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Behavioral patterns of Mustelus canis (smooth dogfish shark) in a captive population

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Megan Vaupel

Mustelus canis, or the smooth dogfish shark, is the second most common species of shark inhabiting the coastal waters of the Western Atlantic. However little is known about the behavior of this species in the wild and in captivity. In an attempt to establish some data on the behaviors of these animals, I observed a captive population of dogfish at the Indianapolis zoo. I quantified the activity level and distribution of the dogfish in various areas of the exhibit, as well as the frequency and durations of stationary ("resting") behavior. I analyzed these results in the context of several factors, including time, location in tank, number of zoo patrons present, and day (feeding vs. non-feeding days). The results from these observations provide a set of baseline data on the behavior of the smooth dogfish sharks for use in future research, and to aid in providing an appropriate environment for this species in captivity.

Introduction

The smooth dogfish shark, or *Mustelus canis*, is a small bottom-dwelling shark which inhabits the western Atlantic Ocean. Populations range in coastal waters from Massachusetts to Argentina (Tee-Van et al., 1948). *M. canis* is categorized in the Class Chondrichthyes with other cartilaginous fishes. More specifically, it is found in the subclass Elasmobranchii, which encompasses all sharks, skates, and rays. It belongs to the Order Carcharhiniformes (ground sharks) and the Family Triakidae (hound sharks), with other small, bottom dwelling sharks. Its name, *Mustelus canis*, translates into "weasel-like dog". The shark was given this name due to its tendency to travel in packs during migration in the wild. The smooth dogfish is the second most abundant shark found in the mid-Atlantic, falling just short of its close relative *Squalus acanthias,* or the spiny dogfish. Typical size ranges for the smooth dogfish shark are 70-90 cm in males, and 70-130 cm in females (Tee-van et al., 1948). The diet of the smooth dogfish consists primarily of crustaceans, including crab, lobster, shrimp, clams, and small fish. The sharks exhibit very blunt dentition, with flat teeth that are used to crush and grind crustaceans found on the sea floor. The dogfish appear to reside along coastal shores until water temperatures begin to drop in the fall, initiating a migration of the sharks south and into deeper waters. This migration pattern has not been well researched, and little is known about the habitat of the dogfish in the winter months. The sharks return to warmer coastal waters in May, just in time for the mating season (Tee-Van et al., 1948).

Mating in this species typically occurs in the summer months from May to July, followed by a relatively long gestation period of ten to eleven months. These sharks are a viviparous species, meaning there is a placental connection between the mother and its young, which are known as "pups" (Conrath & Musick, 2002). In the smooth dogfish, this connection is derived from a primitive yolk sac placenta, which nourishes anywhere from four to twenty offspring. The pups are born live.

The sharks at the Indianapolis Zoo seem to exhibit many of the behaviors that would be expected of a smooth dogfish in its natural environment. The dogfish spend most of the time swimming at a constant rate throughout the exhibit tank, and mating occurs often. Raising pups has yet to be successful. The dogfish are fed a variety of prepared food items (the food is not live and is cut into small pieces) including lobster, crab, shrimp, clams, krill, squid, and fish.

Although *M. canis* (smooth dogfish shark) is one of the most common subjects used for dissection in biology labs, as well as one of the most frequently commercially-fished species, little is known about its behavior and general activity patterns (Conrath & Musick, 2002). Very little has been published about the behavior of the smooth dogfish *in situ*, and virtually no information has been published about its behavior in captivity. Many aquariums have just recently begun to present *M. canis* in public exhibits, a trend most likely attributed to the shark's easy accessibility and docile nature. The Indianapolis

Zoo houses one of the largest captive populations of smooth dogfish in North America. These animals are housed in a public exhibit where patrons can gently touch the sharks as they swim by. The scarcity of information about the activities of the smooth dogfish make it difficult to effectively create a naturalistic environment for the sharks in captivity. Observations that provide baseline data on the behavior of captive smooth dogfish may be important in improving the quality of life of these animals in public exhibits, as well as providing insight into the behaviors of the shark in its natural environment.

I developed an interest in the smooth dogfish while working with the animals during two internships at the Indianapolis Zoo, from January to August 2009. While working with the sharks I observed the animals exhibiting a behavior which employees have termed "resting". When "resting", the sharks remain motionless on the bottom of the tank, typically propped up on their pectoral fins. The smooth dogfish sharks are able to do so due to a specialized respiratory organ called a spiracle, one located behind each eye. Water is taken into the spiracle and pushed over the anterior gills, providing a direct supply of oxygenated blood to the eye and brain of the dogfish (Hickman, 2003). The dogfish can draw water into the spiracle without moving the rest of its body, providing an alternate form of respiration from ram ventilation, which requires the shark to constantly swim to move water over its gills. From an observational perspective, using the spiracle for respiration would seem like an ideal alternative for the shark, allowing the shark to "rest" for short periods of time. However, ram ventilation seems to be used much more frequently by the sharks at the Indianapolis Zoo than respiration by the spiracle only, which may suggest ram ventilation as the energy-preferred method in this population. I will refer to this "resting" behavior with the more objective term, "Stationary" behavior, throughout the remainder of my paper. It remains unclear why sharks engage in this Stationary activity. Perhaps this behavior truly does indicate a state of reduced consciousness or metabolic activity resembling "rest". Obtaining measures of electrical activity in the brain of the smooth dogfish shark while engaging in this behavior could help to resolve this debate.

A study conducted by Carrier et al. (1994), examined stationary and mating behaviors in nurse sharks, *Ginglymostoma cirratum,* in the Florida Keys. Results of the study revealed that successful copulation rarely occurred at depths less than .5 m, and females which were unreceptive to mating often fled to shallow waters and assumed a Stationary position. Carrier suggested that females may use this Stationary position as a behavioral signal of sexual unreceptivity to subdue aggressive males, possibly in conjunction with olfactory cues. The shallow water also makes it difficult for male sharks to arrange females into a receptive position. Male sharks exhibited less stationary behavior than females, and did so primarily after mating attempts. The males exhibited heavy respiration during Stationary periods, which may serve as a "resting" period for the male to "catch his breath" after mating, so to speak. Stationary behavior in nurse sharks seems to be closely associated with reproductive behaviors; however Stationary behavior also occurs outside of mating events. Stationary behavior exhibited by the smooth dogfish sharks at the Indianapolis Zoo may certainly be connected to mating behavior. The female dogfish (5 sharks) in the exhibit were greatly outnumbered by males (20 sharks) when my observations took place, and "chasing" (males rapidly pursuing mates) occurred often. During this time, two female sharks demonstrated severe abrasion of the pelvic and pectoral fins, which the keepers attributed to extensive Stationary behavior on the bottom of the tank. This abrasion may be explained by increased Stationary behavior of these females in an attempt to dissuade male pursuers. The male sharks in this population seem to engage in Stationary behavior often as well, however more information is needed to conclusively compare the frequency of Stationary periods between males and females.

The smooth dogfish also exhibited an interesting behavior which keepers have termed “spy-hopping”. "Spy-hopping" in the smooth dogfish shark is characterized by the animal protruding its rostrum above the surface of the water, and moving it side to side while swimming in either a linear or rotational manner. The behavior seems to be indicative of a stress response. Although I did not gather any conclusive data on the “spy-hopping” behavior for this paper, I offer my hypotheses on its mechanism in the discussion section.

The aim of my thesis was to establish a baseline, or reference, set of data concerning the general activity levels and frequency of Stationary behaviors of the smooth dogfish shark in a captive environment. All measures of activity and behavior were considered in conjunction with 4 other factors. These factors included time of day, location in the tank, number of zoo patrons present, and feeding versus non-feeding days. By taking these factors into account, my hope is that correlations between the factors and observations might provide some insight into the mechanisms underlying the shark's behavioral patterns. Since there is virtually no research on the behavior of the smooth dogfish shark, the results may be used for future reference on research concerning this species.

Methods

Observations of the smooth dogfish sharks took place at the Firestone touch-tank exhibit in the Oceans Biome of the Indianapolis Zoo, between November 2009 and April 2010. The population in this exhibit consisted of 25 sharks: 20 males and 5 females. For research purposes, I categorized the tank into two zones based on relative depth (Figure 1). The "deep end", labeled Zone 1, is approximately 73.3 cm deep (range = 72-74 cm).

Zone 2, or the "shallow end" measures approximately 48.5 cm deep (range = 48.2-48.8 cm). The two zones are separated by a line of artificial rock structures. Zone 1, which has a surface area of approximately 356 sq ft (30.67% of total surface area, excluding rocks and the ledge), has been designated by the zoo staff as a "shark rest zone" in which patrons are instructed not to touch the sharks. Zone 2, or the "shallow area", covers a larger surface area of approximately 804.5 sq ft (69.33% of total surface area: excluding rocks and the ledge). Patrons are allowed to touch the sharks throughout this zone.

All observation sessions lasted a minimum of 30 minutes and occurred in either the morning or the afternoon. Morning sample sessions (AM) began anytime between 9:00 am and 12:00 pm. Afternoon sampling sessions (PM) began between 2:30 pm and 5:30 pm. Zoo personnel feed the dogfish every Tuesday, Thursday, and Saturday, typically in the mornings before 10:30 am. For the purpose of data analysis, sessions recorded on Tuesday, Thursday, and Saturday were designated FOOD days, and sessions on Monday, Wednesday, Friday, and Sunday were designated NOFOOD days. Seven feeding and eight non-feeding morning sessions were recorded, as well as six feeding and seven non-feeding afternoon sessions. Camera 2 was positioned to simultaneously record patron activity around the exhibit, as well as shark behavior. During the sessions, the experimenter estimated the number of patrons which approached the dogfish tank. This included patrons that stood within a foot of the exhibit. A session with fewer than 50 patrons visiting the tank over the 30-minute period was considered a "low traffic session"; a session with 50 or more patrons approaching the exhibit was categorized as a "high traffic session".

To observe the entire area of the tank I set up cameras at three different points around the exhibit. Camera 1 was positioned in Zone 2 approximately four meters away from and parallel to the artificial rock ledge (Figure 1, 2A). This camera was used to measure activity level as the sharks passed across a designated plane. Preliminary observations had suggested that this location allowed experimenters to view the dogfish swimming in both directions across the width of the tank. Stationary behaviors captured by Camera 1 were recorded and classified under Zone 2. Camera 2, positioned about 5m from the end of the shallow section of the tank, recorded the frequency of Stationary behavior in all of Zone 2, as well as the number of patrons which approached any area of the tank throughout the sessions (Figure 1, 2B). Camera 3 was positioned to cover all of Zone 1, and captured the number of sharks in the "deep end" at designated sampling intervals, as well as any stationary behavior that occurred in this zone (Figure 1, 2C).

General activity level was measured by Camera 1, utilizing an interval sampling method (also known as "continuous sampling": Martin & Bateson, 1993). The number of sharks which crossed the designated plane were counted during 120 intervals of 15s throughout the 30 min session. If a shark changed directions and re-crossed the line shortly after crossing it initially, it was included in the overall count.

Shark distribution (the proportion of sharks in Zone 1 to Zone 2), was measured using instantaneous counts of the number of sharks in Zone 1 at 30s intervals throughout the 30 min session (instantaneous sampling: Martin & Bateson, 1993). At every 30s sampling point, each shark with any part of its body within Zone 1 was included in the total count.

Stationary behavior was recorded by all three cameras throughout sampling sessions, and categorized into Zone 1 or Zone 2. Instances of Stationary behavior were tallied to determine frequency of the behavior, and the duration times of each Stationary period were also measured.

Data analysis

I used a variety of statistical methods to summarize and interpret my results. For the Distribution counts and the Activity levels, I used the analysis of variance technique. The data involved counts for the entire collection of dogfish taken at different times on different days. I considered each count to be an independent observation of the behavior of a single entity, the group. These observations seemed to be distributed consistent with a Normal distribution, so parametric statistics were appropriate. For the Stationary behavior counts and the Stationary behavior frequency distributions, which were not distributed Normally, I used a nonparametric test, the chi-square test (x^2: Siegel, 1956).

Results

Zone 1 ("deep end'): Dogfish spatial distribution

In all four conditions (FOOD/NOFOOD x AM/PM), there were significantly fewer dogfish in Zone 1 than would be expected by chance, given the relative sizes of Zones 1 and 2, and the total number of fish in the tank. Compared with an expected average of 7.67 sharks in Zone 1, the highest average in any condition was 5.28 sharks (FOOD PM condition); $t(4) = 6.15$, $p = 0.004$.

The time of day had a significant effect on the distribution of sharks in the exhibit $F(1, 21) = 6.31$, $p= 0.02$. There were significantly more sharks in Zone 1 during PM sessions (mean = 5.20), than AM sessions (mean = 4.59) (Table 2). The number of patrons present had no significant effect on shark distribution; $t(16) = -.251$, $p=.085$.

Activity levels

There were also significant differences in general activity level according to time of day and whether or not feeding had occurred, as well as number of patrons. The sharks were significantly more active in PM sessions, $F(1,15) = 22.2$, $p = 0.0003$, and

FOOD sessions, $F(1,15) = 12.4$, $p = 0.003$ (Table 1). Combining all AM/PM and FOOD/NOFOOD sessions, the dogfish were more active in high-traffic sessions (mean = 4.7 crosses) than in low-traffic sessions (mean = 4.2 crosses); $t(11) = -2.49$, $p = .03$).

Stationary Behavior

Instances of Stationary behavior occurred significantly more often in Zone 2 (136 instances) than Zone 1 (7 instances), and this result remained significant after taking into account the relative surface areas of the zones (Zone 1 = 30.7%; Zone 2 = 69.3%), χ^2 (1) = 44.7, $p < 0.001$. Stationary behavior occurred in the deep end significantly less than would be expected by chance. Stationary behavior also occurred significantly less on FOOD days than NOFOOD days $t(20) = 2.24$, $p = .037$, as well as on high traffic days $t(18) = 2.43$, $p = .026$. Despite occurring less often on FOOD days, the distribution of stationary duration periods remained similar across both FOOD and NOFOOD sessions (Figure 3). The majority of Stationary periods lasted for relatively short durations of one to two minutes. Stationary duration was significantly longer (mean=6.54 min) on high traffic days than on low traffic days (mean=2.55 min); $t(18) = 2.69$, $p = .015$.

Discussion

The finding that shark activity level increased significantly on days with 50 or more patrons is consistent with the findings that Stationary behavior occurred significantly less and for shorter durations on high traffic days. These results may suggest a heightened state of arousal which keeps the sharks at active levels higher than what would be expected when fewer patrons interact with the sharks. This could also indicate increased levels of stress with more patrons present; however, the sharks do not exhibit any startled behaviors (speeding up, spy-hopping, tail-whipping) when patrons touch them appropriately.

Activity level also increased significantly in the afternoons and on feeding days. The increase in activity level on feeding days is likely representative of active foraging behavior, and is consistent with the finding that Stationary behavior occurs less on feeding days. The sharks do not engage in a mass "feeding frenzy" when food is thrown into the exhibit. The dogfish actively forage throughout the day, picking up pieces of food when passing directly over the feeding area. In the wild, the dogfish sharks rely largely on the lateral line system and the ampullae of Lorenzini to detect bioelectrical signals given off by live prey (Kalmijn, 1971). Hearing and olfaction are also important for the detection of live prey in shark species such as the smooth dogfish (Helfman et al., 2009).These systems (apart from olfaction) are not particularly useful in detecting prepared food items. Foraging for prepared food consequently increases reliance on olfaction and poorly developed vision. When a captive dogfish swims near an area with food, it seems first to detect that there is food in the general area through olfaction, then will circle and change direction to pinpoint pieces of food in the area with its short range vision. In the Indianapolis exhibit, food is thrown directly in Zone 2 along much of the plane that was used to detect activity level during observation sessions. The increase in activity on feeding days may be reflective of multiple re-crosses across the plane as the dogfish circle and change directions when actively foraging for food. Introducing live food into the diet may allow the sharks to utilize their other sensory structures and forage naturally.

The increased activity level in the afternoons may also indicate an increase in foraging behavior during this time of day, or may reflect a cumulative effect of heightened arousal from patrons approaching the tank throughout the day. There were also significantly more sharks in the deep end during afternoon sessions, but shark distribution was not effected significantly by feeding days. The analysis of this result is unclear. The general increase in activity level in the afternoon may be correlated with this distribution pattern, resulting in higher counts of the dogfish in Zone 1 during the afternoon.

Stationary behavior occurs far more frequently in Zone 2 than Zone 1. This result persists when the surface areas of the two zones are taken into account, with fewer sharks Stationary in the smaller deep end than what would be expected by chance. Despite being deemed the "shark rest area" by staff members, very little Stationary behavior actually occurs in this zone. This finding that Stationary behavior occurs far more frequently in Zone 2, or the "shallow" portion of the tank, is consistent with the findings by Carrier et al (2003). Female dogfish sharks may use this area of the tank as a refuge from pursuing males, making copulation more difficult in the shallow water. Females may then engage in Stationary behavior in this Zone to signal to the males that they are sexually unreceptive. Despite Zone 2 maintaining a relatively constant depth throughout the entire area, the majority of Stationary periods seem to occur in one particular section of this zone. This location preference could be due to a wide range of factors including slight differences in lighting or temperature in the preferred area. In the wild, shallow waters are correlated with increased lighting and warmer temperatures. Slight increases in these factors may serve as cues for females to seek refuge in a particular area of Zone 2. Although we could not determine the cause of this preference through purely observational methods, these factors are important to consider when determining how to construct an artificial environment for the dogfish.

The finding that the majority of Stationary behaviors lasts for short durations of only one to two minutes is quite surprising. During our observation sessions, Stationary durations ranged from less than a minute to greater than 26 minutes, and durations that began before or ended after the sample sessions were not included in the distribution.

Stationary behavior always seemed to be terminated when an active shark swam towards or brushed past a Stationary shark. This disturbance then resulted in an abrupt startle response and termination of the Stationary period. While another shark's approach seems to be a necessary prerequisite for termination, this effect was not always sufficient. There were plenty of instances in which a shark brushed past, or a patron touched, a Stationary shark and no response was generated. According to the distribution, Stationary behavior was terminated most often in the initial minutes of the Stationary period. This may suggest a threshold: after a couple of minutes of Stationary behavior the likelihood of termination is decreased, and/or the intensity of the Stationary state is increased.

The duration of Stationary periods was significantly shorter on high traffic days. This may be reflective of the increased activity level within the tank, resulting in the sharks coming into contact with one another more often. This decreases the likelihood that a shark will remain Stationary past the one to two minute threshold. External patron activity may have a similar effect. Part of the preferred Stationary area in Zone 2 is within close proximity to patrons. After one to two minutes, Stationary sharks do not seem to be startled when touched by patrons, but the likelihood of reaching this threshold is significantly decreased when many patrons are present.

Future Research

Although I did not include observations on "spy-hopping" behaviors in this manuscript, the behavior is of particular interest to me. The behavior is termed "spy-hopping" due to its superficial resemblance to a similar behavior seen in many species of Cetacea. In cetacean species, "spy-hopping" is a social behavior, and is used for communication, food detection, and as a general method of examining the animal's surroundings (Simmonds, 2004). When cetaceans "spy-hop" they tend to remain relatively stationary in the water. It may be misleading to refer to the behavior of the smooth dogfish as "spy-hopping": although the behavior physically resembles spy-hopping in Cetacea, there is no evidence that it serves the same function. Spy-hopping in smooth dogfish has been noted frequently in other facilities where the species is held in captivity, but it has almost never been recorded in the wild. Field researchers have observed this behavior only in captive settings or immediately upon release of individuals into the wild after having been captured and handled for research purposes, suggesting that "spy-hopping" may be indicative of a behavioral response to stress.

I have reviewed several hypotheses as to the mechanism behind "spy-hopping" in the smooth dogfish shark, by means of personal communication with handlers of the dogfish. David McElroy, a researcher at the Animal and Veterinary Science University of Rhode Island, suggests that "spy-hopping" in smooth dogfish may be a reaction to stray voltage or electrical currents in an aquarium, which agitate the sharks' sensitive ampullae of Lorenzini (personal communication, 4/10/2009). Dr. Cami McCandless of the Apex Predator Program in Rhode Island frequently observed dogfish "spy-hopping" immediately upon release into the wild after being handled (weighed and tagged for research purposes: personal communication, 4/13/2009). Alan Henningsen, a Fisheries Research Specialist at the National Aquarium in Baltimore, has also observed this post-release reaction, and has observed "spy-hopping" particularly when the animals are placed in small aquarium systems (personal communication, 4/13/2009). An intriguing study by G.H. Parker (1911) described behaviors similar to "spy-hopping" after severing nerves in the ears of smooth dogfish sharks, resulting in profound disruption of equilibrium.

Although I have not yet gathered conclusive data on this behavior, "spy-hopping" is demonstrated very frequently by sharks that reside in the holding tank (out of public view) of the Indianapolis zoo. This holding area is much smaller than the public exhibit (dimensions are 18ft x 8ft), but considerably deeper (8ft deep), with a surface area of 704 sq ft. Approximately 20 sharks reside in this holding tank, which does not allow much room for normal, continuous swimming activity. In the public exhibit, "spy-hopping" is relatively rare and seems to occur when a shark is startled after running into or being chased by another shark, or handled by a staff member or patron. In the holding tank, "spy-hopping" occurs far more frequently, with several sharks spy-hopping at all times. My preliminary hypothesis on this behavior is that populations of sharks housed in relatively small systems experience "startling" encounters with one another more frequently, resulting in spy-hopping stress responses that occur at a more frequent, constant rate. Agitation to the sensory structures of the sharks in crowded areas may be one mechanism driving the stress response.

Closer investigation of spy-hopping and Stationary behaviors is important to ensure that the animals are provided with a naturalistic and enriching environment in captivity. There is much potential for future research on the smooth dogfish shark in captivity and in the wild. Results from this study alone generate many questions, including: Why do the dogfish prefer a specific area for "resting"? Under what conditions do the dogfish "rest" in the wild? Does electrical activity in the brain change throughout a "resting" period? Is there a "resting" threshold, and what specifically terminates a "resting" period? What causes spy-hopping? How would the introduction of live food in captivity effect activity level and behavior? How does behavior change when thousands of patrons approach the tank in a day (in the summer)? As smooth dogfish sharks become more common in public aquariums, questions such as these should be considered to guarantee good quality of life for this species in captivity.

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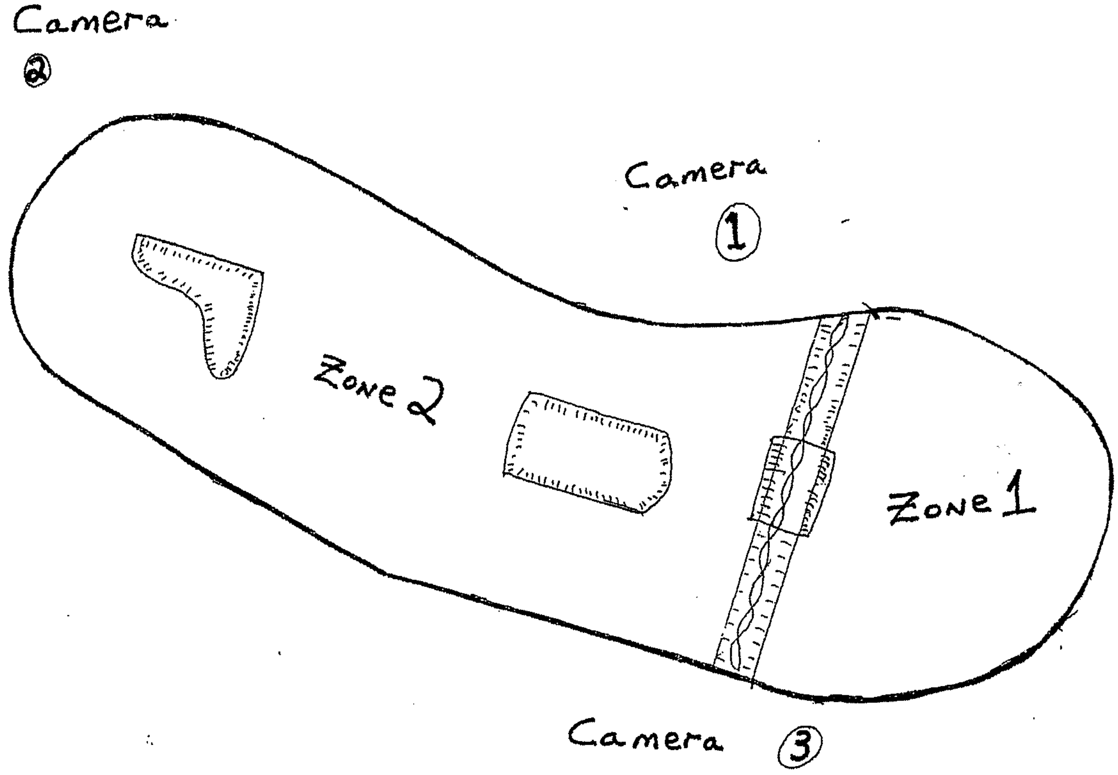
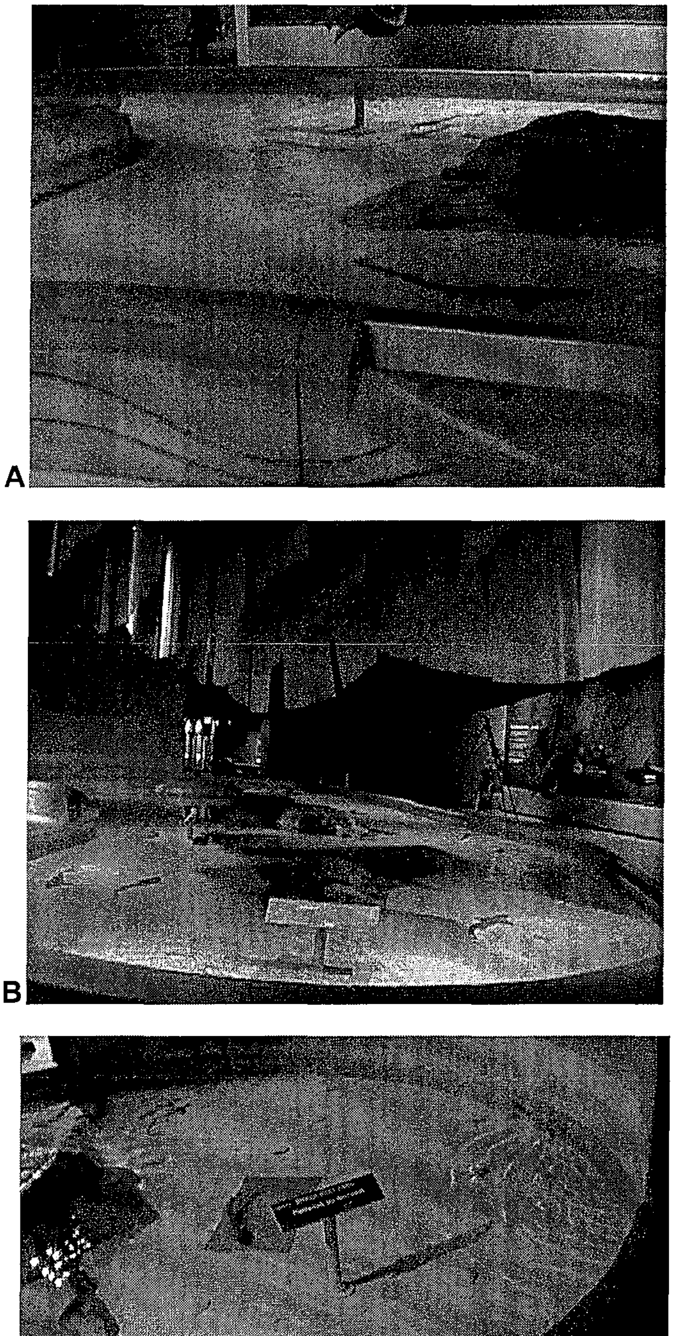


Figure 1: Diagram of main exhibit with camera recording positions, to scale (1cm=4ft).



A B C

Figure 2: View from Cameras 1(A), 2(B), and 3(C). Camera 1 recorded activity level along a designated plane between two rock structures in Zone 2. Camera 2 recorded all of Zone 2 and patron activity. Camera 3 captured shark distribution in Zone 1. All cameras were used to record Stationary behavior.

Table 1: Average number of crosses over the Zone 2 plane across morning and afternoon sessions and feeding and non-feeding days.

	AM	PM
FOOD	4.51	5.25
NOFOOD	4.15	4.51

Table 2: Average number of sharks in Zone 1 at 30s intervals across morning and afternoon sessions, and on feeding and non-feeding days.

	AM	PM
FOOD	4.58	5.12
NOFOOD	4.59	5.19

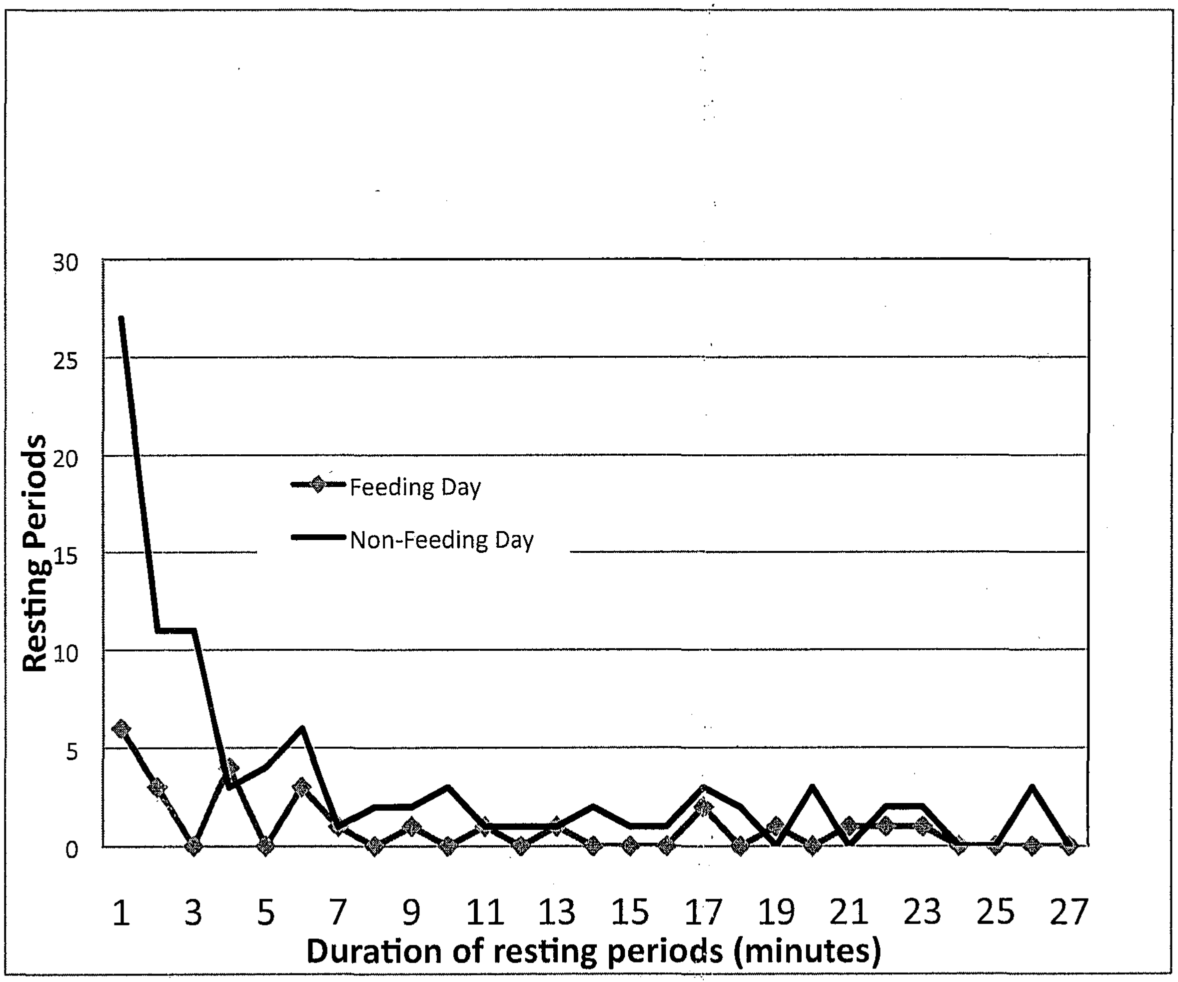


Figure 3: Distribution of Stationary frequency and duration across FOOD and NOFOOD sessions. Resting behavior was more frequent on Non-feeding days, and the majority of resting periods lasted for relatively short durations of 1-2 minutes.