Behavior and Habitat Use of Elasmobranchs in Captivity as an Assessment of Animal Welfare

Submitted by
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Abstract

This thesis project explores the behavior of elasmobranchs (sharks and rays) in captivity at the Michigan Sea Life Aquarium. Little behavioral research is available on elasmobranchs, potentially due to the fact that they are difficult to observe reliably. However, this also leads to a general lack of knowledge about typical behavioral patterns that may impact welfare. Using both scan and instantaneous focal sampling, the location and behavior of seven of these animals was recorded from November 13th, 2018 to June 18th, 2019. As behavior and habitat use are both indicators of animal welfare, these results can be utilized to make positive changes to their current environment. In addition to helping animals currently in the aquarium, these results may aid in positive welfare decisions for elasmobranchs in captivity worldwide, leading to enhanced conservation efforts for these species.

Background

Most of the current behavioral studies done on elasmobranchs have been conducted on wild populations, not on captive populations. Due to this, there is quite a lot of knowledge about how wild populations of elasmobranchs behave in their natural environments. In general, most of the behaviors recorded of elasmobranchs include resting, swimming, group aggregation formation and prey capture/feeding (Carrier, Musick & Heithaus 2004). Elasmobranchs have also been observed performing mating, social and aggressive behaviors as well. Examples include close following and pre-copulatory biting of a potential mate by a male (Chapman et al. 2003; Tricas & Le Feuvre 1985), and social grouping being formed by species such as scalloped hammerhead sharks (Jacoby, Sims & Croft 2011).

How elasmobranchs interact with and use their habitat is another relatively well studied topic. Though there is some commonality between species, many elasmobranchs differ in how they use their environment. Some species, such as blacktip reef sharks and white sharks, are pelagic, meaning they inhabit the upper water columns (Compagno 2008). Other species, such as small-spotted catsharks and southern stingrays, are benthic, meaning they stay closer to the bottom of the sea (Findlay et al. 2016). In wild populations, elasmobranchs also differ in where their home range lies. Some sharks, such as lemon sharks, tend to stay in a restricted home area for most of their lives, whereas some grey reef sharks have been found to be 'nomadic,' with no set home range (Bres 1993). Previous studies also show that factors like prey density and resource availability, in addition to abiotic factors such as water salinity, oxygen levels, and photoperiod, have all been found to influence habitat use as well (Schlaff, Heupel & Simpfendorfer 2014).

Currently, there has been very little research conducted on captive elasmobranchs. There are large population of elasmobranchs in captivity all over the world, including many threatened and endangered species (Janse et al. 2017). Due to this, it is imperative that more research is conducted on these captive elasmobranch populations for conservation purposes.

It has been shown that captive animals that are in a good welfare state perform more species-specific behaviors than abnormal behaviors (Bracke & Hopster 2006). Therefore, this study aimed to compare the behavior and habitat use of elasmobranchs in captivity and compare it to the behavior of wild elasmobranchs in order to determine the welfare state (Ross 2009; Bracke & Hopster 2006). With this in mind, it is important to briefly discuss what the typical behaviors/distribution are in the wild for the species in this study.

The six species assessed in this study were the bonnethead shark (*Sphyrna tiburo*), blacknose shark *(Carcharhinus acronotus*), blacktip reef shark (*Carcharhinus melanopterus*), smooth dogfish (*Mustelus canis*), nurse shark (*Ginglymostoma cirratum*), and southern stingray (*Hypanus americanus*). As different species have been shown to exhibit different behaviors due to different evolutionary histories (Ryan, Phelps & Rand 2001), it is predicted that each species in this study should interact with its environment slightly differently. For example, Bonnethead, blacktip reef, and blacknose sharks all both pelagic, meaning they tend to inhabit the upper water column in the ocean (Compagno 2008). This order of sharks (Carcharhiniformes) are also generally obligate ram ventilators as well, meaning they must be constantly swimming in order to pass water over their gills and respire (Parsons 1990). Therefore, these species of sharks should always be observed in motion and will likely remain in the upper water column in captivity.

Smooth dogfish and nurse sharks, on the other hand, tend to inhabit benthic regions of the water, meaning they are often found along the sea floor (Gelsleichter, Musick & Nichols 1998; Castro 2000). These two species also have an organ called a buccal pump which allows them to continue to respire while remaining motionless (Hughes 1960; Castro 2000). In addition to this, nurse sharks often spend the *majority* of their time resting, often in the same place for long periods of time (Castro 2000). Given this information, these species of sharks in captivity should be seen swimming as well as resting, in addition to other expected behaviors. Southern stingrays are also benthic species that possess buccal pumps, so it is expected that they will be seen resting along the sea floor as well (Findlay et al. 2016).

Given that natural behavior and habitat use can be used to assess captive animal welfare, this study sought to answer two questions: (1) do the animals in the study perform expected species-specific behaviors the majority of the time and (2) do the animals in the study use all of their habitat space effectively? As many of the individuals in this study are of different species, it was hypothesized that they might interact with their environment slightly differently, but still all be reflecting the mannerisms of their species in the wild.

Methodology

Subjects

Seven individuals were observed for this study: a bonnethead shark (female), a blacknose shark *(*female), a blacktip reef shark (male), a smooth dogfish (female), a nurse shark (female), and two southern stingrays (one male, one female).

Exhibit

Observations took place at the SEA LIFE Michigan Aquarium in Auburn Hills, Michigan. The exhibit where the focal individuals resided (called "the Ocean Exhibit") had a volume of 125,000 gallons and a depth of 14 feet. The exhibit aimed to mimic ocean water conditions, with temperature, photoperiod and chemical parameters all held constant. The seven individuals shared the exhibit with about 250 teleost fish and nearly twenty other elasmobranchs. With the exception of the southern stingrays and the black tip reef shark, all focal individuals were the only members of their species in the habitat.

Data collection and analysis

This project was completed by doing observations at the Michigan Sea Life Aquarium from November 13th, 2018 to June 18th, 2019. Initially, an ethogram was devised listing all anticipated behaviors (Fig. 1). The ethogram was made of the previously listed behaviors seen by the species in the wild, as well as behaviors seen during initial observations. Twice a week, observations were taken of the seven individuals at the aquarium using instantaneous and scan focal sampling (Altmann 1974). Observations were conducted in the viewing tunnel for the Ocean Exhibit, which provided a view of virtually the entire exhibit. For every session, each animal was observed separately for ten minutes straight. Scan sampling was done every minute to record the animal's location and behavior, and instantaneous sampling was used whenever an individual exhibited a social, aggressive, or mating behavior. Social behaviors were considered to be seemingly-purposeful behaviors between two individuals where an initiator elicited a response in the recipient, such as deliberately following or resting next to another individual.

Behaviors such as biting or snapping were considered aggressive. Mating behaviors were considered to be pre-copulatory following and biting, followed by clasping.

Observations were recorded using the ZooMonitor program on a tablet (Ross et al. 2016), which allows users to input behavior and location of individual with ease, while also being able to quickly input notes.

In order to randomize observations and eliminate bias, a random number generator was used to determine what day of the week and time at which observations were taken. All seven individuals were then be designated a number one through seven, and a random number generator was used again to determine the order of observations for each session. This was all be recorded on a spreadsheet. By the end of data collection, data was evenly represented so that all animals had their behavior recorded at a variety of times and dates.

After data collection, all "Not Visible" data values were eliminated from the final data set for the purposes of analysis. Time budgets, which show the proportion of time each behavior was recorded, were created for each individual. Utilizing the feature in ZooMonitor, heat maps were also created for each individual, which represent density of location values in the exhibit as shades of color (Gehlenborg & Wong 2012; Wark et al. 2019). These heat maps were then used to determine where each individual spent the majority of their time in the exhibit, as well as to see if they were using all habitat space provided for them. For these heat maps, darker colors (blues and greens) represented a lower frequency of data points, whereas lighter colors (yellows and reds) represented a higher frequency. These data were then interpreted in order to determine if habitat space was evenly used. A 50x50cm grid was then placed over each heat map in order to divide the exhibit into three equal sections of 245cm^2: the front of the exhibit, the back of the exhibit, and the perimeter. Each section of the maps was then colored, with the front being yellow, the back being blue and the perimeter being red (Fig 2). The data points in each section were then counted, and the percentage of time the individuals spent in each section was calculated.

Data for the individuals was then compared with the expected behaviors for the species to evaluate the overall welfare of the animals in the exhibit. Animals in a good welfare state were expected to use all of their habitat space evenly and perform a high level of species-specific behaviors.

Behaviors	*Definitions*
Swimming	Moving through the water from one part of the exhibit to another
Darting	Quickly moving through the water from one part of the exhibit to another in response to a stimulus
Eating	Consuming food items, either from a target or from being thrown into the exhibit
Resting	Lying motionless along the exhibit floor while continuing to respire
Swimming in place	Moving against a water current, resulting in no change in location
Flashing	Rubbing a part of the body against an object or another animal
Stereotypic behavior	Moving through the water in a fashion abnormal to the species (i.e., swimming upside down or sideways)
Not visible	Out of view; behavior cannot be determined

Figure 1. An ethogram of the behaviors expected to be seen by the individuals in this study. The behaviors included were both behaviors expected to be seen based on the species in the study, as well as behaviors noticed of the specific individuals in the study during pre-study observations

Results

Nurse Shark

In total, 238 data points were collected for the nurse shark. The two most frequent behaviors she displayed were resting (77.3% of the time), and swimming (21.0% of the time). She was also noted to be swimming in place and eating as well (Fig. 2A). She spent the 84.9% of her time in the lower water column of the exhibit. In addition, she appeared to have some areas she preferred resting in over others, such as on top of the visitor tunnel. Nevertheless, she was observed exploring all aspects of the exhibit, with her spending 46.2% of the time in the front of the exhibit and 45.0% of the time in the back of the exhibit (Fig. 3A). She spent the least amount of time on the perimeter of the exhibit, at 8.8%. In addition, she was recorded as performing eleven social behaviors, eight of which were during feeding time (Fig. 4).

Blacknose Shark

238 data points were collected for the blacknose shark. She spent almost all of her time swimming (98.5%) but was also noted to occasionally dart as well (Fig. 2B). She spent 91.7% of the time in the upper water column, and only 8.3% in the lower water column. In terms of distribution, she spent 51.9% of her time at the perimeter, 20.5% at the front of the exhibit and 27.6% in the back (Fig. 3B). She was observed performing three social behaviors and two aggressive behaviors (Fig. 4).

Bonnethead Shark

244 data points were collected the bonnethead, and she was observed as swimming for 100% of the time (Fig. 2C). This was the only individual in this study observed performing only

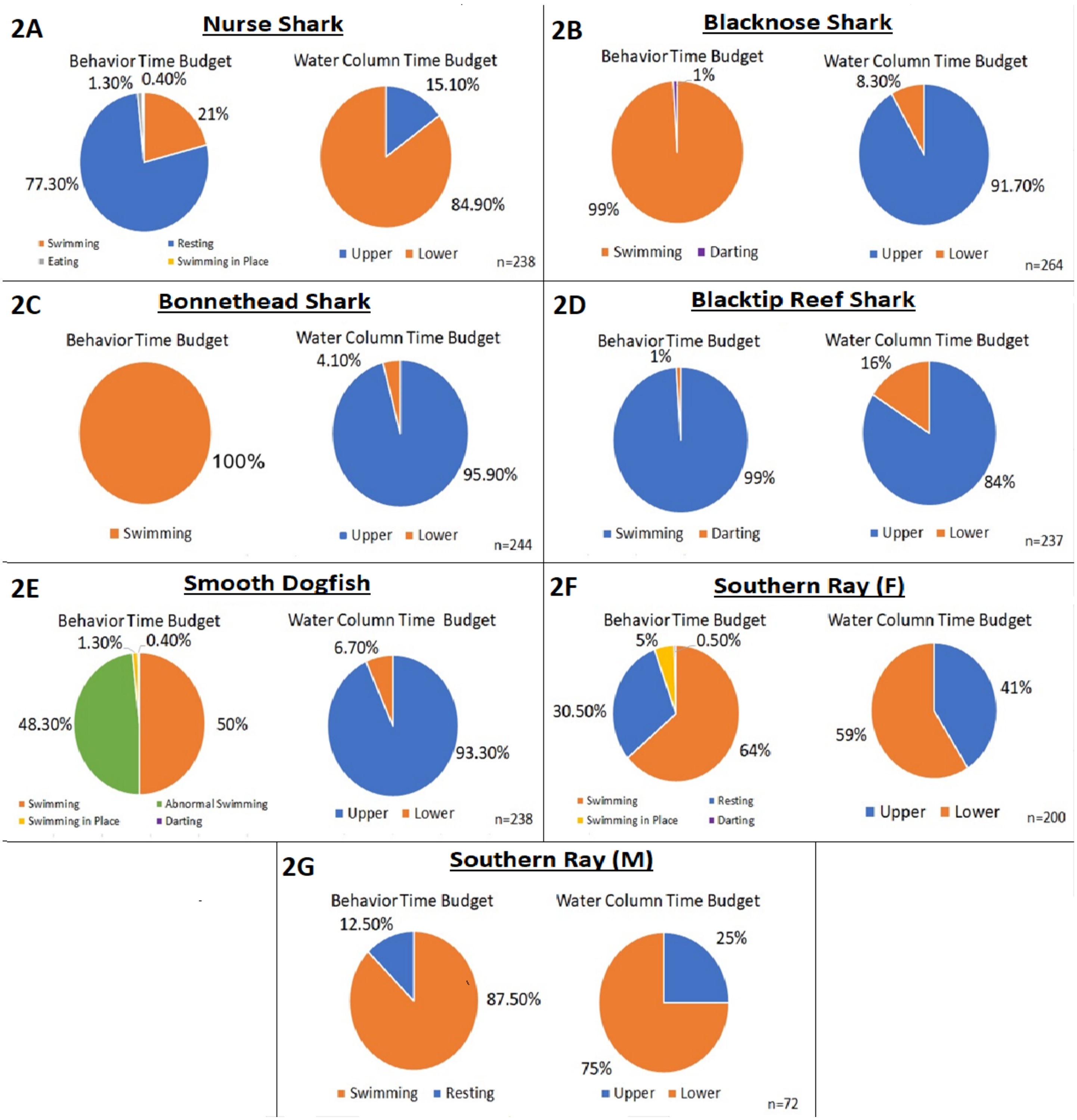

Figure 2. Time budgets for behavior and water column use for all seven individuals in the study. The percentages refer to the proportion of observation time seen performing a particular behavior or inhabiting the upper/lower water column.

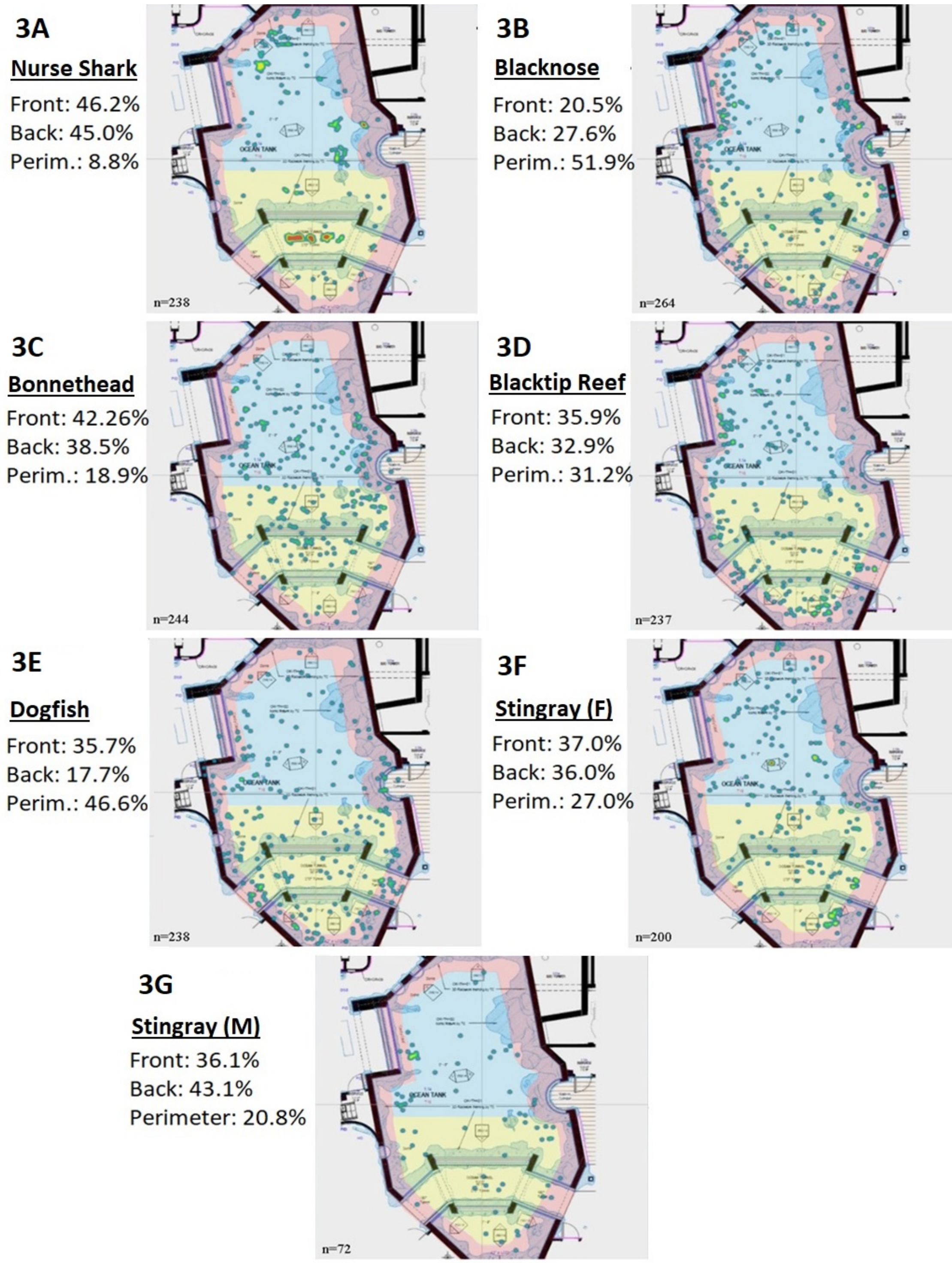

Figure 3. Heat maps for all seven individuals in the study, as well as the proportions of time each individual spent in the front (yellow), back (blue) and perimeter (red) of the exhibit. Each dot represents one data point. Areas dense with data points are portrayed as warmer colors (yellows, reds) whereas areas with fewer data points are portrayed as darker colors (blues, greens).

one behavior. She spent 95.9% of her time in the upper water column of the exhibit and only 4.1% in the lower water column. In terms of habitat use, she spent 42.6% of the time in the front, 38.5% of the time in the back and 18.9% of the time at the perimeter (Fig. 3C). In addition, she was seen performing one social behavior and one aggressive behavior (Fig. 4).

Blacktip Reef Shark

237 data points were collected for the blacktip reef shark. He was almost exclusively seen swimming (99.0% of observations) but was noticed darting as well (1.0% of observations; Fig. 2D) . He spent 84.0% of his time in the upper water column and 16.0% in the lower water column. The blacktip's distribution was the most evenly dispersed out of all animals, with 35.9% of the time spent in the front, 32.9% of the time spent in the back and 31.2% of the time spent along the perimeter (Fig. 3D). He was also observed performing one social behavior (Fig. 4).

Smooth Dogfish

In total, 238 data points were collected for the smooth dogfish. She was the only individual in the study to be observed performing abnormal or stereotypic behaviors, of which she performed nearly half of the time (48.3%; Fig. 2E). In addition, she was also observed swimming normally (50.0% of the time), darting (0.4% of the time) and swimming in place (1.3% of the time). She spent nearly all of her time in the upper water column as well (93.3%) but was occasionally spotted in the lower water column (6.7%). This individual had a relatively even distribution for the perimeter and front of the exhibit, spending 46.6% and 35.7% of her time in each section, respectively (Fig. 3E). She was least often found in the back of the exhibit, observed there only 17.7% of the time. She was observed performing social behaviors twice and aggressive behaviors four times, which was the most frequent out of all other individuals (Fig. 4).

Southern Stingray (F)

200 data points were recovered for the female southern ray. She was observed swimming 64.0% of the time, resting 30.5% of the time, as well as swimming in place and darting a minor percentage of time (Fig. 2F). In addition, she spent 59.0% of observation time in the lower water column. She was relatively evenly distributed throughout the exhibit, spending 37.0% of the time in the front of the exhibit, 36.0% of the time in the back and 26.0% of the time along the perimeter (Fig. 3F). She was observed performing social behaviors thirteen times, which was the most out of any individual in this study (Fig. 4).

Southern Stingray (M)

In total, only 72 data points were recovered for the male southern stingray. During the course of this study, the male stingray was occasionally moved off exhibit and eventually moved to a completely different exhibit due to negatively impacting some of the other animals. This resulted in having substantial less data for this individual (n=72; as opposed to the average of n=237). However, the limited data on this individual showed that he spent 87.5% of his time swimming but was observed resting 12.5% of the time as well (Fig. 2G). For water column usage, he spent 25.0% of the time in the upper water column and 75.0% of the time in the lower water column. He spent 36.1% of the time in the front of the exhibit, 43.1% of the time in the back and 20.8% of time along the perimeter (Fig. 2G). This individual was also observed performing social behaviors six times (Fig. 4).

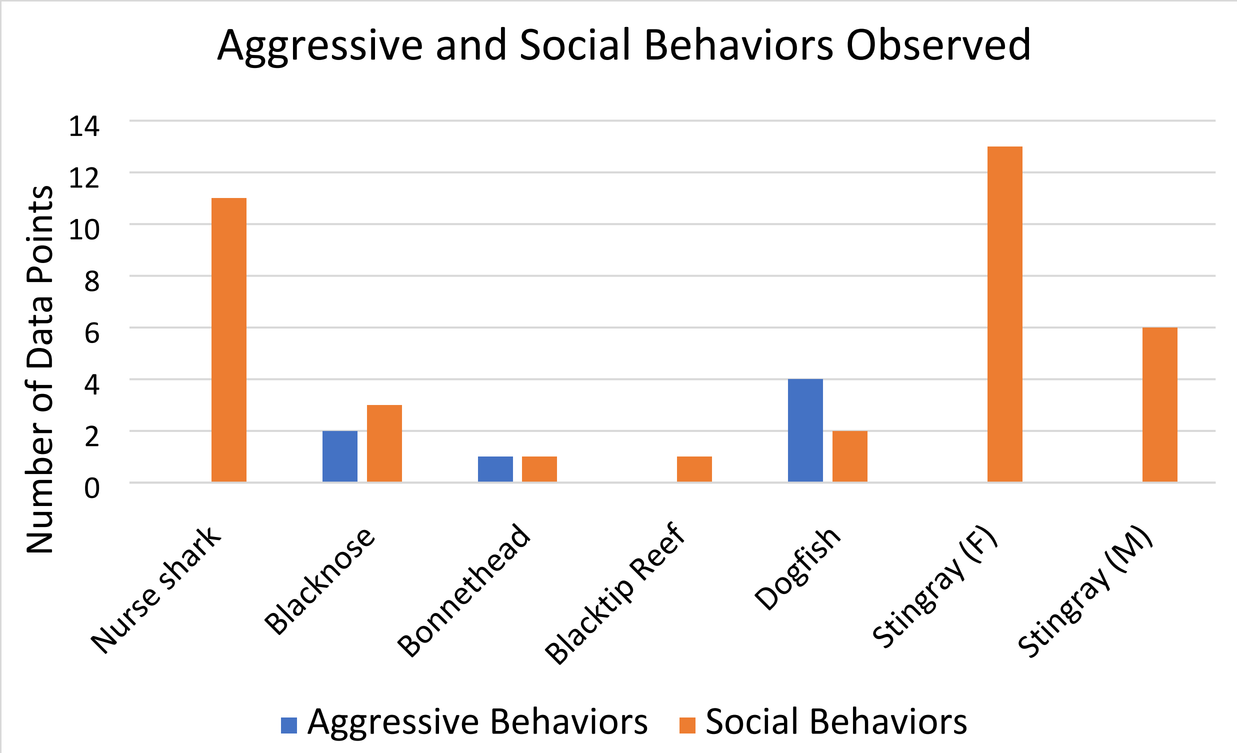

Figure 4. The number of instances each individual was observed performing an aggressive or social behavior. Aggressive behaviors included behaviors such as snapping or biting, and social behaviors included following and nudging.

Discussion

Given the results of this study, the welfare of the focal animals was determined to largely positive, with the exception of the dogfish. All other individuals in this study both performed behaviors expected for their species, as well as distributed themselves in in their exhibit as expected given data in their natural habitat.

The blacktip reef shark, the bonnethead shark, and the blacknose were all almost exclusively seen in the upper water column and swimming (Fig. 2B, 2C, 2D). Given that these sharks are obligate ram ventilators that swim in pelagic waters (Compagno 2008), this behavior is expected. Darting behaviors were occasionally noticed but given that they often occurred due to unexpected events such as two individuals running into each other, it is unsurprising that they were infrequent. The nurse shark was observed resting the majority of the time, which is expected for the species in its natural habitat (Castro 2000). She was also seen in the lower water column most of the time, which is typical in the wild for a benthic species (Gelsleichter, Musick & Nichols 1998). This smooth dogfish was also the only one who was noticed eating, simply because this individual ate much slower than the others, so the one minute intervals were short enough to record this behavior. For all other individuals, food was often thrown into the exhibit and consumed within seconds, which was far too quick to be measured in the scans. The southern stingrays also behaved as expected, even though much less data was collected for the male stingray than the female. Both individuals spent most time in the lower water column and were very commonly seen resting. These behaviors are all consistent with the behaviors of southern stingrays in the wild (Findlay et al. 2016).

In terms of habitat use, all individuals (except for the dogfish) seemed to use the provided space slightly differently, but none of them appeared to be actively avoiding any areas (Fig. 3). The nurse shark clearly had a preferred area, right above the viewing tunnel (Fig. 3A). This is the place she was very commonly seen resting (90/238 data points). In addition, the blacknose shark was also commonly seen along the exhibit's perimeter (Fig. 3B). Overall, data points for each individual were recorded relatively evenly distributed throughout the exhibit.

Social and aggressive behaviors were rare, but some individuals participated in them more often than others. In terms of social behaviors, the female southern stingray and the nurse shark performed them the most often (Fig. 4). These two individuals often partook in these social interactions with each other, very commonly resting next to and following each other. For aggressive behaviors, the smooth dogfish performed them the most, often snapping at other individuals (Fig. 4).

The smooth dogfish was the only individual in the study observed performing abnormal behaviors. These abnormal behaviors included swimming upside-down and surface-breaking. She was also observed almost exclusively in the upper water column, where she performed her abnormal behaviors. In addition, she was the only individual who spent significantly less time in the back of the exhibit. This individual also clearly had a skewed swimming pattern, as she would often only swim along the perimeter of the front of the exhibit and would cut across in the middle to avoid the back half. While along the perimeter, she would often be either upside-down or sideways, and was even spotted spiraling in circles occasionally. Comparing this individual to smooth dogfish in the wild, it is very clear that she is behaving abnormally. Given that she is a benthic shark, she should be seen most often along the lower water column (Gelsleichter, Musick & Nichols 1998). Most striking, however, was the fact that this individual was never observed resting, even though she had the correct physiology to do so. It was expected that she would behave most like the nurse shark, but instead behaved in almost the exact opposite way. These factors led to the conclusion that this individual was in a poor welfare state. It was found, however, that introducing individual-specific enrichment dramatically decreased the frequency of abnormal behaviors, increased her habitat use, and even led to her performing more species-specific behaviors, specifically resting (Hart et al. in prep).

Conclusions

Although millions of aquatic animals live in aquariums globally (Janse et al. 2017), this study is one of the first to assess the welfare of elasmobranchs in captivity. This fact highlights a dramatic gap of knowledge in this area of animal behavior, as these animals are being grossly overlooked. While the majority of the individuals in this study behaved as predicted, it is important to note that one individual behaved in a very unexpected fashion. As this study showed, these captive aquatic animals are just as capable of displaying abnormal behaviors as any other terrestrial species, and display of abnormal behaviors in aquarium species is likely severally underreported. Therefore, more observational studies need to be performed in aquariums around the world to assess the welfare state of their animals. Becoming aware of poor welfare is the first step in devising a plan to mitigating the problem and increasing overall welfare for an individual.

Conducting more observational studies on captive aquatic species can have profound impacts for the conservation of these species as well. By paying attention to how individuals use their environment in captivity, researchers can potentially learn how they might interact with their environment in the wild. In addition, improving welfare state for these animals can be beneficial to their health, which can help in maintaining these captive populations of elasmobranchs (Mason 2010).

In conclusion, by increasing awareness about captive elasmobranch behavior, more attention can be paid to the welfare of these animals, and the quality of life for elasmobranchs living in captivity can be greatly enhanced.

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Biographical Note

I am a biology major with a pre-veterinary concentration. I've always had a passion for animal welfare and knew that I wanted to pursue a career focused around helping animals. I originally thought I wanted to be a veterinarian, but I have since learned that there are many different paths you can take and still help animals. I previously worked at the Humane Society of Huron Valley as an animal care technician, and I was extremely passionate and proud of the work I was able to do there and the impact I have on the animals' lives at the shelter. I am currently thinking of going animal welfare and become a zookeeper once I finish my degree at Oakland University. I would one day like to attend graduate school and get my PhD and study animal behavior and cognition. This project ties in with my academic goals because I am highlighting a field of animal behavior that is relatively untapped. Knowing an animal's behavior is one of the first steps to learning how to conserve a species and given that there are many elasmobranch species that are endangered, this information could potentially be invaluable.

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