; this is a precursor to the completement of the wind farm that is planned to be fully constructed by 2026 (Coastal Virginia Offshore Wind, n.d.). The planning for construction of the next offshore wind farms has already begun. While the creation of offshore wind energy benefits the environment by producing renewable energy, most of what is known about offshore construction impacts on the maritime environment has been from Europe; limited research has been conducted on the impacts in the coastal waters of the United States, specifically on marine mammals.

Studies indicate that there appears to be minimal effects on marine mammals when wind turbines are being operated; however, there have been known negative consequences from anthropogenic ocean noise, such as hearing loss and masking of crucial sounds during the construction of the wind farm structures. Examples of this noise include seismic surveys, heavy boating traffic, helicopter presence, and pile driving (Discovery of Sound in the Sea [DOSITS], n.d.-b; Bailey et al., 2014; Macrander et al., 2022). These sources of noise have been found to cause behavioral adjustments in marine mammals, especially when mixed with pingers and other noises that are used to drive marine mammals away from work sites (Verfuss et al., 2016). As the construction of these offshore wind farms can be detrimental to the wildlife, being able to work on the sites when marine mammals are not as prevalent is crucial to preventing impacts to the populations (Macrander et al., 2022).

The planning specific to worksite avoidance of marine mammals is a challenge, and especially so for large whales. One large whale species of particular interest in the context of offshore wind farm construction is fin whales. Fin whales (*Balaenoptera physalus*) are baleen whales and have been listed as endangered under the Endangered Species Act and depleted under the Marine Mammal Protection Act (NOAA Fisheries, 2022b; Edwards et al., 2015). They are the second largest marine mammal on our planet, weighing between 40 and 80 tons and measuring up to 85 feet in length when fully grown. Their life span ranges from about 80 to 90 years, and they can consume up to two tons of krill and squid daily (NOAA Fisheries, 2022b). Given the vastness and difficult environment and conditions of the oceans as well as limited numbers of whales, especially fin whales, new approaches, technology, and commitment need to be applied to overcome voids in our knowledge and understanding of these large mammals.

Historically, commercial whaling impacted fin whales, greatly diminishing their numbers. When commercial whaling ended around 1980, the abundance of fin whales across the world had decreased by over 70%. Today, there are four major identified stocks: California/Oregon/Washington, Hawaii, Alaska (Northeast Pacific), and Western North Atlantic. There has also been discussion of evidence for subspecies due to the isolation of stocks (Archer et al., 2013). However, the recovery of fin whales post commercial whaling is largely unknown in the North Atlantic (Edwards et al., 2015). Stocks remain under pressure from events such as boat strikes, which have become their largest threat (NOAA Fisheries, 2022b). Based on a 2001 study, fin whales were the most common large whale to be hit by ships (Laist et al., 2001). A more recent study found that fin whale populations have been declining since 2008 in the Gulf of

St. Lawrence as well as having decreasing survival rates (Schleimer et al., 2019). These results show that little is known about the western North Atlantic stock which populates the eastern coastal waters of North America.

Sound plays a key role in the daily existence of fin whales, and focused research is needed to understand and help assess the impact of increased underwater anthropogenic noise generated from ocean activities. These disturbances in general can have numerous effects on whales in the population of the western North Atlantic stock, but a particular issue that can have dire consequences is the masking of sounds that whales depend on (Discovery of Sound in the Sea [DOSITS], n.d.-a). Hearing is the primary sense of marine mammals, particularly cetaceans, and is essential to their survival in the underwater acoustic environment (NOAA Fisheries, n.d.). Sound travels exceptionally well underwater. Water has a much higher density than air that allows sound to cover immense distances at faster and farther rates. This is especially true if they are low-frequency sounds as the sound waves can bend around objects (NOAA Fisheries, 2022a). Marine mammals have evolved to capitalize on sound; they are able to transmit and pick up a variety of complex sounds during their daily routines. They depend on sound to navigate and migrate, forage, find mates and breed, communicate with others and interact between parents and offspring, defend their resources and territories, maintain a social structure, and avoid predators (NOAA Fisheries, n.d.).

Like all cetaceans, fin whales are susceptible to acoustic disturbances in their environment that have potential to mask their call. Fin whales are known to produce two main types of calls. The first type is a typical 20-Hz pulse that is believed to be used for social purposes. The second one is a 40-Hz pulse that is typically irregular and not well-studied. The 20-Hz pulse is thought to be used to maintain contact with other individuals of the species and can be heard from long distances away (Wiggins & Hildebrand, 2020). The dive patterns of fin whales are either short or long; a short dive spans between two and six minutes while a long dive is between six and fourteen minutes (Wiggins & Hildebrand, 2020). Fin whales produce their calls during dives. Wiggins and Hildebrand found that both types of calls are produced in a greater quantity during long dives while no calls were produced when the whales were at the surface. The masking of these calls can lead to many consequences for their population, especially when their only means to communicate becomes limited.

A majority of baleen whales have lower frequency calls that are capable of being heard across large expansions of ocean because of the long sound waves bending around objects (NOAA Fisheries, 2022a). However, many anthropogenic sounds have contributed to the masking of these low-frequency calls. Sources of anthropogenic sound in the ocean have become substantially more detrimental to marine mammals as humans have intensified their activities. The ambient noise is largely the result of commercial shipping, military activities, and oil and gas exploration and drilling. Commercial ships, such as container ships, tankers, passenger ships, and ferries, produce mostly low-frequency (below 500 Hz) underwater noise by their propeller action, propulsion machinery, and hydraulic flow over the hull (DOSITS, n.d.-a). Chronic lower-frequency sound is particularly troublesome for many marine mammals because there is an overlap in the frequency ranges of cetacean hearing and the sound frequencies produced by ship noise (NOAA, 2016). The global forecast indicates considerable increases in the size and quantity of ships in the future that translates into more low-frequency noise coming from long distances as well as higher risk of ship strikes (NOAA, 2016). The amount of low-frequency chronic noise is positively correlated to the level of commercial shipping traffic, especially along the major shipping lanes in the northern hemisphere, with this traffic increase serving to limit the natural distances whales can be heard in the ocean (DOSITS, n.d.-a).

When shipping noises mask their critical signals, some whale species have been known to produce higher frequency calls and raise the amplitude of their calls during increased noise situations (Parks et al., 2007; Parks et al., 2011). Many marine mammals can also alter their behaviors by moving away from the sound source or modifying their vocalizations (Nowacek et al., 2007). Some examples of change in vocal behaviors are increasing the intensity of the call known as the Lombard Effect, shifting their frequency ranges, changing their call rates, or halting their calling altogether (DOSITS, n.d.-a). This can ultimately reduce their communication space, which can result in adverse effects such as lessening of their ability to find a mate, preserve social structure, forage, navigate, and avoid threats (DOSITS, n.d.-a; NOAA Fisheries, n.d.). Understanding these effects becomes crucial when studying populations and predicting how behaviors may change as they are increasingly exposed to the masking of sounds.

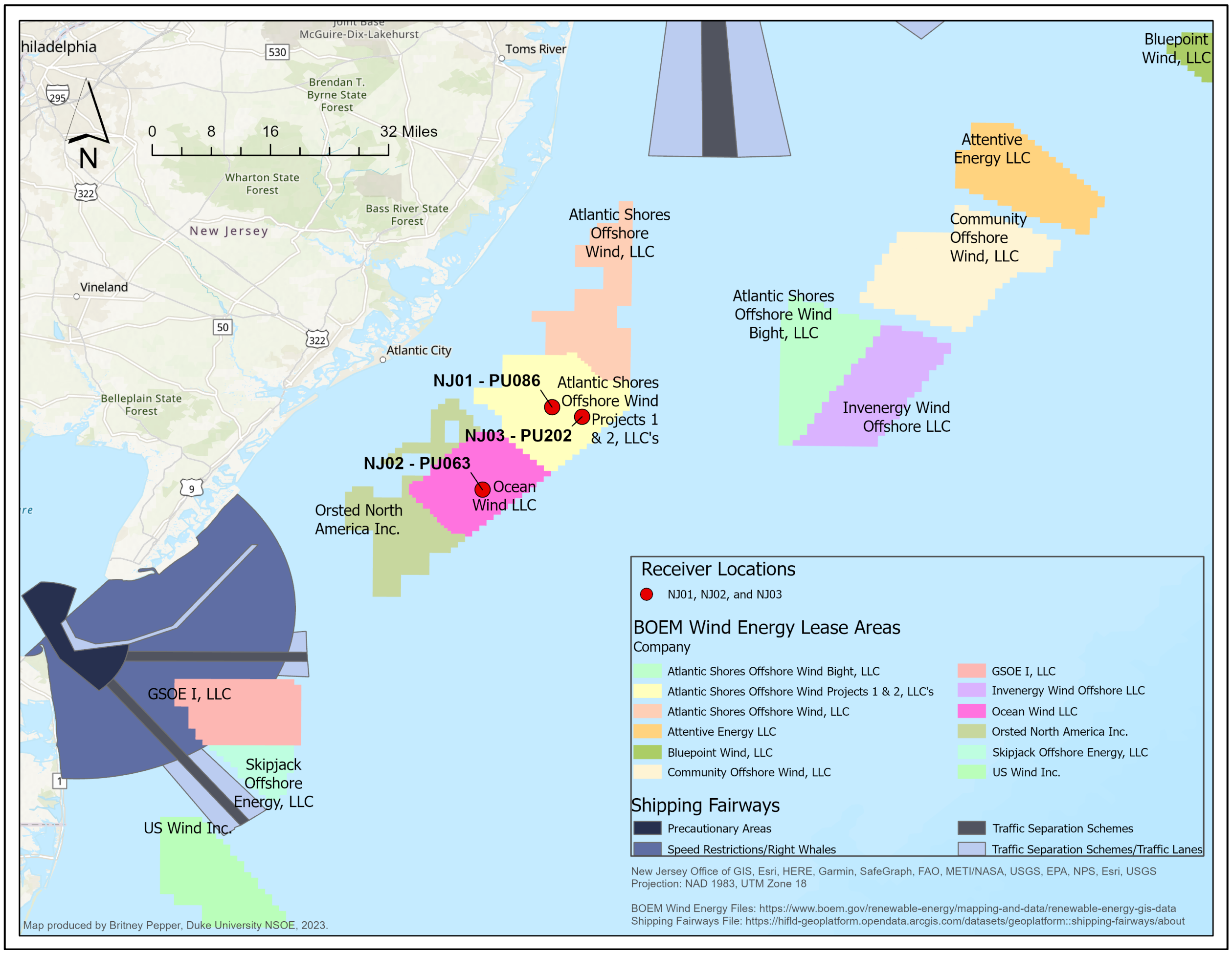
In the mid-Atlantic region, fin whales have been found to be present year-round with a range from Virginia to eastern Greenland (Davis et al., 2020). To date, not much is known about the breeding and migration patterns for the western North Atlantic stock as they typically travel farther away from the coast (Morano et al., 2012). However, it has been noted that fin whales do feed while migrating, unlike some of their other baleen whale counterparts (Silva et al., 2013). Further research shows that fin whales are present in the Massachusetts Bay and the New York Bight areas in large numbers throughout the year which implies that major seasonal migration may not occur for many individuals (Davis et al., 2020). In addition, fin whales are one of the most abundant species of baleen whales found offshore of Massachusetts, Rhode Island, and the New York Bight (Stone et al., 2016; Zoidis et al., 2021).

While fin whales have been found to complete major seasonal migration, some western North Atlantic stock fin whales do not (Morano et al., 2012). There has also been evidence that fin whales stay in middle latitudes during seasonal migration for bouts of time as opposed to moving to higher latitudes quickly (Silva et al., 2013). Noting that fin whales may not migrate far from higher middle latitudes means that there is a higher chance of them being impacted by human-related issues. With the increase in anthropogenic effects, it is essential to further research in these areas to aid in our understanding of the impacts that it has to fin whale population behaviors. A natural target for this research could be the New Jersey and New York coastlines, which have been found to have some of the highest noise levels along the eastern coast of the United States (Rice et al., 2014).

II. Methods

The data for this analysis were previously collected off the southern coastline of New Jersey from March 26 to December 4, 2008. Three different Marine Autonomous Recording Units, commonly referred to as receivers, were deployed during that time for data collection. These three receivers—NJ01, NJ02, and NJ03—were anchored to the seafloor at the locations identified as red circles in Figure 1 below and were located within what are now two wind energy lease areas. Wind energy lease areas are areas in the ocean that the Bureau of Ocean Energy Management (BOEM) manages and has leased or will lease out to companies for construction of commercial offshore wind farms. The receivers used in this study were placed approximately 15 miles off the coast of New Jersey, with the NJ01 and NJ03 receivers located in the Atlantic Shores Offshore Wind Projects 1 & 2 lease area and the NJ02 receiver in the Ocean Wind lease area. The Atlantic Shores Offshore Wind Projects, a partnership between Shell New

Energies and EDF Renewables, aim at achieving the goal of producing 1.5 GW of offshore wind power by 2027 (Atlantic Shores Offshore Wind, n.d.). The Ocean Wind project is a partnership between Ørsted and PSEG that targets to produce 1.1 GW of power in the early 2020's (Ørsted & PSEG, n.d.). Each receiver was deployed for approximately three months. The NJ01 receiver ran from March 26 to May 5, 2008; the NJ02 receiver ran from June 23 to September 17, 2008; and the NJ03 receiver ran from September 30 to December 4, 2008. The depth of the receivers were 58, 78, and 75.9 feet, respectively. To ensure full data capture during the deployment period, the receivers were recovered prior to them running out of memory storage, with the data being downloaded at the lab.



New Jersey Office of GIS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
Projection: NAD 1983, UTM Zone 18

BOEM Wind Energy Files: https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data
Shipping Fairways File: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::shipping-fairways/about

Map produced by Britney Pepper, Duke University NSOE, 2023.

Figure 1. This map shows the locations of the Marine Autonomous Recording Units that were deployed off the coast of New Jersey in 2008. They were located in present offshore wind energy lease areas, where the NJ01 and NJ03 receivers were in the Atlantic Shores Offshore Wind Projects 1 & 2, LLC's leased area, and the NJ02 receiver was in the Ocean Wind LLC leased area.

The sound files from the receivers were investigated for the signature 20 Hz pulses that fin whales produce. To help develop manual capability for fin whale calls identification, data from MobySound were used to identify different types of fin whale calls (Heimlich et al., n.d.). The spectrogram produced by Raven Pro 2.0, which was employed for the data processing within this study, shows the most common type of call that fin whales produce in Figure 2 below. Each sound file of the data was visually processed to determine fin whale presence, in which the date, duration of pulse train, and quantity of pulse trains in each day were recorded.

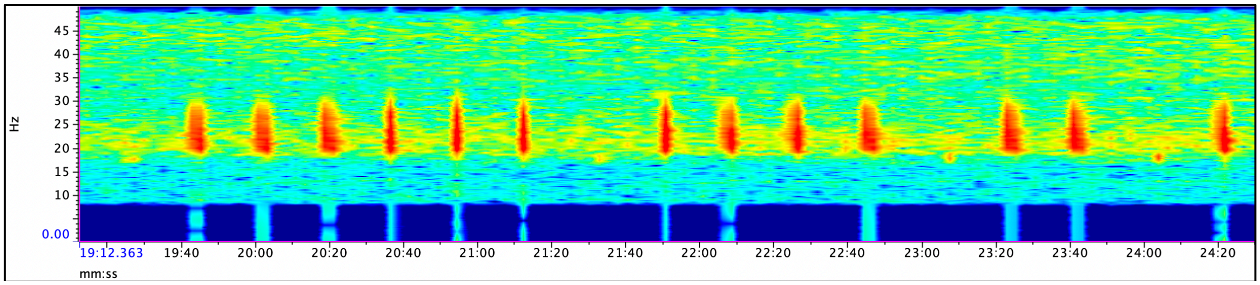


Figure 2. This spectrogram shows a snapshot of one of the sound files from MobySound of fin whales. Their calls can range from 20 Hz to 40 Hz with some variation between individuals. MobySound data were used as a training set to help identify types of fin whale calls.

The automated detector feature in Raven Pro 2.0 was utilized as a secondary processing technique to determine the presence of fin whales. Automated detection uses machine learning to find specific bands of energy of interest. Raven Pro 2.0 has several types of automated detectors that can be used for processing data; the Band Limited Energy Detector (BLED) and the Template Detector (TD) were selected in this study. Prior to running any automated detection, a training set of known fin whale pulses from a separate data set was used to define energy characteristics of a fin whale call, such as the hertz range and duration of a pulse, for the training of the detectors. After the creation of the training set, the trained detectors were run on a test data set, which was created from a ground truth data set of known fin whale pulses, to determine the effectiveness of the detectors.

The input values from the training set of the fin whale calls were used for the BLED; the detector was run on the test data set previously created. After multiple rounds of testing and tuning of the BLED, it did not prove to be effective in detecting fin whale pulses. Because of this, the BLED usage was suspended, being replaced by the TD for processing the test data. The TD uses the boundaries of known fin whale pulses to define and detect the energy characteristics of those pulses. Different numbers of pulses from the training set were used as inputs for the TD to determine the optimum number needed for identification. It was concluded that seven pulses of varying sizes, duration, and intensity provided the most effective results after the testing and thus were used as the template preset for the TD. These seven pulses can be seen in the spectrogram in Figure 3. Finally, the template preset for the TD was run on an evaluation data set to ensure that the detector was effective on a novel data set before being used on the data in the study.

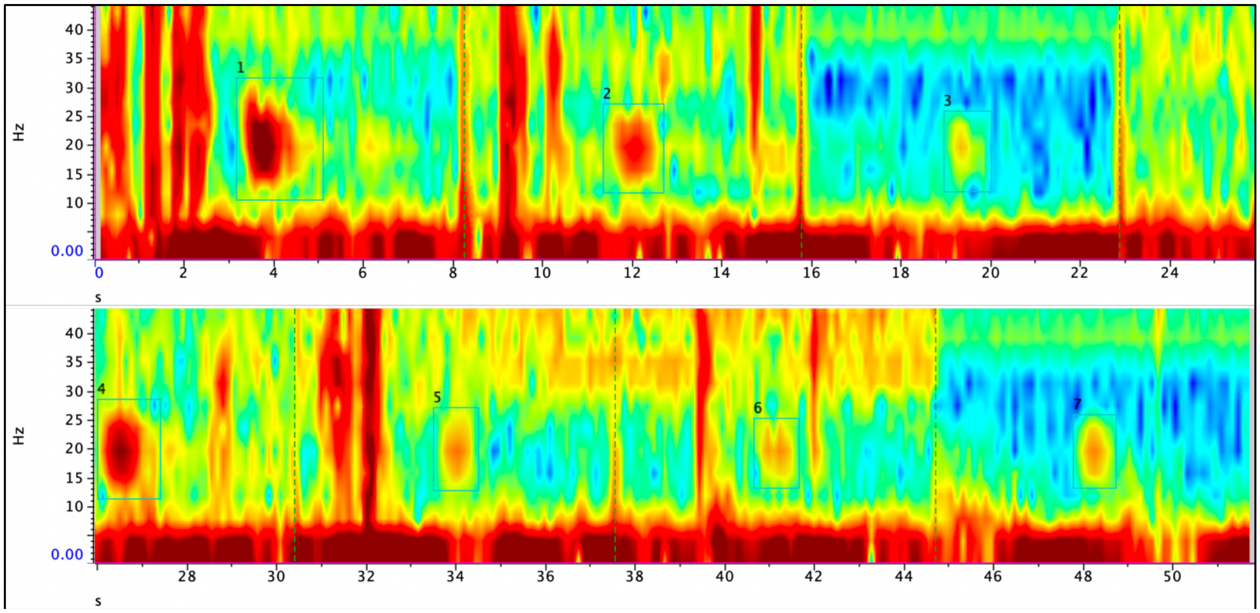


Figure 3. This spectrogram shows the seven different pulses from the test set that were used as the template preset for the Template Detector. These seven pulses were obtained from a test data set that was previously verified as fin whale pulses. Each pulse differed in size, duration, and intensity to maximize the prospect of the Template Detector data capture.

During the visual data processing, the Selection Table feature in Raven Pro 2.0 was utilized to record the presence of fin whales and information regarding the pulse trains as well as running the TD. Receiver operator characteristics from the TD were also recorded in the form of precision and recall rates. These rates were determined by manually verifying the detections made by the TD. The TD returns "positive" events if the detector classifies the energy to be fin whale calls. The detector utilizes machine learning for identification, so errors in some detections are anticipated. Therefore, manual verification of the results is needed to confirm whether the events are “true” or “false”. If the detector accurately detects a fin whale pulse, the pulse is categorized as “true positive”. If the detector selects a band of energy that is not a fin whale pulse, then that selection is categorized as “false positive”. If the detector fails to select a fin whale pulse, the pulse is manually selected for addition to the selection table and categorized as “false negative”. The categorization of “true negative” would be given to the spaces where the detector accurately examines and ignores areas that do not have fin whale pulses. However, the categorization of “true negative” was not recorded within this study. Using the identified categorizations, detector performance was evaluated across the entire dataset with a threshold of 0.89 in calculating the precision and recall rates (Hildebrand et al., 2022). Precision is calculated using the following equation:

$$TP / (TP + FP) \qquad \textbf{Eq. (1)}$$

where TP is the true positive values and FP is the false positive values.

Recall is calculated by using the following equation:

$$TP / (TP + FN) \qquad \textbf{Eq. (2)}$$

where TP is the true positive values and FN is the false negative values.

Next, the detection range of the receivers and impacts that shipping may have on this range were investigated. The detection range of the receiver helps give an estimate of the maximum detection distance a fin whale can be from the detector. This value was derived from the signal-to-noise ratio and the passive sonar equation (Tyack, 2022). The signal-to-noise ratio is:

$$SNR\ (dB) = RL - NL \qquad \textbf{Eq. (3)}$$

where SNR is signal-to-noise ratio, dB is decibels, RL is the receiver level, and NL is the source noise level.

The passive sonar equation is:

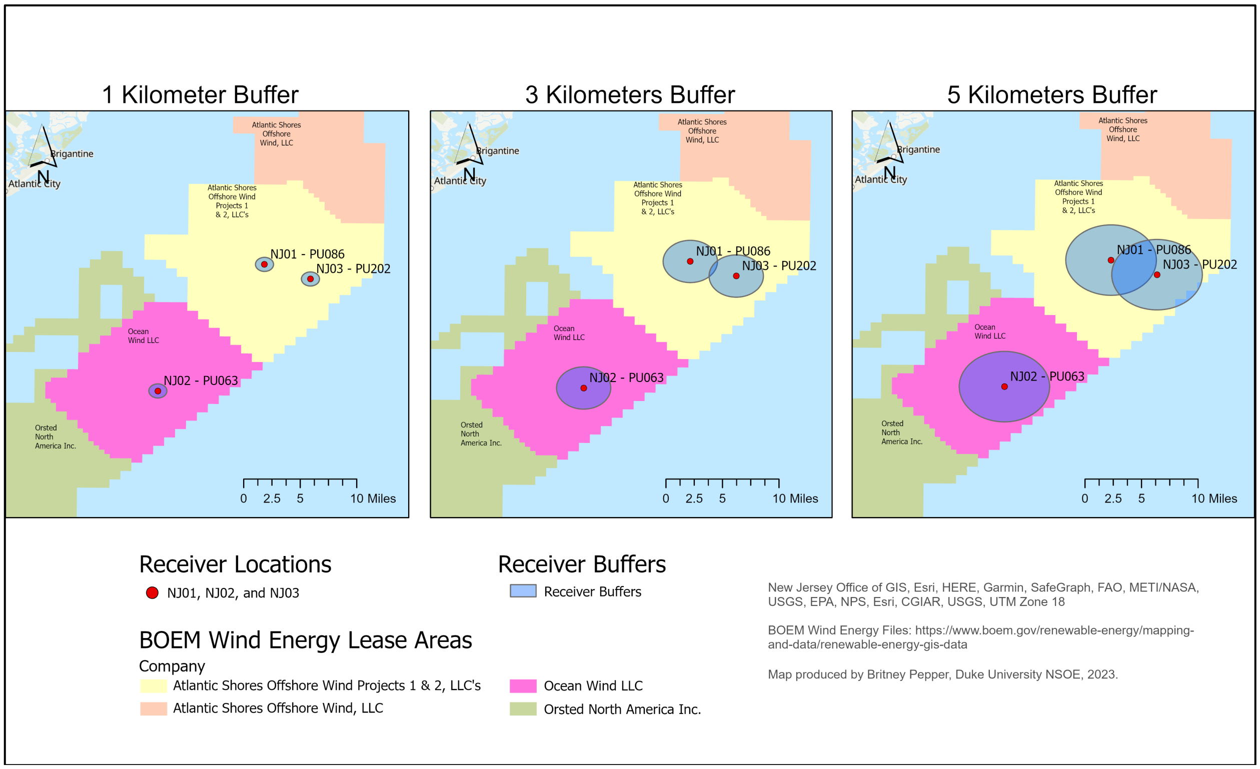
$$RL = SL - TL \tag*{\textbf{Eq. (4)}}$$

where RL is the receiver level, SL is the source level, and TL is the transmission loss.

The passive sonar equation, Eq. (4), does have nuances to consider when being utilized given that the equation does not take into account other possible factors that could affect the received level of the fin whale calls, such as the surface and seafloor may have impacts on sound waves resulting in unequal spreading and absorption. The signal-to-noise ratio, Eq. (3), can also be affected by the amount of noise in the environment; in this study, shipping traffic noise levels are used. Assuming light shipping traffic and cylindrical spreading, the detection range of fin whales from the receivers is approximately 3100 kilometers. However, because decibels are measured on a logarithmic scale, a slight increase in decibels to mimic an increase in shipping traffic would cause the detection range to drastically decrease.

Knowing that one of the factors that affects the detection range and noise in the ocean is shipping, cargo ships were chosen as the type of shipping to be investigated due to the large amount of noise they produce that may prevent detection of fin whales. Automatic Identification System (AIS) data from cargo ships in 2009 were used to study the potential for cargo shipping interference with the receiver detection ranges. As a comparison to discuss how shipping may have changed since the time of the data set collection, AIS data from cargo ships in 2019 were used.

Using ArcGIS Pro, three different buffers with different diameter distances were created around each of the three receiver coordinate points. Each receiver coordinate had a one-kilometer, three-kilometer, and five-kilometer buffers. These buffers can be seen in Figure 4 below. During one month from the time span of which each receiver was deployed, the number of cargo ships from the AIS data that traveled through each buffer distance was determined using the Intersect tool in ArcGIS Pro. The chosen months for the study were April, July, and October. AIS data for these months from both 2009 and 2019 were analyzed for the difference in number of ships traveling through each sized buffer within the same year and also the difference in number of ships traveling through each sized buffer between different years. The sizes of these cargo ships were also used as a means of understanding how cargo ship size may have changed over ten years and potentially impact the acoustic environment as larger vessels generally produce higher noise levels (Hildebrand, 2009). Analyzing the data for the frequency and size of ships passing through the buffer can give insight on increased signal-to-noise ratios and masking that may have prevented the detection of fin whales in the area.



New Jersey Office of GIS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, CGIAR, USGS, UTM Zone 18

BOEM Wind Energy Files: https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data

Map produced by Britney Pepper, Duke University NSOE, 2023.

Figure 4. This map shows the three different buffers that were added around the receiver coordinates used in the study. The maps from left to right show the one-kilometer buffer, the three-kilometer buffer, and the five-kilometer buffer.

III. Results

The purpose of this study was to identify and examine the presence of fin whales in close proximity to future wind farm development locations off the coast of New Jersey. Fin whales were found present for 40 days out of the 219 days in the study. Figure 5 shows the number of days that fin whales were present in each month of the study. August had eleven days of presence, which was the greatest in the study, followed by October and November, with nine and seven days, respectively. Based on the results, fin whales appear off the coast of New Jersey primarily during the late summer into the middle of fall.

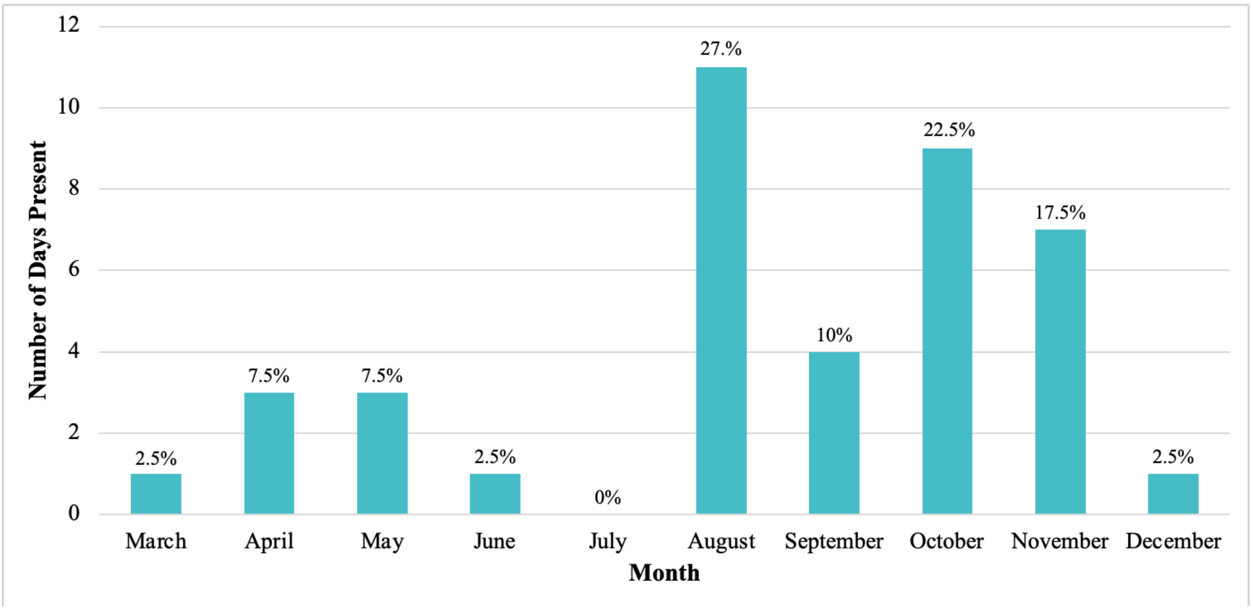


Figure 5. The number of days that fin whales were present in each month of the study are shown along with the percentage of the number of days present in each month out of the total 40 days of presence.

A total of 172 pulse trains were detected over the identified 40 days. The pulse trains in each month can be seen in Figure 6. November was the highest, with 73, followed by October with 36 and August with 22. The number of pulse trains are generally higher from August through December. The duration of pulse trains in each month were measured and can be seen in Figure 7. The months with the longer pulse trains occur in August, October, November, and December, which align with four of the months having the highest number of pulse trains as identified in Figure 6.

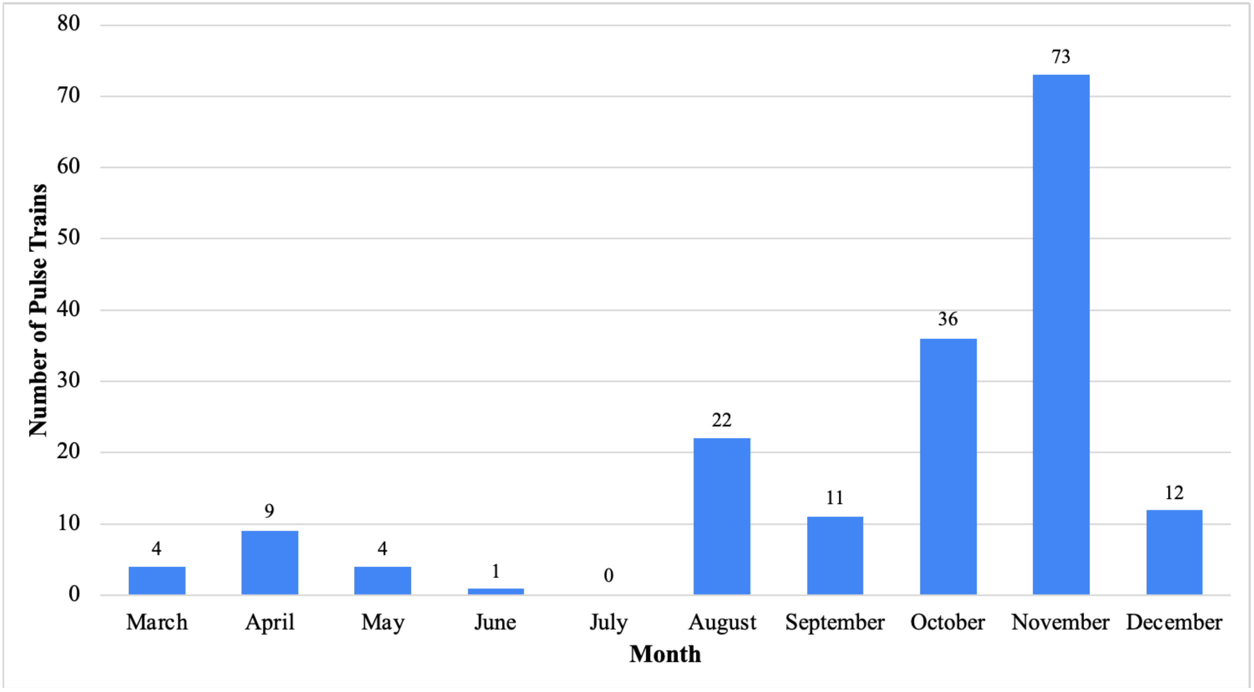


Figure 6. This graph shows the number of pulse trains that occurred in each month of the study. The number of pulse trains began to increase in August and peaked in November.

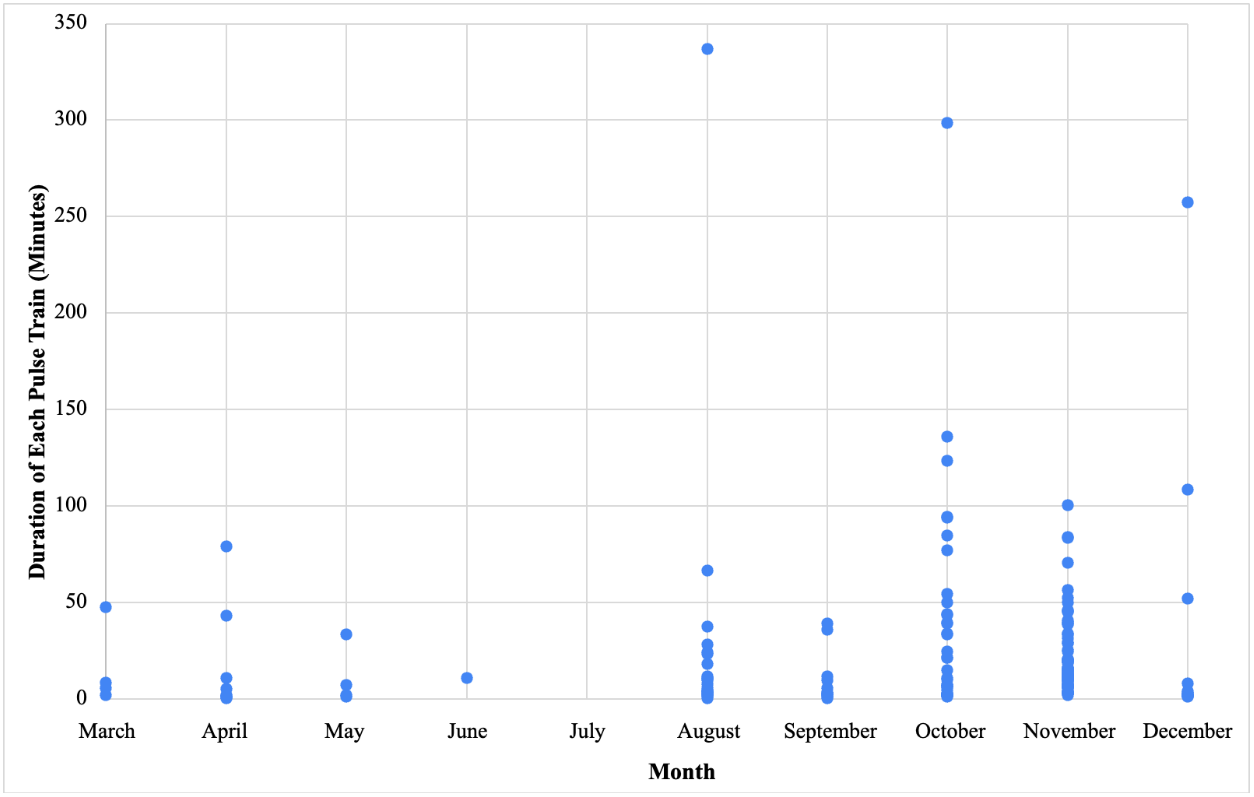


Figure 7. This graph displays the duration of each pulse train in the data set within each month. The months August through December generally had longer pulse trains.

Of the 40 days of presence, 65% of these days had more than one pulse train detected. For the presence days, there was an average of 4.3 pulse trains per day, ranging from one to eighteen on any given day. The average duration of pulse trains was approximately 25.6 minutes long, and the pulses spanned from half a minute to approximately 337 minutes long. The pulse trains were analyzed according to when they occurred during the day. Calls that occurred from the beginning of the day at 12:00 a.m. up until 12:59 a.m. were categorized as the 0 hour of the day, and this categorization process was used for the rest of the hours of the day. The number of pulse trains that occurred in each hour of the day can be seen in Figure 8 below. Calls increased gradually in the morning, reaching the peak at noon, and decreased as the day progressed. These calls happened more frequently from 10 a.m. to 1 p.m.

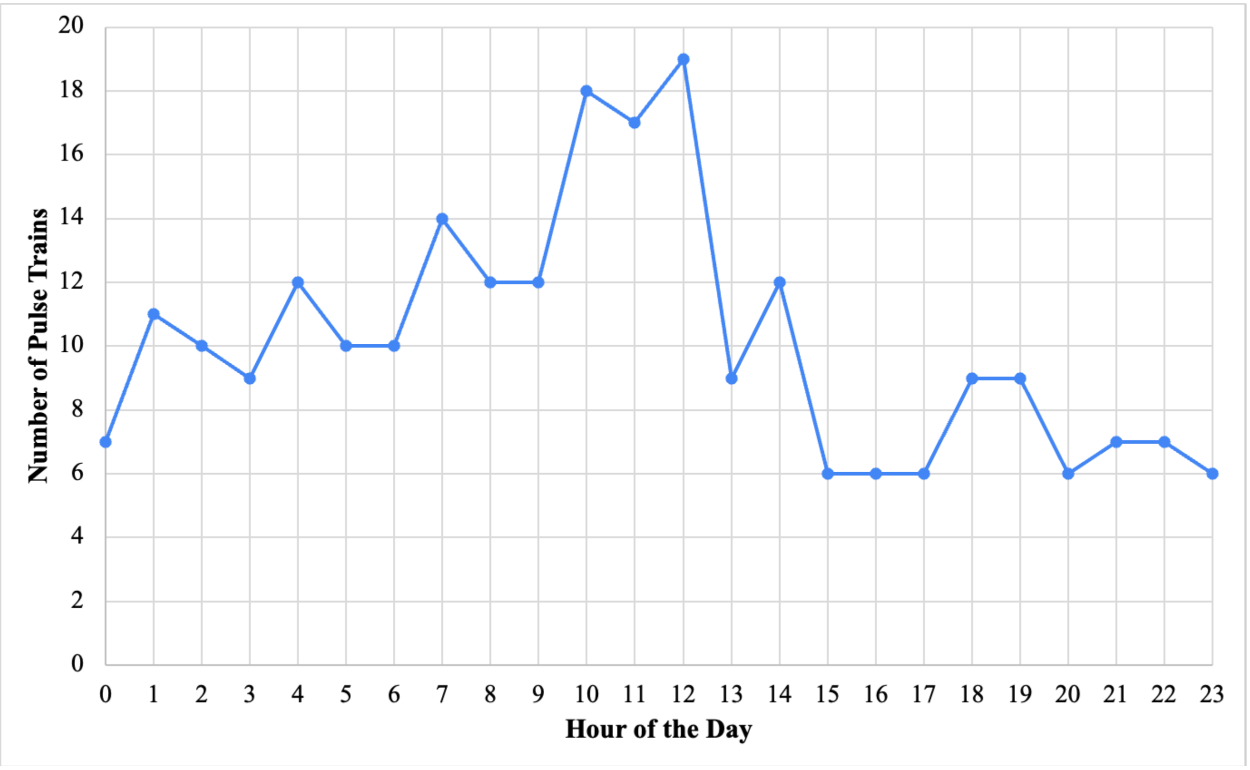


Figure 8. This graph shows the number of pulse trains that occurred in each hour of the day. As the day progressed, the quantity of pulse trains increased until the peak at noon before decreasing the rest of the day.

		Buffer Distance								
		1 kilometer			**3 kilometers**			**5 kilometers**		
		NJ01 - PU086	**NJ02 - PU063**	**NJ03 - PU202**	**NJ01 - PU086**	**NJ02 - PU063**	**NJ03 - PU202**	**NJ01 - PU086**	**NJ02 - PU063**	**NJ03 - PU202**
2009	**April**	6	3	10	15	7	20	19	13	42
	July	7	3	12	17	7	21	20	13	46
	October	4	2	9	11	5	24	19	10	49
2019	**April**	3	5	10	18	13	26	29	20	41
	July	2	5	13	18	8	28	21	17	54
	October	6	4	7	18	10	20	26	18	49

Table 1. This table shows the frequency of cargo ships passing through the one-kilometer, three-kilometer, and five-kilometer buffers around the receiver coordinates during the months of April, July, and October in 2009 and 2019 AIS data.

The AIS data were analyzed, and the results are shown in Table 1. Overall, the NJ03 coordinate buffer areas had the highest number of cargo ships passing through when compared to the NJ01 and NJ02 coordinate buffers. The NJ02 coordinate buffers had the least traffic. The cargo shipping pattern appeared to be relatively consistent throughout the year. There was a slight increase in shipping traffic between 2009 and 2019. Chi-squared tests for independence were run between each month and year at each receiver and found that none of the results were statistically significant.

The AIS data also contained the length of the cargo ships. As larger ships tend to produce more noise, the length of the cargo ships that ran through the buffer areas for each receiver's coordinates were analyzed for both 2009 and 2019. The average length of the cargo ships was 219 and 246 meters for 2009 and 2019, respectively. The lengths of cargo ships in this study can be seen in Figure 9. Both the maximum and minimum lengths of the ships in 2019 were longer than in 2009, but the upper end of the interquartile range and the median ship length is approximately the same.

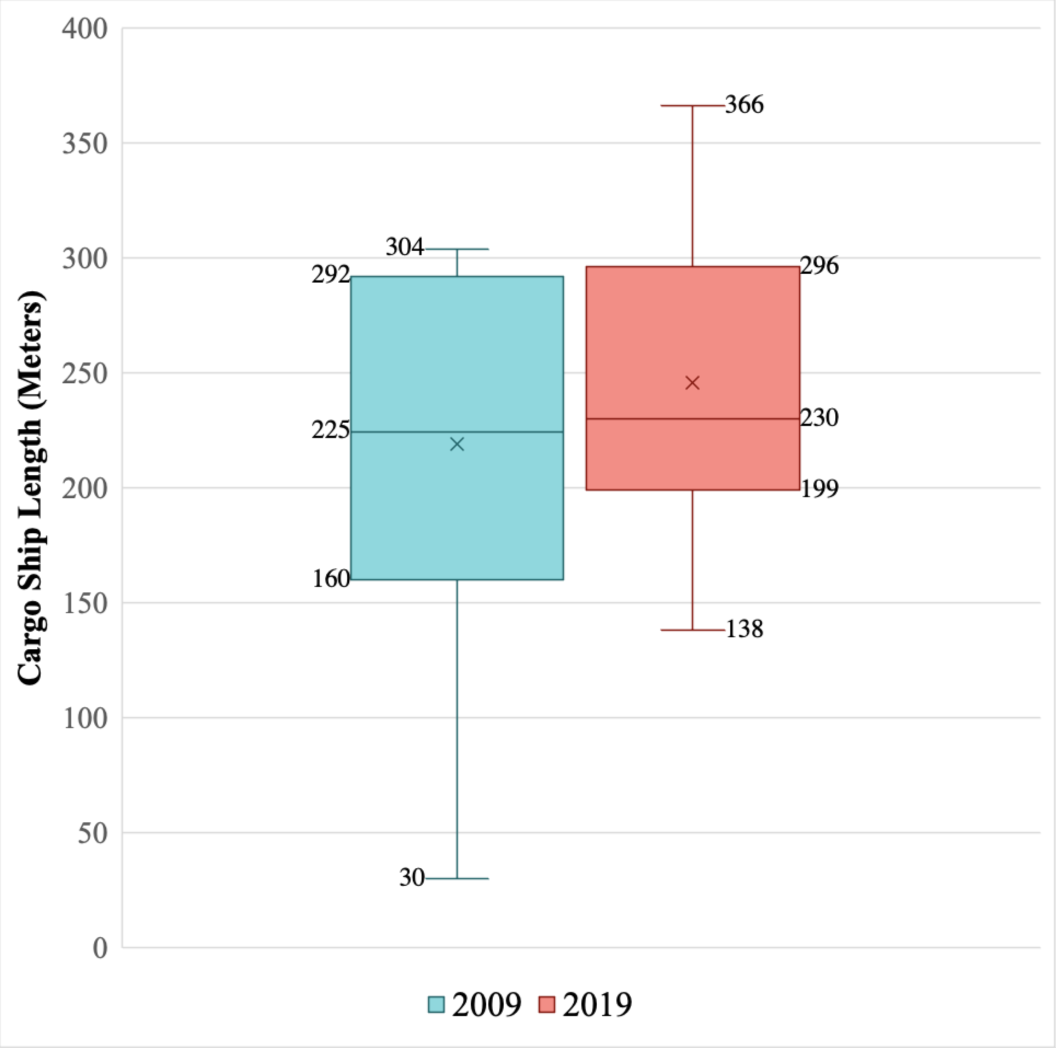


Figure 9. The length (meters) of the cargo ships analyzed from the AIS data in 2009 and 2019 are shown. The median length was similar for both years, and the average lengths were 219 and 246 meters for 2009 and 2019, respectively.

Precision and recall rates were calculated according to Eq. (1) and Eq. (2) for each of the 40 days to evaluate the TD performance on the study's novel data. The average precision and recall rates were approximately 0.34 and 0.65, respectively. The precision and recall rates can be seen in Figure 10 which displays the precision-recall curve. The only threshold used was set at 0.89 for this study, resulting in only points on the precision-recall curve.

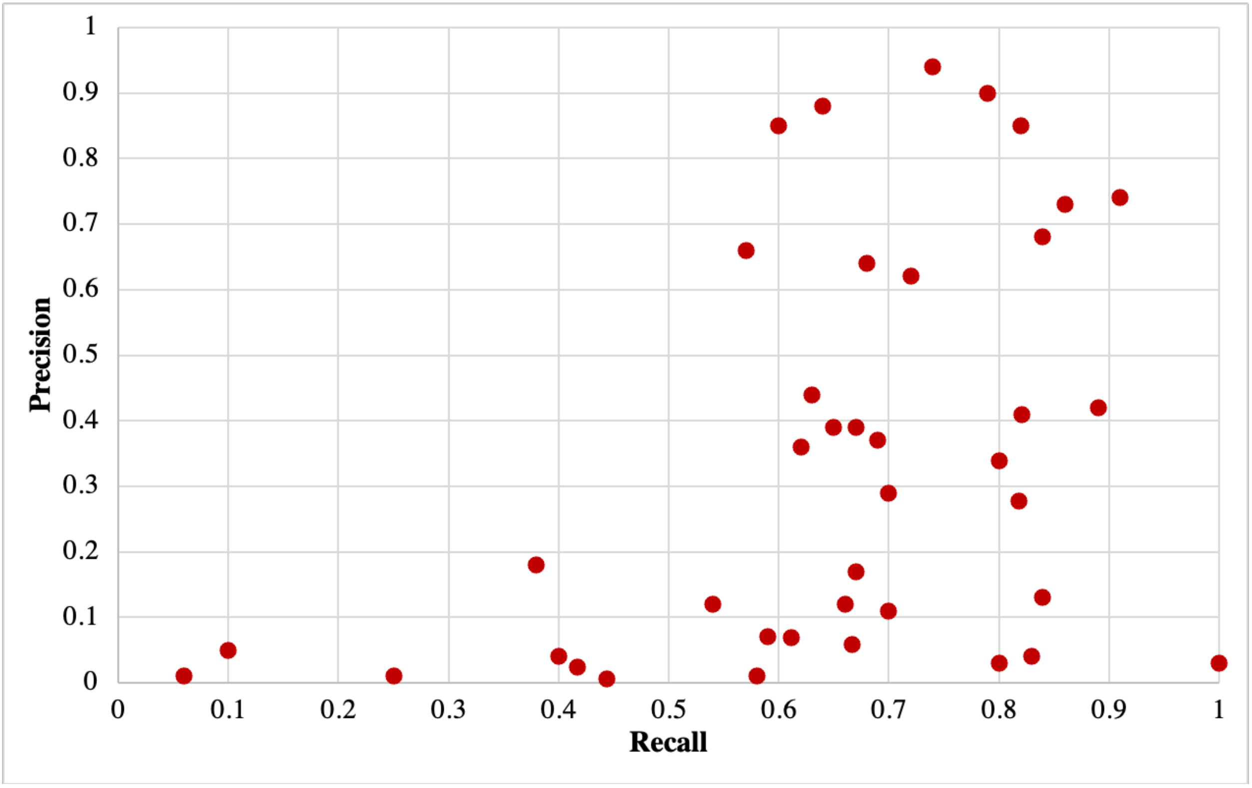


Figure 10. This graph shows the precision and recall rates from the Template Detector. Each day of presence had a calculated precision and recall rates based on the performance of the detector at a threshold of 0.89.

IV. Discussion

Offshore wind energy projects need further research to understand how the construction and operation will impact marine wildlife. It is crucial to understand populations of species as well as distinguishing short and long term effects that construction and operation of offshore wind turbines will have, specifically in displacement. The data set from the receivers in 2008 provides a benchmark for the population characteristics of fin whales prior to the construction of wind farms. It also gives insight to possible migration patterns and how frequently they are in the waters off of New Jersey. By examining the duration and frequency of pulse trains within a day, we can better understand the vocal patterns that may be important social cues for the populations should they be interrupted (Rice et al., 2014). This data would allow the offshore wind energy companies to be informed about the presence of fin whales, the periods of time that they may appear during the installation process, and the consequences that the installation and operation may have on the fin whale population.

As mentioned earlier, New York and New Jersey have higher ocean noise in comparison to other parts of the U.S. east coast (Rice et al., 2014). Rice et al. found the mean equivalent sound level to be 91.05 and 90.70 (dB re: 1 μPa) in New York and New Jersey, respectively, in the 10-100 Hz frequency range. Having higher ocean noise levels can be particularly detrimental to fin whales in the area as well as those that are migrating. Vocalizations of cetaceans can deliver information to other individuals. Besides being a function of communication, vocalizations can be an indicator of fitness and health of an animal (Clark et al., 2019). Research from Clark et al. has found that fin whale singing typically decreases as swimming speed increases and has hypothesized that this is an indicator of fitness for females when choosing a mate. Males that can sing at faster speeds may have a better chance at impressing the females in mate choice. The amplification of ocean noise may limit the distance that these songs can be reached and heard. This will increase the difficulty of distinguishing the songs produced by males and cause all forms of communication to deteriorate. Fin whale songs also decrease when shipping traffic volume is high or when there is seismic airgun activity in the area. Silence persisting past the ending of the anthropogenic noise was noted (Castellote et al., 2011). It has been hypothesized that whales compensate in the presence of increased background noise; whales may adjust their call and song frequencies to compensate for the increased noise (Castellote et al., 2011). The increased ocean noise has the potential to prevent selectivity in mating, hinder communication, and alter natural behaviors in fin whales. Understanding how these anthropogenic noises impact the animals will help prevent issues that might lead to the decline in populations.

Of the 40 days of presence, 26 days or 65% of the time had more than one fin whale pulse, suggesting that there will be more than one pulse train when fin whale calls are detected. This may indicate that there is more than one fin whale calling, or there may be a strategy for recurring calling throughout the day. The month with the greatest number of pulse trains was in November, but the months from August to December had more pulse trains than the rest of the data set. The longest duration of pulse trains was found in the same months that had multiple pulse trains. The number of fin whale calls were also found to increase in the early part of the day and peak from 10 a.m. to 1 p.m., which indicates that the whales may be more active during this time of day.

As fin whales have a higher vocal rate in the late summer to mid-fall, they may be more vocal during this time due to the increased presence helping generate higher numbers of calls for longer durations. Therefore, it may be best to avoid this time period working on activities that may disturb or harm these whales. Masking of calls during these months may severely impact their communication negatively and inhibit necessary biological functions. If construction of wind farms is to occur, it is recommended for the construction to occur when the presence of fin whales is lower.

The TD was used to detect fin whale pulses, and reporting the precision and recall rates of the detector is helpful in understanding how well the detector performed in the study. Given the threshold of 0.89, precision and recall rates were calculated for the 40 days that had fin whale presence. The average precision rate was approximately 0.34 and the average recall rate was approximately 0.65, which are relatively low considering that high values are associated with a high performing detector (Hildebrand et al., 2022). If the detector had a high performance, most of the points in Figure 10 would have been in the upper right corner of the graph. The rates of precision and recall may also change given a different threshold was set. If multiple thresholds were set, curves for the precision-recall curve in Figure 10 would have been made for each day of fin whale presence. Even though the precision and recall rates were low, the stereotyped pulses that fin whales produced allow for the detector to be able to accurately select some pulses in a pulse train. Other species of cetaceans that do not have stereotyped pulses would likely be much harder to be successfully detected with the same precision and recall rates from this study. For the purposes of this study, the reported precision and recall rates were acceptable for the TD that was used for automated detection.

In an attempt to understand the acoustic environment where the receivers were placed, the detection range was calculated using the passive sonar equation as seen in Eq. (1). When assuming light shipping traffic, the equation yields a large detection range of approximately 3100 kilometers as fin whales produce low frequency calls. Prior to human disruption, fin whale calls could be heard across the entire ocean. However, anthropogenic noise has decreased the detection range by lowering the signal-to-noise ratio. While this detection range is informative of how far fin whales may be detected, more complex modeling would need to be performed to understand the true detection range. Some of the factors to account for are directionality of the signal, energy loss in different temperature waters, sediment composition, and type of spreading. One other notable factor occurs when shipping vessels are traveling over the receiver; they essentially mask all signals from being detected. If heavy shipping traffic is assumed, then the indicated passive sonar equation detection range would greatly decrease. Therefore, the calculated detection range is not accurate for the distance that fin whales can be detected, but it is informative as to how far fin whale calls can travel and how detrimental masking of calls may be to the fin whale population.

In the months of April, July, and October, the AIS data were analyzed using the buffer areas of one-kilometer, three-kilometer, and five-kilometer in 2009 and 2019. The results show that the NJ03 coordinate buffers had the highest number of cargo ships passing through all three buffer areas in both years. This is likely due to the placement of the receiver being farther away from the coast and more in line with the traffic lanes as seen in Figure 1. Relatively consistent numbers of cargo ships recorded in each of the three receiver buffer areas for each month suggests that shipping traffic is stable and one-month of data from one receiver may be adequately representative and able to project the cargo shipping volume for the rest of the year. Furthermore, there appeared to be only a slight increase in cargo shipping traffic between 2009 and 2019. Chi-squared tests for independence were run between each month and year at each receiver coordinate and buffer, and none of the results were statistically significant. This indicates that there does not appear to be any relationship between the two years studied and the quantity of shipping traffic; they are independent of one another, and the traffic volume from one year cannot be used to predict future cargo ships annual volume.

Cargo ship length in 2019 has changed moderately as compared to 2009, with the average length increasing by 27 meters, although the maximum ship length has increased by 62 meters. Their median lengths were similar but the interquartile range in 2019 was compressed. As cargo ship size continues to increase over time, there could be negative noise implications in the marine environment. Hildebrand found that cargo vessels had a source level of 192 (dB re 1 µPa @ 1 m) when based on a length of 173 meters and speed of 16 knots. This cargo ship length falls between the lower quartile and the median of the 2009 ship length data and between the minimum and the lower quartile for the 2019 ship length data. Because of this, it is likely that the source level reported by Hildebrand is an underestimate for the source levels of the cargo ships in this study.

Results from this study not only shed light to the population of fin whales off the coast of New Jersey, but also confirm how anthropogenic sources may impact the population. While offshore wind farm construction is one of the most prominent upcoming concerns, there are many other anthropogenic disturbances that can interfere with fin whales. While results from the AIS data show that cargo shipping activities has only slightly increased since 2009, increasing anthropogenic effects can greatly decrease the detection range of fin whales, resulting in a decreased communication range. Given the insights from this study, those conducting activities off the coast of New Jersey should be informed of the potential impacts on fin whales to gain consideration and development of mitigation approaches to the increased anthropogenic noises in the soundscape.

As this study explores the data that were collected in 2008, considerable underwater acoustic environmental change has taken place during the interim period of time that may have caused fin whale populations to shift or avoid specific areas. Offshore wind energy planning and development is growing due to an increased demand in renewable energy. Anthropogenic noises generated from the installation and operation of offshore wind farms have potential to be extremely detrimental to populations and have not been adequately researched. Heavier shipping traffic leads to a lower signal-to-noise ratio and results in masking of communication between species and escalating the chances of ship strikes. The areas of interest are along the east coast of the United States where large shipping vessels are traveling to major ports. While this study gives us insight to the population patterns prior to wind energy development, studies should be conducted on the completed wind farms as well as those planned and under construction to better understand how the presence of fin whales has been altered. Long term studies should also be explored to learn if there is displacement in populations or if the population appears to return.

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