DIPLOMARBEIT

Approach directions and bite angles of white sharks, *Carcharodon carcharias*, on surfers based on wound patterns

verfasst von

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angestrebter akademischer Grad

Magistra der Naturwissenschaften (Mag. rer. nat.)

Wien, 2013

Studienkennzahl lt. Studienblatt: A 439

Studienrichtung lt. Studienblatt: Diplomstudium Zoologie (Stzw) UniStG

Betreuer: Univ.-Prof. Mag. Dr. Kurt Kotrschal

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1. Zusammenfassung

Ziel meiner Diplomarbeit war einerseits herauszufinden, aus welchem Grund Weiße Haie, *Carcharodon carcharias*, Surfer beißen, andererseits, ob sie sich wirklich anschleichen, wie oft verlautet, und die Attacke von „hinten und unten" durchführen. Weiter sollte die Arbeit auch eine gängige Hypothese hinterfragen, ob Weiße Haie Surfer mit Robben oder Schildkröten verwechseln. Diese Hypothese, die auch als „Verwechslungshypothese" bezeichnet wird, wurde bislang nicht auf ihre Richtigkeit überprüft. Um eine mögliche Motivation, weshalb Weiße Haie Surfer beißen, herausarbeiten zu können, wurde die Richtung aus der sich ein Hai vor dem Unfall näherte, was der eigentlichen Beißposition entspricht, mit jener verglichen mit der sie sich ihrer natürlichen Beute nähern. Mit Unfallberichten, die das „Shark Research Institute", Princeton, USA, wie auch das "Shark Research Committee", Van Nuys, USA, für diese Arbeit zur Verfügung stellte, wurden alle Surfunfälle der Jahre 1961-2010 untersucht, von denen auswertbare Bilder vorhanden waren. Das Hauptaugenmerk wurde auf die Westküste der USA gelegt, speziell Kalifornien. Anhand dieser Abbildungen von Wundbildern und Materialschäden an Surfbrettern konnte die Richtung, aus der sich Haie näherten bzw. die Position während des Bisses festgestellt werden. Die Ergebnisse zeigen, dass Weiße Haie Surfer nicht beißen, wie sie das bei pinnipeden Arten tun. Die Resultate zeigen, dass Weiße Haie offenbar zwischen Surfern und bekannten Beutetieren unterscheiden können. Die Wunden, die sie Surfern zufügen, sind zumeist oberflächlich, bestehend aus einem einzigen Biss. Dies bestätigt, dass es sich meist um einen Probebiss handelt, um das Objekt besser verstehen zu können. Die Annäherung von „hinten und unten", wie sie bei der Jagd auf pinnipede Arten vorkommt, wird beim Angriff auf Surfer nicht angewendet. Ebenso zeigen meine Ergebnisse dass die „Verwechslungshypothese", wonach Weiße Haie Surfer mit Robben oder Schildkröten verwechseln würden, wahrscheinlich nicht zutrifft.

Schlagwörter: Angriffsstrategie, *Carcharodon carcharias*, Haiunfall, Pinniped, Weißer Hai, Surfer, Verwechslungsthypothese.

2. Abstract

The goal of this work was to determine the most common approach directions of white sharks, *Carcharodon carcharias*, biting of surfers, based on wound patterns and board damages and thereby, to conclude towards causation of the biting incidents. Furthermore, this thesis questioned the “mistaken identity” hypothesis, which holds that white sharks may mistake a surfer for a pinniped or a turtle. This hypothesis has been questioned in the past but has never been formally checked. To understand a potential motivation why on rare occasions, white sharks bite surfers and from what direction they approach—reflected by the actual bite position—the outcome in this project, this was compared with approach patterns and bites of actual predatory attacks on pinnipeds. The "Shark Research Institute,“ Princeton, USA, as well as the "Shark Research Committee," Van Nuys, USA, made all the incident files of incidents available that took place between 1961 and 2010 especially in California, on the US West Coast. However, only those files were taken into consideration that entailed pictures of injuries or board damages that could be evaluated. Based on this material, the approach patterns and impact positions revealed that white sharks do not target surfers the same way they attack pinnipeds, and the chosen strategy when biting surfers does not fit any common bout patterns. White sharks can seem to distinguish between surfers and their usual mammalian prey. The wounds on surfers are primarily superficial, consistent with a single bite. This supports the idea that white shark mostly performs an exploratory bite to better understand the unfamiliar object. The approach pattern from “behind and below” when hunting down pinnipeds as one of the attack strategies has not been seen among bitten surfers. Overall it can also be concluded that the hypothesis of "mistaken identity" is incorrect and does not apply for white sharks when biting surfers.

Key words: Attack strategy, *Carcharodon carcharias*, incident, mistaken identity, pinniped, surfer, white shark.

3. Introduction

The term "shark attack"—when a shark comes into bodily contact with a human and / or an inanimate object connected to a human—creates a morbid fascination among humans, and even the most superficial incidents often make worldwide headlines. Despite likely being the least harmful top predator roaming the planet, it is the shark that is feared the most, and its simple appearance can create hysteria (Allen 2001; May 2002; Ritter et al. 2008). However, this uncanny phenomenon of branding an animal to be a killer wherever it shows up only reflects a history of the past century rather than hundreds of years. Its origin goes back to the summer of 1916, when a series of fatal incidents rattled the population between Beach Haven and the Matawan Creek at the New Jersey coast (Fernicola 2001). However, it took another roughly 30 years until a second event started to support the notion that sharks might indeed be dangerous. On July 30, 1945, the USS Indianapolis was torpedoed and sank in a very short period of time. Of the about 900 sailors that went overboard, close to 600 would not survive the 4 days lost at sea. While most of the sailors drowned, primarily as a result of exhaustion and injuries from the torpedo attack, one of the main reasons causing their deaths was said to be sharks (Kurzmann 1990; Stanton 2001). The Navy and the general public found their scapegoats (Coppleson & Goadby 1968; Kurzman 1990; Stanton 2001). It was this event, together with the "Black Sunday" events of 1957 in South Africa (Wallett 1978) that encouraged the US Navy to launch the rather pitiful "Shark Attack Panel" in 1958 to look for shark incident causes in particular and related safety and rescue methods in general. At this point, sharks were already dubbed the ultimate killers of the sea (Coppleson & Goadby 1968) and the implication was that it was truly unsafe to go back in the water. Once the movie blockbuster "Jaws" flickered over the big screens in 1975 it confirmed in people’s minds that shark attacks could happen to anybody and not just to a handful of unlucky people (Baldridge 1974a, b).

3.1. Why shark-human interaction?

Of all the sharks that occasionally interact with humans, one species, the white shark, *Carcharadon carcharias*, stands out in many people's eyes as the ultimate predator (Ritter et al. 2008). Despite the fact that nothing could be further from the truth than this media hype, the white shark continues to be portrayed from a far too narrow perspective. Although, as is also true for all other shark species, the incident rate between white sharks and humans is minimal (GSAF 2013), the constant make believe that "Jaws" is merely an exaggerated version of reality prevents many from understanding the white shark's true nature. As with any other interaction with sharks, to understand the true character traits of white sharks, either as a species or as individual animals, it is paramount to comprehend the difference between the Hollywood creation and the true animals that swim through the oceans (Ritter et al. 2008; Ritter & Amin 2012). From that point of view, any type of white shark-human interaction sheds light on the erroneous public image.

Interactions between white sharks and surfers are often assumed to be due to mistaken identity, based on the belief that white sharks mistake surfers for seals based on a similar silhouette. This assumption has been questioned in the past (Ritter 2004), but remains prominent in the public mind. In order to debunk this myth, solid evidence is needed. A change of mind in the general public might happen if reliable evidence indicates a significant difference between wound patterns and board damage caused by white shark bites of surfers and respective wounds due to shark predation of pinnipeds.

It is known that white sharks do not begin including seals as a food source until the shark has reached a size between 3m and 4m, which goes along with a change in tooth shape, enabling them to successfully gouge (Tricas & McCosker 1984). Thus the hypothesis of mistaken identity would predict that the majority of incidents with surfers are caused by sharks of a size that is able to go after seals. If sharks of smaller sizes are found to be involved in incidents with surfers, it would indicate that mistaken identification of the surfer as a pinniped was not the underlying cause of the incident.

3.2. Wound patterns and the purpose of bite angle analysis on surfers

The goal of forensic wound pattern analysis is to reveal information on wound causation. With shark wounds, the wound pattern may disclose information about a shark's length, approach angle, strength applied, and primary and secondary wounds. A secondary would is caused by the ability of a person pulling his or her body part out of a shark's mouth or moving the body part around between the shark's jaws. Together with additional parameters such as surfer position on the board and activity of the surfer at the time of the incident, a complete picture can be drawn of how the animal approached the victim and how the bite was applied. Both disseminate an indication of the animal's motivation.

Wound pattern analysis is an indirect method of determining the events of an attack. However, it is only on very rare occasions that an incident on a surfer is witnessed. The majority of all incidents happen too fast to be documented or for observers to draw any visually relevant conclusions leaving wound pattern analysis as the only solid approach to shed light on shark and targeted surfer.

3.3. Attack vs. accident or incident

An attack is defined as "... (of a person or an animal) act against (someone or something) aggressively in an attempt to injure or kill..." Wounds caused on humans do not show the same outcome as predatory attacks (Ritter & Levine, 2005), and even a fatal outcome is more likely due to the constellation of unlucky circumstances then the intent of the shark to cause fatal harm. Even in cases where humans have been apparently treated as another competing shark, any harm to the person was not due to shark's intention of doing harm, because it treated the person the same way as it would another shark in the same position. But since human skin lacks the robustness of sharkskin, the outcome for humans can be severe. From this viewpoint I will refer to a predatory *attack* directed toward known prey and bite incidents involving surfers as an *accident* or *incident*.

3.4. Hypothesis

Although incidents of white sharks biting surfers are rate, recurring factors can be assumed. However, nothing is known about the white shark—surfer connection beside the rather dubious mistaken identity hypothesis. Thus I decided to examine the anatomy of such bites looking for commonalities among these incidents and distinctions between bites on surfers and predatory attacks on pinnipeds.

I predict that common traits between white shark and bitten surfers exist, and thus hypothesize that these traits indicate certain motivations of white sharks to bite surfers that do not follow the general bite patterns regarding pinnipeds. I furthermore predict that the commonly accepted hypothesis of "mistaken identity" is incorrect.

4. Material and Methods

This project focused on white shark—surfer incidents that primarily took place within the 50 years between 1961 and 2010 along the California and Oregon coasts, with special emphasis on the former. All incidents examined were filed with the “Shark Research Committee” in Van Nuys, California, USA, and the Princeton based “Shark Research Institute” in New Jersey, USA. White sharks are the prominent species with regard to incidents along California’s coast, as shown by Amin, Ritter & Cossette (2013), who concluded that the respective attack risk zones within these waters are largely affected by the presence of that species. More specifically, they concluded that white shark females whose migration patterns are guided by foraging and parturition primarily determine those spatial and spatio-temporal incident clusters.

In order to better understand what may motivate white sharks to bite a surfer, some background information about their biology, behavior and related topics are presented in the following subchapters, including some aspects on pinnipeds, the prime food source for larger white sharks.

4.1. The white shark

The white shark is a heavy, spindle bodied shark, reaching up to 7m in length and over 3 tons in weight (Compagno 2001). This species shows extensive migration patterns (Boustany et al. 2002; Bonfil et al. 2005; Dohmeier & Nasby-Lucas 2008) as well as a worldwide distribution, ranging from the tropics to the Bering Sea in the northern hemisphere and to sub-Antarctic islands in the southern one. White sharks are one of the few shark species that are more or less warm-blooded based on an intricate blood vessel system maintaining a nearly constant body heat, compared to the surrounding waters. Although they often swim into deeper water and onto the high seas, they prefer to remain in shallow waters for extended period of times. This is especially true when pinniped haul outs are situated close to or in shore areas, as pinnipeds are a preferred food source for larger white sharks. Due to this preference for shallow waters, white sharks often cruise along surf lines, and penetrate shallow bays and even estuaries. Larger white sharks show a wider distribution than smaller ones, who are seemingly restricted to more temperate waters (Bruce & Bradford 2012).

4.1.1. Preferred habitats of white sharks along California's coast

Amin, Ritter & Cossette (2013) showed that the incident rates along California's coast are likely caused directly or indirectly by pregnant female white sharks. Based on incident rates, they categorized areas into high risk zones (HRZ) and low risk zones (LRZ). Figure 1 shows the different risk zones for beach goers for the entire California coast between the years of 1991 to 2010. These zones were identified by using StatScan™, a geostatistical software program that uses a scan statistic to identify clusters and tests each cluster for significance. The method tested two null hypotheses along California's coast (1) that shark bites are proportional to human beach activities, and (2) that no pronounced space-time interaction for shark accidents exists along this coast over time. In order to apply SaTScan™ each region along California's coast needed to be defined through a centroid, which was calculated through ArcGIS. The spatial scan statistic then identified clusters by imposing variable size scanning windows that move over a map, including different sets of neighboring coastal regions in the window. If the window includes the centroid of a specific coastal region,

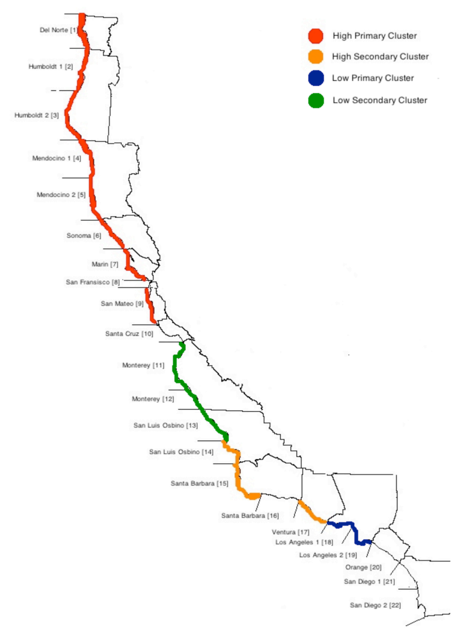


Figure 1 High and low risk areas for all beach goers in California between 1991 and 2010 using SaTScan™ (from Amin et al. (2013)).

then this region is included in the window. The center of the window is positioned only at the county centroids, and the radius varies from zero (only one county included) up to 50% of the population at risk. The method then adjusts for the multiple testing inherent in the thousands of overlapping circles evaluated as potential clusters. Based on this analysis, some well defined HRZs exist: Bodega Bay–Tomales Point, Pigeon Point, Point Conception, and Franklin Point. The most prominent denominator of all these locations is pinniped colonies, the preferred food source for larger white sharks (McCosker & Lea 2006). Availability of this food source seems to encourage white sharks to remain closer to shore, which brings them in contact with swimmers, surfers, and other beach goers. Farther south, secondary high risk zones appeared, including areas like Santa Barbara and Point Conception. One explanation for the existence of these secondary high risk zones was provided by Amin, Ritter & Cossette (2013). As a result of white shark migration patterns, the area south of Point Conception is seasonally visited by mature females to give birth, and is seen as a prominent nursery area for this species within Californian waters. During the late summer when pregnant females reside in these waters, incident numbers increase. This increase, however, does not significantly affect bite rates because of a proportional increase in the total number of beach goers due to the warm water in that season. Females then migrate back to the north after parturition, possibly reflecting one of the reasons that the southern area is only considered a LRZ. To what extent non-breeding female and mature male white sharks patrol these southern waters is not known.

Although, for many incidents in Californian waters, general size estimations of the sharks involved have been given, the sharks' factual sizes needed to be verified, as already mentioned. It has been verified that small-sized white sharks have been involved in some of the incidents (SRI 2012), but they seem to be less involved in incidents as reflected by the examined files. One reason for these smaller sharks to patrol closer to shore might be their preference for demersal fishes, which they hunt close to the bottom but relatively inshore (Dewar et al. 2004). However, there is also the possibility that cannibalistic pressure from larger white sharks forces young-of-the-year white sharks and other smaller animals closer to shore (Amin et al. 2013).

4.1.2. Intraspecific competition and sociobiology among white sharks

The success of white shark predation on seals decreases significantly as predator abundance increases (Martin et al. 2005). Once the success rate dropped to around 40%, white sharks ceased to pursue seals. Klimley et al. (2001) suggested that these sharks might be able to "listen in" where and when another shark caught and killed prey. However, this suggestion needs further examination. Other studies offer evidence for social complexity among these animals (e.g., Compagno 2001; Martin et al. 2005). For example, white sharks not only congregate around natural foods like whale carcasses and create a temporary feeding hierarchy based on animal size but also do so when introduced to humans (Compagno 2001). The same seems true around pinniped haul outs. Such congregations of white sharks seem to be triggered by sociobiological background as well as interactions between single animals, expressed by tail slapping or others behaviors. Some of these behaviors have been labeled as "kill-associated agonistic behavior" (Klimley et al. 1996). Strong (1996a) further adds "repetitive aerial gaping" (RAG) to this repertoire, but Ritter (2012) suggests RAG to be an "expectation behavior" rather than the frustration behavior mentioned by Strong (1996a).

4.1.3. Hunting and related behavior of white sharks

The following paragraphs describe some strategies a white shark uses in the pursuit of pinnipeds.

The attack behavior of white sharks under natural circumstances is still not well understood. Most information relies on bite marks and scars from pinnipeds that survived a bout (Tricas & McCosker, 1984; Ainley et al., 1985; McCosker, 1985) or were killed in the process (Orr 1959; Ames & Morejohn, 1980; Brodie & Beck, 1983; Corkeron et al., 1987; Cockcroft et al., 1989; Ames et al., 1996; Long, 1996; Long et al., 1996; Long & Jones, 1996) and from stomach contents of dead white sharks (Le Boeuf et al. 1982; Scholl 1983; Stewart & Yochem 1985). In recent years, actual bouts of white sharks on different pinnipeds have been observed and documented (Martin et al. 2005) but the approach pattern prior to the initial strike has only been rarely seen and is barely known. One of the hypotheses revolving around the attack behavior of white sharks on seals is called "bite, spit and wait" (Klimley 1996). This hypothesis is based on the idea that sharks release their prey after the initial bite, and withdraw until the prey is exsanguinated, to reduce the risk of getting injured by the attacked pinniped. There is still a lack of solid evidence to support this hypothesis. In fact, Martin et al. (2005) summarizes initial strikes, supported by observations and bite pattern on pinnipeds that question Klimley's idea.

Successful hunting attempts rely on speed and surprise. It is known that white sharks, like other predators, try to appear unpredictably prior to a hunting attempt. Some white sharks optimize their efficiency through high-speed approaches from the deep (Strong 1996b). This form of approach occurred in 85% of white shark attacks on Cape fur seals (Martin et al. 2005). However, in order to increase speed, white sharks must have certain types of muscles. White sharks possess 94 to 97% of the required white muscles to accelerate quickly and reach a high-end speed (Bernal et al. 2001). However, this type of muscle is not made for long chases and shows fatigue very quickly (Bone 1988). Most chases on Cape fur seals last less than one minute, and the success rate strongly decreases with ongoing duration. In addition to stealth, acceleration, and chase duration, pinniped group sizes and motion to and from haul outs also impact hunting success, with single moving animals clearly at a disadvantage by lacking the vigilance a group of seals can offer (Martin et al. 2005).

Gerking (1994) mentioned that foraging models entail three elements: decision making to attack or not attack a potential prey animal, the gain such an attack could bring, and the constraints between gain and decision making. From the viewpoint of predatory choices, such a model can be divided into a five stage predation sequence (Fig. 2) (Endler 1986).

The so called "optimal foraging theory" predicts that a predator should exploit the very prey which is the "...most energetically advantageous..." with regards to net energy (Gerking 1994). This theory also points out that predators should be more selective when high-quality foods are abundant (Helfman et al. 1997). With regards to teleost (and shark), learning and decision making to accomplish foraging appear to be the underlying mechanisms (Dill 1983). Considering the development of a shark's brain (Northcutt 1977), these animals ought to be able to make these predicted hunting decisions (Dill, 1983) and must be able to monitor food availability in order to decide where to feed and what to feed upon.

Over a period of 12 months, a continuous internet search was conducted to look for any type of wounds on pinnipeds. The only pictures used for comparison with white shark bites on surfers where those where it could clearly be identified that the wounds on pinnipeds indeed stemmed from white sharks. Fifty different bite photos of pinnipeds could be used in the analysis. Because this sample size is not representative, its evaluation shall only be used to discuss possible trends and any interpretation should be made with caution.

Predation sequence

Detection → Identification → Approach → Subjugation → Consumption

Figure 2 Predation sequence after Endler (1986).
Surfers are unknown to sharks, hence 'Identification' does not take place in the original meaning and 'Approach' is chosen to further investigate but not to go into an object oriented attack mode.

4.1.4. Ontogenetic development and differences in feeding habits of white sharks

White sharks typically hunt in a 3-dimensional surrounding where vertical approaches are frequently used to successfully hunt down pinnipeds (Strong 1996). The known hunting approach and bite spectrum of white sharks currently consists of four phases: initial strike, secondary pursuit, prey capture, and feeding, and can be categorized into 20 behavioral units (Martin et al. 2005). One common feature is shared by the four phases: high speed and approach from below. Differences only occur once the shark penetrates the surface. The most frequent one seems the so called "polaris breach" (Martin et al. 2005) where a shark partially or even completely jumps out of the water in a vertical position, followed by “surface broach” where the shark uses a 0 to 45 degree angle relative to the water’s surface.

During ontogeny there is a shift in a white shark's food spectrum. Cliff et al. (1996) showed that smaller white sharks primarily feed on fishes, while the diet of larger sharks shifts to pinnipeds. However, on rare occasion even smaller white sharks attack pinnipeds, but only when these mammals are dying (Johnson et al. 2009). Such occasions offer a potential opportunity for these small white sharks to practice how to approach, bite, and possibly try to gouge, their teeth structure is not sufficiently developed yet to accomplish gouging. These opportunistic captures may be an evolutionary precursor for the ambush behavior used later (Martin et al. 2005). Those captures of inattentive seals when still alive may also have the advantage that the shark does not have to invest much energy increasing the success rate. It cannot be determined that the white shark does not still plan this ambush strategy as mentioned by Johnson et al. (2009), but considering that such occasions are rather opportunistic, planning would be likely a “sight of vision decision.”

4.2. Pinniped behavior

To better comprehend incidents on surfers caused by white sharks, bouts on regular prey need to be understood as well. For this, actual attacks on pinnipeds were examined as well as the environmental factors under which these attacks took place.

Confrontation between pinnipeds and white sharks take place under a variety of scenarios, such as when pinnipeds move to or from their hunting grounds, play in the surge, group together in rafts, or even mob white sharks. Although white sharks are known for their stealth and ambush qualities, pinnipeds possess an impressive maneuverability and agility, making it difficult for the sharks to successfully hunt them down.

Probably the most obvious strategy to look for predators transpires during rafting where selected seals constantly search for danger by keeping their heads submerged while pivoting around their axis. Due to this vigilance while in a raft, white sharks naturally prefer to attack seals on the move, or go after the ones, which travel alone. However Ritter (pers. communication) observed white sharks swimming up and down along rafts without seeming to be interested in the pinnipeds at all, until some of the pinnipeds lost vigilance and were then attacked and captured.

4.3. Selected incident files

In order to draw a conclusive picture of the white sharks biting surfers, some criteria needed to be identifiable from wound pictures: 1) body size and jaw dimension of the shark, 2) wound structure and board damages 3) Body position of the shark during impact with reference to the person's orientation, including the board.

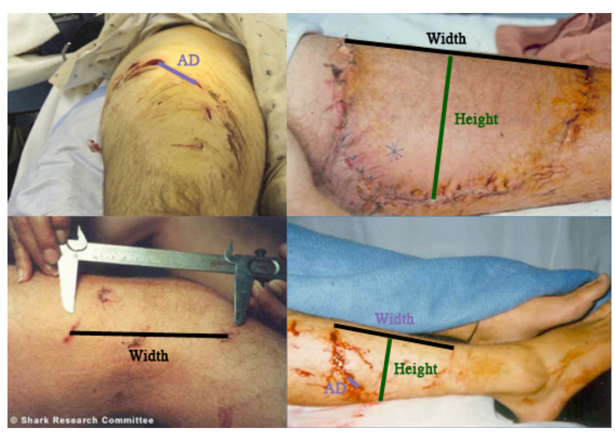


Figure 3 Wound dimension measurement. Measured wounds dimensions, including examples for width, height and apex distance (AD). (Courtesy: Shark Research Institute, Shark Research Committee).

Since only nine cases from California and eight from the neighboring state of Oregon offered pictures from surfer incidents that could be evaluated, I needed to add other cases from around the world to get a better overview. For that purpose I added another 14 cases from New Zealand (1), South Africa (11) and Australia (2) where pictures offered enough details that a reconstruction of approach and bite angle could be determined. Unfortunately many pictures just reflect damages made to body or board without further information of e.g. the position of the person was in when bitten, or valuable "hints" to make a clear understanding of the bite anatomy. The 104 incidents worldwide of white sharks from the same time period were taken, as a reference to get an idea how representative the chosen cases would be.

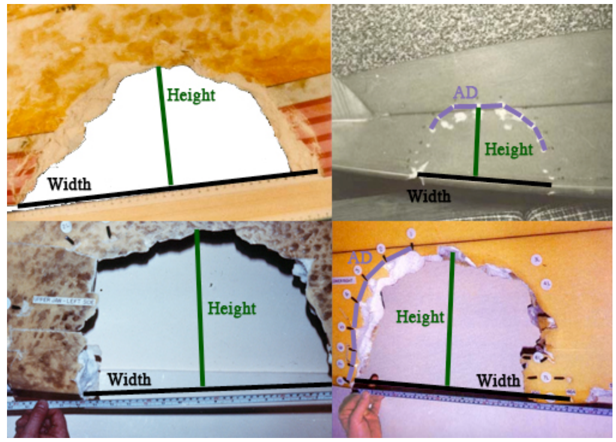


Figure 4 Board damage measurement. Dimensions of board damages, including examples for width, height and apex distance (AD). (Courtesy: Shark Research Institute, Shark Research Committee).

Most incidents were initially filed with an approximate size of the shark involved. However in the early years of incident filing, wounds or board damages were rarely photographed with the necessary scales and estimations were often based on eye witness accounts or an educated guess by the investigator, making the size of the shark frequently questionable. Due to these unfortunate circumstances, all files used in this project needed to be re-evaluated to offer the most accurate measurement of the wounds or board damages possible. When there was not a clear scale included, comparisons were drawn from commercially available boards and their dimensions or respective body parts in comparison to the person's height (Figs. 3 and 4).

4.4. Photographing jaws

The shark size involved in each incident was recalculated based on wound diameter or tooth imprint dimensions. For reference purposes I photographed jaws from white sharks of known body lengths together with a scale for later distance measurements, using a CANON 5D Mark II with a 17-40mm lens and appropriate flash. Detailed measurements of individual teeth and their distances to adjacent teeth were then handled with Pixelstick (Pixelated Software, Pixelstick Version 1.1) (for more details see the following section).

The photographed jaw sets belonged to the collections of Dr. Gordon Hubbell (Gainesville, Florida) and Erich Ritter (Pensacola, Florida), as well as Mr. Glenn Reed (Conway, Alabama).

4.5. Teeth and jaw dimension measurements

Since bites were often reduced to impressions of singular teeth, every apex distance (AD) between individual teeth of anterior (frontal) and lateral teeth of the upper and lower jaw that were available were measured with reference to the respective jaw curvature (jaw radius)—to better understand their positions—and the accompanying body size (Lowry et al. 2009).

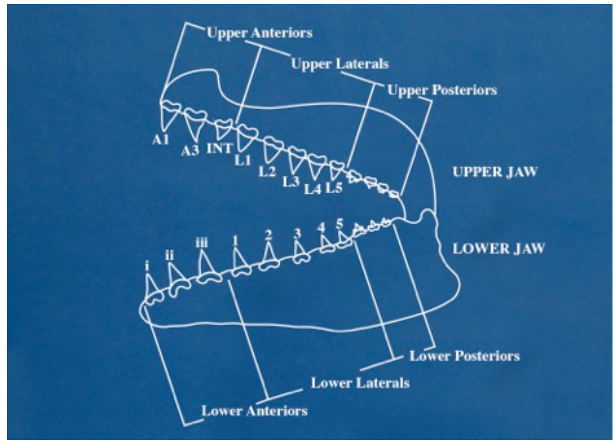


Figure 5 Gross morphology of a white shark jaw. Upper and lower jaw set is divided up in three pairs of teeth: Anteriors, laterals and posteriors. A1, A3: Upper anterior 1, 3; INT: Intermediate; L1-L5: Upper lateral 1-5; i-iii: Lower anterior i-iii; 1-5: Lower lateral 1-5.

The teeth of lamniform species are best described as 'dignathic heterodont', in which there are different upper and lower teeth with each tooth individually identifiable based on position, morphology, and symmetry (Applegate & Arrubarrena 1996) (Fig. 5). Figure 6 gives an overview of the individual tooth terminology for both upper and lower jaws. For the upper jaw, A1 and A3 represent the two anterior teeth immediately adjacent to the symphysis, followed by the much smaller intermediate tooth (I, or INT). The intermediate tooth is reverse positioned, indicating its apex points towards the symphysis (Hubbell 1996; Applegate & Arrubarrena 1996). Its smaller size is due to the curvature of the upper jaw in this area, which is the largest in the entire jaw. Following the intermediate tooth are the five lateral teeth (L1, L2...L5), as well as the four remaining postero-lateral teeth. The more distal, the smaller the teeth, hence for this project, the

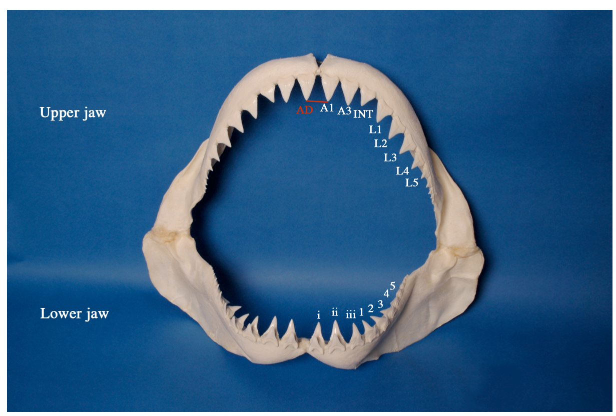


Figure 6 Nomenclature and position of white shark teeth. Frontal view of a white shark jaw. A1, A3: Upper anteriors; INT: Intermediate; L1-L5: Upper laterals; i-iii: Lower anteriors; 1-5: Lower laterals.

postero-lateral teeth were not included in the evaluation.

The lower jaws' basic arrangement regarding anterior and lateral teeth is very similar to that of the upper, with the exception that there is no intermediate tooth but three anterior ones instead (i, ii, iii), followed by five lateral teeth, labeled 1, 2, 3, 4 and 5, as well as three posterior ones. Similarly to the upper jaw, the remaining three most distal teeth of the lower jaw were not included in the measurements due to their small size, which are rarely detectable in a wound pattern. Due to the preparation of each jaw, left and right sides were not identically proportioned regarding teeth setting, hence the measurements of both sites where combined and an average taken. The distance between A1 and A1 across the symphysis was also measured. The full gape measurement entailed the two maximum distances between the upper and lower jaw symphyses, representing maximal height of the gape, and the maximal width between the two junction points of the palatoquadrate and mandibulae (Fig. 7). As with the teeth measurements, the data were pooled and adapted to the different animal sizes between 1.5m and 6m, in increments of 0.5m.

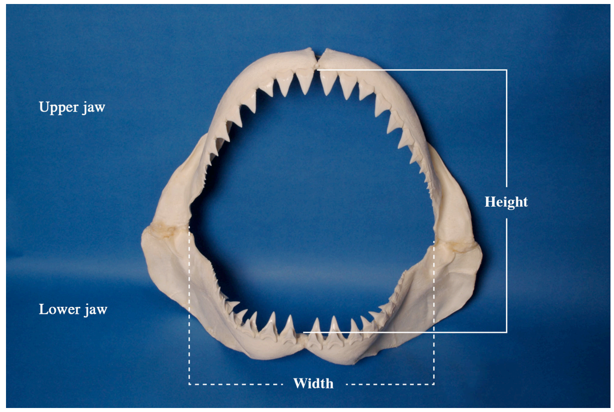


Figure 7 Apex and gape measurements of a white shark jaw. Apex distances occur between the two anterior teeth A1 and A1 in the upper jaw, as well as between i and i in the lower jaw, respectively. Gape height and width represent the maximum distance between the two jaw symphyses as well as the joints between upper and lower jaws.

To make these individual measurements relevant when measuring a wound or damage on a board in hopes of determining the size of white shark involved, linear regressions were created for every distance measurement through the different jaw sizes of the respective size groups, starting with 1.5m up to 6m body length, in increments of 0.5m.

4.6. Bite mechanics

White sharks possess a very impressive upper jaw protrusion (Fig. 8). The opinion on the advantage of this effect varies. Some believe that a shark can close its jaws faster, while others believe that the highly mobile upper jaw enables them to better grab an irregular structure. That white sharks and other species often protrude their upper jaw without actually biting anything has been shown to be a maintenance behavior (Ritter 2008). Jaw mobility enables a white shark to apply different ways of grabbing or biting objects (Tricas, 1985). Nevertheless, upper jaw protrusion is not a necessity when biting prey, especially if the white shark just slightly lifts its snout (Tricas 1985). Should they bite objects at the surface, it was noticed that they often just lift their snouts while depressing the lower jaw at the same time, creating the necessary gape. Upper jaw protrusion is mainly used when a full gape is needed, during which the palatoquadrate cartilage is "disconnected" from the cranial capsule and moved forward and down (Fig. 8) to fully expose upper jaw teeth. At the same time, the lower jaw is elevated. The motion of both jaws reduces the time to close the gap. While the snout is lowered, the upper jaw is retracted again (Tricas and McCosker 1984). Should the shark apply multiple bites, its snout remains slightly lifted.

Figure 8 Jaw protrusion. (Photo courtesy: Shark Research Institute, Shark Research Committee).

During single and multiple bites where the shark clamps down without moving its head sideways, the main teeth involved are the anterior ones with additional support of the first lateral ones.

4.7. Bite volume

The bite volume equals the volume of food a shark can get with one bite by gouging it out of its prey. Since sharks hardly gouge where humans are concerned, this volume is more of theoretical nature when discussing incidents with humans.

Figure 9 Drawing of a white shark biting a pinniped with a lateral snap. Likely the only bout where a white shark primarily uses its upper teeth (lower ones not used) is during a lateral snap. During such a strike, a shark first appears parallel to the pinniped's orientation and then performs a lateral swipe with its frontal body and head. This type of attack is mostly superficial.

To estimate a bite volume, the symphyseal axis projection (SAP) is used. SAP was introduced by Ritter as a tool for forensic analysis to better interpret shark wounds (Ritter & Levine 2005). As per the name, the SAP is the direct, albeit imaginary, connection between the upper and lower jaw symphysis. The projection between the two symphyses, together with the tooth imprints of both jaws, allows estimation of the bite volume. Due to the protrusion of the upper jaw, the closing of a gape will not be entirely straight down, meaning the two symphyses meet in a slightly curved manner. For a full bite volume, anterior and lateral teeth must be involved.

Although a shark can apply more pressure with its anterior teeth than with its lateral ones (Huber et al. 2006), both teeth segments are needed for a full bite. However, the anterior teeth are not always the ones preferred, such as during a lateral snap where primarily lateral teeth are involved (Fig. 9).

4.8. Wound structure and board damages

Description and analysis of bite marks follows commonly used methods and terminology for animal and human bites (Stimson & Mertz 1995; Bowers 2004; Kieser et al. 2005). Although the forensic analysis of shark bite wounds has previously been established (Clark et al. 1991; Guidera et al. 1991; Nambiar et al. 1996; Byard et al. 2000; Caldicott et al. 2001; Ritter & Levine 2004, 2005; Ihama et al. 2009) not many methods have been developed to the extent that adaptation and modification are no longer necessary when it comes down to sharks. Nevertheless, an array of research has been conducted to understand general bite mechanics in greater detail (Frazzetta & Prange 1987; Frazzetta 1994; Motta & Vilga 2001), including relevant bite forces (Huber et al. 2006) that will further help to analyze the wounds and board damages to be examined.

4.9. Relative and absolute body position of a shark during impact with reference to the person's orientation

In order to understand a bite angle, primary and secondary wounds needed to be separated. As already mentioned, a secondary wound transpires due to slight jaw pressure leaving a person able to pull an affected limb at least partially through a shark jaw, making it difficult to detect initial bite angles correctly. A more difficult analysis transpires if a victim has been bitten more than once. However, based on initial screening of the cases (Collier 2003), multiple bites are scarce. Not every wound picture revealed enough data points beyond a general idea of the initial direction towards the human body part. The fewer teeth involved and the softer the actual body part, the less likely a definite angle could be reconstructed (Ridge & Wright 1966). Although teeth marks offer a general direction, it was crucial to understand what part of the upper and lower jaws were involved (e.g. anterior vs. lateral teeth). The more lateral teeth are involved, the more predictable the actual bite radius (Lowry et al. 2009), as well as the symphyseal axis projection (SAP) (Ritter & Levine 2005) will be and, together with general forensic impact angle calculation (Marchetti et al. 2003), the better the approximation of the shark's body axis during the initial bite.

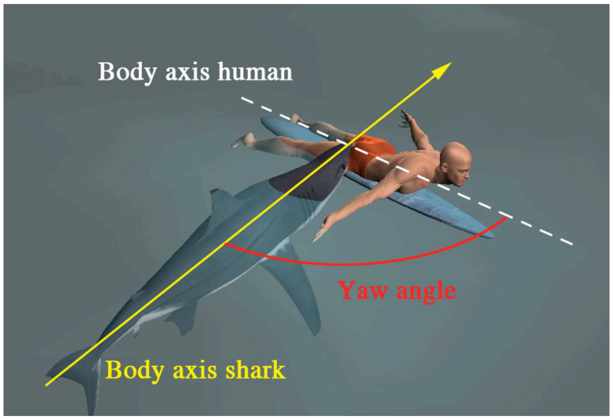


Figure 10 Yaw angle.
Yaw represents the angle between the shark's main body axis (longitudinal axis) and either the main axis of the human body when lying on the board.

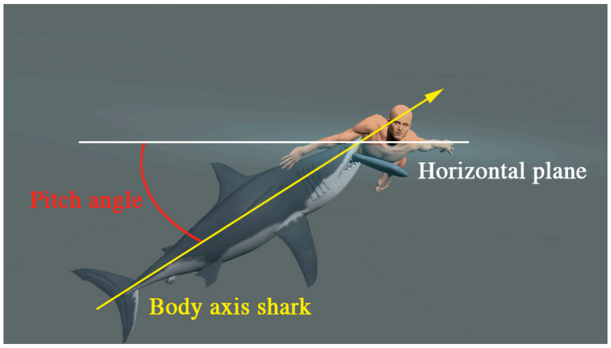


Figure 11 Pitch angle.
Pitch represents the angle between the shark's main body axis (longitudinal axis) and the water surface (horizontal plane).

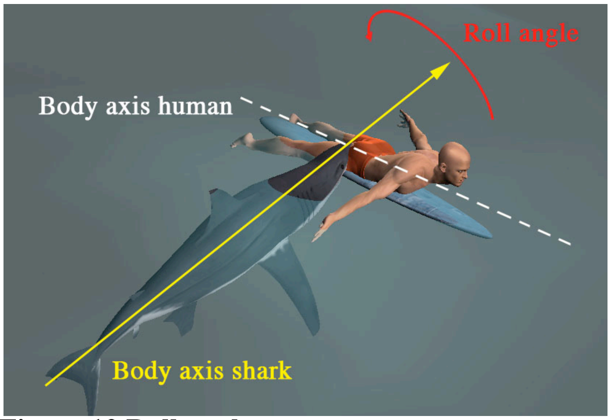


Figure 12 Roll angle.
Roll represents the rotation along the shark's main body axis (longitudinal axis) with reference to the targeted axis of the body limb or the board axis.

For reference, the targeted human body part's axis always equaled the z-axis (0,0,0; 0,1,0). It is understood that reconstruction reflects an approximation, but using predefined angle ranges still gives a clear answer to the initial "behind & below" assumption. Part of most files mentioned the position a person was in at the time of the incident: sitting, lying, paddling (in a lying position), or standing (surfing). To determine the shark's absolute body position with reference to the water column and its relative position with reference to the surfer's body orientation with a person's viewing direction as the main orientation, wound or board damage reconstruction was used. Primarily three angles were determined (Figs. 10-12). The pitch and yaw angle expressed the shark's tilt (with reference to the water's surface) and sideways position (with reference to the person's body orientation), while roll angle expressed the shark's rotation along its longitudinal axis. Either the board functioned as the horizontal reference plane (yaw) when it was a mere board damage, or the respective wound relative to the main axis of the limb or body part as the prime orientation.

4.10. Abiotic factors

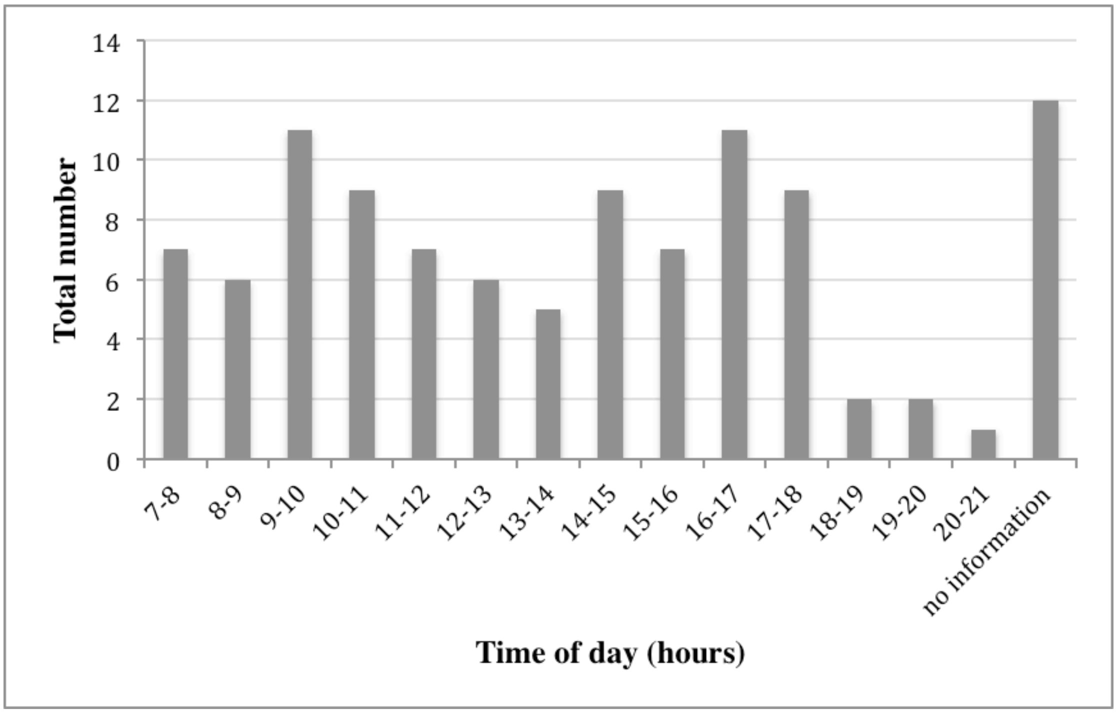
Victims of later years filled out a questionnaire, which was sent out by the "Shark Research Institute", and included questions about weather, temperature and water conditions. To compare bites on pinnipeds and surfers by white sharks, these questionnaires were examined and looked for parallels or differences.

4.10.1. Time of day

Regular bouts on pinnipeds occur during all day and nighttime hours, with the latter less likely for surfers. However, some special anatomical features of sharks especially for use during low lights might still come into play during incidents with surfers.

The eyes of white sharks, and other shark species, are especially adapted to low lights (Gruber & Cohan 1985) through a structure called 'tapetum lucidum' enabling incoming light to pass through the retina for a second time, creating an effect known as 'eye shine,' which enables hunting around dusk and dawn. Martin et al. (2005) showed that white sharks prefer to attack seals within the first two hours of daylight, which takes advantage of low light. The counter-shading pigmentation (darker back, white belly) of white sharks further helps them to get close to their prey without being detected. Because surfers rarely see white sharks prior to the incident, those features appear to be a factor when getting closer to surfers in low light conditions as well. Table 1 shows the number of incidents with regard to daytime hours. As surfing is mostly restricted to daytime hours and less to late evening hours or even night time hours, comparison between daytime surfer incidents and seal bouts of unknown timing should be interpreted with caution.

Table 1 Daytime hours and number of incidents with surfers caused by white sharks based on documented cases between 1961 and 2010.



4.10.2. Water depth

Where noted, water depth the surfer was in at the time of incident was tallied. It is understood that surfers concentrate on the areas with the best surf, which are not necessarily good hunting grounds for white sharks or areas of patrolling. However, the fact that a bite took place in such shallow waters, often less than 5m, indicates that the shark was indeed prowling these water when it noticed the surfer, or was lured in from deeper water when possibly noticing some emission caused by the surfer.

4.10.3. Seasonality

Attacks on pinnipeds depend to a great extent on the migration patterns of white sharks. Several areas on the Northern and Southern hemisphere exist where presence and density of white sharks have been studied in greater detail, e.g. Seal Island in South Africa, Farallon Islands off California, USA or Guadalupe Island off the Baja California, Mexico. Due to the presence or absence of white sharks in these areas and elsewhere, incidents on surfers depend to a great extent on these patterns. For example, Raid, Ritter and Cossette (2013) showed that the incident rate along California's coast (for all activities) likely depends directly or indirectly on the migration pattern of pregnant female white sharks. Nevertheless, even with the presence of sharks, the incident rate does not just depend on the animals but also on factors like preferred water temperature to surf, meteorological influences, etc.

4.11. Shark size comparison between regular bouts and surfer incidents

Of the 104 worldwide incidents filed with the respective agencies, there were only 31 cases that offered suitable pictures and where shark size could be reconstructed based on wound or board damage dimensions. Due to the rather low number of accurately reconstructed shark sizes, the presented frequencies have to be interpreted with caution. Over- and underestimation of sizes (reconstructed sizes vs. estimation based on files) were compared. A reconstructed size that differed by 0.5m from the estimated size qualifies for either an over- or underestimation.

4.12. Wound severity

Based on SRI's 'International Shark Attack File' that documents all the world's shark incidents, between 70 and 100 incidents occur per year, of which five to seven cases are fatal (Ihama 2009; SRI 2013). Although as much information as possible was gathered through the questionnaires, the understanding of why an incident took place remained unclear and speculative (Lea 1985; Collier 1992; Levine 1996). Beside Ritter and Levine (2004) no other case study exists where the biting shark was filmed and the incident could be connected to motivational aspects and bite structure. Nevertheless, even without knowing how a shark approached and bit a victim, the wound structure can reveal a motivational insight as been shown by Ritter & Levine (2005) on three selected cases involving bull sharks, *Carcharhinus leucas*. Each of the 31 files was also looked at from such an angle to create the best hypothesis of what may have led to this incident.

5. Results

5.1. Approach pattern of white sharks on surfers

Seventy-one percent of all examined approaches showed that the shark moved towards the surfer in a perpendicular direction with reference to the viewing direction of the surfer, while 6.4% of the sharks came in from the front, and the remaining 22.6% from the back(Fig. 13).

As regards to the pitch angle, the sharks came in either shallow, between 0º and 30º (54.8%) or rather tilted, between 45º and 50º (38.7%), but none in a steeper or even vertical manner (Fig. 14).

The roll angle depended on the position the surfer was in, either lying down with the extremities in a roughly horizontal manner, or sitting, having the lower legs in a vertical position (Fig. 15). When the surfer was sitting, the majority of sharks (83.3%) bit in a 90º or close to 90º angle with regards to the limb orientation, while the remaining angles ranged around 45º (39.9%). A similar situation was reflected when a surfer was lying on his board. In that case 66.7% bit the limb in a 0º or close to 0º angle and did not roll at all, while 22.2% bit the surfer at approximately a 45º angle.

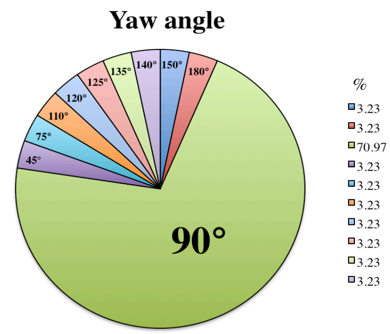


Figure 13 Yaw angle percentages of approaching white sharks during impact.
90°: Approach directly perpendicular to the person's viewing direction; 180°: Approach directly opposite of person's viewing direction.

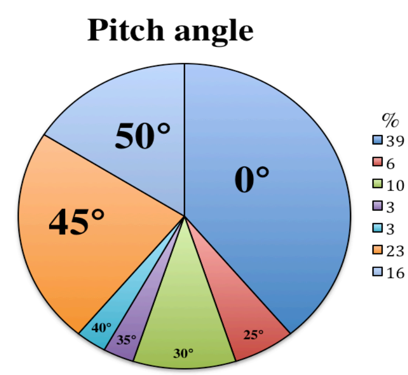


Figure 14 Pitch angle percentages of approaching white sharks during impact.
0°: Shark's moving direction is parallel to and at the surface; 50°: Shark is in a 50° tilting orientation relative to the surface.

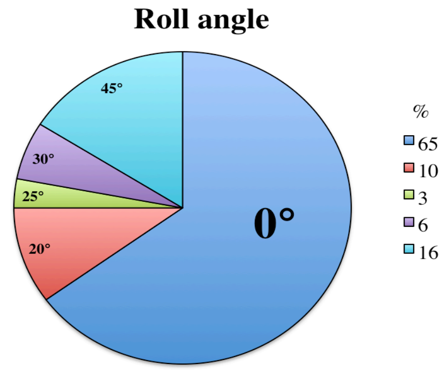


Figure 15 **Roll angle percentages of approaching white sharks during impact.**
0°: No rotation along longitudinal axis rotation (main body axis); 45°: 45° rotation along shark's longitudinal axis (main body axis).

5.2. Approach angle differences between different shark sizes

In order to look for differences or similarities between smaller and larger white sharks when biting surfers, the 4m length marker was used to treat a white shark as either “experienced” (above 4m) or “inexperienced” (below 4m). Table 4 gives an overview of all sharks under these criteria when approaching sitting and lying surfers for all three angles measured.

Figure 16 Drawing of a white shark biting a pinniped with a lateral snap.
Likely the only bout where a white shark primarily uses its upper teeth (lower ones not used) is during a lateral snap. During such a strike, a shark first appears parallel to the pinniped's orientation and then performs a lateral swipe with its frontal body and head. This type of attack is mostly superficial.

Smaller sharks approached sitting surfers (Fig. 16) in a perpendicular manner, the same occurred for the larger ones, with two exceptions where a shark approached a sitting surfer from behind. A similar outcome happened when surfers were lying on the board during impact. Here as well, either all (100%) of the “experienced” ones or the majority (84.6%) of inexperienced white sharks, approached in a perpendicular or nearly perpendicular angle regarding the board's direction.

Pitch showed a variety of angles when surfers were lying on their boards, ranging from 0º to 45º and 0º to 50º, respectively for both "experienced" and "inexperienced" ones with more "inexperienced" sharks approaching in a flat or nearly flat angle (up to 30º). The same outcome presented itself when they were approaching sitting surfers.

Rolling along a shark's longitudinal axis depended of the orientation of the targeted limb or body part. Both groups approached lying surfers in about 2/3 of all incidents with hardly any roll (up to 20º). The same outcome happened while surfers were sitting on the board.

5.3. Gape and tooth measurements

Tables 2 and 3 show all tooth as well as gape distance measurements taken together with the respective regressions and confident coefficients.

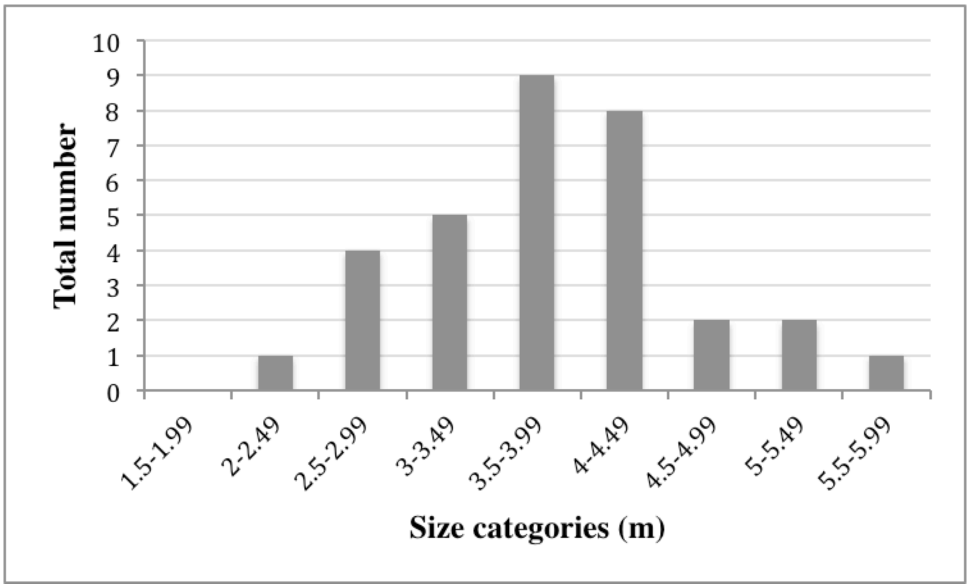
Table 3 Jaw measurements based on body size range (in meters).

Distance	**Total length SC (cm)**	**Gap range (cm)**	**Regression**	**R^2**
Maximal height	1.5- 1.99 2- 2.49 2.5- 2.99 3.5- 3.99 4.5-4.99 5- 5.49 5.5-5.99	17.95 24.22 28.63 38.11 27.75 62.7 62.99	y=0.0728x+1.0206	0.73789
Distance	**Total length SC (cm)**	**Gap range (cm)**	**Regression**	**R^2**
Maximal width	1.5- 1.99 2- 2.49 2.5- 2.99 3.5- 3.99 4.5-4.99 5- 5.49 5.5-5.99	19.43 28.8 36.6 46.25 35.87 82.65 70.17	y=0.0586x+1.033	0.70235

5.4. Size of sharks involved in incidents

Mostly those sharks that investigate surfers do not hesitate to approach larger objects. It is known for white sharks that pinnipeds hardly show up in the diet of animals smaller than 3m. Such is also represented in the length frequencies reconstructed through the examined cases (Table 4).

Table 4 Number and size of examined white sharks involved in surfer incidents.



5.5. Wound severity and board damages

Between 1961 and 2010 2855 incidents were attributed to sharks worldwide. Of these incidents, roughly 1/8, or 12.9%, ended up being fatal. White sharks were conclusively involved in 380 cases with 68 fatalities, whereas 104 cases involved surfers, including 11 fatalities (Table 5).

Of the 104 incidents that involved white sharks and surfers between 1961 and 2010, 60.6% of the surfers suffered bodily harm, of which 17.5% ended up with a fatal outcome. Of the 60.6% of people who were wounded, board damages were noticed on 22.2% whereas in seven cases the boards were only rammed. In five cases of the overall 104 incidents with white sharks filed, no information about potential wounds or board damages were reported (Table 6).

Table 5 Total worldwide incidents including fatalities based on surfer/non-surfer and white shark/non-white shark differentiation between the years of 1961 and 2010.

Activities/ sharks/ fatalities	Total number
All accidents (all species, all activities, all outcome)	2855
All accidents (all species, all activities, fatal)	368
Surfing (all species, all outcome)	682
Surfing (all species, fatal)	31
All non- surfing activities (all species, all outcome)	2173
All non- surfing activities (all species, fatal)	337
Surfing (all non-white shark species, all outcome)	578
Surfing (all non-white shark species, all fatal)	20
Surfing (white sharks, all outcome)	104
Surfing (white sharks, fatal	11
All non- surfing activities (white sharks, all outcome)	276
All non- surfing activities (white sharks, fatal)	57

Of the 104 incidents that involved white sharks and surfers between 1961 and 2010, 60.6% of the surfers suffered bodily harm, of which 17.5% ended up with a fatal outcome. Of the 60.6% of people who were wounded, board damages were noticed on 22.2% whereas in seven cases the boards were only rammed. In five cases of the overall 104 incidents with white sharks filed, no information about potential wounds or board damages were reported (Table 6).

Table 6 Total worldwide surfer incidents caused by white sharks with and without bodily harm and / or board damage.

Damage	Total number
Body & Board	14
Body only (fatal)	49 (11)
Body only (no injury mentioned)	5
Board only (rammed, no damage)	24 (7)
No information	12

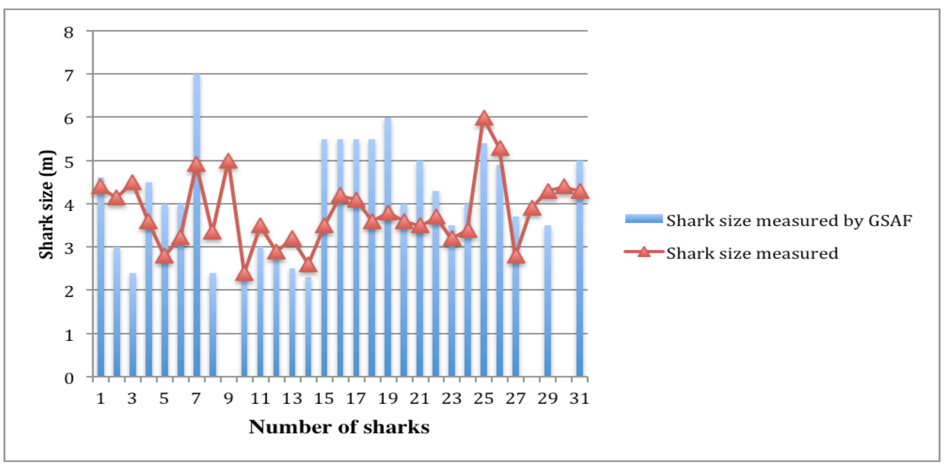
5.6. Wounds on pinnipeds caused by white sharks

Of the 50 pinnipeds examined, 15 carried fatal wounds. Of these, 40% showed wounds in their hind area, of which 46.7% were fatal. With the exception of two attacks, all others showed gouging wounds, sometimes with additional deep lacerations. Including pinnipeds that survived, gouging happened in 56% of all cases. Of the 35 animals that survived the attack, 22 only carried superficial lacerations.

5.7. Over- and underestimation of shark lengths vs. calculated ones

Table 7 shows estimated shark lengths against recalculated ones. Of the 27 comparisons that could be made between filed sizes and recalculated ones, 74.1% showed a difference of ≧ 0.5m. Over 48% (48.2%) of all incidents where shark lengths were noted were overestimated by an average of 1.3m (SE=0.165; N=13), adding close to 1/4 (∅=25.4%; SE=7.659; N=13) to a shark's total length. In reverse, more than 1/4 (25.9%) of all sharks were underestimated by an average of 1m (SE=0.1936; N=7).

Table 7 Shark size measurement comparison
The shark lengths mentioned from the "Shark Research Institute" and the "Shark Research Committee" are best guess estimation and do not reflect reconstructed lengths based on tooth imprints or wound dimensions.



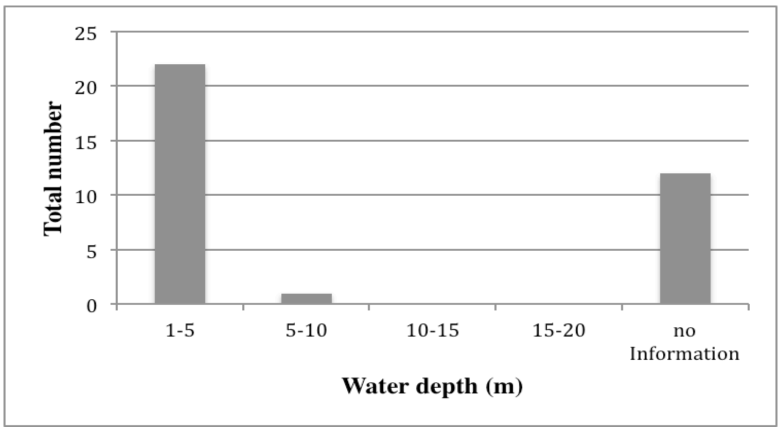
5.8. Abiotic factors

Surfing depends on waves, which rely to a high degree on the water depth, underlying topography, and bottom structures, as well as winds. Due to these circumstances together with the skills of the surfer, the majority of incidents happened within very shallow waters between 1m and 5m.

Tides change on a daily basis, revealing a rather equal distribution of surfers during daytime hours over time. Table 8 shows the distribution of incidents during daytime hours. It has to be pointed out that it must be assumed that the majority of people surf when they can, and not necessarily when the best surf is up.

Although California offers year-round surfing, fall and winter months often bring bigger swells, more suitable for surfing, hence likely an increase in incidents with white sharks might occur as well. Although not conclusive, our data indicate that most (roughly 2/3) surf incidents in California happened indeed during the fall and winter months.

Table 8 Water depths a surfer was in when bitten by a white shark.



6. Discussion

6.1. Surfer exploration and the creation of superficial wounds

The general outcome of the examined incidents are that the white sharks bit the evaluated surfer in a mainly superficial nature based on the rather minor force applied, considering the size of some of these animals. The following explanation will highlight this outcome from different angles.

Exploratory surfer bites do not just reflect the final step of an approach that is guided by the use of the different sensory organs available to the animal, it is also the outcome of a conflict between curiosity and fear (Hammerschlag et al. 2012; Ritter 2012), and the mostly superficial grabbing of the object reflects the final stage of some decision making within this conflict.

Probably the biggest discrepancy between regular bouts on prey and biting surfers is the superficiality of the wounds created or the minor damages made to the boards relative to the severity of injury seen to pinnipeds. This does not reflect the notion that a shark mistakes a surfer for a seal, and disproves the often mentioned hypothesis of "mistaken identity." Ritter (2004) already questioned the correctness of this idea that a shark would erroneously assume a surfer to be a seal. A regular bout entails greater force to either incapacitate or at least stun the prey. If a white shark attacked a pinniped with the same low intensity as it bites a surfer or a board, the prey would hardly be stunned and definitely not incapacitated, hence would likely get away.

"Mistaken identity" originated from the assumption that humans on surfboards resemble the silhouette of seals or even turtles when seen from below. However, this idea has never before been put to the test. The data of this work supports the assumption that the shark is indeed aware that the object to be bitten is not a potential prey. This awareness is mainly supported by the superficiality of the bites and furthermore the approaches used to examine a surfer. These approaches on surfers do, with very few exceptions, not entail common attack traits used with pinnipeds, like approaching from behind.

The prime attack goal of white sharks on seals, sea lions, and other marine mammals is to strike with enough force to prevent an escape. Nevertheless, pinnipeds have gotten away in the past and carried similar superficial wounds that could also be found on surfers or their boards. However, the presence of those wounds on pinnipeds should not lead to the conclusion that just because of the same outcome the same motivation occurred in both cases.

Fifty-six percent of the wounds seen on the examined pinnipeds were either extensive lacerations, or gouging attempts of different severity. These two types were barely seen on surfers or their boards. However, while gouging did not occur in any of the files examined here, some cases are known where superficial gouging occurred (E. Ritter, personal communication). Lacerations very seldom appear on boards due to their hardness and texture, but appeared on surfers a very few times.

Several scenarios come to mind where a shark fails to apply a predatory bite, but only creates a superficial wound. Considering the low number of those pinnipeds that got away, these scenarios represent the very exception and do not occur frequently.

A) Seals are known to mob white sharks, often visible from the wounds they cause on sharks with their teeth (Fig. 17). Often they bite white sharks in the head and snout area close to striking distance of the shark. An inattentive seal might get snapped.

B) A white shark ambushing into a raft of pinnipeds may fail due to the number of seals in close vicinity of each other where the shark's focus on a single animal might be distracted, leading to a rather unsuccessful outcome, hence a superficial injury (Fig. 18).

C) Striking successfully at prey can boil down to speed. Should the goal of a seal's evasive maneuver be to escape, a shark might not reach its respective prey in time, leaving the prey with just a "scratch" at the moment it reaches too shallow of water, the haul out, or the safety of the raft.

D) White sharks are known to compete with each other over food. The appearance of a second shark could prevent the pinniped attacking shark in failing to stun its prey on the first attempt due to pinniped's agility, and prevent the attempt because of the second shark's appearance (Fig. 19).

E) To successfully include seals and sea lions in their diet, white sharks have to reach a certain size. Due to the high agility of pinnipeds, the failing rate of an inexperienced shark is likely high. Any partial success could then end up in a rather superficial bite since the shark could not move into the correct or needed position to attempt a stunning blow to the targeted seal (Fig. 20).

Figure 17 Mobbing marks on the tail and head area.
Mobbing is a typical defense mechanism of pinnipeds against patrolling white sharks. By biting the tail and head area, a group of pinniped can force a white sharks to withdraw. (Photo courtesy: E. Ritter).

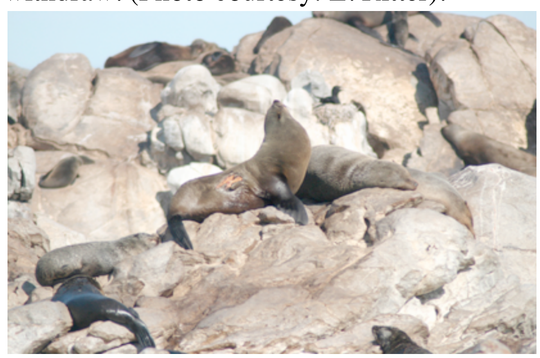


Figure 18 Slash wound caused by a white shark, after an unsuccessful predatory bout.
Although a shark's intention is mostly to kill a pinniped, chances are that the predator is not able to apply a stunning blow or even incapacitate its prey. Several likely scenarios

Although these scenarios offer an explanation to the creation of superficial wounds on pinniped bodies despite the shark's motivation to kill or at least stun its prey, they also show how confusing the interpretation of a superficial wound on a pinniped can be, easily leading to misinterpretation.

That some of the superficial attacks were intended to kill is supported by the fact that in 40% of all pinniped cases examined the hind area—the quarry's blind area—was targeted. In comparison, the head area was only targeted in 8% of all incidents.

Figure 19 Puncture wounds from two bites on the flank of a white shark.
Whenever sharks try to steal food from each other, called kleptoparasitism (Ritter 2012), the aggressor applies multiple bites (but at least two) to force the targeted shark into letting its catch go. (Photo courtesy: E. Ritter).

Figure 20 Agility of a pinniped in the ultimate vicinity of a white shark.
Pinnipeds often pester white sharks when these predators get too close to a haul out or a raft. By swimming close to the face of a shark, the pinniped may be able to distract the shark from its initial intention. (Photo courtesy: E. Ritter).

6.2. Superficial wounds or board damages: what does it tell us

White sharks possess an array of sensory organs (Gruber & Cohen 1985; Tricas 2001) that are used to better understand a novel object. However, it is the bump or grabbing of a person or the board that finalizes an exploratory approach. Because bumping is often a final step used towards accepting or rejecting a novel object, 50% of all white shark incidents in California do not entail damages to bodies or boards (E. Ritter, personal communication; SRI 2013).

Bumping an object is a common trait among white sharks to examine an object (Strong 1996; Hammerschlag et al. 2012). The cutaneous mechanosensitivity (Bleckmann & Hoffmann 1999) gives the shark enough additional clues about the hardness, elasticity, temperature, and even bioelectricity of the structure to reject any further attempts of examining the object. As with bumping, grabbing the object with the jaws and its connected mechanoreception mechanisms reveals similar information for the shark to determine further steps of exploration. Studies showed (Roberts & Witkovsky 1975) that the trigeminal nerves (V) fire when a direct mechanical deflection of teeth and gum areas occur, and it was concluded that these structures act as high threshold mechanoreceptors. This explains that even the slightest grabbing of a board or a human limb can suffice to make a decision how to proceed if unclear. It is assumed (Roberts & Witkovsky 1975) that the mechanosensitivity between skin and teeth/gum area is different with a heightened sensitivity of the latter that could explain that biting may follow bumping of an object should the shark's curiosity not be satisfied after the initial contact.

Since the majority of all white shark bites on surfers are of superficial nature, without attempts of second bites, it can be concluded that the nature of the bites is indeed exploratory.

6.3. Fatal incident with white sharks: contradiction to superficial bites?

Under certain circumstances a shark treats a person like another shark, known as kleptoparasitism. One example would be when a person is spearfishing and the shark tries to steal the fish. During such attempts of kleptoparasitism a shark hits the person as hard as it would be necessary should the person be a shark, but does not attempt to injure the “other shark” (Ritter 2012). Sharks normally do not hurt each other even when applying multiple snaps during such attempts, but people still get wounded during such affairs since the shark is naturally not aware that human skin is less rigid and a ripped femoral artery can be an outcome.

Another scenario would be a paddling surfer that is seen as a competitor by a hunting white shark. This can happen should the surfer accidentally appear on top of a shark that just successfully hunted down prey. Although the shark does not recognize the surfer as such, it falls into a standardized behavior of defending its food against any intruder and fatally injures the surfer. Such a reaction is also known as a claim response (Ritter 2012).

A third scenario where humans would likewise not be treated as unfamiliar objects, which may lead to the human being bitten harder in the process is called "target practice" where primarily subadult white sharks try to hone their skills to later hunting down pinnipeds and use a surfer, or swimmer, as a substitute for target practice (see below for more explanations) (Ritter 2012).

Further incidents that could end up fatal despite rather exploratory attempts where surfers are concerned are as follows:

A) While a shark bites a surfer lying on the board, its lower teeth get stuck in the underside of the board. Even a rather gentle hold may then crush a leg, open an artery, or create a severe wound should the hip and back area be involved. Such an outcome is even more likely should the shark come in with some speed, pushing the board and person in front of it while holding on.

B) A shark grabs a leg or an arm and before letting go, the surfer tries to pull the limb out of the shark's jaw, potentially even severing the limb in the process, which could lead to a fatal secondary wound (Ritter & Levine 2005).

6.4. Object play and manipulation

Object play is described as "... the involvement of inanimate objects of various kinds in an animal's play activities..." (Hall 1998). Despite that humans are not inanimate objects there is the likelihood that the person *per se* is not the targeted object at all but the board itself. One reason could be the sounds a board creates, mainly when turned into the waves' direction. The splashing of water against the underside of the board's front is likely to be heard from some distance. Surfers who are not actively moving but sit or lay on a board still produce sounds with their boards or their limbs in the process of keeping their position against the incoming waves. Due to the motion of the waves and the bouncing of the board, the sounds emitted are non-rhythmical Ritter (unpubl. data) assumed that white sharks exclusively bit and hit a sound box emitting irregular sound patterns but not a constantly moving robot that produced low volume rhythmical sounds when both were presented. This raises the question, as already mentioned, if white sharks would recognize up close that there a two objects present: a person and a board.

6.5. Target practice as a cause for shark bites

Ritter found that white sharks possess a fully developed play behavior (for more detail, see Burghardt 2005). Play is a fixed behavior among many predators e.g., to hone new skills (Heinrich & Smolker 1998; Graham & Burghardt 2010) and can get important during the ontogeny of a white shark to prepare for hunting pinnipeds. However, because it seems that white sharks in this study were not able to distinguish between the front and back of the surfer's orientation, the ambush of the unfamiliar object could not be a priority (see below for further details) and the biting rather equaled plain object manipulation.

Although there is a large food spectrum during a white shark's ontogeny (Tricas and McCosker 1984; Cliff et al. 1989; Hussy et al. 2012) there are suitable foods, beside regular prey, that are occasionally mouthed by white sharks without consuming them. Examples of such animals include sea otters (Ames et al. 1996), penguins (Randall et al. 1988), and others. These animals could likewise be used for target practice. It remains to be seen what the true purpose of mouthing these species is but it fits target practice as well, at least for those specimen that suffered a full gape during impact.

This raises the question if larger white sharks might bite surfers as well for the purpose of keeping the skills honed for later use. Such would fit “low intensity” hunting as mentioned by Treleaven (1980). However, for mature white sharks, this idea is likely to be rejected since the presented results show that the majority of approaches come from the side in a perpendicular angle, easily visible for such vigilant animals, even when using increased speed.

6.6. Ambush or not, or does from “behind and below” still apply for surfer incidents, as well?

Ambush requires stealth (Ebert 1991; Zuberbühler et al. 1999; Fulman et al. 2006; Jobling et al. 2012) or some form of camouflage (Johnsen & Sosik 2003; Stuart-Fox et al. 2008; Stevens & Merilaita 2009). The presented data do not support the idea that white sharks ambush surfers. The ambush of a surfer requires a shark to be able to determine the person's orientation when sitting or lying on the board. Such cannot be assumed if the surfer does not move. While paddling, one could argue that the direction of motion determines the approach of a white shark. However, the yaw angle, which in over 70% was 90°, does not support an approach "from behind." Additionally, more than half of all sharks (54.8%) did not approach from below but in a shallow angle between 0º and 30º and would easily be seen.

6.7. Bite volume

Of the 31 cases analyzed, 17 surfers showed the imprint of a full bite volume. A shark that leaves such a bite—upper and lower jaw imprints must be visible—without corresponding gouging reflects a different motivation than the intention of feeding on the bitten object. To bring as much teeth and gum into contact with the unfamiliar object in order to get as much information as possible seems likely: density, surface structure, and taste are detected through the mechanosensitivity nerves, and the ampullae of Lorenzini come into play for the object's bioelectricity and heat emission. Although the ampullae of Lorenzini (Bleckmann & Hofmann 1999) is a sensory organ that is not located inside the mouth but along the entire outside rim of the mouth, its dense distribution in the entire head area will help to create a more complete emission picture of the bitten object. The larger the bite volume the more information a shark will likely get when grabbing an unfamiliar object.

However, the intention of a shark that rams or bites a person with full gape is not always gouging a piece out of the object or evaluating the object. Probably the most common reason for such a bite imprint, without the accompanying removal of flesh, would occur due to the already mentioned kleptoparasitism (Ritter & Levine 2005).

6.8. Can miscalculated or erroneously estimated shark sizes lead to wrongfully assumed behavior?

Nearly 3/4 of all examined files from the "Shark Research Institute" and the "Shark Research Committee" were off by an average of either 1.3m too long or 1m too short. Such implies that a statement made about a shark that purely depends on impressions or assumptions should not be taken lightly but with the necessary reservation.

Juvenile white sharks differ in many ways from adults, one important factor being the different prey spectrum, requiring different attack strategies. However surfers are novel objects to younger sharks as well as to older ones, assuming no previous exposure occurred. However, smaller sharks could also be repelled due to the size of surfers and the initial fear to approach. A difference could also transpire regarding experience or inexperience for novel objects *per se*. That older animals might have been exposed is possible considering the migration routes of larger white sharks along California's coast, which may have lowered their hesitation threshold to approach. Since younger and older white sharks seem to face the same general problems when approaching surfers, inaccuracies of their lengths do not seem to cause problems.

6.9. Water depth during incidents with surfers

Based on current literature (Klimley et al. 1992; Pyle 1996; Goldman & Anderson 1999; Martin et al. 2005), water depth seems crucial for a successful attack of white sharks on pinnipeds, so a comparison of water depth between regular predatory bouts and the incidents involving surfers was undertaken. Based on Klimley et al. (1992), most attacks on pinnipeds occur in a depth between 5m and 50m. This depth varies depending on the general topography around pinniped haul outs. Goldman and Anderson (1999) estimated that a depth range between 26m and 30m is preferred by white sharks, allowing them to remain undetected when stalking pinnipeds from below. This range seemed deep enough to build up sufficient momentum required for a successful, vertical strike (Hammerschlag 2006). In general, the attack frequencies increase and decrease with both the height of swell and visibility. Other factors also come into play, which influence the ability of pinnipeds to detect sharks and make a quick response regarding an attacking shark (Pyle 1996).

In contrast, of the incidents evaluated, in all but one case the shark bit the surfer in a water depth less than or equal to 5m. Although this depth does not allow a vertical approach by the animal, it still allows motion toward the victim in a rather tilted position typical of regular bouts. However, most sharks approached in a rather flat angle. Furthermore, they also mostly moved in perpendicular to the surfer’s body orientation. Both of these tendencies increase the chance that the shark will be detected prior to the first contact.

It may be a surprise that white sharks are more likely to interact with surfers in such shallow waters. However, the depth of water usually frequented by surfers is likely to play a major role. In addition, one has to remember that whites often patrol right in front of seal haul-outs in very shallow waters, comparable to those and perhaps overlapping those frequented by surfers. Since the approach towards surfers appears to be exploratory rather than predatory in nature, it is less surprising that the animal dared to come into shallow shore waters.

6.10. Constellation of factors

Ritter (2012) coined the term "constellation of factors." COF implies that several—a minimum of two—factors must come together and affect at least two sensory organs in order for a shark to bite a human being should the animal also have lowered its hesitation threshold (Ritter, 2012). COF leads most often to exploratory and stress or reflex related bites with regards to humans.

Figure 21 Non-surfing incidents along California's coast between 1961-2010.

Some typical constellation factors for surfers in California are low visibility, low light (early morning and evening hours), locations close to pinniped haul outs and / or kelp beds, creation of non-rhythmic sound patterns (by e.g. paddling forward, moving the board into the wind, etc.). As already mentioned, Amin, Ritter & Cossette (2013) could identify some of the areas along the California coast where the risk of getting bitten is significantly higher than elsewhere (Figs. 21, 22), however COF for the individual areas have not yet been identified.

Figure 22 Surfing incidents along California's coast between 1961-2010.

The recognized primary and secondary high and low risk zones for all beach goers (Fig. 1) largely overlap with prime areas for pinnipeds and their haul outs, together with islands right off the coast which are also known for pinniped haul outs e.g., Farallon Islands, or Ana Nuevo. Due to this overlap, it can be concluded that pinniped haul outs are one of the most important constellation factors, if not the premier one. More southern areas are also prime areas for white shark bites (High Secondary Zone, Fig. 1), although they are not known for seal haul outs, indicating the potential for different factors at play in those areas. There is the possibility, for example, that the temporary appearance of pregnant white shark females might force smaller white sharks closer to shore due to some cannibalistic effects, or the smaller ones enter shallower water due to their preference of hunting demersal fishes.

6.11. How representative are these data?

Close to 30% of all white shark incidents with surfers worldwide between 1961 and 2010 could be analyzed, of which about half originated from the US West Coast. This raises the possibility that the results gathered from these incidents may not fully reflect worldwide tendencies for white sharks biting surfers. Each area where incidents between white sharks and surfers transpired possesses different COF, but some underlying factors such as presence of pinniped colonies remain present. Since these similarities do exist, the data from the coast of California is likely representative for other areas as well.

6.12. Conclusions

The majority of bites caused by white sharks on surfers are of a superficial nature and are interpreted to have been intended to explore what the unfamiliar object could represent. Since these sharks cannot identify a surfer's body orientation at the surface, the sharks were not able to approach from "behind and below" as a form of stealth or ambush. Rather, they mostly approach perpendicular to the largest visual dimension of the person, which would be represented the length of the surfboard. Overall these approach patterns and relatively superficial wound patterns contradict the "mistaken identity" hypothesis where sharks supposedly mistake surfers for seals and attack accordingly. Would this hypothesis be valid, the human victim would not suffer superficial but severe wounds due to the shark's intention to incapacitate or at least stun the person, which it erroneously assumed to be a pinniped.

7. Acknowledgement

First of all I would like to thank my supervisors Dr. Erich Ritter and Professor Kurt Kotrschal for the opportunity to work on a thesis about my passion the sharks and in particular white sharks.

A special thanks goes to Dr. Gordon Hubbell who let me spend time in his private museum to measure all the shark jaws needed for this thesis.

Likewise I would like to thank Glenn Reed for the opportunity to take measurements in his jaw collection, as well.

Furthermore I would like to thank Marie Levine from the "Shark Research Institute," Princeton, New Jersey, USA and Ralf Collier from the "Shark Research Committee," Van Nuys, California, USA, for providing the data and accident pictures for this work.

Last but not least, I would like to thank my parents for their patience and their continuous support and encouragement to keep going.

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9. Appendix

Table 2 Teeth distance measurements with reference to range of body sizes.
A1, A3: Anterior teeth; INT: Intermediate tooth; L1...L5: Lateral teeth; AD: Apex distance; R^2: Correlation coefficient. Measurements in meters.

Tooth gap	SC Upper Jaw (m)	AD (cm)	Regression	R^2
	1.5- 1.99	2.11		
	2- 2.49	2.05		
	2.5- 2.99	2.30		
	3- 3.49	4.11		
A1-A1	3.5- 3.99	3.65	y=0.7042x+0.843	0.85164
	4- 4.49	3.15		
	4.5-4.99	4.87		
	5- 5.49	6.40		
	5.5-5.99	7.52		
	1.5- 1.99	1.63		
	2- 2.49	3.00		
	2.5- 2.99	2.48		
	3- 3.49	2.63		
A1-A3	3.5- 3.99	3.36	y=0.9934x+0.2854	0.86502
	4- 4.49	2.98		
	4.5-4.99	4.29		
	5- 5.49	5.60		
	5.5-5.99	5.16		

Tooth gap	SC Upper Jaw (m)	AD (cm)	Regression	R^2
A3-INT	1.5- 1.99	0.78	y=1.0772x+1.3047	0.70689
	2- 2.49	1.45		
	2.5- 2.99	1.54		
	3- 3.49	1.70		
	3.5- 3.99	1.98		
	4- 4.49	1.22		
	4.5-4.99	3.27		
	5- 5.49	4.38		
	5.5-5.99	3.17		
INT-L1	1.5- 1.99	2	y=0.7732x+0.9847	0.80743
	2- 2.49	2.26		
	2.5- 2.99	2.29		
	3- 3.49	2.83		
	3.5- 3.99	2		
	4- 4.49	2.13		
	4.5-4.99	4.46		
	5- 5.49	6.22		
	5.5-5.99	5.96		
L1-L2	1.5- 1.99	1.51	y=0.9887x+0.4974	0.94181
	2- 2.49	1.94		
	2.5- 2.99	2.27		
	3- 3.49	2.43		
	3.5- 3.99	3.21		
	4- 4.49	3.00		
	4.5-4.99	4.78		
	5- 5.49	5.00		
	5.5-5.99	5.17		
L2-L3	1.5- 1.99	1.49	y=1.1219x+0.2432	0.91206
	2- 2.49	2.02		
	2.5- 2.99	2.39		
	3- 3.49	2.61		
	3.5- 3.99	3.04		
	4- 4.49	2.51		
	4.5-4.99	4.34		
	5- 5.49	4.57		
	5.5-5.99	4.87		

Tooth gap	**SC Upper Jaw (m)**	**AD (cm)**	**Regression**	**R^2**
	1.5- 1.99	1.27		
	2- 2.49	2.23		
	2.5- 2.99	2.13		
	3- 3.49	X		
L3-L4	3.5- 3.99	3.01	y=1.0425x+0.6107	0.8663
	4- 4.49	2.42		
	4.5-4.99	X		
	5- 5.49	4.70		
	5.5-5.99	4.84		
	1.5- 1.99	1.05		
	2- 2.49	1.35		
	2.5- 2.99	1.62		
	3- 3.49	X		
L4-L5	3.5- 3.99	2.03	y=1.1412x+1.2658	0.75905
	4- 4.49	1.28		
	4.5-4.99	X		
	5- 5.49	3.54		
	5.5-5.99	3.93		
	1.5- 1.99	2.37		
	2- 2.49	3.69		
	2.5- 2.99	4.10		
	3- 3.49	x		
A3-L1	3.5- 3.99	5.55	y=0.3801x+1.4896	0.75513
	4- 4.49	3.36		
	4.5-4.99	x		
	5- 5.49	10.84		
	5.5-5.99	10.40		
Tooth gap	**SC Lower Jaw (m)**	**IDD (cm)**	**Regression**	**R^2**
	1.5- 1.99	2.17		
	2- 2.49	2.61		
	2.5- 2.99	3.09		
	3- 3.49	2.48		
i-i	3.5- 3.99	3.62	y=0.716x+0.861	0.85152
	4- 4.49	3.76		
	4.5-4.99	4.64		
	5- 5.49	7.37		
	5.5-5.99	6.25		

Tooth gap	**SC Lower Jaw (m)**	**IDD (cm)**	**Regression**	**R^2**
	1.5- 1.99	1.97		
	2- 2.49	2.71		
	2.5- 2.99	2.85		
	3- 3.49	3.08		
i-ii	3.5- 3.99	3.49	y=0.8606x+0.3182	0.91936
	4- 4.49	3.60		
	4.5-4.99	5.48		
	5- 5.49	6.30		
	5.5-5.99	6.04		
	1.5- 1.99	1.58		
	2- 2.49	2.23		
	2.5- 2.99	2.45		
	3- 3.49	2.71		
ii-iii	3.5- 3.99	3.52	y=0.9932x+0.4071	0.88463
	4- 4.49	2.53		
	4.5-4.99	4.86		
	5- 5.49	4.79		
	5.5-5.99	5.18		
	1.5- 1.99	1.39		
	2- 2.49	2.30		
	2.5- 2.99	2.42		
	3- 3.49	2.51		
iii-1	3.5- 3.99	2.98	y=0.9971x+0.728	0.77691
	4- 4.49	1.68		
	4.5-4.99	4.06		
	5- 5.49	4.32		
	5.5-5.99	5.11		
	1.5- 1.99	1.29		
	2- 2.49	1.88		
	2.5- 2.99	1.92		
	3- 3.49	2.25		
1-2	3.5- 3.99	2.86	y=0.9317x+1.0794	0.77384
	4- 4.49	1.59		
	4.5-4.99	3.99		
	5- 5.49	3.75		
	5.5-5.99	4.51		

Tooth gap	SC Lower Jaw (m)	IDD (cm)	Regression	R^2
2-3	1.5- 1.99 2- 2.49 2.5- 2.99 3- 3.49 3.5- 3.99 4- 4.49 4.5-4.99 5- 5.49 5.5-5.99	1.16 1.60 2.00 1.94 2.23 1.75 3.33 3.32 3.43	y=1.5497x+0.1371	0.85884
3-4	1.5- 1.99 2- 2.49 2.5- 2.99 3- 3.49 3.5- 3.99 4- 4.49 4.5-4.99 5- 5.49 5.5-5.99	0.78 1.20 1.11 x 1.53 1.57 x 2.49 2.87	y=1.9087x+0.5293	0.92063
4-5	1.5- 1.99 2- 2.49 2.5- 2.99 3- 3.49 3.5- 3.99 4- 4.49 4.5-4.99 5- 5.49 5.5-5.99	0.53 1.02 0.90 x 1.23 1.46 x 2.20 2.04	y=2.3956x+0.4684	0.92406

10. Zusammenfassung

Ziel meiner Diplomarbeit war einerseits herauszufinden, aus welchem Grund Weiße Haie, *Carcharodon carcharias*, Surfer beißen, andererseits, ob sie sich wirklich anschleichen, wie oft verlautet, und die Attacke von „hinten und unten“ durchführen. Weiter sollte die Arbeit auch eine gängige Hypothese hinterfragen, ob Weiße Haie Surfer mit Robben oder Schildkröten verwechseln. Diese Hypothese, die auch als „Verwechslungshypothese“ bezeichnet wird, wurde bislang nicht auf ihre Richtigkeit überprüft. Um eine mögliche Motivation, weshalb Weiße Haie Surfer beißen, herausarbeiten zu können, wurde die Richtung aus der sich ein Hai vor dem Unfall näherte, was der eigentlichen Beißposition entspricht, mit jener verglichen mit der sie sich ihrer natürlichen Beute nähern. Mit Unfallberichten, die das „Shark Research Institute“, Princeton, USA, wie auch das "Shark Research Committee", Van Nuys, USA, für diese Arbeit zur Verfügung stellte, wurden alle Surfunfälle der Jahre 1961-2010 untersucht, von denen auswertbare Bilder vorhanden waren. Das Hauptaugenmerk wurde auf die Westküste der USA gelegt, speziell Kalifornien. Anhand dieser Abbildungen von Wundbildern und Materialschäden an Surfbrettern konnte die Richtung, aus der sich Haie näherten bzw. die Position während des Bisses festgestellt werden. Die Ergebnisse zeigen, dass Weiße Haie Surfer nicht beißen, wie sie das bei pinnipeden Arten tun. Die Resultate zeigen, dass Weiße Haie offenbar zwischen Surfern und bekannten Beutetieren unterscheiden können. Die Wunden, die sie Surfern zufügen, sind zumeist oberflächlich, bestehend aus einem einzigen Biss. Dies bestätigt, dass es sich meist um einen Probebiss handelt, um das Objekt besser verstehen zu können. Die Annäherung von „hinten und unten“, wie sie bei der Jagd auf pinnipede Arten vorkommt, wird beim Angriff auf Surfer nicht angewendet. Ebenso zeigen meine Ergebnisse dass die „Verwechslungshypothese“, wonach Weiße Haie Surfer mit Robben oder Schildkröten verwechseln würden, wahrscheinlich nicht zutrifft.

11. Abstract

The goal of this work was to determine the most common approach directions of white sharks, *Carcharodon carcharias*, biting of surfers, based on wound patterns and board damages and thereby, to conclude towards causation of the biting incidents. Furthermore, this thesis questioned the “mistaken identity” hypothesis, which holds that white sharks may mistake a surfer for a pinniped or a turtle. This hypothesis has been questioned in the past but has never been formally checked. To understand a potential motivation why on rare occasions, white sharks bite surfers and from what direction they approach—reflected by the actual bite position—the outcome in this project, this was compared with approach patterns and bites of actual predatory attacks on pinnipeds. The "Shark Research Institute,“ Princeton, USA, as well as the "Shark Research Committee," Van Nuys, USA, made all the incident files of incidents available that took place between 1961 and 2010 especially in California, on the US West Coast. However, only those files were taken into consideration that entailed pictures of injuries or board damages that could be evaluated. Based on this material, the approach patterns and impact positions revealed that white sharks do not target surfers the same way they attack pinnipeds, and the chosen strategy when biting surfers does not fit any common bout patterns. White sharks can seem to distinguish between surfers and their usual mammalian prey. The wounds on surfers are primarily superficial, consistent with a single bite. This supports the idea that white shark mostly performs an exploratory bite to better understand the unfamiliar object. The approach pattern from “behind and below” when hunting down pinnipeds as one of the attack strategies has not been seen among bitten surfers. Overall it can also be concluded that the hypothesis of "mistaken identity" is incorrect and does not apply for white sharks when biting surfers.

Approach directions and bite angles of white sharks, *Carcharodon carcharias*, on surfers based on wound patterns

12. Lebenslauf

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