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The Talion law "tooth for a tooth": self-defense as a motivation for shark bites on human aggressors

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The concept of "self-defense," based on aggression by one individual responding to an initial aggression by another, has been observed in several animal taxa such as birds and terrestrial mammals but never documented in detail in sharks. Based on a multi-decade study of the characteristics of shark bites on humans in French Polynesia Eastern-South Pacific, we show that certain human activities at sea, such as fishing and particularly underwater spearfishing and the management of passive fish traps, are associated with this type of bite. Following an initial agonistic behavior by a human on a shark, a pattern of self-defense bites ensues, characterized by immediate aggression in return. It is perpetrated without proportionality, often superficial with minimal tearing of flesh, and rarely fatal, except in special circumstances. During these interactions, the shark will sometimes respond to the initial anthropogenic stimulus with repeated bites. The motivation for these defensive bites can be distinguished from other drivers, such as the predation motivation on humans, which involves heavy loss of tissue. In the case of antipredation or fear motivation, when a shark anticipates a potential human aggression before it occurs, the attack is preceded by a characteristic agonistic behavior that is not present in the case of self-defense. The existence of this behavior cautions that attacks on sharks have the potential to trigger retaliatory bites and that untrained persons should never attempt to come to the rescue of a distressed shark, which may bite indiscriminately. Finally, we suggest that the media, which often sensationalizes these types of self-defense bites as attacks, could help to improve attitudes toward sharks and their conservation by more objectively reporting the culpability of humans in triggering them.

KEYWORDS

human–wildlife conflict, shark attack motivation, human aggression, human responsibility, marine predator behavior, shark conservation

Introduction

Negative interactions between humans and potentially dangerous wildlife have always existed but are on the increase, whether in the case of shark bites linked to increased human use of the marine realm (Ferretti et al., 2015) or large carnivore attacks on people in terrestrial settings (Penteriani et al., 2016; Bombieri et al., 2018). Management of these interactions is also increasingly complex given the growing interest in avoiding lethal measures that can have negative impacts on populations of threatened and endangered taxa (Treves et al., 2009). This more sustainable wildlife management approach requires a better understanding of what motivates animals to attack people, so that non-lethal strategies can be tailored to proactively address the drivers of conflict in both terrestrial and marine realms (Inskip and Zimmermann, 2009; Clua et al., 2020). In the marine environment, sharks represent a danger to humans that, although it rarely manifests with just over a hundred bites per year on humans, is nonetheless recurrent and real (GSAF, 2024). To date, there is no consensus on what motivates sharks to bite humans, with some authors supporting the triggering role of environmental factors (Chapman and McPhee, 2016) and others instead focusing on individual differences in personality (Clua et al., 2020). Careful documentation of shark-related incidents and their causes, recognized as important for over 60 years (Gilbert et al., 1960; Hobson et al., 1961), remains a research and management priority.

Animals like snakes and spiders, while predators, do not prey on humans but clearly do attack humans in self-defense (Duntley, 2015), and similar defensive behavior has been documented in some birds (Kofron, 1999) and terrestrial mammals (Ambarl and Bilgin, 2008). Regarding sharks, the self-defense motivation is scarcely evoked in the literature. Gruber (1988) mentions a potential "defensive" motivation (see p. 8), while Baldridge (1988) writes "No shark of any size or species should ever be placed in a situation so untenable that the animal has no alternative but to strike out in defense" (see p. 288). More recently, a comprehensive shark ethogram was compiled by Klimley et al. (2023), including a synthesis of potential agonistic behaviors toward humans, which defines a "self-defense or retaliatory" bite as a "bite on a human that voluntarily or involuntarily has threatened the shark" (see p. 99). Excluding these generic mentions, shark self-defense bites on humans have never been documented in detail nor precisely characterized and discussed.

The waters of French Polynesia fall within an exclusive economic zone (EEZ) spanning 5.5 million km^2 and are used by more than 30 shark species (Farabaugh et al., 2024). In 2006, the French Polynesian EEZ was designated as a shark sanctuary, featuring bans on fishing and trade of products, for all species except the mako (*Isurus oxyrinchus*), which was later added in 2012. A recent global survey of reef sharks indicates that this sanctuary has been successful in maintaining healthy shark populations (MacNeil et al., 2020), making French Polynesia a pertinent reference system for understanding shark behavior, ecology, and also relationships with people.

Here, to address our knowledge deficit as described here above, we use shark bite data collected systematically over the past 60 years in French Polynesia to characterize self-defense bites on humans, while also quantifying the prevalence of this phenomenon and discussing its implications for shark risk understanding and management at a global level.

Methods

To operationalize the concept of "self-defense" motivation as it relates to shark–human interactions, clarify the causes and consequences of this type of bite, and assess its overall prevalence, our approach consisted of a) characterizing the different types of bites in French Polynesia (comparative analysis), b) compiling all bite-related information according to this framework (data curation), c) quantitatively analyzing their prevalence (if possible over the period(s) guaranteeing the greatest completeness of all bites), and d) qualitatively analyzing case studies representative of the conditions in which this type of bite occurs, allowing a rough typology.

Characterization of shark bites

The widespread presence of sharks in French Polynesia, coupled with numerous in-water human activities, results in many superficial and non-fatal bites every year (Bagnis, 1968). These bites fall into several behavioral categories that are described in Klimley et al. (2023) and further detailed by Clua et al. (2024) (see Table 1), each assigned a posteriori by an expert based on victims' responses in a preliminary information form filled out based on interviewing victims after a bite (see questions in ESM1). The categorization of bite motivation by the expert relies on the triggering factors that are listed in the second column of Table 1.

First, bites may be the result of reflexes or clumsiness (not targeting the human as a prey) when a confused shark bites a sea user who is holding bait (Clua, 2018). Second, spearfishers can fall victim to competition/food access bites by sharks targeting wounded prey (Nelson, 1981). Third, sharks may bite by anticipation a diver who voluntarily or involuntarily appears to them as a potential threat (Nelson and Johnson, 1980). Fourth, bites can be triggered by a human who voluntarily or involuntarily penetrates the territory or "idiosphere" (sensu Martin, 2007) of the shark (Clua et al., 2024). Fifth, when a shark is attacked by humans, it may display a retaliation bite driven by self-defense or fear (Klimley et al., 2023; this study) (Table 1). All of these motivations usually lead to superficial and non-fatal injuries on human victims and are mainly inflicted by coastal, medium-sized (<3 m in total length) shark species such as the blacktip reef shark *Carcharhinus melanopterus*, the reef whitetip shark *Trianodon obesus*, the gray reef shark *C. amblyrhynchos*, and the sicklefin lemon shark *Negaprion acutidens*. None are motivated by foraging intent, and some may be preceded by specific agonistic "warning"

behaviors such as swimming with a jerky motion and body twisting or "hunching" (Balbridge, 1974; Johnson and Nelson, 1973). This warning behavior is most frequently observed in gray reef sharks but also occurs in other Carcharinid and Sphyrnid species worldwide (Martin, 2007; Myrberg and Gruber, 1977). Warning behaviors, studied extensively in the 1970–1980s, have been attributed to dominance/territoriality or competition (for marine resources) whereby the shark seeks to evict an intruder, or to an antipredatory strategy, where the shark proactively defends itself (Nelson and Johnson, 1980) (Table 1). However, they have never been described in conjunction with retaliatory bites. Accordingly, there is reason to distinguish bites associated with warning behaviors from retaliatory bites, whose motivation is the focus of the present study.

Data access

A database on shark bites has been set up and maintained at The Center of Insular Research and Observatory of the Environment (CRIOBE) in Moorea since 2009. In addition to the data retrieved from the scientific literature, it is fed by information collected a) via the written and televised media, b) via the distribution and recuperation of a preliminary information form after a bite (see ESM1) in peripheric medical centers, and c) during medical repatriations of bite victims from remote islands to the hospital in the capital city of Papeete Tahiti. Finally, numerous interviews with victims were conducted either at the hospital or during field missions to various islands (>40 among the 118 composing French Polynesia).

TABLE 1 Descriptions of potential motivations for shark bites on humans.

Bite motivation	Main triggering factors	Feeding trigger	Swimming display	Characteristics of the aggression
Reflex/clumsiness	ABC	Yes	No	Bite (most often not repeated) on a human that is the result of poor judgment in the context of the animal's feeding behavior (not directed against humans). No warning signs. The main trigger is based on a state of haste, often exacerbated by competition between sharks for access to a food resource (sometimes leading to feeding frenzies), e.g., a human observer bitten during a feeding frenzy in the context of shark artificial provisioning or in natural conditions.
Competition/ resource access	CDE	Yes	No	Bite on a human who represents, voluntarily or involuntarily, a direct competitor for the access to a food resource. No warning signs. The main trigger is the presence of this food stimulus, e.g., a spearfisher who tries to defend or remove a speared and wounded fish from the grasp of a shark.
Antipredatory	ADGH	No	Yes	Bite on a human who voluntarily or involuntarily appears as a potential threat to the shark. The shark may instinctively display a specific agonistic behavior (lowering pectoral fins, shaking its body, and accelerating its jerky swimming). The distance between the shark and the human is a determining factor in the attack, especially if the human swims quickly toward the shark or reduces its range of escape by pressing it against the substrate, e.g., a scuba diver approaching a shark quickly with an underwater scooter or along a rock face.
Dominance-territoriality	ADH	No	Yes	Bite on a human who has voluntarily or involuntarily penetrated the shark idiosphere (sensu Martin, 2007). The shark may instinctively display a specific agonistic behavior (lowering pectoral fins, shaking its body, and accelerating its jerky swimming). The main trigger is spatial, e.g., a surfer, swimmer, or diver who gets too close to a shark (can be exacerbated by physiological status linked to breeding season or pregnancy).
Self-defense/retaliation	DEF	No	No	Bite on a human that voluntarily or involuntarily constitutes a danger to the shark. The main trigger is based on previous aggression (or behavior perceived as) of humans toward the shark, e.g., a person angling for a shark, a spearfisher shooting a spear at a shark, or a diver attempting to grab a shark. No warning signs.
Predation/ investigation (exploration)	DEI	Yes	No	Biting (most often repeated except for an investigative bite) that is part of a feeding process on human prey, motivated by hunger but only concerning individuals among large shark species (in particular *Carcharodon carcharias*, *Galeocerdo cuvier*, *Carcharhinus leucas*, *C. longimanus*). No warning signs. In this case, the behavior of the human contributes minimally to the genesis of aggression.

Each mechanism includes its main triggering factors: A) close proximity between shark and human; B) accidental bite on human; C) feeding motivation targeting natural prey; D) deliberate single bite on human; E) deliberate repeated bites on human; F) actual aggression by human toward shark; G) anticipated aggression by human toward shark; H) agonistic display by shark; I) feeding motivation targeting a human. NB: The six bite motivations in the first column are described in Klimley et al. (2023).
NB: The "mistaken identity" hypothesis, whereby sharks bite humans with a foraging motivation because of confusion with natural prey when conditions reduce visual acuity (Ryan et al., 2021), could fit in our predation/investigation category. However, it neglects the importance of other shark senses, such as hearing and mechanoreception, which play crucial roles in reducing confusion during predator–prey interactions. Clua and Meyer (2023) have recently argued against this hypothesis, labeling it as an anthropomorphic fallacy. Consequently, it has been omitted from the elasmobranch ethogram by Klimley et al. (2023) and was not considered in our study framework.
Source: Adapted from Clua et al. (2024).

Data analysis

Shark bite data in French Polynesia have been collected since the early 1940s. Among all incidents compiled in the database, an initial selection process was first implemented to identify bites on a human that included a voluntary or involuntary threat to the shark prior to the bite on its perpetrator (see Klimley et al., 2023 and Table 1). These "self-defense" bites were then further characterized with regard to the context of the incident, particularly linked to the human activity associated with the agonistic shark–human interaction.

Although shark bite data were compiled since the early 1940s, efforts to compile the data as exhaustively as possible and with details allowing for the classification of bites according to motivation only began in 2009; our knowledge of bite occurrence and potential motivation is incomplete and not reliable before this date. Therefore, we calculated the prevalence of the self-defense bite motivation in French Polynesia by averaging its yearly occurrence only based on bite data compiled from 2009 to 2023, i.e., a span of 15 years. The descriptive nature of this analysis precluded any need for more sophisticated statistics. Complementary case studies outside the 2009–2023 period were analyzed qualitatively to gain insights into the triggers of the self-defense motivation.

Results

Compilation of self-defense bites from 1942 to 2023

Between 1942 and 2023, a total of 137 shark bites perpetrated in French Polynesia were documented and classified following the criteria listed in Table 1. Among them, 16 bites were classified as having a very high probability of resulting from a self-defense motivation (Table 2). All of them took place in the archipelago of Tuamotu and none in the other Polynesian archipelagos. Among them, ca. 43% ($N = 7$) happened in the context of shark harpooning in fish traps, another 38% ($N = 6$) in the context of spearfishing, and 19% ($N = 3$) in the context of other activities such as shark handling for photography, scientific sampling, and tourist-based exhibition of sharks in open-air tanks. Three bites had major consequences with two deaths. The first one in 1942 involved a fisherman who swam close to a gray reef shark that had previously been shot by a spearfisherman. The shark, presumed to be dead, was lying on the sea floor, but it awoke from its torpor to attack the diver, biting him on the neck, damaging his carotid artery and causing a fatal hemorrhage (see CS01 in Table 2). The second death occurred in 1977 involving a spearfisherman who shot a potentially dangerous sicklefin lemon shark after misidentifying it with a much less harmful tawny nurse shark *Nebrius ferrugineus*, owing to their similar skin color. The lemon shark responded by biting the fisherman several times, leading to his death by exsanguination (see CS08 in Table 2). In 1966, another fisherman who had harpooned a gray reef shark in a fishing trap was severely bitten on his right arm, which had to be surgically removed at the hospital (see CS02 in Table 2). All the other incidents resulted in moderate to minor injuries, although they always required surgery. A couple of the injuries can be considered as moderate because some flesh was lost as a result of the bite, and the bite in the scientific handling context (CS16) required two sessions of surgery with over 50 stitches. The lowest level of gravity was observed with the bite on a 40-year-old man's thigh by a tawny nurse shark that was handled with bare hands for photography (CS05). An individual of this same species bit a 12-year-old child also on his thigh as he was trying to pull the head of the shark out of the water to show it to tourists (CS06).

Five shark species were involved in the bites that appeared to result from a self-defense motivation: 62.5% ($N = 10$) were by the gray reef shark, two bites each (12.5%) were by the sicklefin lemon shark and the tawny nurse shark, followed by single occurrences of defensive bites by the blacktip reef shark (6.25%) and whitetip reef shark (6.25%) (Table 2).

Prevalence of self-defense bites from 2009 and 2023

Over the course of the 15 years from 2009 to 2023, 74 bites were documented including 4 motivated by self-defense, leading to a prevalence of ca. 5%.

Identification of case studies

Following the semantic framework of identifying "bites on a human that voluntarily or involuntarily has threatened the shark" (Klimley et al., 2023), two main scenarios have emerged stemming from spearfishing and use of traditional fishing traps, respectively. Two recent case studies, characteristic of these two activities and well documented including photos, are presented below, along with a third one resulting from a distinct type of interaction linked to shark handling that is much less frequent but nevertheless relevant to this study.

Case study 1: spearfishing

This case study (see CS14 in Table 2) illustrates how freediving fishing for bony fishes with a speargun can trigger defensive shark bites. On the morning of 18 April 2016, two Polynesian spearfishermen, TT 26 years old and HT 22 years old, were fishing in the reef passage at the village of Arikimiro (Makemo atoll) when HT arrowed a grouper of several kilos at a depth of 10 m while surrounded by ca. a dozen gray reef sharks; this was a normal situation for both freedivers. The sharks were displaying nervous behaviors including accelerated swimming and sudden changes of direction triggered by auditory, visual, and olfactory blood stimuli following the capture of several fish that both fishers had managed so far to secure from any shark depredation. As the fisher HT was still moving upward in the water column trying to bring the fish close to him to dissuade the sharks from grabbing it, a bolder shark, around 2 m long, moved toward the wounded fish and HT. His companion TT then dived in and shot an arrow into the shark's side with, according to his testimony, "the aim of only stinging and frightening the shark." However, the arrow got stuck in the shark's body by its barb, so the two divers decided to take the inert animal

TABLE 2 Compilation of potential shark self-defense bites on humans in French Polynesia from 1942 to 2023 (n = 16).

CS	Year	Gender (age)	Island	Bite	Shark	Activity	Trigger	Source	Injuries
CS01	1942	M (U)	Arutua	Sup (simp)	GRS	Spearfishing	Shark spearing	Ref. 1	Major: fatal
CS02	1966	M (43)	Rangiroa	Sup (mult)		Traditional fish trap	Shark harpooning		Major: right arm amputation
CS03	1968	M (U)	Tikehau	Inf (simp)		Traditional fish trap	Shark harpooning	Ref. 2	Minor
CS04	1968	M (10)	Rangiroa	Inf (simp)	SLS	Fishing	Shark harpooning	Ref. 1	Minor
CS05	U	M (40)	Tuamotu isld	Inf (simp)	TNS	Photography	Shark handling		Minor
CS06	1971	M (12)	Manihi	Inf (simp)		Shark farming	Shark handling		Minor
CS07	1972	M (28)	Fakarava	Inf (simp)	GRS	Traditional fish trap	Shark harpooning		Minor
CS08	1977	M (U)	Tepoto Nord	Sup + Inf (mult)	SLS	Spearfishing	Shark spearing	Ref. 3	Major: fatal
CS09	1986	M (19)	Amanu	Inf (simp)	RWT	Spearfishing	Shark spearing		Minor
CS10	1990	M (28)	Katiu	Sup (simp)	GRS	Spearfishing	Shark spearing	Ref. 4	Minor
CS11	2005	M (45)	Tikehau	Inf (simp)		Traditional fish trap	Shark harpooning	Ref. 2	Minor
CS12	2006	M (16)	Hao	Sup (mult)		Spearfishing	Shark spearing	Ref. 3	Minor
CS13	2009	M (44)	Tikehau	Sup + inf		Traditional fish trap	Shark harpooning	Ref. 2	Minor
CS14	2016	M (26)	Makemo	Sup + inf		Spearfishing	Shark spearing	Ref. 5	Medium
CS15	2016	M (28)	Arutua	Inf (simp)		Traditional fish trap	Shark harpooning	Ref. 6	Medium
CS16	2017	M (53)	Rangiroa	Sup (simp)	BRS	Scientific study	Shark handling	Ref. 7	Minor

U, unknown; cs, case study; gender: M, male and age in years; Sup, arm/hand; Inf, leg/foot; Mult, multiple; Simp, simple. Shark species: GRS, gray reef shark, *Carcharhinus amblyrhynchos*; SLS, sicklefin lemon shark, *Negaprion acutidens*; TNS, tawny nurse shark, *Nebrius ferrugineus*; RWT, reef whitetip shark, *Trianodon obesus*; BRS, blacktip reef shark, *C. melanopterus*. Source: ref. 1, Lagraulet 1972; ref. 2, interview during the field mission in Tikehau 2017; ref. 3, interview during the field mission in Amanu 2017; ref. 4, direct interview 26/03/2021; ref. 5, local press 19/04/16 + direct interview of the victims at the hospital; ref. 6, interview during the field mission in Marquesas 2018; ref. 7, pers. comm. EEGC. "Spearing" refers to an aggression with a shaft shot by a gun spearfishing; "harpooning" refers to an aggression by a kind of javelin locally called "patia" handled by a fisherman.

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back to their boat in order to free the shaft and avoid losing it as well as the gun. Suddenly, the shark came out of its torpor and grabbed TT by the calf. TT slapped the shark on the head to get it to let go, which it did but then grabbed TT by the hand and wrist. The shark refused to loosen its jaw, so TT grabbed the animal into his arms and moved closer to the boat. TT managed to board as the shark loosened its grip, but it then directly bit TH, who was still in the water, on the knee. TT managed to grab hold of the shark's tail and cut off its tail stalk with a knife. The shark then let go and sank. The two divers, suffering from several injuries (Figure 1), made their way back to the village to get to the medical center. They were later airlifted to Papeete Hospital Tahiti for reconstructive surgery.

Case study 2: use of traditional fishing traps

A traditional Polynesian fishing method is particularly well-suited for use in coral reef passages that act as large cuts among the coral reef ring of an atoll, providing physical communication between the lagoon and the ocean. These passages host strong daily currents, particularly outgoing flows, that support the presence of numerous fishes. This method consists of building passive traps in or near these reef passages; the traps were traditionally labyrinths delimited by limestone rocks but have been replaced in modern times by wire mesh stretched between submerged posts. Seeking to swim up against the current, the fish enter the labyrinth from which they are then unable to escape. Stays of several days before fishermen retrieve them from the traps lead to the suffering or even death of some fish, thereby attracting sharks that also enter the traps to depredate the dying fishes; like their prey, these sharks remain trapped. Given the large size of the spaces where fish are trapped, fishermen are indeed forced to enter inside the traps to access the bony fishes that expose them to shark attacks.

To get rid of the sharks that may bite them, fishermen usually use a long spear over 2 m long with a metal tip known locally as a "patia" to pierce and hold the shark and remove it from the trap (see CS15 in Table 2). The main author (EEGC) had the opportunity to witness such a process in the atoll of Tikehau in March 2017 (Figure 2A). Fishers usually plant the spear into the muscles of the back of the shark, and owing to the large diameter of the spearhead, this practice is usually lethal for the shark. As the fisherman must enter the trap to catch the shark, this process presents a danger to the fisherman, as the spearing is not always efficient enough to kill or at least immobilize the shark, which can strike back at the human and inflict superficial to severe wounds (Figures 2B, C).

Case study 3: shark handling

This case study (see CS16 in Table 2) is an example of how attempts to grab a shark with bare hands, without the purpose of harming it, can result in a defensive response. In March 2017, a team of three scientists was engaged in a non-lethal capture session of blacktip reef sharks to collect skin and blood samples. The operation consisted of luring the sharks with an olfactory attractant to a shallow depth around 40 cm so that one scientist (operator 1) could grab the anterior third of the animal's body, between the head and the gills, in order to neutralize the head and jaw motion. A second scientist (operator 2) would then grasp the caudal peduncle to limit whipping movements. Once the shark was put in tonic immobility upside down and immobilized, the third scientist (operator 3) would take samples before releasing the animal. After several successful catches, the roles were rotated. On his first attempt, the new operator 1 grabbed the shark behind the gills, giving it room to bend its head backwards and potentially bite operators 1 and 2. Operator 3, aware of the danger, then tried to grab the shark behind the jaw, but it bit him on the right hand. After a few seconds, the shark released its grip and the victim was brought back for medical treatment to suture multiple superficial wounds corresponding to teeth imprints.

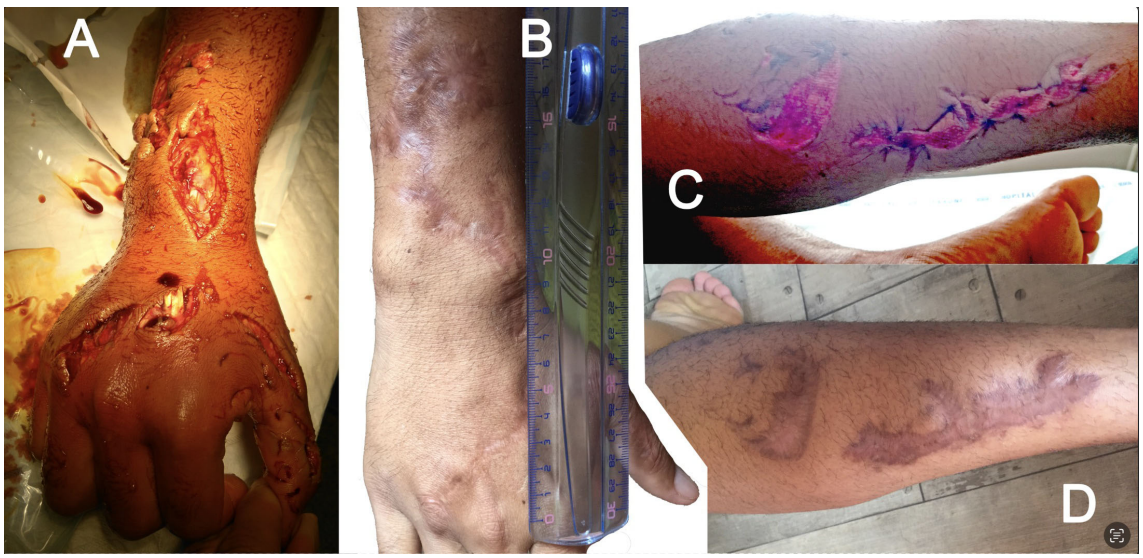

FIGURE 1
Case study 1: superficial bite wounds on TT, a spearfisher, on his right hand and wrist before surgery **(A)** and after healing **(B)** and on his right calf just after surgery **(C)** and after healing **(D)** corresponding to CS14 in Table 2 (photos courtesy of M. Bègue).

Discussion

Characterizing self-defense bites

Self-defense bites by sharks on humans have several points in common. First and as required by its intrinsic definition, 100% of them were triggered by human aggression, whatever its nature. In most of the cases, the trigger was potentially lethal in the form of harpooning by a thick metal tip (N = 7) or the spearing by a speargun shaft (N = 6). In a few cases (N = 3), the shark bites were triggered by simple non-lethal handling. Second, more than 80% resulted in minor to moderate injuries. Regarding the remaining 20%, and excluding the instance (CS08) where the spearfisherman was bitten to death, the severity of the other two injuries can respectively be attributed to injuries affecting a vital area with major blood vessels (CS01) and a lack of efficiency in medical care (CS02). In none of these cases was a significant amount of human flesh removed. Third, in 31% of the cases in Table 1, the shark bit the victim repeatedly, leading to multiple wounds. Fourth, none of the bites were preceded by any abnormal shark agonistic displays such as pectoral lowering or hunched swimming (see Nelson et al., 1986 for a detailed description of such specific behavior), which function as warning signs before a potential strike (Martin, 2007).

Confirmation of the concept of shark self-defense via retaliatory bites

Our analysis of case studies in French Polynesia confirms the concept of "self-defense," intrinsically linked to an initial aggression perpetrated by humans on the shark. The anteriority of this human aggression also validates the concept of "retaliation." In their study on shark agonistic displays when confronted by a submarine, Nelson et al. (1986) similarly invoke the idea of retaliation, suggesting that "display-prefaced gray reef shark attacks might represent anti-predatory 'retaliatory' aggression." By implication, these bites appear to have been delivered in self-defense, with perceived or actual aggression by humans serving as the threatening stimulus, rather than as a response to other motivations such as predation or territoriality. These bites are also characterized by their superficiality and, with a few exceptions owing to unfortunate circumstances such as bites that severed arteries without removing tissue (see CS01 in Table 2), low lethality. Notably, such a pattern of low lethality is also found for self-defense-motivated bites inflicted by terrestrial animals such as large birds (see figures about cassowary *Casuarius casuarius johnsonii* attacks in Australia in Kofron, 1999) and mammalian predators (see figures on brown bear *Ursus arctos* attacks in Turkey in Ambarl and Bilgin, 2008). Accordingly, self-defense shark bites in French Polynesia are consistent with a broader pattern of primarily non-lethal attacks on humans being perpetrated by animals responding defensively to human aggression.

Features and prevalence of self-defense bites in French Polynesia

The fact that all shark bites were recorded in the Tuamotu archipelago and none in the Society islands and Marquesas and Austral archipelagoes is not surprising, given that it accounts for >80% of Polynesian islands, most of which are atolls with reef passages that allow for the deployment of traditional fish traps, the source of the majority of self-defense bites in our study. The high prevalence of these bites associated with spearfishing is also logical, given the importance of this fishing practice for subsistence in French Polynesia, where there are an estimated >200,000

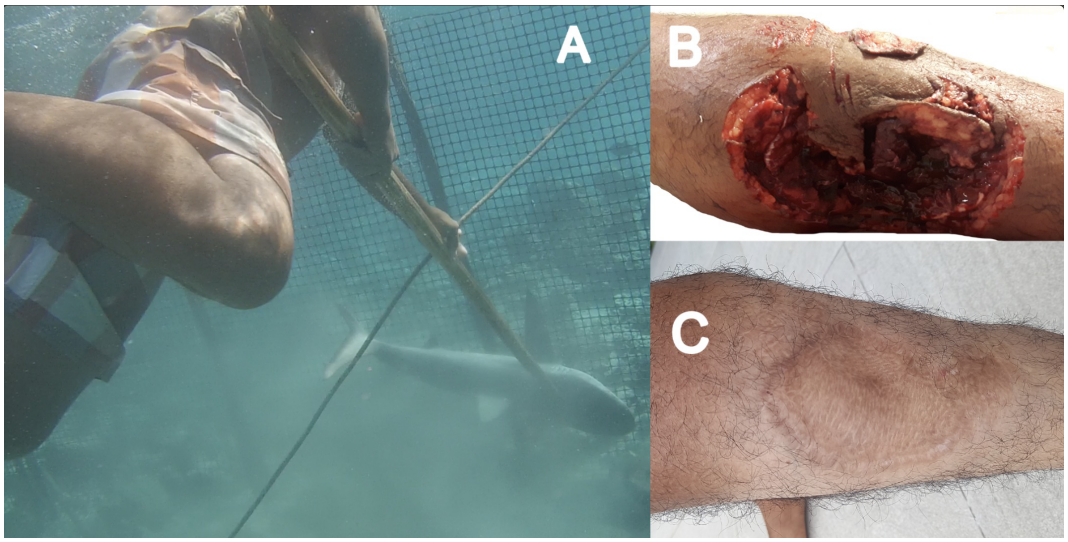

FIGURE 2
Case study 2: Polynesian fisher swimming at the surface into a fishing trap in order to manually spear with a traditional "patia" a gray reef shark and kick it off the trap (photo taken in 2017 in Tikehau atoll). Wounds following a shark bite on the calf of a Polynesian trap fisher before **(A)** and after **(B)** healing corresponding to CS13 in Table 2 (photos courtesy of M. Bègue).

spearfishing sessions per year, assuming an average of one session per week by 4,300 indigenous fishers (ISPF, 2022). Although calculated on a short period, the 15-year prevalence of 5% of this type of bite motivation, which we calculated from 2009 to 2023, is similar to the percentage of 4% of bites registered in connection with fishing traps in the framework of a previous study in French Polynesia that analyzed bites on a 10-year span from 1995 to 2005 (Maillaud and Van Grevelynghe, 2005). Although the self-defense motivation was not evoked in that study, we can suspect that the two shark bites attributed to "fish trap activity" by Maillaud and Van Grevelynghe (2005) would have happened under the same circumstances we describe in case study 2. We also suspect, however, that the rate we report is an underestimate, as shark bites are underreported around the world (Clua et al., 2020), including in French Polynesia, and among them, self-defense bites may be especially prone to being underreported because they are the responsibility of humans (first author, pers. obs.).

Differentiation from other shark bite motivations

Based on the wounds they cause, shark bites motivated by self-defense are clearly distinguishable from feeding-motivated bites, which are characterized by significant removal of flesh and high lethality owing to massive hemorrhaging (Ihama et al., 2009). Based on our data, self-defense bites are instead more superficial, sudden, and unannounced, i.e., by agonistic displays than bites with other motivations. Given the vital stakes the shark likely perceives for itself, these bites are sometimes delivered repeatedly. But even in these cases, little tissue is usually removed (E. Clua, pers. obs.). Moreover, there seems to be no proportionality regarding the nature of the initial human aggression in the severity and violence of a self-defense bite. Notably, this can also typify self-defense cases in humans, where defenders in many situations inflict greater harm on the attacker than the attacker actually delivers or threatens (Steinhoff, 2015). This lack of proportionality is consistent with an animal, including a shark, being unaware of human's intentions. A simple manual and not very traumatogenic manipulation by a human (see CS16 in Table 2) can then generate the same type of reaction from the animal as an action that is clearly intended to harm it such as the removal from fishing traps (see all CS linked to "shark harpooning" in Table 2). In the absence of any proportionality in the shark behavior, the gravity of the wounds delivered by self-defense bites would be directly linked to the dental anatomy of the shark species and the shark's size. Selacii are characterized by a high diversity of teeth anatomy, most of the time with a direct link to their feeding ecology. In that respect and regarding the reef species involved in self-defense-motivated bites in French Polynesia, piscivorous species have teeth that are potentially more harmful than those from more generalist species (Figure 3). As far as we know, self-defense bites have never been documented for large species such as the great white shark *Carcharodon carcharias*, the tiger shark *Galeocerdo cuvier*, or the bull shark *C. leucas*, probably because their size and traumatogenic potential prevents humans from displaying any risky aggression.

Shark bites motivated by self-defense share the characteristic of remaining mostly superficial and non-lethal with those linked to the motivations of competition, territoriality/dominance, or antipredation/fear (see Klimley et al., 2023 for details). It is this last motivation, which is common in the gray reef shark but also present for other species such as the blacktip reef shark or the sicklefin lemon shark (Martin, 2007), to which self-defense comes closest. However, the antipredatory/fear motivation is based on the principle of a shark's bite anticipating a potential aggression by a human (Nelson and Johnson, 1980), without it having actually occurred, whereas self-defense bites are in response to a human action that is, or is perceived to be, aggressive. Another notable difference is that antipredation/fear bites are often preceded by a particular agonistic behavior, e.g., hunching, pectoral fins lowering, gill flipping, and gaping (Nelson et al., 1986), whereas this type of behavioral warning is, as far as we know, never described in self-defense/retaliatory. Finally, these two motivations also diverge in terms of human responsibility, because human harassment in the

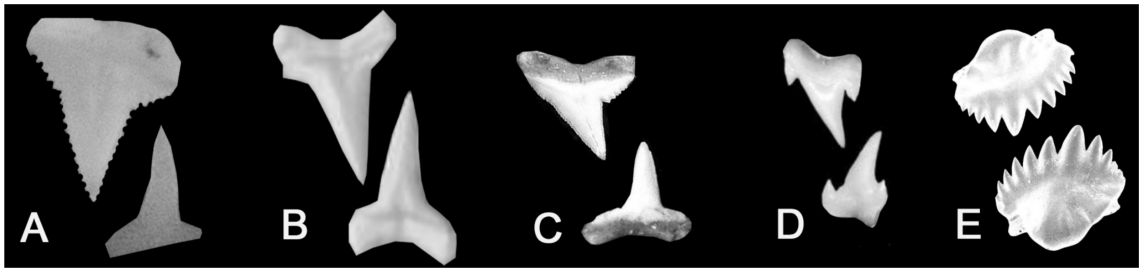

FIGURE 3
Comparison of teeth from the upper top and lower below jaws in the five species involved in self-defense bites in French Polynesia. From left (most harmful) to right (less harmful): **(A)** gray reef shark, *Carcharhinus amblyrhynchos*; **(B)** sicklefin lemon shark, *Negaprion acutidens*; **(C)** blacktip reef shark, *C. melanopterus*; **(D)** whitetip reef shark, *Trianodon obesus*; **(E)** tawny nurse shark, *Nebrius ferrugineus*. Adult gray reef sharks, although smaller in size than sicklefin lemon sharks, have triangular and very sharp teeth, whereas those of the lemon shark are dagger-like and thus lacerate rather than cut tissue, making them less harmful. Nurse sharks can also be of very large size >3 m in length, but their tiny teeth are made for crushing rather than cutting, significantly decreasing the severity of their bites.

case of antipredatory may be involuntary, for example by spatially limiting escape routes for a shark or by approaching a shark too fast with an underwater scooter (Nelson et al., 1986), whereas in the case of self-defense bites, humans are aware of their harassment, even if they underestimate the consequences.

Generalization of the case of French Polynesia

Certain features of French Polynesia make it difficult to directly compare the results of our study with global statistics. For example, fish traps are relatively specific to reef and coral ecosystems, in particular atolls that encompass reef passages and alternate currents that favor passive fishing; they are found in great number (>400 in French Polynesia) and not much anywhere else. However, at a global scale and to allow a comparison, any kind of shark fishing, whether voluntary or not, could functionally substitute for fishing traps to generate self-defense bites. For example, recreational fishing, which is well developed in countries such as the USA (Gallagher et al., 2017) or Australia (Ryan et al., 2019), can involve the handling of caught animals, including sharks, and several cases of apparent self-defense bites by sharks in this context are available online (see ESM 2-1 and 2-2). Moreover, the handling of sharks, sometimes as accessory catches, in the context of industrial fishing (Poisson et al., 2014) could also produce such bites. This problem of equivalence between activities does not exist for the practice of underwater spearfishing, which is highly developed in French Polynesia, but also on a global scale (see ESM 2-3), and can give rise to this type of bite in many tropical countries although Polynesian spearfishermen might differ from others by being globally bolder in the presence of sharks.

Finally, our bite data from French Polynesia are difficult to strictly compare to those at a global scale, as global databases on shark attacks do not use such a motivation and rather classify shark bites under the very generic concept of either "provoked" or "unprovoked" incident. In this context, the case of bites perpetrated by the Wobbegong sharks (*Orectolobus* spp.) in Australia is worth mentioning. Of N = 1,234 bites recorded in this country between the beginning of the 19th century and 2024 through the Australian Shark Incident Database (Meagher, 2024), N = 204 (i.e., 16.5%) are attributed to this species of benthic shark which, although it can reach impressive dimensions of up to 2.5 m, is not very dangerous (not a single human fatality) due to its blunt dentition. Following West (2015), "Wobbegong shark bites tend to be as a result of a defensive reaction by the shark to people


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La Dépêche
Mardi 19 avril 2016
Faits divers
MAKEMO - Un blessé âgé de 28 ans a été évasané à Tahiti et un autre mordu au genou
Pêche sous-marine : violente attaque de requin gris
nouvelle calédonie 1 portail franceinfo:
Deux jeunes attaqués par un requin à Makemo
Accueil > Actu > Monde
Polynésie française : deux pêcheurs attaqués par un requin gris
Midi Libre
Grièvement blessé par un requin gris, ce pêcheur de 28 ans devait être transporté au centre hospitalier de la Polynésie française hier.
Polynésie française : Deux pêcheurs attaqués par un requin
19 avril 2016 No Comment bassin-pacifique-Appli Fil-info-appli Planète Société
TNTV news
Polynésie : deux pêcheurs attaqués par un requin
LINFO.RE - créé le 19.04.2016 à 10h49 - mis à jour le 17.11.2021 à 15h41 - La rédaction
LINFO.RE
Post
L'un des pêcheurs a été grièvement mordu au mollet et au poignet tandis que le plus jeune, âgé de 22 ans, a fini avec une morsure au genou.

FIGURE 4
Samples not exhaustive of the French oversea and mainland daily written newspapers of 19 April 2016—the day following the bite incident involving two Polynesian fishermen that aggressed a gray reef shark (see CS14 in Table 2). All headlines include the word "attack" by the shark on the humans, which misleads the reader's understanding of the event and tends to present sharks as responsible for this negative interaction.

inadvertently getting too close or stepping on them." Of the total number of bites mentioned above, $N = 100$ (49%) are classified as "provoked" with, at the very least, "physical contact" between the human and the shark (Meagher, 2024), likely suggesting "self-defense" motivation. These Australian statistics demonstrate, if proof were needed, that the phenomenon of "self-defense" motivation is far from anecdotal.

At a more global scale, if we extract from the Global Shark Attack File (GSAF, 2024) all the cases of bites (all shark species together) from 1863 until 2024 that are linked to the activity of "fishing+spearfishing" and are classified as being "provoked"—two combined factors that suggest a motivation of self-defense by the shark—we get a total of $N = 322$ events. This figure represents 4.6% of all bites whatever the motivation, $N = 6,944$, a very close result to our assessments of 4% to 5% in French Polynesia. As another interesting result, among the 322 cases, only 10 were fatal, yielding a fatality rate of 3.2% among self-defense-motivated bites. This figure is certainly lower than the 12% fatality rate that emerges from our study (see Table 2), whose sample size is much smaller; but in both cases, the lethality level of this type of bite remains very low, which may help to characterize it in relation to other motivations as proposed in this study, in particular predation, which is significantly more lethal (Ihama et al., 2009).

Improvement of shark risk understanding and management

If humans want to avoid self-defense bites by sharks, the most obvious recommendation based on our assessment is to avoid attacking or harassing these species. What is less obvious, however, is the anthropomorphic way in which humans view animals, including potentially dangerous ones, and the fact that wanting to help a shark in distress, in this case acting in a benevolent manner, will not necessarily be perceived by the animal in this positive way. Such a well-intentioned behavior may instead expose the would-be rescuer to a self-defensive bite with neither discernment nor proportionality. The most frequent case is when a shark, for various reasons, washes up on a beach. Driven by empathy and the desire to help the shark to avoid death by suffocation, it is not uncommon for people to risk handling the animal in order to return it into the water. Several cases are reported such as in California, USA, in 1959 or in Queensland, Australia, in 2013 where two people got bitten as they were trying to rescue a blue shark *Prionace glauca* (GSAF, 2024). These people made two mistakes: first grabbing the animal by the tail, which has the double disadvantage of putting deleterious stress on the animal's spine with the risk of serious dislocation and of bite exposure as sharks are naturally flexible linked to their cartilaginous skeleton (Ebert et al., 2021) and can turn around to bite at almost 180°; and secondly expecting that the animal, most of the time in great distress, will consider would-be rescuers as supportive assets. As a matter of fact, the most instinctive reflex for sharks will be to defend themselves and bite.

Conclusions

The existence of self-defense bites also calls into question the practice of labeling all shark bites as attacks (Neff and Hueter, 2013). The media plays a key role in this perception, tending in the event of bites to portray sharks as the aggressor, even when humans are responsible for initiating the interaction (Bornatowski et al., 2019; Figure 4). This simplistic approach damages the image of sharks and, indeed, their conservation, which relies on public support (Le Busque et al., 2021). For example, pinning responsibility for defensive bites on sharks strengthens the rationale for reprisals and shark control efforts, whereas this type of interaction with humans in fact arises from a preservation instinct (Lorenz, 1950) and thus should not be the basis for lethal management.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because there was no direct contact with the animals. The study is on the characterization of attacks based on the victims' wound description sheets. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

EC: Writing – original draft. TV: Writing – review & editing. AW: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2025.1562502/full#supplementary-material

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