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BRIEF COMMUNICATION

Eye healing in a free-ranging whitespotted eagle ray (*Aetobatus narinari*) following shark-inflicted bite injuries

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Abstract

Here we provide the first photographic records of the eye healing of a free-ranging whitespotted eagle ray (*Aetobatus narinari*) following shark-inflicted bite injuries on the cephalic region. The whitespotted eagle ray with fresh wounds on the cephalic region close to its right orbit, upper jaw and the anterior margin of its right pectoral fin was photographed on 19 July 2017 at the Fernando de Noronha Archipelago. Two subsequent photographs of the whitespotted eagle ray with a blind right eye were taken on 29 March 2018 and 18 April 2018. These records show the whitespotted eagle ray had the capacity to recover from the wounds, although they have led to the blindness of the eye. These findings also demonstrate this individual was able to survive for at least 9 months with a nonfunctional eye.

KEYWORDS
bite mark, elasmobranchs, predation, shark attack, wound healing

Shark predation attempt is one of the main causes of wounds reported in large filter-feeding elasmobranchs (Kitchen-Wheeler, 2010; Marshall & Bennett, 2010; Womersley *et al*., 2021), as well as in small to medium-sized sharks in the wild (*e.g*., Chin *et al*., 2015). Although elasmobranchs are resilient to a range of external wounds, shark-inflicted injuries can negatively affect their fitness, reproductive abilities and survival through the impairment of swimming and organs of the sensory and reproductive systems (*e.g*., Marshall & Bennett, 2010). However, there is little published data on healing rates, recovery and survival in free-ranging elasmobranchs, mainly due to the opportunistic and rare nature of those sightings (Chin *et al*., 2015; Marshall & Bennett, 2010; McGregor *et al*., 2019; Womersley *et al*., 2021).

Elasmobranchs have a high capacity to recover from wounds, which has been attributed to their unique physiological adaptive immune responses (Luer *et al*., 2004). Studies have shown that healing time is species-specific and depends on the type and severity of the injury. For example, shark-inflicted injuries on reef manta rays (*Mobula alfredi*) were reported as completely healed within 126 to 225 days (Marshall & Bennett, 2010). Similarly, a bite wound on an adult blacktip reef shark (*Carcharhinus melanopterus*) was completely healed within 40 days (Chin *et al*., 2015). As such, baseline information on wound healing in sensory organs could help to understand the regenerative capacities of elasmobranchs (*e.g*., McGregor *et al*., 2019). However, to date, there are no published studies of healing rates and recovery from both natural and anthropogenic injuries in organs of the sensory system of elasmobranchs.

Here we provided the first photographic records of the eye healing of a free-ranging whitespotted eagle ray (*Aetobatus narinari*) following shark-inflicted bite injuries. The whitespotted eagle ray is a benthopelagic species over continental and insular shelves from the surface to 60 m depth, with a wide distribution throughout warm temperate to tropical waters (Last *et al*., 2016). This is a large, highly migratory ray species, which exhibits multiyear site fidelity and performs long-distance movement patterns (Ajemian *et al*., 2012; Bassos-Hull *et al*., 2014). The whitespotted eagle ray is currently listed as Endangered by the IUCN Red List, mainly due to its vulnerability to both targeted and nontargeted fisheries (Dulvy *et al*., 2021).

The studied photographs of the whitespotted eagle ray were obtained through a citizen science program launched in May 2021, which aimed to collect elasmobranch records from the Fernando de Noronha Archipelago (3°52′S, 32°25′W) is an isolated group of islands located 345 km off north-eastern Brazil, provided by SCUBA divers, underwater photographers and snorkelers. The whitespotted eagle ray with fresh wounds on the cephalic region close to its right orbit, upper jaw and the anterior margin of its right pectoral fin was photographed on 19 July 2017 (Figure 1a). Two subsequent photographs of the whitespotted eagle ray with a blind right eye were taken on 29 March 2018 (Figure 1b) and 18 April 2018 (Figure 1c). All sightings were recorded in a wreck close to the archipelago's port at 5 m depth. The absence of objects of known size in the available photographs precluded direct measurements of the whitespotted eagle ray and the observed bite marks. The shape of the teeth marks was used to identify the predator that made the wounds according to Compagno (1984, 2001) and Clua and Reid (2018).

The natural spot patterns of whitespotted eagle rays have been increasingly used as a noninvasive method to recognize individuals for population studies (Bassos-Hull *et al*., 2014; Cerutti-Pereyra *et al*., 2018; Corcoran & Gruber, 1999; Flowers *et al*., 2017; González-Ramos *et al*., 2017). The photograph of the wounded individual allows observation of only part of the left pectoral fin. Hence, the specific spots pattern of this section was analysed using the Interactive Individual Identification System (I3S Classic; van Tienhoven *et al*., 2007), a free software (download at: https://reijns.com/i3s/download/). The I3S software uses score matches to calculate the similarity between photo records. Lower scores mean closer fingerprints. A maximum of 27 spots were visible within the 19 July 2017 photograph which, together with the upper and lower visible limits of the left pelvic fin, were used to compare the spot patterns of the two subsequent photographs of whitespotted eagle rays with injuries in the right eye. We used two other records from the citizen science program to have a greater magnitude of scores and be able to compare suggested matches. The care and use of experimental animals complied with Brazilian animal welfare laws, guidelines and policies as approved by SISBIO (ICMBIO/SISBIO #12064).

I3S scores varied between 2.52 and 12.99. The lowest scores (2.52 and 5.51) and the presence of two fused spots resembling a dumbbell/ infinite symbol on the dorsal surface of the left pectoral fin

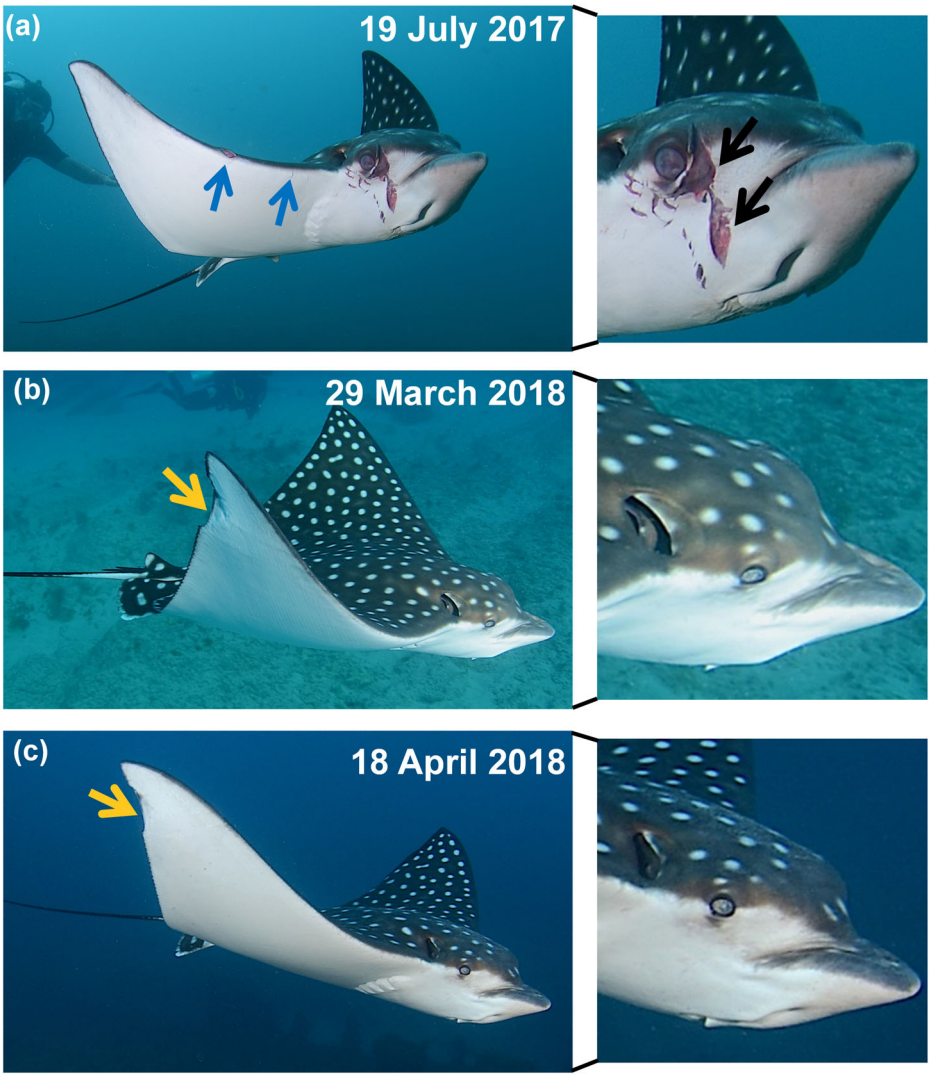

FIGURE 1 Photographs of the recently wounded (a; day 1) and healed (b, c; 253 and 273 days later, respectively) whitespotted eagle ray *Aetobatus narinari* in Fernando de Noronha Archipelago between July 2017 and April 2018. Black arrows indicate fresh scars and yellow arrows indicate a new healed wound of unknown origin. The inset in (b) and (c) shows the opaque and likely blind right eye. The blue arrows indicate the two fused spots resembling a dumbbell used to individualize this eagle ray

demonstrate that the whitespotted eagle rays photographed in three different events are the same individual (Figure S1).

The observed wound pattern of separated teeth punctures suggests the wounded whitespotted eagle ray suffered a predation attempt of a Carcharhinidae shark. The shark likely came from above and behind the left side of the ray, and bit its cephalic region close to the right orbit region with the upper jaw causing the deeper injuries observed (Figure 1a). Based on the ray's injuries, it is possible to suggest that the shark made at least two bite attempts: (a) on the anterior margin of the right pectoral fin (two small superficial parallel lesions); and (b) a deeper bite directly on the edge of this fin. The bite likely hit the whitespotted eagle ray's right eye, which appears opaque. The subsequent photographs taken 253 and 273 days after the first observation show a third healed scar of unknown origin on the posterior margin of the pectoral fin close to its tip (Figure 1b,c).

Information about healing rates could provide an estimate of healing time from nonlethal bite injuries, which could have broad management applications, including those related to survival from natural and anthropogenic injuries. Records showed that the whitespotted eagle ray had the capacity to recover from the wounds, although they have led to the blindness of the eye. Based on the high capacity that elasmobranchs have to recover from wounds (*e.g.*, Chin *et al.*, 2015; Marshall & Bennett, 2010; McGregor *et al.*, 2019), it is possible that the complete healing of the observed whitespotted eagle ray occurred earlier than 253 days elapsed after the first record.

Nonlethal shark-inflicted wounds have been most frequently reported in large filter-feeding elasmobranchs, such as reef manta rays (Marshall & Bennett, 2010; McGregor *et al.*, 2019) and whale sharks (*Rhincodon typus*) (Fitzpatrick *et al.*, 2006; Womersley *et al.*, 2021). The most similar case to the present report was a shark bite on a manta ray's cephalic region close to the left eye (Marshall & Bennett, 2010), apparently with no permanent damage to this organ. Although the species usually does not allow a close approach of divers when swimming (R. Viegas, personal observation), in the three different interactions reported here, the whitespotted eagle ray only swam away when divers came from its left side (Figure 1a–c), supporting its blindness or reduced right eye vision.

Vision is expected to play an important role in elasmobranch species living totally or partially in the pelagic environment, where the light incidence is high (*e.g.*, Lisney *et al.*, 2012). Therefore, vision loss, even in one eye, may have several negative impacts on the fitness and survival of an individual. For instance, vision loss would make an animal potentially more vulnerable to predation and accidents in the coral reef. Indeed, this fact is evidenced by the avoidance behaviour shown by the studied whitespotted eagle ray only when divers came from the side of its functional eye. In addition, in the second and third records (Figure 1b,c) is possible to observe a newly healed scar in the posterior margin of its right fin, suggesting a new predation attempt. This individual was no longer observed after the third record, despite almost daily dives in the dive spot where the photographs were taken (R. Viegas, personal observation). Although limited, this report expands our understanding of healing in elasmobranchs and its effects on behavioural interactions and survival.

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AUTHOR CONTRIBUTION

Conceptualization: All authors formulated the idea. Data curation: R.V., B.S.R. and V.B. Formal analysis: B.S.R., V.B. and R.C.G. Methodology: All authors. Roles/writing – original draft: B.S.R. and V.B. Writing – review and editing: all authors.

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SUPPORTING INFORMATION

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