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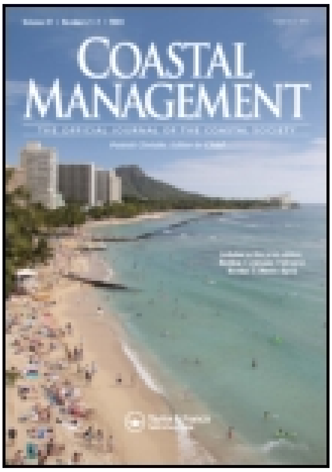

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Unprovoked Shark Bites: Are They Becoming More Prevalent?

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An unprovoked shark bite is an extremely infrequent, but highly disturbing hazard for water sport participants in many parts of the world. Information was analysed on the total number of unprovoked shark bites between 1982 and 2011. In this period, unprovoked shark bite were recorded from 56 countries with 27 recording fatalities; however 84.5% occurred in only six countries - United States, Australia, South Africa, Brazil, Bahamas and Reunion Island. The three shark species commonly responsible for unprovoked bites are the white shark (Carcharodon carcharias), the tiger shark (Galeocerdo cuvier), and the bull shark (Carcharhinus leucas). Over the period examined, the total number of unprovoked shark bites and the number that were fatal increased in frequency. However, fatalities from unprovoked fatal shark bite still represented an infrequent hazard to people utilising the coastal zone for water-based leisure activities. The increase in unprovoked shark bite could not be explained entirely by increases in human population, and this article also concluded that changes in the population of relevant shark species were also unlikely to explain the increase. The paper concluded that both natural and anthropogenic factors may change the amount of spatial overlap between relevant shark species and areas of human use.

Keywords bull shark, human–wildlife conflict, shark bite, tiger shark, white shark

Introduction

Globally, human–wildlife conflict is a growing obstacle to conservation goals (Gore et al. 2008). Sharks can represent a hazard when humans enter the marine environment. While the probability (risk) of the hazard occurring is low, the vivid nature of a shark bite ensures a high degree of media reporting and public concern (Neff 2012), even though most shark bites result in very minor injuries only (Woolgar and Cliff 2001). Unprovoked shark bites on humans is an example of the need to consider and balance anthropocentric and eco-centric views in contemporary coastal management (Philpott 2002). Responses to the hazard that shark bites pose involve public policies and management approaches that contend with the needs of public safety, and the responsibility to protect threatened species (Neff 2012). These responses can include the permanent or seasonal deployment of fishing equipment (shark mesh nets and drumlines) that deliberately target sharks adjacent to populated areas (e.g., Dudley 1997), and ongoing education and warning programs (e.g., Kock et al. 2012).

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Popular media created an image of sharks as omniscient killers of humans—epitomized by the *Jaws* movies. Ongoing reporting of "shark attacks" and "rogue sharks" reinforces this stereotype. Conversely, in recent years, there has been a significant focus on the conservation of sharks and acknowledgment of their important role as apex predators in the food web (e.g., Stevens et al. 2000; Myers et al. 2007; Ferretti et al. 2010). This focus has also included an increase in the number of media articles that focus on shark conservation, although most media coverage still emphasises the hazard sharks pose to humans (Muter et al. 2012).

In this article, information on unprovoked shark bites was assessed for a thirty year period (1982–2011), and trends in frequency elucidated. Factors that potentially explain observed trends are discussed. The influence of gender, shark species responsible, and the human activities undertaken at the time of the bite were also assessed. The key management approaches that potentially address both the hazard itself and the perception of the hazard are discussed.

Methods

Data on shark bites were extracted from the Global Shark Attack File (http://www.sharkattackfile.net/) for a 30-year period between 1982 and 2011. This database contains both provoked and unprovoked shark bites; and those that cause fatalities, injuries, or no injuries at all (e.g., a bitten surfboard). This article assessed unprovoked shark bites only—where the victim had chosen to enter the water and where the person has not specifically encouraged a shark into close proximity (e.g., through feeding) or aggravated a shark (e.g., a diver patting a shark on the head). Reported shark bites where a piece of equipment (e.g., a surfboard or surfski) was bitten or contacted, but where there is no physical contact between the shark or the person, were excluded. Fatalities where drowning was the cause of death, but sharks subsequently scavenged the body were also excluded.

The number of fatal and non-fatal unprovoked shark bites were extracted annually from the database and a linear regression utilized to describe changes in frequency over time. One-way Analysis of Variance (ANOVA) was performed on the average number of bites for five-year intervals for the period examined, and the average number of bites that led to fatalities. The data met the assumptions for ANOVA. One-way ANOVA was performed on the percentage of unprovoked shark bites that led to fatalities. This data was arcsine transformed. The Student-Newman-Keuls (S-N-K) test was used as a post-hoc test to determine which time periods in the ANOVAs differed. Information was also extracted and presented on the gender of the victim, activity undertaken at the time of the bite, shark species reported to be responsible and the country where the bite occurred. Binary logistic regression was used to determine whether fatality rate differed significantly in response to the shark species responsible, or the activity undertaken at the time of the unprovoked bite. All statistical analyses were undertaken using the IBM SPSS software package.

Results

Over the 30-year period examined, the incidence of unprovoked shark bites overall and those that have resulted in fatality has increased (Figures 1 and 2, respectively), although high inter-annual variation is clearly evident with respect to fatalities. When analyzed in blocks of five years, there was a statistically significant difference in the total number of unprovoked shark bites (Figure 3; $F = 49.67$, d.f. $= 5$, $p < .05$) and those that resulted in fatalities (Figure 4; $F = 4.59$, d.f. $= 5$, $p < .05$) over the period examined. For unprovoked

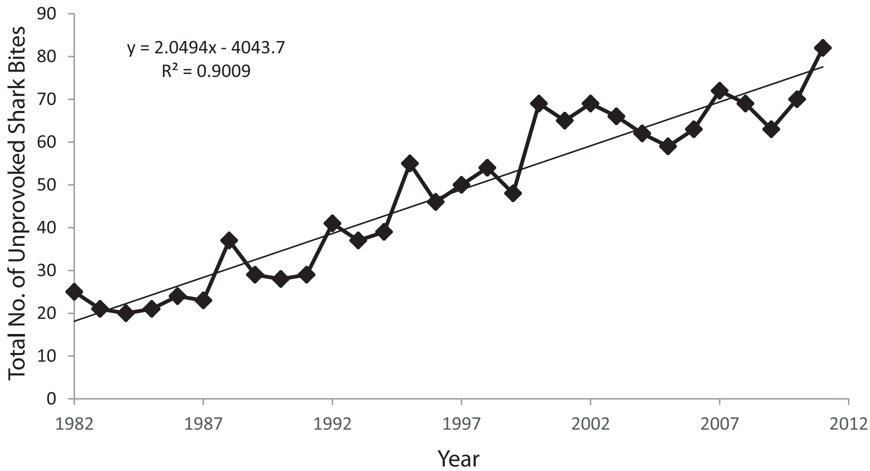

Figure 1. Total number of annual unprovoked shark bites between the period 1982 and 2011.

shark bites overall, the S-N-K test ($p < .05$) identified four groupings of means: 1982–1986 and 1987–1991 combined; and individually 1992–1996; 1997–2001; and 2006–2011. For unprovoked fatal shark bites, the S-N-K test ($p < .05$) identified that the first two time periods (1982–1986 and 1987–1992) were similar to each other, but different from the remainder. Overall 13.4% of all recorded unprovoked shark bites resulted in fatalities, and on an annual basis the ratio was highest in 1993 at 27.0% and lowest in 2007 at 2.8%; and differed significantly when analysed in five year intervals (Figure 5; $F = 3.57$, d.f. = 5, $p < .05$). The S-N-K test ($p < .05$) identifying that the fatality rate for the 1992–96 period was higher than all others.

Unprovoked shark bites are recorded from 56 countries with 27 of these countries recording fatalities. The majority of unprovoked shark bites (84.4%) were recorded from only six countries, with the United State alone recording 53.6% (Table 1). The total number

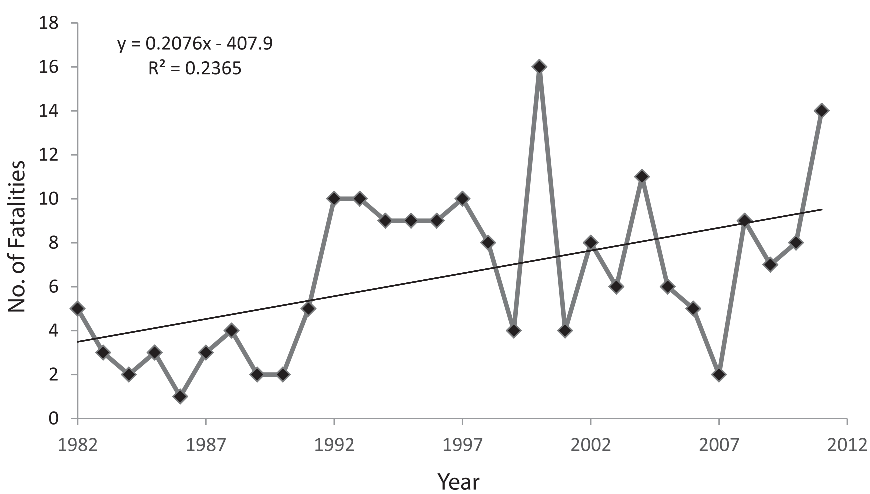

Figure 2. Number of annual unprovoked shark bite fatalities between the period 1982 and 2011.

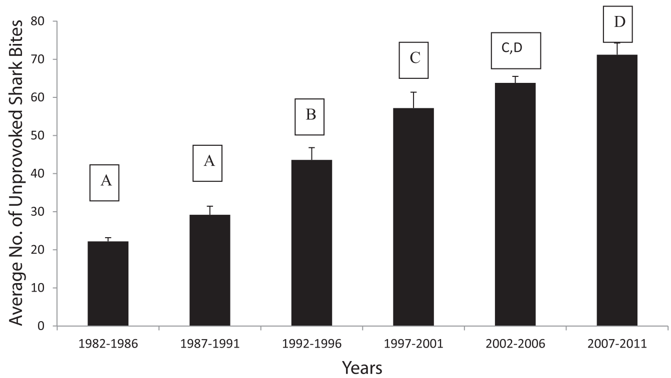

Figure 3. Average total number of unprovoked shark bites (+/– s.e.) for five year intervals for the period 1982 to 2011. The letters in parentheses refer to homogenous groupings of means identified from the S-N-K test ($p < .05$).

of fatalities was higher in Australia and South Africa than it was in the United States. The proportion of unprovoked shark bites that result in fatalities was highest in Reunion. In terms of gender, males were disproportionately the victims of shark bites; they represented 84% of all unprovoked shark bites and 89% of the fatalities.

Where a species of shark was assigned, the white shark (*Carcharodon carcharias*) was responsible for the largest number of unprovoked shark bites; while, combined, the white, tiger (*Galeocerdo cuvier*), and bull shark (*Carcharhinus leucas*) accounted for 55.6% of all bites (Table 2). These three shark species accounted for all fatalities with the exception of three attributed to the oceanic white tip shark (*Carcharhinus longimanus*). The fatality rates for bites from white, tiger, and bull sharks was not statistically significant (Wald $\chi^2 = 0.3$, d.f. $= 1$, $p > .05$). Surfing and swimming (including standing and wading in the water) were the most frequent activities undertaken at the time of an unprovoked shark bite;

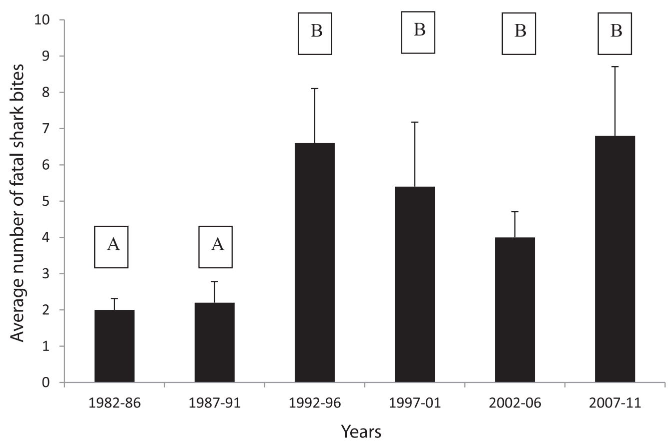

Figure 4. Average number of unprovoked fatal shark bites (+/– s.e.) for five year intervals for the period 1982 to 2011. The letters in parentheses refer to homogenous groupings of means identified from the S-N-K test ($p < .05$).

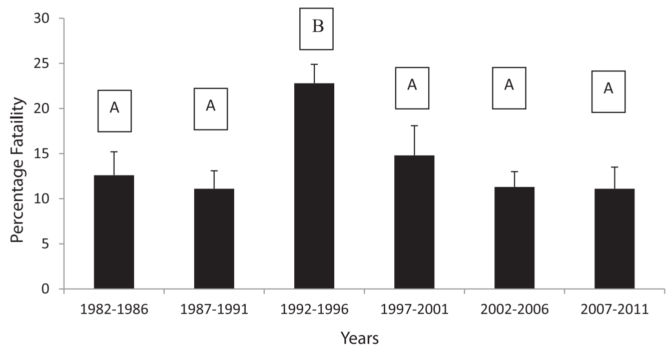

Figure 5. Average percentage of unprovoked fatal shark bites that led to fatalities (+/– s.e.) for five year intervals for the period 1982 to 2011. The letters in parentheses refer to homogenous groupings of means identified from the S-N-K test ($p < .05$).

however, the highest fatality rates were recorded for scuba diving (Table 3). The fatality rates, based on activities undertaken at the time of the unprovoked shark bite, were not statistically significant (Wald $\chi^2 = 2.2$, d.f. = 1, $p > .05$).

Discussion

Over the 30-year period examined in this article, the total number of unprovoked shark bites has increased, as has the number of unprovoked shark bites that result in fatalities. While this increase can in part be explained by an increasing human population, the number of shark bites has increased threefold, while human population growth in the same period has increased by 52% (World Bank 2013). Where the relationship between human population growth and unprovoked shark bites has been examined at a regional level (Western Australia and Brazil), it has also been identified to be above the rate of human population increase in those regions (Hazin, Burgess, and Carvalho 2008; W. A. Department of Fisheries 2012). Overall, an increase in human population alone is not a sufficient explanatory factor for increases in unprovoked shark bites, although it clearly does play a role (West 2011). An assumption inherent in these comparisons is that the total number of hours spent in the water

Table 1
Number of recorded unprovoked shark bites between 1982 and 2011 for the six countries where bites are most prevalent

Country	Total number (Cumulative percentage)	Number of fatalities	% of bites that result in fatalities
United States	769 (53.6)	25	3.6
Australia	171 (65.5)	32	18.7
South Africa	132 (74.7)	28	21.2
Brazil	68 (79.4)	22	32.3
Bahamas	42 (82.3)	3	7.1
Reunion	31 (84.5)	16	51.6

Table 2

Species of shark responsible for shark bites in various countries. The value in parentheses refers to the percentage that resulted in fatality

	Shark species				
Country	Tiger	White	Bull	Blacktip whaler	Other species
United States	33 (27.3%)	51 (7.8%)	19 (10.5%)	21 (0.0%)	57 (0.0%)
Australia	4 (0.0%)	41 (46.3%)	16 (12.5%)	12 (0.0%)	24 (0.0%)
Reunion	4 (50.0%)	0 (0.0%)	8 (62.5%)	0 (0.0%)	0 (0.0%)
South Africa	4 (100%)	59 (27.1%)	5 (20.0%)	1 (0.0%)	17 (0.0%)
Brazil	3 (0.0%)	0 (0.0%)	3 (0.0%)	1 (0.0%)	0 (0.0%)
Bahamas	1 (100%)	0 (0.0%)	7 (14.0%)	2 (0.0%)	9 (0.0%)
Other	16 (18.8%)	20 (20.0%)	13 (15.3%)	3 (0.0%)	20 (15.0%)
Total	65 (29.2%)	171 (23.4%)	71 (28.3%)	39 (0.0%)	127 (2.4%)

Table 3
Water based activities being undertaken at the time of unprovoked shark bite in various countries. The value in parentheses refers to the percentage that resulted in fatality

	Activity					
Country	Swimming/wading/ standing	Surfing	Snorkelling	Spearfishing	Scuba diving	Other
United States	239 (3.3%)	407 (2%)	25 (8%)	17 (5.9%)	19 (10.5%)	20 (5.0%)
Australia	44 (13.6%)	63 (15.8%)	15 (33.3%)	11 (9.1%)	26 (34.6%)	5 (0.0%)
Reunion	2 (100%)	18 (44.4%)	0 (0.0%)	5 (40.0%)	2 (0.0%)	0 (0.0%)
South Africa	23 (34.7%)	69 (15.9%)	6 (0.0%)	25 (24.0%)	3 (33.3%)	3 (0.0%)
Brazil	25 (68.0%)	37 (16.2%)	0 (0.0%)	2 (0.0%)	0 (0.0%)	0 (0.0%)
Bahamas	3 (0.0%)	1 (0.0%)	4 (0.0%)	16 (7.7%)	6 (16.7%)	0 (0.0%)
Other	59 (32.2%)	39 (25.0%)	23 (21.7%)	26 (19.2%)	31 (41.9%)	22 (22.7%)
Total	395 (14.7%)	634 (8.4%)	73 (16.4%)	102 (15.7%)	97 (26.8%)	50 (10.0%)

correlates with human population growth. In addition to the influence of human population growth, other factors that may explain the increase in unprovoked shark bites include an increase in abundance of shark species frequently implicated in unprovoked bites, and/or a natural or anthropogenic change in these species habitat use or behavior.

This article identified a gender bias with males more likely to be victims of unprovoked shark bites than females. This may be a result of the overrepresentation of males in water-based sports such as surfing, although specific data is lacking. Males have been also found to be disproportionately represented in drownings and a number of other forms of accidental death (Browne, Lewis-Michl, and Stark 2003). Contributing to the gender bias may be that females are more risk averse than males and such circumstances occur in varying situations (Powell and Ansic 1997; Weber, Blais, and Betz 2002); however, such a gender pattern of risk behavior is not universal (Maxwell et al. 2010).

Shark Abundance

White sharks have in a number of jurisdictions (e.g., Australia and South Africa) been totally protected for an extended period of time from recreational and commercial fishing, although mortality occurs in shark control activities in South Africa and Australia (Reid and Krogh 1992). In South Africa, Kock and Johnson (2006) identified that populations were stable or increasing only slightly, while later work by Towner et al. (2013) suggests the species has not made a marked recovery since being nationally protected there. Ferretti et al. (2010) and Reid, Robbins, and Peddemors (2011) based on assessment of catch per unit effort data from South African and NSW (Australia) shark nets documented a decline in white shark abundance with no evidence of recovery. Skomal, Chisholm, and Correia (2012) documented an increase in white shark sightings off the Massachusetts coast but this was attributed to changes in range and habitat use, rather than an increase in the population. In many jurisdictions incidental capture of white sharks still occurs, while the high value of the fins for human consumption and their jaws and teeth as curios contributes to targeted fishing mortality (Baum et al. 2003; Dudley 2012; Lowe et al. 2012; Santana-Morales et al. 2012; Jewell et al. 2013). The migratory nature of the white shark (Bonfil et al. 2005; Duffy et al. 2012; Jorgensen et al. 2012) means that protection in a specific jurisdiction may not lead to an increase in the population if sources of mortality remain elsewhere, and populations of large sharks such as the white shark are vulnerable to low levels of fishing mortality (Ferretti et al. 2010). Although definitive data are lacking, given the available information including the continued level of mortality of the species and its life history, a significant increase in the population of the white shark is unlikely.

In terms of the other two shark species frequently implicated in unprovoked shark bites, available information for tiger sharks from catch and effort data in the Queensland Shark Control Program suggests a decline in the population (Holmes et al. 2012), while Carlson et al. (2012) identified only a small increase of 3% in the north-west Atlantic. For bull sharks, Froeschke, Froeschke and Stinson (2013) identified a long-term increase in abundance in the estuary waters of Texas over a 35-year period, potentially as a result of restrictions on gill net fishing. Carlson et al. (2012) found a 12% increase in the population of bull sharks in the north-west Atlantic. However, Ferretti et al. (2010) documented declines in the population in South Africa.

Overall, while some uncertainties exist, there is no compelling body of evidence that suggests that the population abundance of relevant shark species is increasing, or increasing to the extent to explain the increasing trend in unprovoked shark bites. This is particularly the case for the white shark, which is the species most frequently implicated in unprovoked bites (including fatal bites).

Shark Habitat Use

Both natural and anthropogenic factors may influence the habitat use and behavior of shark species frequently implicated in unprovoked bites. These factors may result in changes in the local abundance of sharks rather than changes in the population as a whole. A change in the distribution and abundance of food sources should also be considered as a factor that may increase the incidence of unprovoked shark bites through increasing the overlap between key shark species and humans. The distribution of prey is a key variable in explaining the movement patterns and habitat use of various species of sharks including tiger and white sharks (Heithaus 2001; Weng et al. 2007; Meyer et al. 2009; Kock et al. 2013). Marine mammals are the dominant prey items of large (>3 meters) white sharks (Hussey et al. 2012; Fallows, Gallagher, and Hammerschlag 2013). In Australia, the population of the humpback whales (*Megaptera novaeangliae*) and the New Zealand fur seal (*Arctocephalus australis forsteri*) have increased (Gales, Haberley, and Collins 2000; Bannister and Hedley 2001). The latter is also increasing its geographic distribution in temperate coastal regions in Australia, including in Western Australia in locations where recent fatal shark bites have occurred (Gales, Haberley, and Collins 2000; Berry et al. 2012). Skomal, Chisholm, and Correia (2012) identified that an increase in the gray seal (*Halichoerus grypus*) population was the most likely cause of a local increase in white shark numbers in the Massachusetts area of the United States. Adult white sharks are known to aggregate at and "patrol" coastal areas where seals and sea lions frequent (Klimey et al. 2001; Johnson et al. 2009; Skomal, Chisholm, and Correia 2012).

In terms of anthropogenic factors, coastal development has been specifically implicated in an increase in fatal shark bites in Brazil after 1992 (Hazin, Burgess, and Carvalho 2008). Significant habitat modifications for the construction of a port facility (Suape Port) involved river mouth diversions and this is thought to have displaced bull sharks from previous important habitat to the nearest suitable alternative habitat that has high human use. Additionally in that area, Hazin, Burgess, and Carvalho (2008) also found statistical correlations between periods of high maritime traffic shark bites, and suggested that sharks associate with maritime traffic and follow vessels to inshore areas. Shark tourism, in particular the white shark cage diving industry, has resulted in localized changes to behavior and habitat use of the animals (Laroche et al. 2007; Bruce and Bradford 2013). However, there is no direct causal link between these tourism activities and unprovoked shark bites.

Shark Bites in Context

Sharks of species responsible for unprovoked bites are often consistently present at beaches with high human use, but show no inclination to bite humans (Neff and Hueter 2013). While this article has documented an increase in shark bites, it still represents an infrequent hazard for water users and a very low source of fatalities. For example on Australian surf beaches between 2001 and 2005, 129 people drowned (Morgan, Ozanne-Smith, and Triggs 2008) whereas during the same period fatalities from shark bites numbered five. In Senegal, Trape (2008) identified 322 deaths by drowning between 2001 and 2006 but only two fatalities from unprovoked shark bites over a sixty-year period. While the probability of an unprovoked shark bite is low, perceptions of hazard and risk can be equally important in shaping public attitudes, beliefs, and support or opposition for wildlife management activities.

The reporting of shark–human interactions is often framed in emotive and intent-laden imagery and Neff and Hueter (2013) have called for a more prescriptive code of reporting to clarify the true risk posed by sharks to assist better policymaking. The media portrays sharks as perpetrators of risk and unprovoked shark bites frequently garner international media attention (Muter et al. 2012). The vivid nature of shark bites skews risk perception and the media often highlight low-incidence, high-consequence events such as wildlife-related human fatalities (Muter, Gore, and Riley 2009; Gore et al. 2011). Increased media coverage of a low-risk scenario can increase the level of risk perceived by members of the public (Frewer, Miles, and Marsh 2002; Leschine 2002; Gore et al. 2005). Encouraging more objective and less sensational reporting of unprovoked fatal shark bites can potentially contribute to the overall adoption of management approaches with less impact on marine species of conservation concern.

Managing the Hazard and Risk of Unprovoked Shark Bites

Despite the infrequent hazard that unprovoked shark bites represent, there is often an imperative for coastal managers to consider and attempt to address the issue given its high profile, and this is particularly the case when a number of bites occur in a region in a relatively short timeframe (Kock et al. 2012). Traditional shark control programs including the routine use of mesh nets and/or drumlines that target large sharks are utilized in parts of South Africa and Australia with high levels of by-catch of various marine mammals, marine turtles, and sharks not implicated in unprovoked shark bites (e.g., Paterson 1990; Krogh and Reid 1996; Gribble, McPherson, and Lane 1998; Dudley and Cliff 2010; Cliff and Dudley 2011; Sumpton et al. 2011; Brazier et al. 2012; Atkins, Cliff, and Pillay 2013). Although the timing and operation of the gear has been modified in an attempt to reduce the impact of these activities on non-target species, the catch rates can still remain relatively high (Sumpton et al. 2010; Cliff and Dudley 2011). Following a number of unprovoked shark bites over a short period of time, targeted effort or further targeted effort to cull sharks can be used to attempt to reduce their local abundance (Dudley 2006; Neff and Yang 2013). Weltz et al. (2013) identifies that there is increasingly less justification and support for measures that involve killing large sharks, and more ecologically responsible approaches are being sought to reduce the risk of unprovoked shark bite, which include attempts to understand and exploit patterns in shark behavior to minimize the likelihood of shark encounters.

The effectiveness of routine shark control activities or shark culling at reducing unprovoked shark bite is difficult to assess definitively and will most likely vary according to local biophysical factors and the species of shark. Dudley (1997) by comparing unprovoked shark bites before and after the introduction of shark control activities in South Africa and Australia identified significant reductions and attributed them to these activities. However, in the case of tiger sharks in Hawaii, Holland et al. (1999) concluded that they were unlikely to be effective at reducing the risk of unprovoked shark bites there. They explained that the large home range of the animal and their high mobility means that short-term culling efforts are unlikely to be effective in reducing the number of sharks at a particular location, as "new" sharks may be moving in from a remote area. Shark control programs also have a role in potentially boosting public confidence regarding safety (Neff 2012).

A contemporary view is that beach safety policies should not be about hurting sharks *per se* but rather about regulating, educating, calming, and placating the public—in particular alleviating the short-term anxiety that fear of shark bites can engender (Neff 2012). As such, alternatives to traditional shark control activities have gained increased impetus. Unlike shark meshing, shark enclosures do not entangle marine fauna and provide a complete barrier on a beach. Small shark enclosures are also used in Hong Kong, a number of sheltered locations in Australia, and one is proposed in Fish Hoek Bay (South Africa) (McPhee 2012; Neff and Yang 2013). The approach is generally utilized to provide an area free of sharks for swimming and bathing. If most fatal shark bites in a region are on people undertaking other activities such as surfing or diving, a shark enclosure will not provide protection as people are unlikely to heavily utilize them. However, shark enclosures if properly maintained are effective at protecting people if they remain within its confines.

A number of locations have dedicated education programs (e.g., signage) that communicate information on sharks to the general public. Surf lifesaving patrols, where present can also provide a warning system to alert beach users to the presence of a shark, and also provide critical first aid in a timely fashion should a bite occur. Helicopter patrols near popular beaches are also a tool that have been utilized in parts of Australia. If a shark is spotted, the general public can be alerted and the beach temporarily closed to water users. However, the effectiveness and utility of helicopter patrols is questionable (Neff 2012). They are unlikely to be highly effective in turbid areas or in areas where deeper water or reefs are close to beaches as a shark present may not be spotted.

An ongoing shark-spotting program started at beaches in the Cape Town region in 2004 and aims to alert water users to the presence of sharks at beach locations (Kock et al. 2012). The program uses a combination of warning flags, sirens, and explanatory signage at various locations to communicate to the public shark activity and spotting conditions. The program also benefits research as it provides an understanding of the temporal pattern of habitat use by white sharks (Weltz et al. 2013). In Western Australia, a dedicated Shark Response Unit was developed in 2012 and part of the role of this unit is to provide advice and information such as shark sightings to the public (including via social media) to assist in the making of informed decisions when using the marine environment. New technologies have also been trialled that have the potential to provide in real time information on whether a shark species that is implicated in fatal bites is present near a designated area (e.g., a popular surf beach). In Western Australia, white sharks have been tagged with acoustic tags and a series of "listening stations" placed along the most populated coastal stretch detect the presence of an acoustically tagged shark within a set radius. If an acoustically tagged shark is detected, warnings are issued which allow water users to alter their plans and avoid the area if they choose. Overall, approaches such as those operating at Cape Town and Western Australia can provide an early warning system to alert beach-goers to the presence of a large shark. Stable funding can be limiting factor to the expansion of these programs (Oelofse and Kamp 2006), but any dedicated activities in general for the purpose of minimising unprovoked shark bites require resourcing.

Conclusion

This article has identified that globally unprovoked fatal shark bites are increasing in frequency. However, the risk of an unprovoked fatal shark bite is considerably less than drowning while swimming at the beach. Mitigating the risk of a shark bite represents a challenge for balancing anthropocentric and eco-centric views. Shark control methods such as shark nets and drum-lines continue to have significant impacts on a range of marine animals of conservation significance. A future focus of addressing the interactions between humans and sharks lies in further education of water users. Given unprovoked shark bites largely only occur when people are voluntarily undertaking a leisure activity of their choosing, a focus on individual responsibility is clearly apt, and education can inform individual decisions. Better understanding of the movements and migrations of the shark species principally responsible for unprovoked bites, and in particular real time information on such movements will also significantly contribute to objective assessment of the risk of shark bites and also further enhance the understanding of shark biology. Understanding the media and encouraging more objective and less sensational reporting of unprovoked fatal shark bites can potentially contribute to the overall adoption of management approaches with less impact on marine species of conservation concern.

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