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Characteristics of external injuries of whale sharks (*Rhincodon typus*, *Smith* 1828) in Botubarani waters, Gorontalo, Indonesia

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ABSTRACT

Whale sharks (*Rhincodon typus*) are endangered fish with population numbers continuing to decline globally. Botubarani waters, Gorontalo is an aggregation area for whale sharks in Tomini Bay. The high number of tourist visits has created a persistent risk of injury of the whale sharks in the studied area. This research attempts to provide preliminary information regarding the external injury characteristics of Botubarani whale sharks in a descriptive manner, as well as photographic records of the development and rate of natural wound healing in cases of whale sharks suspected of having papilloma disease. Routine data collection during 2019–2023 using the Photographic Identification (Photo-ID) method accompanied by documentation of various types, positions, and severity of wounds on each individual have been carried out to determine the impact of tourism activities as ongoing efforts to protect and preserve whale sharks in Botubarani. The results revealed that 74% (n = 43) of the observed whale sharks had wounds characterized by abrasion nicks and lacerations, mainly located on the dorsal fin, mouth, and head. Although the 88% severity level was a minor injury, the high percentage of abrasion injuries (59.68%) indicated the high impact of friction on the bodies of whale sharks with tourists' boats during feeding. Routine monitoring for 7 months on the papilloma disease case at the Botubarani whale shark tourism site also showed that the healing process of non-anthropogenic wounds due to disease took longer than anthropogenic wounds. It also showed that the papilloma wound had not shown any signs of complete recovery. This research serves as a reference and consideration for Botubarani whale shark tourism managers to reduce the possibility of injury from tourism by creating guidelines for whale shark interactions and restricting tourism vessels from entering the Botubarani whale shark interaction zone. Further, the implementation of baiting techniques is needed to reduce the probability of injury to this endangered species in the future.

Introduction

Whale sharks (*Rhincodon typus*) are among the largest filter-feeder fish in the world (Rowat & Brooks, 2012). They are widely found in warm waters within tropical and subtropical climates (Guzman et al., 2022). Globally, whale shark populations are estimated to have declined by more than 50% over the last three decades (Pierce & Norman, 2016). The biological characteristics of slow growth, long life, and low fecundity (Dove & Pierce, 2021) make whale sharks highly susceptible to extinction, and they have been included in the list of endangered fish based on the IUCN-Red List (The International Union for Conservation of Nature Red List) since 2016 (Pierce & Norman, 2016). The species was listed as largely depleted based on IUCN-Green List assessment on 2021 (Pierce et al., 2021). In Indonesia, whale shark conservation efforts have been included in the National Action Plan for the conservation of whale sharks (2021–2025) through the decree of the Minister of Maritime Affairs and Fisheries number 16 of 2021. One of the critical objectives of the national action plan was to encourage the availability of survey data, studies, and research on whale sharks in Indonesia.

The waters of Botubarani, Gorontalo, is an aggregation area for whale sharks, which has been designated as an Important Shark and Ray Area (ISRA) in Tomini Bay as it was considered a feeding area for juvenile male whale sharks (IUCN, 2024). Moreover, this area has become a tourist attraction with an important economic value for Indonesian

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whale shark tourism (Djunaidi et al., 2020). The whale shark aggregation area is also located within the Gorontalo Bay Coastal Park marine conservation area, playing a significant role in the local economy with a contribution peaking at IDR 7.8 billion during high season months (Monoarfa et al., 2020). On the other hand, this kind of seasonal aggregation is very susceptible to population decline due to anthropogenic activities (Pierce & Norman, 2016). The anthropogenic impacts of tourist stress can have implications on the health and survival of whale shark populations by triggering severe stress due to unintentional injuries (Harvey-Carroll et al., 2021).

The impact of anthropogenic injuries also tends to be more complex and destructive than natural ones since it may cause long-term physiological adjustments, behavioral changes, and, in the worst case, even death (Womersley et al., 2021). The development of tourism must consider physical damage to endangered species such as whale sharks (Penketh et al., 2020). Various research studies related to external injuries of whale sharks reported their observation in various aggregation areas of the world. These include observations in the Gulf of Tadjora, Djibouti (Rowat et al., 2007), multiple locations in the Indian Ocean (Australia, Seychelles, and Mozambique) (Speed et al., 2008), Ningaloo Marine Park, Australia (Lester et al., 2020), the Cebu and Oslob sites, Philippines (Araujo et al., 2014), and in Cenderawas Bay Papua, Indonesia (Jentewo et al., 2021). The results of several recent studies indicated that whale sharks with severe injuries tend to stay for a long time in aggregation areas such as the South Ari Atoll Marine Protected Area, Maldives (Harvey-Carroll et al., 2021) and aggregation locations with feeding (provisioning site) as in Botubarani. It is worth mentioning that the number of injured whale sharks reached 97% of the total population recorded during 4 years of research in Oslob, Philippines (Penketh et al., 2020).

A good understanding of the characteristics of external injuries, their impact on the long-term health and survival of the whale sharks, and their responses to different types of injuries will provide invaluable insights for future conservation efforts aimed at protecting this endangered species (Womersley et al., 2021). This study presents the first description of the external injury characteristics of whale sharks at the Botubarani aggregation site, Gorontalo, based on the wound's position, type, and severity. Further, it explores the development and healing rate of non-anthropogenic wounds through photographic records of injuries captured over time.

Materials and methods

Time and study site

The research was conducted in Botubarani waters, Gorontalo Province, at coordinates 0°28′28.1″ N 123°06′00.9″ E as shown in Figure 1. This area is within the regional water conservation zone, Gorontalo Bay Coastal Park, which covers 33.45 ha in a limited-use zone. Geographically, Botubarani waters are on the north coast of Tomini Bay, with a steep drop-off beach topography. The appearance of whale sharks was observed every day from 6 am to 5 pm in an interaction zone of 0.82 Ha (approximately 20 m from the beach) from January 2019 to October 2023. The initial appearance was recorded as one appearance /day in the whale-shark interaction zone.

Identification and injury photos

Routine and continuous data collection of the whale sharks were recorded during the 2019–2023 period through Photographic

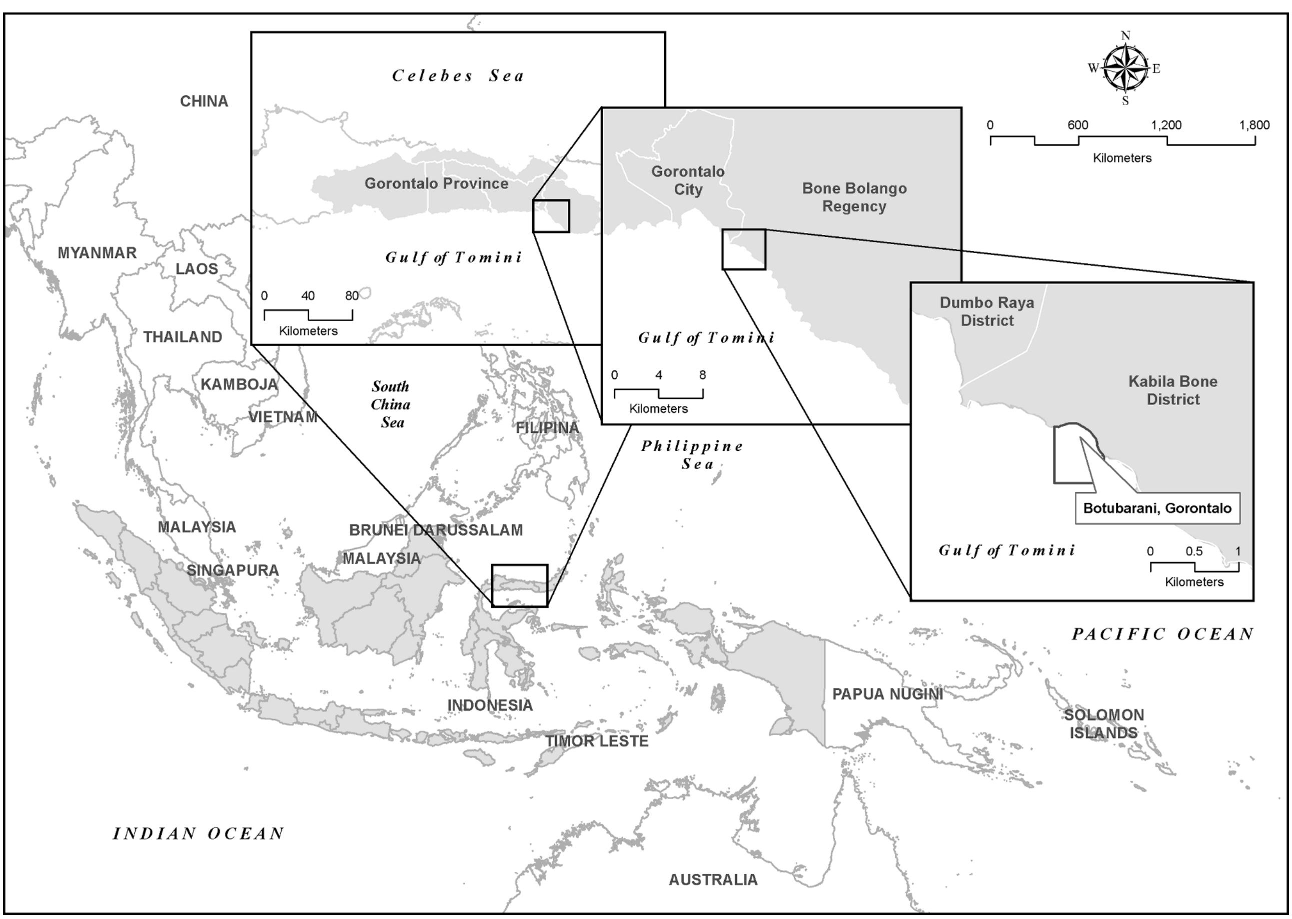


Figure 1. Research location map of Botubarani, Gorontalo, Indonesia.

Identification (Photo-ID) (Pierce, 2007). The Photo-ID technique used the camera's angle around the pectoral fins and gills. The photo's horizontal frame composition included a white spot pattern between the 5th gill and the base of the pectoral fin as a distinctive feature (like fingerprints) between individuals (McKinney et al., 2017). Meanwhile, the border of the photo frame was vertical, starting from the base of the pectoral fins to the tip of the upper back (Arzoumanian et al., 2005; Brooks et al., 2010).

Whale shark injuries were recorded and documented by observing all parts of their bodies. The results of recording and photographing wounds were then grouped based on position, type, and severity of wounds. Whale shark injuries by position were divided into 12 areas following Penketh et al. (2020), namely five areas on the fin (caudal, dorsal, posterior, pectoral, and ventral fin), three areas on the body (posterior flank, anterior flank, and ventral surface), and four areas on the head (eyes, head, ventral head, and mouth).

Injuries were classified into seven categories based on Speed et al. (2008), i.e., abrasions, lacerations, nicks, bites, blunt trauma, amputations, and other wounds. This research added two further types of wounds, according to Womersley et al. (2021): entanglement and parasitic. Meanwhile, the severity of injuries was divided into two categories: major and minor (Speed et al., 2008). Severity assessment followed the method of Allen et al. (2021) by ranking them from 0 to 4 in which a zero score indicated no injury, $\leq$ 2 was categorized as minor injury (mild), $\geq$ 3 was classified as serious injury (major), and 4 indicated severe injury.

Statistical analysis

Identification of individual whale sharks was analyzed using the Interactive Individual Identification System (I3S) software based on Pierce (2007) through the Capture Mark Recapture (CMR) approach from the model and pattern of distinctive white spots on each documented individual whale shark (Arzoumanian et al., 2005). Field identification photos were arranged and named uniformly (referring to the prior photo-ID numbering arrangement) and cropped according to the 3:4 scale using the Photoscape software (version 3.3). This software was used to crop and enhance the color of the photos to ensure improved freshness and contrast, prior to analysis in the I3S software. Through this data processing, it was possible to distinguish whether the observed whale shark was an established individual that has returned or a new arrival previously undocumented. The results of the interpretation of individual ID photo data per day were tabulated into monthly and annual presence data to see the number and frequency of presence of the whale shark population in Botubarani during the research period. The photo documentation of whale shark injury data was grouped and tabulated/graphed based on position, type, and level of injury severity.

Results

Population identity and characteristics

The result of the ID photo identification using I3S software revealed 43 whale shark individuals, with a composition of 42% (n = 18) old individuals and 58% (n = 25) new individuals who had never been recorded in the previous period. The number of individuals appearing per year varied between 9 and 25, with an average of 5 new individuals appearing yearly. The highest attendance occurred in 2021 (n = 25) and the lowest in 2023 (n = 9) (data collection until October) as shown in Figure 2. However, the highest emergence of new individuals occurred in 2020 and 2022 (n = 6).

Whale shark individuals that appeared in Botubarani had a total length range of 2.5 and 7.3 m (m), with an average size ranging from 4.47 to 4.73 m, as presented in Table 1. This indicated that the whale shark population in Botubarani was juvenile. Observations on gender also showed that all the individuals of whale sharks were males. The most frequently observed individual was a whale shark measuring between 4 to 5 m in total length. The whale shark tagged as ID GT050 had the longest size (7.3 m) and appeared for the first time in June 2022. This individual was at the research location for 18 days from early June to early August. Meanwhile, the whale shark tagged as ID GT037 had the smallest size (2.3 m) and appeared once in June 2019.

Characteristics of whale shark injuries

A total of 43 whale sharks appeared alternately in the whale shark interaction zone during the research period and became objects of observation to obtain an overview on the external injuries characteristics of Botubarani whale shark population. This study found that 74% (n = 32) of the total individuals monitored had injuries of various types. Meanwhile, the other 26% (n = 11) had no injuries (Figure 3). Based on wound's severity, Botubarani whale shark injuries were predominantly minor (88%, n = 28) with only four cases (12%) of major injuries in the form of bite marks and amputations, which were thought to be the result of predator attacks.

During the research period, the Botubarani whale shark had seven categories of injuries: abrasion, laceration, bite, blunt trauma, nicks,

Table 1
Estimated body length of whale sharks per year.

Year	N (Ind.)	Average Length Range (m)	Sex	Category
2019	16	2.3–6.3 (4.56)	Male	Juvenile
2020	23	4–6.3 (4.47)	Male	Juvenile
2021	25	2.3–6.6 (4.68)	Male	Juvenile
2022	12	2.5–7.3 (4.73)	Male	Juvenile
2023*	9	2.4–6.3 (4.63)	Male	Juvenile

*Note: *Last data collection in October.*

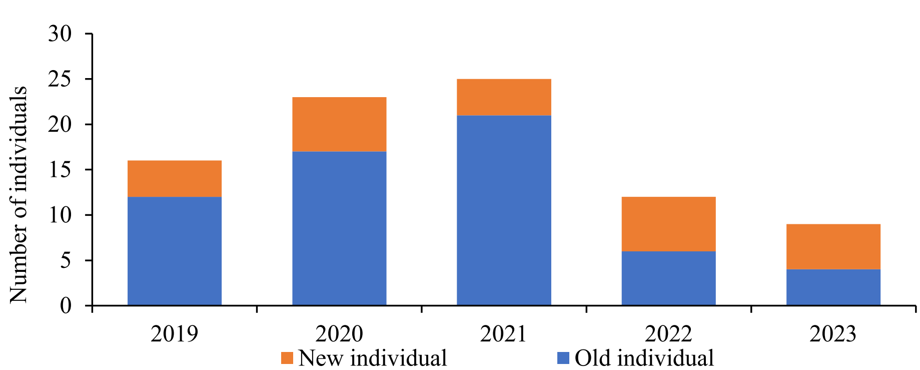


Figure 2. The number of old and new individuals during the research period.

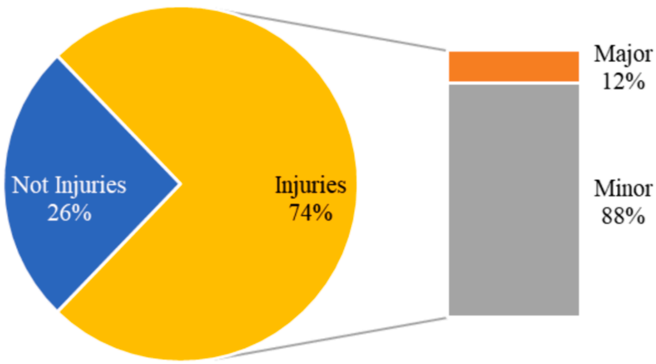


Figure 3. Percentage of the whale sharks' injuries and their level of severity (n = 43) in the area of study.

amputation, and puncture. . The results also included two types of injuries that were unusual and still rarely reviewed in various research, namely parasitic wounds and wounds resulting from disease as shown in Table 2.

The composition of wound types based on injury position on the whale shark body showed that the dorsal fin (Figure 4I) was the area most frequently injured with wounds dominated by abrasions (n = 9), nicks (n = 3) and amputations (n = 2). Other areas that also experienced many injuries were the head (Figure 4D) and mouth (Figure 4A), which were also dominated by abrasions (n = 8), as shown in Figure 5. Abrasions are the type of wound that dominated almost all areas of whale shark injuries in Botubarani. Abrasions were found on 58.9% of the total injured sharks (Table 3). The rest were nick wounds (12.90%, n = 8), lacerations wounds (9.68%, n = 6), bites wounds (6.45%, n = 4), amputations and punctures 3.23% (n = 2), and bruises, while parasites and disease were found as one case each.

Parasite injuries and natural wound healing

This study has successfully observed two additional cases of parasitic wounds and papilloma disease. A case of parasitic wounds was found on the whale shark tagged as ID GT 40 on February 25, 2020, with abrasions in the lower mouth area (Figure 5A), which then became a place for attachment of the copepod parasite *Pandarus rhincodonicus*. Meanwhile, a wound suspected to be a lesion occurred on the whale shark tagged as ID GT 58, which was a new individual that appeared in early 2023. The wound was documented to track its development and the likelihood of natural healing in the whale shark. Similar wounds are rarely documented in whale sharks. Therefore, the present result could provide valuable insights into the adaptability of *R. typus* in responding to non-anthropogenic injuries in its natural environment.

Observations of the lesions of the whale shark tagged ID GT 58 were recorded for 7 months (March-October) in 2023. Initial observations of the development of the wounds began on March 29, 2023 (Figure 6). A small lump began to appear on the surface of the skin between the right eye (Figure 6A1) and left eye (Figure 6B1). The lump size can be estimated by comparing it to the eyelid circle, which still appeared larger than the lump's cross-sectional area. The second observations were recorded on June 15, 2023, by taking the photos of the whale shark's wounds in the same area. The condition of the wound showed a rapid increase in size and even exceeded the area of the eyelid circle. The wound surface appeared pink, rough, and uneven. In addition, there was an increase in the number of new sore lumps around the mouth area. On the right side (Figure 6A2), four new lumps appeared, while on the left side (Figure 6B2), six new ones appeared. The third observations recorded on October 6, 2023 (Figure 6A3) revealed that the wound showed signs of recovery, with the size decreasing and the color turning white. Likewise, observations of the left side were recorded on August 2, 2023 (Figure 6B3). During the healing process, the wound was getting smaller and no new lumps were emerging.

Discussion

Population identity and characteristics

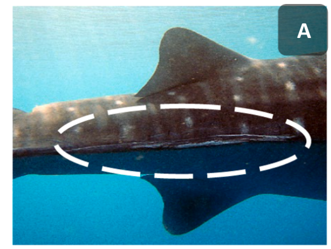
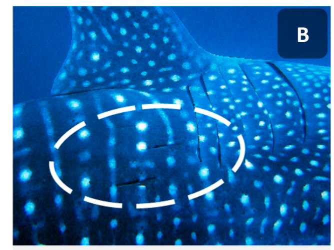
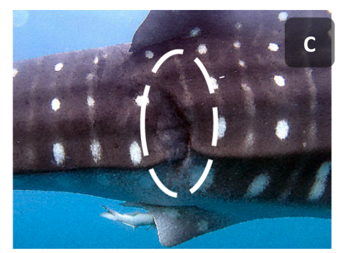
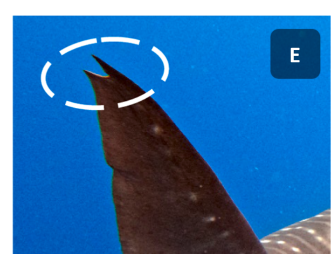
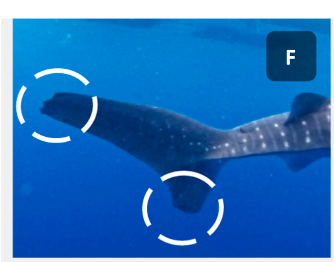
The coastal water of Botubarani is the only seasonal aggregation area for male juvenile whale sharks as their passageway in and out of Tomini Bay (Handoko et al., 2017; Rahman et al., 2017). Initial data collection on Botubarani whale sharks using the Photo-ID method began on April 12, 2016, as collaborative monitoring activities between the Coastal and Marine Resources Management Center (Balai Pengelolaan Sumberdaya Pesisir dan Laut, BPSPL) Makassar, Whale Shark Indonesia (WSID), and the Regional Government. Local fishermen reported whale shark sightings before 2016; therefore, the photo data in 2016 became the ID marking of initial whale shark appearance (ID 001) (Handoko et al., 2017). The ability to recognize different individuals is important in whale sharks in order to predict their number to determine whether the population is increasing or decreasing (Toha et al., 2019).

A total of 58 individual whale sharks have been identified using the Photo-ID techniques over the past 8 years. When compared with the number of individuals in other places, such as the work of McKinney et al. (2017) in the Gulf of Mexico (n = 1361), or the results of Tania et al. (2016) in Cenderawasih Bay, Papua (n = 126), the population of Botubarani whale sharks was relatively small, therefore, it requires further individual-based data collection on the long term. Photographic identification (Photo-ID) techniques are the appropriate method for studying long-term population structure in Botubarani. This method is also widely used to evaluate population structure, residency patterns, population size, residence patterns, habitat use, movement patterns, philopatry assessment, and other population dynamics (Andrzejaczek et al., 2016; Araujo et al., 2022).

New individuals dominated the Botubarani whale shark interaction zone (58%), with an average of five new individuals appearing each year. The remainder were old individuals (42%) with seasonal site fidelity patterns in Botubarani waters. Several studies also showed this return pattern; for instance, 35% of individuals were observed again in Ningaloo Reef, Australia (Holmberg et al., 2009). In Donsol, the Philippines, most of the whale shark population (53%) returned to the same location in at least 2 seasons (McCoy et al., 2018). However, in Panon Island, Philippines, Araujo et al. (2017) found that only 32% of individuals returned to the same location. The phenomenon of the presence of new individuals and the return of old individuals with different presence times every year, increasingly showed that this area is an important habitat in the cycle and development of this endangered species in the waters of Tomini Bay.

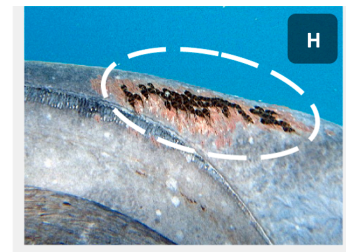
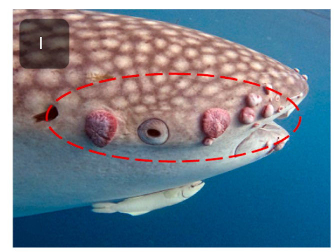
Observations of the total length of the Botubarani whale shark also showed that the population of whale sharks are male individuals that were classified as juveniles. According to Norman and Stevens (2007), whale sharks only reached maturity at a total length of 8 m. Meanwhile, the estimated size range for the total length of the Botubarani whale sharks ranged from 2.5–7.3 m with an average size of 4.6 m. This size is actually not much different from the results of other research in different locations, such as in Cebu, the Philippines, with an average size of 5.5 m (Araujo et al., 2014) and Kwazulu-Natal Beach, South Africa, with whale sharks having a size range of 4–7 m (Cliff et al., 2007). Further, in Holbox Island, Mexico, the whale sharks were recorded with a total length range of 2.5–9.5 m (Ramírez-Macías et al., 2012), while in Cenderawasih Bay, Papua, Tania et al. (2016) recorded estimates of total length with a range of 2–8 m. It is worth mentioning that the use of visual estimation method has received significant attention due to potential errors and biases in observations (McCoy et al., 2018; Ramírez-Macías et al., 2012). Accurate information on the body size of migratory species is essential, as body size and adult age serve as indicators of a species' susceptibility to extinction (Sequeira et al., 2016). The absence of female individuals and adult whale sharks in Botubarani was also

Table 2
Types of scars/injuries identified during the study.

Sources	Scar type	Description	Example
Boat hull strike	Abrasion	Abrasions due to ship impact extending from the base of the tail series toward the posterior flank	
Propeller strike	Laceration	These injuries might have been caused by a propeller of a ship slicing through the fish's skin. The scars look consistent and recurring	
Predatory animals	Bite	A curved and deep bite scar between the anal and 2nd dorsal fins.	
Boat hull strike	Bruising (Blunt trauma)	Bruising in the clasper area and base of the anal fin	
Entanglement (ropes and nets)	Nick	Nicks are small cut-outs on the tip of the tail fin often caused by potential entanglement (ropes and nets).	
Predatory animals and vessels related injuries	Amputation	Amputation scars on the tips of the upper and lower tail fins.	

(*continued on next page*)

Table 2 (*continued*)

Sources	Scar type	Description	Example
Scientific	Puncture (Other)	Puncture wounds due to installation of satellite tags.	
Parasitical	Parasite (Other)	Parasite-covered abrasions on the lower mouth area.	
Skin disease	Diseases (Other)	Skin disease around the eye and mouth area.	

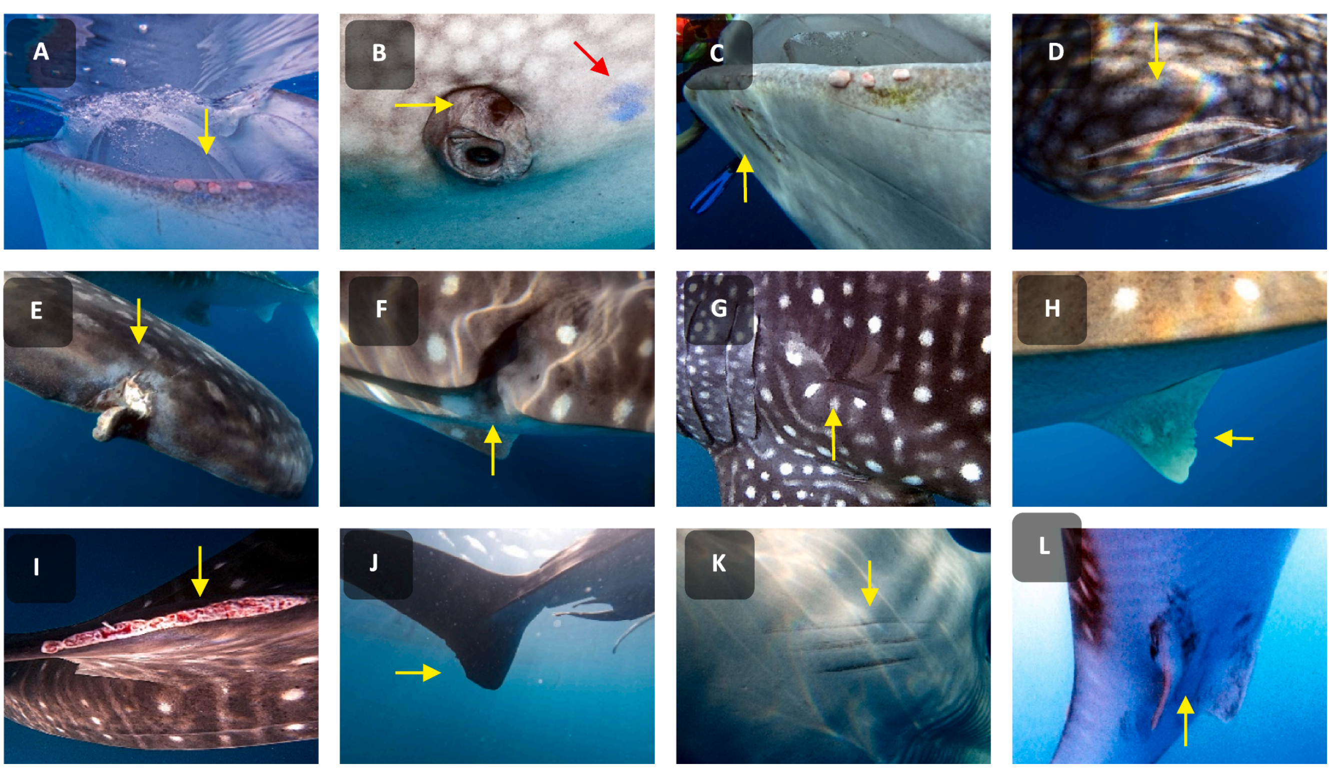


Figure 4. Injuries based on wound position in: (A) mouth; (B) eyes; (C) ventral head; (D) head; (E) pectoral fin; (F) anterior flank; (G) posterior flank; (H) posterior fin; (I) dorsal fin; (J) caudal fin; (K) ventral surface; and (L) ventral fin.

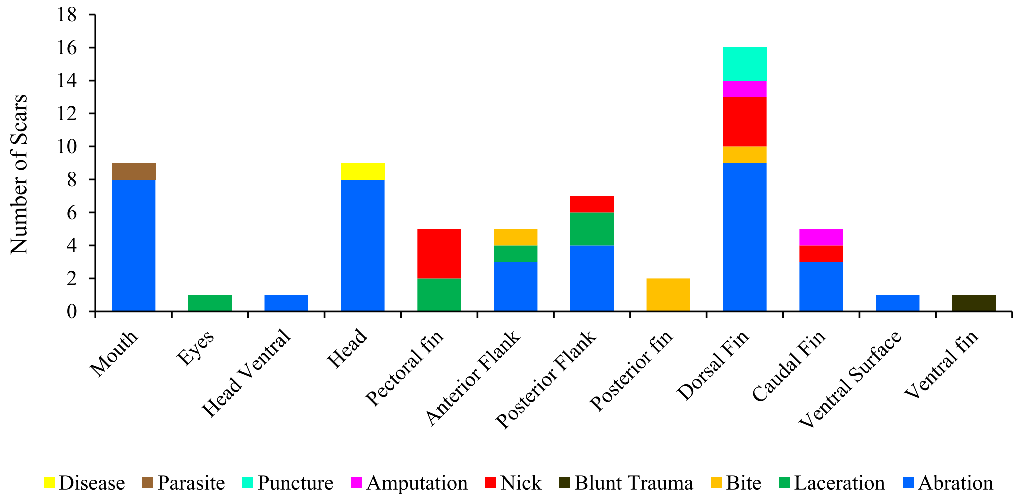


Figure 5. Composition of injury types based on wound position on the body of whale shark.

Table 3
Percentage of individuals based on wound position.

Area of the Body	% Injury (n)
Mouth	14.52 (9)
Eyes	1.61 (1)
Head Ventral	1.61 (1)
Head	14.52 (9)
Pectoral Fin	8.06 (5)
Anterior Flank	8.06 (5)
Posterior Flank	11.29 (7)
Posterior Fin	3.23 (2)
Dorsal Fin	25.81 (16)
Caudal Fin	8.06 (5)
Ventral Surface	1.61 (1)
Ventral Fin	1.61 (1)

n = number of individuals.

important to highlight. This condition showed that Botubarani waters were an important habitat for the development of male juvenile whale sharks (Valsecchi et al., 2021) or as a secondary nursery (Allen et al., 2021) and feeding area for the juvenile male whale sharks (IUCN, 2024) in Tomini Bay.

Characteristics of whale shark injuries

This research attempted to provide initial information regarding the characteristics of whale shark injuries that frequently occurred in the whale shark interaction zone of Botubarani over the last 5 years. The characteristics of whale shark external injuries were described based on position, type, and level of injury severity. A total of 43 individuals who appeared in the interaction zone during the study period were subjected to routine injury observation. A total of 74% (n = 32) of the monitored individuals had injuries, both old scars and new wounds of varying types and positions. When compared with other locations, the percentage of injuries in Botubarani whale sharks was higher than the percentage of injuries in Cendrawasih Bay, Papua (53%) (Jentewo et al., 2021), the Indian Ocean aggregation locations (Australia, Seychelles, and Mozambique) (67%) (Speed et al., 2008), and Ningaloo Marine Park, Western Australia (38.8%) (Lester et al., 2020). However, it was lower than that of the tourist attraction sites with a feeding site model in Oslob, Philippines (Penketh et al., 2020). The high levels of visitors with tourist

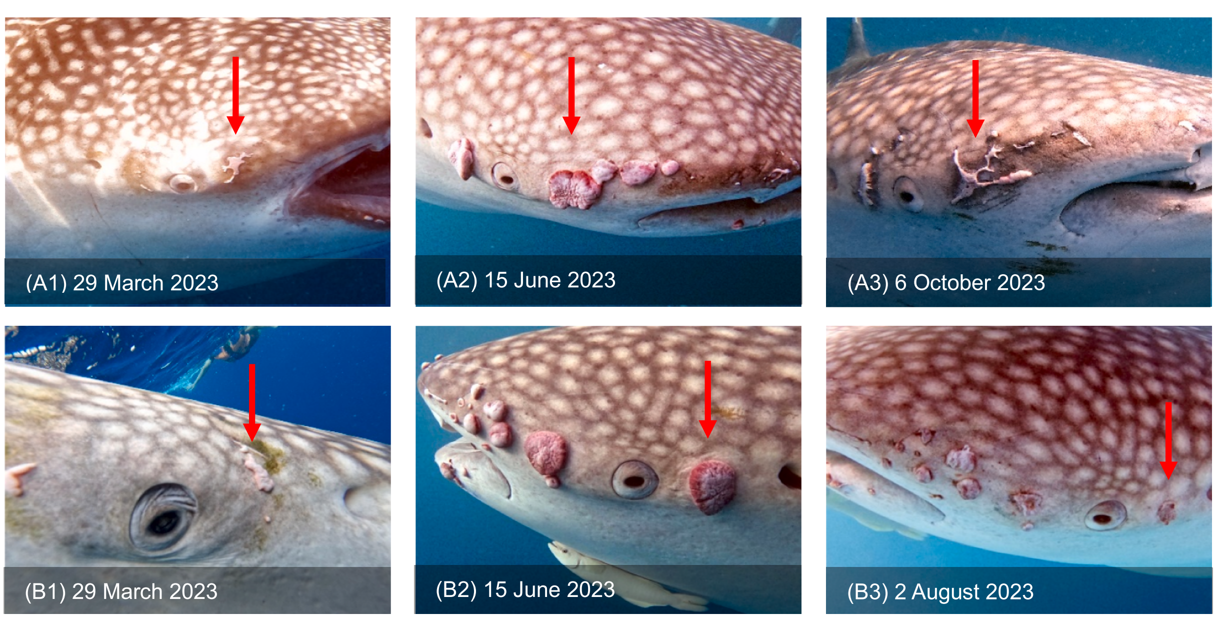


Figure 6. Documentation of the lesion lumps development of the whale shark tagged ID GT58 (A = right side; B = left side).

boat activities overlap with Botubarani whale shark aggregation zone, hence, increasing the possibility of injury and the risk of reinjury (Handoko et al., 2017). Whale sharks reported in Oslob were of 152 individuals, 97% were found to have scars, and more than 90% had more than one wound. It is important to note that various research methodologies, intensity levels, and research time intervals may have led to different injury percentages in various locations (Penketh et al., 2020). Nevertheless, tourism activities using a feeding (provisioning) model have contributed to the high number of whale shark injuries in various whale shark provisioning sites (Araujo et al., 2014; Harvey-Carroll et al., 2021).

The characteristics of external wounds found in Botubarani were dominated by wounds in the dorsal fin area, mouth, head, and body. The dorsal fin was the area that suffered most injuries, as has been the case reported in the Philippines (Penketh et al., 2020) and the Ningaloo Reef, Australia, where the majority of scars were on the body and fin area (Meekan et al., 2006). Apart from boat collisions, ship propeller scars, and predator attacks (Speed et al., 2008), the causes of many injuries to the dorsal fin area also happened in Botubarani. During the research period, satellite tagging was installed 3 times on whale sharks with tag IDs GT 53, 55, and 57. Wounds resulting from the installation of such tagging were classified into the puncture wound category (Table 2). This has not been observed anywhere else.

The most common injury in Botubarani was abrasion, followed by nicks, and lacerations. More than 50% whale sharks had abrasion wounds spread almost all over their body, except for the eyes, ventral fin, posterior fin and pectoral fin. This composition was not much different from the results of a research in the Philippines, where abrasions and nicks were more dominant on the dorsal and caudal fins (Penketh et al., 2020). The high number of abrasions found in Botubarani was probably caused by friction with the tour ships. Feeding activities encouraged whale sharks to approach ships, which caused direct friction between the ships' propellers and the bodies of whale sharks (Penketh et al., 2020). Several photos of injuries in Botubarani showed traces of boat paint stuck to the whale shark's body, for example, the whale shark tagged ID GT 20 showed traces of blue paint near the eye (Figure 4B).

Wounds or scars can be signs of predation and boat strikes (Penketh et al., 2020). However, the percentage of lacerations and bites in Botubarani was not as high as the percentage of abrasions and nicks. Lacerations were characterized by a pattern of parallel and repeated wounds, indicating impact from the ship's propeller (Rommel et al., 2007). Several individuals observed in Botubarani had scars from blows of propellers, mainly on the body and pectoral fins (Table 2B and Figure 4E). Regarding laceration cases, the injury to the eye organ of the whale shark tagged ID GT 32 is highlighted in Figure 4B. This individual was first spotted in Botubarani on August 21st, 2018 and had an eye injury. This whale shark had the longest residence time (386 days) and consistently appeared every year (except in 2023) with an average appearance of 96.5 days/year. It is possible that injuries to vital organs such as the eyes, even though they were small, caused whale sharks to tend to settle in Botubarani probably seeking feeding and recovery.

Botubarani whale shark residents also suffered from predator bite injuries, although not as many as in aggregation sites in the Indian Ocean as in Ningaloo (44%), Seychelles (21%) and Mozambique (14%), where predator bites were the most common source of injury (Speed et al., 2008) and Western Australia, where scarring from predator attacks was 4.8–11% (Lester et al., 2020). The risk of predator bites for whale sharks is higher in coastal waters (Meekan et al., 2020). These bite marks may be caused by attacks by predators such as the killer whales (*Orcinus orca*) and have been recorded at Ningaloo Reef (Fitzpatrick et al., 2006). This mammal with the nickname "assesina ballenas" is often found around the waters of Tomini Bay. A video captured by local diver Reinhard Santoso on April 26, 2023, documented three orca whales passing through South Bolaang Mongondow (see Link https://www.youtube.com/watch?v=hiYh8DnslOY).

Although all whale shark injuries found in Botubarani were categorized as minor injuries (88%), the high number of abrasions that were thought to be caused by ship collisions needs serious attention in future research. Botubarani whale shark managers must reflect on the case of the Oslob provisioning site in the Philippines, where almost the entire population (97%, n = 152) had scars and more than 90% had more than one wound (Penketh et al., 2020). Implementation of good whale shark interaction guidelines and restrictions on tourism vessels entering shark interaction zones need to be well-regulated to reduce the risk of injury to whale sharks in Botubarani.

Parasite injuries and natural wound healing

Collecting photographic records of external injuries to assess the wound healing process is essential for whale shark protection and conservation strategies (Womersley et al., 2021). This study found two additional cases of ectoparasitic wounds and neoplastic lesions as referred by Brunnschweiler et al. (2017). A parasitic wound was found on the whale shark tagged ID GT 40 on February 25th, 2020, with abrasions in the lower mouth area, which then became the attachment site of the parasite copepod *Pandarus rhincodonicus* (Norman et al., 2000). The association between *P. rhincodonicus* and whale sharks is known to be parasitic because it consumes epidermal tissue and produces a substantial amount of mucus (Norman et al., 2022). This ectoparasite can cause infections characterized by the presence of brownish spots, especially along the jawline (Dove & Pierce, 2021). Although the impact of the copepod parasite on wounds in whale sharks is not fully understood, some research results indicated that Copepoda could cause erosion, ulceration, hemorrhage, inflammation, and fibrosis in their hosts (Carrier et al., 2022).

In the case of the whale shark tagged ID GT 58, its periodic appearance in the interaction zone of Botubarani provided a rare opportunity to photograph the development of the wound over 7 months. Even though within the period of observation, the condition of the wound has not completely recovered, this brief observation provided initial information about the adaptive ability of whale sharks in responding to diseases compared to anthropogenic wounds. Womersley et al. (2021) had provided important insights into the healing of anthropogenic wounds where major wounds showed 56% reduction in surface area in 25 days. Even some minor injuries showed 50% reduction in surface area within 4 days.

A case that may be similar to the whale shark tagged ID GT 58 was reported by Brunnschweiler et al. (2017) with the bull shark *Carcharhinus leucas*. Based on macroscopic observations of photos and videos for 7 years, the authors diagnosed this chronic wound case as "proliferative gingivitis and cellulitis", which required a long time to recover. Future studies should focus on the histology aspect of such wounds in order to enhance our understanding of the phenomenon of this rare injury occurrence.

Conclusion

The characteristics of Botubarani whale shark wounds fell into the category of minor wounds, which were dominated by abrasions, nicks, and lacerations. Most injuries occurred in the dorsal fin area because it was the nearest part of the body to the surface of water when boats passed, or when a predator attacked the whale shark. The high frequency of abrasions caused by boat friction requires attention in future research. Standard operation guidelines for whale sharks and restrictions for tourism vessels entering shark interaction zones are needed in order to reduce the injury risk in Botubarani waters.

Ethical clearance

The ethical clearance for the use of animals in scientific research is attached as Supplementary material.

CRediT authorship contribution statement

Moh Yasir: Writing – review & editing, Writing – original draft, Methodology, Data curation. **Retno Hartati:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Elis Indrayanti:** Visualization, Validation, Supervision, Conceptualization. **Fahri Amar:** Project administration, Methodology, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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