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# Shark Attack versus Ecotourism: Negative and Positive Interactions

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**ABSTRACT:** Unprovoked attacks by sharks on humans are exceptionally rare phenomena. Sharks typically have two motivations, feeding or defense, that result in attacks on humans. Three species, the bull, tiger, and white sharks, are responsible for the majority of attacks on humans. These predominantly feeding-motivated attacks are often the result of the shark mistaking its human victim for natural prey. Many species, however, exhibit a defensive, aggressive display that, unheeded, may result in a single bite or slashing wound to a human. The number of unprovoked attacks by sharks on humans worldwide has risen from 8 during 1900-1904, of which 2 were fatal, to 330 during 2000-2004, of which 29 were fatal. The rates of 5.8 fatalities per year during 2000-2004 and 6.4 fatalities per year during 1995-1999 are negligible relative to the average of 42,593 fatalities per year due to automobile accidents reported from 1993-1995 in the United States alone. Taking a look at sharks from another perspective, ecotourism has become immensely popular in the 1990s and 2000s. There are opportunities to view sharks in the wild on every continent except Antarctica, with the scalloped hammerhead, white, whale, and reef sharks being among the most popular subjects. Shark ecotourism is providing the public with an observational experience that can be as pleasurable as whale watching, and it can be a cost-effective alternative source of employment for fishermen. This could lead to reduced shark fishing in certain regions of the world and enable shark populations to recover to their former levels of abundance.

**KEY WORDS:** agonistic display, ecotourism, public safety, shark attack

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## INTRODUCTION

Sharks are many of the oceans' top predators. Along with rays, sharks comprise the subclass Elasmobranchii, a group of mostly carnivorous, cartilaginous fishes that are present in all of the world's oceans. Even though the over 403 species of sharks make up only 1.4% of the 27,977 species of fishes in the oceans (Nelson 2006), none are more feared by humans who enter the ocean. At least 30 species of sharks have been confirmed attackers of humans, but only a few of the largest predatory species, the white (*Carcharodon carcharias*), tiger (*Galeocerdo cuvieri*), and bull sharks (*Carcharhinus leucas*), are responsible for the majority of attacks (Caldicott *et al.* 2001).

A shark attack on a human usually attracts immediate and extensive attention by the media. The newspaper headlines and articles reporting the attack are usually sensational and frightening and may have a negative impact on tourism in coastal recreational areas. The magnitude of the impact is amplified greatly if more than one attack occurs at roughly the same place at the same time. For example, Charles Vansant was killed by a shark swimming in the waters near Beach Haven, New Jersey, on 1 July 1916. Five days later, on 6 July, Charles Bruder was killed by a shark at Spring Lake, New Jersey, 70 km from Beach Haven. Just 6 days following that attack on 12 July, a similar distance away, two men were fatally attacked, and one man was seriously mauled by a shark at Matawan Creek, New Jersey (Schultz and Malin 1975, Femicola 2001). Though the species responsible for these attacks has not been conclusively determined, most experts suggest that the attacker(s) was either a white shark or a bull shark. These 5 attacks, which occurred close to the 4<sup>th</sup> of July holiday, when public

beach recreation is characteristically at its peak, were reported by the media with great sensation, and this bad press resulted in bathers from the New Jersey and New York metropolitan areas avoiding their customary recreational destinations for the rest of the summer. This notorious serious of events, which adversely affected the economy of many coastal communities in New Jersey, was the real-life event which was the basis of the fictional account in Peter Benchley's *Jaws*.

This phenomenon is not confined to the United States of America. A 16-year old boy, Michael Hely, was bit in the hip by a ragged-toothed shark (*Carcharias taurus*) at Amazintoti, Natal during April 1960 (Davies and D'Aubrey 1961a), and although not fatal, this shark attack was reported widely in the South African press. This was followed by a fatal attack on a 25-year old male, Petrus Sithold, 138 km away at Margate, a major resort town in Natal, during December of the same year. These attacks, and two additional ones on young boys, 13 and 15 years old, on 6 and 22 of January 1961 (Davies and D'Aubrey 1961b,c) created widespread fear in the local community. The news of these attacks was reported widely in newspapers across Europe and resulted in a great reduction in the number of tourists visiting Durban, a favorite destination, over the next 5 years. The need to learn more about sharks' motivations to attack humans, and to develop ways of avoiding it, led in part to the creation of the South African Association for Marine Biological Research and the building of the Durban Aquarium, and eventually led to the setting of protective nets along the coast of South Africa to exclude sharks from the beaches and thus reduce the risk of shark attack (Cliff and Dudley 1991).

Over the last 46 years since the attacks in Durban, the

public perception of sharks has slowly changed from one of fear and misunderstanding to one of more fascination. This change in public opinion has been caused in part by the availability of more accurate scientific knowledge of the behavior and ecology of sharks (e.g., Gilbert 1966, Hodgson and Mathewson 1976, Klimley and Ainley 1996, Carrier *et al.* 2005). This research effort was stimulated at first by the Navy's interest in identifying the motivation(s) for sharks to attack humans, in order to avoid attacks or deter them while in progress. Even though the occurrence of shark attacks has risen slowly as human utilization of the seas has risen, sharks are now being perceived by many to be valuable marine resources, both as a food source and a magnet for ecotourism, and not so much as dangerous pests.

The purpose of this article is to review both the negative and positive aspects of the relationship between sharks and humans. We will first identify the motivations that lead sharks to attack humans. Our next step is to establish how commonly sharks attack humans and how significant the risk of losing one's life due to a shark attack is, relative to losing one's life due to other more common hazards. We then briefly discuss the deleterious effect of human fisheries on shark populations. The next subject discussed is shark ecotourism, a pastime enjoyed by divers worldwide that come to view sharks in their own habitat, and we discuss attempts to convert fishermen, who heretofore killed sharks, into members of the ecotourism community.

## METHODS

We base our discussion of the motivation of shark attacks on a review of the scientific literature. The statistics on attacks on humans by sharks are based on records from the International Shark Attack File (ISAF), which is maintained at the Florida Museum of Natural History at the University of Florida. The ISAF is an archive of all known shark attacks worldwide. Since its establishment in 1958, more than 4,000 individual shark-human interaction investigations have been compiled, covering the period from the mid-1500s to the present. Unless otherwise noted, all references to shark attacks only include cases of "unprovoked" attack, defined as incidents where an attack on a live human by a shark occurs in its natural habitat, without human provocation of the shark (G. Burgess, ISAF, pers. commun.). We obtained the statistics on deaths due to various injuries from the National Safety Council, and these were averaged over 3 years, 1993-1995. The compilation of opportunities for shark ecotourism were primarily based on *The Shark Watchers Handbook: A Guide to Sharks and Where to See Them* (Carwardine and Watterson 2002).

## RESULTS

The cause and end result of a shark attack will vary depending on the location, the activity and response of the victim, the species involved, and the motivation behind its attack. Caldicott *et al.* (2001) describe 3 general categories of shark attacks: 1) "hit and run" attacks, 2) "sneak" attacks, and 3) "bump and bite" attacks. "Hit and run" attacks are by far the most common type of attack,

with over 80% of reported attacks following that pattern (Caldicott *et al.* 2001). Swimmers and surfers in shallow waters are common victims of this type of attack, in which the shark makes a single strike, leaving a bite or slash wound before retreating and not returning. The victim rarely sees the attacker during the brief interaction, and the wounds are generally minor. An analysis of 86 South African shark attacks showed that 81% of attack victims suffered only minor injuries, requiring only primary sutures (Woolgar *et al.* 2001).

Victims of "sneak" and "bump and bite" attacks tend to suffer more severe injuries. These attacks tend to occur in deeper waters on divers or swimmers and may involve multiple strikes. The shark is not seen prior to the "sneak" attack, which tends to be a powerful and violent interaction typical of a predatory attempt by the shark using an ambush tactic. In "bump and bite" attacks, the shark circles the victims, often bumping them with its snout prior to attack. This behavior is believed to allow the shark to assess the palatability of the potential prey item, or to determine the potential threats it may pose prior to making a decisive attack. A large percentage of these types of attacks result in fatality (Caldicott *et al.* 2001).

## Motivation to Attack Humans

One can avoid being attacked if one decreases the motivation of the shark to attack. Hunger is one obvious motivation for a shark attack to attack a human. Attack wounds often do resemble bites by which the shark attempted to feed. On the other hand, the magnitude and shape of attack wounds do not always bear this out. If attacks are feeding motivated, one would expect the prey to be consumed either partially or wholly. Indeed, this is the case in some instances. During October, 1939, two divers were witnessed being attacked off a beach in the province of New South Wales, Australia, and on the following day their remains were recovered from the stomach of a 3.5-m (total length) tiger shark (Klimley 1974). Often the evidence is not so conclusive; remains of victims have been found in shark stomachs, but the attacks have not been witnessed. The victims may well have drowned before being consumed, and hence are classified as scavenging event rather than an attack.

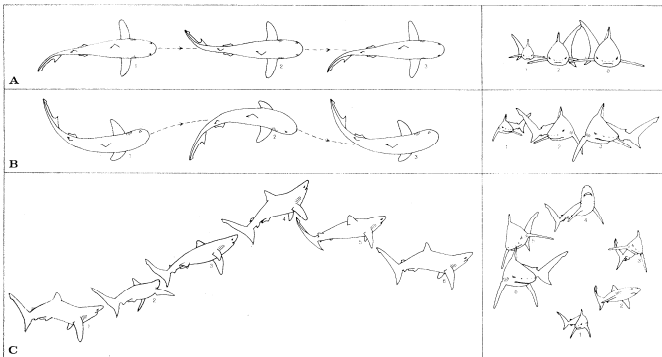
In many instances, victims of shark attacks have experienced the loss of only small amounts of flesh. One such example occurred off West Palm Beach in 1968 (Klimley 1974). A young boy was attacked close to shore while snorkeling. Teeth marks in the shape of a half-moon were impressed upon the bottom of both of his swimming fins. These marks could only result from a slashing movement made by outstretched jaws rather than a vertical bite. Severe wounds were inflicted between the boy's knee and ankle. These also lacked the characteristic puncture wounds of the pointed gripping teeth of the shark's lower jaw. Although close to 1,000 sutures were needed to close the child's wounds, very little flesh was lost. This observation led a U.S. naval physician to publish an important scientific article, entitled "Shark Attack: Feeding or Fighting," questioning the traditional hunger-motivated explanation and suggesting that attack behavior might rather be defensive in nature, triggered by

intrusion into a protected area by the victim (Baldrige and Williams 1969).

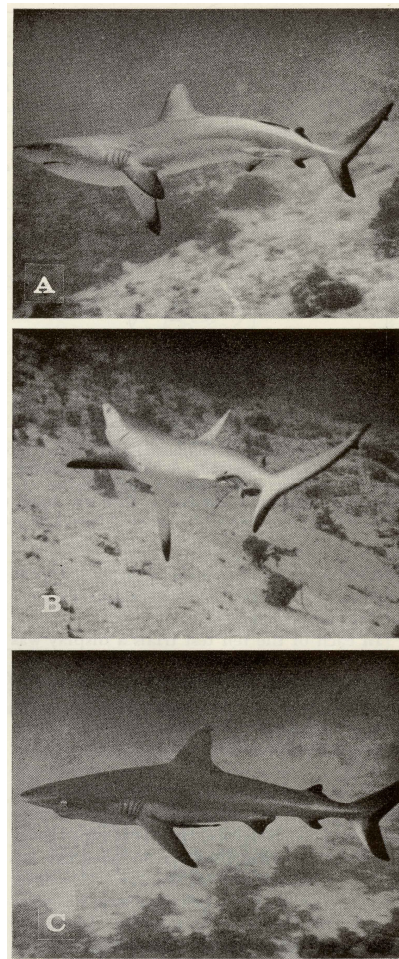
**Defense**

Agonistic displays are conspicuous and exaggerated motor patterns that demonstrate the displaying individual's ill ease due to the presence of another and its capacity to inflict harm, should the intruder come any closer (Burghardt 1970). The hunching posture, erection of hair, baring of teeth, and hissing of a cat when confronted by a barking dog, for example, is a display conveying to the dog the cat's readiness to defend itself by attacking, if the dog moves any closer. The display enables both the cat and dog to avoid the injuries that they would sustain in a fight.

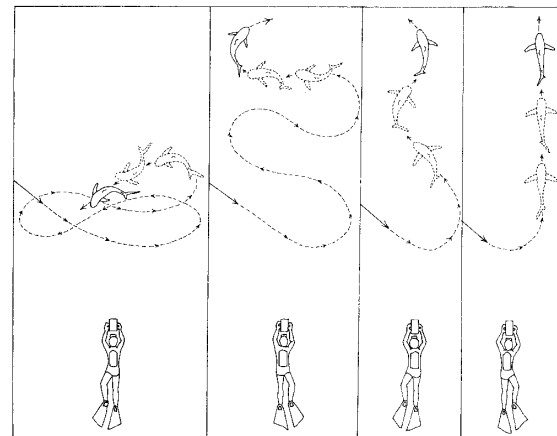
Such a display was photographed and analyzed for the gray reef shark, *Carcharhinus amblyrhynchos* (Nelson *et al.* 1986). Its display was broken down into 2 ambulatory elements and 4 postural elements, for the sake of understanding it better. The former are very exaggerated tail movements on a horizontal plane and swimming to the side in a looping configuration (Figure 1). The 4 postural components are the upward pointing of the snout, lowering of the pectoral fins, arching of the back, and bending of the tail in a lateral direction (Figure 2). The intensity of the display, evinced by the degree of compression of the looping trajectory of the shark, increases with the speed at which the diver approaches the shark and the degree of the shark's confinement (Figure 3). The display results in an attack, if an intruder does not retreat but continues to approach the shark. This relationship was demonstrated experimentally by steering a submersible of the size of a large shark toward a grey reef shark, eliciting an agonistic display, yet failing to retreat but continuing to approach the shark. The reactions of the displaying sharks were to accelerate explosively upward, around, and downward to inflict a slashing bite on the side of the submersible (Nelson *et al.* 1986). Similar displays have been observed by the blacknose (*Carcharhinus acronotus*), lemon (*Negaprion brevirostris*), silky (*Carcharhinus falciformis*), and bonnethead sharks (*Sphyrna tiburo*) (Myrberg and Gruber 1974; Klimley, unpubl. observations).



**Figure 1. Diagram of agonistic display: A. Top and frontal view of normal swimming; B. Similar views of display with laterally exaggerated beating of caudal fin; C. Side and frontal views of spiral looping trajectory of shark** (taken from Johnson and Nelson 1973).



**Figure 2. A. Photograph of gray reef shark from a side view performing agonistic display, evident by slightly opened mouth, upward pointing snout, depressed pectoral fins, arched back, and lateral bend of posterior body and tail; B. View from posterior of shark swimming in rolling mode; and C. Side view of normally swimming shark** (taken from Johnson and Nelson 1973).



**Figure 3. Diagram of agonistic display with swimmer approaching shark swimming at increasing swimming speeds. Note compressed looping trajectory exhibited toward rapidly approaching diver. This high intensity display is often followed by the shark striking the diver** (taken from Johnson and Nelson 1973).

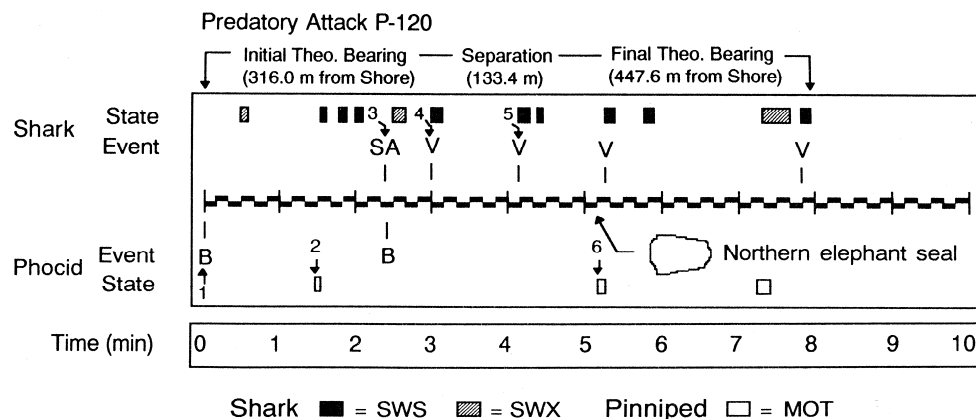
## Predation

Though humans are not a major component of any shark's normal diet, there are 3 species of sharks that have been documented to prey on humans on occasion. They are the bull shark, the tiger shark, and the white shark. Adult tiger sharks feed on a diverse diet of large vertebrates such as bony fishes, sharks and rays, birds, and sea turtles (Lowe *et al.* 1996), and humans have been found in their stomachs. Adult bull sharks occasionally prey on marine mammals including sea lions (Klimley, unpubl. observation) and dolphins (Heithaus 2001), and they are fully capable of consuming humans. This species enters estuaries and rivers and was possibly responsible for the attacks on 3 bathers in Matawan Creek in July 1916. It is difficult to conclude that white sharks that attack humans off Central California, southwestern coast of Australia, and southern coast of Africa intend to feed on humans (as argued by Burgess and Callahan 1996), because the human may be confused with normal prey, seals and sea lions, which are more abundant at these locations (Tricas and McCosker 1984).

Because divers and surfers on the Pacific coast of North America hope to avoid attacks by white sharks and hope to survive attacks when they happen, a great deal of attention has been devoted in the popular media to what happens when a shark attacks. Do the white sharks eat people, or just bite them? Does a shark "bite and spit"—that is, expel its prey and return later to eat it, expecting it to bleed to death? Can an attacking shark be beaten off with a stick? Why do sharks carry their prey for long periods of time before taking a bite? Observations of natural white shark predation at the South Farallon Islands, California, have provided possible answers to many of these questions (Klimley *et al.* 1996). Detailed diagrams were constructed of 129 videotaped predations between 1989 and 1992. These video records were transcribed into diagrams. Shown is a diagram of a white shark predation on a seal (Figure 4). Each behavioral pattern of the shark and pinniped was recorded as either an "event" or a "state" (Lehner 1979). Discrete actions of

short durations were defined as events and represented by alphabetical codes. Continuous actions with longer durations were defined as states and were represented as horizontal bars. Most of the behavioral patterns were directly observed acts, such as the prey being seized by the shark while either in a horizontal or vertical position (V). A few behavioral patterns were indirect indicators of the sharks seizing the prey, such as the sudden appearance of blood, or splashing at the anterior of the shark (SA). An analysis of these diagrams suggested that predatory behavior of the white shark can be broken down into a sequence of typical behavioral states and actions.

In eastern Pacific waters, white sharks feed most frequently on northern elephant seals (*Mirounga angustirostris*), like those that live on the shores of the South Farallon Islands. The sequence of behaviors in predation P-120 is an example of a white shark feeding bout in which the prey is a seal. Observers were alerted to the shark's initial strike by the appearance of a small bright-red area on the sea surface (event B). The shark surfaced and began to swim with exaggerated tail beats 0.3 min later, possibly with the seal held in its jaws (state SWX). The seal surfaced after 1.5 min and floated motionless, no longer bleeding, 75-100 m from the site of the initial strike (state MOT). The seal was no longer inside the area tinted red with blood; the area had by now expanded and elongated toward the site where the dead seal reappeared. The seal had already lost a massive amount of blood. The carcass remained at the surface for 1.1 min before the shark seized the carcass and submerged with it. Splashing and a small amount of blood were observed 1 min later near the head of the shark, indicating that the seal had been bitten again (events SA and B). Later, the carcass was seized 4 more times by the shark from underneath, with no loss of blood (event V). During the feeding bout, the seal moved a distance of 133.4 m almost directly offshore of the location where the attack began. The interval between the appearance of blood (event B) and the bloodless and immobile seal at the surface (state MOT) was 1.5 min, almost twice the duration of the



**Figure 4.** The sequence of behavioral events and states in a feeding bout of a white shark on a seal. Predatory attack P-120 on a northern elephant seal, 15 October 1989. The activity of the white shark is given above the abscissa; that of the prey, below. Behavioral events are indicated by alphabetical codes above the lines leading from the abscissa.

Key: B = blood-stained water, SA = splash at anterior torso of shark, V = vertical shark bite. Behavioral states are denoted by horizontal bars. SWS (solid bar) = shark swimming slowly, SWX (cross-hatched bar) = shark swimming with exaggerated tail beats, MOT (clear bar) = seal floating motionless at surface of water.

0.8-min interval between the second and third events (onset of state MOT and event SA), and almost 3 times the duration of the 0.6-min interval between the third and fourth events (events SA and V).

The behavior of the shark and seal can be interpreted in the following way, based on the review of this and many other predations. The initial strike was rarely witnessed during an attack, suggesting that the prey was seized underwater. Rather, the observers were most often alerted of the attack by a spot of a large blood-stained area of water. The blood stain elongated in one direction, and then the shark reappeared with the seal beside it. In other attacks, the shark would be seen swimming with wide tail beats. Such beats would be necessary for the shark to propel itself forward if it were carrying the heavy seal in its jaws. This sequence of events appears to indicate that the shark carries its prey beneath the surface and then returns to the surface. After a prolonged interval, the seal then floats to the surface in an immobile state with a bite of flesh missing, although, significantly, the wounds in most cases were no longer bleeding. The shark then surfaced quickly and swam to the carcass and seized it. This scenario is consistent with the suggestion that the white shark kills its prey by exsanguination, or blood deprivation. It appears the shark holds the seal tightly in its jaws until it is no longer bleeding.

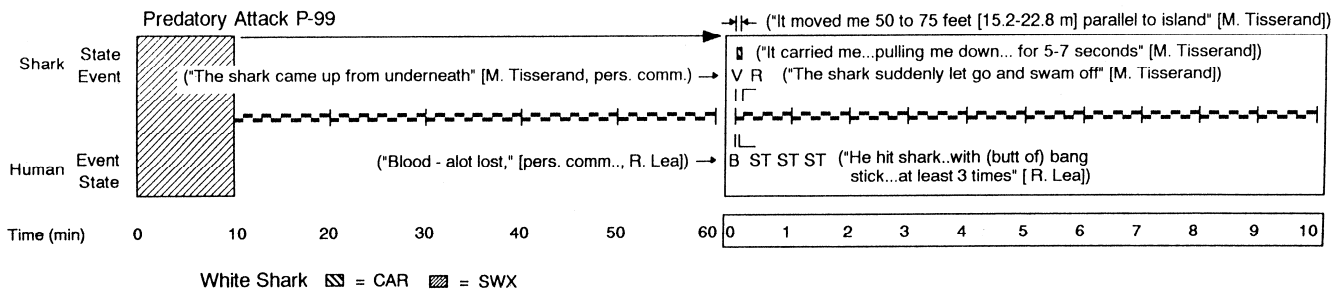
A commonly held belief is that sharks bite seals, and then quickly spit them out in a wounded but intact state to die, before again attacking them. The sharks chased and captured 64% of the seals that survived the original attack at the Farallones. Furthermore, the sharks did not return immediately to feed on the carcass once the seal died. Seal carcasses were observed floating in immobile states for as long as 140 minutes before sharks returned to feed on them.

Interesting contrasts occur in the responses of sharks to different prey. At 2 p.m. on September 9, 1989, a shark attacked a human, and the attack began like many attacks on seals (Figure 5). A white shark seized the leg of Mark Tisserand, a commercial abalone diver, while Tisserand was 5-8 meters below the surface, nearly 200 meters from shore, pausing in a prone position to clear his ears (Robert Lea, pers. commun.). According to the victim (Mark Tisserand, pers. commun.), "the shark swam up from underneath, seized me, carried me down for 5 to 7 seconds, and suddenly let me go and swam off"

(event V, state CAR, and event R). While being carried in the sharks jaws, the victim lost much blood (event B) (R. Lea, pers. commun.). Similar to the situation during feeding bouts on pinnipeds, the shark carried the diver underwater for some distance. The diver struck the shark with the butt of a bang stick 3 times before the shark released him (events ST and R) (R. Lea, pers. commun.). This pattern is consistent with the notion that the shark exsanguinates its prey, but the shark released its human prey intact and swam off. In a seal attack, the shark would have chased down the prey and finished it off. The pattern Tisserand reported, in which he was bitten and then released, is typical of white shark encounters with people off California (Tricas and McCosker 1984). In another attack, a shark seized and released a brown pelican, even though it was quickly disabled and unable to resist further attack. The bird was left bleeding profusely and struggling spasmodically at the surfaced until it died 2 minutes later. The shark never returned to feed on the pelican (Klimley *et al.* 1996). Furthermore, many sea otters are found whole but dead along the California coast, with fragments of white-shark teeth embedded in their open wounds (Ames *et al.* 1996). A sea otter has yet to be found in the stomach of a white shark (Klimley 1985).

There may be a connection between these observations. Humans, birds, and sea otters are composed mainly of muscle, whereas the preferred prey of sharks— seals and cetaceans (dolphins and whales)— are composed mainly of fat. Sharks may prefer energy-rich marine mammals to other comparatively energy-deficient species. Supporting this is the propensity of white sharks to feed selectively on the blubber of baleen whales and not the tissue underneath (Curtis *et al.* 2006). This may explain why white sharks rarely completely consume humans when they attack. Finally, experiments have shown that white sharks do feed on the fat flensed from seals, but not on the remaining muscle on the body of the seal (Klimley 1994).

Further evidence of the reluctance of white sharks to consume humans wholly comes from the ISAF. In only 6.2% of the attacks recorded worldwide from 1910-1995 did a white shark remove 3 bites from a human (Burgess and Callahan 1996), and it is unlikely that the humans were completely eaten in this number of bites. Two bites were observed in 16.8% of the attacks. In striking



**Figure 5. Sequence of attacks on a human who was not eaten. Attack P-99 on a human on 9 September 1989.**

Key: V = vertical shark bite, R = shark releases item, ST = prey strikes shark

contrast, only 1 sea lion escaped from a predatory white shark during the 129 attacks on pinnipeds recorded by video at the Farallon Islands, resulting in a predatory success rate of 99.2% (Klimley, unpubl. data). However, it is possible that some of these attacked seals escaped from the sharks and were unseen afterwards. A success rate of 55% was recorded for a larger sample size of predations (2,088 over a period from 1997-2003) occurring within an hour of sunrise at Seal Island, South Africa, and predation ceased later in the day, when the success rate decreased to 40% (Martin *et al.* 2005). In the majority of attacks on humans, 56.8% of the 125 recorded attacks worldwide, the shark bit only once and then departed; no bites were removed from the human in 10.4% of the attacks. Finally, in none of the shark attack cases were the intact remains of the whole human recovered from the stomach of the attacking shark after its capture (Burgess, pers. commun.). Yet, the possibility exists that a highly hunger-motivated white shark might consume a human in the absence of more nutritious prey.

The bull and tiger sharks may not need to optimally forage on energy-rich prey as does the white shark. These species are ectothermic— their body temperature is equal to that of the surrounding water, and hence tend to occupy warm tropical waters. On the contrary, the white shark, which occupies temperate and polar waters, is endothermic— maintaining its body temperature above that of the cold surrounding waters (Goldman 1997). It possesses multiple *retia mirabilia*, vascular counter-current heat exchangers, to warm its viscera to accelerate the digestion of prey and warm its brain, ensuring uniform integrative processing, and its eyes, to speed up the process of visual processing (Block and Carey 1985). This is also an energetically costly metabolic style of life, and it may require that endotherms such as the white shark prey on high-energy prey (Block and Finnerty 1994).

### Negative Interactions

#### Attacks on Humans

The number of attacks of all species of sharks worldwide on humans per 5-year period has risen from 8 during 1900-1904, of which 2 were fatal, to 330 during 2000-2004, of which 29 were fatal (Figure 6). The number has risen steadily, and this is likely due to the continuous increase in the population of humans worldwide and the increased frequency of human utilization of the ocean. The observed increase in attacks is also, in part, an artifact of the increased reporting efficiency of the ISAF over the last 20 years, including the expanded use of the Internet and communication with cooperating scientific observers around the world. Yet, the average yearly number of attacks by all sharks during 2000-2004 was only 66 attacks per year, of which 5.8 attacks per year were fatal. This was slightly greater than the 266 total attacks, 54.2 attacks per year, and 6.4 fatalities per year due to attacks recorded for the prior 5 years, 1995-1999. Twelve and 9% of the total number of attacks were fatal during the 1995-1999 and 2000-2004 periods, respectively. Thus, comparatively few of the attacks were fatal, as compared to the 60% fatality rate from the 1905-1909 period. The low percentage of fatal attacks in

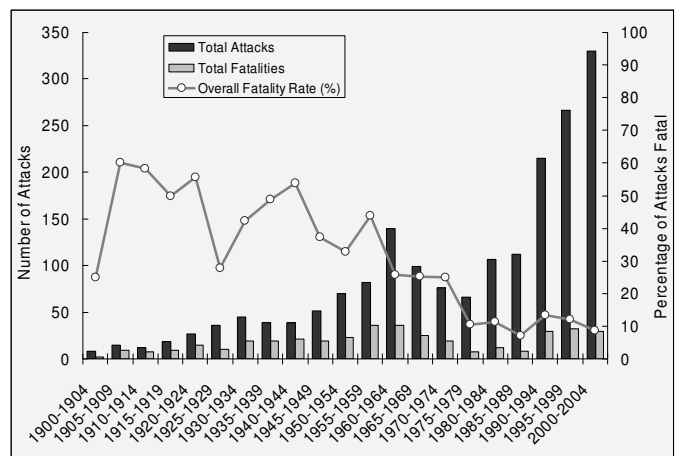


Figure 6. Frequencies of non-fatal and fatal attacks and percentages of the total number of attacks that were fatal during 5-year periods shown for all species of sharks on humans from 1900 to 2005.

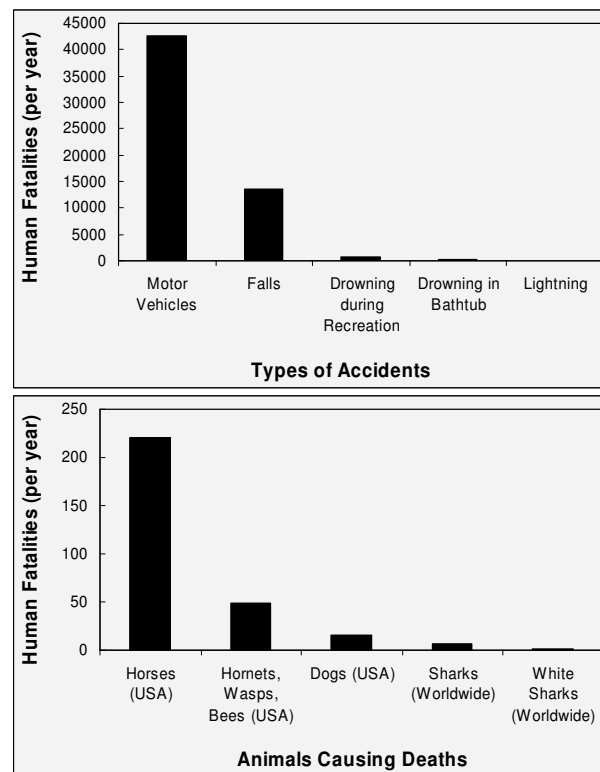


Figure 7. Other risks to humans: (above) average rates of fatalities due to accidents in the United States over 3-year period, 1993-1996; (below) average rates of fatalities due to interactions of other species compared with the rates of shark attack.

recent years is the result of vastly improved medical response and treatment for traumatic injuries like those received from shark bites.

The risk of being attacked by a shark is negligible relative to other risks encountered by humans on a daily basis. Compare the rate of 5.8 fatalities per year during 1990-1994 to the average yearly rates of fatalities caused by other everyday risks during a 3-year period from 1993-1995 (Figure 7). The number of fatalities in motor

vehicle accidents within the U.S. averaged 42,593 per year over this 3-year period. The deaths due to a fall, a common cause of the loss of life among the elderly, averaged 13,524 per year. Many more people die from these two causes in the United States than from shark attacks worldwide. Furthermore, the number of worldwide fatalities due to shark attack worldwide was considerably lower than the deaths due to drowning during recreation (averaging 791 deaths per year), drowning in a bath tub (296 deaths per year), or dying by being hit by a bolt of lightning (72 deaths per year) in the U.S. More common were deaths from falling off a horse (220 deaths per year) or from being stung by a hornet, wasp, or bee (49 deaths per year) in the U.S. Finally, there are fewer deaths from attacks by packs of dogs in the U.S. (16 deaths per year) than deaths due to shark attacks worldwide.

A more robust way to address the relative risk of shark attack is to compare it to the risk of other hazards associated with ocean beaches. Accident records from the United States Lifesaving Association (USLA) for the year 2000 compiled by the ISAF provide a more clear measure of the chance of being attacked by a shark when at an ocean beach (ISAF, unpubl. data, see: [www.flmnh.ufl.edu/fish/Sharks/Statistics/beachattacks.htm](http://www.flmnh.ufl.edu/fish/Sharks/Statistics/beachattacks.htm)). From 68 U.S. Atlantic and Pacific lifesaving jurisdictions, beach attendance (264.2 million) was recorded as well as the number of medical responses (236,642), rescues (70,771), drownings (74), and other beach-related fatalities (58). The ISAF compared these statistics to the number of shark attacks (23) reported from the same 68 beach areas in 2000. None of these 23 shark attacks resulted in a fatality. Based on these numbers, the odds of suffering a drowning or other beach-related fatality were 1 in 2 million, whereas the risk of being attacked by a shark was 1 in 11.5 million, and the odds of a shark inflicted fatality were 0 in 264.2 million. Therefore, there are other potential hazards more likely to be encountered, even when attending a beach area where shark attack could be a possibility.

### **Avoiding Shark Attack**

To avoid being attacked by a shark, it is best to take some basic precautions. Such precautions include avoiding areas where sharks may be feeding and their prey is abundant (e.g., seal colonies, near schools of fish), and acting in a manner that may mimic their natural prey. Do not enter the water if there is chum (macerated fish) dispensed during fishing activities. Do not enter the water alone, as many sharks tend to target solitary individuals. Avoid murky waters or swimming in low light conditions when a shark's vision is limited. If you are in the presence of a shark, it is obviously prudent not to harass or otherwise threaten it, and remove yourself from the water as quickly and calmly as possible (Caldicott *et al.* 2001).

When confronted by a threatening shark, it may be helpful recognize the motivation of the attacker— whether it is attacking in order to defend itself or to feed upon you. For that reason, it is good to wear underwater goggles when in waters where sharks are common. Hence, one can recognize the agonistic display of a shark, and then

act to reduce the likelihood of being attacked. It is imperative not to continue swimming toward the shark, particularly at a rapid rate, or to force it into confinement such as against the face of a coral or rocky reef. When confined, the shark no longer has the option of flight and is likely to fight. Its likelihood of doing so is apparent from the speed at which it swims, and the compressed nature of its trajectory. The shark likely will not accelerate directly toward the diver's torso to deliver a bite, but will dash by the person's side and quickly turn around to seize another part of the body, the arm or leg, and inflict a bite, which usually does not result in the removal of flesh but a slashing wound.

If one sees a large predatory shark such as a bull, tiger, or white shark, it is important to face the shark to indicate that you are aware of its presence. Predators often eschew attacking animals that are aware of their presence because they risk injury from the defensive capabilities of the prey, such as being bitten by the teeth or scratched by their claws. If accompanied by a buddy, it is best to move so that you are back to back and can thus collectively see in all directions. It is essential that you do not appear frightened and try to rapidly swim away from the predatory shark, as this "withdrawal"-type behavior may elicit a strike from predators.

### **Positive Interactions**

#### ***Shark Fisheries and Their Collapse***

Humans have benefited at times in the past by fishing for sharks, but these fisheries have often collapsed over time, leaving shark fishermen bereft of employment. We eat the flesh of sharks, macerate their fins and use the resulting colloid to thicken soups, grind their cartilaginous skeletons ground into a powder and pill (chondrichthin), which when consumed is believed to strengthen the cartilaginous lining of the human bone joints, and fabricate belts made from their non-elastic skin covered with dermal denticles. However, this taxon possesses life history characteristics that make it sensitive to overfishing.

For example, basking-shark (*Cetorhinus maximus*) fisheries have collapsed in both the Atlantic and Pacific Oceans (Camhi *et al.* 1998). A very localized fishery for the species arose in western Ireland in 1947 near Achill Island. Between 900 and 1,800 of these enormous plankton-eating sharks were captured each year from 1950 to 1956; over the following years the catch declined, shrinking to 119 in 1968. The fate of the soupfin (*Galeorhinus galeus*), a relative of the reef sharks, is another prime example (Camhi *et al.* 1998). The need for high-grade oil by the military during World War II created a market for soupfin liver oil. The liver, impregnated with oil, can reach a third of the body mass of an adult shark. The price of oil rose from \$50 per ton in 1937 to \$2,000 per ton in 1941. The catch of soupfin rose from 270 tons per year in the early 1930s to a peak 2,172 tons in 1941 and then dropped to 287 tons in 1994.

Commercial fisheries for sharks have operated in the United States since the 1930s, but they were originally small and restricted to small areas. They did not begin to grow until the late 1980s (see state-by-state statistics in Camhi *et al.* 1998). Massachusetts, until very recently,



had the largest fishery for sharks in the United States. This fishery mainly targeted the spiny dogfish (*Squalus acanthias*), which lives in large schools off New England in the spring and summer and then migrates to the waters off the southeastern United States during winter (Jensen 1966). Historically considered to be a valueless, pest bycatch species, it is now served as “fish and chips” in restaurants in both the U.S. and Europe. The landings of this small but very abundant predatory species rose until the late 1990s before leveling out, despite increased fishing effort. In the National Marine Fisheries Service (NMFS) 2003 stock assessment for spiny dogfish, the stock was classified as overfished, despite regulations that were implemented in 2000 that eliminated all directed dogfish fisheries in the U.S. Atlantic (NMFS 2003). Excluding dogfish from the catch, Florida has historically had the largest shark fishery off North America. The fishery targets many coastal species in the Gulf of Mexico and Atlantic waters, primarily sandbar (*Carcharhinus plumbeus*) and blacktip (*C. limbatus*) sharks. The landings of these reef sharks rose until the early 1990s, when they also began to decrease, despite increased fishing effort. The growth in the commercial shark fisheries in the late 1980s for sharks in the Atlantic and Gulf of Mexico was partly due to a new public appreciation for the value of these species for food. However, a more important reason for the expansion of the shark fisheries was the demand in Asia for highly-prized fins (NMFS 1993).

There are multiple reasons why sharks are particularly vulnerable to intense fishing pressure (Hoenig and Gruber 1990, Klimley 1999). Most shark species are near the top of the food chain and are not abundant. Sharks grow slowly, mature late in their lives, do not reproduce every year, and have few young. Take, for example, the sandbar and scalloped hammerhead sharks (*Sphyrna* spp.), two species frequently caught in the Atlantic and Gulf of Mexico fisheries. The sandbar takes 12-15 years to reach maturity and then gives birth to 6-10 pups every other year (Collette and Klein-MacPhee 2002). Female hammerheads can take up to 15 years to reach maturity and then give birth to 12-40 pups, every 1-2 years (Camhi *et al.* 1998). The spiny dogfish has a long growth period to reproductive maturity (6-12 years) and produces 1-15 young every second year, after an 18-22 month gestation period (Collette and Klein-MacPhee 2002). The Atlantic cod, by contrast, reaches reproductive maturity in only 2-3 years, produces 1-12 million eggs, and reproduces every other year (Collette and Klein-MacPhee 2002). Thus, for sharks there is a lower ratio between the number of young produced and the number of breeding adults, and if a substantial number of adults are captured and consumed, the population can not be expected to be replenished.

By the end of 1980s, concern was voiced over the unmanaged expansion of shark fisheries in the Atlantic Ocean, considering the vulnerability of the species for overfishing (Hoenig and Gruber 1990). In 1989, NMFS began to develop a management plan for the sharks of the Atlantic Ocean and Gulf of Mexico. The plan was implemented in 1993 as the Fishery Management Plan for Sharks of the Atlantic Ocean, and is directed at the

management of 39 species in 3 categories: large coastal sharks, small coastal sharks, and pelagic sharks. Quotas have been set for the commercial fisheries and bag limits for the recreational fisheries for the large coastal and pelagic sharks, to lessen the fishing pressure for these species. Commercial fishers are required to hold a federal permit to fish for sharks and to report their landings by category. This latter regulation permits NMFS to monitor catch per unit effort on an annual basis and regulate fishing pressure based upon knowledge of whether catch is increasing or decreasing annually, relative to the estimated stock abundance. Finally, the plans prohibit the wasteful practice of “finning”, by which only the fins of sharks are retained and the rest of the body is discarded.

### **Ecotourism: Viewing in Natural Habitat**

The perception that all sharks attack humans was dispelled in the early 1980s by scientific studies (Klimley 1981, 1982; Klimley and Nelson 1981), which were featured in nature documentaries, in which scientists were seen swimming among schools of hammerhead sharks without being attacked by the members of the schools. Hammerhead sharks were considered at that time to be the third most dangerous species of shark (Klimley 1974). Scalloped hammerhead sharks feed primarily on fishes and squid (Klimley 1987) and thus might not be expected to feed on humans. This is in contrast to the white (Tricas and McCosker 1984, Klimley 1985), tiger (Lowe *et al.* 1996), and bull sharks (Heithaus 2001), which do feed on mammalian prey and might be expected to attack humans. It is safer to swim among schools of piscivorous sharks, which are not as aggressive and solely concerned with maintaining their uniform separation distance and common heading with other school members (Nelson *et al.* 1986), than confronting a solitary shark, which may exhibit an agonistic display when frightened by an intruder when confined by a nearby reef (Johnson and Nelson 1973).

Shark ecotourism has become immensely popular in the 1990s and 2000s, and has become worldwide in its scale. There are opportunities to view sharks in North, Central, and South America, the Caribbean Islands, Europe, Asia, Africa, and Asia. The diversity of species that may be viewed underwater is great, and these species are identified together with the country and locality of the ecotourism industry in Table 1. Divers from all over the world now take recreational expeditions to seamounts and islands inhabited by schools of hammerhead sharks, in order to view sharks in their own habitat. The schools of sharks avoid SCUBA divers because they are frightened by the hissing sounds emitted as air is drawn through the regulator, or by the pulsed, low frequency sounds and reflection of light associated with the bubbles of air oscillating back and forth as they rise to the surface (Klimley and Nelson 1981). Most sharks can be approached more closely by making breath-holding dives or using “rebreathers” that re-circulate air with the addition of oxygen and avoid the production of bubbles. There are dive operations with boats that take ecotourists to view schools of hammerhead sharks at seamounts off the southeastern coast of the Baja Peninsula in the Gulf of California, the Revilligedos Islands off Mexico, Cocos

Islands off Costa Rica, Mapelo Island off Columbia, and Wolf and Darwin Islands of the Galapagos Islands off Ecuador.

Public viewing of white sharks from a shark cage has also become very popular. Sharks can be viewed from the safety of a shark cage, yet they must usually be attracted with a mixture of fish body fluids, oils, and macerated tissues, called “chum”. There are expeditions to view white sharks at the South Farallon Islands off the coast of Central California in the U.S., Guadalupe Island off the Pacific coast of Baja California, Mexico, multiple islands off the southern coast of South Africa, and Dangerous Reef and the Neptune Islands in Spencer Gulf off the southern coast of Australia. There is concern that food given to these sharks, which are attracted for viewing, is a positive reinforcement, and trains them to approach any boat, regardless of whether shark diving is carried aboard it. Hence, ecotourism operators are prohibited from feeding sharks once they arrive at tourist boats in South Africa. Feeding of sharks does occur at Guadalupe Island and in Spencer Gulf. The likelihood that sharks learning to associate boats with the opportunity to feed is dependent on the frequency with which the same sharks are attracted and feed near a boat. In Spencer Gulf, less than 5% of the sharks viewed from protective cages have been observed to return 5 or more times, the believed threshold for making the association between food and a boat (Robbins 2005).

Sharks such as reef (*Carcharhinus* spp.) and hammer-head sharks can be viewed year round in subtropical and tropical latitudes. However, many of these species migrate into the higher latitudes during the summer months and can be viewed at this time in temperate waters. At some locations in the Caribbean and the South Pacific, reef sharks are attracted and hand-fed by divers. Whale sharks can often be viewed at fish spawning aggregation sites at a variety of tropical locations, where they gather to feed (Table 1). Divers can observe the behavior sharks at these sites and learn first-hand that the bulk of the shark species are of little danger to humans, and this has helped to dispel their much-maligned reputation. It has also helped to promote greater conservation of many threatened shark species around the world. Tourists should always, however, keep in mind that sharks are potentially dangerous predators, and should always be treated with care when in their environment. Shark ecotourism is providing the public with an observational experience that can be as pleasurable as whale watching, and can be a cost-effective alternative source of employment for fishermen. This could lead to reduced shark fishing in certain regions of the world, and thereby enable shark populations to recover to their former levels of abundance.

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Region	Country	Province /State	Locality	Species																				
				AG	BL	BK	HM	HR	LM	LP	MK	NR	RF	ST	SV	SX	SM	TH	SW	TG	WB	WL	WH	ZB
Australia Cont.	Australia	Western Australia	Ningabo Reef, Kalbarri, Rowley Shoals																					
	New Zealand	North Island South Island	Whatuwhiwhi, Tutukaka, Hawkes Bay Kaikoura								5													
South Pacific Islands	Papua New Guinea	Papua New Guinea	Madang, Vitiaz Strait, Milne Bay				2				8													
	Melanesia	Solomon Islands	Russell Islands, Laulasi, Uepi Island								5													
		Vanuatu	Espiritu Santo Island, New Caledonia								8													
	Micronesia	Palau	Mana Island, Koro Island, Beqa Lagoon				2				6													
			Blue Corner, Shark City				2				6													
	Polynesia	Marshall Islands	Majuro Atoll, Bikini Atoll																					
		Marquesas	Eiao, Hatutu, Manihi				2				3													
		Bora Bora	Tapu, Muri Muri								4													
			Tahiti	Moorea								4												

Key: AG = angel shark (*Squatina californica*), BL = blue shark (*Prionace glauca*), BK = basking shark (*Cetorhinus maximus*), HM = hammerhead sharks (*Sphyrna* spp.), HR = horn shark (*Heterodontus* spp.), LM = lemon shark (*Negaprion* spp.), LP = leopard shark (*Triakis semifasciatus*), MA = mako shark (*Isurus oxyrinchus*), NR = nurse sharks (*Ginglymostoma* spp.), RF = reef sharks (*Carcharhinus* spp.), ST = sand tigers (*Odonaspis* spp.), SV = seven gill shark (*Notorynchus cepedianus*), SX = six gill shark (*Hexanchus griseus*), SM = smoothhound shark (*Mustelus henlei*), SW = swell shark (*Cephaloscyllium ventriosum*), TG = tiger sharks (*Galeocerdo cuvier*), TR = Thresher shark (*Alopias* spp.), WB = wobbegong (*Orectolobus* spp.), WL = whale shark (*Rhincodon typus*), WH = white shark (*Carcharodon carcharias*), ZB = zebra shark (*Stegostoma fasciatum*); Numeral = number of species within taxon.

