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Changing patterns of shark attacks in Australian waters

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Abstract. Although infrequent, shark attacks attract a high level of public and media interest, and often have serious consequences for those attacked. Data from the Australian Shark Attack File were examined to determine trends in unprovoked shark attacks since 1900, particularly over the past two decades. The way people use the ocean has changed over time. The rise in Australian shark attacks, from an average of 6.5 incidents per year in 1990–2000, to 15 incidents per year over the past decade, coincides with an increasing human population, more people visiting beaches, a rise in the popularity of water-based fitness and recreational activities and people accessing previously isolated coastal areas. There is no evidence of increasing shark numbers that would influence the rise of attacks in Australian waters. The risk of a fatality from shark attack in Australia remains low, with an average of 1.1 fatalities year^{-1} over the past 20 years. The increase in shark attacks over the past two decades is consistent with international statistics of shark attacks increasing annually because of the greater numbers of people in the water.

Additional keywords: beach recreation, bull shark, marine, ocean swimming, shark biology, swimmer safety, tiger shark, whaler, white shark, wobbegong.

Introduction

Sharks are large top-order marine predators and some species occur in areas of the ocean where human activities occur. Although shark attacks occur relatively infrequently, they often have serious consequences for those involved, invoke a dramatic emotional response from the public and therefore attract a high level of media interest. Given that Australia is well known for its beach culture, with ~35 000 km of coast, containing an estimated 11 900 beaches (SLSA 2010), has a mostly favourable climate, and a range of popular beach- and water-related activities, it is not surprising that it has a relatively high rate of shark attack (West 1993). Globally, the numbers of shark attacks have been increasing and this has been attributed to the increase in the human population and more people entering the water (Burgess 2009).

Records of shark attacks in Australia have been kept since the early days of settlement (first attack was recorded in 1791), although the quality and completeness of reports in the earlier years are variable. In an effort to standardise reporting of shark attacks in Australia, the Australian Shark Attack File (ASAF) was developed in 1984. A report on attacks up to 1990 suggested that unprovoked shark attacks per decade had slowly declined and remained relatively stable after shark-management practices were introduced around Sydney in the 1930s (West 1993). The present paper describes the patterns of shark attacks in Australian waters, examines how this has changed over time, identifies factors that may help reduce the incidence of attacks, and contributes to our understanding of shark behaviour.

Materials and methods

The ASAF is held at Taronga Zoo (Taronga Conservation Society Australia), Sydney, and is affiliated with the International Shark Attack File (ISAF). Initially, Australian shark-attack data were compiled from a variety of sources, including Coppleson (1933, 1958), Whitley (1940, 1951) and Baldridge (1969, 1974). The ASAF is a dynamic database that is continually researched and is subject to change as new incidents occur or new information becomes available on previously recorded incidents.

The ASAF relies on a network of contacts throughout Australia, including shark researchers, scientists and managers in all Australian State Fisheries Departments, researchers at Commonwealth Scientific and Industrial Research Organisation (CSIRO), museum curators, university researchers, surf life-saving organisations, underwater naturalists and film makers who assist in obtaining incident reports. Information also comes from a range of sources including print media and internet news service, State and National Library searches, on-line archival newspaper databases, official investigation reports, coronial and police reports, surf life-saving report logs and personal commi-nication. The most reliable sources of detail come from direct personal communication with victims or witnesses who are sent a questionnaire, and visits at the hospital by investigating authorities where an inspection of the bite wound can be undertaken.

Australian Shark Attack File database

There are 101 fields of information for each incident, including details on the victim, the victim's activities, witnesses'

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activities, injuries sustained, recovery outcome and diversionary action by the victim or others. It contains biological information on the shark, its description, size and behaviour, and any other animals nearby. Environmental parameters such as water depth, temperature and site description are recorded where known. The database includes shark attacks recorded in Australian waters, including the Torres Strait Islands and Cocos, Christmas and Lord Howe Islands, and generally within Australia's 200-nautical-mile Economic Exclusion Zone (EEZ).

Criteria for inclusion

A 'shark attack' is defined in the ASAF as any human–shark interaction where either a shark (not in captivity) makes a determined attempt to attack a person who is alive and in the water or the shark attacks equipment held by the victim or attacks a small-water craft containing the victim (the full criteria can be found at www.zoo.org.au, accessed 1 June 2010).

Incidents classified as 'provoked' are not included in the present paper. The provoked category relates to circumstances where the person involved was fishing for, spearing, stabbing, feeding, netting or handling a shark, or where the shark was attracted to the victim by activities such as fishing, spear-fishing and cleaning of captured fish.

Identification of sharks involved in attacks

Where the species of shark cannot be positively identified either through direct examination of the bite, identification of the captured shark, forensic assessment of the bite marks, teeth or tooth fragments recovered, or identification by a creditable witness, the ASAF establishes the most likely shark species (or family) through a review of the physical and behavioural description of the shark from victim, witnesses, or other available reports. This is compared with previous incidents from the same or similar locations where the circumstances were similar and the species had previously been identified. Environmental parameters, shark-distribution data, location and time of year are also reviewed. Considered opinion from experts in the field of shark research is also sought. The lengths of sharks recorded were usually been estimated by the victims or witnesses. There have been 18 incidents where the shark's size has been identified through bite-mark analysis and three incidents verified through capture of the shark involved.

Impacts on victims

Where injuries are recorded, the location is assigned to the following: 'Legs', including injuries to any part of the foot, calf, knee, and thigh; 'Arm', including injuries to the fingers, hand, forearm and upper arm; 'Torso', including anywhere on the body such as buttocks, stomach, chest or shoulder; or 'Head', including anywhere above the shoulders to the top of the head. 'Multiple bites' relate to two or more bites to different parts of the body (e.g. arm and torso).

The severity of injuries (including fatalities) are classified as follows: 'Minor', where bruising, grazes, teeth marks, scratches or a small laceration requiring first aid or minor stitches occurred; 'Serious', where larger lacerations occurred, requiring extensive stitches, or where small amounts of flesh were removed such that hospitalisation was required; or 'Severe', where flesh was removed (including limbs bitten off) and surgery and/or a long period of hospitalisation was required. Fatalities can be recorded for Serious and Severe classifications following sanguination or post-surgical complications and for events where the body was not recovered and it is suspected that the shark has taken the victim away from the attack site or the body was consumed.

Beach visitations

In the absence of definitive beach-visitation numbers, and for the purpose of the present study, a conservative figure of a 20% annual increase was assumed as a surrogate for assessing the probable increase in beach visitations and water-related activities over the past decade. This figure is derived from an average of the Australian population increase of 15% and an increase in surf life-saver beach rescues of 29% over the past decade.

Results

Over the 218 years for which records were available, there have been 592 recorded unprovoked incidents in Australian waters, comprising 178 fatalities, 322 injuries and 92 incidents where no injury occurred. Most of these attacks have occurred since 1900, with 540 recorded unprovoked attacks, including 153 fatalities, 302 injuries and 85 incidents where no injury occurred. Attacks have occurred around most of the Australian coast, most frequently on the more densely populated eastern coast and near major cities (Fig. 1).

In the first half of the 20th century, there was an increase in the number of recorded shark attacks, culminating in a peak in the 1930s when there were 74 incidents (Fig. 2). The number of attacks then dropped, to stabilise ~35 incidents per decade from the 1940s to the 1970s. Since 1980, the number of reported attacks has increased to 121 incidents in the past decade (Fig. 2). There had been a decrease in the average annual fatality rate, which had fallen from a peak of 3.4 year^{-1} in the 1930s, to an average of 1.1 year^{-1} for the past two decades. The number of fatal attacks relative to the number of total attacks per decade has also decreased over this period, from 45% in the 1930s to 10% in the past decade. These declining chances of a shark attack resulting in fatality are also reported elsewhere in the world (Woolgar *et al*. 2001; Burgess 2009). In the 20-year period of the 1930s and 1940s, the fatality ratio was 1 : 2.4 incidents. In the past 20 years, the fatality ratio has been 1 : 8.5 incidents. Comparison of attacks per capita indicated that the number of incidents was highest in the 1930s, at 10 attacks per million people per decade, decreasing to an average of 3.3 attacks per million people per decade until the 1990s. The past two decades have exhibited an increase in attacks, up to 3.5 attacks per million people per decade (1990–1999) and 5.4 attacks per million people per decade 2000–2009 (Fig. 3).

In the 20 years since 1990, there have been 186 reported incidents, including 22 fatalities (Table 1). This represents a 16% increase in reported attacks during 1990–1999 and a 25% increase over the past 10 years (Fig. 3). The majority of attacks occurred in New South Wales (NSW) with 73 incidents (39%), then Queensland with 43 incidents (23%), Western Australia (WA) with 35 incidents (19%), South Australia with 20 incidents (11%), Victoria with 12 incidents (6%), Tasmania with

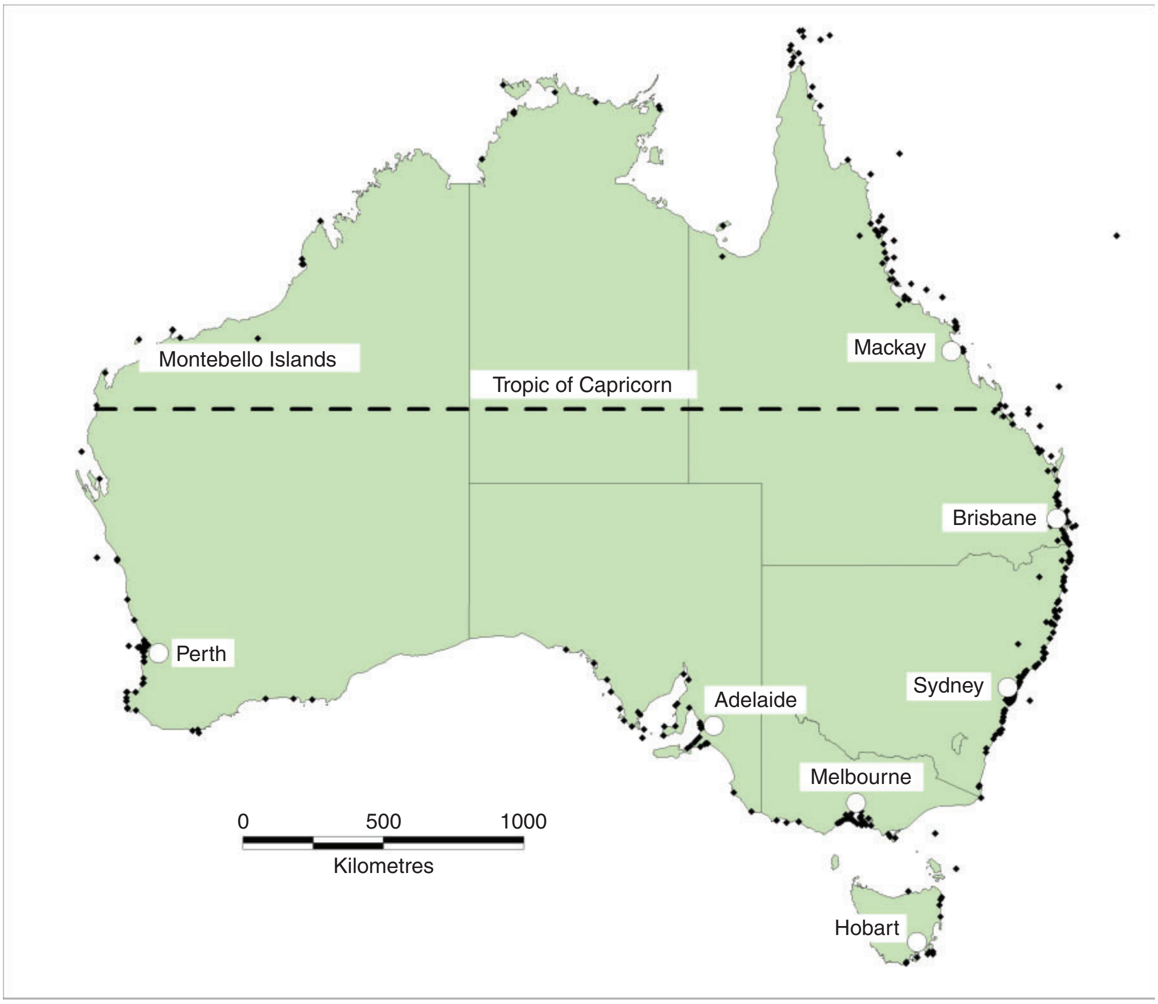

Fig. 1. The distribution of Australian shark attacks 1791–2009. Each attack is represented by a black dot.

two incidents (1.5%) and Northern Territory with one incident (0.5%).

Species of shark involved in attacks

Of the 186 recorded incidents since 1990, there have been 57 incidents (30%) where the shark species (or family) was identified beyond a reasonable doubt. in 13 incidents (7%), the species was unknown because of insufficient detail to make a considered assessment. For the remaining 117 incidents (63%), sufficient information was recorded to assign the 'most likely' species (or family) involved.

Since 1990, 12 species of shark were identified as responsible for unprovoked attacks (Table 2). The three species historically considered to represent the biggest threat to humans (the white, tiger and bull shark combined) represent 48% of attacks. A further 20% of attacks was attributed to unidentified species in the Carcharhinidae family (designated as 'whaler sp. Group') and 20% for the wobbegong shark.

Only three shark species have been responsible for fatal attacks over the past 20 years. These were the white shark (*Carcharodon carcharias*), with an increase from 24 incidents during the previous two decades to 55 incidents, including 15 fatalities, 23 injuries and 17 uninjured incidents, the bull shark (*Carcharhinus leucas*), with an increase from three incidents during the previous two decades to 25 incidents, including four fatalities, 15 injuries and six uninjured incidents, and the tiger shark (*Galeocerdo cuvier*), with a decrease from 14 incidents for the previous two decades down to 10 incidents, including three fatalities, two injuries and five uninjured incidents (Table 2).

Of the 15 fatalities attributed to white sharks, seven involved a single bite and seven resulted from multiple bites (unknown number of bites for one fatality). Seven fatal attacks by white sharks occurred at the surface while the victim was surfing (33%), swimming (7%) or sailboarding (7%). Eight of the fatalities by white sharks occurred while the victim was submerged, either SCUBA diving (40%) or snorkelling (13%). Of the four fatalities attributed to bull sharks, one involved a single bite and three involved multiple bites. All four fatal incidents occurred at the surface; three while swimming and one while surfing. Two of the four fatalities occurred in human-made canals. Of the three fatalities attributed to tiger sharks, two involved a single bite. One fatal attack occurred at the surface on

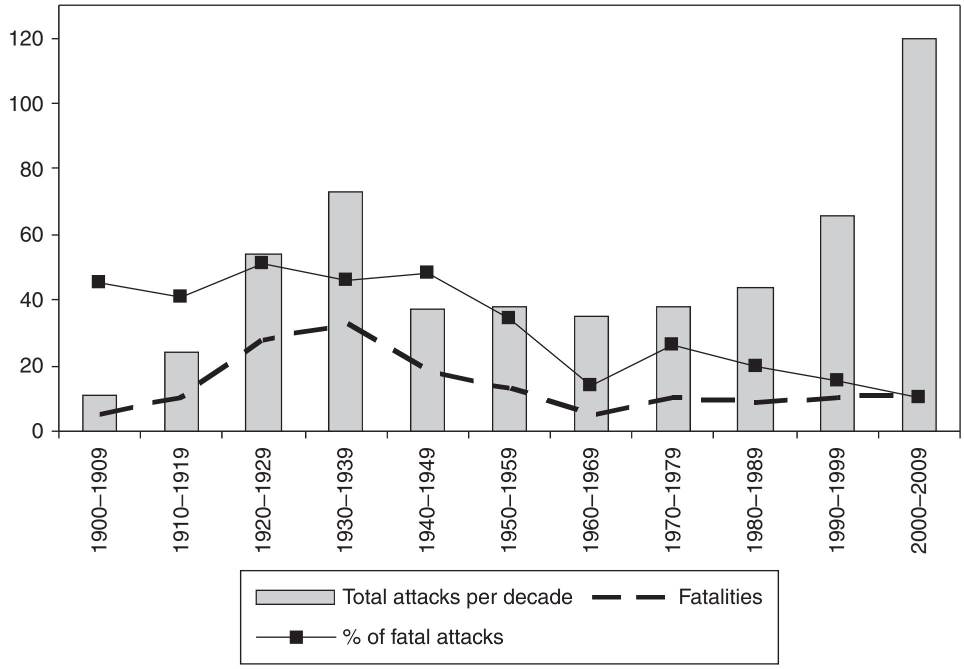

Fig. 2. Number of unprovoked shark attacks, number of fatalities and percentage of attacks that were fatal from 1900 to 2009 by decade.

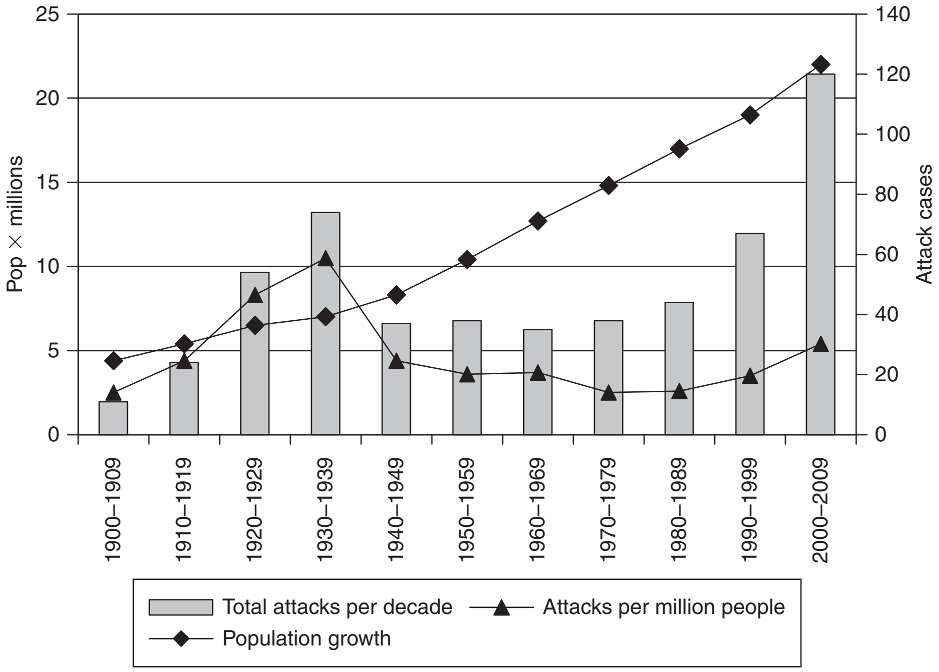

Fig. 3. Decadal distribution of shark attacks in Australia between 1900 and 2009, including total number of attacks, the total population of Australia and the shark attacks per million people.

a sailboarder and two occurred subsurface on a snorkeler and a hookah diver.

Species involved in attacks that did not result in a fatality include the wobbegong with 33 incidents (all resulting in injuries), an increase of 20% over the previous decade, and the whaler sp. group with 37 incidents, including 26 injuries and 11 uninjured incidents. The bronze whaler had six incidents recorded, with four injuries and two uninjured incidents, and the dusky whaler had two incidents recorded, with one injury and one uninjured incident. There were five other species with one incident recorded for each (Table 2).

Shark size

There have been 121 incidents where the length of the shark was recorded. The reported size ranged between 0.4 and 6.0 m. Over 80% of incidents involved white sharks and tiger sharks >3 m; for bull sharks, 78% of incidents involved sharks >2 m, 56% of whalers (sp.) were >2 m, and 72% of wobbegongs exceeded 1 m. Of the 28 incidents where a shark was reported to be >4 m, 85% were white sharks (24 incidents), resulting in nine fatalities. Large tiger sharks >4 m long were involved in four incidents, with one fatality. Bull sharks >2 m in length were involved in 13 incidents, resulting in four fatalities. There were no fatalities recorded for any species <2 m.

Activities of victims

The activities of victims (1990–2009) were recorded for 186 incidents, of which 78 (42%) occurred while surfing on a board or body board, 38 (21%) while swimming, 25 (14%) while SCUBA or hookah diving, 14 (7%) while snorkelling, 12 (6%) while standing in shallow water, 15 (8%) on small water craft (kayak, ski, dinghy, rowing scull) and four (2%) while kite-boarding or sailboarding (Fig. 4). By comparison, for the two previous decades (1970–1989), there were 83 incidents where the victim's activity was recorded. During this period, 24 (29%) occurred while surfing on a board or body board, 25 (30%) while swimming, 11 (13%) while SCUBA or hookah diving, three (4%) while snorkelling, four (5%) while standing in shallow water, and two (2%) in small boats (Table 3). Because of increased activities occurring in cooler waters all year round, 49% of all shark-attack victims were wearing a wetsuit.

Victim's injuries

Of the 186 incidents recorded for the past 20-year period, 117 incidents (63%) resulted in an injury to the victim. Fatalities accounted for 22 incidents (11.8%), which include eight incidents where the body was not recovered (six attributed to a white shark and two to a tiger shark). The fatality rate is consistent with the International Shark Attack File (ISAF) global fatality rate of 10.1% for the same period.

Table 1. Number of shark attacks for each state of Australia (1990–2009), including number of fatalities, injuries, or where the person was uninjured and the location of the last fatality since 1990

State	Total no. of cases	No of fatal attacks	No. of injured	No. of uninjured	Last fatality (since 1990)
NSW	73	2	45	26	2008, Ballina, Lighthouse Beach
Qld	43	5	32	6	2006, North Stradbroke Island
WA	35	6	23	6	2005, Houtman Abrolhos Islands
SA	20	8	11	1	2005, Glenelg Beach
Vic.	12	0	5	7	
Tas.	2	1	1	0	1993, Tenth Is, Georgetown
NT	1	0	0	1	
Total	186	22	117	47	

Table 2. The total number of unprovoked shark attacks by identified shark species from 1900 to 2009, including the number of fatalities (in parentheses)

Decadal details are provided post-1970

Species	No. of cases (fatal) 1900–2009	No. of cases (fatal) 1970–1979	No. of cases (fatal) 1980–1989	No. of cases (fatal) 1990–1999	No. of cases (fatal) 2000–2009
White shark (*Carcharodon carcharias*)	120 (41)	14 (5)	10 (3)	16 (7)	39 (8)
Bull shark (*Carcharhinus leucas*)	84 (38)	2	1	10	15 (4)
Tiger shark (*Galeocerdo cuvier*)	85 (41)	4 (4)	10 (5)	6 (3)	4
Whaler sp. (*Carcharhinus* sp.)	70 (11)	1	4 (1)	13	24
Wobbegong (*Orectolobidae* sp.)	51	1	8	9	24
Bronze whaler (*C. brachyurus*)	13 (1)	1 (1)	3	4	2
Dusky whaler (*C. obscurus*)	3	–	–	1	1
Whitetip reef shark (*Triaenodon obesus*)	1	–	–	1	–
Silvertip reef shark (*C. albimarginatus*)	1	–	–	–	1
Grey reef shark (*C. amblyrhynchos*)	1	–	–	1	–
Hammerhead (Genus: *Sphyrnidae*)	1	–	–	–	1
Mako (*Isurus oxyrinchus*)	1	–	–	–	1
School shark (*Galeorhinus galeus*)	1	1	–	–	–
Unknown	108 (21)	14	8	4	9
Total (fatal)	540 (153)	38 (10)	44 (9)	65 (10)	121 (12)

Of the 139 injuries and fatalities recorded, there were 85 (61%) that occurred on the legs, 20 (14%) on the arms, 17 (12%) bites to the torso and one injury was reported to the head (2%) and multiple bites occurred in 16 incidents (12%). There were 47 incidents (25%) where no injury occurred. This concentration on the body extremities is to be expected, considering the propensity of attacks on surfers and swimmers, whose arms and legs are most likely to be exposed to the potential attack. Of the 139 incidents where injuries or fatality occurred, 107 incidents (77%) were minor injuries, nine incidents (6%) were serious and 15 incidents (11%) were severe. In eight incidents (6%), a body was not recovered.

The numbers of bites were recorded in 164 incidents; in 126 incidents (77%), contact or an attempted bite occurred via a single bite, resulting in 10 fatalities, 91 injuries and 25 incidents of attempted bite with no injury occurring. In 38 incidents (23%), there was a consistent or persistent attempt to bite a person more than once (multiple bites). Multiple bites resulted in 11 fatalities, 25 injuries and two uninjured incidents (Table 3).

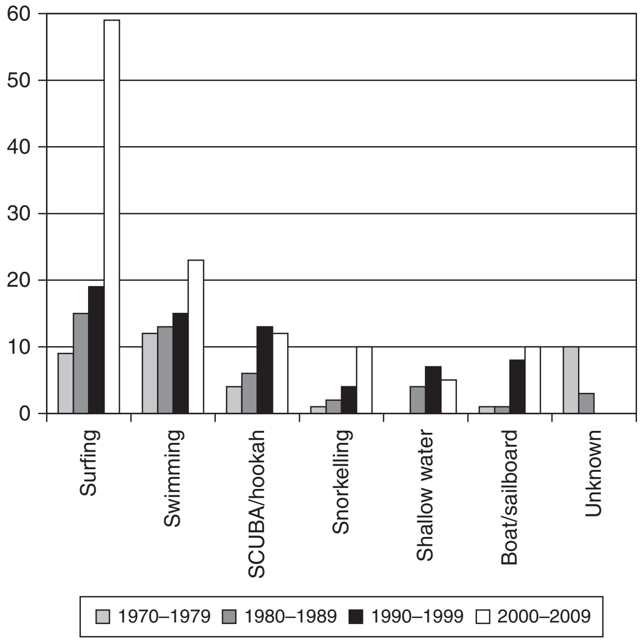

Fig. 4. Frequency of activities conducted by shark-attack victims when attacked (1970–2009).

Of the 186 records, there were 27 incidents (14%) recorded where the victim was bitten by the shark following an initial close pass without contact or a pass with contact (e.g. bump) and in 35 incidents (19%) the victim was recorded as being aware of the shark before the attack. In all incidents for the past 20 years, a single shark was recorded as being involved in the attack. In 22 incidents where a person was reported as rescuing a shark-attack victim, no injuries were recorded.

Diversionary actions

There were 54 incidents where physical diversionary action was taken by the victim to deter the attacking shark. In 50 incidents, the victim hit, punched, gouged the eye, kicked, pushed or grabbed the shark. On four occasions, the victim pushed a surfboard (2 occasions), a spear gun, or clipboard into the shark's mouth resulting in the shark either swimming away or it keeping at a distance from the victim. In 36 incidents (67%), the shark released the victim, ceased the attack or swam away. In 17 incidents (32%), there was no reported change to the attack behaviour.

Temporal patterns

Attacks occurred throughout the year, with most incidents (134, 72%) occurring in the warmer months from November to April (Fig. 5). There were 138 incidents where the time of day was recorded, over the past 20 years, and ranged from 0130 hours to 2030 hours (Fig. 6). The following 5-h periods were identified: dawn (0300–0800 hours), 22 incidents; morning (0800–1300 hours), 44 incidents; afternoon (1300–1800 hours), 55 incidents; dusk (1800–2300 hours), 16 incidents; and late night (4-h period, 2300–0300 hours), one case occurred. The three main groups of sharks responsible for the majority of attacks throughout a 24-h period were the white shark, bull shark and the whaler shark group, which feature in all periods from dawn to dusk (Table 4).

Other animals in the vicinity of attacks

There were 54 records where other animals were observed as being in the area of the attack. In all cases, no specific identification to species was made. In some incidents, multiple species of aquatic animals were recorded. Schools of fish were observed in the immediate area in 32 incidents. Marine mammals were recorded for 21 incidents, with 11 involving dolphins (one of

Table 3. The activity of victims, number and type of interaction with the shark and the outcome of the interaction, for attacks from 1990 to 2009
Some incidents may have more than one bite or close-pass behaviours recorded

Activity (total no.)*	Single bite	Multiple bites	Bump/graze	Close pass, no contact	Fatal	Injury	No injury
Surfing (79)	47	19	15	18	6	46	27
Swimming (39)	28	10	2	4	4	37	2
SCUBA diving (23)	17	3	2	4	6	13	4
Snorkelling (14)	9	3	2	2	3	9	2
Boat (15)	11	1	1	4	–	2	13
Shallow water (11)	11	–	–	–	–	11	–
Kite/sailboard (4)	2	1	–	–	2	2	–
Hookah diving (3)	2	–	–	1	1	1	1

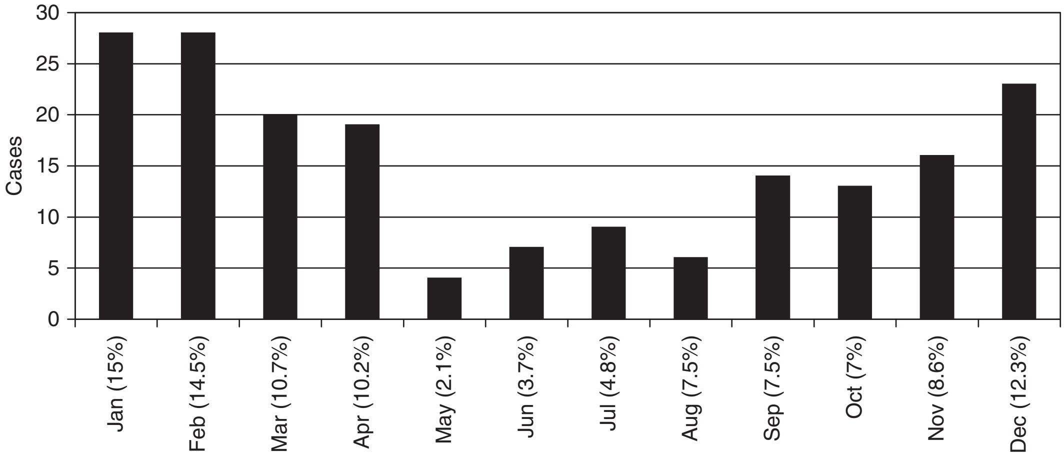

Fig. 5. Monthly distribution of shark attacks (percentage of total in parentheses) between 1990 and 2009.

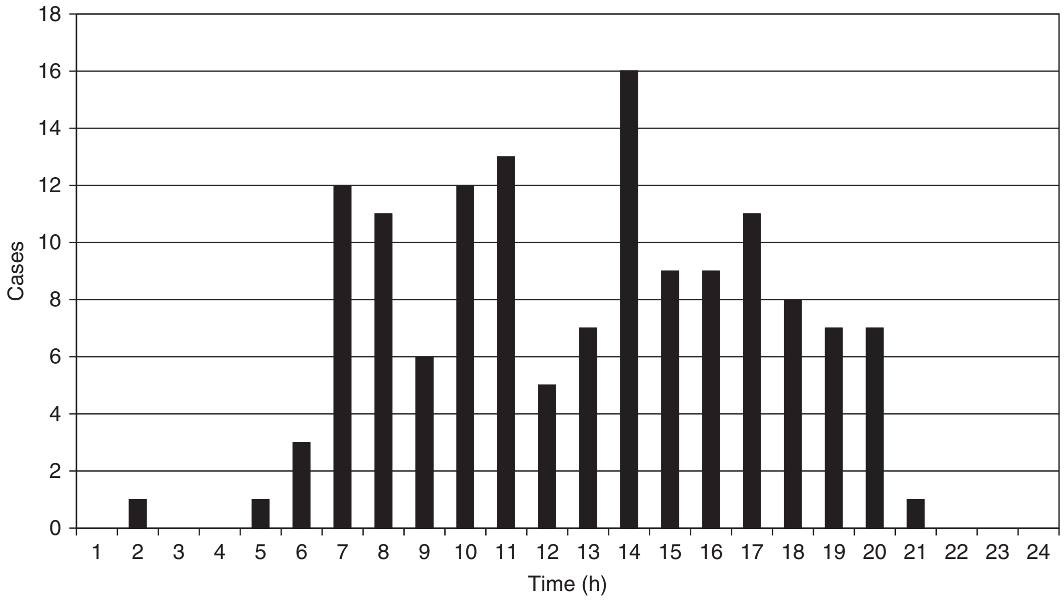

Fig. 6. The hourly temporal distribution of shark attacks between 1990 and 2009.

Table 4. Species involved in shark attacks during the 24-h period for 186 incidents during 1990–2009

Species involved	Dawn (0300–0800 hours)	Morning (0800–1300 hours)	Afternoon (1300–1800 hours)	Dusk (1800–2300 hours)	Night (2300– 0300 hours)
White shark (*Carcharodon carcharias*) (%)	31	36	36	20	
Bull shark (*Carcharhinus leucas*) (%)	23	11	13	20	100 (one incident)
Whaler sp. (*Carcharhinus* sp.) (%)	32	14	18	20	
Wobbegong (Orectolobidae sp.) (%)		20		20	
All other sharks (%)	14	19	33	20	

which was a dead dolphin), nine incidents involving seals and one involving a whale. One report recorded the proximity of a penguin and in three incidents other sharks were reported to be in close proximity.

Discussion

The results of the current analysis have demonstrated that shark attacks in Australia have increased over the past 20 years. This increase can be explained through (1) changes in population size that has resulted in more contact between sharks and people, (2) changes in the behaviour of people, (3) changes in the methods of reporting or (4) an increase in the abundance of sharks. Information supporting some or all of these explanations for the increase in attacks is examined below.

Over the past century, the population of Australia has increased from 3.7 million in 1900 to 17 million in 1990, and to 22 million people in 2009, with a 13% and 15% increase, respectively, for the past two decades. Over the past decade, the number of international tourists visiting Australia has increased, with ~470 000 visiting Australia each year (Australian Bureau of Statistics 2009). The increased population, tourism and popularity of water sports and activities such as swimming, surfing, snorkelling, SCUBA diving and kayaking have resulted in more people being in the water at beaches, harbours and rivers around Australia, therefore increasing the risk of a possible interaction with sharks. The increases in shark attacks of 16% and 25% over each of the past two decades are of a very similar magnitude to those of the population and tourism increases, suggesting that the increase could largely be the result of changes in population. However, population increases before 1990 did not result in increases in the rate of attacks, indicating that other factors also need to be considered. The trend in the Australian shark-attack rate is consistent with international statistics that indicate the number of shark attacks have increased over a similar period, apparently as a result of the greater numbers of bathers in the water (Burgess 2009).

The majority of the population increase has occurred along coastal areas, primarily in NSW and Queensland (ABS 2009), with many people leaving the big cities and inhabiting or holidaying in more isolated coastal areas, consequently accessing previously isolated beaches, fishing and surfing spots around the coast. Analysis of the distribution of shark attacks indicates that 171 incidents (91%) in the past two decades have occurred away from the major population centres, along the eastern coast where shark-control programs are not deployed. This may be interpreted as highlighting the efficiency of the various shark-meshing programs in reducing shark attacks, a view historically taken by the authorities managing the programs (Dudley and Cliff 1993; Queensland Government Department of Primary Industries and Fisheries 2006); however, it may also relate to differences in the spread of people to outlying areas that may support a larger shark population than occurs around major metropolitan meshed beach sites.

At the same time as the increase in population, there has been a dramatic increase in the popularity of water-based activities for leisure or fitness. Given this, it would be expected that the risk of a person encountering a shark would also increase because they are spending longer periods in the water. There has been a large increase in beach visitations, indicated by figures from Surf Life Saving Australia (SLSA 2010), of ~100 million beach visitations in 2009, an increase of 20% on the previous year's estimate of 80 million. This increased beach use is also reflected in the SLSA data (SLSA, pers. comm.) which indicate that there has been a 29% increase in the number of beach rescues over the past decade (from 10 226 in the 1999–2000 season to 13 185 in the 2008–2009 season) and an 1100% increase in the number of preventative actions taken by surf life savers (from 55 212 in 1990 to 662 955 in the 2009 season). The popularity of surfing in current-day Australia was highlighted in a survey administered in 2005–2006, which estimated that ~12% of the adult population of Australian cities participated in the sport of surfing, resulting in ~1.68 million recreational surfers in Australia (www.surfersvillage.com, 10 June 2009). Applying a 20% increase, similar to the percentage increase recorded for beach visitations, it is conservatively estimated that there were ~2.061 million recreational surfers in Australia in 2009. Another water-based activity that has increased over the past few decades is SCUBA diving. There has been an increase in the popularity of SCUBA diving worldwide, with ~3 381 254 Professional Association of Diving Instructors (PADI) registered certified SCUBA divers in 1990, increasing up to 17 532 116 in 2008 (418% increase). The Asian Pacific region (including Australia) has had an average of 132 000 new diver certifications per year from 2002 to 2008 (PADI 2009).

Changes in the popularity of water-based activities over the past four decades was reflected in the activities of the victims. For example, there has been a 310% increase in attacks on surfers since 1999. There have also been substantial increases in the attacks on swimmers, SCUBA divers and sailboarders.

Historically (pre-1950s), human–shark interactions predominantly occurred in the summer months. In recent decades, swimmers, surfers and divers are continuing to pursue these activities outside of the traditional summer season because of improvements in wetsuit technology. This is reflected in the occurrence of shark attacks throughout the year since the 1950s; particularly for surfers, snorkelers and SCUBA divers who can enter the water at any time of the year and extend the time they spend in the water in areas that, in earlier decades, were likely to be too cold for recreational purposes. In the past 20 years, 49% of all shark-attack victims were wearing a wetsuit. These data support a similar account by Cliff (1991) regarding the effect of wetsuits on shark-attack increases in South Africa.

There have been 26 attacks recorded in the cooler months (May–August) during the past two decades (resulting in six fatalities), compared with 15 incidents (resulting in four fatalities) during the same months in the previous 20-year period. (Fig. 5). There is no suggestion that wetsuits in themselves are the cause of an attack, but rather that their use has allowed people to extend their time in the water, increasing the risk of encountering a shark.

It is likely that in the early 1900s until the 1960s, not all shark interactions were reported or recorded, particularly in incidents where serious injury did not occur. The increased awareness of the existence of the ASAF and the extensive network of the ASAF has increased diligence in reporting incidents. In addition, the capacity of the media to easily access these encounters via mobile phones and the internet is likely to have contributed to the 190% rise in reported non-injury attacks in the past decade (2000–2009), compared with the previous decade (1990–1999).

Changes in the abundance of sharks

Throughout the world, human populations are increasing whereas shark populations are decreasing because of direct and indirect human impact (Castro *et al.* 1999). There is evidence that at least some shark populations in Australia have declined as a result of commercial and recreational fishing pressure (Punt and Walker 1998; Punt *et al*. 2000; Simpfendorfer *et al*. 2000; McAuley *et al*. 2007) and, at least in NSW and Queensland, as a result of shark nets and drum lines (Green *et al*. 2009). These declines will not be consistent over all of Australia, with local shark densities influenced by a wide range of factors, including the type and intensity of fishing.

One indicator of shark abundance is the beach protection program in NSW where catches have been monitored for decades and provide a long-term data series. From the introduction of the shark-meshing program (SMP) in Sydney (1937), ~1500 sharks were caught in the first 17 months, an average of 88 sharks per month (Green *et al*. 2009). Within a decade, catches from the SMP averaged less than eight sharks per month in the Sydney region (Reid and Krogh 1992). Almost all species have declined over that period. Declines in the number of sharks captured following the introduction of shark-control measures were also found in Queensland (Simpfendorfer 1993), South Africa (Cliff and Dudley 1992), New Zealand (Cox and Francis 1997) and Hawaii (Wetherbee *et al*. 1994). The shark meshing and commercial catch-rate declines suggest that the increase in reported shark attacks over the past two decades is not a result of increasing shark numbers.

Environmental influences on shark attacks

Shark attacks occur all year round in Australian waters. Over the past 20 years, the majority of the attacks (71%) occurred between November and April (Fig. 5). This seasonal peak period coincides with warmest air and water temperatures and school holiday, Christmas, New Year and Easter holiday periods. This is the time of maximal use of beaches, harbours and rivers for recreation, and the time when most people are in the water, increasing the risk of a shark encounter.

A review of attack frequencies indicated that attacks can occur at any time of the day. Beach surveys conducted in South Australia (Department for Environment and Heritage South Australia 2003) have indicated that most visitations occur in the morning and afternoon periods (66% combined), peaking at 1100–1300 hours, and are most likely related to the increasing air temperature throughout the day and fewer people visiting the beach during the dawn and dusk periods (18% and 15%, respectively). Of the three main groups of sharks implicated in attacks, the white shark, bull shark and whaler shark group are relatively evenly represented throughout the day (Table 4). More shark attacks are recorded during the morning and afternoon periods and fewer attacks are recorded in the dawn and dusk periods, which reflects the beach-visitation survey data.

There has been a long-held belief that the relatively small number of people in the water at dawn or dusk are at a potentially higher risk of shark attack because of increased shark-feeding behaviour. While crepuscular and nocturnal feeding behaviour is known in many species of large predatory sharks (Klimley *et al*. 1992), they are also known to be opportunistic and inquisitive and have been observed to investigate opportunities to feed day and night (Wetherbee 1990; Strong 1996). The small number of incidents analysed for patterns of attack (Fig. 6) are inconclusive and do not indicate when a specific species is more likely to attack.

Surfboard riders, SCUBA divers and snorkel divers along the southern Australian states are the main victims of white-shark attacks (16 incidents) occurring during the cooler months between June and September and resulted in nine fatalities. White-shark attacks have not been recorded above the latitude 26°39′S (Maroochydore), Queensland, or 28°43′S (Houtman Abrolhos Islands), WA, although they are known to occur in higher latitudes (Last and Stevens 2009). Although white sharks represent only 29% of the attacks, they are responsible for 68% of the fatalities, highlighting the potential severity of their bite.

The popularity of water-based activities in harbours, estuarine areas and rivers has seen an increase in attacks by bull sharks (*Carcharhinus leucas*), with two fatalities occurring in man-made canals (open to the ocean) and two occurring off ocean beaches. The increase is possibly due to the propensity of this species to inhabit shallow near-shore coastal waters, harbours, estuarine habitats and fresh water (including man-made canals), where encountering people would be enhanced. There were eight bull-shark attacks recorded from December to March in the Sydney area. This reflects their seasonal movement along the NSW coast that is consistent with the annual changes in water temperature (A. F. Smoothey, Cronulla Fisheries Scientific Officer, pers. comm.). Similarly, bull-shark attacks off South Africa are biased to warmer-water months (Cliff 1991). This affinity to warmer water is corroborated by a lack of bull-shark attacks below the latitude 34°32′S (Wollongong, NSW) on the eastern coast and 31°58′S (Swan River, WA) on the western coast. Like bull shark, the tiger shark is also known to move south in the summer months and attacks have been recorded as far south as latitude 34°03′S (Port Hacking, NSW) and 31°59′S (Cottesloe Beach, WA) on the eastern and western coasts, respectively. There have been 20 attacks by bull sharks in estuarine harbours and man-made canals (and 5 in coastal areas) along the eastern coast, suggesting that increased human activities have increased the risk of an attack by this species in these locations.

Attacks by the wobbegong shark (*Orectolobus* sp.) has seen an increase of 9%, compared with the previous 20-year period. Although not considered dangerous, the relatively small and sometimes aggressive species has a history of attacking people that inadvertently come close to it in its natural habitat, while swimming, snorkelling and SCUBA diving in relatively shallow water. The whaler group of shark (unknown species identified to family *Carcharhinidae*) has shown a 14%increase in recorded attacks, compared with the previous 20-year period. It is believed that most of the increase related to this group may be due to confusion with juvenile white sharks (<3 m), which can easily be misidentified as whaler sharks and contribute to this increase (Bruce 1992).

The size of the attacking shark indicated that the larger the shark the more damage it can inflict on the objects it bites. Large white, tiger and bull sharks >2 m in length were involved in the 22 fatalities. There were no fatalities recorded for any species <2 m in length. These results support the contention that any shark >2 m in length should be considered potentially dangerous.

There were several marine animals recorded near the attack site before or during the attack, with 54 incidents where schools of migrating fish, other predatory fish, marine birds and marine mammals were observed. Schools of fish were observed in the immediate area of an attack in 32 incidents, suggesting that sharks in these circumstances may have mistaken the person for their prey item while feeding on school fish. Dolphins (unknown species) were recorded in close proximity in 11 incidents.

Seals (unknown species) were observed in the vicinity in nine incidents and white sharks were involved in eight of these incidents. Swimming, surfing or diving near seals or seal colonies has the highest rate of severe injury and fatalities (89% combined). These results have confirmed the apparent selectivity of pinnipeds in white-shark diet (Bruce 1992; Long *et al*. 1996), to the extent that prey can shape white-shark predatory strategies (Bruce *et al*. 2006). These data have highlighted that swimming, diving or surfing near or amongst schooling fish, dolphins, seals or near seal colonies has the potential to substantially increase the risk of an interaction with a shark.

Conclusion

Patterns of attack have changed substantially over time as a result of the changing population and human behaviour. If human activity related to water-based activities and the use of beaches, harbours and rivers continues to change, we can expect to see further changes in the patterns, distribution, frequency and types of attacks in the future. Encounters with sharks, although a rare event, will continue to occur if humans continue to enter the ocean professionally or for recreational pursuit.

It is important to keep the risk of a shark attack in perspective. On average, 87 people drown at Australian beaches each year (SLSA 2010), yet there have been, on average, only 1.1 fatalities per year from shark attack over the past two decades. It is clear that the risk of being bitten or dying from an unprovoked shark attack in Australia remains extremely low.

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