UNCOVERING THE SPATIAL AND TEMPORAL ASSEMBLAGE OF PELAGIC SPECIES USING BOAT-BASED TRANSECT SURVEYS IN THE EXUMA SOUND, THE BAHAMAS

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ABSTRACT

The marine pelagic environment is the most substantial environmental realm on the planet, accounting for approximately 99% of the entire biosphere. Unlike the more static nature of coastal and terrestrial habitats, the dynamic composition of the pelagic environment makes it a much more complex system to both study and conserve. As The Bahamas is moving towards conserving 20% of their marine and coastal environment by the end of 2020, this study aims to start addressing the gap in the nation's pelagic marine protected areas. This study consists of the preliminary results of a multi-species offshore visual survey in the Exuma Sound, The Bahamas. Throughout the duration of this study, sightings per unit effort (SPUE) was calculated for 28 species present across 5 species groups of marine vertebrates. SPUEs were analyzed against multiple environmental factors (wind speed, wind direction, transect location, and season) to characterize patterns in the epipelagic community structure. Pearson correlation matrices were run to uncover covariance of species over the same spatial and temporal scales. Only two spatio-temporal relationships exhibited significance, both between tuna and birds. The first was between the general 'bird' group and 'tuna' group, with a moderate temporal and a strong spatial correlation. The second relationship was seen between brown noddies and tuna, showing very strong correlations both spatially and temporally. Although the results are preliminary, these data provided a valuable first glance into the associations of various species in northeastern Exuma Sound, as well as establishing a baseline for the abundance and diversity of life within the epipelagic zone of these waters.

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INTRODUCTION

The marine pelagic environment is the most substantial environmental realm on the planet, accounting for approximately 99% of the entire biosphere (Game, et al., 2009). The pelagic ecosystem can be defined as the physical, chemical and biological attributes that make up the open-ocean marine water column from the surface to the sediments on the ocean floor, with an average depth of 3.8 km (Verity, et al., 2002). It supports almost all marine life, and maintains an ecosystem that provides nearly half of all photosynthesis on Earth (Game, et al., 2009). Unlike many coastal and terrestrial ecosystems, the pelagic environment is driven largely by the properties of water masses, surface currents, and wind-driven mixing (Briscoe, 2016). Away from the coast in these pelagic waters, species interactions are spread away from geomorphic features through dynamic coupling between biological and physical processes. These active processes spread interactions over much larger spatial scales, but much shorter temporal ones. Although there are ways to use geomorphic structures to predict “biological hotspots” in the open ocean, the transport of nutrients through this dynamic coupling of processes leads to an ephemeral environment that is more patchy in nature (Briscoe, 2016). Within these systems, many organisms have complex life histories and migratory behaviors, which leads to the blurring of defined habitats (Briscoe, 2016). Unlike the more static nature of coastal and terrestrial habitats, the dynamic composition of the pelagic environment makes it a much more complex system to both study and conserve.

Since the expansion of industrialization, technology and human exploitation, these pelagic ecosystems have faced numerous threats including climate change, overfishing, species introduction, pollution, eutrophication, and mining (Game, et al., 2009; Grantham, et al., 2011). These stressors often act synergistically, and have led to visible negative shifts in the fundamental structure of pelagic ecosystems (Game, et al., 2009). Although there is still debate on the extent to which these systems are being impacted, the decline in biodiversity and overexploitation of species makes it clear that current protection for pelagic ecosystems is inadequate (Briscoe, 2016; Game, et al., 2009; Verity, et al., 2002).

Across the globe, the protection of biodiversity is seen as one of the most important ways in which to conserve the environment. Typically, marine conservation approaches have mirrored that of terrestrial systems, however this process is now considered flawed due to processes, patterns, threats, and habitats that differ greatly between them (Briscoe, 2016). For this reason, there is still a lack of agreement on the best way to apply conservation approaches to pelagic ecosystems. As a result, there has been limited establishment of marine protected areas (MPAs) in pelagic habitats. Part of the challenge of implementing these MPAs comes from the conflict of these waters crossing the national jurisdiction of various countries and even extending into the high seas, which only are loosely governed by voluntary non-legally binding regimes such as the United Nations Convention on the Law of the Sea (UNCLOS, UNCLOS Part VII, 1994; Game, et al., 2009). Outside of these regulations, the only real way these areas are managed is through pelagic fisheries management which are largely focused on single species instead of entire ecosystems (Bakun, et al., 2009; Game, et al., 2009). This is largely attributable to the fact that it is these fisheries that are imposing the greatest threat onto pelagic ecosystems, but even so, due to the lack of research and understanding on these ecosystems, and accountability, the management is inadequate.

Many countries are moving toward goals to establish more of their national waters as protected areas. The Bahamas, for example, is working towards protecting 20% of coastal and marine ecosystems by the end of 2020 (Moultrie, 2012; Knowles, et al., 2017). The plan increases the obligation to acquire knowledge on the significance of offshore resources and to site potential pelagic marine protected areas that are typically ignored in conservation plans. A large portion of the Bahamas' national waters consist of marine mammal habitat, and for that reason emphasis has been placed on the lack of data on these habitats and the marine mammal species that reside within them. To help increase the knowledge base on pelagic ecosystems and to help the Bahamas reach their goals for conservation, researchers at the Cape Eleuthera Institute (CEI) on the island of Eleuthera, The Bahamas, have begun an overarching research project that aims to describe the biodiversity and ecology of life in the slope and near-slope deep-water habitats of Exuma Sound, a partially enclosed body of water covering approximately 10,000 square kilometers of open ocean habitat.

This study aims to address the knowledge gap within pelagic ecosystems, in hopes to assist the Bahamas in creating marine protected areas. In order for this to be accomplished, a greater understanding of the composition and interactions within the ecosystem need to be understood. The scope of this project is to begin exploring the community structure of the Exuma Sound, The Bahamas, using boat-based transect surveys to investigate the seasonal diversity and abundance of pelagic species. Our second objective is to then begin to inquire into relationships some of these species share with wind speed and direction, with the hope that these variables could later on serve as predictors for sightings. Our last objective is to look at correlations between the different sightings of species within the study on both temporal and spatial scales. Through looking at the crossover of these correlations, we might begin to reveal relationships between species that either directly or indirectly interact within the same space and time.

METHODS

Study Area

The Exuma Sound is a large, partially enclosed open ocean habitat (approximately 10,000 km$_2$) in the eastern Bahamas. It is extremely environmentally diverse, spanning depths of 0-1500 m. This deep ocean basin is unique in its close proximity to coral reefs, shallow sandbars, and mangrove creek ecosystems and is highly oligotrophic. This study took place in northeastern Exuma Sound, approximately 5.5 km offshore from Powell Point, Eleuthera, The Bahamas (Figure 1). Data were collected between May 22, 2018 and May 25, 2019.

Transects

Data were collected through two boat-based visual transect surveys once a week (Figure 1). Each of the two parallel transects was 7 nmi (13km) long, taking, on average, 50 minutes. The first transect, positioned between two stationary Fish Aggregation Devices (FADs), was over water approximately 500 meters in depth and 1.5 km from the shelf edge. The second, 3.2 km from the shelf edge, was in water roughly 1,000 meters in depth between two fixed points. All transects were run during daylight hours, typically in the midmorning or afternoon.

Before each transect began, various abiotic factors were recorded, including estimates of wind speed and wind direction. Wind speed was recorded as a continuous numerical value, whereas wind direction was binned into one of the eight main cardinal directions. Other factors that were collected, but not used within this analysis of the data, were glare direction, glare intensity, cloud coverage, Beaufort sea state, and visibility. Beaufort sea state was estimated on a scale of 0 to 12 based on observed sea conditions combined with wind speed, developed by Sir Francis Beaufort in 1805. Transects were only run in conditions with a Beaufort state of 4 or below, due to inability to sight individuals and vessel safety. Glare direction was binned similarly to wind direction into the eight main cardinal directions. Cloud coverage was estimated as a percentage, from 0% (clear skies) to 100% (full clouds). Glare intensity and air visibility were ranked within categories low, medium, and high.

The number of observers participating in the exercise varied from transect to transect. There were always two observers facing approximately 45º from the direction of travel on either side of the boat, one observing off the bow, and, if there were enough individuals, there were two people stationed off the back. The vessel used for each transect was a 28 foot center console, traveling between 9 and 12 knots throughout the duration of the transect.

In the event of a sighting, a GPS location was recorded using a Garmin® eTrex 10. Along with location, we recorded time of sighting, notes on animal behavior, and species identification to the lowest taxonomic level possible. Photos were taken, when possible, during the sighting of an unknown species for later identification.

Statistical Analysis

Sightings per Unit Effort

SPUE was calculated to best estimate the relative abundance of a species based on the number of individuals sighted and the effort of the observers. This calculation was made as follows:

$$SPUE = n_{sightings} \, / \, Transect\ Effort$$

$$Transect\ Effort = \left(n_{staff} \times t\right) + \left[(n_{citizens} \times t) \times 0.25\right]$$

where sightings was the number of individuals of a particular species that the calculation was being made for, n_{staff} was the number of CEI staff members during the transect, t was the total time on transect, and $n_{citizen}$ was the number of students participating in the survey. Citizen scientists were assigned an effort equal to one quarter of staff scientists due to a lack of experience but still a quantifiable contribution to the survey.

In order to look at the general community structure of the epipelagic zone, the average SPUE was calculated for the warm and cold seasons, the 500 and 1,000 meter transects, and overall by species and species group. Along with these calculations, the SPUE was calculated for each species present in the study for every transect ran in order to explore its relation to other species and with various environmental conditions that could be drivers of sightings.

Species Correlations

All Pearson correlation matrices were computed in R using the SPUE of each species. Species were only included in the matrix if they had three or more sightings.

Temporal Correlations

A bivariate correlation matrix was run between transects to highlight environmental conditions that could be conducive to the sighting of various species. In order to ensure we were analyzing the proper significance, a Bonferroni adjustment was made, and the threshold of significance used was 0.001. Both r and p values were calculated to see the strength of significant relationships. A visual map of species correlations was also created for the temporal matrix.

Spatial Correlations

The GPS location of each sighting, along with all the transect data collected with it, was displayed in ArcMap over a satellite base layer of the Exuma Sound. Using the ‘Fishnet’ spatial analyst tool, boxes about 1.13 km by 1.25 km were projected over the study site. Through using this sized fishnet we were able to assign the various species sightings to 43 of these sized boxes. Box sizes were selected to maximize sightings per box for the purpose of statistical analysis and small enough to investigate spatially-relevant associations between species (Figure 2). Using various spatial joins, each sighting was assigned to one of the 43 boxes. For each box in the transect, an average SPUE was calculated for each species seen throughout the duration of the study. Using a bivariate correlation matrix, calculations were made to highlight any significant relationships between the spatial locations of various species. In order to ensure we were analyzing with proper significance levels, a Bonferroni adjustment was made, and the threshold of significance used was 0.001. Both r and p values were calculated to see the strength of significant relationships. To better visualize the interconnectedness of the species within this analysis, a visual map was created for the significant relationships.

Correlations in Space and Time

In order to highlight relationships between both the spatial and temporal component of species presences, overlaps in significant relationships between the two matrices were scrutinized. By looking at the crossovers between the two types of correlations run, we were hoping to find relationships between species alluding to possible direct and indirect interactions.

Drivers of Sightings

For all species recorded that had over 15 sightings, the relationships between SPUE and environmental factors (wind speed, wind direction, transect location, and season) were investigated. Out of the 28 species identified over the course of the study, five fell into this category. These species were the flying fish, brown noddy, shearwater, tern, and unknown bird. Histograms were constructed in order to visualize the distribution of SPUE for each of the five species. All of the species displayed a heavy right skew and could not be pushed towards a normal distribution, therefore non parametric tests were used for analysis. In analyzing wind speed and SPUE, linear relationships were assumed and respective models run in R. The Pearson correlation coefficients were calculated in order to quantify the strength of the relationship. For transect location (500 or 1000 m) and season, Wilcoxon rank-sum tests were run and evaluated at a p=0.05 significance level. Season was binned into Warm (May to October) and Cold (November to

April) due to changes in average water temperature. The relationships between SPUE and wind direction were analyzed using Kruskal-Wallis tests. If the Kruskal-Wallis tests revealed to be significant to the 0.05 level, then individual Wilcoxon rank-sum tests were run between the different wind directions, to determine which direction differed from the rest. The p-values were calculated using a Bonferroni adjustment to ensure a correct significance was calculated.

RESULTS

Community Structure and Environmental Drivers

Fish

Flying fish was the most frequently spotted species both within the entire study, but also within the fish group, with an average SPUE of 0.0535 flying fish per observer minute (Table 1). Due to feeding activity there were a handful of tuna and mahi-mahi sightings, with the other species only being sighted once or twice. Tuna had an average SPUE of 0.0039 while mahi-mahi was as low as 0.000595 (Table 1).

Flying fish SPUE varied by season and transect. Flying fish SPUE was higher for the transect run in 500 m (SPUE: 0.067) than the transect run in 1000 m (SPUE:0.034) and was also higher during the winter months (SPUE: 0.065) than the summer months (0.047) (Table 1). Results from Wilcoxon rank-sum tests show that although there are visible fluctuations in the SPUEs of flying fish between transect locations and season, neither were statistically significant.

Additional statistical tests were run on flying fish to determine if wind speed and direction played a role in the number of sightings on a given day. Although there was no significant difference between wind direction and flying fish sightings, there was a significant correlation with wind speed. The relationship between the SPUE of flying fish and wind speed was a moderate, positive linear correlation, where with increased wind speed there was an increase in SPUE (Figure 3) ($r = 0.22$, $n = 84$, $p = 0.044$).

Birds

The next most common species group seen within the study were birds (SPUE: 0.035). Unknown birds were the most commonly sighted species group (SPUE: 0.00903), followed by shearwaters (SPUE: 0.00888), brown noddies (SPUE: 0.00862), and terns (SPUE: 0.00664). All of the other birds sighted throughout this study, on average, had sightings per unit effort less than 0.001 birds per observer minute, for specifics refer to Table 1.

The changes in presence between warm and cold seasons within the bird community is extremely visible within the calculated average SPUE (Table 1). As a whole, the community had an SPUE of 0.00365 during the colder months of the year, increasing to 0.0554 birds per observer minute during the warm season. The most common group for the warm season (SPUE: 0.0145), and the second most common for the cold season (SPUE: 0.000982) was the unknown birds, showing enough evidence there is a significant difference between the seasons ($p < 0.0001$, $W = 1294$) (Figure 5a). Terns were, on average, the most abundant species group for the colder months (SPUE: 0.00211), and the third most sighted for the warmer months (SPUE: 0.00947).

The difference in the mean SPUEs between the two seasons was statistically significant for this species ($p = 0.0014$, $W = 1168$) (Figure 5b). The shearwaters were the third most sighted group in the colder months (SPUE: 0.000179), and second most in the warmer ones (SPUE: 0.0143), showing a significant difference in sightings between seasons ($p < 0.001$, $W = 1217$) (Figure 5c). All the other species had SPUE values less than 0.00017 (Table 1). Out of the 12 species groups identified within the bird community within this study, six of them were completely absent during the winter. Only in one case, for black capped petrel, was it the opposite, where they were only sighted during the winter. Although for the black capped petrel it is hard to make any assumptions about the species because there was only one recorded sighting during the duration of the study. During the warmer months, brown noddies were the fourth most abundant species within the bird community with an SPUE of 0.014. Brown noddies were absent in the colder months, which led to a significant difference in average SPUEs between the two seasons ($p = 0.0036$, $W = 1072.5$) (Figure 5d). All other bird species during the warm season had SPUE values of 0.0022 birds per observer minute or less (Table 1).

The SPUE for all birds was 0.046 at the 500 meter deep transect, dropping to 0.0203 at the 1,000 meter transect. At the 500 meter transect, the five most common species were shearwaters (SPUE: 0.0135), unknown birds (SPUE: 0.0134), terns (SPUE: 0.0082), brown noddies (SPUE: 0.00776), and white-crowned pigeons (SPUE: 0.00233). For the transect over 1,000 meter water, SPUE values for all bird species were lower than the transect in 500 m of water except for that of brown noddies, which saw an increase in SPUE of 0.0021 (Table 1). Although there were visible changes in the average SPUEs of bird species between transect locations, when additional Wilcoxon rank-sum tests were run on brown noddies, terns, shearwaters, and the unknown bird group, there was no significant difference at a 0.05 significance threshold.

Similarly to flying fish, additional analysis was run on unknown birds, brown noddies, terns, and shearwaters to determine if wind was a driver in species sightings. Although there was no significant difference in sightings between the various wind directions for the bird species, terns did have a significant correlation with wind speed. For the terns, a moderate negative linear relationship was seen as sightings decreased with increasing wind speeds (r = -0.22, n = 84, p = 0.044) (Figure 4).

Cetaceans

Throughout the duration of this study we were able to identify a general group of marine mammals, unknown beaked whales, and Blainville's Beaked Whales within the infraorder Cetacea. As a group, the average SPUE was 0.000949 cetaceans per observer minute for the duration of the study (Table 1). The most frequently sighted was unknown marine mammals, with an average SPUE 0f 0.000627 marine mammals per observer minute. The next most abundant group was unknown beaked whales at 0.000165, and lastly Blainville’s Beaked Whales with an average SPUE of 0.000157 whales per observer minute.

In terms of seasonality, as a group there were more sightings during the warmer months with an SPUE of 0.00145, dropping to 0.000137 in the winter. The only species sighted during the winter was unknown beaked whales with an SPUE of 0.000137, increasing to 0.000181 whales per observer minute during the warm months. Unknown marine mammals increased to 0.00102 during the warm season, while the Blainville's Beaked whales increased to 0.000256.

Observing the locations cetaceans are most commonly sighted, they have an SPUE 0.00152 higher at the deeper transect than at the shallower one. The only group with sightings at the 500 meter transect were that of unknown marine mammals, but even so their sightings increased from 0.00106 to 0.000332 at the 1,000 meter transect.

Sharks

Similar to cetaceans, sharks overall had lower sightings as a group. Tiger sharks were our most frequently sighted species within the elasmobranchs, with an average SPUE of 0.000359 sharks per observer minute (Table 1). Out of the total eight shark sightings during this study, seven were tiger sharks, and the other one was unable to be identified. Though tiger sharks were sighted year round, sightings were higher by 0.000053 during the warmer months with an SPUE of 0.00038. Tiger sharks were more typically sighted at the 500 meter transect with an SPUE of 0.000426, decreasing to 0.000262 at the 1,000 meter transect.

Species Correlations

Temporal Correlations

Within the bird species group, terns and shearwaters were significantly correlated. Terns were also correlated with brown noddies (Figure 6). Shearwaters were correlated with the unknown bird group and White-tailed Tropicbirds (Figure 6).

The bird group as a whole displayed a correlation with Tuna, but specifically the brown noddies shared a very strong correlation (Figure 6). In terms of mahi-mahi, they only shared a strong correlation with the terns. White-crowned Pigeons had a strong correlation to Flying Fish and the general fish group (Figure 6).

Spatial Correlations

Within the bird species groups there were a handful of correlations. Shearwaters correlated with the unknown bird group along with the White-crowned Pigeons (Figure 7). The only other interspecies correlation within the birds was with white-tailed tropicbirds and brown noddies.

The most correlations seen were between the bird and fish species groups, between the general two groups there was a very strong correlation (Figure 7). Specifically, the general fish group experienced strong correlations with white-tailed tropicbirds, brown noddies, terns, and the unknown bird group (Figure 7). Flying Fish experienced correlations with terns, shearwaters, and the unknown bird group (Figure 7). In regards to the bigger game fish, such as mahi-mahi and tuna, there were a handful of correlations with various birds. As a whole the overarching bird group had a very strong correlation with tuna. Specifically, the brown noddies and white-tailed tropicbirds had very strong correlations with the Tuna (Figure 7). Mahi-mahi only had a correlation with the unknown bird group (Figure 7).

Cetaceans shared a handful of interesting correlations with various species. Within the birds, cetaceans shared a moderately strong correlation with the unknown bird group and the white-tailed tropicbirds (Figure 7). The cetaceans also were observed to have a correlation with flying fish, but no other fish within the overarching fish species group (Figure 7). The unknown marine mammals also shared these three correlations alongside the overall cetacean group, having the strongest relationship with white-tailed tropicbirds, and decreasing in strength from unknown birds to flying fish, respectively (Figure 7). A very interesting correlation was revealed between the cetaceans and the general shark group, but not with the unknown marine mammals (Figure 7).

Sharks also shared moderately strong correlations with the unknown bird group and flying fish (Figure 7).

Correlations in Space and Time

Though there were numerous species correlations revealed between the spatial and temporal matrices, only two overlapped between the matrices with the more stringent significance threshold provided by the Bonferroni adjustment. Both of these relationships were between birds and tuna. The first was between the general bird group and tuna group, with a moderately strong temporal and a strong spatial correlation ($r = 0.57$, $n = 86$, $p<0.001$) ($r = 0.89$, $n = 100$, $p<0.001$). The second relationship was seen between brown noddies and tuna, showing very strong correlations both spatially and temporally ($r = 0.89$, $n = 100$, $p<0.001$) ($r = 0.87$, $n = 86$, $p<0.001$).

DISCUSSION

The pelagic ecosystem is difficult to study due to the large spatial and short temporal scales in which the species within these systems interact. More so than other ecosystems, they are driven by environmental factors such as wind and ocean circulation, and how these factors interact with topographic structures (Briscoe, 2016). Due to the fluid nature of these ecosystems, past research has used mechanisms such as aggregation devices and physical capture to describe the species composition of these areas. Both of these mechanisms are extremely valuable in understanding the composition of these dynamic ecosystems, but this study aimed to investigate this system observationally as it exists in nature. Through using the boat-based transect surveys, we were able to gather data on where spatially these taxa are organizing themselves and how they may be directly or indirectly interacting with each other and the environmental conditions of this area of the Exuma Sound. Through going about the study in this manner, we are also looking to get a holistic view of the species assemblage, all the way from the deep-diving cetaceans to the birds above the pelagic waters.

This study has a lot of potential for future growth, but the data already collected is able to provide a good framework to help the project move forward, and get a better understanding of the spatial and temporal assemblage of pelagic species in the Exuma Sound. The first step in this is understanding the community structure, diving into the various taxa groups present.

Fish

Flying fish were the most abundant species within both the fish community as a whole and the entire study, likely due to their predator-avoidance behavior that is triggered by an approaching vessel (Churnside, 2016). The ability to sight fish during these transects was difficult. Aside from flying fish, other fish species were only sighted when they were in close proximity to the boat and were breaking the surface to feed. The poor likelihood of seeing fish species while on transect suggests that any trends seen within the SPUEs of these species are due to chance rather than actual differences in species abundance. For that reason we can note their presence, but cannot draw conclusions from patterns within their sightings. This was confirmed to us as the difference between season and location showed no significant difference for the flying fish. The one significant relationship that revealed itself within the flying fish community, was between their sightings and wind speed. They shared a positive correlation, which tells us that with increased wind speeds there are increased sightings of these species. This pattern is congruent with a past study done by Khokiattiwong in 2000, where more flying fish were captured during days with higher average wind speeds attributed to water disturbance from increased swells.

The only other fish species with sufficient sightings to analyze were mahi-mahi and tunas. Though no patterns could be detected in their sightings between seasons and locations, these species were seen primarily during feeding aggregations.

Birds

The next group of species we saw the most of was the birds. It was within this grouping we saw the most significant patterns between species abundance and environmental drivers. It was extremely difficult to identify many of the birds down to a species level due to their distance from our vessel, but we were still able to come up with a few general species groupings to help us begin to identify the composition of the bird community. For this reason our most commonly sighted group was that of the unknown birds, followed by the shearwaters, terns, and brown noddies. For all of these species we saw no statistical relationships in regards to their distance from the shelf wall or depth of water. This makes sense because many of these birds are known to be longer distance seabirds, known to disperse up to 50 km from shore to forage in the case of brown noddies, and our furthest transect is only about 3.2 km from shore (BirdLife, 2018).

It appears that many of these species are seasonally present in the Exuma Sound. Unknown birds, shearwaters, terns, and brown noddies had fewer sightings during the colder months of the year than the warmer months of the year. It can be speculated that they are all primarily migratory seabirds, often moving to the Southern Hemisphere for winter, returning to northern latitudes in the summer (González-Solís, et al., 2007). In regard to the brown noddies, they appeared to be completely absent from the winter months. The migratory patterns of brown noddy are poorly understood, especially considering they are typically year-round residents of tropical colonies. They are known to be seasonally absent from various subtropical colonies, migrating to the open ocean after the breeding season is over (BirdLife, 2018). Due to the significant difference in the sightings per unit effort between the seasons and the absence during the colder months it is probable that the group of brown noddies present in this region migrate from the area during the winter months. For the other bird species within this study, it was hard to draw any conclusions on their seasonality due to the low number of identifiable sightings within the study.

We analyzed the relationships between brown noddies, terns, shearwaters, and unknown birds in relation to wind. None of these species displayed any notable difference between the various wind directions. The only group that showed a significant correlation with wind speed was the terns, where the terns were less present at higher wind speeds. It is plausible if wind speeds were recorded more accurately and transects were taken in stronger wind conditions, this would be a pattern seen across all bird species within the area of the Exuma Sound. Although it differs based on the morphology of the bird species in question, with increased headwinds, more energy is required for flight, making foraging more difficult for seabirds (Lietchti, 2006). With increased inclement weather conditions, birds are sighted less as more take shelter and their sight and sound detection of prey is thrown off through increased wind speeds and rough water (Robbins, 1981).

Cetaceans

Many cetacean species are deep-divers, meaning they spend long periods of time sub-surface, typically only spending short periods of time at the surface to breathe and to occasionally travel. For this reason individuals can only be recorded when they break the surface, and it can become difficult to track the individuals for proper identification. Due to this, our team's inexperience identifying different species within this order, and sheer distance from the sighted individuals, many of our sightings were unable to reach the species level. Oftentimes photographs were taken for identification out of the field. Within this study we were able to identify a general group of marine mammals, unknown beaked whales, and Blainville's Beaked Whales.

Past studies have shown Blainville's Beaked whales prefer habitats along intermediate depth gradients found along continental shelves, averaging about 4.39 km from shore within water 200 to 1,000 meters deep (Ritter and Brederlau, 1999; MacLeod and Zuur, 2005). A similar benthic structure is seen at the 1,000 meter transect within our study, which is 3.2 kilometers from the continental shelf. It is thought these are areas of increased prey abundance due to the interactions between local water currents and topographic features (MacLeod and Zuur, 2005). Although this study has revealed no new research on these species, they are considered to be ‘data deficient’ by the IUCN red list, which means their mere presence and potential for future studies is important in the conservation and understanding of this species especially considering their status hasn’t been assessed since 2008 (NOAA, 2020). Although we were unable to identify the other cetaceans down to the species level, the presence of unknown beaked whales at the deeper transect may highlight the use of the interaction between currents and topography of the continental shelf in order to feed on mesopelagic and benthic prey such as squid (NOAA, 2020).

In terms of seasonality, whales in general are known to make long migrations, moving across latitudes between various seasons to feed and breed. Within this study there were more sightings in the warmer months than colder ones, suggesting the seasonal migration of the species present in the area, but because there are so few sightings and few identified to the species level, no concrete conclusions can be drawn. Blainville’s Beaked are present throughout tropical and subtropical waters across the globe, and have been known to display long-term site-fidelity in regions such as the Hawai’i archipelago and off Great Abaco in the Bahamas (Claridge, 2006; McSweeny, et al., 2007; MacLeod et al. 2006). These studies suggest that we can expect similar patterns in site fidelity within the Exuma Sound. Also, the range of beaked whales extends throughout oceans across the globe, and for that reason no conclusions can be drawn speculating the seasonality behavior of our unknown beaked whale group, but their mere presence is something to be noted within the ecosystem of the Exuma Sound (MacLeod et al. 2006).

Sharks

Our last group within this study were the sharks, and although there were only eight total sightings recorded, there still were interesting patterns revealed. The only time they were sighted was when finning on the surface. Most sharks don't spend much time swimming along the surface, unless they are feeding or drawn to the surface by potential prey. One species that has been known to fin at the surface is tiger sharks, which accounted for seven of the eight elasmobranch sightings within this study. This is indicative of their behavior for studies have shown they spend the majority of time in the top 5 meters of the water column, often finning at the surface, despite being known to take deep dives up to 250 meters (Vaudo, et al., 2014). This behavior makes this species more likely to be spotted during our transects, while other species are unlikely to be spotted even if they are present due to being deeper in the water column. Similar to the fish group, sharks can only be sighted during data collection if they are near the vessel or breaking the surface, making it difficult to get an accurate representation of the epipelagic elasmobranch assemblage in the Exuma Sound using boat-based transects.

Due to their low sightings it becomes difficult to draw any concrete conclusions from the patterns seen, but regardless their presence between transects and seasons line up with their typical spatial behavior. These species were seen mostly at the transect closer to shore, for tiger sharks are generalist predators spending a lot of time in more coastal regions, moving between open ocean and shallow productive reefs (Afonso and

Hazin, 2015). Concerning their seasonal patterns, tiger sharks are found in tropical and subtropical waters, and though this species of shark is known to have large home ranges even crossing oceans, others have been known to remain in the same general location year round, which could explain the lack of fluctuation seen in their seasonal sightings within the Exuma Sound (Afonso and Hazin, 2015).

Species Correlations

Though it is important to understand which species are present within the area, the next step is uncovering how they interact. Through correlation matrices we were able to look into one of the main objectives of this study, determining the ways in which the taxa of the Exuma Sound are interacting in space and time. Through looking at the two scales separately we are able to get an understanding of conditions conducive to both species, but through looking at the crossover of scales we can see interactions that may be more direct through sharing the same space at the same time.

Temporal Correlations

The first focus was on how species covary with each other in time: which ones co-occur in the transects during the same time? This analysis collapses the data across the whole transect and asks how species covary with each other across time. The temporal scale helps to uncover how environmental conditions might be favorable to the sighting of various species across the whole transect.

Within the bird community itself we were able to uncover numerous correlations of sightings. Terns were associated with both brown noddies and shearwaters, while the shearwaters were also correlated with the unknown bird group and white-tailed tropicbirds. It appears there was a commonality between these groups of birds: they typically feed on the same prey. Although the exact species composition of these bird groups cannot be determined using our methods, diets of terns and shearwaters are primarily small fish and pelagic cephalopods (BirdLife, 2018; Petry et al., 2008). For the two species we can determine to the species level, white-tailed tropicbirds and brown noddies, they primarily feed on small pelagic fish, and the tropicbirds are known to specifically feed on flying-fish (BirdLife, 2018).

Another interesting interaction story that revealed itself was between the larger game fish within this study, tuna and mahi-mahi, and various birds. In examining the various tuna species known to be within the region, all of them had diets consisting of small fish and cephalopods (Collette, et al., 2011). A few of these species, specifically Skipjack Tuna and Little Tunny are known to be associated with flocks of birds at the surface, particularly during feeding events (Collette, et al., 2011; Collette, et al., 2011). In regards to mahi-mahi, they shared a temporal correlation with the tern group. The diet of mahi-mahi also appears to have crossover with terns, as they feed on small fishes, squid and crustaceans (Collette, et al., 2015). Similarly to the birds, it appears that these species are interacting by feeding on the same prey, but strict conclusions are unable to be drawn until these interactions carry over to the spatial scale.

The only other temporal interaction that was seen was between the White-crowned pigeons and flying fish. These birds are not known to stray far from their mangrove and hardwood forest habitats. White-crowned pigeons are known to be primarily frugivorous, only occasionally known to feed on grain, making it unlikely they are feeding on these fish (Bancroft and Bowman, 1994). Therefore, this correlation was very surprising and there is currently no easy explanation for it. It would be interesting to see if this correlation extends into the future of this study.

Spatial Correlations

This analysis looks at the co-occurrence of species within the same geographic location disregarding the time of the occurrence. It answers the question of whether certain species co-occur at the same locations rather than at the same time. Co-occurrence in the same geographic location can be due to the patchy distribution of shared resources or favorable conditions. In uncovering correlations over a spatial scale, we can begin to understand which species may be utilizing the same space as each other throughout the duration of the study, but these relationships don't necessarily extend over the same time periods.

In the bird group, the shearwaters shared a correlation with the unknown bird group and the white-crowned pigeons. The only other spatial association seen within the birds was between the white-tailed tropicbirds and brown noddies. Similar to the temporal scale, it can be assumed by interacting within the same space they are also feeding on similar prey. This is likely not the case for the shearwaters and white-crowned pigeons, for as mentioned previously the pigeons primarily eat fruit and do not typically stray far from shore.

The most spatial correlations seen were between the birds and fish within this study, as seen by the significant spatial correlation between the birds as a group and the fish as a group. This reveals these birds and fish are utilizing the same physical space, which could be indicative of feeding either on these fish or the same prey as these fish. This feeding distinction can be made as more specific correlations between species are revealed. The fish group as a whole had strong correlations with the brown noddies, white-tailed tropicbirds, shearwaters, and the unknown bird group. Brown Noddies, shearwaters, and white-tailed tropicbirds are all known to primarily feed on small fish, and because the unknown bird group also shares this correlation it is likely they are also feeding on the same prey. Flying fish also had numerous associations, correlating with terns, shearwaters, and the unknown bird group over a spatial scale. This could unveil that these birds are either feeding directly on the flying fish, or that flying fish could be indicative of other smaller fish in the area. In regards to the relationships seen between birds and the bigger game fish, mahi-mahi and tuna, some interesting relationships can be seen on the spatial scale. The entire bird group ended up having a strong association with tuna, specifically the brown noddies and white-tailed tropicbirds. All three of these species are known to feed on small fish, making it probable this is the reason for utilizing the same space within the epipelagic waters. Mahi-mahi only shared a correlation with the unknown bird group. As mentioned previously, it is likely the unknown bird group is primarily seabirds who feed on fish and squid, which is also the diet of mahi-mahi.

The next relationships seen were with the cetaceans and other groups. Although these relationships did not display themselves to be significant on a temporal scale, it is interesting to note how they possibly interact with other taxa spatially. The first species we see in correlation with the cetaceans are with the unknown bird group and the white-tailed tropicbirds. Seabirds have been known to have overlapping distributions with other top predators, such as cetaceans, due to the ability of these mammals to drive prey from the depths of the epipelagic zone to the surface (Lascelles, et al., 2011; Hebshi, et al., 2008). Cetaceans were also seen to share a correlation with flying fish. Beaked whales do feed on small fish, but typically they are benthopelagic fish found at much greater depths in the water column than flying fish. There is no clear reason this correlation is seen. The specific unknown mammal group also shared these same three correlations, likely for the same reasons. The last correlation seen within this family is between cetaceans and sharks. There is no clear reason for this correlation, however it is rather interesting and should be followed up in a future study.

Sharks also shared correlations with the unknown bird group and flying fish, though there is no clear evidence for these co-occurrences. It is possible these seabirds are associating with the sharks for the same reason as the cetaceans, and that due to the generalist feeding of tiger sharks they could be feeding on the flying fish. Until these species covary in the temporal scale, no concrete conclusions can be drawn.

Correlations in Space and Time

Although there were many relationships that revealed themselves over these two scales, there were only two associations that carried over between the two. These are the relationships where co-occurrence existed at the same place and time. This is the strongest indication of direct relationships between the species that show these correlations. Finding these correlations requires a lot of statistical power, given the fairly small sample size within this study, it is unsurprisingly that I found only two spatio-temporal relationships to be significant. Both were between tuna and birds. The first was between tuna and the general bird group, and the other between tuna and brown noddies.

As I explained earlier, brown noddies typically feed on small fish and squid, sometimes eating pelagic mollusks and jellyfish (BirdLife International, 2018). Tunas are a large group of species, but typically these epipelagic fish feed on other small fish, squid, and crustaceans (Collette, et al., 2011). Due to the overlap in diet we can assume their correlation was due to predation on the same food sources, whether it is the same species of prey or the same aggregations of prey. This can be extended over to the general bird group and tuna as well, for the majority of identifiable bird groupings in this study feed on small fish and squid. Not only do their diets overlap, but past studies on seabirds have revealed that they often associate with these subsurface predators due to their ability to drive potential prey to the surface (Hebshi, et al., 2008). Specifically, brown noddies have been known to forage in association with schools of tuna more frequently than expected if it was chance alone (Hebshi, et al., 2008). This is the most concrete conclusion we are able to draw within this study, for not only are we able to identify more specific taxa, there is significant evidence these species are overlapping in both space and time within the epipelagic waters of the Exuma Sound.

CONCLUSION

These data provided a valuable first glance into the associations of various species in northeastern Exuma Sound, as well as establishing a baseline for the abundance and diversity of life within the epipelagic zone of these waters. Although with these boat-based transects we were unable to get an accurate representation of the species that lie below the surface, an interesting focal point to note about this study is the birds present.

Past research has allowed researchers to use birds as indicators for ecosystem health and biological hotspots in open-ocean systems, even going as far to use them as a way to establish and monitor marine protected regions (Lascelles, et al., 2011). Although they are extremely important in their own conservation priorities, they can be highly effective proxies for the conservation of other species that are considered to be data deficient, for many seabird species are considered to be top predators with global distributions (Lascelles, et al., 2011). They also have been deemed good indicators due to their distributions often overlapping with other top predators, including cetaceans, along with their prey extending across a wide diversity of marine taxa (Lascelles, et al., 2011).

If this study continues, and we are unable to gather more information on the fish, sharks, and cetaceans within this area, turning focus on the birds in this study may prove to be extremely valuable. Through gathering more knowledge of the bird community of the Exuma Sound we will be able to get an understanding of the overall productivity of the ecosystem, possibly even using it as a mechanism to assist the Bahamas in establishing marine protected areas within pelagic waters. This research will in turn allow for the progress towards moving beyond traditional 2-dimensional conservation methods, finding ways to conserve and protect the highly fluid and dynamic pelagic ecosystems that are vital in the health and resilience of our oceans.

FUTURE DIRECTIONS

The most beneficial task for the future of this project would be the continuation of data collection over the course of one or two more years. With an increase in the volume of data, more species would have enough sightings to run statistics, giving more weight to our findings. Though there is much less data within the analysis of this study, it was still able to begin scratching at the surface of uncovering the pelagic community structure of the Exuma Sound.

A major area for future growth within this study would be to determine more accurate and consistent ways at identifying species throughout the transects. If we can become more specific, it will allow for better understanding what exact species compose the Exuma Sound epipelagic ecosystem and how they interact with each other and environmental factors. Many of our current unidentified species were due to the distance away from sighted individuals, therefore it will be difficult to fully fix this issue as the study continues. With an improved understanding of biodiversity and species presence within the Exuma Sound, important future research directions can be determined to further the Exuma Sound Ecosystem Research Project's goals for describing the pelagic ecosystem. This aspect of maturation within the study may even allow for the possible description of range extensions for various species. This can assist in the protection and increased knowledge on various species that may have been previously unknown, along with increasing knowledge on the biodiversity of the Exuma Sound.

Another aspect that could bolster the future of this study would be to uncover a way to calculate sightings and understand conditions conducive to species abundance, which could be accomplished through more precise collection methods of environmental data. In regards to wind, it would be beneficial to collect actual wind speeds on vessel, allowing for it to become a continuous variable, rather than categorical, which would improve data analysis. Also, if possible, collecting average wind speed data for the 24 hours prior to the transect would be beneficial in understanding how wind can shape the pelagic community. Similarly, it would be useful to collect wind direction data at the time of the transect, and possibly the average wind direction data for the 24 hours prior to the transect from 0 to 360° (North). By collecting wind direction data this way we will be more confident in being able to bin data into various cardinal directions and it will no longer be an estimation. We are currently in the works of acquiring wind data from the Bahamas Meteorological Data Survey to accomplish these goals for the future of this study, but data were not attained in time for the analysis of this particular study. Along with assisting in data collection, relationships between wind and sightings would allow for more exact SPUE calculations, allowing for modifications between different species groups. In addition to these adjustments in SPUE, it would be advantageous to find a way to also incorporate the Beaufort state into calculations. Although Beaufort state would also cover wind speed, it would add the important factor of how wind speed influences the overall conditions of the water. The higher the Beaufort state the less likely we are able to sight species, which would inherently influence the calculated SPUEs.

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TABLES & FIGURES

Table 1. This table displays the average sightings per unit effort for all of the different species sighted throughout the duration of this study.

Species Group	**Species**	**Scientific Name**	**Cold Season SPUE**	**Warm Season SPUE**	**500 m Transect**	**1000 m Transect**	**Average SPUE**
Bird			0.003647918	0.055407777	0.046022213	0.020281733	0.035546436
	Unknown Bird	*Aves*	0.000982243	0.014481099	0.013371224	0.003370853	0.009301306
	Shearwater	*Procellariidae*	0.000179175	0.014290605	0.013466128	0.002186924	0.008875754
	Tern	*Sternidae*	0.002105995	0.009465741	0.008202072	0.004367898	0.006641653
	Frigate	*Fregatidae*	0.00017567	0.000112309	0.000230382	0	0.000136622
	White-Crowned Pigeon	*Patagioenas leucocephala*	0	0.002242137	0.002330063	0	0.001381782
	Brown Noddy	*Anous stolidus*	0	0.013981402	0.007762541	0.009860706	0.008616446
	Royal Tern	*Thalasseus maximus*	0	0.00021897	0	0.000331583	0.000134947
	Bridled Tern	*Onychoprion anaethetus*	0	0.000126963	7.54148E-05	8.23681E-05	7.82446E-05
	Sooty Tern	*Onychoprion fuscatus*	0	7.48727E-05	7.78089E-05	0	4.61425E-05
	Laughing Gull	*Leucophaeus atricilla*	0	0.000252414	0.000262312	0	0.000155557
	White-Tailed Tropicbird	*Phaethon lepturus*	0.000117	0.000161264	0.000187432	8.14001E-05	0.000144279

	Black Capped Petrel	*Pterodroma hasitata*	8.78349E-05	0	5.68343E-05	0	3.37041E-05
Fish			0.065257735	0.054065478	0.069309853	0.042404945	0.058360181
	Flying Fish	*Exocoetidae*	0.064575186	0.046670476	0.066983493	0.033953091	0.053540888
	Mahi Mahi	*Coryphaena hippurus*	0.000137429	0.000879296	0.000913779	0.000129576	0.000594626
	Tuna	*Scombrid*	0	0.006325647	0.000971471	0.008163265	0.003898364
	Unknown Fish		0	8.1591E-05	8.47907E-05	0	5.02828E-05
	Ocean Trigger	*Canthidermis maculata*	0	6.28931E-05	0	9.52381E-05	3.87597E-05
	Needle Fish	*Belonidae*	0.000129639	4.55747E-05	0.000131246	0	7.78318E-05
	Triggerfish	*Balistidae*	6.76407E-05	0	0	6.37755E-05	2.59551E-05
	Billfish	*Istiophoridae*	0.000158447	0	0.000102525	0	6.07995E-05
	Houndfish	*Tylosurus crocodilus*	0.000189394	0	0.000122549	0	7.26744E-05
	Chub	*Kyphosus sp.*	0.000292783	0	0.000189448	0	0.000112347
Shark			0.000475367	0.000379705	0.000522484	0.000261851	0.000416412
	Unknown Shark	*Chondrichthyes*	0.000148544	0	9.61169E-05	0	5.69995E-05
	Tiger Shark	*Galeocerdo cuvier*	0.000326823	0.000379705	0.000426367	0.000261851	0.000359413
Cetacean			0.000137429	0.001454983	0.000331634	0.001849598	0.00094941
	Blainville's Beaked Whale	*Mesoplodon densirostris*	0	0.000255629	0	0.000387096	0.000157539
	Unknown Marine Mammal		0	0.001017931	0.000331634	0.001058201	0.00062733
	Unknown Beaked Whale	*Hyperoodontidae*	0.000137429	0.000181422	0	0.000404301	0.000164541
Turtle			0.000140292	5.11673E-05	0.000143951	0	8.53662E-05
	Unknown Turtle	*Chelonioidea*	0.000140292	0.073680844	0.000143951	0	8.53662E-05

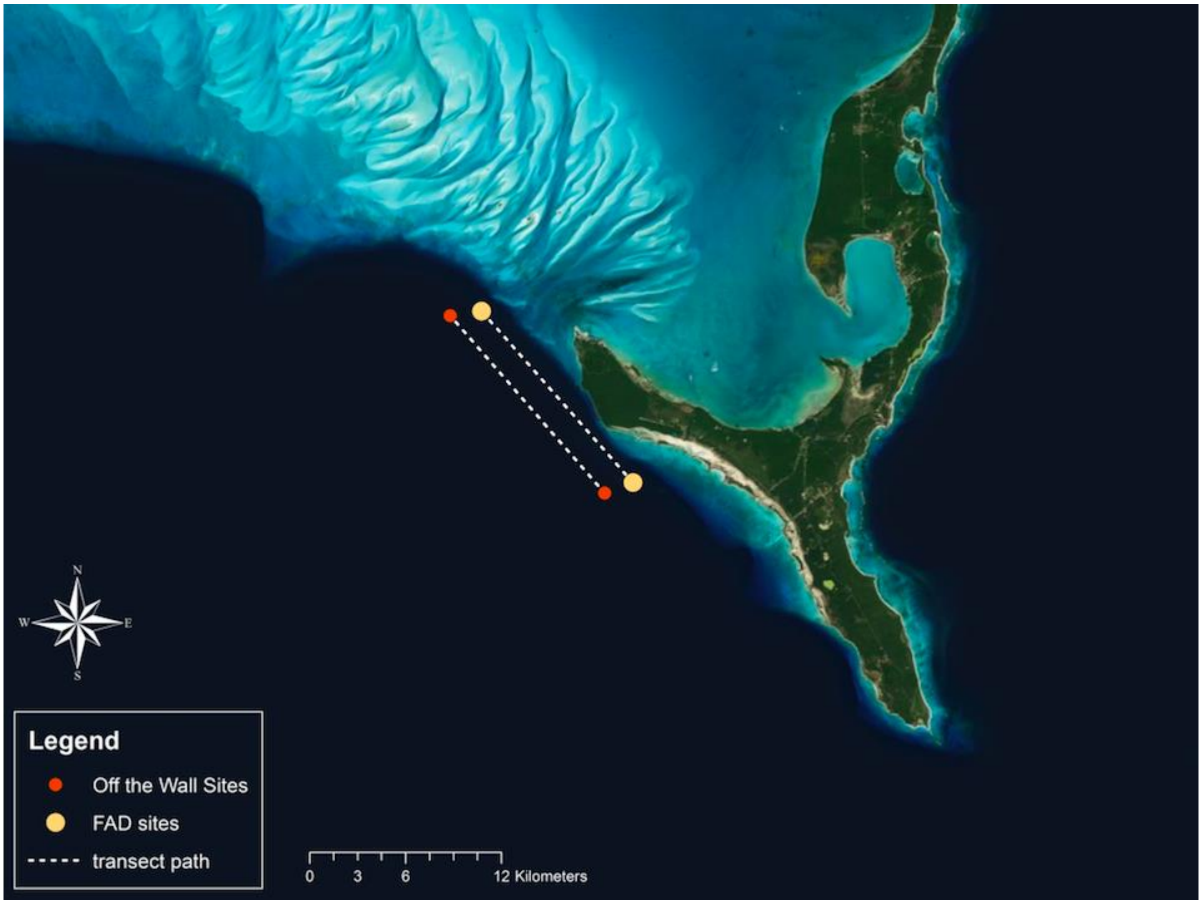

Figure 1. This figure displays the two transect locations within the Exuma Sound used for this study. The 500 meter transect runs between the two fixed FAD (Fish Aggregation Device) sites, while the 1,000 meter transect runs between the two ‘off the wall’ sites. These transects are located off the southern tip of Eleuthera, The Bahamas.

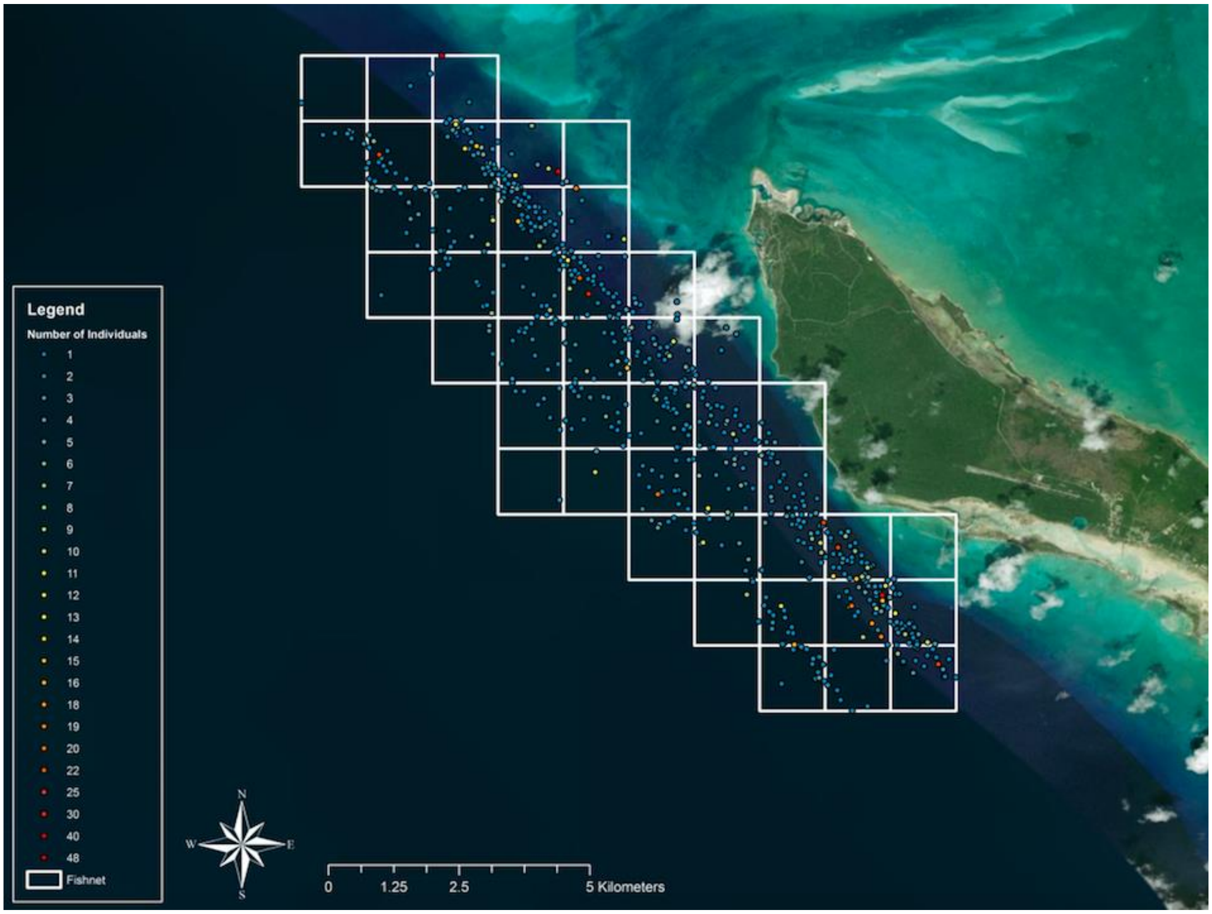

Figure 2. The distribution of species sightings for all species combined and the applied spatial fishnet used for correlations. For every sighting the number of individuals varies from 1 to 48, and is indicated by the color of the point.

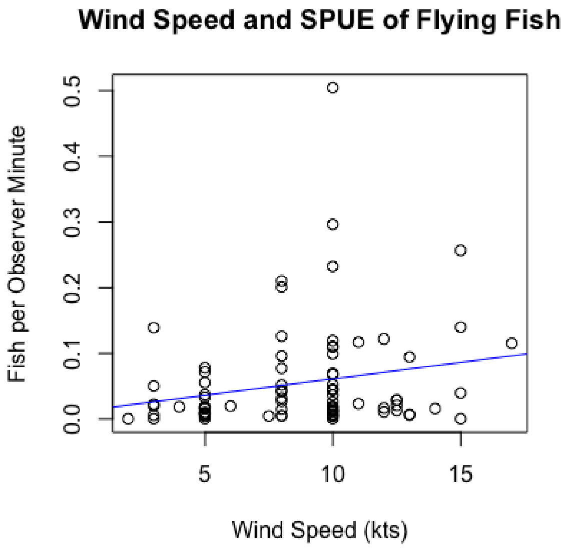

Figure 3. Flying fish sightings per unit effort and wind speed. There was a significant, positive linear correlation between SPUE and wind speed (r = 0.22, n = 84, p = 0.044).

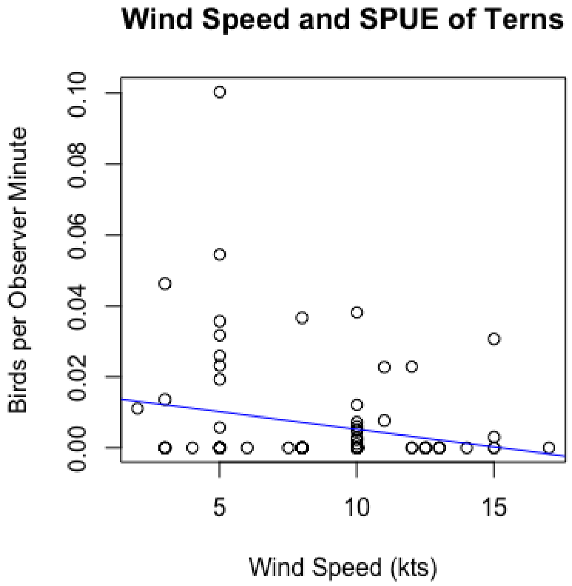

Figure 4. Tern sightings per unit effort and wind speed. There was a significant, negative correlation between wind speed and the SPUE of terns (r = -0.22, n = 84, p = 0.044).

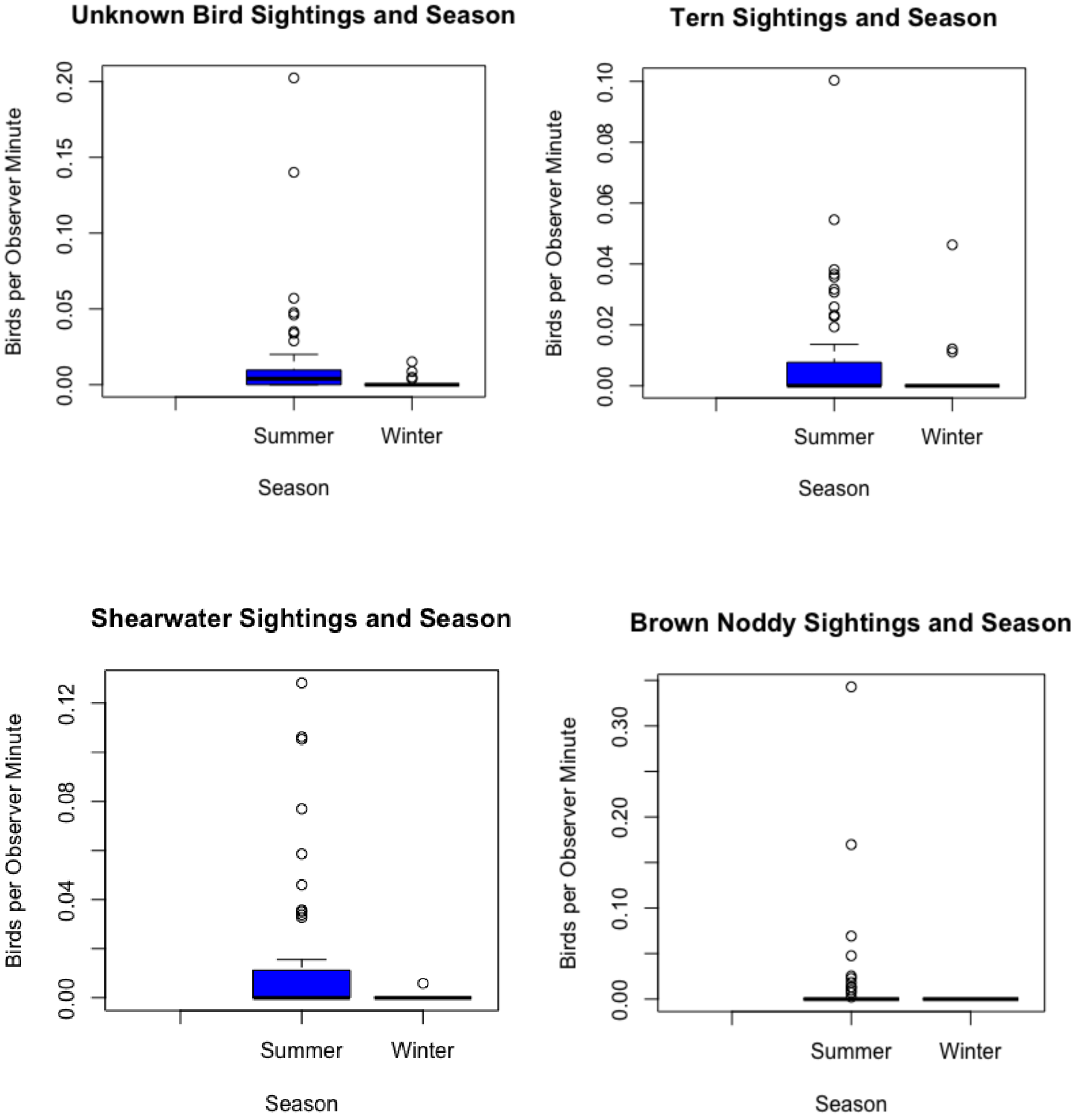

Figure 5. Sightings per unit effort of various species of birds between the cold and warm seasons. Across all four bird groups, there were more sightings in the warmer months than the colder ones. A) The SPUEs of unknown birds between the warm and cold seasons ($p < 0.0001$, $W = 1294$). B) The SPUEs of terns between the warm and cold seasons ($p = 0.0014$, $W = 1168$). C) The SPUEs of shearwaters between the warm and

cold seasons (p < 0.001, W = 1217). D) The SPUEs of brown noddies between the warm and cold seasons (p = 0.0036, W = 1072.5).

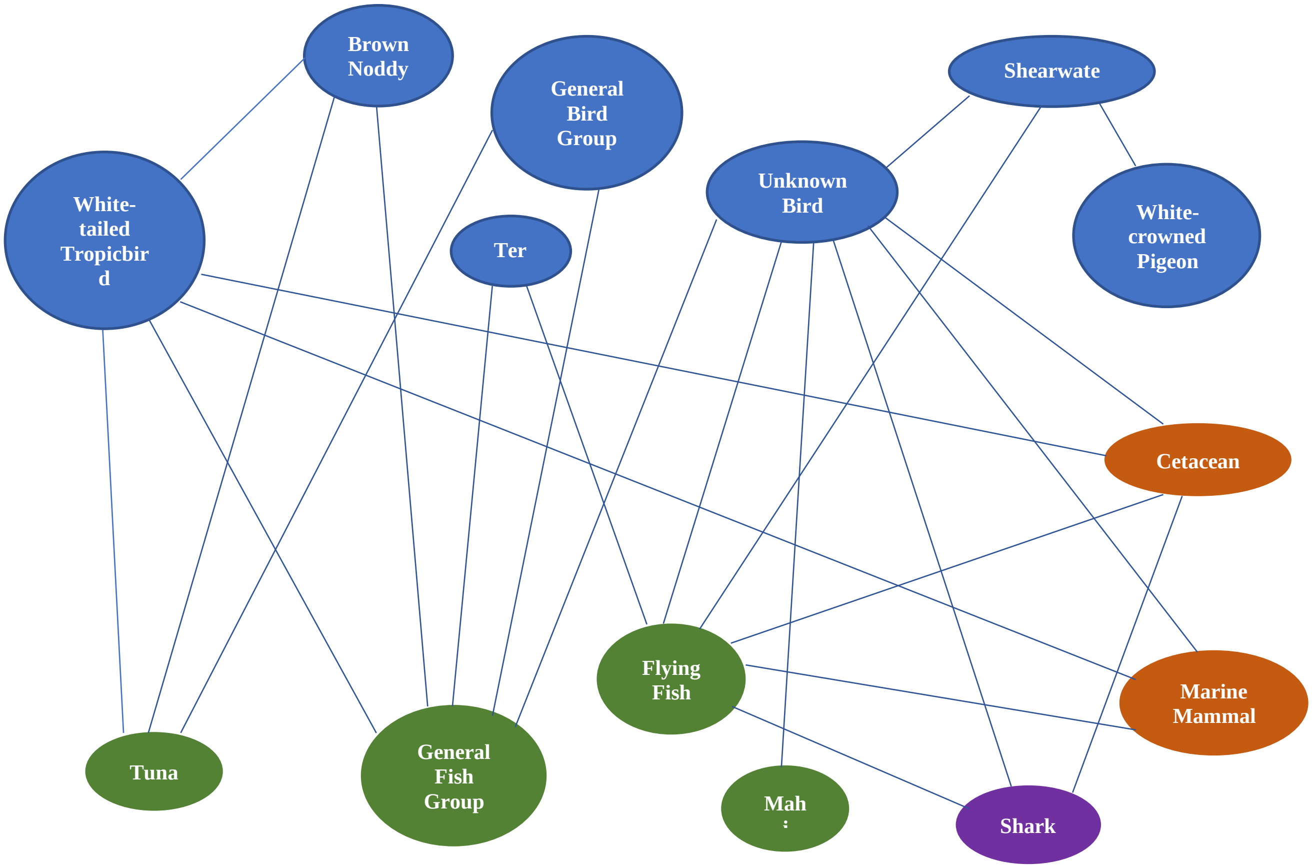

Figure 6. This is a diagram of the spatial correlations seen within this study. It maps out which species covary with each other in the same geographic location. All relationships seen are significant to p < 0.001, with Pearson correlation coefficients larger than 0.30.

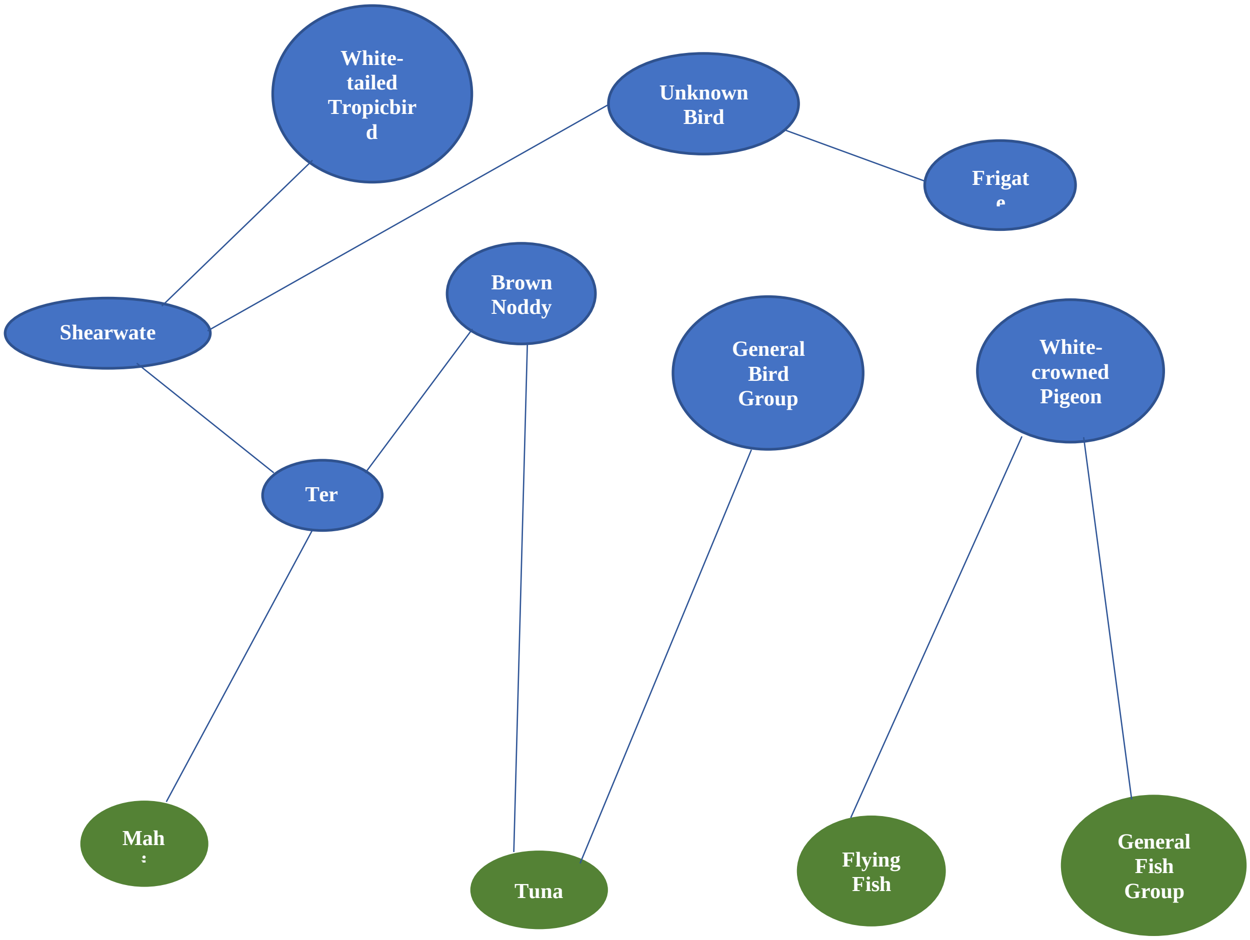

Figure 7. This is a diagram of the temporal correlations seen within this study. It maps out which species covary with each other within the same environmental conditions. All relationships seen are significant to $p < 0.001$, with Pearson correlation coefficients larger than 0.30.