Seasonal Patterns of Fin Whale Calls in the Northeast Pacific

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Abstract

After a century of commercial whaling fin whales are currently listed as a vulnerable species and are increasingly at risk of endangerment from new anthropogenic noise, vessel traffic, entanglement, and habitat degradation. Fin whales have been observed to congregate near areas of high bathymetric relief along the U.S. Atlantic and the Gulf of Mexico. Visualization of patterns and gross call differences of fin whales in the Northeast Pacific were made to analyze seasonal trends in call counts at two sites over five years. Data was collected with a low-frequency hydrophone and a vertical seismometer from a cabled observatory at the southern foot of a submarine seamount ~475 km from the Oregon coast, and adjacent to the continental slope ~125 km from the Oregon coast respectively. Fin whale calls were identified and analyzed with an algorithm for automatic detection. The trend of detections shows the fin whale calling season appears earlier in the year in greater magnitude on average closer to the continental shelf, with presence in more pelagic waters following in the subsequent two to three months. This trend may be correlated to the behavioral movement and bathymetric preference in the Northeast Pacific fin whale population.

Plain Language Summary

Male fin whales have been known to call during the fall and winter for breeding purposes. As there are currently no studies on fin whale location preference in the Northeast Pacific, this study sought to identify fin whale calls to analyze patterns in distribution, or trends, based on movement and site preference. This study analyzed fin whale calling trends in the Northeast Pacific at two sites on a cabled observatory over five years with data collected from a low-frequency hydrophone and vertical seismometer. Across our data we identified a trend of fin whale presence being closer to the continental shelf earlier in the calling season, with a presence

farther from shore following two to three months later. This could be due to the relationship between climate and the amount of prey available at coastal sites, and fin whale migration in response to prey distribution.

Introduction

Over a century of commercial whaling has endangered many species of whale. As of today fin whales are classified as vulnerable by the International Union for Conservation of Nature (IUCN 2020). Since the international ban of commercial whaling, several species have made recoveries in populations. However vulnerable species are increasingly at risk of endangerment from new anthropogenic noise, traffic, entanglement, and habitat degradation (Clapham et. al, 1999). Methods for observing whales include visual surveys, satellite tagging, and passive acoustic monitoring (Weirathmueller, 2016).

Visual surveys are used to estimate abundance and identify individual animals, but this method is limited by field conditions such as rough seas and any hindrance to one's vision can make sightings difficult. Tagging experiments are restricted by the deployment methods used and the sample size of whales tagged but can report when a whale is near the surface (Panigada et. al, 2017), and some even give insight to diving and swimming patterns below the surface which cannot be accounted for visually. Passive acoustic monitoring of whale calls has the benefit of recording data for long periods in locations that do not have to be visited regularly in person. This can also provide insights into their social behavior below the surface. A drawback of this method is that only vocalizing whales are recorded, therefore determining population densities requires separate methods to account for non-vocalizing whales.

Fin whales are the second-largest species of whale. They travel in deep-water well offshore to migrate from feeding and breeding grounds. Their diet consists of euphausiids and small schooling fish, and is determined through analysis of stomach contents from necropsies, faecal samples (Hunt et. al, 213), and whales captured during whaling. However, knowledge of the prey species is limited by the seasonality and location of catches (Mizroch et. al, 2009). Fin whale distribution ranges from the Subarctic Boundary to the southerly reaches of the California Current, and have been recorded in the Northeast Pacific year-round. Studies of fin whale call abundance in the Southern California Bight show calling trends consistent with visual survey estimates (Širovic et. al, 2015).

Observations of seasonal calling patterns show peak call detections occur during the fall and winter months (Stafford et. al, 2009). A track of fin whale calls predominantly headed northwest along the continental shelf suggests that a portion of the fin whale population maintain residency rather than the expected seasonal southern migration pattern that most baleen species follow (Soule and Wilcock, 2013). Fin whale migration behavior may be linked to the distribution and abundance of this species' food source, which in turn may be correlated to climate covariates such as sea surface temperature (SST) and winter mixing.

Though there are currently no studies on fin whale preference for bathymetry and proximity to the coast in the Northeast Pacific, it has been found that baleen species along the eastern coast of North America congregate near the continental shelf and areas of high bathymetric relief (Roberts et. al, 2016). This study seeks to detect and identify fin whale calls to analyze distribution trends between two sites with differing proximity to the coast during the fall and winter months. Analysis of fin whale vocalization trends during the fall and winter months would provide more insight to fin whale call distributions in the Northeast Pacific. I hypothesize there to be a greater presence of fin whale calls closer to the continental shelf, as compared to pelagic sites further offshore due to greater coastal production and high bathymetric relief. Biological productivity at the coast and offshore from covariates related to bathymetry and SST may contribute to the understanding of fin whale spatial ecology in the Northeast Pacific.

Methods

Fin whale call data was obtained from two IRIS stations HYSB1 and AXBA1 (https://www.iris.edu/hq/), with their coordinates (44.51°N, -125.41°W) and (45.80°N, -129.74°W) respectively (Fig. 1). Data was collected with a vertical seismometer (channel HHZ, Guralp manufacturer, model CMG-DM24 Mk3) at -2920.5 meters with a 200 Hz sampling rate at the Slope Base site (~125 km from the coast), and a low-frequency hydrophone (channel HDH, High Tech manufacturer, model DM-24 Mk3) at -2607.2 meters with a 200 Hz sampling rate at the Axial Base site (~475 km from the coast). Instrumentation used is connected through the Oceans Observatories Initiative Cable Array Network located in the Northeast Pacific off the coasts of Washington and Oregon (https://ooinet.oceanobservatories.org/). SST data from both sites were obtained from NASA's Physical Oceanography Distributed Active Archive Center (https://podaac.jpl.nasa.gov/) and provided through Simons Collaborative Marine Atlas Project (https://simonscmap.com/). Data is derived from a combination of multiple AVHRR (Advanced Very High Resolution Radiometer) satellites along with in-situ sea surface temperature measurements from ship and buoy measurements.

Figure 1. Study site locations along the cabled array. Reproduced from OOI Regional Cabled Array

Fin whale calls were automatically detected using spectrogram correlation (Mellinger and Clark, 2000). This method cross-correlates a time−frequency kernel, created with the specifications of a human-verified fin whale call, with a spectrogram and waveform of the recording. Detection is considered to have occurred when the correlation value exceeds the specified time and frequency threshold. In the case of our detector a duration of 2 s and frequency between 15 and 25 Hz (Fig. 2). To optimize precision and recall values, threshold prominence values of 0.6 for both sites were determined, where detection scores are scaled by an arbitrary constant so only relative heights of values are significant. Reliability was determined by human visual confirmation of validity with the use of the waveform panel. Fin whale calls from August through April from 2015 through 2020 were observed for trend analysis.

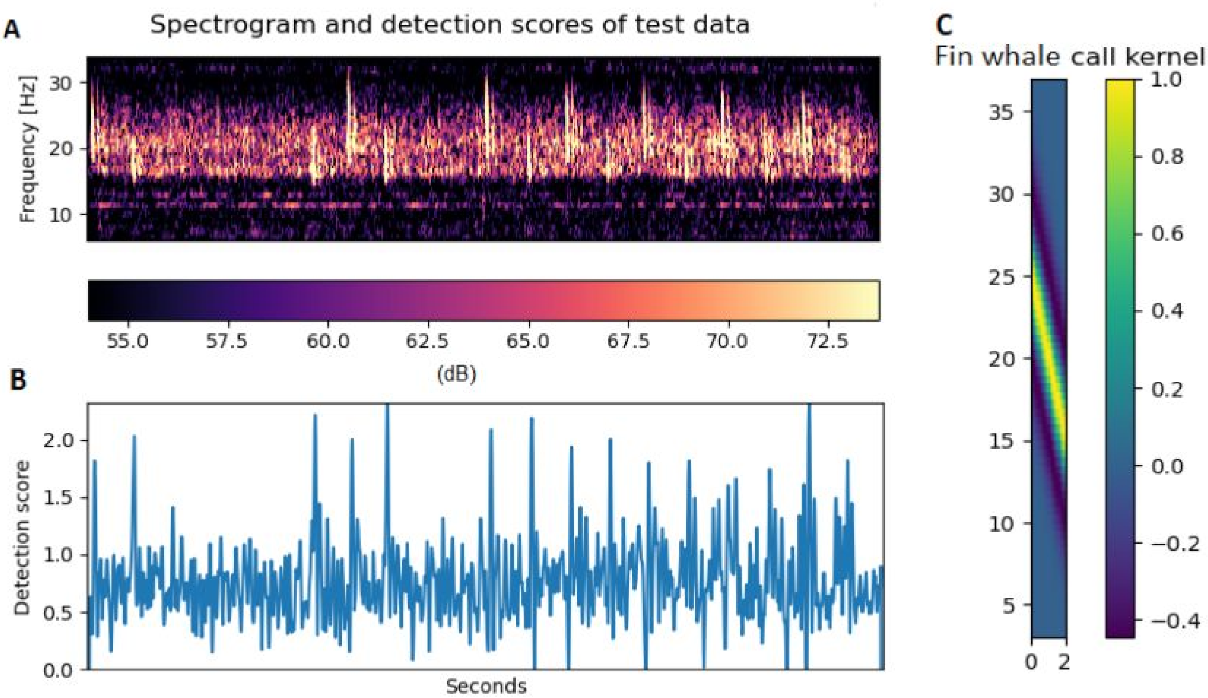

Figure 2. (a) Example spectrogram of a recording showing seven fin whale call doublets. (b) The resulting detection score of fin whale calls in a waveform, where detection scores are scaled by an arbitrary constant so only relative heights of values are significant. (c) The spectrogram correlation kernel, with violet representing negative areas, yellow representing positive areas, and navy representing the zero background.

Methods for analysis include a histogram code created in Python (Python Software Foundation. Python Language Reference, version 2.7. Available at http://www.python.org) for visualizing patterns and gross count differences, and Microsoft Excel (V. 2101). Seasonal and interannual trends in the abundance of fin whale calling across sites were evaluated by overall monthly and annual mean daily fin whale call detection rate and hourly call presence index. All available data were used for analysis.

Results

A total of 143,102 fin whale calls were detected at two sites over five seasons (1,243 days), although some calls may have been falsely detected or neglected due to instrument variation. The highest calling anomalies occurred in the 2015-2016 season at the Slope Base site, and in the 2017-2018 season at Axial Base where a very high number of fin whale calls were detected (Table 1). These suspect increases in call counts may be attributed to sensor or code error, therefore analysis is focused on seasonal patterns. Total call counts over all five years of data are greatest at the Slope Base site as well as average seasonal call counts.

Table 1. Seasonal and Total Call Counts

Season	Axial Base	Slope Base
2015-2016	8413	48371
2016-2017	5892	11312
2017-2018	30306	7248
2018-2019	2282	13268
2019-2020	3840	12170
Total Call Counts	50733	92369

Table 1. Total fin whale call detections per annual season and over five years of data collection.

Call detections for both sites are correlated with hours of call presence. Their comparison helps account for detection biases by providing a simple “true/false” metric for fin whale presence (Fig. 3). Patterns of peak months for calling correlate with hours of call presence across the 2018-2019 season demonstrating reliability. The count detection and hours of presence scale for Slope Base is larger than at Axial Base showing a greater number of calls and longer call presence detected at the site.

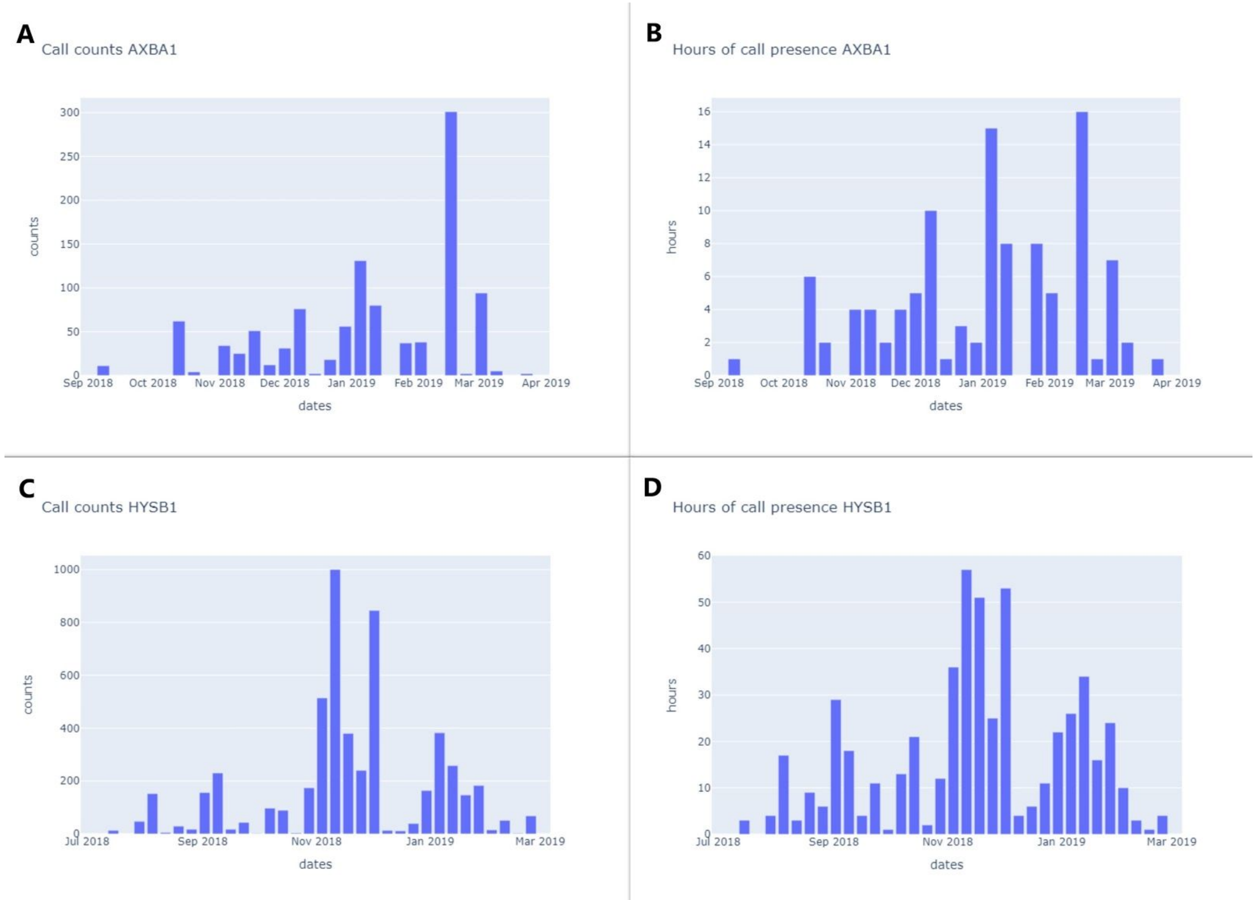

Figure 3. Detection counts for the 2018-2019 calling season sorted into bins of 7-day periods over months corresponding to the calling seasons at both sites. The count and hour axes are scaled for respective call counts and call presence detected at the sites.

The Slope Base site has a larger amount of seasonal call counts on average compared to Axial Base. A noticeable flip in the trend where Axial Base had the most call counts occurred in the 2017-2018 season (Fig. 4). The highest call count at Slope Base occurred in the 2015-2016 season, where a very high number of fin whale calls were detected (Fig. 4). The 2015-2016 season is notable for a large mass of relatively warm water in the Pacific Ocean commonly known as the “blob”.

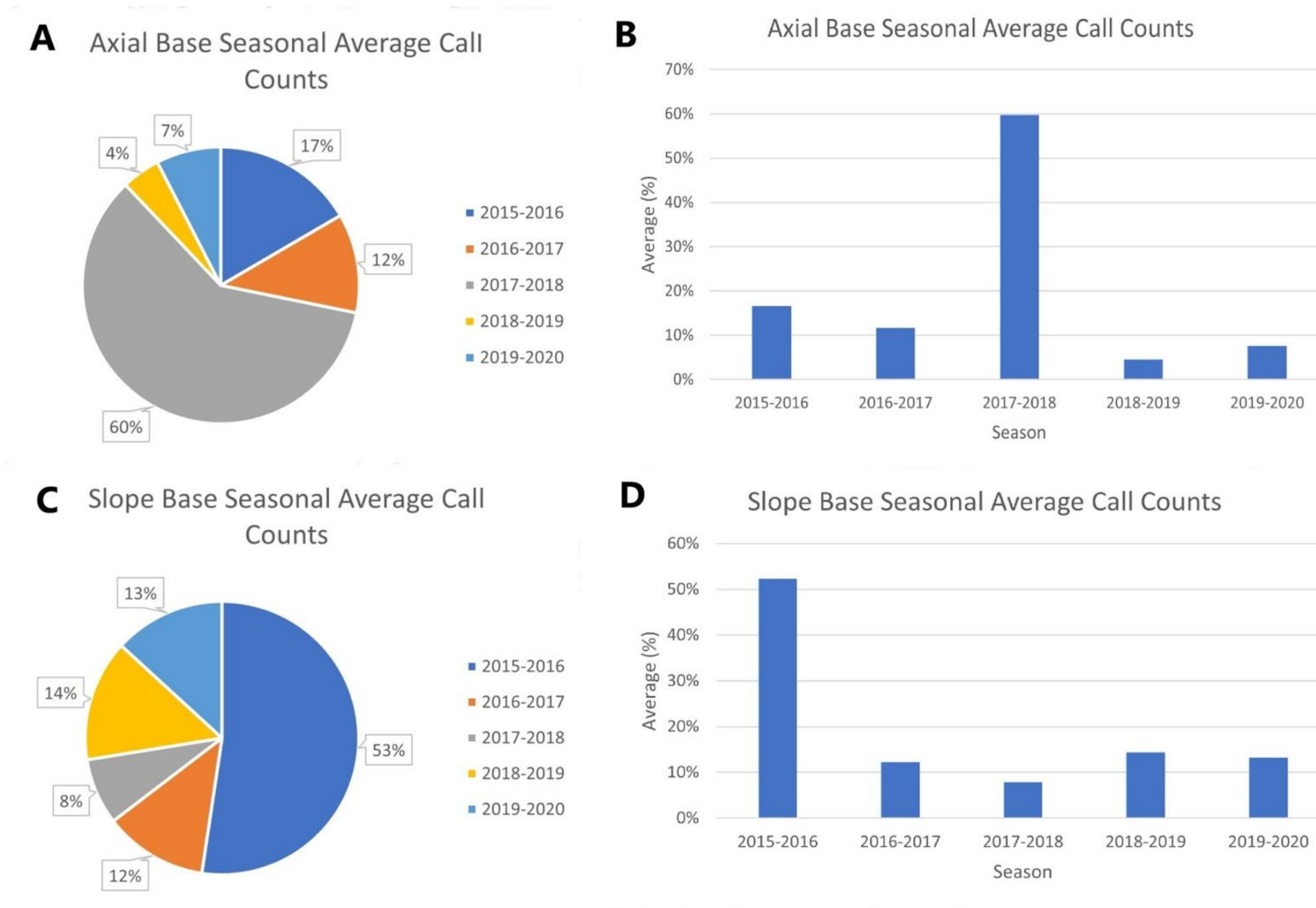

Figure 4. (a, c) Average percent of seasonal fin whale call detections at Axial and Slope Base respectively, visualized in a pie chart. (b, d) Average percent of seasonal fin whale call detections at Axial and Slope Base respectively, visualized in a histogram. Visualization of seasonal call counts are averaged over all five years of data collected and normalized with hours of presence.

Fin whale calls were generally detected at Axial Base between October and April, and at Slope Base between October and January with peaks in August and February (Fig. 5). While the average monthly call counts at Axial Base show a single peak in January with high percentage from December to March, the Slope Base site has two peaks in November and January. January peaks in greatest monthly average call counts at both sites in this study match the reported timeframe for winter mixing in the Pacific Ocean (Venrick et. al, 1993). The most notable observation is that fin whale presence is detected two to three months earlier at the Slope Base site than at Axial Base, with both calling seasons lasting approximately seven months (Fig. 5).

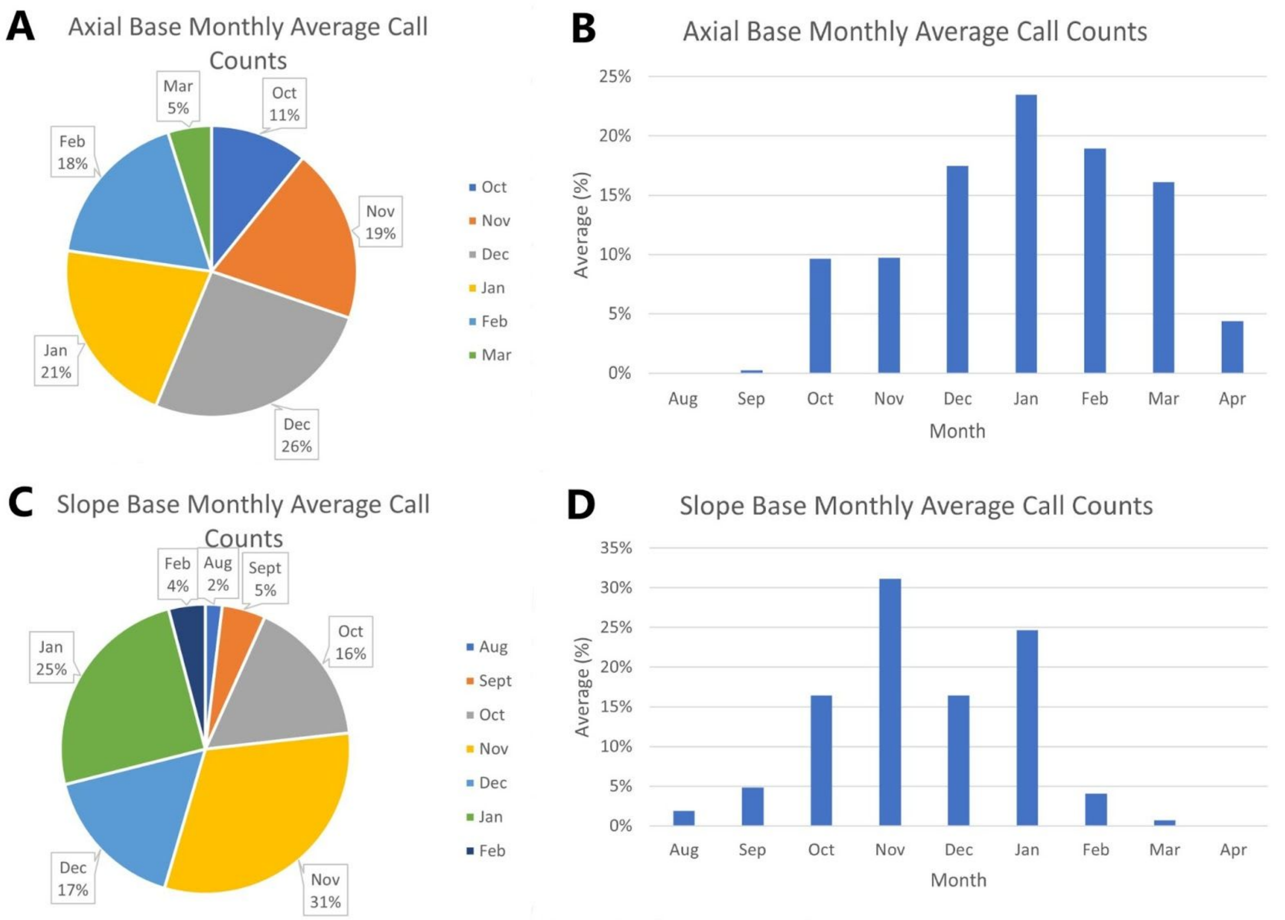

Figure 5. (a, c) Average percent of monthly fin whale call detections at Axial and Slope Base respectively, visualized in a pie chart. (b, d) Average percent of monthly fin whale call detections at Axial and Slope Base respectively, visualized in a histogram.

Sea surface temperatures from available data (January 1, 2015 through April 27, 2019) were plotted in Simons CMAP to find correlations between trends of increased calling at both sites. High winter SST values in early 2015 may cautiously be associated with the "blob" and correlate with the greatest number of calls at the Slope Base site during the 2015-2016 season (Fig. 6). A spike in temperature can be seen in the 2017-2018 season at Axial Base which may correspond to the anomalous flipped trend in calling averages, if not attributed to sensor error or background noise (Fig. 7).

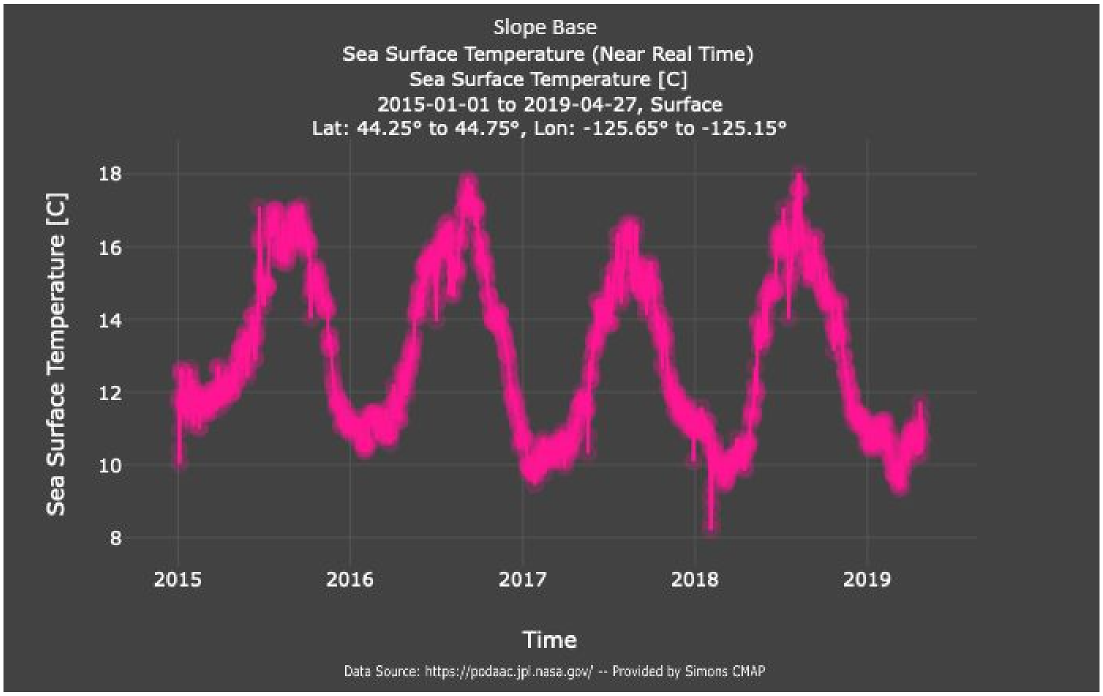

Figure 6. High winter values in early 2015 may cautiously be associated with the "blob", corresponding with the greatest number of fin whale calls during the 2015-2016 season. Sea surface temperature from January 1, 2015 through April 27, 2019 at the Slope Base site.

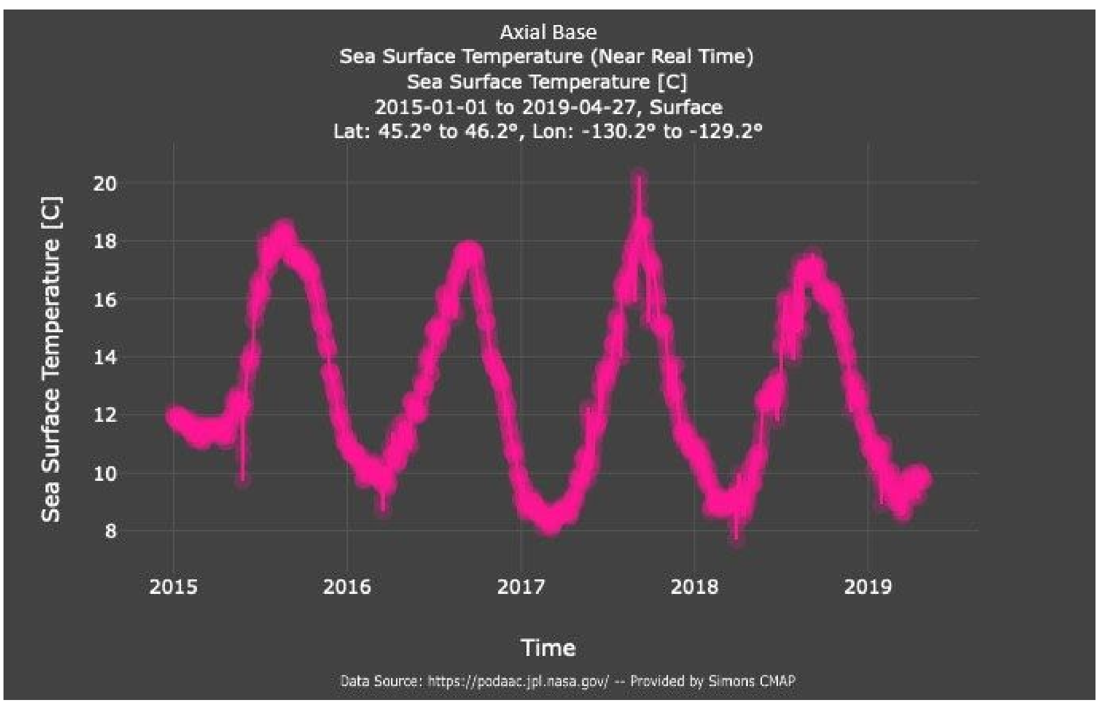

Figure 7. A spike in temperature can be seen in the 2017-2018 at Axial Base season corresponding to the flipped trend in call averages. This covariate may correlate to the distribution of prey over the season. Data only available from January 1, 2015 through April 27, 2019.

Discussion

This study analyzed five years of data from sites at the base of the continental slope and 300 km further offshore for fin whale counts. It enables a comparison of both temporal patterns and spatial trends between and near offshore sites. The analysis was limited to investigating patterns in relative counts and gross differences in counts as it is extremely hard to normalize data between sites for sensor and sensor installation differences or acoustic propagation. Detection events only occur when whales are vocalizing, therefore determining population densities requires separate methods to account for non-vocalizing whales and the calling rate of whales that vocalize.

Call counts are generally larger at Slope Base than at Axial Base, this could be due to preference in bathymetric proximity to the coastal shelf. Fin whales are present two to three months earlier at the Slope Base site than the Axial Base site over all five seasons, with the calling season at Axial Base subsequently ending two to three months later. This may suggest seasonal East-West fin whale movement in addition to the previously known North-South migrational movement. This trend of calling presence could be correlated with this species' food source, as productive coastal waters would have more resources available for a greater abundance of prey. This may cause a phytoplankton bloom earlier in the season and then a lag following zooplankton grazing, where fin whales congregate in productive coastal waters and then disperse offshore later in the season either in search of food or for breeding.

Conclusion

While studies along the Eastern coast of North America have found an abundance of fin whale calling near areas of high bathymetric relief, this study aimed to analyze seasonal call patterns between two sites at different distances from the coast. Fin whale calling occurs two to three months earlier at the Slope Base site than further offshore at Axial Base, with the calling season at Axial Base ending a subsequent two to three months later. This could be indicative of the relation between climate and prey abundance, as measured by sea surface temperature and productivity from winter mixing. Overall trends show greater counts of fin whale call detection and presence at the Slope Base site likely due to the proximity to the coastal shelf and prey. As availability of prey in productive waters decreases, fin whales may disperse offshore in search of food or for reproduction. Further studies can be done to determine the relationship between climate and species' prey, visualize migration of fin whale populations, account for total population densities, and assess the precision of instrumentation used to collect data.

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