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Effects of Guest Interactions on Cownose Ray (Rhinoptera bonasus) Behavior in a Zoo Touch Tank

Lauren Hope
Montclair State University

ABSTRACT

Touch tanks are increasingly popular exhibits at zoos and aquariums, and are at the center of scientific engagement with the public. Touch tanks can provide benefits to marine species through conservation outreach and research, and to guests through education, recreation, and stress reduction. Cownose rays are a popular species found in touch tanks due to their putative stress tolerance and docile nature. Yet, questions remain about ray tolerance to captivity, and studies are rare on their behavioral responses to touch tank environments and guest interactions. Here, I used an observational study to examine: (1) baseline ray behavior in a touch tank environment; (2) how rays in the touch tank respond to guest interactions, including apparent stress responses; and (3) whether rays demonstrate individual variation in these responses. I found that captive rays spent less than 4% of their time interacting with guests and displayed a range of typical ray behaviors, had an increase in stress behaviors with guest crowding, were more likely to approach a hand with food than without food, preferred adult over child guest interactions, and varied individually in their responses and apparent stress tolerance to guest interactions. Based on these findings, I recommend that guest numbers should be limited and that the suitability of rays for touch tanks should be individually assessed and monitored. This study of guest-ray interactions gives us crucial insight into ray behavior that can lead to improved management of captive rays, conservation opportunities for wild rays, and an enhanced guest experience.

MONTCLAIR STATE UNIVERSITY

Effects of guest interactions on cownose ray (*Rhinoptera bonasus*) behavior in a zoo touch tank

by

Lauren Hope

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[redacted]

Dr. Colette J. Feehan, Thesis Sponsor

[redacted]

Dr. Cortni Borgerson, Committee Member

[redacted]

Dr. Julian Paul Keenan, Committee Member

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LAUREN HOPE

Montclair State University

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INTRODUCTION

Zoos provide the general public with an opportunity to closely experience wildlife, inspiring a conservation ethic for even rarely observed or poorly understood species (Kopczak et al. 2013). Globally, 75% of zoos offer interactive exhibits that allow guests to physically interact with their animals (Spooner et al. 2021). Of these allowed interactions, 43% of zoos offer opportunities to touch and 23% to feed the animals (Spooner et al. 2021). These include interactive touch tank exhibits that offer guests the opportunity to touch and feed aquatic animals (Biasetti et al. 2020). Touch tanks provide an educational experience to guests, increasing their exposure to marine animals and encouraging guests to consider the behavior and ecological importance of the world's marine species (Kopczak et al. 2013). Such feelings increase the likelihood that guests will discuss marine conservation beyond the zoo limits, increasing the visibility of this topic often overlooked by society (Kopczak et al. 2013). Touch tank interactions benefit guests as well as support marine conservation, as interacting with the animals decreases stress and increases positive feelings in guests (Sahrmann et al. 2015). Yet, touch tanks come with the responsibility to maintain the health and wellbeing of the marine animals held within them. Many species display behavioral changes during interactions with guests–in response to both physical and non-physical interactions (Boyle et al. 2020). Understanding how these behavioral changes translate to animal health and wellbeing is crucial. Thus, touch tank species could greatly benefit from a sound scientific backing behind the strategies used to care for them (McCormick-Ray 2005).

The subclass Elasmobranchii (rays and sharks) includes species commonly held in touch tank exhibits (Mylniczenko 2012). Rays are often selected as touch tank species because of their putative high tolerance to stress (Dogu et al. 2011). For example, the cownose ray (*Rhinoptera bonasus*) is a species common in touch tank exhibits that is currently vulnerable to extinction in the wild (Carlson et al. 2020). As such, touch tank exhibits are important for promoting cownose ray conservation. Given that cownose rays have a lengthy gestation period, require years to mature, and typically only produce a single pup (Rangel et al. 2018), touch tank exhibits can provide unique insights into their reproduction, particularly given the difficulty of tracking them in the wild over their ~14 year lifespan (Poulakis et al. 2013, Carlson et al. 2020). In the wild, cownose rays inhabit tropical and temperate oceans and estuaries worldwide, making them an important species to study (Neer et al. 2005). Cownose rays are bottom feeders, using their strong jaws to eat mollusks, crustaceans, and polychaetes (Sasko et al. 2006). Touch tanks may allow scientists to study these feeding behaviors more closely.

It is clear that ray touch tank displays provide a learning opportunity for humans; however, little is known about how life in captivity affects ray health and wellbeing (Lawrence et al. 2021). A previous study found that wild rays at sites frequented by tourists had higher oxidative stress and other adverse health effects as compared to rays at non-tourist sites (Semeniuk et al. 2009). While this study did not directly assess the response of rays to guest interactions in captivity, it does indicate negative effects of human interactions on rays in the wild (Semeniuk et al. 2009). Effective captive care may depend on: (1) a properly designed enclosure, as it has been found that enclosures similar to a natural environment, with proper physical enrichment, cause rays to display more natural behaviors (Lawrence et al. 2021, Sabalones et al. 2004, Zhang et al. 2022); and (2) routine physical and behavioral checks to ensure continued overall animal health and wellbeing in response to the captive environment and guest interactions (Spooner et al. 2021). Unfortunately, few studies have examined the effects of captive conditions on rays (Greenway et al. 2016) and little is known about how the behavior of captive rays varies in response to these pressures, at both a species and individual level, hindering the capacity to provide the best possible care.

Here, I examine the interactions between rays and guests in a touch tank exhibit in New Jersey, USA, with the goal of improving both animal health and wellbeing and guest experience. I use 20,617 behavioral observations recorded over a six month period to examine: (1) baseline ray behavior in a touch tank environment; (2) how rays in the touch tank respond to guest interactions, including apparent stress responses; and (3) whether rays demonstrate individual variation in these responses. The information gathered here can begin to fill important knowledge gaps in the care and maintenance of rays in touch tank environments and improve zoo guest experience. This could act to minimize adverse health risks to animals while maximizing the potential for conservation benefits.

METHODS

Ethics

I received IACUC approval from Montclair State University (#2021-071). The study was conducted with the approval of Turtle Back Zoo, and all animals were treated within Association of Zoos and Aquariums (AZA) guidelines (aza.org)

Study Site

The study took place at the Turtle Back Zoo, located in Essex County, New Jersey. This AZA certified zoo manages over 33 exhibits for terrestrial and aquatic animals. The zoo receives 755,000 guests annually and has a focus on conservation and education (Turtle Back Zoo 2022). The study occurred at a 1,600 gallon indoor touch tank exhibit that houses both rays and sharks. The touch tank contains 12 cownose rays (*Rhinoptera bonasus*; five adult females, two adults males, two juvenile males, and three newborns), two Atlantic rays (*Dasyatis subina*; both adult males) and six epaulet sharks (*Hemiscyllium ocellatum*; one adult female, five adult males). I focused on the five adult female cownose rays (*Rhinoptera bonasus*) in the tank and their interactions with guests (children and adults). The adult female cownose rays were selected due to their possible importance in representing the reproductive potential of the captive population. The keepers add daily enrichment to the tank that includes hollow pipes, pool noodles, hoops, and frisbees. Enrichment typically stays consistent daily but new items are added occasionally. The data were collected by two observers (LH and MM) from February to July 2022.

Guests interacted with the rays through physical touch (two fingers gently placed on their backs or wings) or through feeding (small fish purchased by the guest and then placed between two fingers that the rays can approach and take from the guest). From here on, the term "food" used in this study refers to guest feeding interactions with purchased fish. Rules are in place–guests must follow the two finger touch rule, are only permitted to feed rays with the fish provided by the zoo, must remove all jewelry from hands, and must wash hands with only water before touching the rays. Guests are asked to keep their volume low when in the touch tank room. There are no time limits to guest interactions or limits to the number of guest interactions occurring at once.

Figure 1. The study touch tank containing rays and sharks at the Turtle Back Zoo, located in Essex County, New Jersey. Photo credit: Lauren Hope.

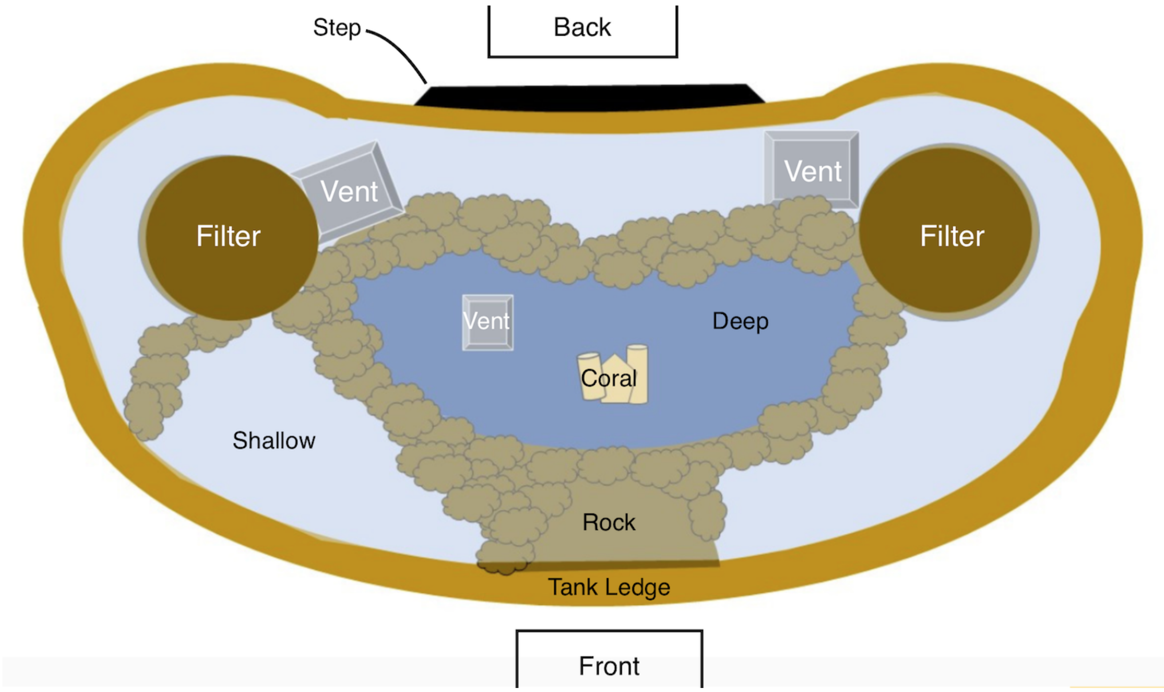

Figure 2. Graphic created of the touch tank exhibit and used to document the location of rays and guests presented in Figure 3 and 4, at the Turtle Back Zoo, located in Essex County, New Jersey.

Data Collection and Analysis

20,617 data points were collected using the mobile application software ZooMonitor (Lincoln Park Zoo, 2022; ZooMonitor, Version 4.1). Data were collected by the two observers in the same session once a week between the hours of 8am and 3pm for approximately three hours per session. The observers used two main data collection methods to quantify guest-ray interactions and behavioral responses: time-point and all-occurrence sampling. “Time-point sampling” captured ray behavior at regular intervals (5 min) to characterize how rays spend their time in a touch tank. “All-occurrence sampling” documented any occurrence of an interaction with guests during a session, as these were not likely to be captured by the time-point sampling given the relative rarity of guest interactions. During time-point sampling, one focal female cownose ray was observed at a time. Each observer followed the ray closely around the perimeter of the tank during the session. At five-minute intervals the ray's location and behavior were recorded (solitary swim, solitary rest, social swim, social rest, colliding with another ray, ray is vertical near ledge, ray has swam into the wall). During time-point sampling, interactions with people, enrichment, and mating were recorded if they occurred. Each of the five female rays were observed consecutively for 30 min with time-point sampling during a session. To ensure that both observers did not record the same ray at the same time, observers would set an observation schedule beforehand. Guest count and location were also recorded at each five-minute interval. For all-occurrence sampling, behaviors of the same focal ray as in the time-point sampling were recorded that involved eating, mating, interacting with enrichment, or guests in different ways (when guests reached out to rays above the water surface [no contact], below the water surface [no contact], directly contacted them physically, contacted the touch tank ledge, fed the rays or interacted inappropriately with the rays–e.g., broke the two finger rule, splashed the ray, etc.). During guest interactions, guest age was recorded as either child (guests age 12 and under) or adult (guests age >12), as estimated by the observer. I used the observations of rays and guests to answer the following three main questions:

<u>How do rays behave in touch tanks?</u>

To understand how rays behave in captivity, I quantified behavioral budgets using time-point data to calculate the percentage of data points (time) the rays spent doing each of the behaviors listed above on an individual level as well as group averages. I analyzed these baseline behaviors to examine how the rays behave when anthropogenic factors (feeding and touching) are not present. I included a general category of guest interactions as part of their behavioral budget to quantify the portion of the ray's time spent interacting with guests.

How do rays interact with guests at touch tanks?

To understand how rays interact with guests, all-occurrence sampling data were used, as that was how the majority of the guest interaction data were recorded. I calculated the average group percentage of datapoints (time) the rays spent in each type of guest interaction (i.e. guest hand above the water, below the water, touching the ray, leaning on the ledge of the tank, feeding, and inappropriate ray-guest interactions) along with their responses (i.e. approach, avoid, linger, or ignored a hand) to those interactions.

I ran partition analyses to rank the importance of guest and ray traits in predicting a ray's response to a guest interaction (including guest age [adult vs. child], food stimulus, and ray identity). I used t-tests to determine the significance of these predictors (guest age, food stimulus, and ray identity) in determining ray response to guest interactions.

How do guest numbers affect ray behavior?

To specifically examine how guest number affected ray behavior, all-occurence (guest number) and time-point sampling (behavior and location) data were used. I used linear and general linear models (GLMs) to examine the effects of guest number on ray responses (whether they approached, lingered, avoided, or ignored a hand). I determined the number of guests at which ray behavior significantly changed (e.g. time spent resting) using a partition analysis. I created heat maps using ZooMonitor to identify how guest location around the tank affected ray location and spatial use of the tank.

How do individual rays demonstrate variation in behavioral responses to guest interactions?

To determine variation in behavioral responses to guest interactions on an individual scale, I used both time-point (general behavior) and all-occurrence (guest interactions) data. I used Chi-square analyses to determine: (1) if individual rays spent their time differently from each other; (2) whether guests interacted preferentially with certain rays; and (3) how behavioral responses to guest interactions differed between rays. Rays were classified into one of two types of rays: bold (50.00% or higher approach rate to guests) and shy (49.99% or lower approach rate to guests). I examined how spatial use varied between bold and shy rays using heat maps created in ZooMonitor.

Ethogram

The ethogram that was used for this behavioral observation-only study to record the behaviors of the cownose rays (*Rhinoptera bonasus*) at the Turtle Back Zoo is available as supplementary materials (adapted from Boyle et al. 2020).

RESULTS

How do rays behave in touch tanks?

Although rays spend their time surrounded by guests, less than four percent (3.64%) of a ray's time is spent interacting with guests. Of the time rays spent not interacting with guests, they spent most (55.26%) of this time swimming solitarily, followed by socially swimming with other rays (21.94%), resting with other rays (14.70%), and resting solitarily (8.09%) (Table 1). Rarely, rays also bumped into other rays while swimming (0.10%).

Table 1: Percentage of time spent in social vs. solitary resting or swimming behaviors by individual rays. Data are from time-point sampling.

Focal Ray	Social Rest %	Social Swim %	Solitary Rest %	Solitary Swim %
Sugar	0.51%	26.15%	1.54%	71.79%
Tsunami	20.86%	21.93%	7.49%	49.73%
Mocha	17.61%	17.05%	8.52%	56.82%
Stumpy	13.43%	21.89%	9.95%	54.73%
Diamond	21.08%	22.70%	12.97%	43.24%
Mean	14.70%	21.94%	8.09%	55.26%

How do rays interact with guests at touch tanks?

The most common ray interaction with guests was when a guest touched the rays underwater (88.50%). Less frequently, guests also reached underwater without touching a ray (6.33%), leaned against the ledge of the touch tank (2.64%), reached their hand out to a ray above the surface of the water (1.48%), and inappropriately interacted with a ray (1.05%). Feeding interactions were only a small part of all interactions that took place (6.80%). Of the aforementioned interactions with a guest hand, rays primarily ignored the hand's presence (45.78%), followed by approaching (28.43%), avoiding (14.49%), and lingering (11.30%) by a hand (Table 2).

I could predict how a ray responded to a guest's hand using both ray and guest traits (partition analysis: R^2=0.09). The most important predictor of a ray's response to a guest was whether or not that guest held food (R^2=0.04), followed by ray identity (R^2=0.03), and guest identity (R^2=0.02). When food was present, rays were significantly more likely to approach a guest's hand than when it was not ($\chi2$=70.05, R^2=0.06, p<0.0001; 80.36% vs 25.03% of interactions resulted in a rays approach, respectively). When food was not present, individuals responded differently from one another; two 'bold' rays (Sugar and Tsunami) were more likely to approach hands without food (34.11% of interactions without food resulted in an approach) than 'shy' (Mocha, Stumpy, and Diamond) ones (15.84%) ($\chi2$=38.69, R^2=0.04, p<0.0001). However, bold rays were more likely to approach adults than children (58.33% vs 31.64% of interactions resulted in approach). Overall, all rays approached adults more than children when food was not present ($\chi2$=13.75, R^2=0.01, p<0.0002; 36.53% of adult vs 22.24% of child interactions resulted in a ray approach when food was not present). As the number of people at the touch tank increased, rays were significantly less likely to approach hands without food items ($\chi2$=3.95, R^2=0.005, p=0.03). While rays may ignore a hand with food, they always approached or lingered near hands with food, regardless of guest number (no variance).

How does guest number affect ray behavior? As the number of people in the room increased, significantly fewer rays approached the hands that entered the tank (R^2 (DF 1, 173)= 0.04, F= 6.66, p= 0.01). Even when controlling for increased interactions with guest presence, rays were less likely to approach any given hand as the number of people at the touch tank increased ($\chi2$=28.57, R^2=0.01, P<0.0001). However the number of people at the tank did not similarly affect either the number of interactions, or the likelihood that any given interaction, resulted in a ray avoiding (R^2 (DF 1, 108)= 0.01, F= 0.88, p= 0.35; R^2 (DF 1, 108)<0.01, F= 0.41, p= 0.52), lingering by (R^2 (DF 1, 77)= 0.03, F= 2.44, p= 0.12; R^2 (DF 1, 77)= 0.01, F= 0.52, p= 0.47), and/or ignoring (R^2 (DF 1, 244)= <0.01, F= 0.06, p= 0.80;(R^2 (DF 1, 244)= <0.01, F= 0.76, p= 0.38) a hand. A partition analysis showed that after the number of the guests in the room were equal to, or exceeded, 68, rays were significantly less likely to approach hands and more likely to avoid them (R^2=0.01).

As the number of guests increased at the tank, rays spent significantly less time resting and more time swimming and interacting with guests ($\chi 2$=76.20, R^2=0.09, $p<0.0001$). A partition analysis showed that when there were five or more guests at the tank, the rays swam more (62.21% vs. 82.81%) and rested less (36.21% vs.10.22% of their time), with resting time decreasing to less than 4.12% when guest number exceeded 31 (R^2=0.12). Rays rested in areas where guest-ray interactions occur less frequently (Figure 3). During the less busy times of this study (February to April), guests primarily interacted with the rays at the front of the tank closest to the entrance and in the back of the tank where there is a stepping stool to help smaller children reach inside the tank. When the exhibit had more guests (May–July), instead the entire perimeter of the tank was occupied with guests as they squeezed in anywhere they could to interact with the rays (Figure 3). During these times, the rays were often moving more, which is demonstrated in the heat map in Figure 3. Resting decreased while swimming rates increased as guest counts went up.

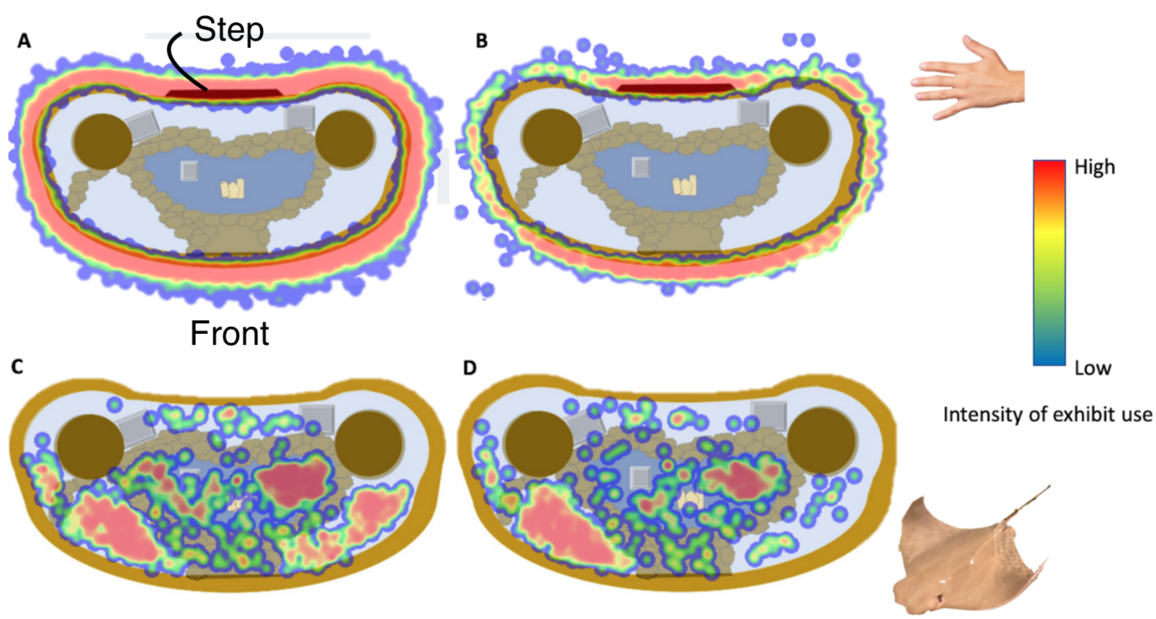

Figure 3: Variation in spatial use by cownose rays in relation to guest location during peak and non-peak seasons. (**A**) Average spatial use of guests during peak season (May-July), compared to (**B**) non-peak season in relation to (**C**) average female ray spatial use in peak season and (**D**) non-peak season.

How do individual rays demonstrate variation in behavioral responses to guest interactions?

While rays spent their time differently from one another ($\chi2$=129.30, $p<0.0001$; Table 1), guests did not preferentially interact with certain rays ($\chi2$=6.01, p=0.65). However, individual rays responded differently to guests depending on the individual ($\chi2$= 103.15, R^2=0.05, $p<0.0001$) and their personality type ($\chi2$= 41.33, R^2=0.02, $p<0.0001$; Table 2); bold rays were more likely to approach, whereas shy rays were more likely to avoid or ignore a hand (Table 2).

Table 2: Contribution of each ray individual to the total observed guest interactions (%) and the breakdown for each individual of their interaction types (approach, avoid, linger, and ignore; %) of those interaction types across all rays. Data are from all-occurrence sampling.

Personality Type	Focal Ray	Total Guest interaction %	Approach %	Avoid %	Linger %	Ignore %
Bold	Sugar	27.05%	36.42%	8.06%	15.82%	39.70%
	Tsunami	17.61%	36.89%	13.11%	1.64%	48.36%
Shy	Mocha	20.21%	24.71%	9.41%	18.24%	47.65%
	Stumpy	18.16%	20.89%	23.42%	6.96%	48.73%
	Diamond	16.96%	13.60%	28.80%	4.80%	52.80%
All	All	100% (total)	28.43% (mean)	14.49% (mean)	11.39% (mean)	45.78% (mean)

The individual rays used the spaces in the touch tanks differently from one another. Bold rays spent their time in areas of the tank with easier access to guests, while shy rays were typically found in areas that were harder for guests to reach (Figure 4).

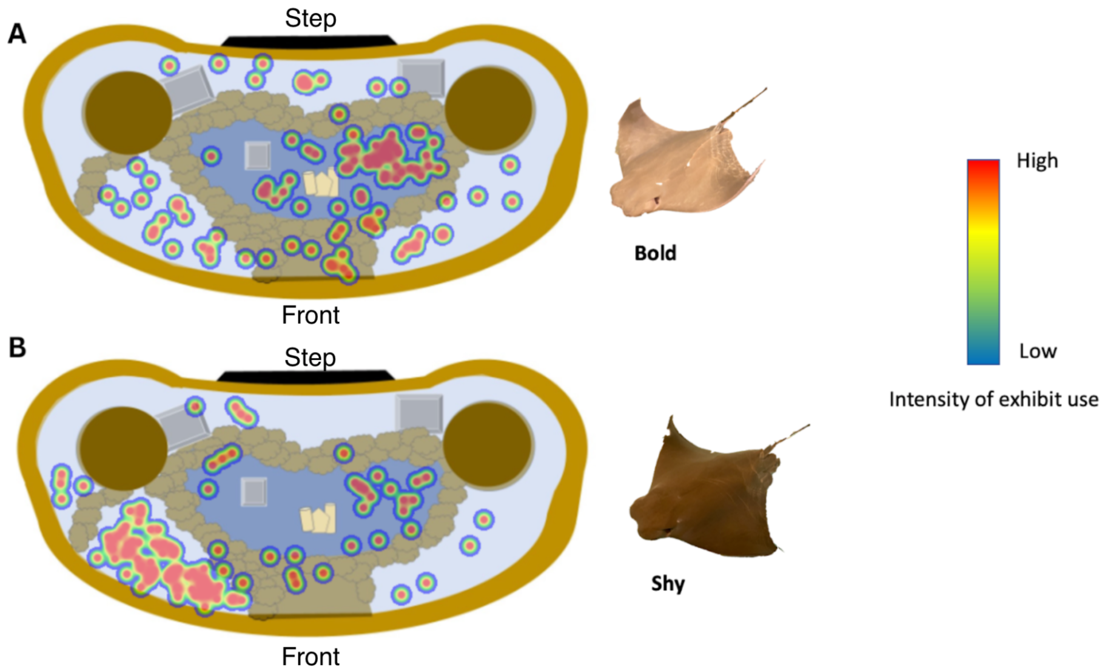

Figure 4: Variation in spatial use by bold and shy cownose rays. **A**) Average spatial use of a bolder ray (Sugar) more likely to approach a guest's hand as compared to **B**) the average spatial use of a shyer ray (Mocha) less likely to approach a guest's hand.

DISCUSSION

Touch tanks provide a unique educational and recreational experience for zoo guests (Rowe and Kisiel 2012). Given that zoo guests make strong connections with the animals they visit, zoo experiences are a crucial part of the conservation process (Falk et al 2007). Indeed, guests who visit a zoo more than once are even more likely to partake in conservation efforts (Godinez and Fernandez 2019). Assessing guest experience, as well as understanding animal behavior, is therefore key to continuing to promote positive interactions at zoos and furthering conservation efforts. Over the course of six months, I accessed ray behavior and ray-guest interactions at a touch tank. The goal of the study was to understand ray behavior in this unique environment, and to determine how guest interactions affect ray health and wellbeing at a group and individual level, and the follow-on effects for guest experience.

Ray Behavior in a Touch Tank

Assuming captive rays behave comparably to their wild counterparts, touch tanks could help fill data gaps on reproduction, socialization, and stress in an understudied species. Here I observed that rays spent a majority of their time in the touch tank (approximately 96%) swimming, resting, and eating, rather than interacting with guests, whose presence they primarily ignored. This observation suggests that touch tanks could be a suitable environment within which to study typical ray behaviors, such as feeding and reproduction.

Major knowledge gaps currently exist in ray reproduction due to their migratory nature and the logistics involved in observing wild rays (Poulakis et al. 2013, McCallister et al. 2020). Observing mating behaviors in a touch tank environment should be easier than in the wild. While observations of mating behaviors were rare in this study, the bodies of some females were physically marked (bruises, small cuts, and scrapes) during the breeding season, potentially indicating mating behavior (Sheldon et al 2018, McCallister et al. 2020). However, the markings could conversely have resulted from injury from collision or a flight or fight response (Wosnick 2023). Future studies are needed on mating behaviors in rays to increase successful mating in captivity. Additionally, studies of offspring survival requirements could assist in developing approaches to enhance juvenile survival rates in captivity and the wild, facilitating conservation.

Guest-Ray Interactions

The number of zoo guests surrounding the touch tank altered ray behavior. Guest number is a unique factor to zoos, and it can impact an animal's wellbeing in a multitude of ways (negative, positive, or neutral) (Sherwen and Hemsworth 2019). Because of this, understanding these impacts is crucial for proper care and management of zoo animals. Alongside crowding, guest attributes and individual ray personality determined whether a guest-ray interaction occurred, also affecting both ray behavior and guest experience. When too many people were in the touch tank room, the quality of interactions was lower. A similar study noted that careful monitoring of guest interactions (including guest count and feedings) can help to lower negative behavioral responses displayed by captive rays in these environments (Little 2022).

I found that the approach percentage by rays dropped as the number of people in the room increased, suggesting that crowding may cause stress in rays. While physical handling is a known stressor in elasmobranchs (Wosnick et al 2023), there are limited studies on behavioral stress responses to touch in elasmobranchs. The fight or flight response could indicate stress in rays, given their relationship with physiological allostatic overloads (Wosnick et al 2023). Once the room capacity reached 68 people, ray avoidance behaviors increased and the rays moved to isolated areas of the tank. This simultaneously reduced guest experience, because guests were less likely to touch a ray, which is the goal of many adults and children who enter the touch tank environment for an interactive learning experience. Standing space also became limiting for guests at high numbers, likely decreasing the value of the experience and possibly the motivation to learn. From these observations, I recommend that a guest capacity is put in place that matches the size of the exhibit; in this case, less than 68 people.

In addition to crowding, individual ray identity and the attributes of guests affected the likelihood that a guest would interact with a ray. Guests with food were more likely to be approached by a ray, indicating a strong food stimulus that may suppress fear or anxiety in the animals (Burnett et al. 2016). The approach behavior was also dependent on the individual ray, as the rays were classified here as bold vs. shy based on personality differences. Adults also were more likely to be approached than children when food was not an available stimulus. This is likely due to the fact that adults engaged with the rays in a calmer fashion–obeying the two finger rule, and only touching the rays on their wings and backs. Adults were also typically quieter and did not splash in the water, which may be a deterrent to the rays. Future studies are needed on how sound levels affect ray behavior. Currently, it is understood that elasmobranchs can hear frequencies from approximately 20–1,000 Hz (Mickle et al. 2020). Only a few species out of the 1,100 species of elasmobranchs have been studied, leaving knowledge gaps on ray hearing and the effects of guest noise on wellbeing (Mickel et al. 2022).

Only five guests were required to cause a change in resting behavior. As captive rays may default to rest behavior when little to no stress stimulators are present (Mickel et al. 2020), guest presence in the room may have strongly affected ray stress levels. On average, it was observed that rays rested in areas where guests could not easily access them, which indicates a general aversion to interactions. Animals may cope with stress in different ways, including flight (moving away) and hiding (resting in inaccessible spots in the tank) (Korte et al. 2005). It is clear that guest attributes and crowding affected both guest experience and ray behavior. However, our data indicated that individual rays had varying levels of tolerance, and therefore it is relevant to look at behavior on an individual scale.

Individual Variation in Tolerance to Guest Interactions

Personality differences in rays led to variation in how they spent their time, and their responses to guests at the touch tank. In the absence of guests, it was observed that the rays (apart from Sugar and Tsunami who were usually active regardless of guest presence) would spend a large portion of their time socially resting. Some behavioral stress indicators in elasmobranchs (fight or flight response, body rigor, body injury, eye retraction, stomach eversion, flaring and clasper crossing, etc.) are currently recognized, but new stress proxies should be continuously explored to increase our understanding and care of wild and captive elasmobranchs (Wosnick et al 2023).

When rays are solitarily swimming, they are more likely to have a guest interaction because the rays are slowly circulating the tank, allowing for more hands to graze their wings and backs as they pass. On average, all rays spent more of their time in a solitary swim than anything else; however, the rays all varied in the percentages of time they spent swimming or resting (solitary vs. social). Rays are naturally schooling fish (Bizarro et al. 2007) and resting may be indicative of low stress in captive environments (Mickel et al. 2020) so it can be assumed that social resting in the touch tank may indicate a lower state of stress in the rays. These percentages can be used to indicate which rays may have higher stress tolerance–the ones who are socializing and resting more than those solitary and swimming.

Rays classified as bold had a higher approach percentage during guest interactions. If an animal is voluntarily approaching a guest’s hand it may be assumed the animal is experiencing relatively low levels of stress. Looking at approach percentages for individual rays is one way keepers can assess which rays are better suited for the unique interactive environment of a touch tank. Their spatial use may also be indicative, as I found that bold rays spent more time in locations where guests could easily touch them.

Cownose rays are considered a species that is appropriate for a touch tank environment due to their hardiness (Mylniczenko 2019). However, certain individuals may not be, and this may be due to differences in personality and preference. Personality can greatly affect an animal's wellbeing in a captive environment and therefore is an essential factor to monitor (Watters and Powell 2012). The rays in these interactive exhibits may benefit from routine physical and behavioral checks to ensure they are suited for these interactions, and removed if these exhibits affect their overall wellbeing (Spooner et al. 2021). I recommend that zoos and aquariums understand and tailor protocols to the individuals in their care when necessary, rather than the species as a whole, to ensure the animals' health is not negatively affected.

CONCLUSION

Touch tanks provide beneficial opportunities for detailed ray research and observation that would be challenging or even impossible in the wild, while providing unique learning opportunities for zoo guests. However, guest capacities are essential for limiting ray stress and improving guest experience. Further, individual rays should be assessed for suitability in the dynamic and stimulating touch tank environment. Future research to understand the effects of sound on captive rays, the proper design of the physical tank and use of proper enrichment, and further behavioral and reproductive research may also enhance the care of captive rays and opportunities to support wild ray conservation. Through this study, I began to fill important knowledge gaps about the proper care and management of touch tank rays, and I provided insights into largely understudied ray behaviors. The results in this study may be applied to zoos and aquariums globally, with the goal of improving the quality of life for captive rays, and furthering wild ray conservation. Enhanced guest experience could also lead to better education, awareness, and funding for important animal conservation issues. This impact is broad and significant, making zoo and aquarium research a crucial focus for improving captive and wild animal wellbeing and the planet’s biodiversity.

Finally, this study was carried out because of a collaboration between Montclair State University and the Turtle Back Zoo. Researchers from academic institutions can be offered opportunities to conduct meaningful research from their connection with zoos, and these relationships benefit both sides while producing meaningful results (Schulz et al 2022). Because academic institutions and zoos often share similar goals (Fernandez and Timberlake 2008) these connections should be strongly encouraged.

ETHOGRAM

Code	Behavior Name	Definition
SLS	Solitary Swim	Individual swims more than two body lengths from another ray or in the opposite direction
SOS	Social Swim	Individual swims in the same direction within two body lengths of another ray
SLR	Solitary Rest	No movement: individual is at the bottom of the pool more than two body lengths from another resting ray
SOR	Social Rest	No movement: individual is at the bottom of the pool
VNL*	Vertical Near Ledge	Individual is vertical and touching the side of the tank
CLR*	Collision with Ray	Individual has made direct contact with another ray in the tank
CLS*	Collision with Shark	Individual has made direct contact with another shark in the tank
SWC*	Side Wall Contact	Individual has made direct contact with the side of the tank wall
ENR*	Enrichment Interaction	Individual is interacting with the enrichment in the tank by making contact with it, swimming through it or next to it
SEX*	Mating Behavior	Two rays are displaying active mating or mating signs (i.e., chasing or biting between males and females)
SPL*	Excessive splashing	Individual is excessively splashing
Ray-Guest Interactions		
ASW*	Above Surface Water	Guest hand hovers above the water but does not break the surface
BSW*	Below Surface Water	Guest hands goes below the surface of the water but makes no contact with the focal ray
BSC	Below Surface Contact	Guest hand makes contact with the ray
CWL*	Contact with Ledge	Guest hand contacts the ledge of the tank and is within six inches of the focal ray
III*	Inappropriate Interaction	Guest interacts inappropriately with the focal ray (i.e., any interaction other than two fingers gently touching the ray's back or wings)
Ray Responses to Guest Interactions		
Linger	Stay by hand for more than three seconds	
Avoid	Change swimming direction to avoid hand	
Approach	Change swimming direction towards hand	
Ignore	Swimming direction is not changed	

*Indicates all occurrence behavior

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