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A Case Study of Rhincodon typus Scarring in Ningaloo Reef: An Assessment of the Current Scarring Classification System

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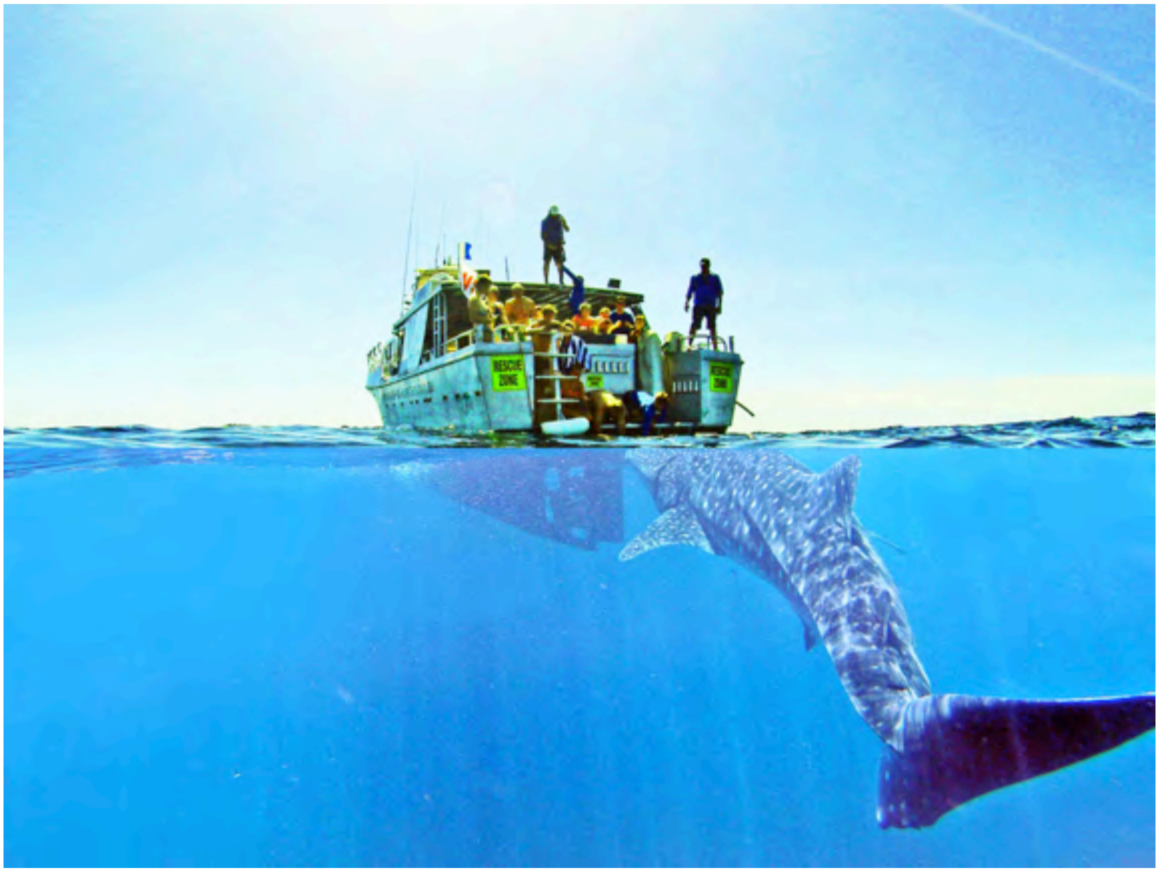

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Abstract

Rhincodon typus are the largest fish in the sea, but little is understood about this elusive species. They are known to annually aggregate in Ningaloo Reef, Western Australia—the location of this study. In order to better understand this species, scarring was observed on a subset of the population that aggregates in Ningaloo Reef. In addition, the scarring classification system was examined to determine if it is the most effective classification system. *R. typus* were observed, and photographed from April 9th-April 25th, 2014. These photos were then used for identification and scarring classification purposes. The analysis of the scars on *R. typus* indicated the current scarring classification system was not sufficient. Therefore, I reconstructed a more effective method of classification. This allows future scarring studies to better organize scarring type, and causation. Consequently, this classification system will help others who examine the scarring of *R. typus* to do so more effectively.

Introduction

1.1 Current Biological and Ecological Understanding of *Rhincodon typus*

The whale shark, *Rhincodon typus,* is the world's largest fish, but little ecological and biological information is understood about this species. This species was only recently scientifically described in 1828 by Dr. Andrew Smith (Rowat & Brooks, 2012). It is the sole member of it's biological genus and family, although the fossil record indicates there were three ancestral species (Rowat & Brooks, 2012). *R. typus* existence dates back to 245-35 million years ago, during the Jurassic and Cretaceous period (Norman, 2014). This ancient fish can reach up to 18 meters in length, and weigh over 34 tons (Rowat & Brooks, 2012). Despite this species' recent discovery, the International Union for Conservation of Nature (ICUN) and Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) have already indicated *R. typus* is a vulnerable species (Hsu, Joung, & Liu, 2012).

While it is enormous in size, it is almost entirely harmless to humans. This is due to this species' docile nature, and feeding habits. *R. typus* is one of three shark species that is a filter feeder; consuming plankton, and other microorganisms (Martin, 2007). *R. typus* uses over 3,000 small teeth to sieve prey items through its' mouth (Norman, 2014). *R. typus* has been observed to feed on the coral spawn, crab spawn, plankton, zooplankton, krill, small fish and crustacean species. These food sources are most commonly found globally in warm temperate, and tropical waters. Therefore, the general distribution of this species lies within latitudes between 30°N and 35°S (Norman, 2005).

R. typus aggregations have been correlated with areas that exhibit high rates of productivity, and large food source pulses (Wilson, Polovina, Stewart, &

Meekan, 2005). While little is known about the behavior of *R. typus,* they are known to seasonally aggregate in the Ningaloo Reef area to feed. They are generally spotted alone, and in search of a food source pulse (Martin, 2007).

1.2 Ningaloo Reef - Seasonal Aggregation Site

The research and data from this report was collected in the Ningaloo Reef Marine Park area, due to the seasonal aggregation of *R. typus* in this area*.* This seasonal aggregation occurs annually in Ningaloo Reef from approximately March until June (Wilson et al., 2005). This aggregation was discovered in 1989 (Taylor, 1989). There has been an ongoing record of this aggregation that is comprised of around 300 to 500 individuals and, includes over 4,000 sightings of *R. typus* (Bradshaw, Fitzpatrick, Steinberg, Brook, & Meekan, 2008).

It is hypothesized that these sharks aggregate in this location, due to the high primary productivity of the water in this geographic region. This geographic region is greatly influenced by the Leeuwin Current, which flows south along the continental shelf. This current carries warm nutrient-poor water along the coast of Western Australia (Bradshaw et al., 2008). The Leeuwin Current is intercepted by the Ningaloo Current, which carries cold, nutrient-rich water that originates from areas of upwelling (Bradshaw et al., 2008). These currents mix, creating warm nutrient-rich water, in which it is hypothesized *R. typus* like to aggregate, and feed.

In addition to these unique environmental factors, the geology of the Ningaloo Reef facilitates accessibility for mega fauna, like *R. typus.* The geology of this landscape was influenced by the separation of Pangaea and Gondwanaland, around 180 to 50 million years ago (Norman, 2005). The break-up of this super continent created an extraordinary small coastal margin along Ningaloo Reef. This small coastal margin allows large pelagic species, like *R. typus,* to very easily approach the reef, and coastline.

Tagging studies have shown that the *R. typus* which annually aggregate to Ningaloo Reef have a migration route up to 1,500 kilometers northeast of this region of Australia (Wilson et al., 2005). Although, these migration patterns could be ever greater; satellite tagging studies have shown one individual from the Ningaloo Reef area traveled over 12,000 kilometers in approximately 37 months (Wilson et al., 2005).

R. typus is protected in Australian waters, but does not have global legislative protection (Wilson et al., 2005). It is protected in: the Maldives, Philippines, India, Thailand, Malaysia, Honduras, Mexico, US Atlantic waters, and some waters off the coast of Belize (Norman, 2005). While their migration routes are unknown; there is the possibility that these sharks are passing through waters that activity hunt this species. Additional observations, and behavioral studies are necessary in order to better understand this species.

1.3 Importance of Study

This study is of great importance, due to the lack of biological knowledge known about *R. typus.* Due to the large size of this animal, studying this species proves to be very difficult; there is a lack of information on its' reproduction habits, and global migrations routes. In addition to how little biological information is understood about this species, there is a lack of understanding of what threatens *R. typus.* This species is known to face threats such as natural predation, active harvesting, marine ecosystem modification, encounters with fishing gear, and collisions with boating vessels (Norman, 2005).

As stated previously, according to the ICUN Red List, *R. typus* is listed as a vulnerable species. Although, this species is protected in many countries' waters, there is the potential that they are still being actively hunted, or fatally injured in boating collisions. In 1995, the Maldivian Government banned hunting of *R. typus*, although some observations indicate active hunting is still taking place (Riley, Harman, & Rees, 2009). In addition, previous research has shown *R. typus* was actively hunted in Taiwan; this activity could still be occurring in this region of the globe (Chen, 1997). Further examination of *R. typus* scars can provide a greater insight into the practices of active hunting. In addition to active hunting, boat collisions can be observed from scarring. Through the continual study of this species' scars, a greater behavioral understanding of *R. typus* can be gained. Furthermore, if supplementary studies indicate boating collisions are harming *R. typus*, and active hunting is being observed, this could encourage comprehensive protective legislation for *R. typus.*

In addition, further understanding of this species can help to safeguard the ecotourism industry which is dependent on the annually aggregation in Ningaloo Reef, Western Australia. The whale shark ecotourism operators and their clients are in an ideal position to gather observations on this species (Martin, 2007). The company I worked with, Oceanwise Expeditions, is an ecotourism boat operator based of out Ningaloo Reef, that actively conducts research. The marine scientists of this organization conduct research on a variety of organisms that are found in the Ningaloo area. Although, I worked specifically with Suzanne Hillcoat and Alexander Gorham—who are actively conducting research on growth rates, and scarring information of *R. typus.*

The need to examine, and correctly classify scars of *R. typus* is vital in order to ensure this species' population is being properly managed. Vast amounts of information can be derived from the examination of scars. The study I conducted aimed to examine how the current methods of scarring classification can be altered, in order to better understand the biology of this species. In addition, information gathered from this study can provide a greater understanding of behavioral information of *R. typus*, of which there is very little known.

Due to the lack of information known about this species, I examined the scars on *R. typus* to try and better understand its' ecology, behavior, and potential management options. Within the course of three weeks, I examined a small subset of the aggregation that annually comes to the Ningaloo Reef Marine Park. I examined the current methods of scarring classification, and the information that can be gained from studying this information. Previously, scarring information was examined while looking at mortality rates of *R. typus.* This includes examining natural predation, interactions with boating vessels, active hunting, and other potential causation of scarring. The objective of this study was to gain insight on the behavior of *R. typus,* and examine the current methodology of scarring classification.

Materials and Methods

2.1 Study Area

This data was collected off the Northwest Cape of Western Australia in the Ningaloo Reef area (21°54'44.6"S 113°58'38.4"E). The window of time in which I collected data was from April 9th-April 25th, 2014. The locations of the sharks observed were all within the Ningaloo Marine Park Area. The beginning and end global positioning system (GPS) coordinates of each shark we observed were recorded. This information allowed us to observe where the shark was spotted, and how far the shark traveled while we encountered it.

Figure 1 - Map of Drive from Exmouth to Ningaloo Reef

The sharks were spotted by airplanes, which then gave the GPS coordinates of the sharks to our boat. The number of individual sharks varied daily, but the following procedure was the same for all sharks observed. In order to collect data while swimming with the sharks, we had to follow the ecotourism code of conduct.

2.2 Ningaloo Reef: Ecotourism Code of Conduct

These regulations included maintaining an exclusive zone of contact around the shark. This zone forms a 250-meter radius around the shark. All other vessels in the area must maintain a distance of 400 meters. Within this zone, the ecotourism vessel can only reach a maximum speed of eight knots, and no other vessels are permitted in the exclusive zone of contact (DPaW, 2013). The boat was allowed to intercept the direction the shark was traveling, and drop of the tourists in the water. This allowed the shark to continue to swim uninterrupted, and the tourists would be able to swim along side the shark.

All people in the water with the shark maintained a three-meter distance from the shark’s head and body, and a four-meter distance from the tail of the shark (DPaW, 2013). A new clause was added to the code of conduct this year, stating that you cannot place a GoPro camera on a pole within this distance.

In addition, the vessel that was in contact with the shark could only maintain contact with the shark for 90 minutes (DPaW, 2013). These regulations were put in place to reduce stress placed on the shark. The constant editing of this code of conduct ensures that the government of Western Australia is continually safeguarding the well being of the *R. typus*.

2.3 Data Collection

The boat would approach the shark, and a spotter would get in the water. The spotter was the individual who located the shark, then swam along side the shark with one arm in the air. This was to guarantee that the shark remained visible at all times. The spotter used hand signals to communicate to the boat the position of the shark. This communication is necessary because many times we had to ‘handball’ the sharks between boats. ‘Handballing’ is the term used to describe handing off the shark from one ecotourism boat, to the next ecotourism boat. Once our boat, Ningaloo Spirit, got the shark, and the spotter was in the water, the tourists were allowed to get in. I jumped in after the spotter, but before the tourists to guarantee I had a clear line of sight on the shark. The two methods of data collection were photography, and videography based—so good visibility of the shark was necessary to guarantee proper data collection.

2.4 iPad Application

All of the information gathered in the field was recorded using an iPad application that was created by Alexander Gorham—copyright pending. This application expedited data collection, and accuracy while on the boat. Each day that I collected data we created a new file on the application. At the end of the day, this file was then exported onto a computer for further analysis.

This application recorded pertinent information on each shark. The first information recorded was the initial time we starting swimming with the shark. Immediately after recording our start time, I would log the GPS coordinates of the shark. I would then record if the shark was shared with another boat operator if so; I would indicate which vessel we shared the shark with. At this point, my colleagues and I would jump in the water to collect data. I would then return to the iPad, and log the GPS position when we stopped swimming with the shark; simultaneously, I recorded the time in which we stopped swimming with the shark.

I would then enter observations I had made in the water into the application, including a length estimate of the shark. My two colleagues and I would estimate the length of the shark, and the average of these estimates was recorded. For the first eight sharks observed, the length measurements were not recorded—as our lead researcher was absent.

Figure 2 - Screenshot of iPad Data Collection Screen

If it were possible to sex the shark, I would record the sex, and status of the shark. The status refers only to males, because it is impossible to determine the sexual maturity of a female shark by means of visual observation. In relation to the male sharks, I would indicate the status of the shark by observing if the sexual organs, clapsers, of the shark had matured. The *R. typus* aggregation in Ningaloo is comprised of mainly immature males. Therefore, recording the sex of the shark was important to determine if this phenomenon was still occurring. I then recorded behavioral information, scarring information, tagging information, fish assemblage information, still image information, and stereo-video information.

2.5 Still Images

The still images were collected on two types of cameras a GoPro Hero3, and a PowerShot SX260 HS. We collected still images in order to gather identification shots, and record observed scarring on the sharks. The identification shots had to meet specific parameters in order to correctly identify the shark. These parameters ensured that the photos could be processed using the I^3S computer software.

I took photos of the left and right flanks of the sharks. The left flank of the shark was most important to photography properly, because this image was most commonly used for identification purposes. In order to capture the correct image; I took still images at a right angle to the shark, and I was approximately three to five meters away from the shark. The areas that were necessary to include were the upper fifth gill slit, lower fifth gilt slit, and the inner trailing edge of the pectoral fin (Pierce, 2006). Capturing an image of the shark at this angle provides a standard for observing the dot, and strip pattern on the flanks of the shark. This pattern is unique to each individual shark, therefore providing valuable identification information.

In addition to capturing identification shots, I also took photos of the sexual organs of the sharks. At the end of each encounter, I would duck-dive and observe the sex of the shark. If it were possible to capture an image, and not frighten the shark, I would take a photo.

The final images I captured, were images of scarring on the sharks. After I collected all of the above images, I would observe the shark for any signs of scarring. This includes swimming along both sides of the shark, and visually observing the health of the shark. If there were any visible scarring, I would photograph it.

2.6 Methodology of Scarring Classification

After capturing images of the scars, I would record the classification of the scar, and the position of the scar on the shark. The observed scarring was classified into seven categories. Conrad Speed created these categories, and I continued to use them to classify the observed scars (Appendix A).

The scarring categories include: abrasion, laceration, nicks, predator bites, blunt trauma, amputations, and other.

These categories were described in addition to the location of the scar on the shark (Figure 3).

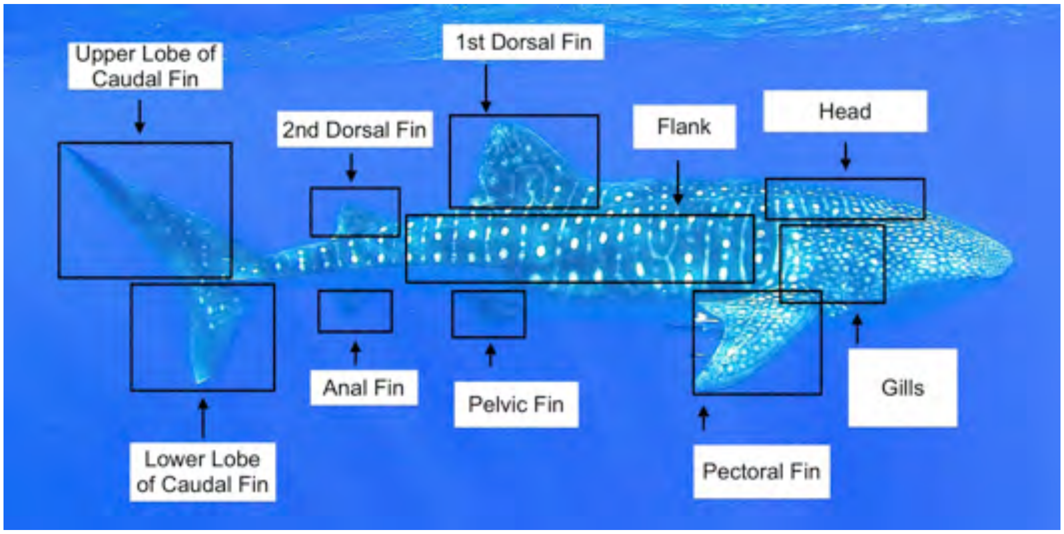


Figure 3 - Described Locations of Scars on *R. typus*

2.7 I^{3}S Classic 4.01: Computer Software Analysis

Once I gathered identification photos of the sharks; I would run Interactive Individual Identification System, I^{3}S, on the images of the shark. This software can be downloaded for free, and used to assist with the identification process of a multitude of species, although I used it solely on *R. typus*.

In order to run I^{3}S, I opened a correctly framed identification image (Figure 4). There were three reference points that I identified on the image of the shark. These reference points included: the top of the fifth gill slit, the edge of the pectoral fin, and the bottom of the fifth gill slit. Once these reference points were identified, I would click on each visible spot on the shark's body within these points. For the data collection I completed, you needed to include a minimum of twelve spots selected for analysis.

Within the database I used, I also a collected a record of metadata. Metadata refers to broader categories that describe the individual shark that is being examined. The metadata elements used within the database were: view of the shark, sex of the shark, the position of the first scar, the type of the first scar, the position of the second scar, the type of the second scar, and a record if the shark had a tag, or remnants of a tag. Then I would run the program. I^{3}S would then extract the spot pattern and compare the pattern against all other sharks in the database (I^{3}S, 2014). The closer the spot patterns matched up, the lower the score the match would receive. If you had a pair of photos with a very low score, the likelihood that the sharks were a match was greater.

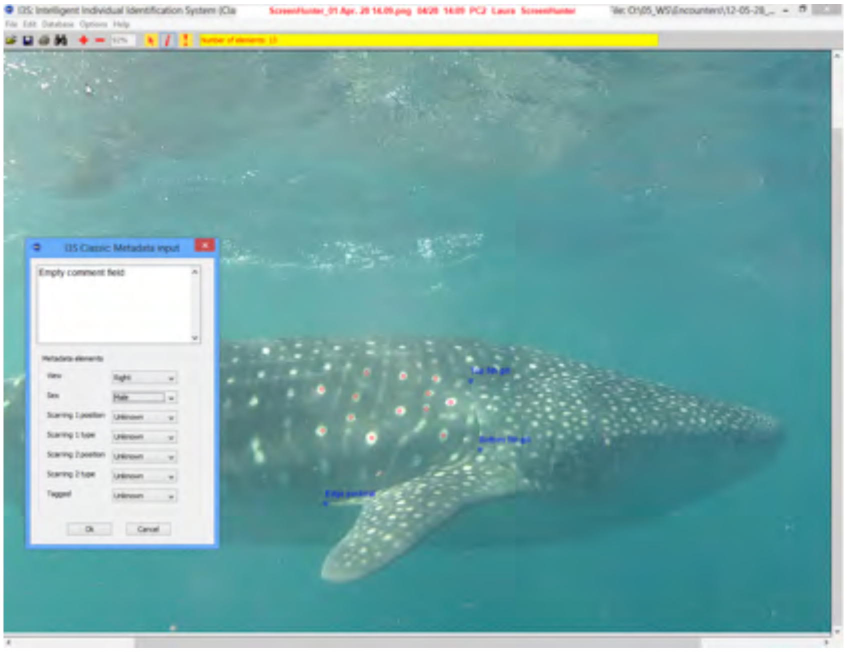


Figure 4 - I³S Reference Points & Metadata Elements

Results

3.1 Sex Distribution of Observed *R. typus*

Of the 34 individual sharks observed in seventeen days, the majority of individuals were males. Nineteen males were recorded comprising 55.88% of the population; of these males only two sharks were observed as mature males. Therefore, 89.47% of male sharks observed in this time were immature males, while only 10.53% of the males were sexually mature. The females in this population comprised 14.71% of the population. Although, 29.41% of the observed sharks were not sexed.

3.2 Length Measurements of Observed *R. typus*

Total length estimates were recorded for each individual shark. All observed sharks were less than ten meters in length. The range of these length estimates was three and a half meters to nine meters. The estimated lengths of the identified female sharks ranged from three and a half meters to six and a half meters. The estimated lengths of the observed male sharks ranged from four and a half meters to nine meters.

3.3 Re-sightings of Observed *R. typus*

Over the course of seventeen days, three sharks were re-sighted. The first re-sighted individual was observed on April 9th, 2014. This shark was then seen again on April 21st, 2014. When first observed the sex, and status of the shark was unknown. Through the application of I³S, and scar paring, it was confirmed that the same individual was sighted eight days later. On the second encounter with the shark, the sex and status of the shark was confirmed. This individual was an immature male, which was approximately six and a half meters in length. In addition, this shark had noticeable scarring.

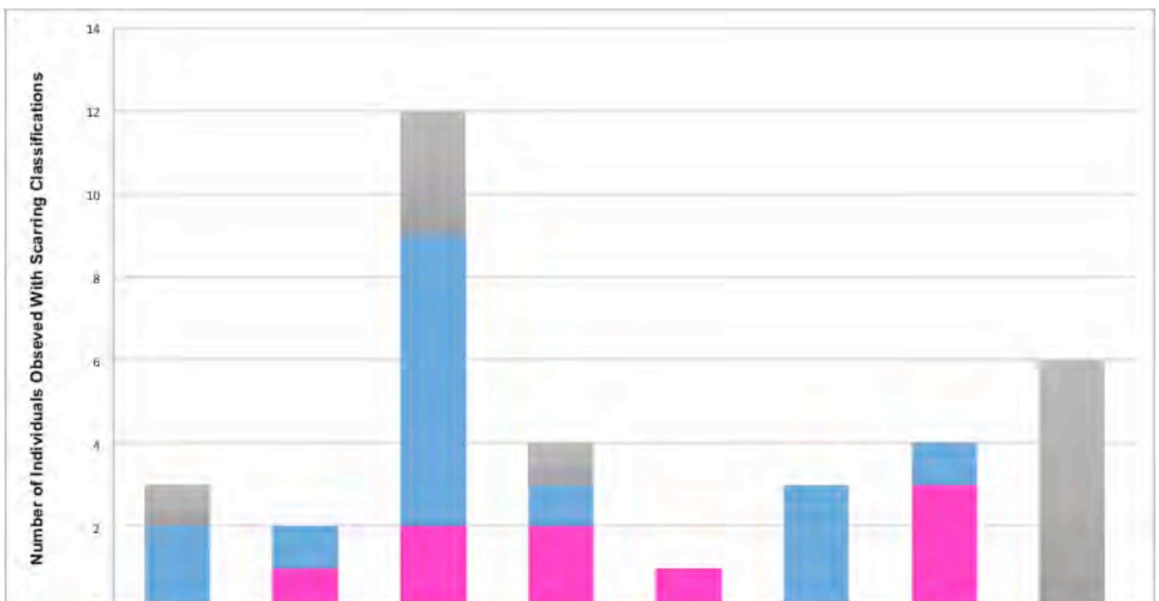
The second re-sighted individual was observed on April 17th, 2014. Upon the first encounter, the sharks' sex, status, and scarring were denoted. Once again, through the use of I^3S software, and scar pairing—this shark was correctly re-sighted. This individual was a female that was approximately six and a half meters in length, and had identifiable scarring. This shark was seen six days later on April 23rd, 2014.

The last re-sighting was an individual that was first identified on April 18th, 2014. Once again, upon the first encounter the sex, status, and length estimate of the shark was recorded. This individual was a mature male, which was seven and a half meters in length, and did not have quantifiable scarring. This shark was seen the following day on April 9th, 2014.

3.4 Observed Scarring Information on *R. typus*

Within this subset of the Ningaloo aggregation, 58.82% of these sharks exhibited some form of scarring. All of the observed females, 100%, had at least one identifiable scar. While only 52.63% of the males had at least one identifiable scar.

Of the sharks that sex went undetermined, four had identifiable scarring, and one of the unknown sexed sharks had no scars. The remaining four sharks that sex remained unknown had scarring that was unknown as well.



	Abrasions	Amputations	Nicks	Bites	Blunt Trauma	Lacerations	Other	Unknown
Unknown	1	0	3	1	0	0	0	6
Male	2	1	7	1	0	3	1	0
Female	0	1	2	2	1	0	3	0

Figure 5 - Graph of Scarring Distribution

Discussion: Case Studies of Scarring Classification

4.1 Abrasions

According to Speed, the current classification of an abrasion is a superficial skin-deep wound. These wounds can either be a scratch or broad scrape (Speed et al., 2008). All abrasions according to Speed are considered to be minor wounds. In previous calculations of morality rates, scars that were classified as abrasions were not included in statistical tests. These scars were not included because they were unlikely to affect survival rates and were often not recorded on individuals in the Ningaloo area (Speed et al., 2008). While these wounds can be superficial, and may not apply for extrapolating data on survival rates, they can provide insight into *R. typus* behavioral studies. The current potential causes of abrasions include collisions with natural benthos, or vessels. Currently, this classification includes both natural and anthropogenic threats to *R. typus*.

Considering the short period of data collection in the Ningaloo Reef area, I saw few sharks with scars that could be categorized as abrasions. A total of two individuals were observed with clear abrasions. This only accounted for 0.58% of the observed sharks. This lack of data could be due to the fact that once an abrasion heals, it is almost impossible to identify. Consequently, if scars were used for an identification process, it would be beneficial to exclude abrasion—to remove as much potential error as possible. Therefore, in order to record any abrasion information; you would have to observe a fresh wound. Previous studies have shown that 21.4% of sharks in Ningaloo have abrasions (Speed et al., 2008). This statistic has the potential to be skewed due to the small sample size, and the fact that scars induced by anthropogenic and natural causes were grouped together.

I believe it would be more beneficial to gather behavioral information from scars, by categorizing natural and anthropogenic abrasions separately (Appendix B). If an abrasion were caused by a natural interaction, it would be classified as minor. If an abrasion were caused by an anthropogenic interaction, it would be classified as major. This would allow you to observe how anthropogenic factors influence the behavior, and health of *R. typus,* in comparison to wounds that are naturally inflicted*.* Overall, the abrasion scarring classification may not be useful for calculating mortality rates, or useful for identification, but it can serve a greater purpose for further behavioral ecology studies. Comparative studies of scarring have been conducted comparing multiple aggregation sites of *R. typus*. These studies concluded that although abrasions may not influence the overall health of the shark, they could act as an indicator of potential threats (Speed et al., 2008).

From the data I collected, an individual shark was observed on April 9th, 2014 that exhibited a scar that fit within the current classification on an abrasion. This same shark was re-sighted on April 21st, 2014. This shark was an immature male, and approximately six and a half meters in length. This recorded abrasion was located on the left pectoral fin of the shark. In addition to the observed abrasion, there was a second scar, classified as a nick, observed on the trialing edge of the same pectoral fin (Figure 6). While these scars are considered minor, they can provide greater understanding for potential threats of *R. typus*. This abrasion scar appears to be caused by a natural source, such as an encounter with benthos, or coral. This can be inferred because the scar is located on the front edge of the pectoral fin, indicating the shark most likely swam into natural debris. The nick is located on the trialing edge of the fin; once again signifying the shark encountered natural debris, rather than an anthropogenic threat.

This shark was discovered as a re-sighting by using a combination of I^3S results, and the use of scarring photographs to identify a positive match. In the course of thirteen days, this observed abrasion had healed in a considerably fast manner (Figure 7). This healing process made the re-identification of this abrasion noticeably more difficult. These results support the conclusions that abrasions should be void when using scars as an identification tool. Although these scars may not prove useful for this application, they can give us more information about *R. typus*. Collecting a record of these scars can help create a baseline for healing rates of *R. typus*. In addition, the constant observation, and monitoring of these scars could provide further supplementary information about additional threats *R. typus* face.

Figure 6 - Abrasion Observed on April 9th, 2014

Figure 7 - Abrasion Observed on April 21st, 2014

4.2 Lacerations

The current classification of a laceration according to Speed is a linear cut that penetrates the sub-dermal layer of the shark. Unlike a bite, these wounds are clean-cut, and do not have ragged edges (Speed et al., 2008). According to Speed, all lacerations are considered to be major scars, and potentially life-threatening. There are multiple possible causes of major lacerations. The current hypothesized causes include wounds inflicted by vessel propellers, vessel hulls, fishing gear, or fishing gaffs (Speed et al., 2008). According to previous studies conducted by Speed, 8.3% of sharks recorded in Ningaloo had scars that were classified as lacerations. This data is consistent with the information I collected in Ningaloo; 8.82% of the sharks I examined had scars that were classified as lacerations. This correlation suggests that continually few sharks in this area have major laceration scars.

While there may be few lacerations recorded in Ningaloo, the severity of these scars can be extreme; the individual examined in this case study had a severe, laceration. This laceration started on the front of the head, and trailed down the first dorsal fin of the shark (Figures 8 & 9). This individual was observed on April 10th, 2014. This shark was an immature male, and a total length estimate went unrecorded for this individual. This specific shark was not re-sighted during my study period in Ningaloo.

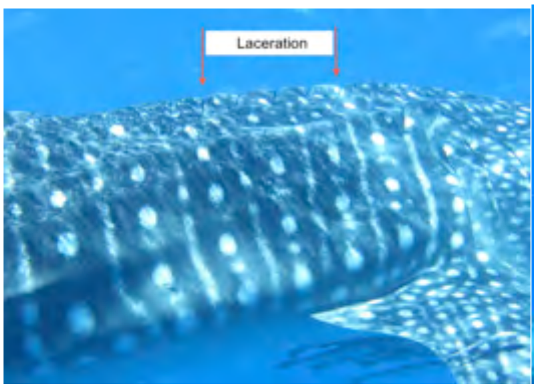


Figure 8 - Observed Laceration on Head

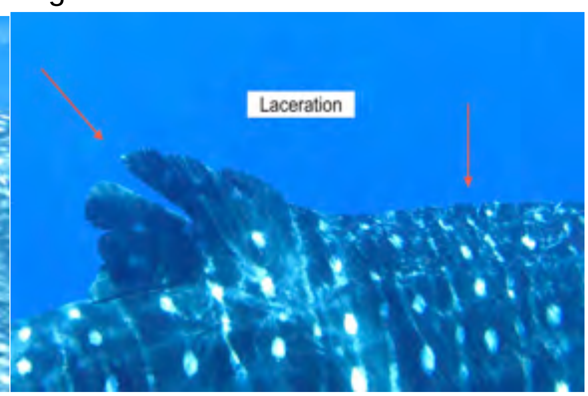


Figure 9 - Observed Laceration on 1st Dorsal Fin

This shark exhibited a major laceration, which was very clearly inflicted by a vessel propeller. The parallel rows of deep lacerations provide clear evidence of strikes from a boating propeller (Rommel *et al.,* 2007). It is hypothesized that the most common cause of a laceration among *R. typus* is a collision with a boating vessel (Speed et al., 2008).

While the scar on this shark was major, the wound was entirely healed. No portion of the flesh was white, and the scars did not appear to show any signs of infection. While the wound could have had the potential to be life threating, *R. typus* has proven to be extraordinary resilient, and often times recover from a major boating collision. Despite this major injury, the overall health of this shark was not negatively impacted. This suggests that this species is resilient enough to recover from a major boating collision. In addition to the biological resilience of this individual, the overall behavior of this individual seemed to go unchanged.

While swimming amongst a group of tourists, this shark did not exhibit behavior that would indicate fear of humans. This shark did not dive, or exhibit any banking behavior.

This scar indicates that some immature males fall victim to propeller collisions. This collision could have been inflicted in the Ningaloo Reef area due to the increase in boating traffic in this area. It has been suggested that the cause of the *R. typus* aggregation in the Ningaloo area is due to the high productivity of water, and the food source pulse. Therefore, these sharks are aggregating in this area to feed, and then bask in the warm waters. These sharks come to the surface to feed, where they are more vulnerable to collide with vessels. It is hypothesized that due to their behavioral habits, *R. typus* may be more vulnerable to boat strikes (Barrier, Marine, & Authority, n.d.).

One instance of a potential boat strike fatality was recorded through the use of tagging. One individual was tagged of the coast of Australia, and traveled to some of the busiest shipping waters off the coast of the continent. The tag used on this shark was a pop-up archival tag, which stores data until it floats to the surface and transmits this data to Argos satellites (Eckert, Dolar, Kooyman, Perrin, & Rahman, 2002). These tags float to the surface after an individual tag remains at a stable depth, and temperature for over two days (Speed et al., 2008). This tagged, four meter shark entered the shallows of busy shipping waters, then rapidly descended to a depth of over 900 meters and did not move for twelve hours, when the tag rose to the surface (Speed et al., 2008). This tagging incident could potentially indicate that a vessel hit this individual, fatally injuring this shark, where it soon after it sank to the bottom. This tagging record could indicate that sharks are being struck by boats, and suffering fatal injuries, where the sink to unreachable deaths. One reason little biological information is known about *R. typus* is due to the difficultly of accessibility of this species. If *R. typus* are found to sink after dying, collecting samples and proving boat strikes induced fatalities is nearly impossible. This incident proves why the study of scarring needs to be recorded. While we cannot collect information on deceased sharks, seriously injured sharks can provide an enormous amount of information about this species.

Furthering tagging information, and scarring observations need to be conducted in order to determine if a significant number of individuals are being fatally injured by anthropogenic causes. The addition of more intensive scarring studies could help provide evidence to support legislation to lower boat speeds, and enforce the use of propeller protectors in areas of aggregations, or migration routes.

While Ningaloo Reef had fewer lacerations recorded than other aggregation sites, the severity of the lacerations may be greater than in other areas. We are unable to gather this information, due to the generalized scarring categories. All lacerations are considered major according to the current scarring methodology; therefore there is little distinction between a laceration caused by a propeller, and a laceration caused by a gaff. In addition you cannot effectively categorize and distinguish lacerations. I think it would be more beneficial to classify lacerations into scars educed by propellers, and scars created by other fishing gear (Appendix B). If this classification was used, you could directly extrapolate how many sharks were being hit, and wounded by boats. This information would be useful for providing evidence to support stricter boating speed regulations.

4.3 Nicks

According to Speed, the current classification of a nick is a removal of a small piece of flesh from the trailing edge of a fin. A nick can be identified by generally have a geometric shape (Speed et al., 2008). The possible cause of a nick is hypothesized to be a vessel propeller, or a natural cause. Similar to abrasions, all nicks are classified as minor scarring—and therefore insignificant when gathering information on mortality rates. Although, gathering information, and photographs of nicks can prove beneficial for identification purposes. While I^3S can help provide accurate identification matches, the additional matching of scars can create an undeniable positive match.

Of all of the scarring categories, nicks were the most abundant on the sharks I observed in the Ningaloo Reef Marine Park. Twelve individuals were sighted with nicks, comprising 35.29% of the total observed population subset. This finding is consistent with previous scarring studies. In three observed aggregation sites, Ningaloo Reef, Seychelles, and Mozambique; nicks were the most abundant forms of scarring (Speed et al., 2008). Previously examined Ningaloo populations demonstrated that 11.9% of sharks had nicks. The increase in observed nicks in this 2014 study could be a byproduct of the small sample size.

The individual I examined which had a nick, was observed April 10th, 2014. This shark was an immature male, and total length estimates were not gathered for this shark. In addition, this shark was not re-sighted. This shark had a visible nick on the first dorsal fin. This scar was categorized as a nick because a small piece of flesh was removed from the trailing edge of the first dorsal (Speed et al., 2008). This scar was visible from both sides of the shark.

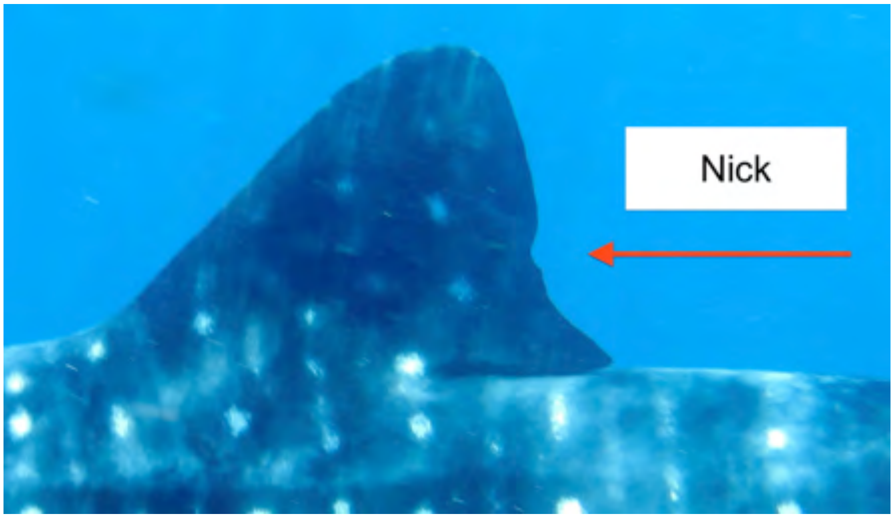


Figure 10 – Nick Observed on April 10th, 2014

The current classification of nicks can lead to an abundance of scars placed in this category. Currently, the causation of a nick includes collision with a vessel propeller, or natural causation. Due to the vague nature of this category, a surplus of scars can be labeled in this category. This over classification of nicks can lead to skewed data. I have suggested a new classification method for nicks in order to gain a more accurate understanding of the causation of these scars. My proposal includes dividing nicks into two categories: nicks that were inflicted by a natural cause, and nicks inflicted by an anthropogenic cause (Appendix B). Including the specificity of causation will help provide information for others conducting research on behavioral studies. Scars allow humans to gain some understanding of *R. typus* behavior; if these scars are classified into these categories it will help clarify behavioral characteristics of *R. typus*.

4.4 Bites

The current classification of a bite is a semi-circular wound, or removal of flesh. This removal can range from a puncture wound, to the complete removal of flesh, including a fin (Speed et al., 2008). The possible causation of this scar includes other shark species, such as tiger sharks, great white sharks, ectoparasitic sharks (Fitzpatrick, Meekan, & Richards, 2006) or odontocete whales species (Speed et al., 2008). All of these predator species can be found within the Ningaloo Reef Area (Fitzpatrick et al., 2006).

The individual shark observed in this case study which had a recent bite wound was seen on April 25th, 2014. The wound was located on the left flank of the shark, closest to the pelvic fin (Figure 13). This shark was a female of approximately three and a half meters in length. Through the use of I^{3}S, and scar pairing, this shark was correctly matched as a re-encounter. This female was seen last year on July 11th, 2013. When this individual was last observed the total length estimate was approximately three meters. This infers that over the course of nine months and two weeks (288 days), this shark has grown approximately half a meter in length. Upon the first sighting of this shark, this bite wound was not observed. This implies that this bite wound was inflicted within these past nine months, and has already exhibited significant signs of healing. While it is known that *R. typus* has the thickest skin of any animal in the world, measuring at 14 centimeters thick (Martin, 2007), the rate of healing of major wounds still remains unknown. Although, superficial dermal wounds have been reported to heal quickly in whale sharks (Riley et al., 2009), major wounds, like this predator bite may exhibit different rates of healing. The continual observation of *R. typus'* scars, like the one on this individual provides insight into greater biological understanding of this species, including the rate of healing of major, and minor wounds.

In addition to the bite wound on the lower left side flank, this shark exhibited other unique scars. According to data from 2013, this shark had a wound inflicted from a potential harpooning incident. There is an entry wound from an object on the upper right hand side flank of the shark, and an exit wound located on the upper left hand side flank of this shark. On the lower left flank of the shark, an entry wound can be observed, and on the lower right hand side flank of the shark an exit wound can be observed (Figures 11 & 12). The causation of these wounds is hypothesized as a harpoon due to the unique matching wounds on both sides of the shark.

Other incidents of harpooning of *R. typus* have been sighted, and recorded. A male whale shark off the Maamigili-Dhigurah Reef, was observed with a wooden harpoon shaft protruding from its' right hand side flank (Riley et al., 2009). Upon this sharks' first sighting, the harpoon was visible. When this shark was re-sighted almost a year later, the harpoon was missing but clear entry and exit wounds were visible (Riley et al., 2009). The entry and exit wounds observed on the shark from Maamigili-Dhigurah Reef are very similar to the wounds observed on the shark in Ningaloo Reef. While no definitive conclusion can be drawn, it seems very likely that the wounds observed on this shark from Ningaloo Reef were indeed remnant harpoon scars.

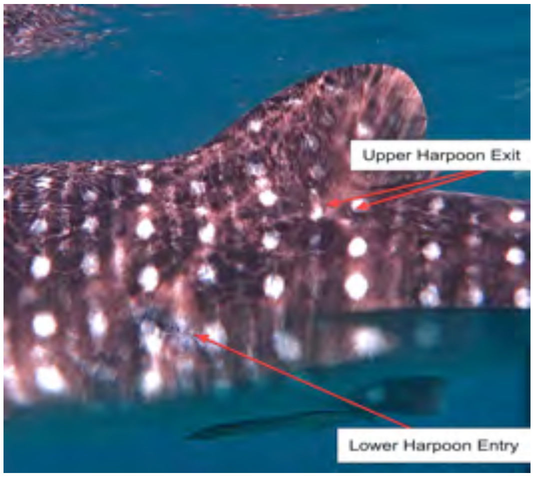


Figure 11–Left Hand Side of Shark Observed in 2013

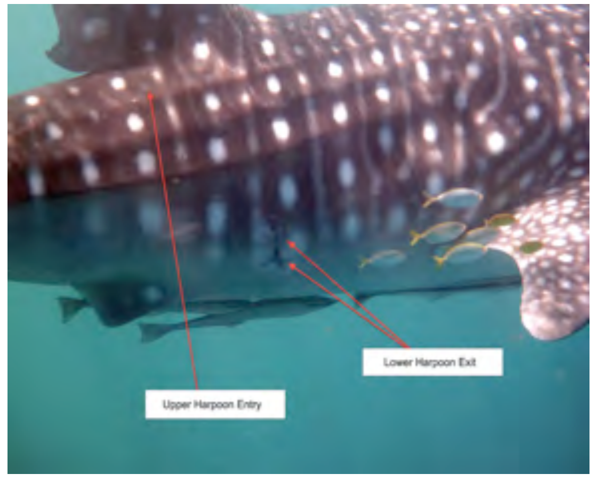


Figure 12–Right Hand Side of Shark Observed in 2013

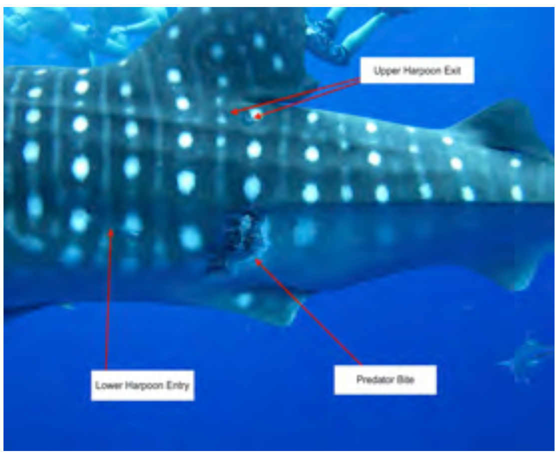


Figure 13 - Right Hand Side of Shark Observed in 2014

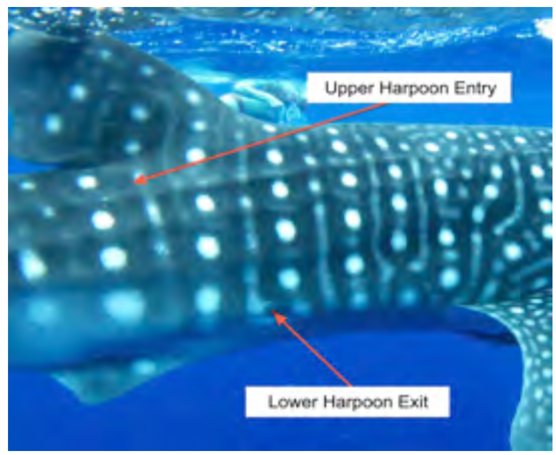


Figure 14 - Left Hand Side of Shark Observed in 2014

This indicates that this individual shark has encountered both anthropogenic, and natural threats over its' lifetime. This specific individual was also very small in size. Further studies need to be completed to determine if younger sharks face a greater threat of injury. While this shark has clearly faced potentially life-threatening injury, its' behavior was not influenced by these incidents. This shark exhibited normal behaviors, and appeared to be unaffected by snorkeling eco-tourists along side it. This behavior is dissimilar to the other observed harpooned individual. The shark observed in Maamigili-Dhigurah Reef, with a clear harpoon wound, appeared to be elusive, and dove rapidly at the sight of humans (Riley et al., 2009). Further behavioral studies need to be conducted to determine if major scars, like potential harpooning scars, are influencing the behavior of *R. typus*.

In addition, the information gathered from scarring data could tell the scientific community if active hunting is still occurring among *R. typus* populations. In Taiwan, there appears to be a demand for *R. typus* meat, as it is refereed to as the 'tofu shark', due to the tofu-like appearance of its' meat

(Fowler, Reed, & Dipper, 1997). This meat is considered a delicacy by consumers and is valued at US$15 per kilogram of meat (Fowler et al., 1997). Harpoon fisheries in coastal cities of Taiwan have harpoon-equipped vessels in which the annual *R. typus* catch was estimated to be 114 individuals in 1997 (Fowler et al., 1997).

If the behavior of the sharks is influenced due to anthropogenic causes, this could have the potential to greatly disrupt the booming ecotourism industry associated with *R. typus* aggregations. In the Ningaloo Reef community the ecotourism industry is vital for the local economy. In 2004, over the course of approximately two months the ecotourism industry had a revenue of US$7.8 million (Conservation, Overview, & Proceedings, 2005). This is an enormous amount of money that is dependent on the return of *R. typus.*

Therefore, if more sharks in Ningaloo Reef appear to have scars indicative of hunting, there could be the potential to end this activity, to safeguard the ecotourism industry. Although the intrinsic value of this species should be motivation enough to ensure protection, the monetary value of this species has the potential to motivate the majority of others. In order to determine this kind of information, the classification of scarring needs to be modified. Currently, there is no classification for sharks that exhibit this scarring indicative of hunting. I suggest, in order to extrapolate how many sharks are possibly facing hunting—a scarring category needs to be created to group these individuals (Appendix B). Therefore, when you examine scarring evidence you can estimate how hunting activities are influencing the population demographics.

4.5 Blunt Trauma

The current classification of blunt trauma is an unnatural indentation on the body, often these indentations are surrounded by scar tissue (Speed et al., 2008). The current hypothesized causation of these scars is a collision with a vessel (Speed et al., 2008). This current classification appears to be a suitable descriptor of observed scarring.

Of the *R. typus* individuals I observed in Ningaloo Reef, only one individual displayed a scar that corresponded with this classification, this individual accounted for only 2.94% of this population subset. The individual that had a blunt trauma scar was a female shark of approximately four and half meters in length. This shark was observed on April 17, 2014. This was the only sighting of this shark. This shark had a major indentation of flesh on the top of its' head (Figure 15). Similar to other sharks in this case study this individual exhibited multiple scars. This shark had what appeared to be a minor scar from rope entanglement on its' caudal fin, and a major predator bite scar on right hand side flank. This shark also had a sub-dermal tag remnant located on its' right hand side next to the first dorsal fin.

Figure 15 - Observation of Blunt Trauma on Head

This specific individual is a very interesting member of this population subset. This shark is a female; females only comprised 14.71% of this population subset. In addition to being a minority, this shark had multiple scars—caused by both anthropogenic, and natural threats. Further studies need to be conducted in order to determine if an anthropogenic wound, like blunt trauma, increases the likelihood that a shark will suffer additional injuries.

Unlike the other scarring classification categories, the blunt trauma category perfectly encompasses the causation of the scar. In addition, the causation of this scar is solely anthropogenic. This allows information to be extracted from the data that provides a greater understanding of anthropogenic activities effects on *R. typus*.

4.6 Amputations

The current classification of an amputation is the partial or complete removal of a fin (Speed et al., 2008). According to Speed, these scars have linear edges, and were most likely caused by a vessel propeller.

One of the individuals I observed in Ningaloo Reef exhibited a scar that fit these parameters. This shark was observed on April 15th, 2014. This shark was an immature male, which length measurements were not estimated. In addition, this shark was not re-sighted. The second dorsal fin of this shark was entirely amputated, and only a small nub of flesh remained (Figure 16). In addition to this major scar, there was a minor scar along the left flank, near the second dorsal. There was a remnant of paint along this side of the shark (Figure 17). Therefore, I concluded this shark endured a collision with a vessel, leaving behind paint, and the removal of the second dorsal fin. While this scar coincides well with the definition of an amputation, not all amputations observed fit into this category well.

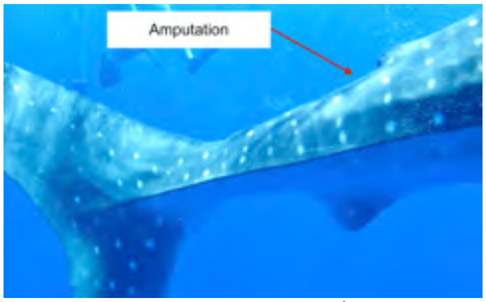


Figure 16 – Amputation of 2nd Dorsal Fin

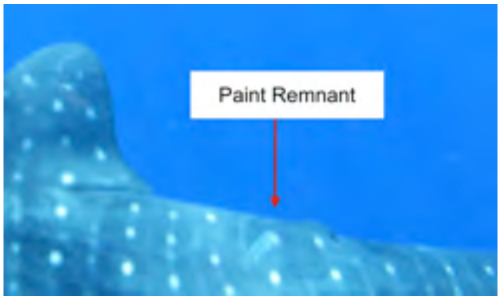


Figure 17 – Remnant Paint Scar near 2nd Dorsal Fin

The rate of amputations among this subset was very minimal, only one male and one female were observed with amputations. The amputation observed on the male shark fit into the current scarring classification, but the amputation on the female shark did not fit as well. This female shark was observed on April 23rd, 2014. This female was approximately four and a half meters in length. This female shark had the lower lobe of her caudal fin entirely removed (Figure 18). While the current scarring classification system suggests a vessel propeller or fishing gear could cause this scar, my fellow colleagues and I disagreed with this classification. While this scar should be classified as an amputation, the causation does not appear correct. After further examination of this scar, we concluded the cause of this scar was most likely caused by rope entanglement. Unlike the previous amputation shown on the male shark, the amputation of this shark has jagged edges. This suggests that this shark did not encounter a vessel, which would have created a linear edge. Therefore, this shark encountered a ghost net, or was actively being hunted.

In addition to harpooning, there is also the practice of finning *R. typus* for their highly valuable fins. *R. typus* are now being hunted because of the trophy value of their fins, which are displayed in shark-fin soup restaurants (Rowat & Brooks, 2012). Sharks in the Maamigili-Dhigurah aggregation have exhibited signs of continued hunting for fins (Riley et al., 2009). In order to capture *R. typus*, sharks are lassoed around the caudal fin. Once lassoed and exhausted, their fins can be more easily removed. The amputation on this second female shark coincides with this type of injury. The jagged edges along

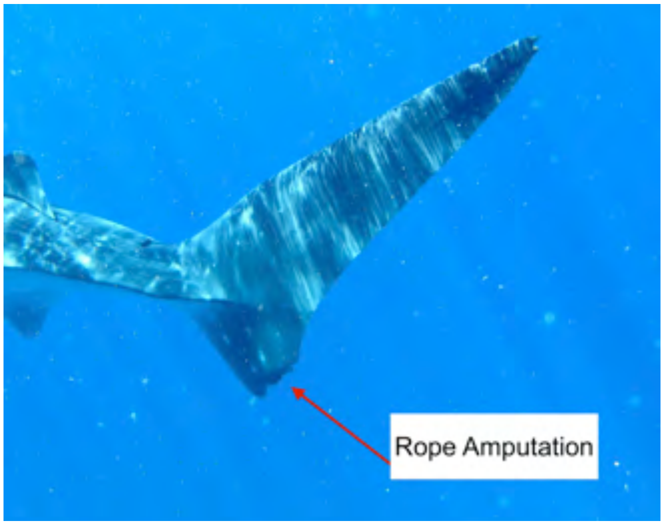


Figure 18 - Amputation of Lower Lobe of Caudal Fin

the area of amputation, suggest this shark was lassoed—where it then escaped, and in the process removed the lower lobe of her caudal fin.

The impact of these amputations on the behavior of *R. typus* still remains unknown. In the case of the male shark, the behavior of this shark appeared to be unaffected by this amputation. This shark did not exhibit any behavior that indicated fear of humans. In the case of the female shark with the amputation, her behavior was more unusual than most sharks. Although this shark had suffered a major injury, she was very curious about the snorkelers in our group, and our vessel. As the snorkelers on our eco-tour got back onto the boat, this shark appeared to follow them. She then proceeded to approach the back of the boat, and attempted to feed on the bubbles the vessel was producing. This shark circled around the boat, rubbing the boat with her flank, and surfaced at the back of the boat one again, before sinking away. Further studies are needed in order to determine the impacts these injuries are having on the behavior of *R. typus*.

Overall, both of the observed injuries in Ningaloo were caused by an anthropogenic source. Although, not all recorded amputations in this area have been the byproduct of an anthropogenic source. Dr. Ben Fitzpatrick recorded a well-documented natural amputation in 2003. An individual *R. typus* had two observed shark bites, one bite entirely removed the first dorsal (Fitzpatrick et al., 2006). This shark was then observed in 2004, and the wounds had exhibited intensive healing. Therefore, not all amputations can be induced by anthropogenic sources.

I believe amputations caused by evidence of possible active hunting should be classified differently from those of boat collisions, or natural causes (Appendix B). So little biological, and behavioral information in understood about these animals, therefore it would be more beneficial to categorize scarring indicative of hunting separately. This would allow for a greater understanding of anthropogenic threats to *R. typus*.

4.7 Other

The final scarring classification was other. Scars that were classified as other were uncommon wounds or irregularities such as abscesses, lumps or unusual markings (Speed et al., 2008). According to Speed, the hypothesized causation of these scars includes infection, or parasite infestation. Of the population subset I examined 11.76% showed signs of scars that were classified as other. This 11.76% included one male, and three females.

The one male was observed on April 18th, 2014 and was re-sighted the following day on April 19th, 2014. This shark was a mature male, which was approximately seven and a half meters in length. The only scars observed on this individual were the scars that were classified as other. These scars were observed on the right-hand side gills of the shark. These scars appeared to be some kind of skin infection.

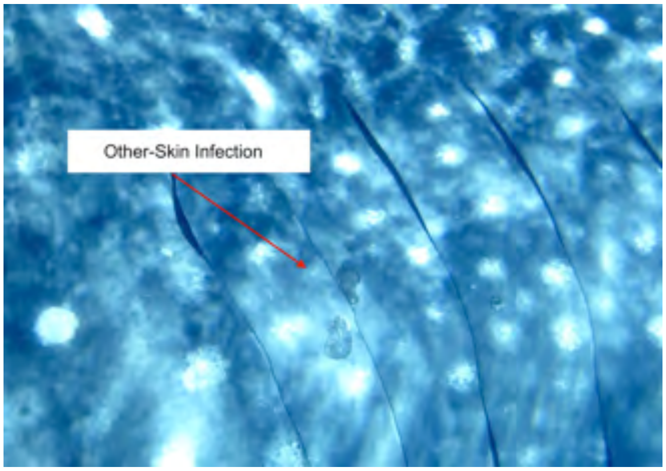


Figure 19 - Skin Infection Observed on April 18th, 2014

Overall, all of the sharks observed with scars that were classified as other, were correctly classified. The causation of these scars correctly defined the causation of the scars observed in Ningaloo. While many of the other scarring classifications needed modification, this classification accurately described the observed scarring.

General Discussion

The data I collected provided further insight into the study, and observation of a poorly understood species, *R. typus*. This study was conducted over a very brief period of time, and therefore had many limitations. This brief period of time reduced the observed sample size. Therefore, this small sample size could skew the data that emerged from my results. In addition, I was only able to observe *R. typus* at the start of the aggregation period. This limitation could influence the observed population. In addition, due to the small sample size, greater biological processes like mortality rates, and predation rates cannot be concluded from this data. Despite, the major limitations of this study, the results from my primary research can be beneficial for further study of *R. typus*. The inherent issues of the current scarring classification system became clear within my brief study of this species. Therefore if any greater studies of *R. typus* scarring are to be conducted, there is a need to alter the current scarring classification system.

Conclusion

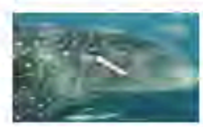
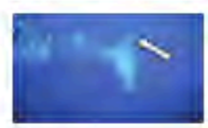
This study examined the current scarring classification system of *R. typus*. The aim of this study was to identify what scarring classifications were appropriate for scars found of *R. typus*. The results of this study found the existing classification system was useful, but was in need of revisions to provide more information about the scars. The generalized causation of scars did not provide a greater understanding of threats to *R. typus*. Therefore, the outcome of this study was a revised version of the scarring classification system. This new system can be applied to further studies of *R. typus*, and allow for more behavioral knowledge, and information of threats to be extracted from the data.

Appendix A.

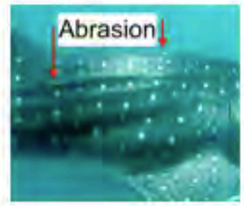
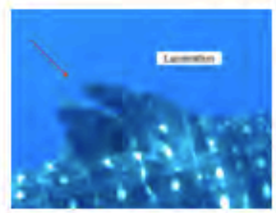
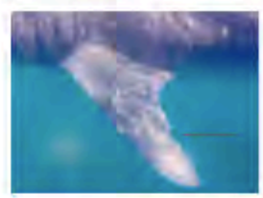
Appendix. Wound type, description and potential cause of scarring of *Rhincodon typus*. Shown are examples of 'abrasions' which are visible on the front and left side of the head, 'lacerations' showing parallel slashes along the caudal peduncle and cuts along the left pectoral fin with fishing net still attached, 'nicks' denoting a small piece of flesh removed from the trailing edge of the 1st dorsal fin, 'bites' showing a semi-circular piece of flesh removed from the trailing edge of the caudal fin, 'blunt trauma' indicating deep indentation and lacerations around the head, 'amputations' showing a caudal fin which has the top section removed, and 'other' indicating a large lump on the right side of the head.

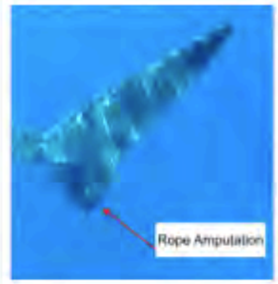
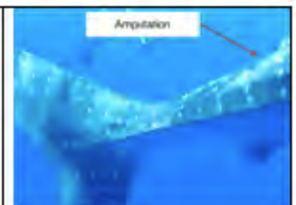
Wound type	Description	Possible cause	Image
Abrasions	Superficial skin-deep wound. These may either be distinctive scratches or broad scrapes.	Collision with ship, benthos or floating debris	
Lacerations	A linear cut that penetrates the flesh. These are deep wounds that are generally clean (*i.e.* no ragged edges).	Vessel propeller or hull, fishing gear, or gaff	 
Nicks	Removal of a small piece of flesh from a fin's trailing edge. These usually have a geometric shape.	Vessel propeller or natural	

Appendix. Continued

Wound type	Description	Possible cause	Image
Bites	Semi-circular wound or removal of flesh from body or fin. These range from puncture marks, to complete removal of flesh or fins.	Attack by sharks or odontocete whales	
Blunt trauma	Unnatural indentation on the body. These often include scar tissue around the indentation.	Collision with a vessel	
Amputations	Partial or complete removal of fin. Unlike bites, fins that have been amputated have linear edges.	Vessel propeller or fishing gear	
Other	Uncommon wounds or irregularities such as abscesses, lumps or unusual markings.	Infection, parasite infestation	

Appendix B.

Wound Type	Description	Severity	Possible Cause	Image
Abrasions	1. A shallow wound that could appear as a scratch or scape.	1. Minor	1. Minor- →Natural -Potential collision with benthos, such as coral.	
	2. A severe wound, a scrape that removes a large piece of flesh. An injury that could impact the overall health of the shark.	2. Major	2. Major- →Anthropogenic - Potential collision with a vessel.	
Lacerations	1. A series of shallow repeated linear cuts, or removal of the first dermal layer.	1. Minor	1. Minor- →Anthropogenic -Encounter with fishing gear, i.e. a gaff.	
	2. A series of deep repeated wounds. Repeated deep lacerations are visible. Impact is sever and potentially life threatening.	2. Major	2. Major- →Anthropogenic -Collision with a vessel propeller.	
Nicks	1. Nick with jagged edge, not life threatening.	1. Minor	1. Minor →Natural -Potential encounter with benthos.	
	2. Nick with clear linear lines where flesh is removed.	2. Major	2. Major →Anthropogenic -Encounter with fishing gear, including a ghost net or other fishing gear.	

Bites	1. A removal of flesh. Including the removal of a fin, or large chuck of flesh. The wound has ragged edges around the site of the bite. Generally a lunar shaped wound.	1. Minor or Major	1. Minor or Major →Natural -Successful flesh removal predator attack. Most commonly inflicted by another shark species. Can also include attempted unsuccessful predator bite.	
Amputations	1. Partial or complete removal of a fin. The fin wound site has ragged edges.	1. Major	1. Major →Anthropogenic Entanglement in rope, potential escape from capture attempt	
	2. Partial or complete removal of a fin. The fin wound site has linear edges	2. Major	2. Major →Anthropogenic -Removal by vessel	
Blunt Trauma	1. Indentation of flesh on a part of the body—most often the head.	1. Major	1. Major →Anthropogenic -Collision with a vessel—impact scar	

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