Evaluating White Shark Presence in Oregon’s Coastal Waters

by
Kyra Kappos

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Fisheries, Wildlife, and Conservation Sciences
(Honors Scholar)

Presented August 30, 2024
Commencement June 2024

AN ABSTRACT OF THE THESIS OF

Kyra Kappos for the degree of Honors Baccalaureate of Science in Fisheries, Wildlife, and Conservation Sciences presented on August 30, 2024. Title: Evaluating White Shark Presence in Oregon's Coastal Waters.

Abstract approved:____

Taylor Chapple

Observations of white sharks (*Carcharodon carcharias*) are rare in Oregon waters, however, historical evidence indicates predictable seasonal presence. The time, location, and nature of white shark occurrences (where an occurrence is the spatial evidence of white shark presence from different data streams), especially when complemented by associated environmental characteristics, provide valuable information regarding species presence. By curating these available data and visualizing the relationships between occurrences and environmental variables, researchers can better interpret the limited observations to inform research efforts and gain insights into the roles this species plays in Oregon's marine ecosystems and economies. Here, I developed a comprehensive summary of the available evidence of species presence in Oregon from white shark-human interactions, white shark-related marine mammal strandings, and acoustic detections of white sharks, as well as associated factors of habitat suitability. With all the data combined, I found that white sharks are more prevalent off the Oregon coast in the fall, between September and December, with species relative occurrence highest in October and lowest in May. This study has advanced our understanding of the broader datasets of white shark presence in Oregon and can inform future directed studies.

Keywords: White shark, acoustic tagging, stranding, human-shark interactions, Geographic Information Systems (GIS)

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Honors Baccalaureate of Science in Fisheries, Wildlife, and Conservation Sciences project of Kyra Kappos presented on August 30, 2024.

APPROVED:

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Kyra Kappos, Author

Acknowledgements

Thank you to Jim Rice at the Oregon Marine Mammal Stranding Network for providing us with the strandings dataset; to Dr. Sarah Henkel of Oregon State’s Department of Integrative Biology for providing us with the acoustic data; to Dr. Alexandra McInturf in the Big Fish Lab for the sea surface temperature data; and to Josh Bowman for advising me during the beginning stages of this project. I am especially grateful to my committee members Dr. Taylor Chapple, Tom Robinson, and Dr. James Sulikowski for the time and mentorship they contributed to make this study possible. I greatly appreciate my friends and family, especially my parents, for their ongoing support.

Introduction

The white shark is the largest predatory fish, with global distributions including coastal and pelagic habitats in the northeastern Pacific (NEP) (Dewar et al., 2013). Individuals within the genetically distinct NEP population likely play an important top-down ecological role in structuring the California Current Large Marine Ecosystem and sustaining the health of the broader NEP ecosystem (Block et al., 2011). As apex predators, white sharks exert top-down controls and can have cascading effects on marine ecosystems (Kim et al., 2012). For example, at the Southeast Farallon Islands, white sharks control elephant seal (*Mirounga angirostris*) populations through direct predation (Brown et al., 2010; Jorgensen et al., 2019). Conversely, these same predators have stalled the recovery of the sea otter (*Enhydra lutris*) (Moxley et al., 2019). Apex predators have characteristically smaller abundances than their prey species, yet exert strong influences on their respective food web. Therefore, minor increases or decreases in the number of NEP white sharks can have a considerable effect on the numbers of their prey items, and in turn, on the broader NEP ecosystem (Jorgensen et al., 2019). The significance of the NEP population underscores the need to understand its distributions and ecological roles across its full range.

White sharks exhibit individual behaviors, inherently low abundances, and variation in migratory patterns, which, in conjunction with financial constraints to *in situ* research efforts, can make individuals of this species logistically difficult to locate (Huveneers et al., 2018). In addition to these factors which limit available data on their distributions, understanding white sharks at the edge of their range, where data are sparse by definition, is especially challenging. In the Pacific Northwest (PNW), which is the northernmost edge of the NEP population's range, very little is known about their spatiotemporal distribution. Therefore, curating and analyzing available data on historical observations of white sharks in this region is crucial to developing an understanding of species presence. This can optimize future efforts to discern their distributions and to determine how this population factors into the ecological and economic structures of Oregon's coastal waters.

Oregon hosts a large number of bountiful fisheries, including albacore tuna (*Thunnus alalunga*), salmon (*Oncorhynchus* spp.), and Pacific halibut (*Hippoglossus stenolepis*). Any potential cascading effects which may cause instability or increased variability in the system, or depleted fish stocks, will need to be understood and accounted for by marine resource management (Baum & Worm, 2009). Therefore, given the likely ecological role of white sharks in Oregon waters and their importance to maintaining marine ecosystems, we need to develop a more comprehensive understanding of white sharks in the region.

In this project, I collated the available spatial evidence from different data streams (occurrences) of white sharks in Oregon across space and time. I also identified a set of environmental variables that may be associated with white shark presence, so that I could explore any relationships between those variables and white shark occurrences in Oregon. To my knowledge, this has not been done before and represents a first step in identifying the extent and role of white sharks in Oregon.

Materials and Methods

As a first step, I conducted a literature review to gain a comprehensive understanding of the movement, behavior, and habitat preference of the NEP white shark. Such information offers valuable background context to the Oregon population, identifies which environmental characteristics should be evaluated, and provides insight for interpreting relationships between white shark occurrences and their habitat. The literature review also included past scientific uses of Geographic Information Systems (GIS) mapping technology to model species presence with the objective of predicting future occurrences.

The second step was to curate datasets, each representing a different element of coastal habitat suitability or evidence of white shark occurrences. These datasets included marine mammal strandings which likely involved white shark interactions, acoustic detections of white sharks, reported white shark-human interactions, pinniped haul-out sites, lithological habitats, temperature, and bathymetry. The purpose for each including each dataset and the way in which they were individually processed to extract the most meaningful information are described in the following sections.

Mapping

I used ArcGIS Pro, a GIS digital mapping program, to visualize the datasets. GIS has emerged as an important tool to describe habitat suitability and build the foundation for predicting when and where a population can be found. I made the informed decision to set up the map using the Projected Coordinate System *OCRS Oregon Coast NAD 1983 2011 OM (Feet Intl)*, the projection *Hotine Oblique Mercator Azimuth Natural Origin*, and the datum *D NAD 1983 2011*. These foundational elements determine how the GIS program measures and defines locations on my model of the Earth's surface.

After developing plots from the ArcGIS Pro map to visualize the relationships between the environmental variables and historical species presence (see below), I interpreted the results gathered from patterns in the attribute data by generating a wide variety of figures. To determine the relative frequency of interactions in more generalized regions, I divided the coast into longitudinal quadrants using the natural breaks method. To compare the absolute number of total white shark occurrences with the relative proportion of occurrences, I standardized the data by the number of occurrences.

White Shark-Human Interactions

Interactions that occur between white sharks and humans represent a concrete form of regional and temporal evidence of species presence. In October of 2023, I downloaded three datasets of reported white shark-human interactions in Oregon spanning 48 years from 1974 to 2022, nearly all of which involved surfers. The Global Shark Attack File provided 31 records from September of 1974 to December of 2020. The International Shark Attack File offered 15 reported interactions from September 2002 to March 2019. Finally, six reports of interactions were made to the Big Fish Lab, five of which occurred in 2022 and one of which took place in 2021. I derived unique interactions from these separate datasets by identifying identical reports between each, and then added the unique interactions to the ArcGIS Pro map as a new layer.

Temperature

Water temperature and white shark thermoregulatory capabilities (as regional endotherms) can help explain their movement and behavior. In California, NEP white sharks spend the majority of their time in ambient temperatures of 10-14°C (Weng et al., 2007). When individuals choose to move into water of a different temperature, it may indicate that there is something unique about that habitat which the individual finds suitable. To develop an understanding of the water temperature in which white sharks have been historically recorded spending time in Oregon, I identified the satellite-derived sea surface temperature (SST) value corresponding to the time and location of each white shark occurrence. These data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) ERDDAP in June of 2024. Hadley SST values scaled at 1 degree monthly were available for each occurrence from September of 1974 to present. For occurrences during and after the year 1981 (therefore excluding the four earliest available shark-human interactions), fine-scale AVHRR SST values were available, scaled at 0.25 degree daily. Then, I compared the average monthly nearshore temperature estimates off of Newport, Oregon (a proxy for average water temperature in Oregon) to the temperatures averaged between white shark-human interactions by month to explore if interactions tracked seasonal changes or occurred in unique temperature conditions.

Acoustic Detections

An acoustic tag is a small device that can be attached to an aquatic animal and emits sound waves which are detected by acoustic receivers. The tag can indicate an individual's presence at locations with receivers, thereby providing passive means to identify residency of an animal. I collected acoustic detections of animals tagged during ongoing tagging studies in Mexico and California from seven acoustic receiver arrays throughout Oregon. I sorted the individual detections by unique event identification (Event ID) codes (which account for unique individuals) and unique 24-hour days. Detections were grouped by Event ID and day, and each grouping was deemed to be an "acoustic detection occurrence," which were then linked to their associated metadata in a table. These metadata included the individual animal's acoustic tag Code, the date, the time of day (averaged between detections of the same individual in the same 24-hour day), the number of times the individual was detected in the given time range of that day, the length and sex of the individual, and the latitude and longitude of the receiver with the greatest number of detections for the given acoustic detection occurrence. I defined these occurrences as "detections days," where one detection day is equivalent to one unique individual being detected any number of times by any number of acoustic receivers in one unique 24-hour day. The detection days were uploaded as a layer into ArcGIS Pro.

Marine Mammal Strandings

A marine mammal stranding occurs when a marine mammal, such as a dolphin, pinniped, or whale, washes ashore alive, injured, or dead. In October of 2023, I downloaded the dataset containing reported strandings of marine mammals ranging from December of 2006 to January of 2020 provided by the Oregon Marine Mammal Stranding Network. I analyzed the descriptions and images of each stranding and then assigned each a confidence value (1-3) based on the likelihood of the stranding being caused by white shark predation. I used the provided observer notes to assess each stranding case, making my own notes of the stranded animal's species and its estimated size or maturity, the measurements of the bites (when reported), the extensiveness of the injuries, the season and location at which the stranding occurred, and whether the bites appeared to be pre- or post-mortem. For the cases which provided images of the stranding, I used the size and shape of the bite as indicators of a white shark predation event. Bite sizes that were either reported by the observer or that I visually estimated were compared to known NEP white shark bite width measurements from Long & Jones (1996). Bites which exhibited wide and thin, slit-like teeth markings (indicative of serrated teeth, as opposed to an orca's rounded teeth) and those which had relatively wide gaps between teeth were given a high confidence value (Long & Jones, 1996).

The strandings with the highest confidence value (3) were those I determined to indicate white shark presence and those I added to the map using each point's corresponding latitude and longitude values. Because the original coordinates were representative of the stranding site on the beach, I transposed the points about 500 meters west of the shoreline to appropriately represent the presence of a white shark. While admittedly animals can drift long distances, I made this simplified assumption to standardize analysis. Using the bathymetry, lithological habitat, pinniped haul-out site, and temperature datasets, I queried the associated attribute data for each high confidence stranding event and recorded those data in the summary table.

Pinniped Haul-out Sites

Pinniped haul-outs are an important element of habitat suitability because adult white sharks feed on marine mammals, and aggregations of NEP white sharks have been documented near pinniped rookeries in northern California (Brown et al., 2010; Compagno, 1984). In October of 2023, I accessed a recently-updated ArcGIS shapefile containing all of Oregon's known pinniped (seal and sea lion) haul-out and rookery sites from the Oregon Department of Fish and Wildlife Marine Mammal Program on the ArcGIS website (https://www.arcgis.com/home/item.html?id=1e11239eab9b4d30bc2c485c519a2efe). The points within the shapefile, which I added to my ArcGIS Pro map as a feature layer, indicate either a specific location of a haul-out or rookery, such as a single offshore rock, or a more general region in which animals are likely to be found (e.g., a large stretch of rocky intertidal habitat). The attribute data included species-specific site use and relative abundance values for Pacific harbor seals (*Phoca vitulina*), northern elephant seals (*Mirounga angustirostris*), Steller sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus californianus*), based primarily on summer breeding season surveys from May through July. To evaluate the relationship between the location of pinniped haul-out sites and historical white shark occurrences, I used the Near (*Analysis*) tool in ArcGIS Pro to calculate the distance from each white shark occurrence to the nearest pinniped haul-out site (by pinniped species) and added those measurements to the summary table.

Lithological Habitats

Lithological habitat is likely an important factor in white shark scavenging, as rocky habitat may provide obscurity for white sharks since they are ambush predators which exhibit countershading. Anderson et al. (2008) found that NEP white sharks in central California were more often observed scavenging over rocky substrate than sandy. Therefore, lithological habitat was a critical element of habitat suitability to visualize. I downloaded data on the Oregon coast's lithological habitats provided by the Oregon State University College of Earth, Ocean, and Atmospheric Sciences Active Tectonics and Seafloor Mapping Lab from the Data Basin website (https://databasin.org/datasets/029a66c38d8847ecbb47ce7612aadf6c/). Then, I manually re-classified the original 20 classes, which were as follows: Boulder, Cobble, Cobble Mix, Gravel, Gravel Mix, Gravelly Mud, Gravelly Sand, Hard, Mixed, Mud, Muddy Gravel, Muddy Sand, Rock, Rock Mix, Sand, Sand Mud, Sandy Gravel, Sandy Mud, Shell, and Soft into four lithological classes relevant to white shark habitat suitability based on what may provide different levels of obscurity for scavenging: Boulder, Gravelly Mud, Rock, and Sand.

Bathymetry

Bathymetry plays an important role in the predation strategy of white sharks; for example, a study of NEP white sharks revealed that they employed a silhouette-based hunting strategy while near pinniped rookeries in autumn and winter, avoiding the surface and using water to 50 meters depth (Weng et al., 2007). It was therefore important to evaluate the steepness of the underwater terrain along the Oregon coast by visualizing the bathymetric slope. I acquired a bathymetry layer from the General Bathymetric Chart of the Oceans. I projected this raster by inputting the coordinate system with the geometric transformation *WGS_1984_(ITRF08)_To_NAD_1983_2011*. I also added a local illumination angle to accentuate bathymetric detail using a Hillshade (*Esri Spatial Analyst*). Then I generated a 20-kilometer buffer along the shoreline layer, converted that buffer to a raster, and extracted that from the bathymetry layer to obtain especially meaningful bathymetric data. I then used the Slope *(Esri 3D Analyst)* tool to take the slope from the buffered region and accentuate the small changes in depth.

Summary Table

Finally, I defined the characteristics of the occurrences by generating a summary table. The summary table is a matrix of events and environmental characteristics in which each occurrence data point is specified with attribute data from the other layers based upon its geographic location.

Results

With my curated datasets, I generated a map in ArcGIS Pro with seven feature layers; layer 1 (Figure 1), layer 2 (Figure 2)…layer 7 (Figure 7). White shark-human interactions identify where white sharks have occurred historically. I identified 36 unique white shark-human interactions from 52 total available reports (Figure 1). The coastline was broken into four quadrants with 22 unique interaction sites (Figure 8). The highest number of white shark-human interactions (Figure 9) occurred at the end of the calendar year, with the October value being highest (8 interactions). In contrast, the lowest number of interactions occurred at the beginning of the calendar year, with the fewest number observed in February and April (one interaction each). No interactions occurred in May. Each interaction that took place in Quadrant 1 (the northernmost quadrant of the Oregon coast) occurred in the latter half of the calendar year. Three of the four (75%) Quadrant 4 (the southernmost quadrant of the Oregon coast) interactions took place in September, and one (25%) occurred in June. Quadrants 2 and 3 were the locations of white shark-human interactions at the beginning and end of the calendar year, with a higher number having taken place in the latter months than in the former. Based on our data, across all four seasons (fall, winter, spring, and summer), the highest proportion of historical interactions occurred in the fall, and the lowest proportion occurred in the spring; the only season in which interactions occurred in all four quadrants was the summer (Figure 10). On an hourly scale, 30% and 43% of the human interactions (6 records did not have specified times) occurred within 3.5 hours of sunrise or sunset, respectively (Figure 11).

I found that when the average water temperature of Newport (our proxy for seasonal trends in Oregon) was 10°C, interactions occurred at an average of 10°C. However, when the average water temperature off Newport was 15°C, interactions took place in water that was cooler than 15°C (Figure 12). This suggests that white shark-human interactions took place in slightly cooler water temperatures than the average temperature as the water warmed.

I consolidated over 2,100 historical acoustic detections of white sharks from seven acoustic receiver arrays into 103 detections days (Figure 3). Acoustic detections occurred in all months of the year except for April, May, and June, with the lowest number of detection days observed in August (Figure 13). The month with the greatest number of detection days (25), as well as the highest degree of diversity in detection locations (6 different sites), was February; January experienced the second-largest number of detection days (23), with detections occurring at four different sites (Figure 13). Newport was the site of 21 detection days total, which occurred in the greatest number of different months (five), as opposed to Salmon River, which only had four detection days that all took place in September. Astoria had the greatest number of detection days total (30), the majority of which took place between September and November (Figure 13). Oswald State Park was also the site of a large number of detection days (23), all of which took place in the first two and last two months of the calendar year. Across all months, the two northernmost arrays of receivers (Astoria and Oswald State Park) have the two highest relative proportion values for detection days.

I determined that 13 of 253 total recorded stranded animals likely had a white shark interaction (Figure 2), and therefore provide regional and temporal evidence of white shark presence. When all the data sources were combined, the highest number of white shark occurrences took place in February with 28 total occurrences (25 of which were detection days), followed by January with 26 total occurrences, from which all but three were detection days (Figure 14). A high range of values was recorded at an average of 19.75 occurrences between September and December. In contrast to the total occurrences in January and February (i.e., at the beginning of the year), of which the majority were from detection days, a higher proportion of the total occurrences in September and December (i.e., at the end of the year) came from white shark-human interactions, as well as some strandings that were likely caused by white sharks (Figure 14). Across all three datasets of occurrences, none occurred in May (Figure 14). April and June only observed one occurrence each, both being white shark-human interactions (Figure 14). Given the effect of different datasets on the absolute number of total white shark occurrences (Figure 14) and that the probability of detection was different across the different data streams (i.e., acoustic data are not influenced by the number of people in the water), I normalized each data stream by the number of occurrences. The normalized data reflect that the highest relative proportion of white shark occurrences has historically been at the end of the calendar year, between September and December, with the highest value in October (~0.65; Figure 15). The lowest relative proportions were in April and June, similarly to Figure 14. The average temperature recorded from the occurrences each month is lowest at the beginning of the calendar year (9.62°C), between January and February, and highest near the middle, namely in July and September (Figure 14).

Figures 4-7 depict the three elements of habitat suitability for white sharks on which I focused for the purposes of this project. Preliminary analysis on the distances from each recorded white shark occurrence to the nearest pinniped haul-out site by pinniped species did not reveal a significant relationship between historical white shark occurrences and pinniped haul-out sites as an element of habitat suitability. I have not done rigorous analysis on the environmental characteristics data yet, but they were recorded in the Summary Table along with all of the other attribute data used to generate these results in order to complement our understanding of the conditions in which each occurrence took place. Comprehensively, the Summary Table listed the type of occurrence, the time of year and day, the site and its coordinates, the sea surface temperature, the depth, the lithological habitat, and the distance to the nearest pinniped haul-out site by species.

Discussion

This work represents the first efforts to determine the historical presence of white sharks in Oregon. My results suggest that white sharks are more prevalent off the Oregon coast at the end of the calendar year, between September and December. This timing of seasonal presence in Oregon coincides with data from California (Jorgensen et al., 2009).

White shark-human interactions are more likely to take place at the end of the calendar year, particularly in the fall in September and October within three-and-a-half hours of sunrise or sunset, which is similar to the trends observed in California (Jorgensen et al., 2009). Interestingly, our acoustic data showed that white sharks are more prevalent off the Oregon coast at the beginning of the calendar year, with detection days between acoustic receiver sites being highest at Astoria, Oswald State Park, and Newport. There are a few reasons that might be driving the difference between these datasets. First, white shark-human interactions coincide with popular surf times of the day and of the year. Fall is usually the most popular time of the year to surf in Oregon, especially in September and October, because conditions are ideal; the waves are more consistent, there is less wind, and the average temperature of the water is warmer (Kuprianowicz, 2024). Additionally, the early morning (around sunrise) and the late evening (around sunset) are generally the best times of the day to surf because there is swell in the water (Robichaud, 2019). Therefore, the probability of an interaction occurring may be higher in the fall because beach use may be higher at those times, not because of an increase in shark numbers. White sharks can only be interacted with when there are people in the water to interact with and observe them.

Second, acoustic tags do not require an observer so they may be more representative of true presence. Third, it may be that white sharks are present further offshore (where receivers are located) in the winter, as opposed to hunting along the shoreline in the early fall. Lastly, while these acoustic data are useful in the context of understanding historical white shark presence, the deployment period of the acoustic receivers was variable, and therefore the sampling time may differ at each location (which is why we can generalize the data by time, but not by location). Many of these receivers were deployed for other projects, so they were in the water for short periods of time or at non-ideal sites for white sharks. Therefore, the receiver data have some potential bias.

The utility of these data is subject to the purpose of use. For example, for the purpose of evaluating the probability of a human interacting with a white shark off the Oregon coast, it would be beneficial to use our white shark-human interaction data and for future work to incorporate a beach use scale similar to Ferretti et al. (2015). Alternatively, for researchers aiming to locate white sharks in Oregon, it would be useful to employ our acoustic data in conjunction with a longer timeseries that has consistent, year-round deployments of acoustic data.

Standardizing across different data sources by the number of occurrences of each indicates that white shark presence historically peaked in October. Within the sampling period of one month, the relative occurrence of white sharks in Oregon is highest in October and lowest in May with all the data aggregated. These findings coincide with data from California, which indicate that the peak onshore period for white sharks is between September and November, and the peak offshore period between April and July (Jorgensen et al., 2009).

White shark-human interactions took place in slightly cooler water temperatures than the average temperature as the water warmed. This suggests that Oregon white sharks may be selecting cooler waters when average sea surface temperatures increase. Therefore, the water in which they are found may not solely be associated with seasonal trends; based on the available data on shark-human interactions, the habitat selection of NEP white sharks in Oregon may be influenced by water temperature anomalies. More data on white shark movements in this region are needed to substantiate this possibility.

I was not able to draw definitive conclusions on the relationships between the elements of Oregon’s habitat suitability and historical white shark occurrences. Future work should examine the relative importance between the elements of habitat suitability including bathymetry, lithological habitat, and pinniped haul-out sites. While we cannot use these datasets individually to make conclusions, collectively they offer valuable insights regarding species presence in Oregon to inform and guide future research efforts.

Despite these caveats, this study has contributed to the greater understanding of the broader datasets of white shark presence in Oregon. As a result of this work, we can describe at what times of the year the highest and lowest relative occurrences of white sharks historically took place in Oregon. I have taken this first step for generating a predictive model by curating data on the historical occurrences of white sharks in the region and assessing environmental elements of coastal habitat suitability. These data can be used by researchers to develop more concrete predictions regarding when and where NEP white sharks can be found at the Oregon edge of their range. The predictive model can be used to facilitate more targeted research efforts so that researchers can build a more robust dataset of white shark presence and impact in Oregon. This methodology can be applied to similar datasets from other elusive species to further understand their presence and the relationship between species occurrences and seasonality. This is a new frontier of shark science in the Pacific Northwest, the results of which will provide important insight into the roles NEP white sharks play in the marine ecosystems and economies of the region, and will increase our understanding of the coastal ecosystem's trophic structure.

Figures

Figure 1. The 36 locations of historical white shark-human interactions, curated from the Global Shark Attack File (GSAF), International Shark Attack File (ISAF), and direct reports to the Big Fish Lab.

Figure 2. The 13 historical marine mammal strandings indicative of white shark predation along the Oregon coast. This dataset is courtesy of Jim Rice, the Stranding Program Manager at the Oregon Marine Mammal Stranding Network.

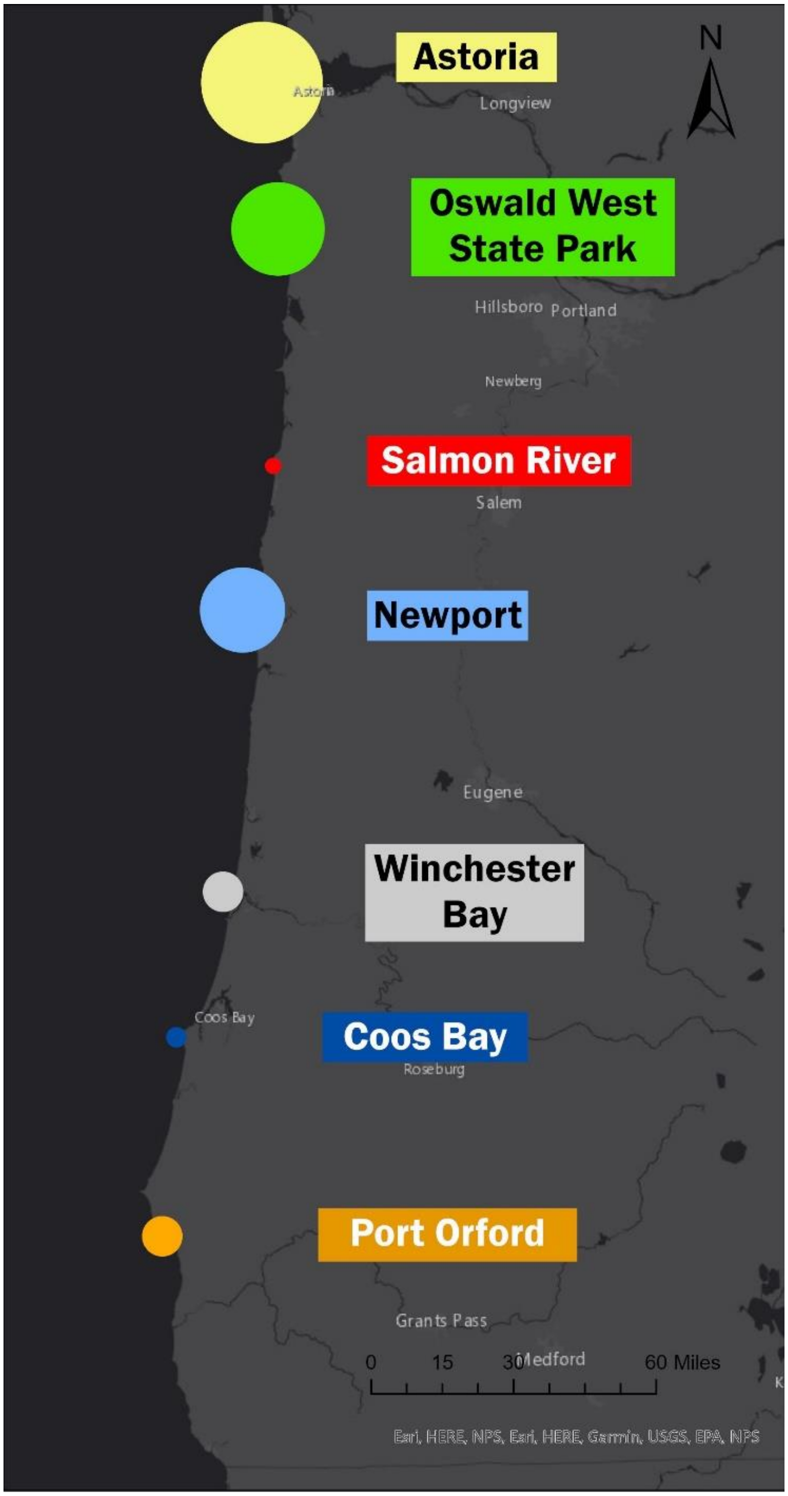

Figure 3. The relative proportions of detection days between seven acoustic receiver sites where white sharks have been uniquely detected historically. One detection day is equal to a unique individual being detected any number of times on one unique day. There are 103 detection days total in this dataset.

Figure 4. Bathymetry of the Oregon coast, sourced from General Bathymetric Chart of the Oceans (GEBCO).

Figure 5. Bathymetric slope.

Figure 6. All known pinniped haul-out sites along the Oregon coast, updated by Marine Mammal Program staff from the Oregon Department of Fish and Wildlife (ODFW) on October 3, 2023. The species at these haul-out sites are Pacific harbor seals (*Phoca vitulina*), northern elephant seals (*Mirounga angustirostris*), Steller sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus californianus*). According to ODFW, site use and count data attributed to this layer are based primarily on summer breeding season surveys, which take place May through July, and do not necessarily apply to other times of the year.

Figure 7. Lithological Habitat GIS layer. Data provided by Active Tectonics and Seafloor Mapping Lab, College of Earth, Ocean, and Atmospheric Sciences (CEOAS), Oregon State University (OSU). Accessed from Data Basin.

Figure 8. The longitudinal quadrants of the coast (distinguished using natural breaks/Jenks method) in the 22 unique interaction sites. Quadrant 1, the northernmost sector, is composed of Tillamook Head, Indian Beach, Oswald West State Park, Seaside, Short Sand Beach, and Haystack Rock at Cannon Beach. Quadrant 2 encompasses Cape Kiwanda, Siletz River mouth, Gleneden Beach, Agate Beach, Neskowin, South Beach in Newport, and Nelscott Reef in Lincoln City. Quadrant 3 includes Florence, Winchester Bay, Bandon, Florence, Bastendorf Beach, and the Umpqua River mouth. Quadrant 4 is the southernmost sector and features interaction sites at Gold Beach, Sporthaven Beach, and Myers Creek.

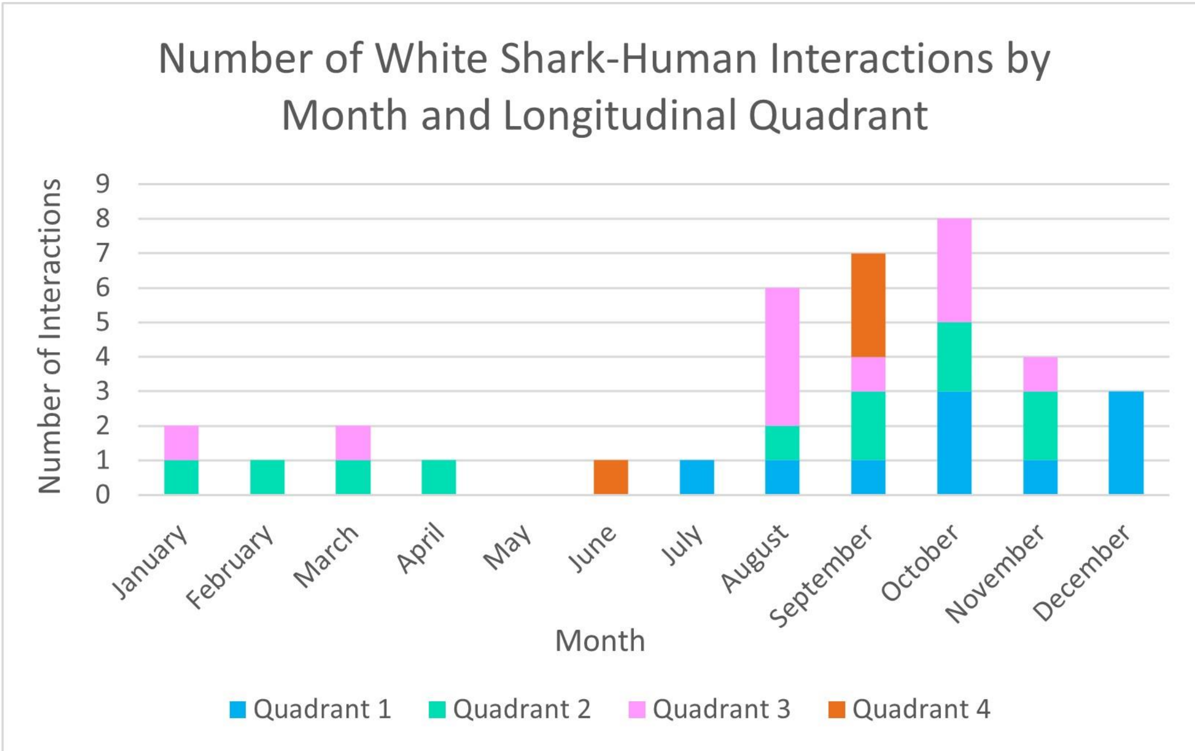

Figure 9. The number of white shark-human interactions between months by longitudinal quadrants of the Oregon coast.

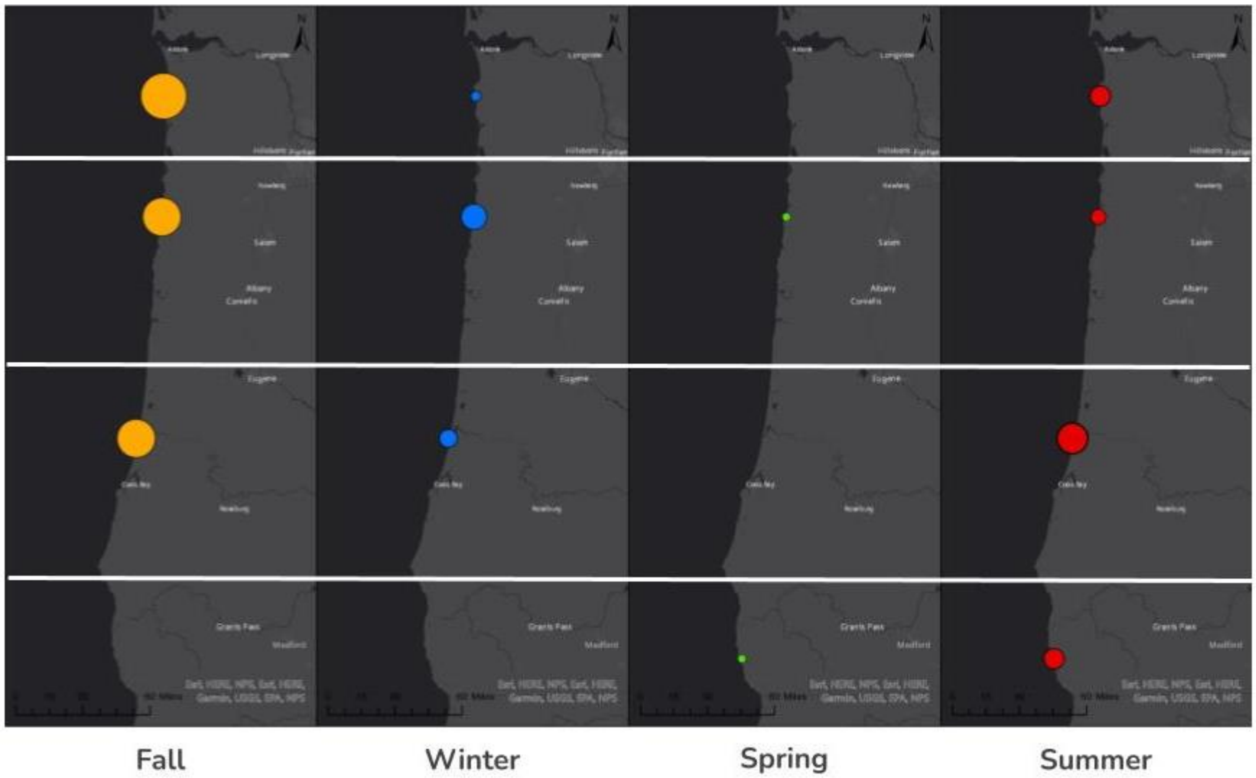

Figure 10. Proportional symbol layers in a facet plot format showing the relative proportions of white-shark human interactions between the coast's longitudinal quadrants (divided by natural breaks/Jenks method) and seasons of the year. Seasons were distinguished by NOAA's meteorological and astronomical seasons in the Northern Hemisphere, where fall is September 22 to December 20, winter is December 21 to March 19, spring is March 20 to June 20, and summer is June 21 to September 21.

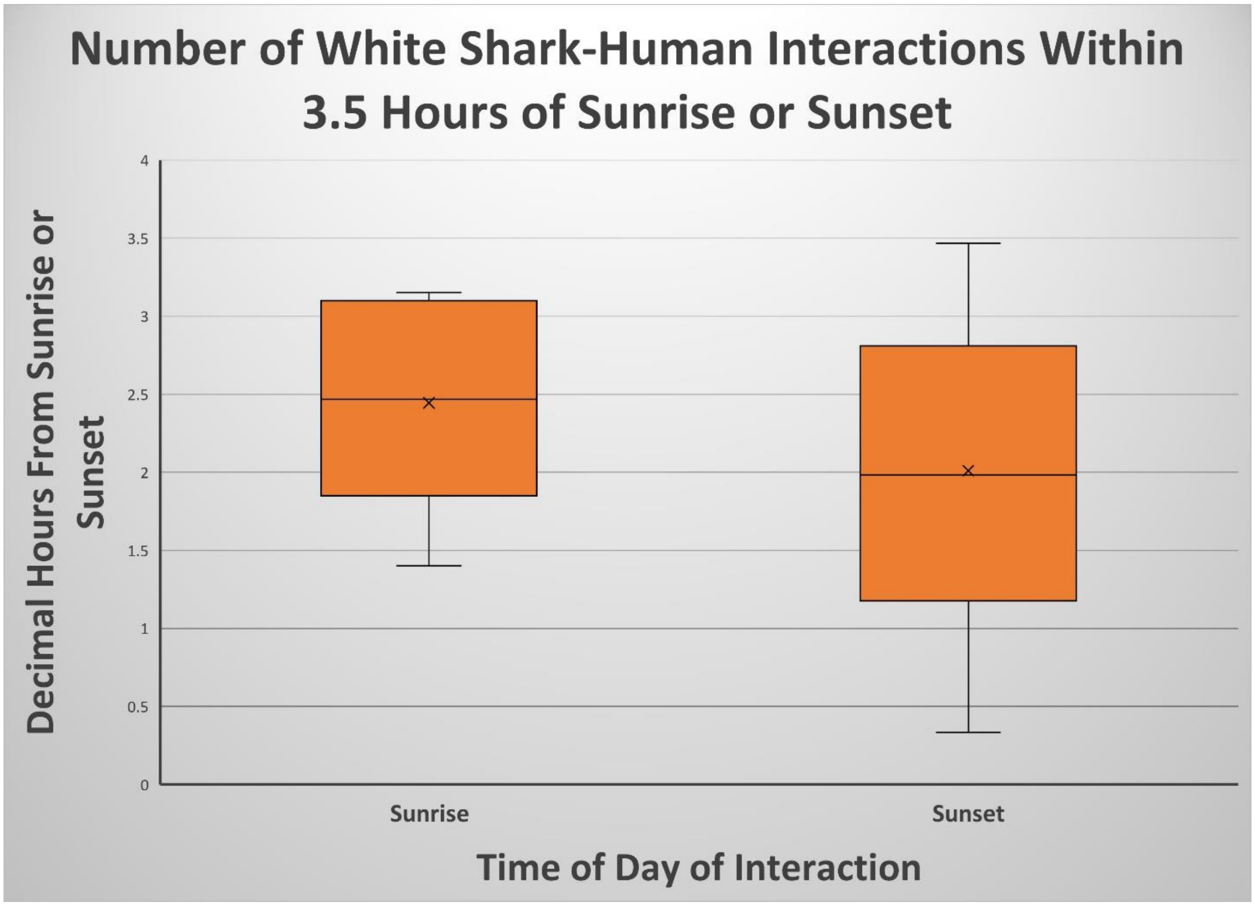

Figure 11. The distribution of interactions within 3.5 hours of sunrise (n=9) or sunset (n=13).

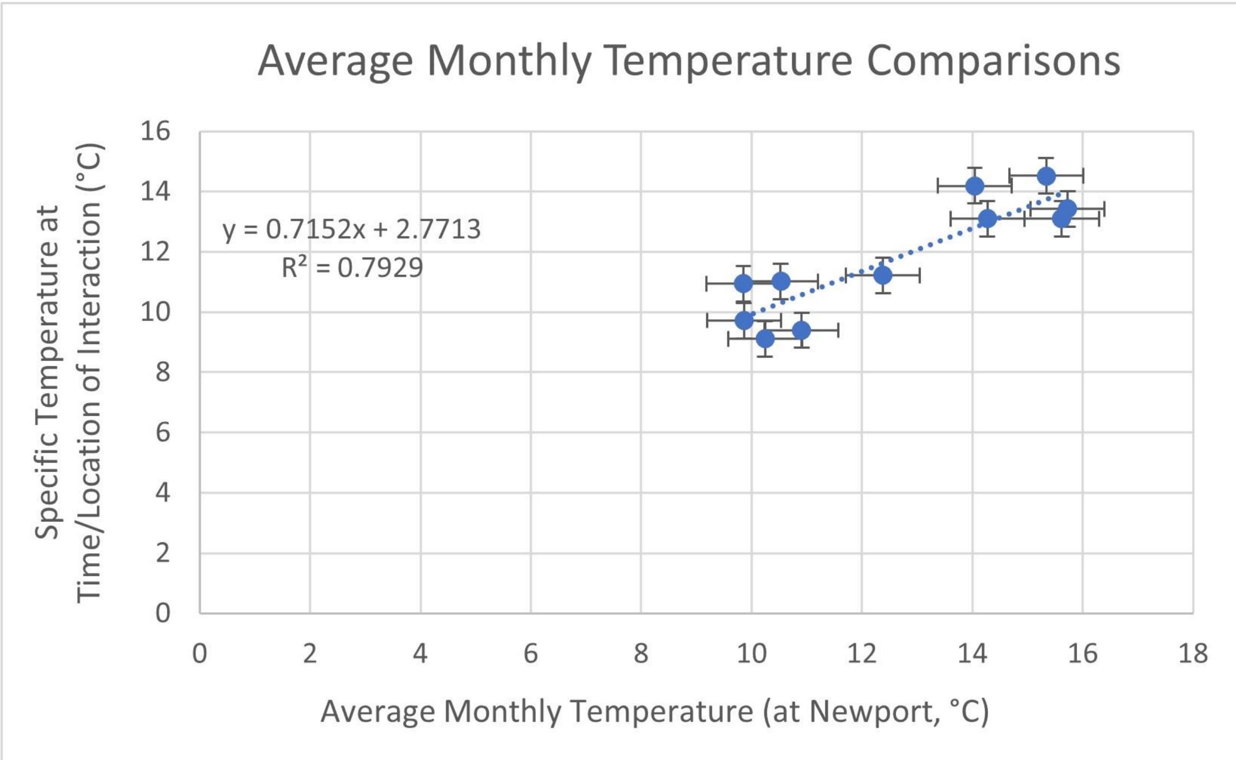

Figure 12. Comparison of the average monthly nearshore temperature estimates off of Newport (x-axis), which are representative of the general trend off the Oregon coast, with the average temperature data for interaction sites and times (y-axis).

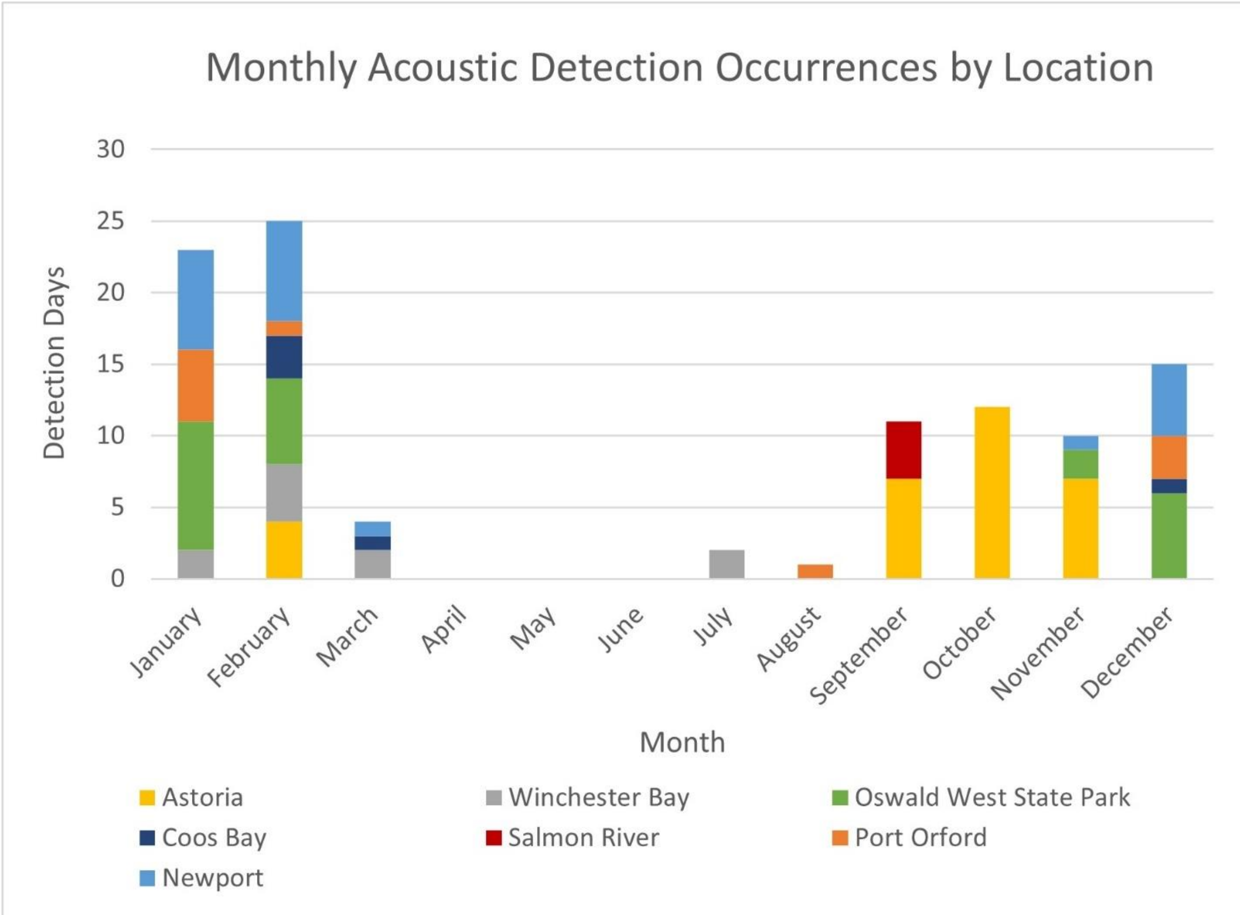

Figure 13. The number of detection days between months by each individual location of acoustic receivers that have historically detected white sharks. Here, detection days are the measure for occurrences. One detection day is equal to one unique individual being detected any number of times by any number of acoustic receivers in one unique 24-hour day.

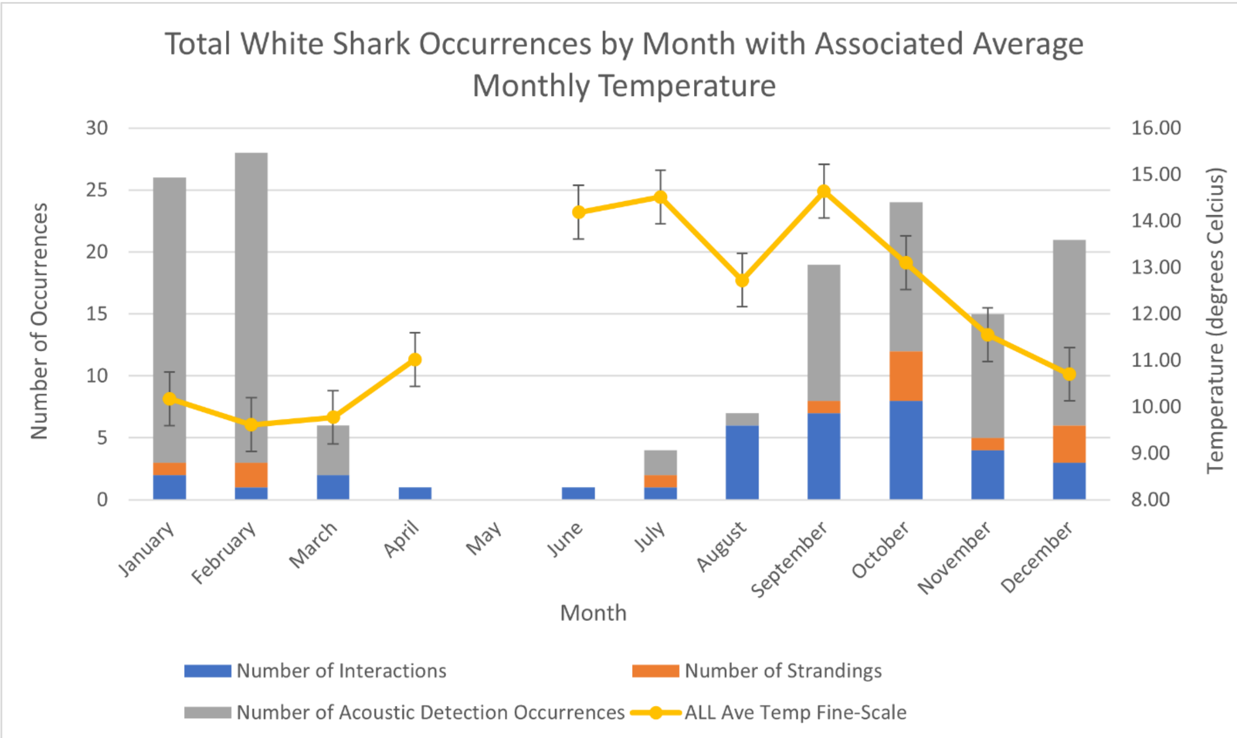

Figure 14. The number of historical white shark occurrences by month with each data point's associated average monthly temperature, represented by the yellow line. The occurrences were categorized by type: white shark-human interaction, marine mammal stranding that likely had a white shark interaction, and detection day. The temperature data is fine-scale, available for all data points except for four interactions, which occurred in years preceding the availability of fine-scale temperature data. Temperature values corresponding to all but those four occurrences were averaged within each month and plotted here.

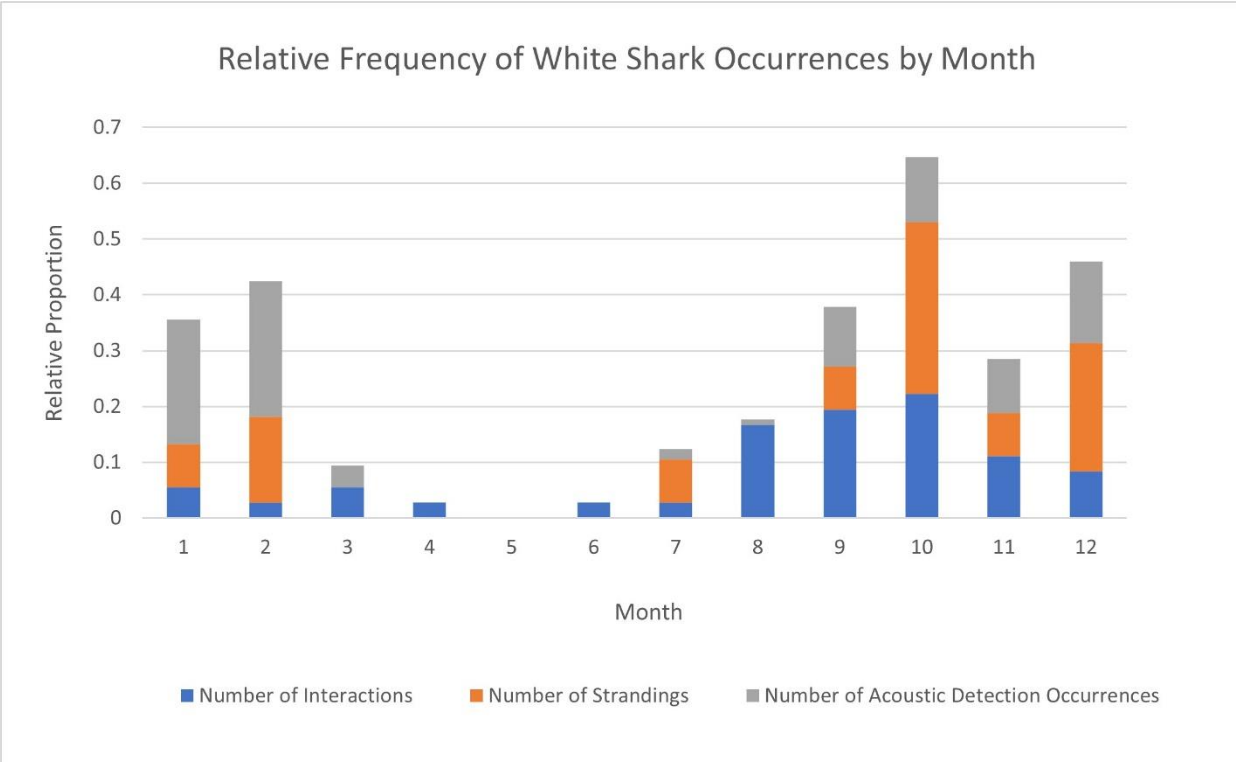

Figure 15. The relative frequency of white shark occurrences between months by the type of occurrence: detection day, stranding likely caused by a white shark, and white shark-human interaction.

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