Shark Attack Theories

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Shark Attack – Why does it happen?

Over the years there have been many theories raised to try and explain or justify the cause of shark attacks around the world. This paper lists the common theories (historical and modern) as to why unprovoked shark attacks on humans occur and briefly discusses each in relation to today's knowledge of shark biology and shark attack behaviour, specifically in Australian waters.

Theories include:

1. Sharks are hungry: Sharks like all animals are not hungry all the time (Wetherbee, *et al*, 2012; Semmens, *et al*, 2013). Research has also shown that large predatory sharks are extremely adapted to catching their prey and have been found to have a broad range of prey items in their stomach (Wetherbee, *et al*, 2012; Bruce, *et al*, 2006; Simpfendorfer, 2001) indicating a varied diet. Large predatory sharks also has the ability to remove large pieces of flesh from its prey, however, the vast majority of bite wounds to humans are single lacerations where no flesh is actually removed. The injuries to humans range from minor teeth marks to slashing type wounds resulting in minor to severe lacerations, sometimes resulting in the death of a person. However, in these interactions it would seem that sharks are not intent on feeding on humans and may find human flesh unpalatable (Klimley, *et a*l, 1996a). While they do bite people they rarely eat them.

Humans are not a normal part of a large predatory shark's diet, but there have been rare occurrences where a human has been partially or totally consumed or the body was not recovered and suspected of being devoured. There have been 37 cases recorded in Australia since 1791. A large predatory shark would have to eat a lot of people to survive and this clearly does not happen. When a shark has been found with human remains in its stomach the presumption is that hunger was the motivation. However, finding human remains in a shark may just indicate that the shark has eaten a person after they died (post-mortem).

There are many observations between sharks and humans where a shark shows no interest in the human or just gives a cursory look as it swims past, further supporting the research that finds they are not hungry all the time.

2. Mistaken identity (mistaking humans for prey): Mistaken identity may be possible in some cases given the variety of environmental conditions in which shark interactions occur (not always clear water on sunny days). In harbours, estuaries and rivers, where bull shark (*Carcharhinus leucas*) attacks occur, mistaken identity is more likely due to turbid water conditions. Because of the reaction speed of some sharks to the capture of a potential prey item and possible speculative hunting strategies employed, full recognition of an object as a prey item may not occur (Johnson, 2003) and they may react instinctively to a stimuli such as sudden movement (e.g. a human splashing about in turbid water). Although a

particular object may not exactly resemble normal prey, the stimulus may be sufficient to trigger a predatory reaction (Curtis, *et al*, 2010).

Sharks have highly sensitive teeth and taste cells in and around their mouth (Hammerschlag, *et al*, 2012) and once a bite takes place it is thought that this is the point at which a shark determines if it continues the bite or rejects the object. Unfortunately, if this scenario is correct, the shark has already bitten the human before it realises its mistake and, in the case of a white shark, (*Carcharodon carcharias*), tiger shark (*Galeocerdo cuvier*) and bull shark (*Carcharhinus leucas*), injuries can be severe and even fatal.

3. Sharks are inquisitive: Given that the only reliable way for a shark to determine if an object is palatable (or not) is to bite it, then this theory suggests that sharks are simply using their sensitive taste, touch and smell to attempt to identify an object as something palatable. In most cases humans do not look like or act like a shark's normal prey but a shark may be attracted to an unfamiliar object because they are very inquisitive (Collier, *et al*, 1996; Hammerschlag, *et al*, 2012; Strong, 1996).

Sharks have highly sensitive taste cells, in and around their mouth, and it is thought that this is the point at which a shark determines if it continues the bite or rejects the object. It is thought that once the shark realises that the object being investigated is not what they thought it should be, or the taste is unacceptable, they abandon the bite. Unfortunately for the human, an 'inquisitive or investigative bite' by a large predatory shark could result in severe injury or death.

4. Sharks are attracted to sound: It has been well documented that sharks are attracted to low level frequency sounds particularly in the range or 10 Hz - 50 Hz which is within a frequency also given off by struggling or injured fish. Tests have determined that sharks are most sensitive to frequencies ranging between 40 Hz and 800 Hz (Myrberg, 2001) and use their lateral line and inner ears to locate prey as far away as 250m or more.

Human activities in the water may attract a shark's attention. Sound, rather than sight or smell, seems to be a shark's primary cue for moving into an area from any distance. However, once they are attracted to the source of the sound they are more likely to investigate the object relying more on sight than hearing.

5. Sharks are attracted to human blood and urine: Popular literature suggests sharks can detect a drop of blood and follow the scent to its source from kilometres away. Sharks are known to detect odours in small amounts but the sharks sense of smell may not be any more acute than some bony fish species e.g. tuna (Demski and Northcutt, 1996).

It has been suggested that sharks may be attracted to one person to the exclusion of others because the person is bleeding, has urinated in the water or simply because the person emits a stronger body odour or electromagnetic field. However, blood, urine, body odour and electromagnetic fields will quickly dilute or dissipate in the ocean. One drop of odour concentration in moderately turbulent flowing water would dilute out from 10^{-6} to 10^{-21} at one kilometre away which would not be recognised as blood or even register as a stimulus (Atema, 2012). There would need to be large amounts of blood flowing from the source for this to occur. As an example, one need only consider the amount of 'chum' or 'burley' needed to attract a shark to a fishing boat. Some sharks have been known to swim past several people in the water to

focus their attention on an individual within a group of swimmers or surfers. It is more likely that the shark's selection process may be more related to the behaviour or activity of an individual rather than the scent of an individual's blood or other excretions.

6. Sharks are attracted to bright colours: Long-term research on elasmobranch visual systems have found that sharks that possess rods and one or more cone receptors have the capacity for colour vision (Van-Eyk, *et al*. 2011; Hueter and Gilbert, 1990; Gardiner, *et al*, 2011; Gruber and Cohen,1985). Some people have suggested that sharks may be attracted to one person rather than others because of the colour of their skin or clothing. Some theorise that the colour yellow is a particular attractant to sharks. However, colour is quickly absorbed as the water depth increases.

Scientists do not know if colour plays a role in sharks' hunting behaviour but sharks are acutely sensitive to light, movement and contrast rather than colour and this is thought to be more useful in the hunting behaviour of sharks (Springer and Gold, 1989). It is most likely that an object at the surface of the water viewed from below would be silhouetted and appear as a dark shape contrasted against the lighter surface of the water, irrelevant of the actual colour of the object (Collier, *et al*, 1996).

7. Sharks are simply confused: Sharks can become confused by competing sensory information and bite objects because they emit a stronger electromagnetic field than other objects in the vicinity. This type of confusion is often observed when large sharks are attracted to boats (usually attracted by fishing activities). While swimming around the boat they often mouth the boat's metal propeller and this behaviour has been interpreted as the shark 'attacking the boat'. Elasmobranchs are highly sensitive to electromagnetic fields especially from their prey and detectable at <1 nVcm^{-1} (Huveneers, *et al*, 2013) and at a distance of around 0.25m (Haine, *et al*, 2001).

When metal is in salt water it emits a very strong electromagnetic field which can over stimulate (overload) the shark's sensory perception and a confused shark is then likely to bite at the strongest source of stimuli (e.g. a metal propeller). If sharks are attracted to humans by their electromagnetic fields they would have to be very close to the human – within a metre or so (Kalmijn, 1971). It is more likely that a shark is attracted by a person's activity in the water rather than the relatively low level of electromagnetic field a human may produce.

8. Sharks are defending themselves: A shark may initiate an anti-predatory response if it perceives a human as a potential predator or threat. Defensive behaviour has been observed in the grey reef shark (*Carcharhinus amblyrhynchos)*, where the shark's exaggerated swimming posture indicates a potential pre-attack behaviour (Johnson and Nelson, 1973). These studies were carried out by research divers trying to elicit the defensive response by putting the shark in a position where it would feel threatened. Several species of sharks are known to display these characteristics to varying degrees but it is not known if anti-predatory defensive behaviour occurs in sharks generally.

An anti-predatory bite may have been initiated against a person in the water in some cases. However, a person at the water surface is unlikely to notice any warning behaviours leading up to the bite or even be aware of the shark before an attack occurs.

9. Humans have invaded the shark's personal space:
This theory is similar to the defensive behaviour theory (see point 8) in that a reaction to the invasion of its personal space may provoke an anti-predatory defensive response towards the treat (animal or humans). In most cases, sharks inflict relatively minor bites or a single slashing wound, which may indicate a warning to tell interlopers to move away or stay away from them. Similar kinds of wounds have also been seen on sharks that are known to congregate and interact socially, or just get too close to each other (Myrberg and Nelson, 1991).

White sharks (*C. carcharias*) will react to and bite one another in possible dominance-related aggressive interactions and adult male sharks will bite females during courtship (Compagno, 2001). White sharks (*C. carcharias*) have been observed with bite marks to both males and females suggesting that these types of injuries are from social interaction such as food related competitive exclusion behaviour (Bruce, 1992; Klimely, *et al*. 1996b). This theory may have some potential in relation to the kinds of wounds inflicted and humans, especially if they get too close to each other.

10. Sharks are aggressive to humans, as they are to other sharks: Many species of sharks display social and aggressive behaviours towards each other (Myrberg and Nelson, 1991) (see point 9). These behaviours, which are common in species that congregate in large schools are usually associated with size and hierarchies of dominance or subordinance (Klimely, *et al*, 1996b).

It has been observed that smaller white sharks (*C. carcharias*) give way to larger white sharks especially when feeding. Interspecific relationships (those involving members of different species) also occur. It has been observed, for example, that when white sharks turn up, other shark species react to their presence, often by moving away from the area (Ian Gordon, pers. comm.). The types of wounds seen on some sharks are similar to those inflicted on humans from a single raking type bite.

11. Sharks are defending their territory: A long-held theory that sharks are territorial is frequently suggested when an attack occurs. While some species do have a home range as small as 0.55km^2 for black tipped reef sharks *(Carcharhinius melanopterus)* to several thousand kilometres for a tiger shark (*G. cuvier*) there is no conclusive evidence that any shark is territorial and defends that territory (Gruber, *et al,* 1988; Myrberg and Nelson, 1991).

12. Sharks are starving because of overfishing: There has been speculation that because the world's fish stocks are being depleted by overfishing sharks are starving and seek out humans as a source of food. While it may be true that commercial fishing has depleted fish stocks in some areas of the ocean most large predatory shark species (particularly those species known to bite humans) have the ability to travel long distances to other feeding grounds and do so as part of their normal distribution and migration behaviour (Bruce & Bradford, 2012; DPI, 2011; Semmens, *et al*, 2013; Simpfendorfer, 1992; Werry, *et al*, 2014).

Changes in prey item preference and the diversity of food items found in shark's stomachs would also give these sharks a broad range of food items to pick from (Wetherbee, *et al*, 2012). A 'starving' shark is more likely to move to where their preferred food is more available.

13. Sharks will eat anything: Some early authors have suggested that most sharks are opportunistic feeders out of necessity, existing in a 'feast or famine' regime because of their ineptness at catching prey. However, recent research shows that large predatory sharks are extremely adapted to catching their prey and have a variety of prey items in their stomach (Wetherbee, *et al*, 2012). Sharks' opportunistic feeding nature is also suggested in some species by changes in their diet with size, season and habitat (Bruce, *et al*, 2006; Simpfendorfer, 2001).

It is also true that some sharks (mainly the tiger shark *G. cuvier*) have been found with various indigestible objects in their stomach. It is most likely that sharks ingest these items during their normal feeding behaviour as incidental components of their feeding behaviour (e.g. picking up rocks while feeding on a stingray in the sand) or while investigating an object (Collier, *et al*, 1996; Hammerschlag, *et al*, 2012). Metal objects (like tin cans) are most probably ingested while being investigated as a potential food item as the strong electromagnetic field metal produces in salt water can be very attractive to sharks.

14. Sharks think humans are competitors: It has been suggested that sharks may see a human as a competitor for food resources, a perceived threat (see points 1, 9 & 13) or possibly as something interfering with its courtship behaviour. Unfortunately, there are few data on the sex of attacking sharks to determine whether or not single-sex sharks are responsible for the majority of attacks.

15. Sharks are just playing: A theory that sharks are just playing with humans has been raised. There have been observations where white sharks (*C. carcharias*) have been observed to mouth seaweed, bite floats and even pick up an aluminium can and moved it around and to investigate various animate and inanimate objects throughout the water column (Barry Bruce, CSIRO, pers. comm.; Collier, *et al*, 1996; Hammerschlag, *et al*, 2012; Strong, 1996). Most of these objects are unlike their normal prey. It is possible they are attracted to the electromagnetic field from the metal can or in the case of the seaweed, investigating the opportunity to disturb a prey item possibly hiding in or under the seaweed. These observations are most likely curiosity behaviour by the shark (see point 3).

16. Attacking sharks are 'rogue sharks': The Australian surgeon Dr Victor Coppleson raised the theory of the rogue shark in his pioneering study on sharks in 1958 (Coppleson, 1958). He theorised that a sick shark unable to catch its normal prey was the instigator of most of the shark attacks he studied. He concluded that a 'rogue' shark is a single shark that maintains, even for years, a beat along a limited stretch of shore.

Coppleson based his theory on linking a series of attacks from the 1930s to the 1950s that occurred in particular areas over many years or even decades and on attacks that occurred within short periods of time, even though they were up to 140 kilometres apart. Current knowledge of large predatory shark behaviour and their migration patterns does not support this theory.

17. Sharks only attack when the water temperature warms up: Coppleson in his book 'Shark Attack' (1958) suggested that shark attacks only occurred when the water temperature was about 70^0F (21^0C) and referred to the zone as the 'thermal belt' being between 21^0 North and South of the equator. It was suggested that this is

when sharks breed and may bring their young into shallow water and were ferocious at this time. It is now widely accepted that people will usually enter the ocean or harbour water when it is comfortable for the human which is around 20-21^{0}C and above.

In Australia these warm water temperatures occur around the same time as the summer school, Xmas & New Year holidays when most beach visitors would enter the water to cool off. The species of shark known to bite humans (white, tiger and bull sharks) migrate long distances north and south along the east and west coast of Australia (Bruce & Bradford, 2012; Simpfendorfer, 1992; Simpfendorfer, *et al*, 2001; DPI, 2011) and are found in the same waters, at the same time when most people are in the water.

With the common use of thermal wetsuits over the last 60 years, people can enter the water all year round and shark attacks do occur throughout the year (even in the cooler winter months). With the current knowledge of shark breeding biology there is little doubt that it is the increased number of people entering the water that increases the risk of encountering a shark rather than breeding sharks being aggressive towards people as the water warms up.

18. Shark populations have increased: In relation to unprovoked shark attacks in Australia there are three main species of shark that are associated with severe and fatal bites to humans - the white shark (*C. carcharias*), tiger shark (*G. cuvier*) and bull shark (*C. leucas*).

There are currently no reliable estimates of the size of the white shark (*C. carcharias*) population in Australian waters. However, Blower, *et al*, (2012) using genetic techniques, suggest a genetically effective population size of 1500 for the Australian population and this number should be considered a minimum estimate. There is clear evidence from a range of sources (game fishing records, shark control programs, monitoring at the Neptune Islands) of a decline in the relative abundance of the white shark population in Australian waters over the last 60 year. At least some changes (both increases and decreases in observed numbers) are likely to be a function of temporal changes in distribution, rather than an increase in population size. If purely distribution driven, increases in numbers of white sharks in areas where human activity is also high may indicate periods where shark populations are also most at risk from interactions, rather than indicating a recovery of the population (Issue Paper, 2013). This species is classified as Vulnerable on the IUCN Red List of Threatened Species (Fergusson, et al, 2009)

In terms of the other two shark species - tiger shark (*G. cuvier*) and bull shark (*C. leucas*), available information for the tiger sharks from catch and effort data in the Queensland Shark Control Program suggests a decline in the population (Holmes, *et al*, 2012) but in other areas populations vary. This species is classified as 'Near Threatened' on the IUCN Red List of Threatened Species (Simpfendorfer, 2009).

Bull sharks population estimates vary around the world with increases in some areas and declines in others. This species is also classified as 'Near Threatened' on the IUCN Red List of Threatened Species (Simpfendorfer and Burgess, 2009).

Overall, while some uncertainties exist, there is no compelling body of evidence that suggests that the population abundance of relevant shark species is increasing, or

increasing to the extent to explain the increasing trend in unprovoked shark bites (McPhee, 2014).

Discussion:

In 1988 Dr David Baldridge studied 1,700 shark attack cases from the International Shark Attack File database and proposed that between 50 and 75 per cent of attacks were motivated by drives other than feeding – what he called 'non-foraging aggression'. Baldridge theorised that non-foraging aggression could include the shark defending its territory, or that the human appeared to be a threat, invading the shark's personal space or interfering with its courtship behaviour, among other possible motives. Baldridge also noted that the means available to sharks for effecting non-foraging aggression are exactly the same as those used for capturing food, namely their teeth, skin, body mass, speed and agility.

Baldridge (1988) writes that sharks are limited to direct action to neutralise a real or perceived threat, establish dominance or otherwise exert influence for change. Such direct physical exchanges, particularly those involving large predatory sharks, are inherently violent and, when directed towards a human, would more often than not produce injuries. If the sharks are relatively unexcited when they initiate non-foraging aggression the wounds are more likely to be single bites with lacerations of a slashing type or abrasions. If an unprovoked shark attack feeding behaviour is described as the removal of flesh or the body is consumed or the body is not recovered (presumed eaten) then 77% of Australian shark attack cases in the last 100 years would be considered non-foraging aggressive behaviour based on Baldridge's (1988) model.

Unprovoked shark attacks have little in common apart from the fact that a human and shark are in the water at the same location at the same time. Attacks occur under different circumstances, involve different shark species and sizes, under different environmental conditions (water quality, depth, clarity, etc), in different places at different times of the day and year and with humans behaving differently in each incident.

Broadly speaking all the theories discussed in this paper fit into one of three main categories a) hunger; b) curiosity and c) aggression. Analysis of shark attack cases by the Australian Shark Attack File, the International Shark Attack File and other shark researchers around the world over the last two decades indicate that curiosity, mistaken identity, hunger and possibly social defensive or aggressive behaviours all play a part in interactions with humans to some extent. In most cases we know nothing of the shark's behaviour just before the attack. It may well have been pursuing its prey or actively feeding prior to encountering the human. We may never know for sure.

It is most likely that it is a combination of competing sensory stimuli that alerts the shark and it initiates an inquisitive investigation leading to a hunting behaviour, bump or exploratory bite. Anywhere along this process the shark can abandon the investigation or attack behaviour. Recent research also suggests that the sub-adult white sharks (*C. carcharias*) are mechanically venerable when handling large prey and suggests that the jaws of white sharks <3m long are too weak to capture and kill large prey (Ferrara, et al. 2011). This may explain why many shark attacks are aborted after a single exploratory bite, as the whites involved may have been juveniles who may sustain jaw injury if they persevere with the attack.

It must be said that just because a shark is in the water nearby it does not mean that it will attack. There are many instances where large free swimming predatory sharks were observed to have swum past people in the water and took no or only a cursory, interest in them. Growing numbers of thrill seekers are diving with large predatory sharks outside of protective cages without being attacked. There is no doubt that sharks see more people in the water than people ever see sharks with the vast majority of victims being unaware of the shark before the incident.

Shark behaviour is complex and the more we find out about their normal behaviours the more questions are raised. To properly interpret shark behaviour, especially in relation to human / shark interactions much more neurological and behavioural research will need to be done.

Historically shark attack theories are convenient explanations based on limited observations that made people feel that they understand shark behaviour with the possibly to predict what sharks may do in the future. However, the motivation for an unprovoked shark attack remains unclear in most cases and predicting unprovoked shark attacks virtually impossible.

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