Habitat Preference of Leopard Sharks (*Triakis semifasciata)* at Chicago Zoological Society Based on Bottom Substrate

Amanda (Williams) Flannery
Miami University, Oxford, OH
2016 Chicago Zoological Society Cohort

Abstract

Much like several other species of near shore elasmobranchs, the leopard shark (*Triakis semifasciata*), relies on estuaries in the wild throughout their life histories to hide from predators, reproduce, and to use as pupping grounds and nurseries. However due to anthropogenic forces, these habitats have been subjected to development, pollution and agriculture which have led to destruction or alteration of nearly 90% of these environments along the Californian coastline. The objective of this study was to observe the *Triakis semifasciata* at Chicago Zoological Society in Brookfield, Illinois to determine how this social group of females use their habitat space based on bottom substrate. The sharks were observed for 6 days for 2 ½ hour periods in the morning (10:00am - 12:30pm) and early afternoon (12:30pm - 2:00pm) with a timer set to five minute intervals, at which point the position of each shark within the habitat was recorded. A behavioral ethogram was developed to capture behaviors relevant to habitat use. An ANOVA indicated there was statistical significance of habitat preference of sharks based on bottom substrate (F= 5.00, p= 0.049, F crit= 4.96), while a two-way ANOVA indicated there was no statistical significance between the time of observation and habitat bottom substrate preference by *T.semifasciata* females (F= 0.03, p= 0.84, F crit= 5.31). There was no statistical significance between the two observation periods and behaviors, as the standard errors overlapped significantly, indicating a great deal of variance in behaviors. This study was limited to only two time periods and 6 total observations occurring in the same season from June to July of 2016. It has been found in studies with wild populations of *T.semifasciata* that these sharks perform seasonal migrations often corresponding with the females' annual reproductive cycle; thus in a long term study of this shark population at the Chicago Zoological Society that includes data of lunar cycles, it may be possible to observe a pattern in habitat preference associated with seasonal or lunar changes, which is not possible to perceive in this short term study.

Introduction

One of the most charismatic shark species is the leopard shark, *Triakis semifasciata*, with its elongated body, flattened head, dual dorsal fins of nearly equal size, striking dark saddle-like spots against a sandy or silver background, and a stark white belly (Figure 1) (Farrrer, 2009; Nosal et al., 2013; Tricas, et al., 1997). These stunning features are why *T.semifasciata* are one of the most commonly featured sharks in zoos and aquariums (Delius, 2015). For their commonality, these predators are found in a surprisingly small region just off the Pacific Coast of the United States, reaching from Oregon to Northern Mexico (Figure 2) (Farrrer, 2009; Hopkins & Jr, 2003; Lewallen, et al., 2007; Nosal et al., 2013; Smith, 2001, 2007), staying close to shore in the shallow bays and estuaries along the intertidal regions (Smith, 2001, 2007). While their habitat range extends all the way to Oregon, they often migrate south towards Southern California and Northern Mexico when the waters begin to cool, reaching between 10 to 12 °C (Ackerman, et al., 2000; Carlisle & Starr, 2009; Carlisle & Starr, 2010; Farrrer, 2009; Hopkins & Jr, 2003).

Within the estuaries, *T.semifasciata* actively use the rise and fall of the tides to navigate through their habitats, finding food, shelter, pupping grounds, and even each other when it is time to aggregate for reproduction (Ackerman et al., 2000; Carlisle & Starr, 2009; Carlisle & Starr, 2010; Farrrer, 2009; Hopkins & Jr, 2003; Nosal et al., 2013). *T.semifasciata* tend to aggregate together in social groups with individuals of similar size, age, and gender (Hight & Lowe, 2007; Hopkins & Jr, 2003). These social groups usually consist of juveniles, mature females of similar size, and mature males of similar size; however, *T.semifasciata* have been known to travel among other species of elasmobranchs such as smoothhound sharks (*Mustelus* spp.) and bat rays (*Myliobatis californica*) (Hight & Lowe, 2007; Hopkins & Jr, 2003). Each year between March and July in the warmer waters of Southern California and Northern Mexico, females aggregate in the shallows to pup (Farrrer, 2009; Hight & Lowe, 2007; Hopkins & Jr, 2003; Jacoby, et al., 2011; Smith, 2001, 2007). Shallow embankments such as estuaries have been documented to serve as nurseries for several species of elasmobranchs (Carlisle & Starr, 2009) possibly because they provide abundant prey resources, nutrient rich waters, and low predation risks to the pups (Duncan & Holland, 2006; Knip, et al., 2010). This makes estuaries incredibly important for a pregnant female because she is ovoviviparous (Solomon, et al., 2004), meaning her young are incubated inside her for 10 to 12 months, with the pups depending on her body for nutrition because they are aplacental (Delius, 2015). When the mother gives birth, she can have up to thirty-seven pups ranging from 20.3 to 24.4 cm in total length (Farrrer, 2009; Hopkins & Jr, 2003). Her pups will only grow at a rate of 2 cm per year, with males taking 7 to 13 years to reach sexual maturity and females taking 10 to 15 years (Farrrer, 2009; Hopkins & Jr, 2003; Smith, 2001, 2007). With such a long gestation period and a slow growth rate, pupping in a safe place, with high food availability and low predation, is the only maternal instinct this mother will ever show for her young. And although predators themselves, these sharks are often prey for larger shark species such as the seven gill shark (*Notorynchus cepedianus*) and the great white shark (*Carcharodon carcharias*). Thus their preference for shallow, turbid waters and their cryptic bodies may give them an advantage when avoiding predation even into adulthood (Smith, 2001, 2007).

Like other near shore elasmobranch species, *T.semifasciata* are threatened by anthropogenic activity (Knip et al., 2010). In a California study of wetland destruction over the past century, it has been estimated that nearly 91% of all estuarine habitat in California has been altered or all together destroyed by anthropogenic forces (Larson, 2001). With their limited habitat range and dependence on these estuary environments throughout their life history,

T.semifasciata are particularly vulnerable to the loss of these critical environments (Carlisle & Starr, 2009). Some studies suggest that the habitat erosion of the California coast line continues to be high due to agriculture, development, and pollution (Smith, 2001, 2007; Tacutu et al., 2013), and have a potentially damning effect on the populations of *T.semifasciata* off the coast of California (Carlisle & Starr, 2009). DNA sampling of *T.semifasciata* in California waters determined that genetic diversity was lower than anticipated because there appeared to be seven distinct populations that were not interbreeding with the other populations (Lewallen et al., 2007). At present the IUCN has *T.semifasciata* listed as "Least Concern" on the Red List of Threatened Species (Carlisle, et al., 2015), though, it has been suggested that due to their long gestation period, slow growth rates, limited genetic diversity, and delayed sexual maturity they should be declared "Vulnerable" (Smith, 2001, 2007; Tacutu et al., 2013).

Sharks are often a difficult research subject in the wild. Observations can be hindered for many species due to wide home ranges, sometimes stretching for thousands of miles (Carlisle & Starr, 2009; Duncan & Holland, 2006; Farrrer, 2009; Wetherbee, et al., 2001), some inhabit concealing environments that make finding them nearly impossible by design (Delius, 2015; Knip et al., 2010; Nosal et al., 2013; Silliman, & Gruber, 1999), and other species may be simply too dangerous to make regular observation practical (Editors of Reader's Digest, 1998; Tricas, et al., 1997). When this is the case, turning to sharks under human care to observe for extended periods of time in order to better understand their behavior, their movements, and their biology to assist in conservation efforts in their natural environments is a practical option (Editors of Reader's Digest, 1998). A vast array of knowledge of elasmobranchs has come from studies done in research labs, zoos, and aquariums (Editors of Reader's Digest, 1998). While studies have been done in the wild with *T.semifasciata*, they are cryptic animals that live in turbid waters and often observations are done by tracking telemetry alone (Ackerman et al., 2000; Carlisle & Starr, 2010). The objective of this study was to observe the sharks at Chicago Zoological Society in Brookfield, Illinois from underwater viewing to determine how this social group of females use their habitat space based on bottom substrate. I hypothesized that with no males in the social group, no natural predators in their environment, and with the observations being done during the summer months of June and July, the *T.semifasciata* females would use their habitat space with preference for the open substrate. I also hypothesized that the females would be more active in their environment in the morning hours, as previous studies have shown that leopard sharks tend to be more active at night and rest during day hours (Ackerman et al., 2000).

Methods and Materials

Study Site

Triakis semifasciata were studied at the Chicago Zoological Society at Brookfield Zoo's Living Coast habitat. The habitat consisted of a social group of four female *T.semifasciata* along with Half Moon fish (*Medialuna californiensis*), Kelp Bass (*Paralabrax clathratus*), Garibaldi Fish (*Hypsypops rubicundus*), Striped Surfperch (*Embiotoca lateralis*), California Sheephead (*Semicossyphus pulcher*), Damselfish (*Chromis* spp.) Pacific Moray Eels (*Gymnothorax mordax*), and Humboldt Penguins (*Spheniscus humboldti*). All of these species were meant to simulate their natural environment along the coastal regions of the Pacific Northwest (Figure 2) (Delius, 2015), with the exception of the *Spheniscus humboldti*, which are found along Chilean and Peruvian coastlines between 42°S and 5°S (Culik & Luna-Jorquera, 1997). In the wild these two species would not be found crossing paths with one another.

The habitat is held at a constant 17.16 °C, which is slightly above their preferred temperature range in the wild between 13-16 °C (Ackerman et al., 2000; Hopkins & Jr, 2003; Lewallen et al., 2007; Smith, 2001, 2007). In the wild *T.semifasciata* prefer temperate, shallow bays and estuaries but have been known to venture into open-ocean. They have often been found in areas with sandy, muddy bottom substrates because it is hypothesized these areas offer abundant food supplies and areas to reproduce. It is in these substrates, that they have been found closest to the bottom in 4 to 20 meters of turbid waters (Ackerman et al., 2000; Farrrer, 2009; Smith, 2001, 2007).

In the habitat at Brookfield Zoo, the waters are clear with very low turbidity to allow for guest viewing of the animals. The habitat is divided among two different bottom substrates, an open region, void of any coral, rocks, or kelp beds and a region of high rocky kelp beds. These two substrates are in stark contrast of each other as the rocky region suddenly drops off to a flat bottom. The tank has a relatively small round window for viewing the open region only. The majority of the observations were taken from the large window (Figure 3) that allows for viewing of both the open water and kelp bed regions of the habitat.

Behaviors Captured During Observation

During my initial observation period prior to taking any recordings, I made note of each female's dorsal fin markings and body patterns. The four females were identifiable from each other by their dorsal fin markings (Figure 4), which are as distinct from each other as human fingerprints and are used in the field to identify individuals in long term studies (Casagrande, 2016)**.** An ethogram of behaviors which the sharks expressed while interacting with their habitat as also developed. Bumping was defined as bumping the nose or snout into any region of the habitat. While rubbing was defined as any part of the body, excluding the pectoral fins, rubbing or touching the habitat surfaces. The reason for the exclusion of the pectoral fins from the rubbing behavior was that the pectoral fins touching the bottom of the open water habitat often indicated a female was about to come to rest at the bottom for a period of time; while the rubbing of the body on the habitat was often done in the rocky kelp bed region. Because of the relative closeness in the behaviors, bumping and rubbing on the habitat were combined into one category of behavior while pectoral fins touching the bottom remained its own category. Another behavior observed often was slow, leisurely swimming in the jet stream on the habitat. Interaction with other animals throughout the habitat could include nipping, gaping, chasing, bumping into or being bumped into, being pecked at while at rest, or any other interaction. If the interaction was between a shark and another fish species, the interaction was recorded as 1 interaction. If the interaction occurred between two sharks, the interaction was recorded as 2 interactions.

Data Collection

The sharks were observed on six days which were selected at random. On each day the sharks were observed for 2 ½ hour periods from either 10:00am to 12:30pm or 12:30pm to 3:00pm. During these observation periods a timer was set to five minute intervals, at which point the position of each shark within the habitat was recorded. During the five minute intervals, behaviors associated with habitat as defined by the developed ethogram were also recorded. Any other unusual behaviors were also noted. At the end of each 2 ½ hour period, all positions and behaviors were summarized and an Excel sheet was created for ease of data analysis. An ANOVA was used to determine to statistical significance of the shark's habitat preference based on bottom substrate. A two way ANOVA was used to determine statistical significance between time of observation and habitat preference based on bottom substrate.

Results

Habitat Preference Based on Bottom Substrate

After a total of 15 hours of observation over six days, the four females were recorded in the kelp bed region of the habitat a total of 321 times, while they were recorded in the open water region of the habitat a total of 377 times, and were out of view 18 times (Figure 5). The mean number of sharks recorded in the kelp bed region on each day of observation was 53.50 with a standard error of 7.09 (Figure 6). The mean number of sharks recorded in the open water region on each day of observation was 62.83 with a standard error of 7.36 (Figure 6). An ANOVA indicated there was statistical significance of habitat preference of sharks based on bottom substrate ($F= 5.00$, $p= 0.049$, F crit= 4.96) (Figure 7). The presence of an F value greater than 1, an F critical value less than the F value, and a p-value less than 0.05 all indicate the results are statistically significant.

Bottom Substrate Preference vs Time of Observation

After the 7.5 hours of 10:00am to 12:30pm observation, the four females were recorded in the kelp bed region of the habitat a total of 148 times, while they were recorded in the open water region of the habitat a total of 203 times, and were out of view 9 times. The mean number of sharks observed in the kelp bed region on each day of morning observations was 49.33 with a standard error of 8.50 (Figure 8). The mean number of *T.semifasciata* recorded in the open water region was 67.67 with a standard error of 8.02 (Figure 8).

After the 7.5 hours of afternoon observations from 12:30pm to 3:00pm, *T.semifasciata* were recorded in the kelp bed region of the habitat a total of 173 times, while they were recorded in the open water region a total of 174 times and were out of view 9 times. The mean number of *T.semifasciata* recorded in the kelp bed region on each day of afternoon observations was 57.66 with a standard error of 1.15 (Figure 8). The mean number of sharks recorded in the open water region was 58.00 with a standard error of 1.00 (Figure 8). A Two-Way ANOVA indicated there was no statistical significance between the time of observation and habitat bottom substrate preference by *T.semifasciata* females (F= 0.03 p= 0.84, F crit= 5.31) (Figure 9). The presence of an F value less than 1, with an F critical value greater than the F value, and a p-value greater than 0.05 all indicate the results are not statistically significant.

Behaviors Captured During Observation

During the 15 hours of observation, all behaviors were observed with varying frequency (Figure 10). The total number of bumping and rubbing observed was 151 with a mean of 25.16 per observation with a standard error of 13.12. The total number of jet stream play observed was 252 with a mean of 42.00 per observation period with a standard error of 26.08. The total number of pectoral fins touching the bottom observed was 200 with a mean of 33.33 per observation period with a standard error of 17.55. The total number of animal interactions observed was 99 with a mean of 16.50 per observation period with a standard error of 12.11 (Figure 10). When the collections were divided between 10:00am-12:30pm and 12:30pm-3:00pm time periods there was no statistical significance between behaviors observed and the time periods in which they were recorded, as the standard errors overlapped significantly, indicating a great deal of variance in behaviors (Figure 11).

Discussion and Conclusions

In this study, *T.semifasciata* was found to have a statistically significant preference for the habitat region with the open water bottom substrate (F= 5.00, p= 0.049, F crit= 4.96) (Figure 7), though, these findings were not tied to the time of day the sharks were observed (F= 0.03 p= 0.84, F crit= 5.31) (Figure 9), suggesting one of two things: the preference for this portion of the habitat may be consistent throughout the day or the time periods observed were too closely related to perceive any change in habitat preference. This did not support my hypothesis of seeing no preference in habitat bottom substrate given the lack of natural predators and no males present within the social group.

This study was limited to two time periods that were close together only ranging from 10:00am to 3:00pm and only had 6 total observations occurring in the same season from June to July of 2016. It is also a possibility that while conducting this study, there was some observer bias despite my best efforts to avoid them. The large viewing window in front of the habitat (Figure 3B) gave the best view point for observing and recording the movements and behaviors of all four females at the same time, but it was also the most popular choice for zoo guests and school groups. During morning observations I was often alone or only had a handful of people come through at a time. In contrast the afternoon viewing sessions often had large school groups, or zoo camp groups come through one after the other, blocking large sections of the window at a time. If a shark was resting on or near the bottom of the habitat, I often lost track of her movements during these times due to my ability to move about the habitat viewing area being restricted by the overcrowding. There were also a handful of days were crowds were so overwhelming that I had to cancel a planned observation because I was unable to get into a good viewing position from the beginning.

Another issue I realized on my second day of observation was the data sheet I had created was less than ideal. I had a sheet with a sketch of the habitat which I marked the locations of the sharks at the 5 minute interval and I had a section for behavior comments at the bottom (Figure 12). I realized that I may have been missing key behaviors due to spending too much time looking down at my data sheet writing, than actually observing. I did not want to change my data sheet to a more precise method of recording part way through my study as it would potentially skew my data.

It has been found in studies with wild populations of *T.semifasciata* that these sharks perform seasonal migrations often corresponding with the females' annual reproductive cycle (Carlisle & Starr, 2009, 2010; Kusher, et al., 1992), with the sharks preferring habitats consisting of intertidal mudflats, like those found at Elkhorn Slough National Estuarine Research Reserve in California (Carlisle & Starr, 2009). It has also been reported that while in these intertidal mudflats *T.semifasciata* have been known to move with the tides to feed in the shallows and then move back out to deeper waters as the tides begin to ebb (Ackerman et al., 2000; Carlisle & Starr, 2009). Several species of elasmobranchs have been known to exhibit movements that are linked to tidal ebbs and flows including southern stingray (*Dasyatis americana*) (Gilliam, Sullivan, & Gilliam, 1993), spotted eagle rays (*Aetobatus narinari*) (Silliman, & Gruber, 1999), Atlantic stingrays (*Dasyatis sabina*) (Teaf, 1980), dusky sharks (*Carcharhinus obscurus*) (Huish, & Benedict, 1977), cownose rays (*Rhinoptera bonasus*) (Smith & Merriner, 1985), and young sandbar sharks (*Carcharhinus plumbeus*) (Wetherbee et al., 2001). Although the Great Lakes are considered to be non-tidal (US Department of Commerce, 2014), in a long term study of this shark population at Chicago Zoological Society it may be possible to observe a pattern in habitat preference associated with seasonal or lunar changes which is not possible to perceive in this short term study.

The behaviors observed during this study were not found to be statistically significant as they happened with varying frequency and had very large standard errors (Figure 11). Some behaviors only occurred within a particular portion of the habitat and rarely had any overlap between bottom substrates. For example, when a shark would allow her pectoral fins to touch the bottom, she would only perform this behavior while in the open water region where the bottom was smooth. She would then raise her body and pectoral fins well above the bottom when coming into the rocky kelp bed region of the habitat. Bumping and rubbing on the habitat occurred most often on the rocky kelp bed and on the large glass viewing window. Though, there were a few times when the sharks would bump the side wall of the open water habitat. All jet stream play occurred while in the rocky kelp bed region as the jet stream is situated in this section of the habitat only, starting from the observer's upper right hand side of the habitat while at the large viewing window (Figure 3B). Animal interactions occurred throughout the habitat in all ranges of the water column over all bottom substrates. During observations there were a handful of threat displays including gaping mouths, nipping, and body gesturing. While these gestures are known threat postures in other species such as the Caribbean reef shark (*Carcharhinus perezi*) (Ritter, 2008), threat postures in *T.semifasciata* have not been greatly studied due to their skittishness in the wild; they will often vacate the area rather than defend themselves (Ebert & Ebert, 2005). This study may be the start of a larger behavioral study with our population of *T.semifasciata* at Chicago Zoological Society.

The results of this study and studies to follow may be given to zoo keepers, habitat designers, and those in other institutions which house *T.semifasciata* in order to help them enrich their habitats for their sharks. It has been documented in a number of shark species under human care which have been kept in inadequate, unenriched spaces that their health has suffered greatly from physical deformities to sudden death (Goodman, 2007; McPhate, 2016; Tate, et al., 2013). Great white sharks (*Carcharodon carcharias*) are notoriously difficult to house in in zoos and aquaria. They constantly bash themselves against the sides of their habitats, are known to stop eating, and often die suddenly within a few days of capture (McPhate, 2016). Only the Monterey Bay Aquarium in California have successfully housed juvenile *C.carcharias* for an extended period of time before releasing them back into their natural environment. However, after 9 years of successfully housing these sharks on and off, Monterey Bay Aquarium called it quits in 2013 (Ho, 2013). The sand tiger shark (*Carcharias taurus*), a very commonly displayed species in zoos and aquaria, has been known to suffer from spinal deformities when placed in a habitat that does not allow for their minimum linear swimming length of 31 meters for an average shark of 7 meters in total length (Tate et al., 2013). In order to keep these amazing animals as ambassadors to our communities, we need to best support them under our care with proper habitats suited to their ideal environmental and dietary needs.

From a conservation perspective the results of this study may also be given to those conducting studies in California on how to better protect these animals in their natural environment. Nearly 10 percent of the world's land mass is protected in some capacity including national parks, wildlife refuges, and wilderness areas. The oceans, and thus sea life, are incredibly vulnerable with less than 1 percent of the oceans protected in marine reserves and marine protected areas ("Marine Protected Areas," 2016). In March 2015, the United Kingdom established an 836,000 square kilometer no-take marine reserve (Howard, 2015). This reserve, the Pitcairn Islands Marine Reserve, an area nearly 3 ½ times the size of the United Kingdom, established the world's largest no-take marine reserve (Howard, 2015). Along the Californian coastline there are small sporadic marine protected areas which vary from limited-take, to no-take, to no-entry (Figure 13) ("California's Marine Protected Area (MPA) Network," 2016). While these networks offer *T.semifasciata* and other near shore elasmobranch species some limited protection, it barely scrapes the surface in protecting species with long gestation periods, slow growth rates, limited genetic diversity, and delayed sexual maturity. With continued research, public education, and government cooperation the establishment of more marine protected areas could ensure the survival of thousands of threatened marine species ("Marine Protected Areas," 2016).

Literature Cited

Ackerman, J. T., Kondratieff, M. C., Matern, S. A., & Cech, J. J. (2000). Tidal Influence on Spatial Dynamics of Leopard Sharks, Triakis semifasciata, in Tomales Bay, California. *Environmental Biology of Fishes*, *58*(1), 33–43. http://doi.org/10.1023/A:1007657019696

California's Marine Protected Area (MPA) Network. (2016). Retrieved July 23, 2016, from https://www.wildlife.ca.gov/Conservation/Marine/MPAs/Network

Carlisle, & Starr. (2009). Habitat use, residency, and seasonal distribution of female leopard sharks Triakis semifasciata in Elkhorn Slough, California. *Marine Ecology Progress Series*, *380*, 213–228. http://doi.org/10.3354/meps07907

Carlisle, & Starr. (2010). Tidal movements of female leopard sharks (Triakis semifasciata) in Elkhorn Slough, California. *Environmental Biology of Fishes*, *89*(1), 31–45. http://doi.org/10.1007/s10641-010-9667-0

Carlisle, Smith, Launer, & W. (2015). The IUCN Red List of Threatened Species: Triakis Semifasciata. Retrieved June 24, 2016, from http://www.iucnredlist.org/details/39363/0

Casagrande, A. (2016). Isle of Jaws. *Discovery Channel*.

Culik, B. M., & Luna-Jorquera, G. (1997). Satellite tracking of Humboldt penguins (Spheniscus humboldti) in northern Chile. *Marine Biology*, *128*, 547–556.

Delius, B. (2015). Triakis semifasciata. Retrieved July 10, 2016, from https://www.flmnh.ufl.edu/fish/discover/species-profiles/triakis-semifasciata

Duncan, K. M., & Holland, K. N. (2006). Habitat use, growth rates and dispersal patterns of juvenile scalloped hammerhead sharks, *312*, 211–221. http://doi.org/10.3354/meps312211

Ebert, D. A., & Ebert, T. B. (2005). Reproduction, diet and habitat use of leopard sharks, Triakis semifasciata (Girard), in Humboldt Bay, California, USA. *Marine and Freshwater Research*, *56*(8), 1089. http://doi.org/10.1071/MF05069

Editor's of Reader's Digest. (1998). *Reader's Digest Explores: Sharks* (1st ed.). Reader's Digest.

Farrrer, D. (2009). Northern range extension of the leopard shark, Triakis semifasciata. *California Fish and Game*, *95*(1), 62–64.

Gilliam, D. S., Sullivan, K. M., & Gilliam, D. (1993). Diet and Feeding Habits of the Southern Stingray Dasyatis americana in the Central Bahamas NOTES DIET AND FEEDING HABITS OF THE SOUTHERN STINGRAY DASYATIS AMERICANA IN THE CENTRAL BAHAMAS. *Bulletin of Marine Science*, *52*(33), 1007–1013. Retrieved from http://nsuworks.nova.edu/occ_facarticles

Goodman, B. (2007). Georgia Aquarium Mourns Another of Its Whale Sharks. *New York Times2*. Retrieved from http://www.nytimes.com/2007/06/14/us/14shark.html

Hight, B. V., & Lowe, C. G. (2007). Elevated body temperatures of adult female leopard sharks, Triakis semifasciata, while aggregating in shallow nearshore embayments: Evidence for behavioral thermoregulation? *Journal of Experimental Marine Biology and Ecology*, *352*(1), 114–128. http://doi.org/10.1016/j.jembe.2007.07.021

Ho, L. (2013). Monterey Bay Aquarium to suspend collection/display of great white sharks.

http://doi.org/http://www.advancedaquarist.com/blog/monterey-bay-aquarium-to-suspendcollection-display-of-great-white-sharks

Hopkins, T. E., & Jr, J. J. C. (2003). The Influence of Environmental Variables on the Distribution and Abundance of Three Elasmobranchs in Tomales Bay, California. *Environmental Biology of Fishes*, *66*(3), 279–291. http://doi.org/10.1023/A:1023907121605

Howard, B. C. (2015). World's Largest Single Marine Reserve Create in Pacific. *National Geographic*. Retrieved from http://news.nationalgeographic.com/2015/03/150318-pitcairnmarine-reserve-protected-area-ocean-conservation/

Huish, M. T., & Benedict, C. (1977). Sonic Tracking of Dusky Sharks in Cape Fear River, North-Carolina. *Journal of the Elisha Mitchell Scientific Society*, *93*(1), 21–26.

Jacoby, D. M. P., Croft, D. P., & Sims, D. W. (n.d.). Social behaviour in sharks and rays: analysis, patterns and implications for conservation. *Fish and Fisheries*. http://doi.org/10.1111/j.1467-2979.2011.00436.x

Knip, D., Heupel, M., & Simpfendorfer, C. (2010). Sharks in nearshore environments: models, importance, and consequences. *Marine Ecology Progress*. Retrieved from http://www.intres.com/abstracts/meps/v402/p1-11/

Kusher ', D. I., Smith3, S. E., & Cailliet ', G. M. (1992). Validated age and growth of the leopard shark, Triakis semifasciuta, with comments on reproduction. *Environmental Biology of Fishes*, *35*, 187–203.

Larson, E. J. (2001). Coastal wetlands-emergent marshes. *California's Living Marine Resources: A Status Report. California and California Department of Fish and Game, Sacramento, California*, 483–486.

Lewallen, E. A., Anderson, T. W., & Bohonak, A. J. (2007). Genetic structure of leopard shark (Triakis semifasciata) populations in California waters. *Marine Biology*, *152*(3), 599–609. http://doi.org/10.1007/s00227-007-0714-0

Marine Protected Areas. (2016). Retrieved July 10, 2016, from http://www.oceanconservancy.org/our-work/marine-protected-areas/?referrer=https://www.google.com/

McPhate, M. (2016). Great White Shark Dies After Three Days in Captivity. *New York Times*. Retrieved from http://www.nytimes.com/2016/01/09/science/great-white-shark-dies-afterthree-days-in-captivity.html?_r=0

Nosal, A. P., Cartamil, D. C., Long, J. W., Lührmann, M., Wegner, N. C., & Graham, J. B. (2013). Demography and movement patterns of leopard sharks (Triakis semifasciata) aggregating near the head of a submarine canyon along the open coast of southern California, USA. *Environmental Biology of Fishes*, *96*(7), 865–878. http://doi.org/10.1007/s10641-012-0083-5

Ritter, E. K. (2008). Mouth gaping behavior in Caribbean reef sharks, Carcharhinus perezi. *http://dx.doi.org.proxy.lib.miamioh.edu/10.1080/10236240802373925*.

Silliman, W., & Gruber, S. H. (1999). Behavioral biology of the spotted eagle ray, Aetobatus narinari. *Bahamas J Sci*, *7*, 13–20.

Smith, J. W., & Merriner, J. V. (1985). Food Habits and Feeding Behavior of the Cownose Ray, Rhinoptera bonasus, in Lower Chesapeake Bay. *Estuaries*, *8*(3), 305. http://doi.org/10.2307/1351491

Smith, S. (2001). Leopard Shark. *California's Marine Living Resources: A Status Report*, (December), 252–254.

Smith, S. (2007). Leopard Shark. *Status of the Fisheries Report*, (14), 1–7.

Solomon, E.; Berg, L.; Martin, D. (2004). *Biology* (7th. ed.). Belmont, CA: Brooks/ColeThomson Learning.

Tacutu, R., Craig, T., Budovsky, A., Wuttke, D., Lehmann, G., Taranukha, D., … de Magalhães, J. P. (2013). Human Ageing Genomic Resources: integrated databases and tools for the biology and genetics of ageing. *Nucleic Acids Research*, *41*(Database issue), D1027–33. http://doi.org/10.1093/nar/gks1155

Tate, E. E., Anderson, P. A., Huber, D. R., & Berzins, I. K. (2013). Correlations of Swimming Patterns with Spinal Deformities in the Sand Tiger Shark, Carcharias taurus. *International Journal of Comparative Psychology*, *26*(1).

Teaf, C. M. (1980). *A study of the tidally-oriented movements of the Atlantic stingray, Dasyatis sabina (LeSueur) in Apalachee Bay, Florida.* Florida State University, Tallahassee, FL.

Tricas, T.C.; Deacon, K.; Last, P.; McCosker, J.E.; Walker, T.I.; Tayloer, L. (1997). *The Nature Company Guides: Sharks and Rays*. (L. Taylor, Ed.). Hong Kong: The Nature Company, Time Life Books.

US Department of Commerce, National Oceanic and Atmospheric Administration (2014). Do the Great Lakes have tides? Retrieved from http://oceanservice.noaa.gov/facts/gltides.html

Wetherbee, B. M., Rechisky, E. L., Pratt, H. L., & McCandless, C. T. (2001). Use of Telemetry in Fisheries Management: Juvenile Sandbar Sharks in Delaware Bay (pp. 249–262). http://doi.org/10.1007/978-94-017-1402-0_12

Appendix

Figure 1. The Leopard Shark (*Triakis semifasciata*) is known for its elongated body, dual dorsal fins, and saddle-like dark markings against a sandy or silvery body that gives it the look of, its namesake, the leopard. (Photo is original content taken while at Monterey Bay Aquarium, dated March 17, 2016.)

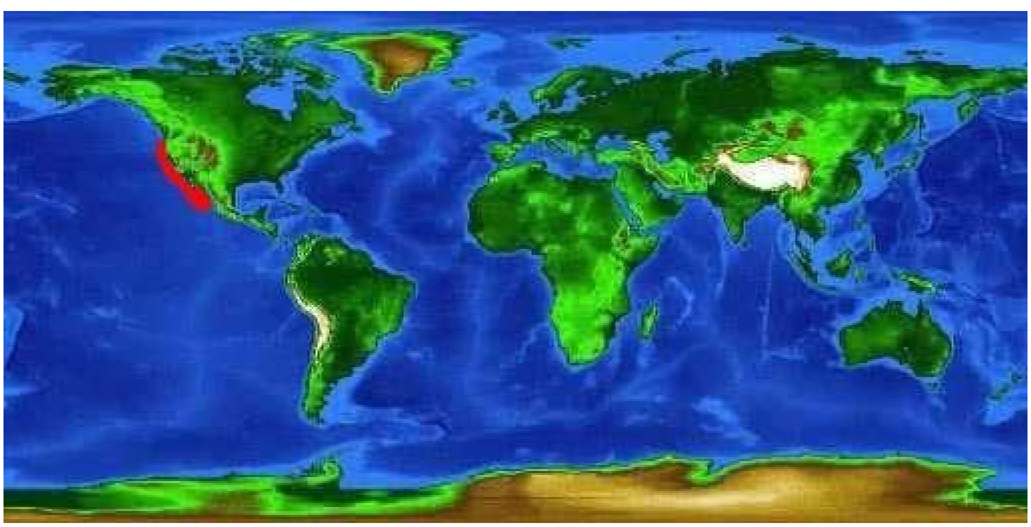
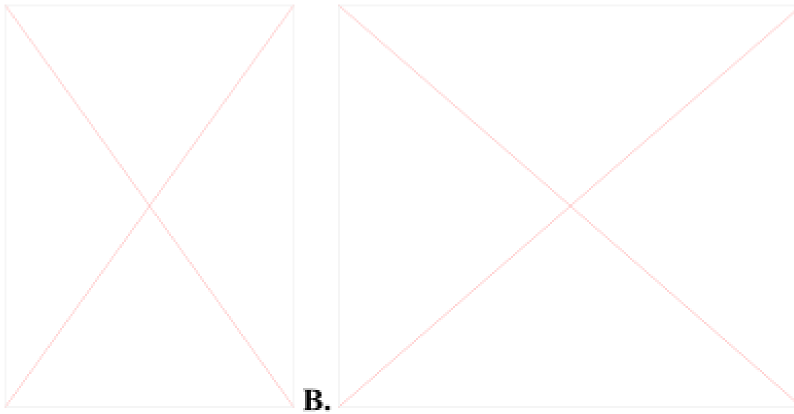


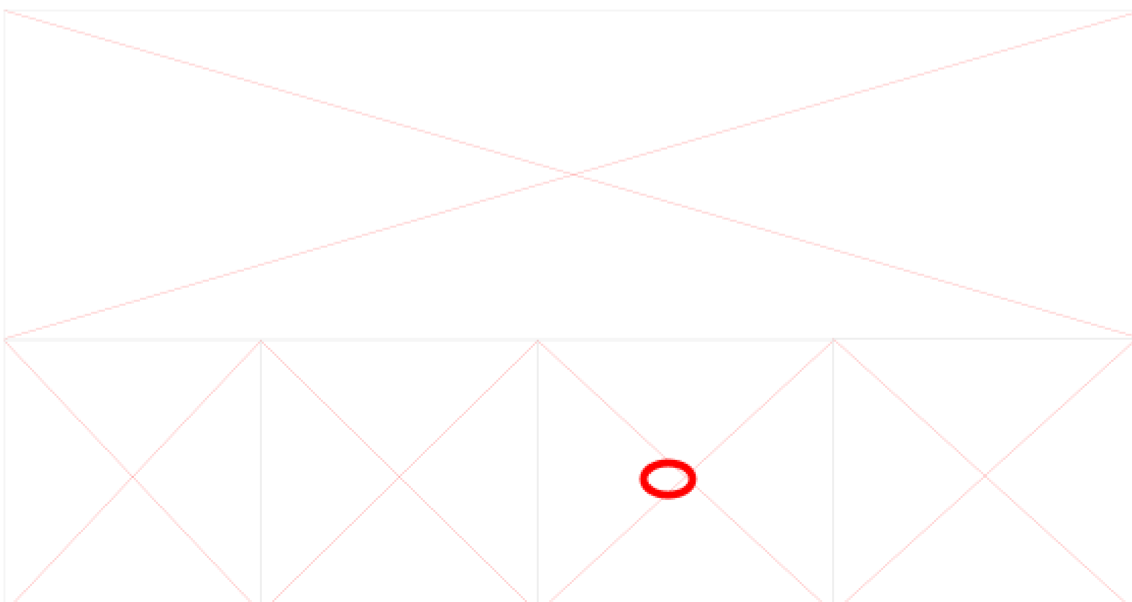
Figure 2. *Triakis semifasciata* natural habitat range highlighted in red. They are found from Oregon to Northern Mexico (Delius, 2015).



A. B.

Figure 3. A. Relatively small round window that allows for good views of the open water region and some limited viewing of the rocky kelp bed region of the sharks' habitat.

B. The large viewing window where the majority of the observations were taken. Both regions of the habitat (open water and kelp bed) are visible from this viewing area and it allowed for greater maneuverability around groups of people. (Photo is original content taken during an early morning observation at Chicago Zoological Society June-July 2016.)



A.

B.

Figure 4. A. Hand sketch of each female's dorsal fin during my initial observation period. Each female was given a short hand notation based on the markings of her dorsal fin. In Figure 4 A, the females are as follows left to right: Weathered Dorsal (WD) like a weather flag, Jagged Dorsal (JD) both dorsal fins had large sections missing, Smooth Dorsal (SD) perfectly smooth with a small with spot at the base, circled in red in Figure 4B, and Two Notched Dorsal (2ND) smooth with two notches cut in.

B. Each photo taken of the females dorsal fins corresponds with the drawing above. (Photos are original content taken during observations at Chicago Zoological Society June-July 2016).

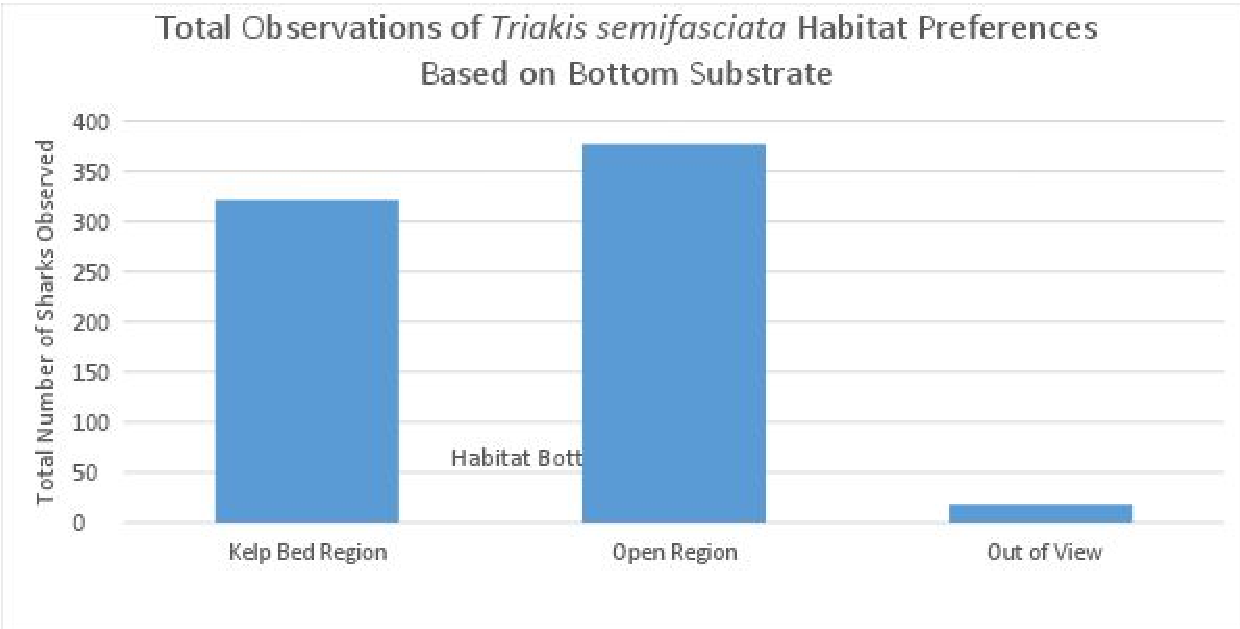


Figure 5. Total number of *T.semifasciata* recorded in each habitat substrate after 15 hours of observation over six days. *T.semifasciata* was recorded in the Kelp Bed Region a total of 321 times, in the Open Water Region 377 times and Out of View a total of 18 times.

Figure 6. Totals, Means and Standard Errors for *T.semifasciata* observed in Kelp Bed Region, Open Water Region and Out of View over six days of observations. * Indicates one corrupt data point which eliminated a data set of four shark positions, leading to 716 total observations instead of 720 total observations.

Date	**Collection Time**	**Kelp Bed Region (# of Sharks)**	**Open water Region (# of Sharks)**	**Out of View (# of Sharks)**	**Total Observations (# of Sharks)**
6/22/2016	10:00-12:30 pm	49	67	4	120
6/27/2016	10:00-12:30 pm	41	76	3	120
7/7/2016	10:00-12:30 pm	58	60	2	120
6/14/2016	12:30-3:00 pm	57	57	2	116 *
6/29/2016	12:30-3:00 pm	59	58	3	120
7/6/2016	12:30-3:00 pm	57	59	4	120
	Total	**321**	**377**	**18**	**716**

Mean	**53.5**	**62.83333333**	**3**	**-**
SE	**7.092249291**	**7.359800722**	**0.894427191**	**-**

Figure 7. An ANOVA was used to determine statistical significance of habitat use based on bottom substrate of the four female *T.semifasciata*. The presence of an F value greater than 1, with an F crit value less than the F value, and a P-Value less than 0.05 all indicate the results are statistically significant.

ANOVA

Source of Variation	*SS*	*df*	*MS*	***F***	***P-value***	***F crit***
Between Groups	261.3333	1	261.3333	**5.003191**	**0.049273**	**4.964603**
Within Groups	522.3333	10	52.23333			
Total	783.6667	11				

Figure 8. Means and Standard Errors for sharks observed by habitat bottom substrate region per observation time period.

Date	**Collection Time**	**Kelp Bed Region (# of Sharks)**	**Open water Region (# of Sharks)**	**Out of View (# of Sharks)**
6/22/2016	10:00-12:30 pm	49	67	4
6/27/2016	10:00-12:30 pm	41	76	3
7/7/2016	10:00-12:30 pm	58	60	2
	Mean	**49.33333333**	**67.66666667**	**3**
	Standard Error	**8.504900548**	**8.020806277**	**1**
6/14/2016	12:30-3:00 pm	57	57	2
6/29/2016	12:30-3:00 pm	59	58	3
7/6/2016	12:30-3:00 pm	57	59	4
	Mean	**57.66666667**	**58**	**3**
	Standard Error	**1.154700538**	**1**	**1**

Figure 9. A Two-Way ANOVA was used to determine statistical significance of habitat use based on bottom substrate and time of observation of the four female *T.semifasciata*. The presence of an F value less than 1, with an F crit value greater than the F value, and a P-Value greater than 0.05 all indicate the results are not statistically significant.

Anova: Two-Factor With Replication

SUMMARY	# in Kelp Bed Region	# in Open water Region	Total
10:00-12:30			
Count	3	3	6
Sum	148	203	351
Average	**49.33333333**	**67.66666667**	**58.5**
Variance	72.33333333	64.33333333	155.5
12:30-15:00			
Count	3	3	6
Sum	173	174	347
Average	57.66666667	58	57.83333333
Variance	1.333333333	1	0.966666667
Total			
Count	6	6	
Sum	321	377	
Average	53.5	62.83333333	
Variance	50.3	54.16666667	

ANOVA

Source of Variation	*SS*	*df*	*MS*	***F***	***P-value***	***F crit***
Sample	1.333333333	1	1.333333333	**0.0383693**	**0.849587462**	**5.317655**
Columns	261.3333333	1	261.3333333	7.52038369	0.025357666	5.317655
Interaction	243	1	243	6.99280576	0.029511519	5.317655
Within	278	8	34.75			
Total	783.6666667	11				

Figure 10. Totals, Means and Standard Errors of behaviors observed during each observation period as defined by ethogram during trial observation.

Date	Collection Time	Bumping/ Rubbing (# Sharks)	Jet Stream Play (# Sharks)	Pecs Touching Bottom (# Sharks)	Animal Interactions (# Sharks)
6/22/2016	10:00-12:30 pm	14	39	21	6
6/27/2016	10:00-12:30 pm	28	33	53	7
7/7/2016	10:00-12:30 pm	45	84	42	37
6/14/2016	12:30-3:00 pm	10	4	8	9
6/29/2016	12:30-3:00 pm	20	40	27	16
7/6/2016	12:30-3:00 pm	34	52		24
	Total	**151**	**252**	49 **200**	**99**
	Mean	**25.16666667**	**42**	**33.33333333**	**16.5**
	SE	**13.12122962**	**26.08447814**	**17.5575245**	**12.11197754**

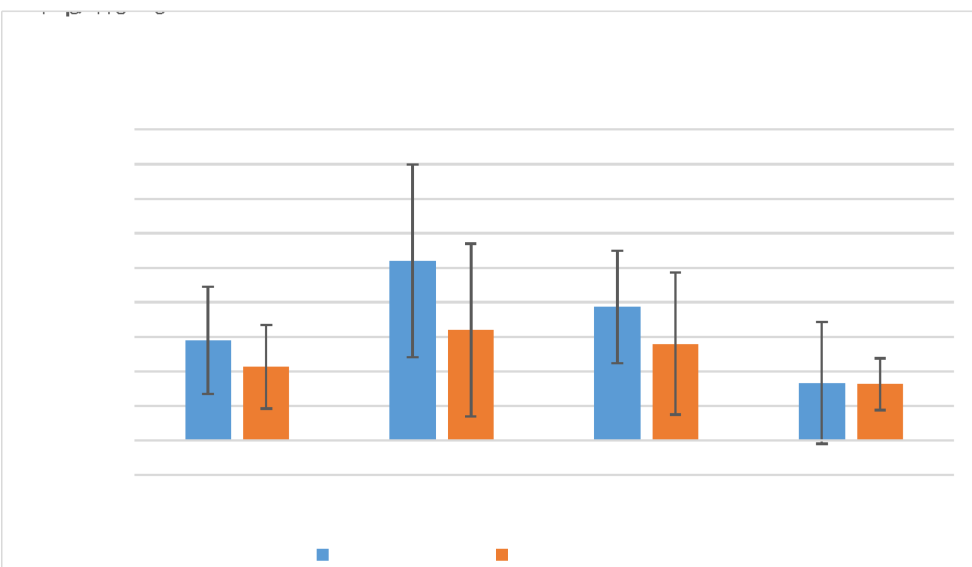


Figure 11. Mean behaviors recorded during morning (10:00am-12:30pm) and afternoon (12:303:00pm) observation periods with standard errors indicated significant variance in behaviors observed each day of collection.

Date:__________________ Time Recorded:_________________ Observer:___________
Total Sharks Observed:___________Total Females: ____________Total Males:__________

Females Marked By:_____ Males Marked By:______

Time Observed:___________ to:___________
Comments:____
____
____
____
____

Figure 12. Data sheet used during observations. Females were marked by a pink "X" on the sketch of the habitat at the 5 minute interval. Notes of behavior were taken in the comments section during the 5 minute intervals. The vertical line of demarcation indicates the separation between the open water region (left) and the kelp bed region (right).

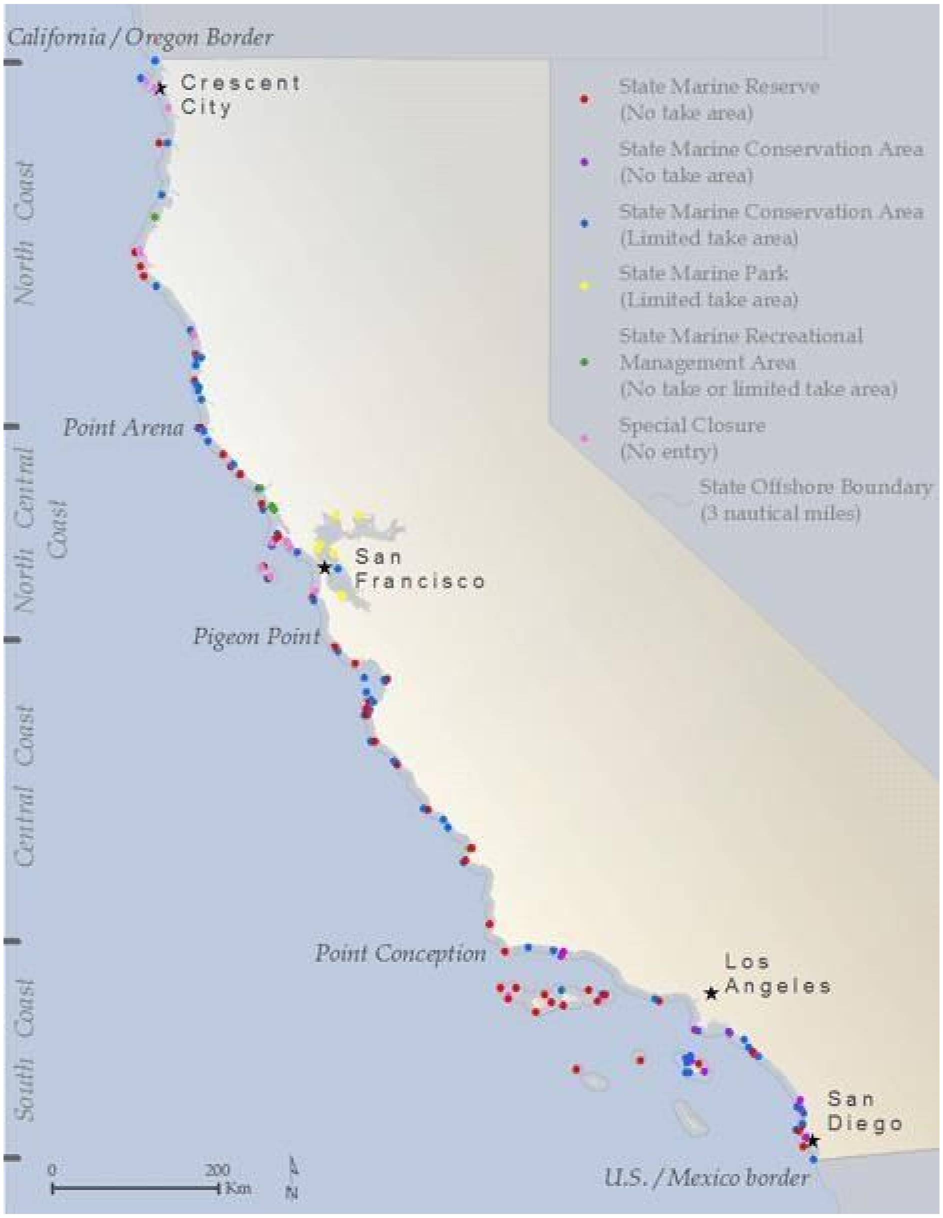


Figure 13. Network of Marine Protected Areas (MPAs) along the Californian coastline. These MPAs extend a maximum of 3 nautical miles offshore to the State's offshore boundary. Red dots represent State Marine Reserves (No Take Areas). Purple dots represent Stat Marine Conservation Areas (No Take Areas). Blue dots represent State Marine Conservation Areas (Limited Take Areas). Yellow dots represent State Marine Parks (Limited Take Areas). Green dots represent State Marine Recreational Management Areas (No Take or Limited Take Areas). Pink dots represent Special Closure Areas (No Entry Areas). ("California's Marine Protected Area (MPA) Network," 2016)