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CASE REPORT
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Suspected predatory bites on a snorkeler by an oceanic whitetip shark *Carcharhinus longimanus* off Moorea island (French Polynesia)

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Abstract

Understanding why sharks bite humans is essential for developing strategies to prevent these incidents. Here, we use bite wound characteristics and eye witness descriptions of shark behavior to determine the likely motivation for several bites perpetrated by an oceanic whitetip (OWT) shark *Carcharhinus longimanus* on an adult female snorkeler off Moorea island (French Polynesia) in October 2019. The victim was snorkeling with others in pelagic waters as part of an organized whale-watching tour when the shark—without any warning behavior—bit her at least three times resulting in severe injuries with substantial loss of soft tissue from the chest and both forearms. The victim survived these injuries thanks to rapid and effective first aid provided by her companions. The sudden, unprovoked and repeated bites with substantial tissue removal are consistent with predatory behavior although the dominance hypothesis cannot be fully ruled out. This would be the first case of a predatory shark bite ever documented in French Polynesia in over 70 years of data collection. Given the routine association of OWT sharks with cetaceans, in-water whale watching activities should adopt appropriate risk management strategies in regions hosting this species of shark.

KEYWORDS
agonistic behavior, attack, dangerous marine wildlife, forensic anthropology and forensic odontology

Highlights

- Identifying the culprit shark species and understanding shark motivations for biting humans is paramount to better risk manage in ocean recreation.
- We analyzed a unique case study from French Polynesia involving a series of bites on a snorkeler engaged in whale-watching.
- An oceanic whitetip shark, a species often associated with cetaceans, was responsible for these non-fatal bites.
- The features of the repeated unprovoked deep bites are more consistent with predatory rather than dominance behavior.
- Given the potential dangerousness of this species, whale watching should adopt appropriate risk management strategies.

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1 | INTRODUCTION

Shark bites are very rare (<10 fatalities per year [1]) but receive huge media attention leading to a distorted public perception of shark bite risk [2]. A public perception of high shark bite risk can damage local economies in locations dependent on marine tourism [3]. We need to understand what motivates sharks to bite humans in order to better anticipate and mitigate these rare events.

Pelagic sharks, such as the oceanic whitetip (OWT) shark *Carcharhinus longimanus*, rarely encounter humans in the water because most in-water human activities occur in shallow near-shore environments. However, when encountered, OWTs are often highly inquisitive and persistently circle and approach humans [4]. OWTs are thought to be responsible for a large number of deaths of floating survivors from the sinking of the USS Indianapolis on July 28, 1945 [5]. Between 1955 and 2020, OWTs were responsible for at least 21 attacks on divers ($n = 9$), surface swimmers ($n = 8$), fishermen ($n = 2$), shipwreck survivors ($n = 1$), and downed pilots ($n = 1$) of which five were fatal [6]. However, none of these incidents resulted in a precise and scientifically documented description of the conditions of the attack. This formerly abundant species has been intensively overfished and is now classified as critically endangered by the International Union for Conservation of Nature [7]. Despite this drastic decline in OWT numbers, increasing human recreational activities in pelagic waters have increased encounters with this species especially in the Red Sea [8] where several attacks were recently observed [9]. Recreational snorkeling with whales in pelagic waters is especially risky because OWTs routinely associate with humpback whales (*Megaptera novangliae*) and pilot whales (*Globicephala* spp.) [10].

Here, we provide a detailed description of a serious, non-fatal bite incident involving an OWT and a snorkeler observing whales in French Polynesia. We discuss the likely motivation for the incident and the risk management implications for ecotourism activities where OWTs are present.

2 | MATERIAL AND METHODS

2.1 | Data collection

The first author participated in the official investigation of the incident and was provided with photos of the shark bite injuries taken at the hospital during the treatment of the victim, and eyewitness accounts of the incident. He interviewed both the victim and the professional guide present in the water when the incident occurred.

2.2 | Incident background

On October 21, 2019, around 11:00 a.m., several whale watching boats were operating around the island of Moorea, taking advantage of the presence of several pilot whales and humpback whales accompanied by OWT sharks (Figure 1A). The sharks were not aggressive and did not approach people during several initial snorkel-dives close to the cetaceans. On a subsequent dive, a group of six snorkelers (four adult women, a 10-year old child and a female professional guide) entered the water in the path of a group of pilot whales accompanied by three humpback whales. This group was observing the cetaceans from a distance of 50 m when the guide, who was ~10 m in front of the main group, observed a <2 m Total Length (TL) OWT shark swimming at a depth of about 4 m behind the cetaceans (Figure 2A). This shark swam slowly toward the surface before turning abruptly and swimming rapidly toward the main group of snorkelers who had not seen it. The guide then asked the snorkelers to regroup. At this point, four adults and the young child were together, while one adult was a few meters behind the group, on the surface cleaning her fogged mask (Figure 2B). While addressing the group, the guide lost sight of the shark and, without being certain it was the same shark, she observed an OWT shark in an upright position, biting the isolated person in the group. She then called out to the boat by hitting the surface of the water with her hand. The boat that was nearby approached the victim at high speed and the shark instantly abandoned the victim (Figure 2C). The guide suspected that the shark responsible for biting the snorkeler was the individual observed swimming rapidly toward the group but could not discount the possibility that another shark approached the snorkelers unseen (Figure 2B). While the bite victim was recovered from the water by the boat crew, the guide continued hitting the surface with her hand to distract the shark which bit her fin during attempts to repel it (Figure 2C) and then bumped her twice before swimming away.

2.3 | Shark size assessment

Shark size can be estimated from bite impressions using the demonstrated correlation between shark size and average interdental distance [11]. This method also works for the symphyseal spaces (SS) of both jaws (Figure 1D). Successful use of the IDD method requires bite impressions with clear tooth imprints. However, shark bite impressions commonly result in a continuous arc without discernable tooth marks (such as for the chest wound in our case). To estimate the size of the OWT shark responsible for biting the snorkeler, we used the bite impression from the victim's left shoulder (Figure 3A). This wound presented (i) a symphyseal tooth impression (see Figure 3A [ST]), present in the lower jaw of OWTs (see Figure 1G), (ii) rather disjointed teeth imprints (consistent with narrow teeth present in the lower jaw rather than broader triangular teeth present in the upper jaw), and (iii) a large intact skin flap likely corresponding to the inferior SS rather than the superior one (see Figure 3A [SS]). These features led us to conclude that the shoulder wound was caused by the lower jaw. In absence of clear teeth marks and a validated IDD algorithm for this

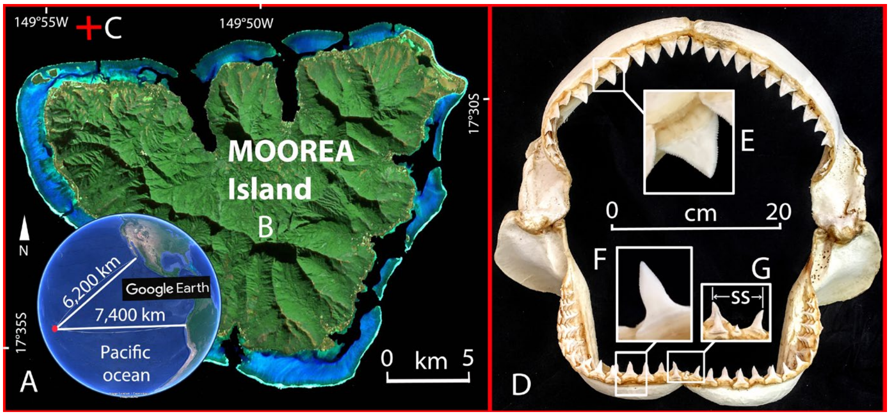

FIGURE 1 (A) Location of the Moorea island (French Polynesia) in the Central Eastern Pacific. (B) General features of the volcanic island surrounded by a lagoon delineated by an outer slope which is cut by several reef passages. (C) The red cross indicates the location of the bite incident in open ocean ~1 km from the northern coast. (D) General features of the heterodont jaw of an OWT shark *Carcharhinus longimanus*, with close up on (E) a triangular shaped and serrated tooth from the upper jaw, (F) a dagger-like and smooth lower jaw tooth and (G) a symphyseal tooth as well as the SS from the lower jaw (Photo courtesy of S. DeMarchi)

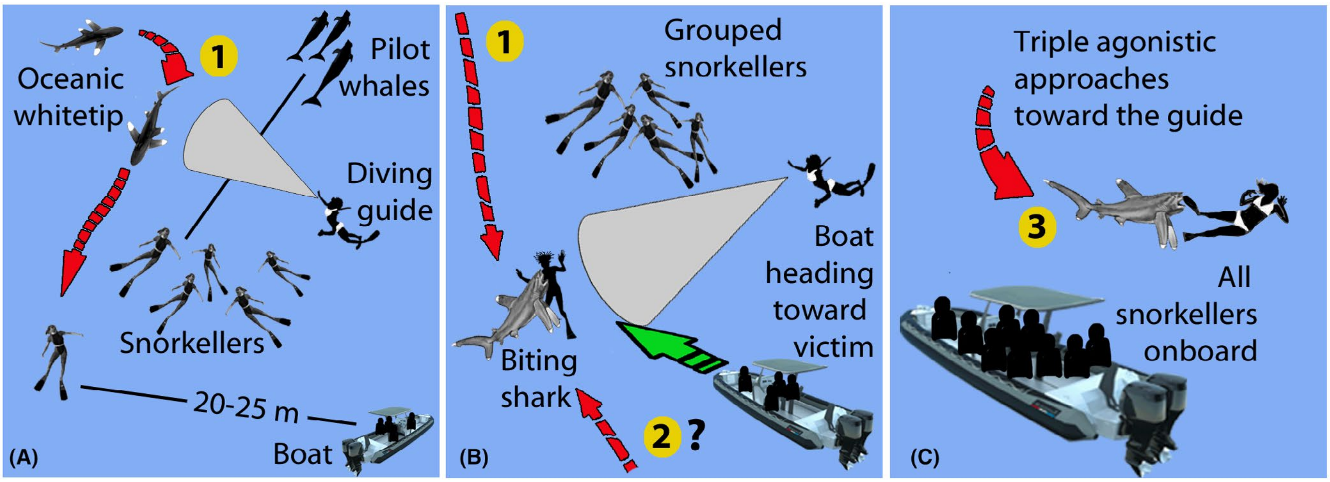

FIGURE 2 (A) Schematic diagram of the snorkelers position—including the victim a few meters behind the group—lead by the guide in the wake of the pilot whales that were also followed by an OWT shark, which (1) modified its trajectory to investigate the snorkelers. (B) Direct observation of bite incident by the guide who had just gathered the snorkelers. The culprit is believed to be the shark observed swimming rapidly toward the snorkel group (option 1), but it is also possible that it was another shark that approached from behind without being detected (option 2). (C) Last phase of the event involving the guide who remained in the water while all the divers went back on board, after the taking care of the victim

species, shark size was estimated by comparison of width of the inferior SS (calculated from the flap of intact skin; Figure 3A [SS]) with SS widths obtained from three OWT jaws (two from Simon DeMarchi's personal collection and one from CRIOBE collection ref#Clo3010EJ) from sharks of known TLs. We used a power regression to calculate the relationship between OWT SS width and TL because SS width exhibited a nonlinear relationship with body length due to allometric growth [12,13]. The relationship between SS width and TL can thus be expressed as: $SS = b \times TL^{a}$, where a and b are constants. We log-transformed the relationship as $\text{Log SS} = \text{Log } b + a \times \text{LogTL}$ [14]. Regression analyses were conducted in R (V 4.0.5 [15]).

3 | RESULTS

3.1 | Wound characteristics

The 35-year-old female victim was bitten at least three times. The left breast was largely removed by an almost-circular and relatively superficial bite (Figure 3A). The left shoulder received multiple superficial puncture wounds from teeth but no tissue was removed (Figure 3A). Finally, each of the two forearms were severely damaged by bites that removed substantial amounts of tissue (Figure 3B,C). The right arm suffered a single deep wound, just above the wrist, that resulted in the amputation of three fingers several days after reconstructive surgery. The left forearm had two different bites, one above the wrist and the other below the elbow, but overall less severe, allowing the victim to maintain a fully functional hand. When questioned on the subject, the victim was unable to recall most details of the shark's attack including the sequence of the various bites but remembered defensively crossing her two forearms to block the shark.

3.2 | Shark size estimation

OWT specimens of 180 cm TL (CRIOBE collection), 220 cm TL, and 300 cm TL (DeMarchi collection) had inferior SS widths of 17.1, 16.3, and 21.4 mm, respectively. The determination coefficient R^2 of the linear regression relationship between the Log of SS and the Log of TL explains more than 43% of the variance. The equation used was: $SS = 0.4672 \times TL^{0.4732}$. Thus, the measured SS on the wound of the victim (15.5 mm) allowed us to extrapolate a TL for the shark of 163.7 cm TL. This corresponds to an immature individual for this species where males mature at >190 cm and females mature at about 220 cm TL in the Pacific Ocean, respectively [16].

4 | DISCUSSION

A combination of detailed eye witness accounts and forensic analysis of this incident provide a unique insight into agonistic behavior of OWTs toward snorkelers observing whales. We are confident in the species identification because OWTs are easily recognizable due to their rounded, white-tipped dorsal and pectoral fins, and the professional guide was highly experienced in shark identification. Our size estimation of ~160 cm TL, based on bite wound analysis, was obtained in comparison with only $n = 3$ individuals where over 50% of variability was not explained through our regression. However, it is consistent with eye witness testimony and corresponds to a sexually immature individual.

Oceanic whitetip sharks are considered a traumatogenic species, and are responsible for multiple previous fatal shark bites [1,6,9]. Although we cannot be certain of the shark's motivation for biting, two primary possibilities are predation and dominance. OWT sharks live in an oligotrophic environment where prey distribution is patchy and unpredictable compared to coastal habitats such as coral reefs. Thus, they may respond more aggressively to potential feeding opportunities than coastal shark species simply because prey is harder to find in open-ocean. Innate prey assessment behavior would explain why OWTs are routinely inquisitive and frequently aggressive toward humans. This case involved repeated bites and hence is unlikely to be exploratory behavior characterized by a single bite [17]. Another possible motivation for this particular incident is that the presence of divers triggered a defensive [12,18,19] or dominance [20,21] reaction by the shark, but no threat posturing (e.g. lowering of pectoral fins, exaggerated swimming or jaw gaping [22]) by the shark was observed prior to the bites. We suggest predation is the most plausible explanation for this incident because repeated bites ($n \geq 3$) resulted in removal of tissue (especially from the chest) [23]. The overall relatively limited tissue removal from the victim is correlated to the small size (~160 cm TL) of the shark (particularly that of its jaw) and defensive forearm crossing by the victim which may have reduced the shark's ability to complete the bites and remove more tissue. Although the shark was a relatively small individual, the victim was also relatively small (height of 150 cm) and isolated from the group which made her vulnerable to an opportunistic predator. The sudden nature of the incident was consistent with a predator seeking to surprise and dominate its prey as quickly as possible for energetic efficiency [24]. Collectively, these facts together with a lack of characteristic OWT threat posturing prior to the strike point to a predatory rather than a dominance motivation for these bites.

Regardless of the motivation, this incident demonstrates that OWTs can bite suddenly and unpredictably without any obvious external trigger other than the presence of humans in their environment. The whale-watch snorkeling activities leading to this shark bite were utilizing their standard operating and safety protocols and no agonistic shark behavior was observed during previous snorkels on the same day. The shark observed by the guide (assuming it was the aggressor) switched rapidly from non-threatening slow swimming to highly aggressive behavior consistent with an ambush predation strategy (including approaching the victim in their blind spot). The shark gave no forewarning (e.g. agonistic displays) that could have alerted the guide and prevented the bite incident. This demonstrates that although basic safety protocols (e.g. pre-dive customer briefings, in-water professional guide, support vessel in close proximity) were in place, they were wholly inadequate to prevent this sudden incident. Key elements that enabled this shark bite were (i) a lack of group cohesion among the snorkelers, (ii) exposure of naïve snorkelers to a traumatogenic species, and (iii) an inability to anticipate the sudden change in shark behavior.

5 | CONCLUSION

Oceanic whitetip sharks routinely associate with cetaceans and are a known traumatogenic species that can display sudden aggressiveness toward humans. Commercial in-water whale watching activity has increased substantially in French Polynesia over the last decade, with at least 45 operators active in 2019, including 29 around the single island of Moorea (source: Direction de l'Environnement – DIREN). This combination of factors makes it imperative to develop and implement appropriate risk assessment protocols for tourists snorkeling in pelagic waters to observe marine mammals. New safety protocols could be developed via an industry/region-wide consultative process. Highly conservative measures such as eliminating all snorkeling in the presence of any OWTs could be avoided with appropriate in-water protocols. For example, ensuring a ratio of at least one guide equipped with a stick for every three tourists and ensuring all snorkelers link arms

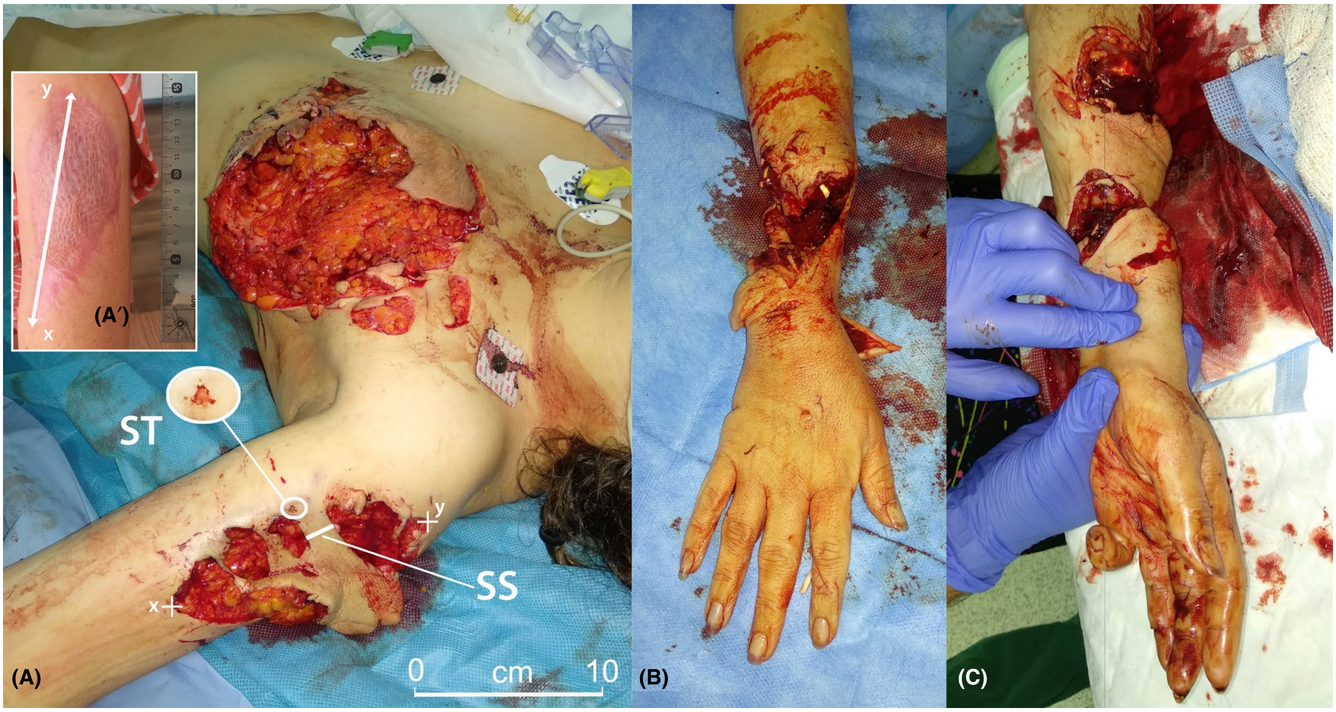

FIGURE 3 (A) Bite wounds to the chest and shoulder of the victim. On the shoulder the mangled appearance of the lower wound margins (left side on the photo) is consistent with an impression from the lower jaw where teeth further apart and less sharp than those of the upper jaw. It is possible to observe the small impression—see close up (ST)—of a symphyseal tooth (Figure 1G) from the lower jaw. The large flap of intact skin corresponds to the inferior SS. (A′) shows the shoulder's victim after healing of the wound, which allowed an accurate measurement of the wound (x–y = 14.1 cm) and subsequently the SS width (15.5 mm). These details indicate that the shark was facing the victim during the bites as reported by the guide's testimony. (B) Right and (C) left arms of the victim displaying wounds from either two different bites or a single bite when the victim crossed her forearms to fend off the shark

and remain in a group when OWTs are present. All participants should be comfortable snorkeling and able to rapidly re-board a vessel in an emergency.

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REFERENCES

1. International Shark Attack File (ISAF). http://www.flmnh.ufl.edu/fish/Sharks/ISAF/ISAF.htm. Accessed 23 May 2021.
2. Neff C, Hueter R. Science, policy, and the public discourse of shark "attack": a proposal for reclassifying human–shark interactions. J Environ Stud Sci. 2013;3(1):65–73. https://doi.org/10.1007/s13412-013-0107-2.
3. Lemahieu A, Blaison A, Crochelet E, Bertrand G, Pennober G, Soria M. Human-shark interactions: the case study of Reunion Island in the south-west Indian Ocean. Ocean Coast Manag. 2017;136:73–82. https://doi.org/10.1016/j.ocecoaman.2016.11.020.
4. Compagno LJV. FAO species catalogue, Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2. Carcharhiniformes. FAO Fisheries Synopopsis, No. 125. Rome: Food and Agriculture Organization of the United Nations; 1984. p. 251–655.
5. Haynes LL. Survivor of the Indianapolis. Navy Med. 1995;86(4):13–7.
6. Global Shark Attack Files (GSAF). https://www.sharkinfo.ch/SI1_99e/gsaf.html. Accessed 23 May 2021.
7. Rigby CL, Barreto R, Carlson J, Fernando D, Fordham S, Francis MP, et al. *Carcharhinus longimanus*. The IUCN Red List of Threatened Species. 2019;e.T39374A2911619. https://doi.org/10.2305/IUCN.UK.2019-3.RLTS.T39374A2911619.en.
8. Shawky AM, De Maddalena A. Human impact on the presence of sharks at diving sites of the Southern Red Sea, Egypt. Boll Mus St Nat Venezia. 2013;64:51–62. https://doi.org/10.13140/RG.2.2.26027.13609.
9. Levine M, Collier RS, Ritter E, Fouda M, Canabal V. Shark cognition and a human mediated driver of a spate of shark attacks. Open J Anim Sci. 2014;4(5):263. https://doi.org/10.4236/ojas.2014.45033.
10. Migura KA, Meadows DW. Short-finned pilot whales (*Globicephala macrorhynchus*) interact with melon-headed whales (*Peponocephala electra*) in Hawaii. Aquat Mamm. 2002;28(3):294–7.
11. Lowry D, de Castro ALF, Mara K, Whitenack LB, Delius B, Burgess GH, et al. Determining shark size from forensic analysis of bite damage. Mar Biol. 2009;156(12):2483–92. https://doi.org/10.1007/s00227-009-1273-3.
12. Jublier N, Clua E. Size assessment of the Gray Reef Shark *Carcharhinus amblyrhynchos* inferred from teeth marks on human

wounds. J Forensic Sci. 2018;63(5):1561–7. https://doi.org/10.1111/1556-4029.13738.
13. Shimada K. The size of the megatooth shark, *Otodus megalodon* (Lamniformes: Otodontidae), revisited. Hist Biol. 2019;7:904–11. https://doi.org/10.1080/08912963.2019.1666840.
14. Gayon J. History of the concept of allometry. Am Zool. 2000;40(5):748–58. https://doi.org/10.1093/icb/40.5.748.
15. R Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2020. https://www.R-project.org/. Accessed 5 Aug 2021.
16. D'Alberto BM, Chin A, Smart JJ, Baje L, White WT, Simpfendorfer CA. Age, growth and maturity of oceanic whitetip shark (*Carcharhinus longimanus*) from Papua New Guinea. Mar Freshw Res. 2017;68(6):1118–29. https://doi.org/10.1071/MF16165.
17. Ritter E, Levine M. Use of forensic analysis to better understand shark attack behaviour. J Forensic Odontostomatol. 2004;22(2):40–6.
18. Clua EE, Haguenauer A. Nonfatal bites by a sicklefin lemon shark *Negaprion acutidens* on a surfer in Makemo Atoll (French Polynesia). J Forensic Sci. 2020;65(3):979–83. https://doi.org/10.1111/1556-4029.14228.
19. Fellows DP, Murchison AE. A noninjurious attack by a small shark. Pac Sci. 1976;21(1):150–1.
20. Baldridge HD. Shark aggression against man: beginnings of an understanding. Calif Fish Game. 1988;74(4):208–17.
21. Gruber S. Why do sharks attack people? Naval Res Rev. 1988;40(1):2–19.
22. Martin RA. A review of shark agonistic displays: comparison of display features and implications for shark-human interactions. Mar Freshw Behav Physiol. 2007;40(1):3–34.
23. Ihama Y, Ninomiya K, Noguchi M, Fuke C, Miyazaki T. Characteristic features of injuries due to shark attacks: a review of 12 cases. Leg Med. 2009;11(5):219–25. https://doi.org/10.1016/j.legalmed.2009.06.002.
24. Curio E. The ethology of predation. Berlin: Springer-Verlag; 1976.

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