CHAPTER 31

Responding to the Risk of White Shark Attack

Updated Statistics, Prevention, Control Methods, and Recommendations

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ABSTRACT

Unprovoked attacks by sharks on humans are traumatic events that may sometimes have tragic consequences. One of the species most commonly associated with shark attacks is the White Shark (*Carcharodon carcharias*), the world's largest predatory fish. The White Shark's seasonal distribution along some coastlines and natural predatory tactics provide ample potential for interactions with humans utilizing the ocean, and its large size gives it the potential to inflict serious injuries if an attack is initiated. Unprovoked attacks by White Sharks on humans, however infrequent, tend to draw significant and often exaggerated attention from the media and general public, and pressure is often placed on local governmental organizations (public safety, law enforcement, fisheries agencies, etc.) to respond in some manner to prevent further attacks. The purpose of this paper is to review records of White Shark attacks and provide recommendations to help organizations make informed decisions when responding to White Shark attacks. Included are facts on White Shark biology, attack statistics, and a review of response plans that have been implemented in various sites around the world. The recommendations are intended to help reduce sensationalistic, irrational, or ineffective responses by decision makers and benefit the beach-going public as well as vulnerable White Shark populations.

INTRODUCTION

The marine environment is a vast wilderness filled with many thousands of species, most of which are benign to humans or indifferent to their occasional intrusions. As human utilization of the ocean has increased over the last century, encounters with more dangerous species have become more frequent. Few marine species are more feared than sharks. Unprovoked attacks by sharks on humans are infrequent, but they can be extremely traumatic events. In general, the risk of shark attack is exceptionally low when compared with other dangers potentially encountered by beachgoers (e.g., drowning, rip currents, surfboard accidents, stingrays, jellyfish, etc.) (Klimley and Curtis, 2006; Burgess et al., 2010). However, similar to other animal attacks, they draw a disproportionate amount of public and media attention because of their dramatic circumstances. Millions of people engage in swimming, surfing, boating, snorkeling, or scuba diving in the ocean each year, providing billions of dollars in revenues to coastal communities worldwide. Repeated shark attacks within a certain area that result in injuries or deaths are not only extremely traumatic to those involved but can also lead to adverse economic impacts on coastal communities in close proximity to attack locations (Hazin et al., 2008). This may result in considerable public pressure to take action to reduce the risk of shark attacks in such areas. There are over five hundred shark species in the world's oceans, yet only about thirty species have been documented to attack humans (International Shark Attack File, unpublished data: http://www.flmnh.ufl.edu/fish/sharks/statistics/species2.htm).

Worldwide, one of the species most often associated with attacks is the White Shark (*Carcharodon carcharias*) (Baldridge, 1996; Burgess and Callahan, 1996). The White Shark is the world's largest predatory fish, growing to lengths exceeding 6 m. It is sparsely distributed in tropical to temperate seas around the world (Compagno, 2001) but is known to seasonally aggregate in certain coastal locations to feed on preferred prey species, including marine mammals (seals, sea lions, whale carcasses, etc.) and a variety of pelagic and demersal fishes (Tricas and McCosker, 1984; Casey and Pratt, 1985; Klimley, 1985; Ellis and McCosker, 1991). Known aggregations of White Sharks occur off the coasts of South Africa, Australia, New Zealand, and the west coast of North America (Ellis and McCosker, 1991; Compagno, 2001). Therefore, it is not unexpected that these regions experience the greatest frequency of unprovoked White Shark attacks on humans (Burgess and Callahan, 1996).

Despite the White Shark's reputation as a powerful predator and "man-eater," this species is actually quite sensitive to exploitation by fisheries. As apex predators in the marine environment, they are naturally low in abundance (Chapple et al., 2011). Additionally, because of their slow growth, late maturity, and low fecundity (Francis, 1996), the ability of White Shark populations to rebound from depletion is limited. White Shark fins, jaws, teeth, and meat are all considered highly valued products, and there has been and continues to be considerable trade in these products (Compagno, 2001). Bycatch of White Sharks in commercial fisheries has occurred throughout its range, whereas in some regions, trophy hunting was also common practice. However, because of evidence of declining populations around the world, the White Shark is afforded some of the highest protections of any marine fish. Trade in White Shark products is now internationally regulated through their listings on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, in the Convention of Migratory Species, and in the United Nations Convention on Law of the Sea. The International Union for Conservation of Nature Red List of Threatened Species identifies White Sharks as globally "vulnerable." Furthermore, they are protected from harvest in territorial waters of numerous countries, including South Africa, the United States, Canada, Australia, New Zealand, Namibia, and some Mediterranean nations.

Responses to White Shark attacks and attack-prevention efforts have varied over time and by region. A variety of fishing (shark removal) and nonfishing (no shark removal) methods have been employed with varying degrees of costs and benefits (Dudley and Cliff, 1993, 2010), but standard-response guidelines are lacking. In addition to the potential trauma inflicted on a shark bite victim, the hours following an attack by a White Shark can be extremely chaotic for those involved in the response (emergency medical personnel, law enforcement, news media, and local officials and scientists). Repeated attacks, uncontrolled shark hunts, or other unfortunate situations may arise in the absence of a formal response from those in authority. There are clear incentives to reduce the risk of shark attack where White Sharks and humans potentially interact, but organized response protocols are also necessary to protect the public.

The purpose of this chapter is to inform the beach-going public, managers, and authorities (e.g., beach management, law enforcement, fisheries agencies) about White Shark attacks, including attack statistics, and to review the methods of attack prevention and response. We identify the pros and cons of these methods at reducing the risk of shark attack and provide managers with the facts necessary to make informed decisions when responding to White Shark attacks. By reducing irrational or ineffective responses, the resulting recommendations are intended to benefit the safety of the beach-going public as well as sustain vulnerable White Shark populations.

WHITE SHARK ATTACK STATISTICS

Definition of Shark Attack

A shark attack for the purpose of this paper follows the definitions of Cliff (1991, 2006), West (1996), and Burgess and Callahan (1996) as any unprovoked, physical contact between shark and victim or the victim's diving equipment, if worn on the body, or the victim's personal craft, even if the rider was uninjured. Such craft include a surfboard, body-board, sailboard, kiteboard, or surf-ski (resembles a long, narrow kayak) but exclude motorized or larger sailing craft. We have included attacks on spearfishers as unprovoked, although some researchers argue that the act of spearing fish may illicit an attack and thus should be regarded as provocation to do so.

Identifying a White Shark Attack

One of the primary objectives in a shark attack investigation is to determine the species responsible. Two important sources of information are a description of the attacking shark from the victim or eyewitnesses and a forensic examination of the bite. This information should be combined with knowledge of the species, size, diet, and behavior of sharks occurring at the attack site when attempting to ascertain its identity.

White sharks have several anatomical features that set them apart from most other sharks, especially those members of the family Carcharhinidae, such as the tiger (*Galeocerdo cuvier*), bull (*Carcharhinus leucas*), blacktip (*C. limbatus*), and gray reef shark (*C. amblyrhynchos*), which are also implicated in attacks. These include the White Shark's lunate tail, with a lateral keel at the base; large, strap-like gill slits; a relatively large dark eye and a prominent conical snout. The White Shark is also one of very few large sharks with sharp demarcation between the dorsal (grey) and ventral pigmentation (white).

The most conclusive evidence of a White Shark attack is the discovery of a tooth or part thereof, often only a small fragment, with its distinctive serrations (Figure 31.1). Such fragments may be embedded in the victim's equipment, such as a board or paddle craft, or lodged in larger bones, such as the femur. Because shark teeth are radio-opaque, it may be beneficial to x-ray the bitten area for the presence of such fragments.

Figure 31.1 White Shark tooth fragment with characteristic serrations recovered from the wetsuit of an Australian attack victim. (Courtesy of Terry Walker.)

White sharks have serrated, cutting teeth in both their upper and lower jaws (Figure 31.1). Their bites are usually relatively clean-cut, leaving a crescent-shaped perimeter. This is most evident when the shark bites a firm, inanimate object such as rider's board. Here the result is often a neat arc, in which the position of the individual teeth can be determined, and consequently intertooth distances and bite circumference can be measured. When a White Shark bites into soft tissue, the victim invariably pulls away, thereby increasing the ripping or tearing effect, making measuring far more difficult. Lowry et al. (2009) looked at interdental distances in ten species of sharks, including the white, tiger, and bull and related them to shark length. They found that of the sharks with serrated, cutting teeth, White Sharks have the highest interdental distances, up to 48 mm in the case of extremely large individuals (5.6 m total length), although there is some overlap with large tiger sharks. Depth of penetration is another important indicator, because White Shark teeth are very long in comparison with other species such as the tiger and bull shark. West (in press) provides the AQ1 criteria used to establish the identity of sharks responsible for attacks in Australian waters.

Global Trends

Data on White Shark attacks worldwide are collected and cataloged by the International Shark Attack File (ISAF) based at the Florida Museum of Natural History, University of Florida (http://www.flmnh.ufl.edu/fish/sharks/isaf/isaf.htm). The ISAF is a compilation of all known shark attacks and currently includes over four thousand individual investigations dating as far back as the mid-1500s. A comprehensive analysis of worldwide patterns in unprovoked White Sharks was presented by Burgess and Callahan (1996). This section provides a brief summary and update from this work and also incorporates recent records compiled by ISAF collaborators in California, Australia, and South Africa.

White sharks have been implicated in a total of three hundred forty-six unprovoked attacks on humans worldwide since 1839, including one hundred two fatalities. Although the majority of shark attacks around the world can be attributed to more common carcharhinid sharks (e.g., *Carcharhinus leucas*, *C. limbatus*, etc.) (Burgess et al., 2010), the White Shark is most frequently cited as responsible where the identity of the attacking species is ascertained. This is due to the White Shark's readily identifiable physical features and the generally diagnostic nature of bite patterns and tooth impressions described above. Attacks by White Sharks, therefore, have a higher likelihood of being correctly identified compared with attacks by other species, even though the numbers of attacks by other sharks are more frequent.

Over the last century, the frequency of White Shark attacks each decade has been gradually increasing (Burgess and Callahan, 1996). Between 1900 and 1909, there were less than five attacks reported, but between 1950 and 1959 there were over twenty attacks, and from 1990 to 1999 there were at least sixty attacks. This increase is largely due to increasing human populations and growing use of the ocean for recreation, as well as increased communications in reporting of attacks (Klimley and Curtis, 2006; Burgess et al., 2010). However, over the same period, the percentage of White Shark attacks resulting in a fatality has significantly declined. In the early 1900s, nearly 100% of White Shark attacks resulted in fatality, but by the end of the twentieth century, with improved medical response, the fatality rate has declined to less than 20%. The White Shark is still considered to be the most potentially dangerous shark in the world, given that it is responsible for more human fatalities than any other species.

The number of attacks by country/region is given in Table 31.1 (N.B., these numbers may differ slightly from those given in the subsequent sections because of regional variations in recordkeeping). Approximately 85% (two hundred ninety-four attacks) of White Shark attacks have occurred in three regions: Australia (one hundred twenty-six attacks), the Pacific coast of the United States (one hundred twelve attacks), and South Africa (fifty-six attacks). White Shark attack trends in these regions are described in more detail below. A number of attacks have also been reported in

Table 31.1 Number of Unprovoked White Shark Attacks and Fatalities by World Region (1876–2008)

Region	Total Attacks	Fatal Attacks
Australia	126	50
West United States	112	12
South Africa	56	19
Mediterranean Sea	23	11
New Zealand	10	3
East United States	8	4
South America	3	0
Japan	2	2
Hawaii	1	0
Mexico	1	1
Caribbean Islands	1	0
South Korea	1	0
Other	2	0
Total	346	102

the Mediterranean Sea (mostly Italy and Greece), New Zealand, Chile, and the Atlantic coast of the United States (South Carolina to Massachusetts) (Table 31.1). The higher frequency of White Shark attacks in these areas can be attributed to a combination of three primary factors:

1. High human use of coastal waters (swimming, surfing, diving, etc.)
2. Water temperatures consistent with the White Shark's natural preferences (~15–22°C; Casey and Pratt, 1985; Compagno, 2001)
3. High density of natural prey, resulting in high local White Shark abundance

Regional Trends

Northeast Pacific

The White Shark is essentially the only shark species responsible for unprovoked attacks on humans in the northeastern (NE) Pacific. Since 1950, at least one hundred attacks have occurred, primarily in California, and considering the dramatic increase in human recreational ocean use during the last four decades, it is remarkable that shark attacks are so uncommon. Reviews and extensive treatments of eastern Pacific White Shark attacks include Miller and Collier (1981), Engaña and McCosker (1984), Lea and Miller (1985), McCosker and Lea (1996, 2006), and Collier (2003).

The trends, location, months, and human activity during eastern Pacific attacks are listed in Tables 31.2 and 31.3. In summary, humans have been attacked during each month (Table 31.2); however, the majority of attacks have occurred during August (16%), September (20%), and October (13%). Geographically (Table 31.3), the vast majority of attacks have occurred north of Point Conception, California (34°30' N latitude), and only a single attack has occurred off Washington State. Attacks south of Point Conception are rare because of the rarity of nearshore pinniped colonies, and the abundance of attacks further north is related to the abundance of pinnipeds and the high level of water use by humans in that area. Within California, 80% of attacks have occurred from Humboldt County south to Monterey County, and 62% of total attacks have taken place along an approximately 160-km stretch of coast between Marin County and Monterey County and out to the Farallon Islands (43 km offshore), an area called the "red triangle" by the mainstream media. Attacks have occurred between 7 a.m. and 7 p.m., peaking at 1 p.m. (McCosker and Lea, 2006). Victims are mostly men, however, we lack information about water-use activity by sex and therefore

Table 31.2 Monthly Record of Confirmed Attacks by White Sharks in the Eastern North Pacific (1950–2009)

Month	California and Baja	Oregon and Washington	Total
January	5	1	6
February	3	1	4
March	2	1	3
April	4	2	6
May	7	0	7
June	2	0	2
July	10	0	10
August	16	2	18
September	18	4	22
October	14	1	15
November	8	2	10
December	8	1	9
Total	97	15	112

Source: Adapted from McCosker, J. E. and Lea, R. N., *Proceedings of the California Academy of Sciences*, 57, 479–501, 2006.

apply no significance. Nearly all attacked California water users were wearing neoprene (usually black) wet suits. However, this is no doubt a function of black being the most common color used in commercially produced wetsuits. We are unable to correlate attack behavior with the color of the wet suits, surfboards, or the kayaks used by the victims.

The activities of humans when attacked (Table 31.3) has shifted each decade, as new and different recreational activities have become more popular. The majority of attacks in California between 1950 and 1980 were upon swimmers and surface divers (often spearfishers or abalone divers). Attacks on hookah divers and scuba divers are rare. The increasing popularity of surfing, particularly using shorter and more maneuverable surfboards, has made surfers the primary target since the 1980s. Kayakers, windsurfers, and body-boarders (also called "boogie-boarders" or "belly-boarders") are becoming more common.

The trend in attack frequency during 5-yr. intervals has decreased since 1991–1995 (nineteen attacks). During this century, there are typically one to three attacks per year. We are unable to

Table 31.3 Confirmed Unprovoked Attacks by White Sharks upon Humans in the Eastern North Pacific (1950–2009)

	Swimmer	Surface Diver	Surfer	Hookah	Scuba	Kayaker	WS	BB
Washington			1		1			
Oregon			14					
Central and Northern California	6	33	32	6	5	5	1	2
Southern California	1					2		
Guadalupe Island		2						
Total attacks	7	35	47	6	6	7	1	2
Total fatalities	5	4	1	1		1		

Source: Adapted from McCosker, J. E. and Lea, R. N., *Proceedings of the California Academy of Sciences*, 57, 479–501, 2006.
"Surface divers" includes scuba divers, breathhold divers, and a hookah diver who were attacked while at the surface. WS, windsurfer; BB, body boarder.

correlate an increase in attack occurrence with extreme El Niño (Southern Oscillation) events. Only twelve fatalities have been recorded since 1950. The rarity of consumption of human victims in the NE Pacific remains unexplained. Consumption has been recorded in South African and Australian waters (Martin, 2003; West, 1996) but not to our knowledge in California, Oregon, or Washington. However, three bodies that we have reported in previous papers have not been recovered. It is certainly possible that humans reported as "missing at sea" or "drowned but not recovered" in the NE Pacific might have been consumed by White Sharks. It is difficult to fully explain the low fatality rate in the NE Pacific (~10% of victims), as compared with much higher rates in Chile (80%), Australia (34%), and South Africa (24%), but it is likely linked to differences in available medical response (McCosker and Lea, 2006) or variation in human behavior (e.g., use of the "buddy system") or possibly shark behavior between regions.

South Africa

White sharks occur along the entire South African coast (Compagno, 2001) and have been implicated in attacks in three of the four coastal provinces, namely: KwaZulu-Natal (KZN, formerly Natal), Eastern Cape, and Western Cape (Wallett, 1983; Cliff, 1991; Levine, 1996). Information on this species in southern Africa is summarized in Chapter 32, this volume.

In the last two decades (1990–2009), there were one hundred twenty shark attacks in the region. This equates to, on average, 6.0 unprovoked attacks per annum on the South African coast, of which 15% were fatal (Table 31.4). White sharks were responsible for nearly half (47%) of these attacks at 2.8 per annum; 21% of White Shark attacks were fatal ($n = 56$). Most (59%) of the White Shark attacks and the majority (67%) of those that were fatal took place in the Western Cape. This province is the center of the species' distribution in South Africa (Bass et al., 1975). It has all but three of South Africa's thirteen breeding and nonbreeding colonies of Cape fur seal *Arctocephalus pusillus pusillus* (Kirkman et al., 2006), many of which are on small islands within sight of the coast. The waters around these colonies are important feeding grounds for larger (>3 m total length) White Sharks (Ferreira and Ferreira, 1996; Martin et al., 2005; Hammerschlag et al., 2006; Kock and Johnson, 2006; Laroche et al., 2008). Given that larger White Sharks are more likely to regard humans as prey, it is not surprising that the incidence of both White Shark attacks and White Shark-inflicted mortalities is highest in the Western Cape, where these sharks are most common (Kock and Johnson, 2006), and decreases through the Eastern Cape to KZN.

In the warm temperate water of the Western Cape, White Shark attacks took place throughout the year with some evidence of a seasonal pattern; 51% took place between April and July. Of the victims, 39% were snorkel divers, 30% were surfers or other wave riders, and 15% were surf-ski riders paddling well beyond the surf zone. Only 9% were scuba divers. Of the snorkel divers, 69% were engaged in spearfishing. Spearfishers appear to be at greater risk than other recreational users

Table 31.4 Annual Number of Shark Attacks in Each of the Coastal Provinces of South Africa (1990–2009) and for the Entire South African Coast (1960–1990)

	All Shark Attacks per Annum	All Fatal Shark Attacks per Annum	White Shark Attacks per Annum	Fatal White Shark Attacks per Annum
KwaZulu-Natal	1	0.1	0.2	0
Eastern Cape	3.1	0.4	1	0.2
Western Cape	2	0.5	1.7	0.5
Northern Cape	0	0	0	0
Total (1990–2009)	6	0.9	2.9	1.2
Total (1960–1990)	3.3	0.4	1	0.2

of the sea, in that they often venture into very deep water, well beyond the surf zone and handle struggling, bleeding fish which are highly attractive to sharks.

White Shark attacks in the Eastern Cape averaged 1.0 per annum (Table 31.4), of which 16% were fatal (*n* = 19). All but one of the victims were board riders, most of whom were on a surfboard. The attacks took place throughout the year with a peak in July (32%). The Eastern Cape, which lies between the subtropical waters of KZN and the warm temperate Western Cape, has a single seal colony and is also thought to include the pupping grounds for this species (Cliff et al., 1996a; Dicken, 2008), although no pregnant female has yet been examined (Chapter 32, this volume).

In KZN there were, on average, only 0.2 White Shark attacks per annum, none of which were fatal (*n* = 4; Table 31.4). White sharks entering nearshore KZN waters are largely immature individuals and appear to be highly nomadic (Cliff et al., 1989, 1996a, 1996b). In the first half of the twentieth century, most South African shark attacks took place in KZN, with the bull shark probably responsible for many of them (Wallett, 1983; Cliff, 1991). The longstanding presence of shark nets, first introduced in Durban in 1952 (Cliff and Dudley, 1992), some recently replaced with drumlines and currently deployed at thirty-eight locations, has reduced the rate of shark attack at protected beaches by over 90% (Dudley, 1997). Only two serious but nonfatal attacks have taken place at protected beaches since 1980.

For South Africa as a whole, but not in KZN, there has been an increase in the total number of shark attacks with time. Between 1960 and 1990, South Africa experienced 3.3 attacks per annum, 11% of which were fatal (*n* = 103; Cliff, 1991; Table 31.4). In this period, there were 1.0 White AQ2 Shark incidents per annum, with a 16% fatality rate (*n* = 31). The increase from 1.0 to 2.9 White Shark attacks (3.3 to 6.0 total shark attacks per annum) is a feature not confined to South Africa and reflects a global trend in which more and more people are using the sea for recreation (Burgess and Callahan, 1996). By using wetsuits, board riders and divers can spend long periods in relatively cold water (Compagno, 1999). Both factors increase the exposure to sharks. The frequency of shark attack is not, however, simply related to the number of people in the water. The premier school holidays in South Africa are in midsummer—December and January—when beaches along the entire coast are at their busiest. Despite this, the number of White Shark attacks in these 2 months was only 14% of the total.

Australia

The first attack attributed to the White Shark in Australian waters was a fatality recorded in Victoria in 1839. Since then, White Sharks have been identified or implicated as the species involved in one hundred forty-seven attacks (one hundred twenty-six unprovoked to April 2010), and they represent the species responsible for the highest number of unprovoked attacks for any shark at 19.5% of all shark attacks in Australian waters. Of the attacks recorded, fifty (34.0%) have resulted in fatality, fifty-six victims (38.1%) sustained nonfatal injuries, and forty-one (27.9%) received no injuries. Attacks have been primarily confined to the southern regions of the continent, ranging from the vicinity of Brisbane in southeast Queensland (27.5° S latitude), around the south coast to the Abrolhos Islands in Western Australia (28.5° S latitude). This is more restricted than the Australian range of the species, which extends from at least Mackay in eastern Queensland to the Montebello Islands in northwest Western Australia (Bruce et al., 2006; Last and Stevens, 2009; Chapter 19, this volume; Figure 31.2). The highest numbers of White Shark attacks have been recorded in the state of New South Wales (NSW) followed by South Australia, Victoria, and Western Australia, respectively. However, the highest rate of fatality occurs in South Australia, with over 50% of attacks being fatal (Table 31.5).

White sharks are widely but not evenly distributed across their range in Australia, with South Australian waters generally having both a higher abundance relative to other states (based on commercial bycatch rates; Malcolm et al., 2001) and a relatively high percentage of medium to large

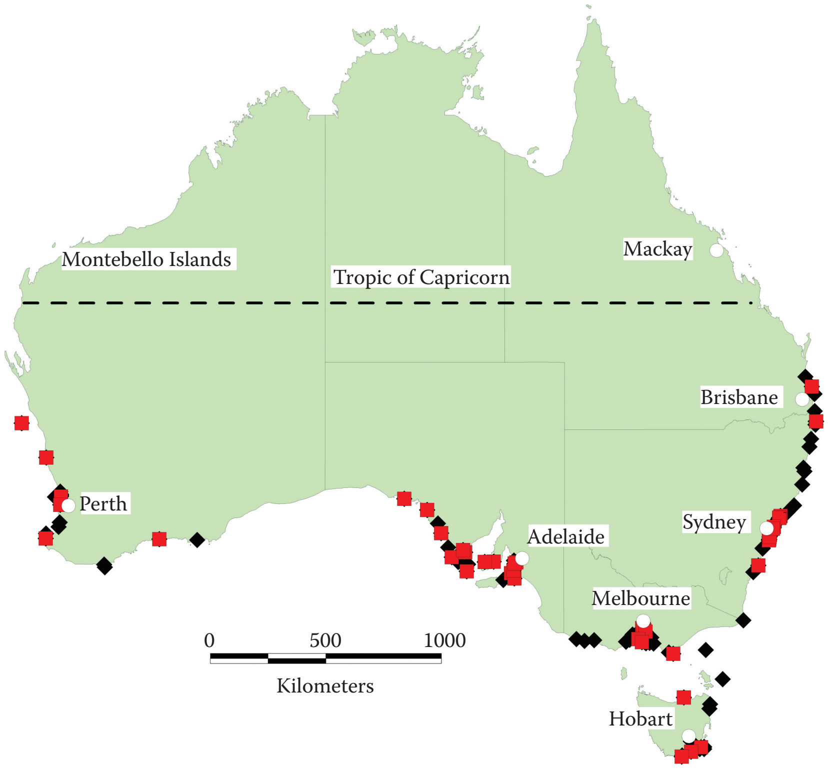

Figure 31.2 The locations of recorded White Shark attacks in Australian waters (1836–2010). Red squares indicate fatalities; black diamonds indicate that the victim was not injured or sustained injuries and survived.

sharks (>3.0 m) (Bruce, 1992; Malcolm et al., 2001). This probably contributes to the observed differences in fatality rate for that state. The high number of attacks by White Sharks in NSW is in part because of its populous nature, with the state holding approximately 33% of Australia's population, of which a large proportion is coastally located. Hence the number of people using the ocean for recreation is large relative to other states.

The veracity of lengths for White Sharks involved in attacks is difficult to confirm and notoriously overestimated, particularly when reported in the media. Length estimates of sharks involved in attacks range from <2.0 m to >6.0 m (Figure 31.3). However, unlike areas such as California (McCosker and Lea, 1996), a significant number (24%) of White Shark attacks have been attributed to juveniles (<3.0 m) and in most cases along open ocean, sandy beaches. White sharks more commonly appear at pinniped colonies at sizes >3.0 m in Australian waters, although occasional

Table 31.5 White Shark Attacks in Australian Waters by State (1839–2010)

State	Fatal (%)	Injured (%)	Uninjured (%)	Total
Queensland	1 (33.3)	2 (66.7)	0	3
New South Wales	13 (26.5)	19 (38.8)	17 (34.7)	49
Victoria	9 (32.1)	12 (42.9)	7 (25.0)	28
Tasmania	4 (30.8)	3 (23.1)	6 (46.2)	13
South Australia	17 (51.5)	10 (30.3)	6 (18.2)	33
Western Australia	6 (28.6)	10 (47.6)	5 (23.8)	21
Total	50 (34.0)	56 (38.1)	41 (27.9)	147

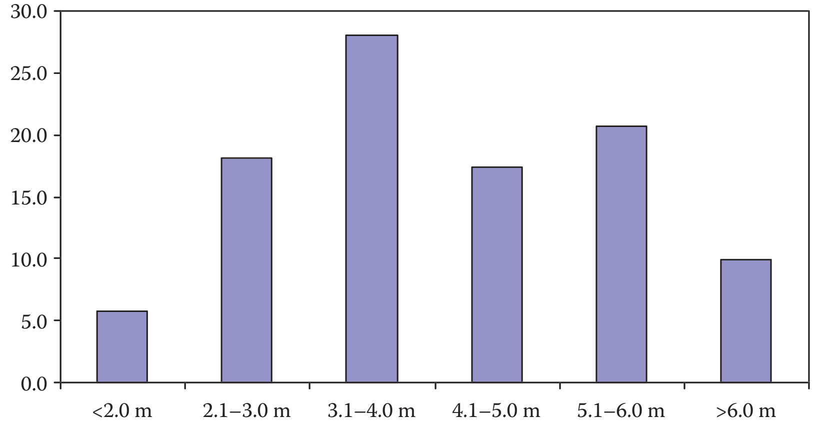

Figure 31.3 Frequency of size categories of White Sharks involved in attacks in Australian waters.

observations of sharks <3.0 m are made. The smallest White Shark examined with seal remains in its gut contents was a 2.7-m specimen examined by Bruce (1992). Thus, attacks in surf zones by juvenile White Sharks are unlikely to represent an attack scenario supportive of the mistaken identity theory proposed by Tricas and McCosker (1984) and McCosker (1985). The highest percentage of attacks attributed to juvenile White Shark in Australian waters, some as small as 1.8–2.0 m, occurs in surf zone localities in NSW (52%); the lowest occurs in South Australia (19%), again supporting encounters with generally larger sharks in the latter.

The occurrence of juvenile White Sharks in surf zones is well documented (Klimley, 1985; Chapters 14 and 17, this volume). In some areas of eastern Australia (e.g., the Port Stephens region of NSW and the Corner Inlet region of Victoria), juvenile White Sharks aggregate seasonally along restricted areas of the coast (Chapters 18 and 19, this volume). However, despite the abundance of juvenile White Sharks within size ranges capable of attack, very few attacks have been recorded at these aggregation sites despite the presence of swimmers and surfers and frequent encounters between sharks and people. On the other hand, higher numbers of attacks are recorded in areas where juvenile White Sharks are not known to be seasonally or temporarily resident. Clearly the abundance of White Sharks alone is not always a good predictor of shark-attack risk. This may be due to a difference in prey focus of the sharks in different localities and is likely to vary with shark size as well as location. In any event, White Sharks over 2 m in length should be considered potentially dangerous.

As in most other jurisdictions, the number of total shark attacks has risen per decade since records began (West, in press; Burgess and Callahan, 1996). The number of attacks attributed to AQ3
White Sharks in Australia has also risen significantly in the last decade from what was a reasonably stable figure of approximately 1–1.5 per annum in the 1920s through the 1990s (n = 99) to an average of 4.7 per annum in the 2000s (n = 48). West (in press) estimated that the number of beach AQ4
users in Australia rose by approximately 20% between 1999–2000 and 2008–2009 based on data on beach visitations and surf rescues from Surf Life Saving Australia.

The significant rise in attacks attributed to White Sharks in the 2000s cannot be accounted for by increasing population and sea-based recreational lifestyle changes alone. The rise equates to over a doubling of the rate of attacks per million persons since the 1990s. Increasing reporting and recording rates combined with the advent of the internet, mobile phones, digital cameras, more reliable identification of White Sharks as being the attacking species, as well as a growing awareness of the Australian Shark Attack File (affiliated with the global ISAF) may all have played a role in increasing the reports over the last decade. There were four main activities of victims involved in White Shark attacks: diving (including scuba, snorkeling, spear-fishing, and on hookah); swimming,

Table 31.6 Activity of Australian White Shark Attack Victims at Time of Attack

Activity	Total Number of Attacks	Number of Fatal Attacks	Percentage of Fatal Attacks
Diving	40	18	45
Swimming	37	20	54.1
Surfing	52	6	11.5
Water craft	14	2	14.3

surfing (surfboard or body-board), and watercraft use (including kayaks, surf skis, sailboards, and boats; Table 31.6). Interestingly, although surfing as an activity sees the highest number of attacks, it records the lowest frequency of fatalities, whereas swimming records the highest frequency of fatalities. This may in part be due to a surfboard providing some protection to the victim such that injuries are either lessened or are not sustained, whereas a swimmer without a board is more unprotected. However, there is a temporal component to these overall statistics, in that attacks on swimmers and swimming fatalities were primarily confined to decades prior to the 1950–1960s. This was also prior to the more recent popularity of surfing and to the development of current emergency medical response practices. The increasing efficacy of medical response teams, the rise of surf life saving organizations—with patrolled beaches, as well as the propensity to swim or surf in groups—whether intentional or driven by larger crowds at swim/surf localities, has no doubt decreased response times to victims after an attack and has lead to an increase in survival rate. The high level of fatalities in attacks on divers corresponds with the large size of sharks generally involved with those attacks and, to some extent, the remoteness of this activity to emergency services compared with most swimming and surfing activities.

Motivation for Attacks

There are essentially two motivations that cause sharks to attack humans: defense and hunger. When animals feel threatened, they experience conflicting instincts: one is to escape and another is to fight. If they are unable to flee because their opportunity to escape is blocked, they do not always fight but often perform an agonistic or defensive display. If such displays are not heeded, it can trigger, in some species of shark, an aggressive attack. Such displays are well described for the grey reef shark, *C. amblyrhynchos*, by Johnson and Nelson (1973). An agonistic display in the form of an aerial tail slap has been described for the White Shark by Klimley et al. (1996b) and was recorded by these authors directed both toward conspecifics and toward a vessel in the vicinity of pinniped kills or floating baits. Such behavior has rarely been associated with attacks by White Sharks on humans, although it is possible that the significance of some displays may not always be recorded by eyewitness or victim accounts.

The second, and more common, motivation to attack is hunger. Humans have rarely been consumed by White Sharks. However, the behavior of White Sharks during attacks on humans frequently reflects their known predatory behaviors. Human divers are often seized by White Sharks but usually released without being consumed, as explained by Tricas and McCosker (1984). Those authors proposed the "bite and spit hypothesis," whereby a feeding shark swims in mid-water, looking upward and mistakes a surface diver or surfer on a short surfboard for a pinniped (i.e., seals, sea lions). It then swims rapidly upward to seize and immobilize its prey and then will often retreat allowing the victim to lapse into shock or bleed to death, thereby reducing the potential injury to the shark caused by the teeth and nails of its presumed pinniped victim. Once a pinniped victim has been exsanguinated, the shark will return to feed on the body at leisure.

Although White Sharks may have a search image for pinnipeds, the variety of colors and shapes of objects struck at the surface in the turbid waters of central California, such as flotsam, a crab-pot buoy, an inflatable raft (Collier et al., 1996), or a marine kayak (McCosker and Lea, 1996), would indicate that they are not extremely selective. Although a particular object may not exactly resemble normal prey, the stimulus may be sufficient to trigger a predatory reaction (Burgess et al., 2010). Their ability to discriminate has been demonstrated during an experiment carried out in the clear waters of the Gulf of Spencer, South Australia, in which White Sharks were presented a square and seal-shaped object at the surface with a preference being shown toward investigating the latter (Strong, 1996). Available evidence indicates that when surfboards or kayaks of different lengths are in the water together, White Sharks show a higher rate of attack at the shortest of the group (McCosker and Lea, 2006).

In central California, the water conditions are turbid, with limited visibility unlike sites such as Guadalupe Island, Mexico, and the Neptune Islands, South Australia. Hence, it would be more difficult for a shark to see objects clearly at the surface in the former region, and this would likely support a feeding tactic of directing indiscriminate predatory strikes at any object at the surface. However, in situations where a shark can discriminate a novel object at the surface, it may attempt to gauge its palatability with low impact investigatory bites. If the texture, taste, or odor of the object deems it edible, the shark may commence more typical predatory feeding behavior. White shark bites on humans are often consistent with "investigative strikes," but because of the White Shark's large size and dentition, such bites can still cause severe damage (Burgess and Callahan, 1996).

The observations of natural predatory events on seals have been used extensively in the literature to interpret attack patterns on humans. Much of this work has been carried out at the Farallon Islands off central California (Klimley et al., 1992, 1996a). Researchers observing feeding White Sharks often noticed first the appearance of blood-stained water and only later could see the seal float to the surface. What was significant was that the carcass did not exude blood when it rose to the surface. This lead to the hypothesis that the sharks carry their prey under water until it exhausts its blood supply and dies due to asphyxiation, a predatory strategy termed exsanguination (Klimley, 1994; Klimley et al., 1996a). The remaining carcass of the prey, which at this time was immobile, was consumed without hesitation. This behavior contrasts with the seeming hesitation in consuming a human. Humans have been partially consumed by White Sharks (Engaña and McCosker, 1984; Martin, 2003), and there are attacks where the victim's body has not been retrieved and presumed to have been completely consumed (West, in press). However, an entire human has yet to be found AQ5 in the stomach of a White Shark (Burgess and Callahan, 1996). For all practical purposes though, the capture of a White Shark after an attack has occurred is rare, and particularly in cases where the victim is not recovered. Over 50% of the divers seized either are released without taking a bite or with a single bite inflicted to the body. This is consistent with the sharks not having a preference for humans.

An explanation proposed was that White Sharks prefer to feed on seals and sea lions because of their energy-rich, external fatty layer. This layer comprises roughly half of the body weight of returning yearlings and has twice the caloric value of muscle tissue (Klimley et al., 1996b). Evidence cited to support this hypothesis is drawn from observations that White Sharks tend not to feed upon lean prey at certain locations. A White Shark was observed to strike a pelican at South Farallon Island, but it refrained from feeding further on it (Klimley et al., 1996a). The carcasses of sea otters often wash up on the beaches of Santa Cruz, California, with White Shark tooth fragments embedded in their skin, yet they do not have any part of their body missing from a bite (Ames and Morejohn, 1980). Although White Sharks commonly scavenge whale carcasses in many oceans (Curtis et al., 2006), White Sharks prefer not to feed on rotting prey at the Farallon Islands (Klimley et al., 1996a). White sharks at the Farallones fed on fatty tissue, in which transmitters were embedded, removed from a seal (Goldman et al., 1996). However, a shark did not feed on the muscular tissue of a seal, from which the fat was removed (Klimley et al., 1996b). The propensity for White Sharks to target seal prey around the site of seal colonies is not unexpected, and in such locations, their preference to do so over other prey may be driven by feeding on seals being the reason for sharks visiting such areas in the first place. More experiments are needed to support the above mentioned hypotheses in order to establish their veracity under different situations and locations.

White sharks, even large individuals, are not obligate pinniped predators, and recent analyses of chemical signatures of vertebrae suggest that some sharks may rarely feed on pinnipeds (Estrada et al., 2006; Kerr et al., 2006). Large sharks (>3.0 m) are known to target pinniped prey during certain seasons, but they also feed on a variety of finfish, elasmobranchs, and invertebrates that lack fatty tissues in other locations and at other times of the year (Bruce, 1992; Casey and Pratt, 1985; Klimley, 1985). White sharks make regular long-distance migrations away from seal colonies into areas where pinnipeds are rare (although cetaceans may be common), moving through a wide variety of marine ecosystems from coastal to open ocean, cool temperate to tropical waters (Boustany et al., 2002; Bonfil et al., 2005; Bruce et al., 2006; Weng et al., 2007; Domeier and Nasby-Lucas, 2008; Jorgensen et al., 2009; Nasby-Lucas et al., 2009). Predatory strategies and prey preferences consequently vary depending on where sharks occur. Therefore the behavior of White Sharks during attacks on humans may not always reflect pinniped-predation strategies. Elucidating the reasons why White Sharks attack humans across the range of shark habitats and their behavior during and after attack sequences is a fertile area for new research that may provide some clues as to how to further minimize the risk of White Shark attack.

REVIEW OF METHODS OF RESPONSE TO THE RISK OF SHARK ATTACK OR IN THE AFTERMATH OF SUCH ATTACKS

Removal of Sharks

Shark "Hunts"

Historically, the most common response to high profile or multiple shark attacks in an area was to initiate a public shark hunt. A number of fishing vessels would voluntarily go out to sea, deploy a variety of gear (rod and reel, longline, gillnet, harpoon, etc.), and attempt to harvest as many sharks as possible in the hope of capturing the "culprit" shark. This type of response was portrayed in the fictional Peter Benchley novel and Steven Spielberg film *JAWS* and has been documented to occur in the United States (Fernicola, 2001), Australia, and South Africa in the past. These tactics typically lacked organization or any coordination of fishing effort. Larger-scale hunting efforts would typically subside after days or weeks, providing only temporary results. Sharks of several species would sometimes be landed, often including small individuals or species not likely to attack humans.

The capture of the shark responsible for an attack is exceptionally rare and is difficult to confirm, given the low likelihood of finding human remains even if the appropriate shark was caught. In general, the motivation to undertake such hunts are due to a perceived risk that the shark may remain active in the area and may therefore strike again or that having attacked a human in the area the individual shark may become predisposed to doing so again. White sharks are highly mobile animals that can travel 70–100 km over the course of a day (Boustany et al., 2002; Bruce et al., 2006) and may quickly leave the general vicinity of an attack. Multiple White Sharks may also be present in the area of an attack or may visit the area under their normal movement patterns over time. The chances of catching the shark responsible after an attack by fishing in the immediate vicinity can therefore be low, and the risk of killing the wrong shark may be high under some situations. There is no evidence to support the notion that White Sharks having once attacked a human are any more or less likely to do so again. Therefore, the effectiveness of shark hunts for preventing subsequent attacks is likely to be low and in most cases is difficult to ascertain (Wetherbee et al., 1994).

In more recent years, White Sharks have been protected in many parts of the world under either fisheries or conservation-based legislation, and their indiscriminate killing is either restricted or illegal. Some jurisdictions where White Sharks are fully protected maintain the option to kill individual sharks should they represent a clear public danger (e.g., Western Australia and South Australia), but such actions are only considered a last resort and generally require case by case Government approval under strict protocols (see section below on shark-response plans). Given the lack of evidence for the effectiveness of shark hunts, this approach is not currently considered an efficient means to consistently reduce the risk of shark attack, and support for such actions has been short-lived in instances where it has been trialed (Holland et al., 1999).

Shark Culling

A shark "culling," or control, program is defined here as a government-controlled shark-fishing effort, designed to reduce the number of potentially dangerous sharks in an area of human use and thus reduce the risk of human-shark encounters and attack frequency. These programs are typically carried out by Government Departments or contracted fishing crews and vessels. They tend have more standardized effort than shark hunts. They may be intensive programs run over relatively short-term periods in the form of commercial-style longlining or the deployment of nets or baited lines (e.g., drum-lines) in specific localities on an ongoing basis.

Short-Term Shark-Control Programs

One of the most well-documented short-term shark-culling programs was the series of fishing activities conducted in the Hawaiian Islands (Wetherbee et al., 1994). The primary targets and the drivers for initiating this program were attacks by species such as tiger sharks (*Galeocerdo cuvier*). However, White Sharks occur in the Hawaiian Islands (Taylor, 1985; Wetherbee et al., 1994; Boustany et al., 2002); they have been implicated in attacks on humans there (Taylor, 1993; Wetherbee et al., 1994), and thus they were featured as one of the species of concern. Human remains were found in a 3.5-m White Sharks caught off Oahu in 1926, and a surfer was confirmed bitten by a White Shark off the island of Oahu in 1969 (Taylor, 1993). As a result of several notable shark attacks in the late 1950s and early 1970s, the State of Hawaii funded two major shark-culling programs around the main Hawaiian Islands (MHI) between 1959 and 1976. The objectives of these programs were to determine what species of sharks were found in Hawaiian waters and to reduce their population numbers based on the assumption that reducing the numbers of sharks in near-shore waters would reduce the probability of attacks on humans (Wetherbee et al., 1994). Extensive longline fishing for sharks was conducted around all the MHI, resulting in the culling of over 2,849 sharks, comprising mostly sandbar (*Carcharhinus plumbeus*) and tiger sharks. Out of a total of 36,122 hooks set throughout both control programs around all MHI, only two White Sharks were captured during the 1959–1960 program (Wetherbee et al., 1994).

Despite large numbers of sharks caught and killed, Wetherbee et al. (1994) found no evidence of a subsequent reduction in shark attacks. The 1990s saw a renewed call for shark culling in Hawaii after a series of widely publicized attacks. However, because of the expense of mounting a repeat operation, the recognition of the potential ecological ramifications of removing large numbers of sharks, and cultural opposition to shark culling, the state opted to fund studies of shark behavior as an alternative, as well as smaller-scale "targeted" hunts, as discussed above, the latter in attempts to capture sharks potentially responsible. Public education about sharks, their ecology, and their behavior obtained from targeted research significantly reduced public outcry following attacks and eliminated the state's support of targeted hunts, particularly because movement data indicated that tiger sharks could travel up to 30 km/day and easily move between islands (Holland et al., 1999; also see discussion under "Electronic Tags" below).

Ongoing Shark-Control Programs

Permanent or semipermanent deployment of shark-fishing gear off high-use beaches as a means of reducing the risk of shark attack has been utilized in several countries. Two types of gear are generally used: large-meshed, anchored gillnets (Figure 31.4) and drumlines, which consist of a large baited hook suspended from an anchored float (Queensland Department of Primary Industries and Fisheries, 2006; Dudley, 1997; Green et al., 2009). Neither of these gear types create barriers between the open sea and the beach front but are used as fishing apparatus to catch and remove a percentage of the sharks that occur in the area. Nets are typically up to 200 m in length, may be set singularly or in multiple configurations, are either surface or bottom set, and do not extend throughout the entire water column. Nets were first deployed off certain beaches in New South Wales, Australia, in 1937 (Collins, 1972; Coppleson, 1962; Reid and Krogh, 1992) and off KZN, South Africa, in 1952 (Davies, 1961, 1964; Dudley, 1997 and references therein). A mix of nets and drumlines was introduced off the beaches of Queensland, Australia, in 1962 (Dudley, 1997; Paterson, 1979), and nets were first deployed off Dunedin, New Zealand, in 1969 (Francis, 1998). In 2004, a combination of drumlines and two longlines with one hundred hooks each was deployed off Recife, Brazil (F.H.V. Hazin, personal communication in Dudley, 2006). In Queensland, such gear is deployed permanently, but deployment is seasonal in NSW (September to April) and Dunedin (December to February), and in KZN, the gear is removed at affected beaches during the annual winter "run" of sardines (Armstrong et al., 1991) in order to avoid catches of predators accompanying sardine shoals (Dudley and Simpfendorfer, 2006).

The rationale behind these programs is that long-term fishing reduces local numbers of potentially dangerous sharks, thereby reducing the likelihood of an encounter between sharks and humans, hence achieving a reduction in the risk of shark attack (New South Wales Shark Menace Committee, 1929; Cliff and Dudley, 1992; Davies, 1961, 1964; Dudley, 1997, 2006; Last and Stevens, 1994; Paterson, 1979; Springer and Gilbert, 1963). The two Australian operations and that in South Africa are the largest, each operating at a number of discrete beach locations distributed over large stretches of coastline (Paterson, 1990; Queensland Department of Primary Industries and Fisheries, 2006; Dudley, 1997; Green et al., 2009). Numbers of shark attacks prior to the introduction of protective measures were not high in absolute terms (Collins, 1972; Wallett, 1983; Paterson, 1986; Cliff, 1991; Queensland Department of Primary Industries, 1992), but each program was introduced because sufficient attacks had occurred to elicit concerns for public safety and because

Figure 31.4 Staff of the KwaZulu-Natal Sharks Board removes a White Shark from the protective beach nets off Durban, South Africa. (Courtesy of KZNSB.)

of the potential negative economic effect on tourism, which is important to each region (Dudley, 2006 and references therein).

All of the programs have been very successful in reducing the incidence of shark attack at the protected beaches (Paterson, 1990; Queensland Department of Primary Industries and Fisheries, 2006; Dudley, 1997, 2006; Green et al., 2009). In KZN, for example, twenty-one attacks occurred at the beaches of the largest city, Durban, in the decade prior to the introduction of nets in 1952 (Wallett, 1983), but there were no incidents involving large sharks in the subsequent 58 yrs. (KZN Sharks Board, unpublished data). Elsewhere in KZN, nets reduced by over 90% the number of incidents occurring per annum. Similar success has been reported for the other programs, but given that neither nets nor drumlines physically prevent sharks from entering a protected bathing area, shark-fishing gear does not eliminate attacks completely.

The bull shark was probably responsible for the bulk of attacks in the years prior to the introduction of shark-control programs at each of the above locations other than Dunedin, with a lesser number of incidents probably attributable to the White Shark and the tiger shark (Cliff, 1991). Through long-term fishing, the nets and drumlines are thought to have removed bull sharks that were locally resident in the vicinity of each protected beach (Wallett, 1983; Cliff and Dudley, 1991). The gear does also have the potential to catch itinerant white and tiger sharks moving through an area and, indeed, given the near-cessation of all shark attacks at protected beaches subsequent to the introduction of fishing gear, incidents attributable to these species have also declined. At Dunedin, all attacks prior to the introduction of nets are believed to have been by White Sharks, and these attacks ceased with the introduction of nets, although no captures of White Sharks were reported by the program after accurate records were established from 1986 to 1991 (Francis, 1998). White sharks were, however, reportedly caught by the program during the 1970s. It is probably not coincidental, however, that the two attacks by large sharks that occurred at protected beaches in KwaZulu-Natal in the 30-yr. period 1980–2009 were attributable to itinerant White Sharks rather than resident bull sharks (KwaZulu-Natal Sharks Board, unpublished data), suggesting that the effectiveness of the gear is lower in the case of nonresident animals.

None of the programs operate at known White Shark aggregating sites, and catch rates of White Sharks in the KZN program, for example, showed no trend over the period 1978–2003 (Dudley and Simpfendorfer, 2006), suggesting that catches in that program are sustainable or do not provide an effective index of population size. The deployment of shark-fishing gear, whether nets or drumlines, at White Shark aggregating sites would almost certainly reduce the number of White Sharks and hence overall risk of attack, but it is likely also that long-term fishing for White Sharks at such sites would have a significant effect on the population and may be unsustainable.

The benefit of the long-term deployment of shark nets and drumlines, particularly in locations where locally resident bull sharks are responsible for the majority of shark attacks, is that the rate of occurrence of attacks is reduced significantly, with positive consequences for public safety and tourism. There are costs, however, that include the following:

1. The financial cost of maintenance of the gear, which requires regular servicing and, in the case of drumlines, rebaiting of the hooks
2. The fact that the mechanism for providing protection is shark fishing; i.e., it is an extractive process
3. The bycatch of animals that pose no potential threat to people in the water

(Cliff and Dudley, 1992; Collins, 1972; Dudley and Cliff, 1993; Dudley and Simpfendorfer, 2006; Keith et al., 2002; Krogh, 1996; Natoli et al., 2008; Paterson, 1979, 1986, 1990; Reid and Krogh, 1992; Simpfendorfer, 1993). In the case of nets, this bycatch includes dolphins, rays, turtles, and, occasionally, large teleosts. Drumlines are more selective than nets and take a considerably reduced bycatch (Dudley et al., 1998), but an installation consisting of drumlines only may not provide the same level of protection as an installation consisting of mixed gear (Gribble et al., 1998).

In KZN, various measures have been implemented to reduce catches of marine animals, including:

1. An overall reduction of the quantity of gear deployed per beach
2. The replacement of some nets with drumlines
3. The removal of fishing gear during the annual sardine run
4. The release of all live animals, with most released sharks being tagged for research purposes
5. The attachment of acoustic devices to the nets in an attempt to deter marine mammals

Also, sharks that do not survive capture are retained for research purposes, thereby ensuring that the biological material is not wasted. Some of these measures have also been implemented in one or more of the other programs (Green et al., 2009).

Nonfishing Methods for Minimizing Risk of Shark Encounter and Attack

Beach Closures

Beach closures are a precautionary action aimed at reducing the risk of shark attack when the risk of attack is higher than normal. In most cases, beaches are closed in the following instances:

1. Following a shark attack in the vicinity
2. When shark sightings are higher than usual for areas that have regular sightings
3. When a shark is sighted in an area that is not well known for shark sightings

Beaches have also been closed when there has been an abundance of potential prey in an area (i.e., schools of fish, seal haulouts, or when a large cetacean has stranded because these are well known for attracting sharks). Beach closures can last from a few minutes to days, depending on the situation and managing authorities. Beach closures are relatively easy to implement provided adequate staff are available to alert swimmers to get out of the water, and temporary signs should be erected to warn water users that the beach is closed. Beach closures are a low-cost way to reduce the risk of shark attack. However, beach closures are only a temporary solution and may cause locals and visitors to leave the area. Guidelines for beach closures should be drawn up for each area to ensure that beaches are closed only when appropriate, because frequent beach closures can frustrate water users and impact local business (Chapter 29, this volume). However, the effect of a shark attack on local business would be far greater, and so beach closures are justified. Examples of such guidelines can be found at http://www.slsa.com.au/site/_content/resource/00000298-docsource.pdf.

Shark Barriers

Mechanical barriers, or shark fences, have been erected in various parts of the world as a means of physically excluding sharks from bathing areas. Barriers have been constructed of various materials, including small mesh nets (too small to capture animals and thus different from mesh nets used to catch sharks), concrete, wooden or steel pylons, rocks, etc. These have tended to be erected at locations in sheltered waters given the difficulty of maintaining such structures in surf conditions. Probably the most well-known examples, consisting of small mesh or vertical steel bars, are at beaches found in Sydney Harbor (Green et al., 2009). Barriers also exist in Queensland's Gold Coast canal system and at other Queensland locations (Queensland Department of Primary Industries and Fisheries, 2006; Dudley and Gribble, 1999). Shark barriers have been constructed in the past at a number of other sheltered locations, including Florida, Croatia [I.K. Fergusson, personal communication (in Dudley and Gribble 1999)], Panama (Springer and Gilbert, 1963), and
AQ6 Maputo, Mozambique (Da Graça, 2005).

Attempts have been made to construct shark barriers at surf beaches. In 1907, a semicircular enclosure with a diameter of 183 m (600 ft) was constructed of steel piles and vertical steel grids in the surf at Durban, KZN (Davies, 1964). It was demolished in 1928 because of damage caused by wave action and corrosion, and because of high maintenance costs (Davies, 1964). Barriers of various designs were constructed at several beaches on the KZN south coast after a number of attacks occurred in the late 1950s, and again maintenance in surf conditions was difficult (Davies, 1964), with the barriers eventually proving impractical (Wallett, 1983). A fence was built at the surf beach at Coogee, New South Wales, in 1929 (New South Wales Legislative Assembly, 1935) but again proved impractical and costly to maintain and ultimately was abandoned (Coppleson and Goadby, 1988). There is one location, Hong Kong, where shark barriers currently are maintained in surf conditions, although swell size is typically small at most of the protected beaches (Dudley, 2006). Maintenance is difficult, however, and costs are high (Dudley, 2006; Green et al., 2009).

Shark Spotters and Aerial Surveys

Another method used to reduce the risk of attacks is to use visual surveys in the form of land-based “spotters” or aerial surveys from planes or helicopters at beaches where the propensity for encounter with sharks is high. In areas where water visibility is sufficient to see a large shark approaching a bathing area, spotters on the ground or in the air can relay the sighting to lifeguards and warn swimmers of the potential danger. Historically, temporary spotting has been conducted by lifeguards and through aerial surveys at particular beaches, but within the last 6 yrs., a permanent (the first of its kind) land-based spotter program has been implemented in Cape Town, South Africa (Chapter 29, this volume). A summary of the program is described below.

“Shark Spotters” is a shark-safety and outreach program used in Cape Town, South Africa. The objective is to reduce the risk of shark attack by warning water users when sharks are in close proximity and then closing the beach. Shark Spotters is part of an overall safety strategy that includes research on White Shark spatial and temporal patterns and public education. The initiative was driven at the community level after a spate of fatal and major shark attacks on recreational water users (Oelofse and Kamp, 2006). Shark Spotters are positioned at strategic points along the Cape Peninsula, primarily along the False Bay coastline. The program currently employs fourteen to twenty-eight spotters at five to ten of Cape Town’s popular beaches (numbers are seasonally dependent) throughout the year (Chapter 29, this volume). The shark spotters scan coastal waters for sharks from an elevated platform above the beach during daylight hours, 7 d a week. A standardized protocol using four informational flags and a shark siren warn water users of the nearby presence of sharks. Upon hearing the warning, the beach is closed, and water users exit the ocean and wait until the shark spotters give the “all clear” sign before returning to the water. Two spotters are positioned at each beach. One spotter is placed on the mountainside equipped with polarized sunglasses to remove glare and improve spotting conditions and binoculars for close-up scans. This spotter is in radio contact with a second spotter located on the beach. The spotter on the beach is in charge of changing the flags to communicate that a shark has been seen, assisting water users in getting out of the water, and providing on-site explanation of the situation. Both spotters have the ability to set off the warning siren when a shark is in close proximity to water users. Daily data are recorded on the number of sharks detected, shark behavior, sea conditions, and the number of water users (Chapter 29, this volume).

The Shark Spotters program has proven to be an effective warning system with a total of six hundred nineteen shark sightings recorded since the start of the program in November 2004 until December 31, 2009. Consistent data collected on shark sightings provide seasonal and regional information on shark sightings, which can be used to predict higher risk areas and times of the presence of sharks and therefore the likelihood of shark attack. Constant monitoring allows for the identification of high shark activity and can be used to issue shark alerts and press releases or close beaches. Information collected on shark behavior (e.g., distance sharks swim from shore) can be used to keep safety tips current for specific areas. The program provides job opportunities and skill development for previously disadvantaged nationals. Shark spotters are accessible to the public on a daily basis, which plays a valuable role in education and outreach to both locals and visitors. Scientists can benefit from the program by being notified of shark sightings close to shore in those cases where tagging of animals is necessary. The annual budget to run a shark-spotting program is relatively low compared with other methods (i.e., exclusion nets or antishark gillnets) (Oelofse and Kamp, 2006).

One of the limitations of the program is that not all sharks may be spotted, which means there is still a risk of shark attack. However, this is arguably the case in all other methods implemented to reduce risk with the exception of shark barriers. White sharks in the False Bay area are large, may spend lengthy periods near the surface, and are often readily visible over open sandy areas in the vicinity of surf beaches which makes detection easier for spotters (Figure 31.5). Spotting smaller sharks or species that do not spend a lot of time at the surface could be more difficult (e.g., bull sharks). Poor weather and sea conditions and glare influence the ability of shark spotters to see sharks and can reduce the effectiveness of the spotters. The program is restricted to beaches with an elevated platform nearby and ideally a sandy bottom to allow for the dark silhouette of a shark to be visible from above. The program is open to human error, because constant observation and concentration are difficult. The spotters often have to operate in poor conditions, i.e., rain, cold, heat, or wind. To address the problem of spotter fatigue, daily shifts should be as short as possible. The program is most beneficial for swimmers and surfers, whereas there is limited benefit for divers and kayakers using waters further away. Managing public expectation of the program is crucial to address concerns of liability and to make sure that water users do not feel a false sense of security. It needs to be communicated adequately that shark spotters are not responsible for water-user safety, and entering the ocean will be at the individual's own risk.

Aerial surveys of high-risk beach areas using small planes or helicopters can also be used to inform beachgoers of the presence of a potentially dangerous shark (Figure 31.5). Such surveys have been attempted sporadically in the United States, South Africa, and Australia, but they have similar limitations to land-based shark spotters and can be more costly, and because of the nature

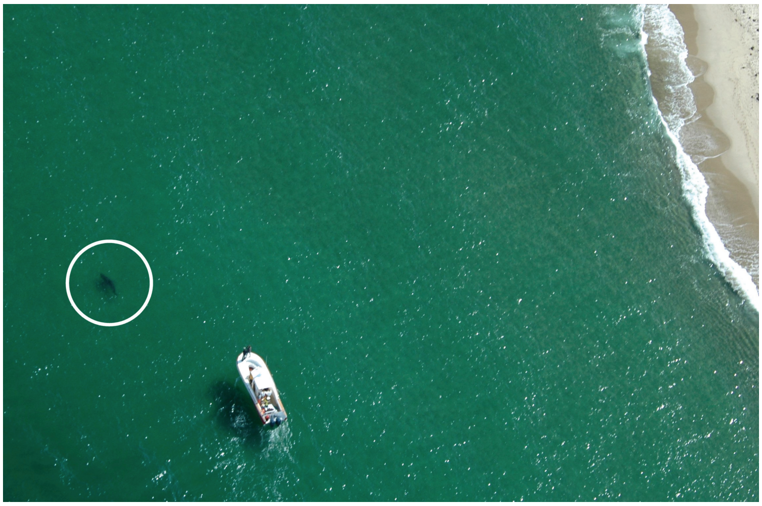

Figure 31.5 Aerial photograph of a White Shark (see circle) patrolling a Massachusetts beach. (Courtesy of Dan McKiernan, Massachusetts Division of Marine Fisheries.)

of aerial observation, these programs are limited in the amount of time that continuous observation is possible.

Research

Increased knowledge can clearly be an effective tool when considering a variety of management strategies. The field of research on White Sharks has dramatically expanded over the last 50 yrs., providing us with many of the insights that we are able to share throughout this volume. Much of shark research, particularly in the early years, was carried out with shark-attack prevention as its primary goal. Continued research in regions with relatively high shark-attack frequencies can therefore be very beneficial for developing strategies to reduce the risk of attack. In many cases, shark-attack prevention efforts themselves have helped improve the body of knowledge on the attacking species (Cliff et al., 1989, 1996a; Wetherbee et al., 1994).

Data collection, of course, is the key to successful research efforts. Data from shark attacks or from any shark monitoring or control efforts should be collected in a standardized fashion. Any available information from a shark-attack incident should be compiled and shared with the ISAF, or regional shark scientists that collaborate with the ISAF. As the number of cataloged attack events increases over time, more patterns, correlations, or activities can be identified that are associated with the risk of shark attack (Baldridge, 1996; Burgess and Callahan, 1996; Burgess et al., 2010). The same is true for data collected from any of the shark-control methods described here. Data collection protocols should be an integral part of any program upon its implementation.

Focusing research in areas that have a high risk of shark attack can help identify shark behaviors or environmental conditions that may contribute to the presence of sharks in high-use areas and hence the risk of interactions and attacks. Such research can be purely observational, such as visually monitoring natural predatory activity (Klimley et al., 1992, 1996a), photographing or tagging individual sharks for mark-recapture analyses (Klimley and Anderson, 1996; Domeier and Nasby-Lucas, 2006), or more technologically sophisticated research using electronic tags to track the movements and behaviors of individual sharks (Goldman et al., 1996; Klimley et al., 2001; Jorgensen et al., 2009; Chapter 17, this volume). Using data derived from well-designed research efforts, scientists and managers will have the tools to implement meaningful measures to:

1. Control anthropogenic activities that may impact the sharks
2. Establish protocols and procedures for the prevention of shark attack
3. Educate the public to allay the fear of shark attack

Electronic Tags

The rapid development of fish-tagging technologies in recent years has provided the scientific community with exciting new insights into fish movements. There are currently a variety of acoustic, archival, and satellite-linked telemetry devices that can be attached to sharks to study migration, site fidelity, physiology, behavior, and ecology (Goldman et al., 1996; Lowe and Goldman, 2001; Klimley et al., 2001; Boustany et al., 2002; Bonfil et al., 2005; Weng et al., 2005; Bruce et al., 2006; Domeier and Nasby-Lucas, 2008; Sims, 2010). Results from such studies have not only vastly improved our understanding of the biology of sharks but have also proven useful in fisheries management and conservation.

As noted above, electronic tags also clearly have the potential to aid in shark-attack response decision-making. For example, Holland et al. (1999) tracked the movements of tiger sharks off Hawaii to determine their level of site fidelity. Managers wanted to know whether fishing for sharks near the site of a recent attack would be likely to capture the shark responsible for the attack. If tiger sharks demonstrated a degree of site attachment, then fishing near the attack location would make capturing the "culprit" shark more likely. However, the tracking study demonstrated that tiger sharks ranged widely and made long-distance offshore movements within 24 h of tagging near the coast. Given the tiger shark's expansive home range, Holland et al. (1999) concluded that shark-culling programs would not be effective at reducing the frequency of attacks from this species, and fishing near an attack location would be unlikely to result in capture of the culprit shark. Hawaii has since suspended its shark-control programs.

Satellite tagging of large White Sharks has revealed that they also make long-distance movements into offshore environments (Boustany et al., 2002; Bonfil et al., 2005; Bruce et al., 2006; Weng et al., 2007; Domeier and Nasby-Lucas, 2008; Nasby-Lucas et al., 2009; Jorgensen et al., 2009), but during certain times of the year they demonstrate site fidelity to feeding grounds near pinniped colonies (Goldman et al., 1996; Klimley et al., 2001). Beach areas in close proximity to natural White Shark feeding grounds, therefore, may have a higher than average risk of encounter and attack. Tagging White Sharks with transmitters can provide long-term data on patterns of seasonal occurrence, as well as daily movements in and out of these beach areas. It can also enable areas of temporal residency *versus* transit beach areas to be identified and thus inform focused efforts for monitoring beachgoer safety (Chapters 17 and 19, this volume). Correlations with physical and biological parameters can also be identified to provide a potential predictive ability for the movement of White Sharks into beach areas (Chapter 19, this volume).

Tagging technology is currently available to provide beachgoers with an "early warning system," utilizing receivers that detect the presence of tagged sharks and immediately alert beach safety authorities onshore. Although there are numerous potential benefits in the use of this technology, both for beachgoer safety as well as scientific advancement, the costs are quite high. For such an early warning system to be effective, large numbers of White Sharks would have to be tagged, but monitoring every individual shark in the population is not possible. There is always the potential for an untagged shark to move about undetected. The life expectancy of these tags is also finite (up to 10 yrs. with current batteries), so sharks have to regularly be re-tagged throughout their lifespan, which can be a costly and time-consuming process. However, such programs offer opportunities to identify conditions that may predispose higher risk of shark encounters and hence direct surveillance resources during such periods. As electronic tag technology continues to improve, such efforts may become more cost-effective. Research both past and present on shark movement patterns, temporary residency, and behavior provide considerable information for decision makers, and continued research should be encouraged.

Education, Outreach, and Preparedness

Providing current information on sharks, shark attack, and safety tips are a crucial part of any shark-safety strategy. By increasing the level of understanding in the public, one can reduce the hype and fear that goes along with a shark attack. Education can also help beachgoers be aware of high-risk behaviors. Timely shark alerts can reduce the risk of shark encounter and attack. It is important to provide information on sharks to the public throughout the year and not only in the event of a shark attack. Education and outreach is relatively low cost to implement. However, outreach programs can be time consuming, and the information content of such programs needs to be kept current. Shark researchers should be encouraged to share their research findings with the public in the interest of outreach.

Various media are available to communicate information to the public. These include the following:

1. Warning and educational signage at beaches (Figure 31.6)
2. Brochure or pamphlets easily available in local stores or in parking areas
3. Regular newsletters and/or Internet blogs

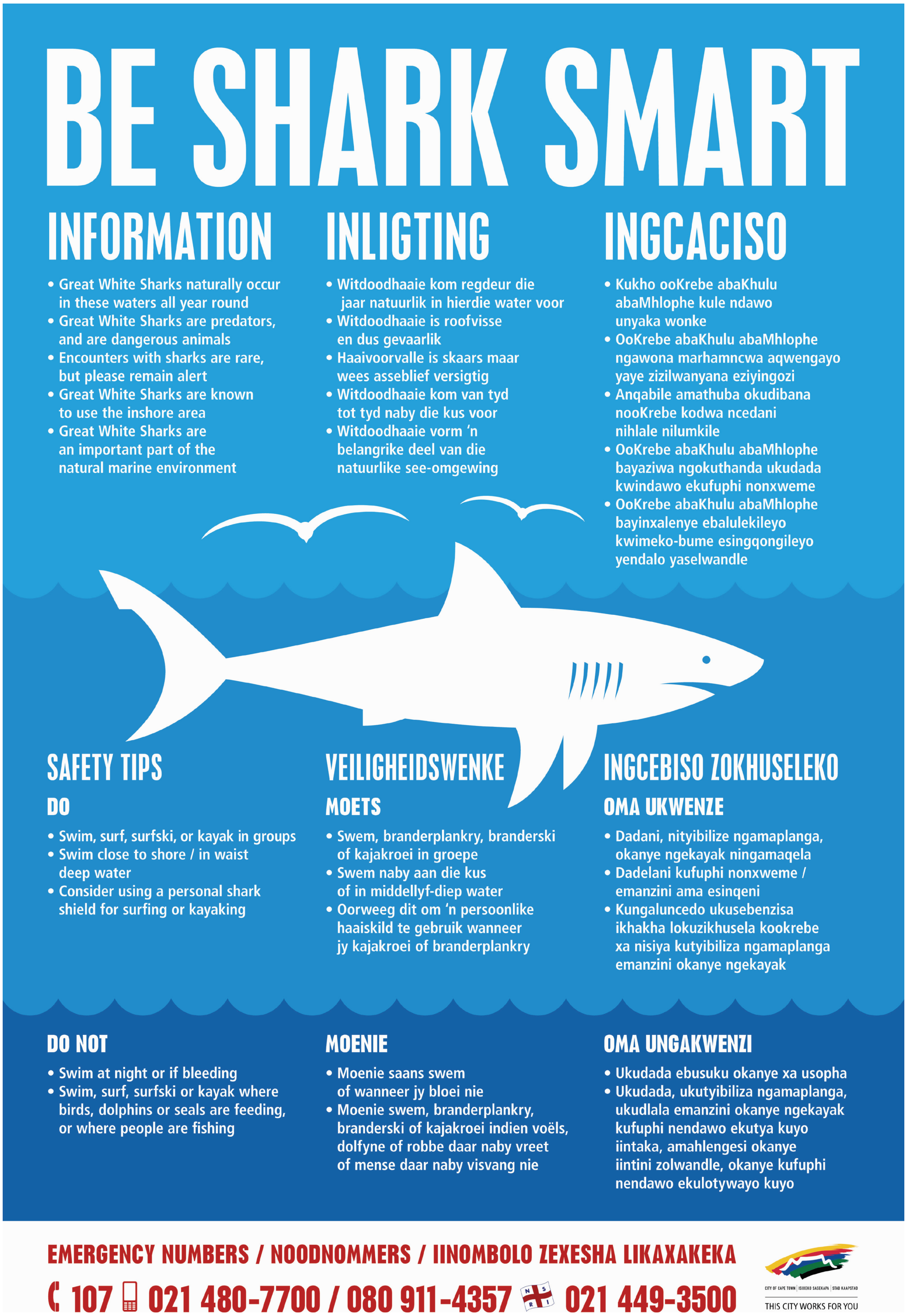

Figure 31.6 Multilingual signage used to educate beachgoers about shark-attack risk in South Africa. (Courtesy of City of Cape Town.)

4. Press releases
5. Newspaper articles
6. Popular articles in magazines
7. Websites with up-to-date information
8. Presentations to various clubs and organizations
9. Radio and/or TV reports
10. Informational stands at beach and surfing festivals
11. Social networking websites (e.g., Twitter or Facebook)

In many cases, shark behavior cannot be predicted or controlled. However, beachgoers can control their own behavior and should be encouraged to avoid high-risk activities that may increase the probability of encounter with White Sharks. There are numerous documents on government and nongovernment agency websites that provide guidance for beachgoers, and the common themes include simple and arguably effective guidelines for minimizing the risk of encounter and shark attack as follows:

1. Swim at a patrolled beach and between the safety flags.
2. Leave the water immediately if a shark is sighted.
3. Do not swim alone or too far from shore.
4. Do not swim at dawn, at dusk, or at night.
5. Do not swim near seal haulouts or near schools of fish.
6. Do not swim near, or interfere with, shark-control equipment.

High-risk beach areas should also be prepared for emergency medical response in the event of an attack. In industrial nations, sophisticated paramedic infrastructure to deal with traumatic injuries is already largely in place. In developing countries, however, timely responses to medical emergencies like shark attack may be lacking. Locations with a high risk of shark attack should consider putting together a medical trauma kit, or “shark-attack pack,” that would include materials to control blood loss (e.g., sterile gauze dressings, elastic bandages, tape, forceps), reduce the effects of shock (e.g., blankets, painkillers, IV fluids), and provide sufficient first aid until a victim can be transported to a hospital. These packs should be kept in close proximity to beaches, such as in a lifeguard facility or nearby hotel or shop. Coordinated, timely responses with appropriate medical equipment and skills can significantly improve the chances of saving life or limb.

In addition to receiving information on beach safety and shark-attack prevention, the public also needs to be educated about the importance of White Sharks to marine ecosystems. White sharks are apex predators that are essential to maintaining ocean ecosystem health. They are well-developed hunters, not the mindless killers often portrayed in the popular media. Similar to numerous terrestrial predators (tigers, lions, wolves, etc.), their conservation and continued existence should be valued. Although interactions between White Sharks and humans can never be fully eliminated, educating the public is key to limiting emotional or fearful responses subsequent to a shark incident.

In addition to proactive outreach and emergency planning, an official shark-incident protocol may be a beneficial component to shark-attack preparedness. These protocols are essentially emergency response plans implemented by governmental officials that clearly outline the roles and responsibilities of agencies and personnel in the event of a shark attack. Shark-incident protocols have been implemented in some form in several locations, including parts of Australia, South Africa, and the United States. Official staff that are typically included in a protocol include police, medical responders, lifeguards, beach managers, coast guard/marine patrol, local fisheries agencies, local government officials, scientists, and media contacts. The protocol is often maintained and coordinated by a fisheries agency that employs scientists familiar with shark research and management.

It is important for all parties involved in a shark-incident protocol to cooperate in its development and implementation. A common policy statement should be agreed upon regarding if and when a shark can be killed following an attack. A comprehensive roster of official contacts in each organization should be established and maintained. When a shark attack is reported, the first responders should be familiar with the contacts necessary to start the official response according to the protocol.

Existing shark-incident protocols include specific instructions and contacts for the following response steps:

1. Immediate response: activating a rescue and emergency medical response
2. Controlling the scene: making the incident site safe, establishing access for emergency vehicles and personnel, providing first aid to the victim, and interviewing witnesses
3. Informing the public and media: official statements released regarding incident details, and the formal response
4. Short-term response: closing beaches, shark removal (if deemed appropriate), data collection, and continued media communications
5. Long-term response: shark control or attack-prevention efforts, outreach, and refinement of procedures

In regions with higher shark-attack risk, effective implementation of a clearly defined shark-incident protocol can save lives, improve public safety, and reduce the chaos that often follows a shark attack. It can demonstrate a unified and coordinated response by local government, allowing control of the response, and help avoid miscommunication and negative impacts on the public, local economy, and the public's attitude to White Shark conservation. Examples of government agency response plans are available at: http://www.cottesloe.wa.gov.au/__data/page/217/Shark_Incident_Response_Plan_2003.pdf http://www.pir.sa.gov.au/__data/assets/pdf_file/0017/13094/gw_shark1.pdf. AQ7

Dealing with the Media

Shark attacks receive a disproportionate amount of media coverage given the rarity of such events compared with other traumatic events. An effective communication strategy that is kept current is crucial to the dissemination of factual and objective information to the public. Traditionally, the headlines and associated stories are hyped-up accounts of the attacks, fraught with inaccuracies on sharks and perpetuating the reputation of the shark as a man-eater. Common problems in news articles and news reports are as follows:

1. Inaccuracies in information on sharks and the attack
2. Misquotes
3. Information taken out of context
4. Sensationalism
5. Interviews with self-proclaimed shark experts

These kinds of reports create fear and confusion and do not constitute responsible reporting. Reporters and media agencies, like most of the public, know very little about sharks and need to be educated as much as the public does.

A clear communication strategy should be in place within the delegated authorities (Preen and Richards, 2006; Peschak, 2006). Stakeholder agencies should take a proactive approach to liaising with the media and not just rely on being reactive in the event of a shark attack (Preen and Richards, 2006). Proactive steps can include the following:

1. Fostering relationships between stakeholders and local reporters
2. Providing ongoing information on sharks and behavior to the public through seminars and written reports to media outlets
3. Issuing regular press releases making the public aware of the times of year when shark activity is higher and therefore there is an increased risk

4. Providing the press with a list of people whom they can contact to get information from
5. Development of a press kit that includes the above information, as well as appropriate copyright-free shark photographs (Peschak, 2006)

Providing both information and images to the media appropriate to the event (in case of an attack) can minimize the use of incorrect images (e.g., the wrong species of shark) and thus make for more reliable reporting that has stronger educational outcomes.

Within each stakeholder organization, the responsibility of dealing with the media should be delegated to an experienced communications person. A support structure is essential in dealing with shark attack, and it will take a coordinated response to deal with the situation effectively. A strong recommendation based on a recent fatal attack in Cape Town, South Africa, on January 12, 2010 (http://www.fishhoek.com/sharks.html) demonstrated the effectiveness of a timely press conference at the scene of the attack. Media representatives from around the country, including international correspondents flocked to the scene and attempted to interview eyewitnesses and gather information from various bystanders. The National Sea Rescue Institute coordinated a press conference with representation from emergency response, a local shark scientist, and the lifesaving club. The information provided was factual and timely and was broadcast around the world. In the absence of such press conferences or media releases, the reporters will use whatever information they can gather, even if it includes statements from unqualified people, because they are under pressure to report on the story and are often under impending deadlines to get the story in the earliest edition.

Another recommendation is to as quickly as possible gather the facts about the shark attack and formally report on the findings of the incident. People are encouraged not to make assumptions about the event or offer up information that is not directly linked to the incident. In many cases, information is taken out of context to make the story even more newsworthy. It is important to remember that shark attacks are traumatic events where somebody has either been hurt or has died. Responsible communications personnel need to be sympathetic to the victim and their families and friends when disseminating information on sharks and shark attack.

Trying to find the balance between acknowledging the tragedy and putting shark attack in perspective is not an easy task. Only through a planned communications strategy can this be achieved. Being caught off guard and not prepared in the event of a shark attack is a recipe for disaster. Continued communication between government, local law enforcement, lifesaving clubs, sea rescue organizations, shark scientists, nongovernment organizations, and the media will have a positive influence on the way shark attack is reported in the media.

CONCLUSIONS

The risk of shark attack is low; however, it is an unavoidable risk that must be considered when entering the ocean for recreation. As human utilization of the ocean increases, together with possible increases in White Shark numbers where protection of populations is enforced, so will the frequency of shark encounters and thus the likely risk of attacks on humans. Certain locations around the world have higher frequencies of attacks by White Sharks than others, including the Pacific coast of the United States, Australia, and South Africa. These regions have both significant populations of White Sharks and increasing human populations using coastal waters for recreation. We have identified a number of methods that have been used to help reduce the risk of White Shark attacks in these regions and may be applied in other regions should the risk of shark attack render such actions prudent. Each approach has its own costs and benefits that need to be considered, and no single method is applicable in all scenarios.

Some of the methods presented here use fishing methods to remove potentially dangerous sharks from the waters near beach areas. Of these, fixed or semipermanent beach meshing and drumlines have proven effective at reducing the risk of shark attack at the beaches they protect, whereas shark hunts and state-run shark-control programs have been less effective. The successful programs have provided the benefits of protection to beachgoers and minimized the potential economic harm to coastal communities affected by shark attacks. The consistent maintenance of the fishing gear, however, can be very costly and have long-term ecological impacts that must be considered. The effectiveness of such extractive measures may be higher for shark species that develop residency patterns. In general, White Sharks are not resident to areas commonly used by beachgoers and are transient visitors. Shark-control programs are likely to be less effective in these cases because they depend entirely on the chance encounter of transient sharks and fishing gear rather than providing an effective barrier between sharks and people. There are some areas, however, where White Sharks are more common and will develop periods of temporary residency (e.g., around seal colonies and in some surf zone locations; see examples above). Deployment of shark-control methods in such areas is likely to have significant impacts on both local and regional White Shark populations and is not recommended.

Nonfishing methods attempt to use more of a preventative approach and have more positive conservation results for White Sharks. Temporary beach closures in areas or during seasons of high shark-attack risk are the simplest methods to protect beachgoers without impacting shark populations. Such closures, however, can result in adverse economic impacts on local communities. In these cases, other methods should be considered, including shark spotters, aerial surveys, or—if coastal conditions allow—shark barriers. Research efforts, particularly acoustic and/or satellite tagging studies, can help inform decision making as well as provide direct indications of White Shark presence in specific areas (e.g., "early warning systems"). Depending on the approach, research can be costly, but some level of scientific investigation near potential attack sites can provide numerous benefits and should be encouraged. Finally, formal education and outreach programs about White Sharks should be implemented to help reduce ignorance and hysteria in the general public. With a well-informed public, responses to a potential White Shark attack will be less emotional or irrational, and shark-attack prevention efforts will be more effective.

RECOMMENDATIONS

Given all of the information described above, we offer the following recommendations to managers who may be considering implementation of a program to reduce the risk of White Shark attacks in their jurisdiction:

1. **Study the area and the sharks within it.** By examining the available data on the occurrence of shark attack and initiating a research program to investigate local shark species, their seasonal patterns of occurrence, environmental factors, and the typical behavior of sharks in the area, managers will have the information they need to select the most appropriate shark-attack minimization strategy.
2. **Develop a shark-incident protocol.** This protocol would be an official document that describes in detail the agencies, personnel, procedures, and responsibilities involved in the response to a shark attack or shark sighting. Medical response procedures should be prioritized. Such documentation will help avoid confusion and increase the efficiency and coordination of governmental responses.
3. **Educate the public.** Beachgoers need to be made aware of the potential for shark attack around high-risk areas. High-risk human behaviors also need to be identified. Proactive outreach efforts can also help allay public fears by dispelling many of the popular myths about the nature of White Sharks.
4. **Avoid public shark hunts.** There is little evidence that supports indiscriminate hunting of sharks as a means to reduce shark-attack risk. Standardized, state-controlled fishing efforts or a variety of nonfishing methods are considered more effective. In regions where White Sharks are legally protected, only government officials have the authority to kill White Sharks. Although this is a stated

option in, for example, Australian state shark-response plans, these plans have a series of prescriptive actions to avoid reaching this endpoint, and such an action would only ever be enforced as an unlikely last resort.

5. **Conserve White Shark populations to the extent practicable.** White sharks play important ecological roles in the marine environment, but their populations are vulnerable to overexploitation. Permanent beach meshing or other shark control gears should not be used in natural White Shark aggregation sites, because they can quickly deplete regional populations. Finding a balance between public safety and shark conservation is essential.

By following these recommendations and applying the information provided in this chapter, governmental organizations will be able to develop appropriate methods to deal with shark-attack risk within their affected communities. Effective shark attack prevention programs will serve to benefit the safety of the public, while sustaining ecologically important White Shark populations.

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Author Queries

AQ1: If updated publication information is available, please insert year for West (in press) and update corresponding reference.
AQ2: Please verify that "In this period, there were 1.0 White Shark incidents per annum" is as meant. The previous sentence says 3.3 attacks. Should this 1.0 statistic be worldwide or in another region? Or should the type of incident be more specifically described? Please make any necessary changes.
AQ3: Again, please insert year for West (in press), if possible.
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