Global shark attack hotspots: Identifying underlying factors behind increased unprovoked shark bite incidence

Article *in* Ocean & Coastal Management · December 2016

DOI: 10.1016/j.ocecoaman.2016.09.010

2 authors:

Blake Kristin Harahush
Blake Chapman Communication
8 PUBLICATIONS **89** CITATIONS
SEE PROFILE

Daryl Mcphee
Bond University
32 PUBLICATIONS **392** CITATIONS
SEE PROFILE

Ocean & Coastal Management 133 (2016) 72–84

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Global shark attack hotspots: Identifying underlying factors behind increased unprovoked shark bite incidence

Blake K. Chapman*, Daryl McPhee

Faculty of Society and Design, Bond University, Robina, Queensland, Australia

A R T I C L E I N F O

Article history:
Received 22 October 2015
Received in revised form
31 August 2016
Accepted 15 September 2016

Keywords:
Unprovoked shark bite
Tiger shark (*Galeocerdo cuvier*)
White shark (*Carcharodon carcharias*)
Bull shark (*Carcharhinus leucas*)
Human-wildlife interaction

A B S T R A C T

Unprovoked shark bite remains a rare, unlikely occurrence; however, shark bite incidence is increasing world-wide. In an effort to understand why shark bite incidence is increasing, we examine recent trends in unprovoked shark bite statistics and other media from the six global shark bite "hotspots", the United States, South Africa, Australia, Brazil, Reunion Island and the Bahamas, and review recent literature that identifies potential causative factors that may contribute to rising shark bite incidence. Increases in shark bite incidence are likely attributable to rises in human population, as well as other causative factors, including habitat destruction/modification, water quality, climate change and anomalous weather patterns and the distribution/abundance of prey. Our analysis shows that increases are likely the result of a set of conditions that disrupts the natural balance of an area at a local or regional level and increases the probability of shark-human interaction. We also present recommendations for future management of shark-human interaction.

1. Introduction

Globally, the frequency of unprovoked shark bite has been increasing (McPhee, 2014). While unprovoked shark bite over the last 30 years has been recorded from 56 countries and territories, the majority (84%) have occurred in six: the United States, South Africa, Australia, Brazil, the Bahamas and Reunion Island (McPhee, 2014). While the probability of unprovoked shark bite is low, and most shark bites result in very minor injuries only (Woolgar and Cliff, 2001), the results can be traumatic or fatal and the vivid nature of a shark bite ensures a high degree of media reporting and public concern (Neff, 2012). The public perceives the probability of an unprovoked shark bite as much greater than it actually is, and a greater fatality risk than drowning, despite evidence to the contrary (Caldicott et al., 2001; Crossley et al., 2014; McPhee, 2014; Myrick and Evans, 2014).

In order to address public concern, management agencies may implement measures that attempt to reduce the risk posed, placate the public, or provide information aimed at allowing water users to make more informed decisions about utilising a particular area at a particular time. Traditional measures, such as shark nets and drum lines, which attempt to capture and kill large sharks, are highly controversial (Gibbs and Warren, 2014; Meeuwig and Ferreira, 2014). Assessment of the efficacy of these programs has demonstrated in terms of actual reduction in the probability of an interaction that they may be equivocal or ineffective (Wetherbee et al., 1994), and the perception among the public of their level of efficacy is not high (Crossley et al., 2014). Further, as well as targeting species such as the white shark (*Carcharodon carcharias*) and the tiger shark (*Galeocerdo cuvier*), which are of conservation concern, the methods used result in high levels of by-catch, including protected or threatened species (Brazier et al., 2012; Dudley, 1997; Dudley and Cliff, 2010; Dudley and Simpendorfer, 2006; Gribble et al., 1998; Krogh and Reid, 1996; Paterson, 1990), and could have detrimental effects to entire populations (Weltz et al., 2013). Additionally, the shift in human perception from the need to be protected from sharks to the need to protect sharks from humans leads to the necessity to formulate ecologically-responsible approaches to mitigating the risk (Gibbs and Warren, 2014; Meeuwig and Ferreira, 2014; Simpfendorfer et al., 2011).

Unprovoked shark bite is not a homogenous phenomenon, complicating assessment of the event. Bites may occur over a range of different habitats (e.g. coral reefs, surf beaches, rivers), and the various species implicated in bites differ substantially in biology and ecology. However, the three main species of concern to humans

---

Abbreviations: ISAF, International Shark Attack File; NSW, New South Wales; SST, Sea surface temperature; US, United States; WA, Western Australia.

* Corresponding author.
E-mail address: blakechapmancomms@gmail.com (B.K. Chapman).

http://dx.doi.org/10.1016/j.ocecoaman.2016.09.010
0964-5691/

are white sharks, bull sharks (*Carcharhinus leucas*), and tiger sharks (McPhee, 2014). Furthermore, the pattern of human usage of coastal waters also differs both spatially and temporally, and unprovoked shark bites occur during a range of human water-based activities (McPhee, 2014).

Identifying that the frequency of unprovoked shark bite has been increasing globally is important, but given its heterogeneous nature, further understanding requires analysis of trends at regional levels, and a focus on the drivers of any trends at this level. There are a number of factors that may contribute to the global trend of increasing unprovoked shark bite. Paramount is simply that a growing human population means that more people are likely to be in the water, and hence the probability of an unprovoked shark bite is increased. However, McPhee (2014) identified that, globally, this factor alone was insufficient to explain the observed trends, and Amin et al. (2012) determined that unprovoked bites were not proportional to beach attendance in Florida. Other contributing factors may include changes in the abundance of prey (e.g. seals and whales), which may increase the spatial overlap between relevant shark species and water users; an increase in the population of relevant shark species; and anthropogenic factors, such as coastal development, which may change the pattern of habitat use of relevant shark species (McPhee, 2014). These potential contributing factors are not mutually exclusive.

In this paper we analyse International Shark Attack File (ISAF) records from the global "hotspots" of unprovoked shark bite between the years 1982 to 2013. We aim to determine the trends in the frequency of unprovoked shark bite at these six hotspots and offer explanations of observed trends. Identifying potential factors that may be responsible for observed trends can assist in understanding the phenomenon, and, thus, contribute to better informed decision-making regarding mitigating the risk of unprovoked shark bite.

2. Methods

Data for this study were extracted from the International Shark Attack File (ISAF), http://www.flmnh.ufl.edu/fish/sharks/isaf/isaf.htm from the time period of 1982 to 2013. The ISAF is the longest running database relating to shark attacks and serves as a long-term database containing information on known shark bites. It is a globally-comprehensive, scientifically-based shark attack database, with much of the data obtained through voluntary submissions by cooperating scientists across the globe, who act as regional assessors.

While it is clearly plausible that some (predominantly minor) incidents are not reported, it should be recognised that the database, nonetheless, represents a highly valuable resource, without which advanced efforts into understanding shark bite incidence would not be possible. Further, the public interest in unprovoked shark bite means that even minor incidents (including encounters where no physical contact occurs) are generally reported in the media, from where regional observers can investigate the interaction and log a report. We consider that there is likely to be a lack of reporting in countries where national and international media and communications are generally poor (e.g. Papua New Guinea), or where war or political instability reduces information exchange with the outside world (e.g. Sudan). Such countries, though, are not the focus of this paper, which instead examines unprovoked shark bite in locations where media and communications are effective, and where the relative prevalence of bites leads to an understanding of the importance of systematic reporting of incidents, and how to go about reporting. As such, while potential regional biases in the database were considered in the early stages of analysis, we did not feel that they would detract from or invalidate the analyses and interpretations presented herein.

The data extracted from the ISAF database included information on the date and locality of shark bite (year, date, time, country, state/territory, county/beach), the source of information, and as much information as possible on the activity performed at the time of the bite, the victim (name, sex, age, injury sustained) and detail of the shark. Prior to analysis, all names and individual identifiers were removed from ISAF data sets used in this study to anonymise and de-identify the records. Our dataset was filtered through the ISAF data download tool and by scanning the activity and injury details of each file to include only cases that were confirmed and unprovoked. Our analysis excludes provoked bites, bites to motorised or non-motorised water crafts or equipment where no physical contact between the shark and a human occurred, and cases where the victim was dead prior to shark interaction. The bites must have occurred in the sharks' natural environment and without prior provocation by a human (e.g. encouraging a shark through feeding or aggravating the shark by purposefully touching or attempting to touch it). Cases where the presence or accountability of a shark towards human injury or death were not definitive are excluded. Additional information on shark bite data collection and current shark bite data (including maps showing where bites have occurred) can be found on the ISAF website (https://www.flmnh.ufl.edu/fish/isaf/home/).

Shark bite data were broken down by country, state/territory and county, and yearly incidence was qualified and plotted. Linear regression trendlines were fitted to the data to determine change in frequency (rate of change). Regional data were also broken down by month and activity. Within the manuscript, peak incidence years are identified by calendar year, followed by the number of incidents in parenthesis. Human population trends are based on statistics downloaded from the Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT, 2014).

Where species information is provided, it is only given when the case file provides a definitive species identification. If the file states "possibly", "probably", "thought to be", or includes a "?", the species is considered unknown. Shark species data were broken down by region and quantified to determine species accountability. Sharks were described as specifically as possible within the file data, but in some cases, could only be identified to the genus level. Unless otherwise stated, shark species accountability percentages are given based on the total number of bites (and not the total number with species identified).

While commonly denoted in the literature and media as "shark attack", we utilise the term "shark bite" to refer to the same occurrence, as we believe this to be the more appropriate term. However, no difference between the two descriptors exists.

3. Results and regional discussion

3.1. United States

Unprovoked shark bite is most prevalent in the United States (US), comprising 52.0% of global recorded unprovoked shark bite between 1982 and 2013. The incidence of unprovoked shark bite in the US has shown a gradual rise over the past 32 years, at an average rate of change of 1.07 bites per year (Fig. 1). The years with the highest incidence of unprovoked shark bites were 2001 (50), 2007 (48), 2012 (46) and 2013 (46). In the peak year of 2001, all 50 unprovoked bites occurred between the warmer spring and summer months of March through September. The vast majority of unprovoked shark bites occur off the coast of Florida (Fig. 2, Table 1). The risk of unprovoked shark bite within the coastal waters of Florida is not uniform, with a disproportionate number occurring in Volusia County. In contrast, the counties of Duval, St

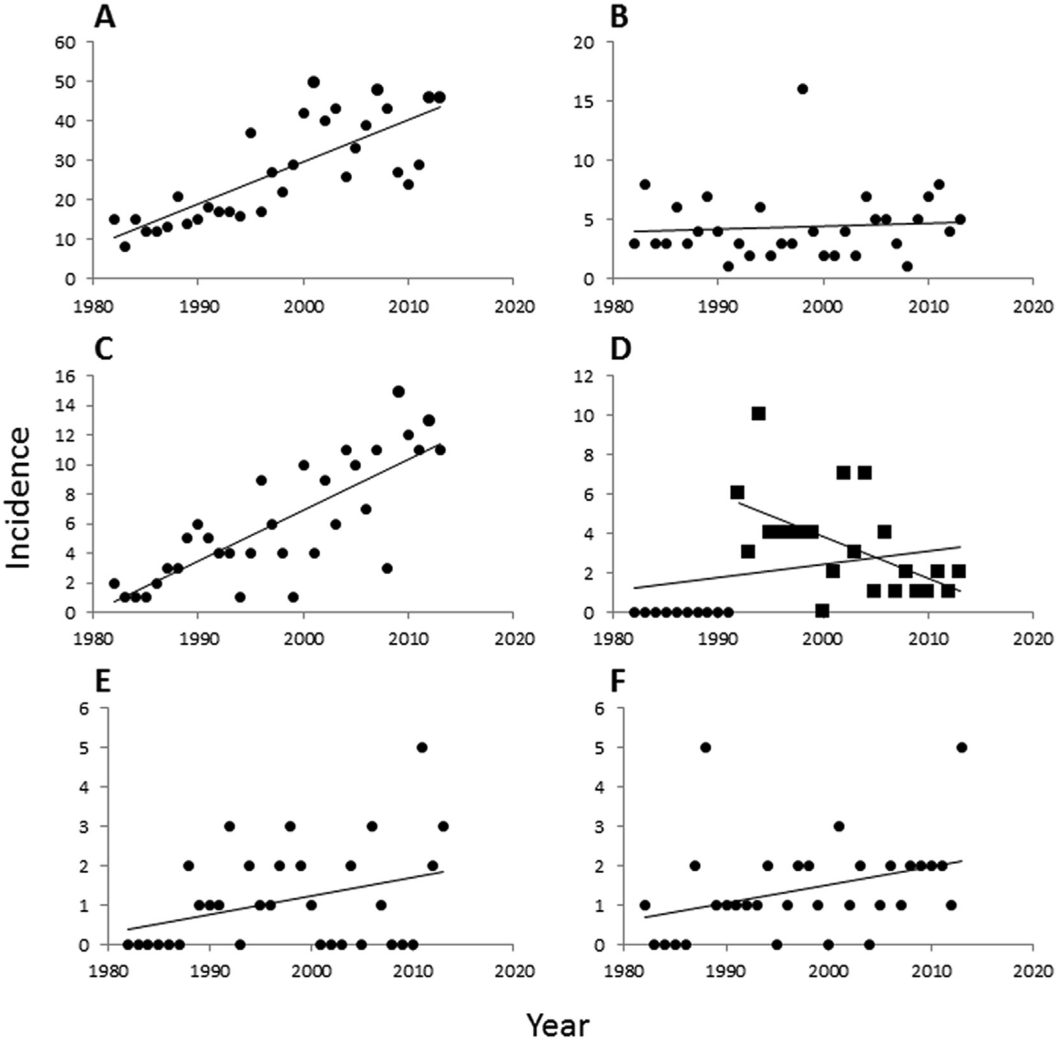

Fig. 1. Unprovoked shark bite incidence between January 1982 and December 2013 in six of the global "hotspots". Incidence within the United States (A), South Africa (B), Australia (C), Brazil (D), Reunion Island (E) and the Bahamas (F). Trendlines for incidence in Brazil is calculated based on data from 1982 to 2013 (circles and squares), and since the beginning of recorded incidence in 1992 (squares). The trendline represents the linear regression fit through year incidence.

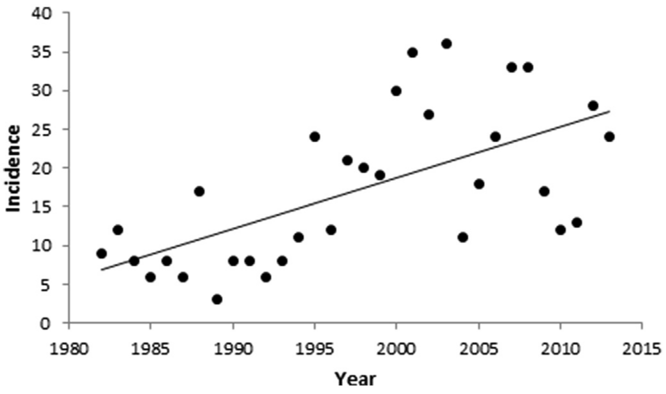

Fig. 2. Unprovoked shark bite incidence between January 1982 and December 2013 in Florida. The trendline represents the linear regression fit through year incidence.

Johns, Broward and Miami-Dade are low risk areas (Amin et al., 2012). In 2001, 35 of the 50 bites (70%) within the US occurred off the coast of Florida and 23 occurred off Volusia County (46% of US bites).

Amin et al. (2012) identified that unprovoked shark bite in Florida was explained by neither spatial or temporal factors in isolation, but rather, an interaction between the two, that led to some areas being relatively high-risk, and others relatively low-risk, with some years being different in risk level. Volusia County is renowned for its 80 km of pristine beaches. However, the main draw to the area is the surf conditions. The majority of bites in Volusia County (62.8%) between 1982 and 2013 occurred during surfing activities, compared with 44.9% in other Florida locations. Dredging to maintain the channel and manmade rock jetties in the area facilitates sandbar development and affects natural water flow, producing highly favourable surfing conditions. Surfing behaviours have been suggested to expose people to sharks more than most other water activities, due to surfers' duration of time in the water, distance from shore, isolation, and "provocative" arm and leg movements (Burgess et al., 2010). Volusia County beaches are also naturally susceptible to large amounts of runoff following heavy rain (which was anecdotally considered to be a factor leading to an increase in shark-human interactions in August 2012) and 75% of Volusia County shark bites between 1957 and 2008 occurred during decreased clarity ("turbid", "murky", or "muddy" water) (Burgess et al., 2010). Additionally, an abundance of baitfish is also found

Table 1
Shark bite incidence by species between 1982 and 2013 in the United States, Florida and Volusia County, where the identification of the species was definitively recorded.

	USA	% (883)	Florida	% (547)	Volusia county	% (234)
Carcharodon carcharias	54	6.12				
Sphyrna sp.	4	0.45	3	0.55	1	0.43
Carcharhinus leucas	27	3.06	18	3.29	2	0.85
Carcharias taurus	6	0.70				
Galeocerdo cuvier	46	5.21	2	0.37		
Prionace glauca	1	0.11				
Carcharhinus limbatus	20	2.27	16	2.93	3	1.28
Carcharhinus falciformis	2	0.23	2	0.37		
Negaprion brevirostris	6	0.68	5	0.91	1	0.43
Carcharhinus brevipinna	10	1.13	10	1.83	2	0.85
Carcharhinus plumbeus	1	0.11				
Isurus sp.	1	0.11				
Carcharhinus obscurus	1	0.11				
Ginglymostoma cirratum	6	0.68	6	1.10		
Carcharhinus perezii	1	0.11	1	0.18	1	0.43
Squatina sp.	1	0.11				
Isistius brasiliensis	1	0.11				
Alopias sp.	1	0.11				
Carcharhinus galapagensis	1	0.11				
Lamna ditropis	1	0.11				
Triaenodon obesus	1	0.11				
C. limbatus/C. brevipinna	8	0.90	8	1.50	7	3.00
TOTAL	200	22.65	71	12.96	17	7.26

Percentages are given based on the total number of shark bites in the specified region (in parentheses) over this time period. A high number of shark bites in Florida (8) and Volusia County (7) are also attributed to "blacktip or spinner sharks" (highlighted row), as the identity of two species is often mistakenly interchanged (Burgess et al., 2010). The species in most bites (USA: 77%, Florida: 87%, Volusia County: 93%) is unknown or unconfirmed.

in this area (Burgess et al., 2010). Combined, these conditions produce an environment that would be favourable to many elasmobranch species, and in fact, the area has been found to be a nursery area for blacktip sharks (*Carcharhinus limbatus*) and spinner sharks (*C. brevipinna*) (Aubrey and Snelson, 2007), the two species that, when combined (as they are often not distinguishable by bite victims and witnesses), are most often implicated in Florida shark bites (6.2% of all Florida bites during the study time period). Similarly, these conditions would also be favourable to juvenile bull sharks (Werry, 2010), which are also implicated in unprovoked bites in Volusia County and Florida more broadly (Table 1, Fig. 3).

While increasing human population is not considered to be the sole factor in increasing unprovoked shark bites globally, beach usage is clearly a contributing factor. This is apparent, especially, when considering the US shark bite statistics. Incidence decreased sharply in the four years during and following the global financial crisis (2008–2011) when economic conditions led to a major reduction in tourism and the cancellation of travel. With the improvement in the American economy from 2011 onwards, a surge in tourism (VISIT FLORIDA Research, 2015) mirrors the increasing trend in unprovoked shark bites. Similarly, trends in Florida's population growth have been shown to be closely linked to economic conditions, with increased immigration and decreased emigration during economic booms, and the opposite during economic busts (Smith and Cody, 2015). Florida's residential population increased 5.8% between April 2010 and July 2014, above the US average of to 3.3% (United States Census Bureau, 2015).

Another trend that is apparent through assessment of Florida shark bite incidence is that communication and funding play large roles in shark bite statistics. At first glance, it appears that there were significant increases in unprovoked shark bites in 1987 and 1993 (Burgess, 2014). However, this is noted as being an artefact of the ISAF moving to the Florida Museum of Natural History (1987), resulting in increased resources, scope of coverage and reporting (particularly of minor injuries), and advances in communication between Volusia County lifeguards and emergency responders in 1993 (Burgess, 2014). Both events increased the reporting of minor shark bites, which had most likely been previously underreported. While the Florida data highlights these factors, advances in communication and reporting, the evolution of information mining strategies and awareness through online and social media will all manifest as otherwise unjustified (but quantifiably inextricable) increases in shark bites globally.

3.2. South Africa

While identified as one of the global hotspots for unprovoked shark bite incidence, and one of two countries (along with Australia) with the greatest number of shark bite fatalities each year, the rate of unprovoked shark bite in South Africa has remained virtually unchanged over the past 32 years (average rate of change of 0.03 bites per year). However, incidence showed a substantial elevation in 1998, with 16 unprovoked bites, as opposed to the 32 year average of 4.4 unprovoked bites. While South Africa boasts 2,000 km of coastline, all of the recorded bites in 1998 occurred along the southern stretches of the Western and Eastern Cape Province beaches from Saldanha Bay on the west to the Kei River on the east. While most unprovoked shark bites in South Africa are from white sharks (Table 2, Fig. 3), the catch per unit effort (CPUE) from the KwaZulu-Natal gillnet, which represents the most reliable long-term data on white shark abundance in South Africa, shows that white shark numbers decreased from 1995 to 1998, and were lower than average in 1998 (Dudley and Simpendorfer, 2006). However, this data should be correlated to white shark activity in South Africa as a whole with some reservation, as it does not include shark numbers for June and July, a time period which represents 31% of the years' unprovoked bites, and KwaZulu-Natal is approximately 900 km northeast of the mouth of the Kei River (the north-eastern most location of shark bite incidence in 1998). White sharks, instead, more reliably congregate around the South Western Cape of South Africa (Jewell et al., 2013; Kock and Johnson, 2006; Wcisel et al., 2015), which is reflected in the higher proportion of bites (39% in the Western Cape Province and 43% in the Eastern Cape Province, compared with 18% in KwaZulu-Natal).

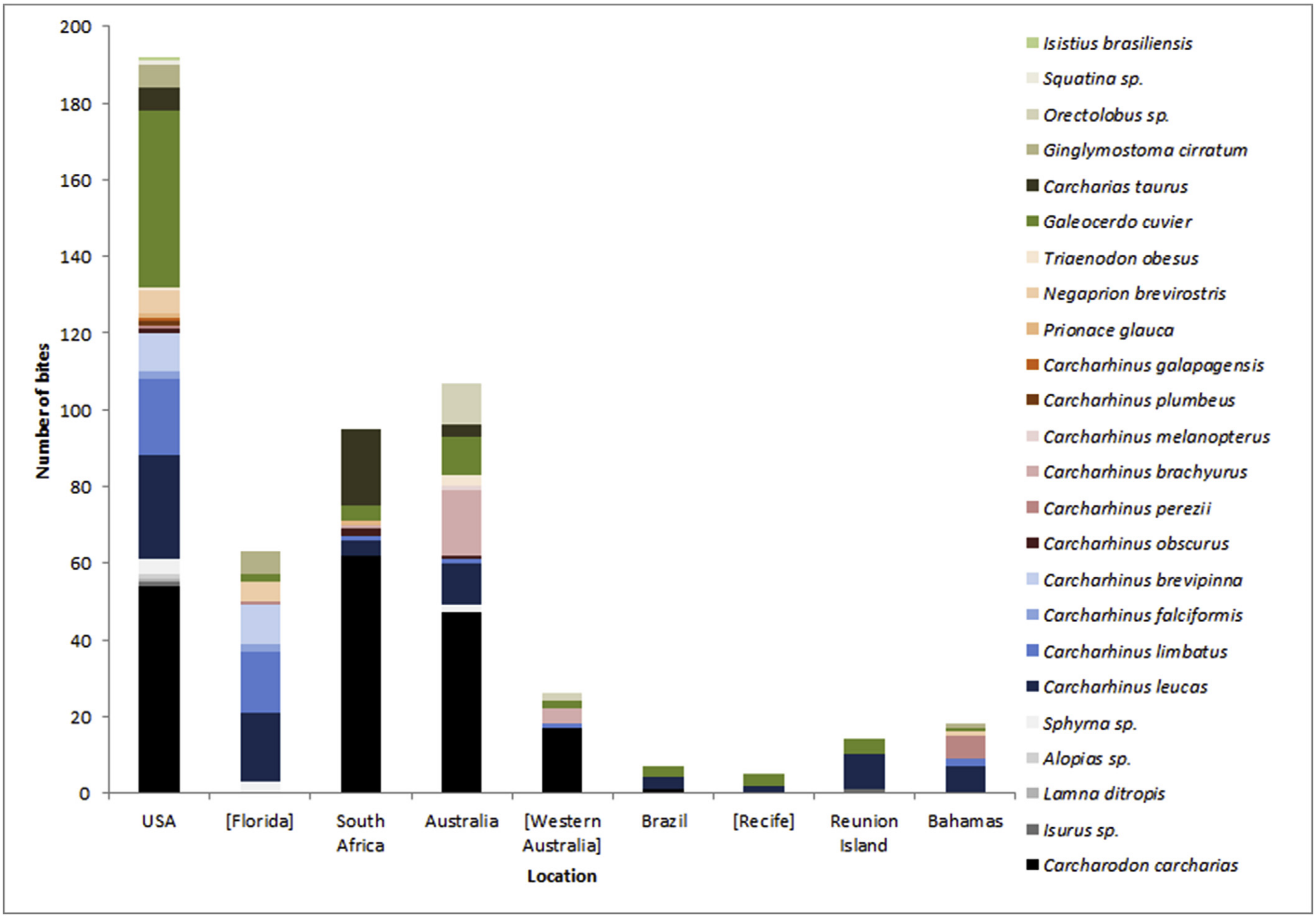

Fig. 3. Shark species responsible. The species responsible for unprovoked shark bites in the six global shark bite "hotspots", the United States [and a subset from Florida], South Africa, Australia [and a subset from Western Australia], Brazil [and a subset from Recife], Reunion Island and the Bahamas.

Nonetheless, white sharks are known to migrate along South Africa's entire coast (Bonfil et al., 2005; Kock and Johnson, 2006), and therefore, population trends are expected to be reflected in KwaZulu-Natal (Kock and Johnson, 2006).

During late 1997 and early 1998, an anomalous climactic event, attributed to the El Niño phenomenon, occurred throughout the Indian Ocean, resulting in cool sea surface temperature (SST) anomalies in the eastern and equatorial Indian Ocean and warm SSTs (up to 1–2 °C above long term averages) in the western Indian Ocean. The anomalous SSTs coincided with decreased rainfall in South Africa (Murtugudde et al., 2000; Ropelewski, 1999). Changes to rainfall events and disruptions to current patterns can have significant effects to upwellings of nutrient rich water, leading to changes in biological productivity and prey availability throughout the food chain (Kingsford and Welch, 2007). Abnormally high SSTs could also alter natural shark habitat through the alteration, deterioration or destruction of habitat important for prey, resulting in the displacement of sharks that utilise these habitats for reproductive, developmental and predation purposes. Interestingly, though, none of the other shark bite hotspots examined in this study showed such drastic shifts in incidence numbers as South Africa, despite the 1997–1998 El Niño event being a global phenomenon (although affecting various regions differently and to varying extents) (Ropelewski, 1999). The conclusion from the information available in South Africa is that there is no clear and consistent trend of increasing numbers of unprovoked shark bites over time, although there was a single period of time that coincided with an anomalous climactic event that may have altered the distribution of white sharks.

3.3. Australia

Unprovoked shark bite in Australia has risen steadily over the past 32 years (rate of change = 0.35 incidents per year), with peak incidence years of 2009 (15), 2012 (13) and 2010 (12) (Fig. 1). While Australia has the second highest number of bites (following the US), bites are spread over a far greater length of coastline (59,700 km, including island coastline) (Australian Bureau of Statistics, 2010) compared with any of the other shark bite hotspots (especially when considering that a large percentage of unprovoked bites around the US occur along just 80 km of coastline in Florida). The rise in Australian shark bite incidence has largely been attributed to increased human population, increased human beach usage, increased interest in water-based recreational and sporting activities, and greater visitation to previously isolated and relatively underutilised beaches (West, 2011). Over the past 32 years, Australia's permanent resident population has grown 35% (FAOSTAT, 2014) and the coastal zone supports some of the largest growth in terms of population (2010). Eighty-five percent of the Australian population lives within 50 km of the coastline (Maguire et al., 2011) and the population density of Australia's coastal areas increased by 14.0% between 2001 and 2009 (above the Australian average of

Table 2
Potential causative factors of unprovoked shark bite incidence in the six global shark bite 'hotspots' between 1982 and 2013.

Region	No. of bites	Species responsible	Peak years	Rate of change (bites/year)	Possible contributing factors					
					Human population/ tourism increase	Habitat destruction/ modification	Water quality	Climate change (incl. ENSO)	Shark numbers	Distribution/ abundance of prey
Florida (United States)	548	*Carcharhinus leucas* (3.3%), *Carcharhinus limbatus* (2.9%), *Carcharhinus brevipinna* (1.4%)	2001 (50), 2007 (48), 2012 (47), 2013 (46)	1.00	Yes (FAOSTAT, 2014)	Yes (Burgess et al., 2010)	Yes (Comas, 2012)	Yes (Matich and Heithaus, 2012)	Unlikely (Carlson et al., 2012)	▨
South Africa	146	*Carcharodon carcharias* (42.5%), *Carcharias taurus* (13.7)	1998 (16)	0.03	No (FAOSTAT, 2014)	▨	▨	Yes (Murtugudde et al., 2000)	Unlikely (Dudley and Simpendorfer, 2006; Towner et al., 2013)	▨
Australia	199	*Carcharodon carcharias* (23.6%), *Carcharhinus brachyurus* (8.5%), *Carcharhinus leucas* (5.5%), *Galeocerdo cuvier* (5.0%)	2009 (15), 2012 (13), 2010 (12)	0.35	Yes (2010; FAOSTAT, 2014; Neff, 2012, 2014)	Potentially (Werry et al., 2012)	▨	Yes (National Climate Centre, 2009)	Unlikely (Holmes et al., 2012; Reid et al., 2011)	Yes (Bruce et al., 2014; Campbell et al., 2014; Holmes et al., 2014; Noad, 2011; Sprivulis, 2014)
Brazil	74	*Carcharhinus leucas* (4.1%), *Galeocerdo cuvier* (4.1%)	1994 (10), 2002 (7), 2004 (7)	0.07	Yes (Koening et al., 2003; Paschoa, 2013; Rolland et al., 2012)	Yes (Koening et al., 2003; Paschoa, 2013; Rolland et al., 2012)	Yes (Marie and Rallu, 2012)	▨	No (Afonso et al., 2014)	▨
Reunion	37	*Carcharhinus leucas* (24.3%), *Galeocerdo cuvier* (10.8%)	2011 (5)	0.05	Yes (Marie and Rallu, 2012; Van Grevelynghe, 2000)	Terrestrial (Dias and Peron)	Yes (Bigot et al., 2006; Marie and Rallu, 2012)	▨	▨	▨
Bahamas	48	*Carcharhinus leucas* (14.6%), *Carcharhinus perezii* (12.5%), *Carcharhinus limbatus* (4.2%)	1988 (5), 2013 (5)	0.05	Yes (FAOSTAT, 2014)	▨	▨	Yes (Chollett et al., 2012; Dennis and Wicklund, 1993)	▨	▨

Information in the shaded cells remains undocumented.

13.1%) (Australian Bureau of Statistics, 2010). In addition to permanent resident population growth, tourism statistics have shown that short-term visitor numbers to Australia have grown by up to 8.2% per year (Tourism Australia, 2014). While tourism numbers do not unequivocally equate to beach usage, beaches are the most popular recreational destination in Australia and have been reported to attract 58% of international tourists (Maguire et al., 2011).

3.3.1. *Western Australia*

Western Australia (WA) contains some of the fastest growing coastal areas in Australia over recent years and has concurrently shown a steady increase in shark bite prevalence at a rate of 0.1 bites per year (Fig. 4A). Between 1982 and 2013, 22.1% of Australian bites occurred off of the WA coast, increasing to 27.0% when just looking at the last 10 years, and 38.3% in the last four years (following the lack of any incidence in 2009) (Fig. 4B). White sharks are most commonly identified with unprovoked bite in WA, and have been implicated in 39.5% of incidents (Fig. 3).

Australian waters have concurrently seen a steady and significant rise in previously depleted megafauna populations that are known to be preferred prey items of large sharks, such as white sharks and tiger sharks. Humpback whale (*Megaptera novaeangliae*) populations on Australia's east coast have shown one of the highest growth rates for any mammalian population (Bruce et al., 2014) with an annual rate of increase of 10.6% from 1987 to 2004 (Noad, 2011), and New Zealand fur seal (*Arctocephalus forsteri*) populations have increased at a rate of 10–15% over the past 20 years (Campbell et al., 2014). These populations have recovered from previous overexploitation to a point where they are now thought to be reaching their theoretical reproductive limit and maximum carrying capacities (Bruce et al., 2014; Campbell et al., 2014). Sprivulis (2014) strongly associated the rise in unprovoked bites from white sharks in WA to the concurrent increase in humpback whale population. Increases in New Zealand fur seal populations were also correlated with the rise of unprovoked shark bite in WA (McPhee, 2014). Marine mammals have been shown to be a major prey source for large adult white sharks (Fallows et al., 2013; Kim et al., 2012; Klimley et al., 2001; Long and Jones, 1996) and Klimley et al. (2001) states that hunting strategies of white shark are fine-tuned to the life history of pinnipeds. Bruce et al. (2006) found that white sharks will remain in areas rich in prey availability for extended periods of time before rapidly dispersing, likely in search of further food sources. Similarly, tiger sharks have also been tracked along humpback whale migration routes (Holmes et al., 2014). It is logical, therefore, that a higher density of prey will support greater numbers of predators.

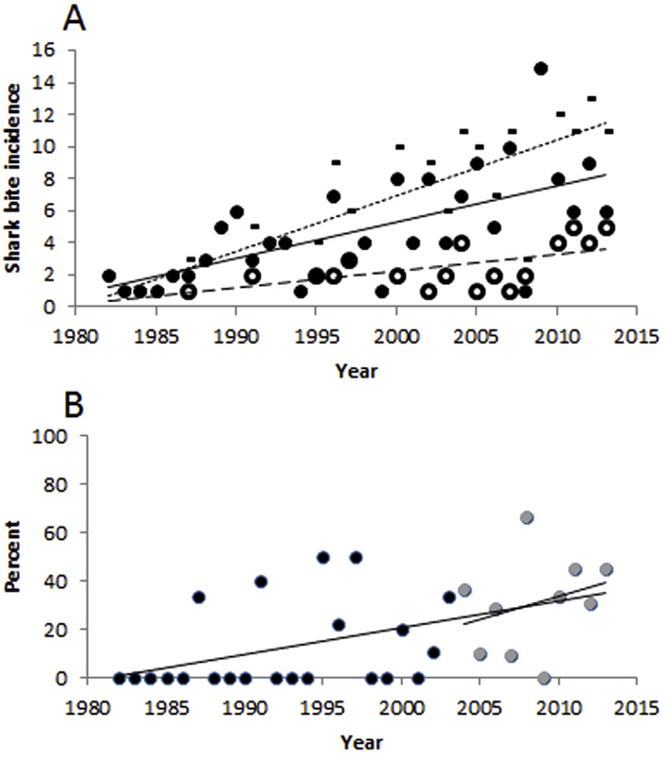

Fig. 4. Shark bite incidence in Australia. (A) Shark bite incidence per year in south and east Australia (SE AUS; solid circles), Western Australia (WA; open circles) and Australia as a whole (AUS; dashes). Incidence is increasing in AUS at a rate of 0.35 bites per year, and at rates of 0.23 and 0.11 bites per year in SE AUS (solid line) and WA (dotted line), respectively. (B) The number of shark bites in WA as a percentage of shark bites in AUS is increasing (black circles), especially when isolating the statistics since 2004 (grey circles).

3.3.2. *South and eastern Australia*

While unprovoked shark bite off the coast of WA has increased over recent years, interestingly, none of the 15 bites in the peak year of 2009 occurred off of WA. Incidence along the south and east coasts of Australia is also increasing at a rate of 0.23 bites per year (Fig. 4A). Although population and tourism growth appears to be the major contributing factors to the rise in shark bite in Australia, this alone does not completely account for the increase in shark bite incidence (Fig. 5), and the prominent rise in prevalence in 2009 still deserves further investigation. Eleven of the 15 bites (73%) in 2009 occurred off of the 2,137 km continental New South Wales (NSW) coast, compared with 34% in all other years combined (and 30% when excluding 2009 from the data). The other four bites occurring in 2009 were all on the eastern (Queensland) or southern (Tasmania and South Australia) coasts of Australia. January, February and December had the highest number of bites (four, three and three, respectively), and incidence was 13% and 6% higher in January and February 2009, respectively, compared with the same months in all other years examined. Australia was subject to a variety of weather extremes during 2009, which could have had substantial impact on shark-human interaction. The south-eastern portion of the country was affected by abnormally high temperatures and lower than average rainfall in January and February (National Climate Centre, 2009), and overall, 2009 was the warmest year on record for NSW. West (2011) reports approximately 100 million beach visitations in 2009 throughout Australia, a 20% increase compared with the previous year and Bondi Beach (NSW) saw a 23% increase in weekend attendance in 2009, compared with 2008 (Neff, 2012). There was also a 29% increase in beach rescues from 1999/2000 to 2008/2009 (West, 2011). While the south-eastern coast of Australia experienced high temperatures and low rainfall, WA concurrently experienced seven tropical cyclones/tropical lows between January and March 2009 bringing high levels of rain to the area (Bureau of Meteorology, 2015), potentially deterring human beach usage.

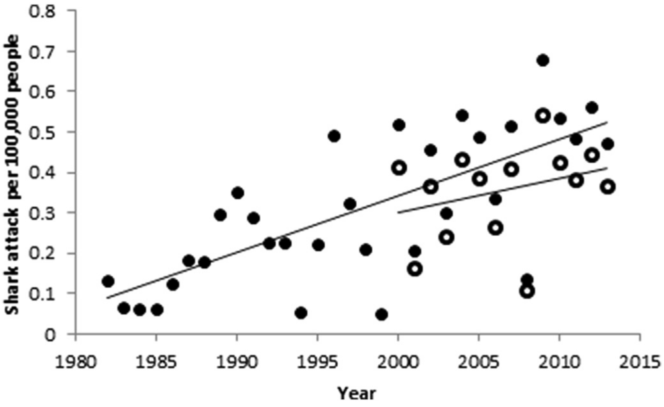

Fig. 5. Shark bite incidence in Australia in relation to human population. Shark bite incidence in Australia per 100,000 people, based on the Australian resident population (closed circles) (FAOSTAT, 2014) and resident population plus tourists (open circles) (Australian Bureau of Statistics, 2014) between 1982 and 2013. The trendline represents the linear regression fit through year incidence.

3.4. *Brazil*

Unprovoked shark bite off of Brazil is not as frequent as some of the other shark bite hotspots, and in the 10 years of 1982 to 1991, there was not a single reported unprovoked shark bite off Brazil (and only a few unconfirmed anecdotal reports of bites since the early 1950s (Hazin et al., 2008)). However, since 1992, bites have become a relatively regular occurrence, with up to 10 reported in 1994. Shark bite data for the period of 1982 to 2013 show a slightly positive change in bite prevalence of 0.07 incidents per year; however, data from the more recent period of 1992 to 2013 show a decreasing trend of −0.21 incidents per year. Eighty-two percent of bites in Brazil have occurred off of the coastline of Pernambuco state. Furthermore, the 10 bites in 1994 all occurred off of beaches within 20 km of Recife, making this one of the highest areas of unprovoked shark bite per unit of area in the world (Afonso, 2013). However, Recife also shows a decreasing trend (−0.16) in shark bite

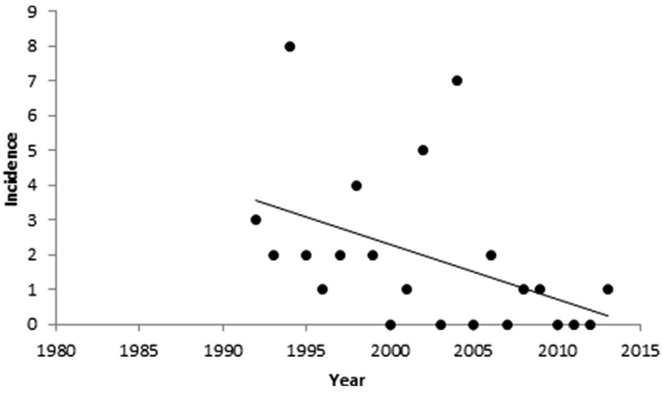

Fig. 6. Unprovoked shark bite incidence between January 1982 and December 2013 in Recife. Note the first recorded shark bite in Recife in this time period was not until 1992. The trendline represents the linear regression fit through year incidence.

incidence over the past 22 years (Fig. 6).

A number of factors have been identified as potential reasons for the sudden spate of bites off of Recife, nearly all of which are anthropogenic. Construction of a commercial port in Suape began in 1979, and by 1989 to 1991, large numbers of vessels began to utilise the port (Hazin et al., 2008). Port construction utilised explosives to remove coral reefs to deepen the channel used for ship passage, destroying coral reef habitats and killing a wide variety of fish species (Paschoa, 2013). Port construction also caused a significant amount of habitat degradation, including the destruction of a mangrove area, strangulation of the Ipojuca and Merepe river mouths and diverted estuaries (Rolland et al., 2012). These environmental changes displaced species that utilised and traversed the river mouths, such as bull sharks (Hazin et al., 2008), one of the species most implicated in bites at this location (Fig. 3). The nearest similar habitat to those that were destroyed is Jaboatão, which is closer to the heavily utilised beaches of Recife. The changes to local ecosystems following port construction also included a decrease in plankton in Suape (Koening et al., 2003), decreasing the influx of fish and crustaceans, leading to changes throughout the food web (Hazin et al., 2008), and requiring resident populations to source alternate food sources. The increased boat traffic in and out of the port is also implicated in the increase in local shark activity, as sharks have been found to be attracted to boats and the low-frequency sounds emitted by vessels (Hazin et al., 2013). Hazin et al. (2008) found that shark bites were significantly more frequent in months when more than 30 ships entered the Suape Port.

In response to the dramatic increase in shark bite incidence, the State Government of Pernambuco implemented a multistage, multidisciplinary approach to shark bite mitigation. The first was the introduction of a seasonal ban on surfing (and related activities) at certain beaches beginning in May 1999 (Sawers, 2012). Surfers (including body/boogie boarders) have been implicated in 52.7% of shark bites in Brazil since 1992; however, since the ban, surfing activity has dropped to 29.7% of shark bite incidence in Brazil. Subsequently, the government created the Committee for the Monitoring of Shark Attack Incidents (CEMIT), and one of its initiatives was a relocation program for sharks that could pose a risk to humans using baited longlines and drumlines (Hazin and Afonso, 2014). Potentially aggressive sharks were transported away from populated beaches and released live, whereas non-threatening sharks and bycatch were released live at the catch site. The latter initiative resulted in statistically high success rates of decreased shark bite incidence, and proved to be less damaging to target and bycatch species than many other mitigation strategies employed elsewhere (Hazin and Afonso, 2014). The recent decrease in shark bite incidence in Brazil is largely attributed to these strategies.

3.5. *Reunion island*

Although shark bite incidence on Reunion Island is low (with an average of just over 1 bite per year, and occasional year(s) with no incidence), it is of concern for the local population and incidence has been increasing at a rate of 0.05 bites per year. Shark bite at Reunion Island is also noteworthy in that a higher proportion of bites result in fatalities, compared with anywhere else in the world (McPhee, 2014). Reunion is a popular tourist destination, largely due to its pristine beaches and wealth of marine life and recent incidence of shark bite off Reunion Island is attributed to the rise of water and underwater sports (Van Grevelynghe, 2000). However, increased attention and awareness of shark bite is affecting visitation (Adigun, 2015; Mull, 2015; Stewart, 2015). Reunion Island has a variety of measures in place to protect local marine life, including a ban on the commercial capture of sharks implemented in 1999 (due to potential ciguatera contamination), a ban on shark finning implemented in 2004 and the creation of a marine reserve in 2007, with fishing banned along a 40 km stretch of the west coast of the island. However, the rise in shark bite incidence prompted the decision for a one-off cull of 90 sharks, including 45 bull sharks and 45 tiger sharks (Mull, 2013; SBS, 2014). A ban on swimming, surfing and bodyboarding off of more than half of the coast was also introduced in 2013 (Mull, 2013). While it is still too early to assess the success of these measures, culling local bull and tiger sharks is unlikely to be an effective management practice, as these are generally not resident species, but migrate long distances to meet physiological and reproductive demands (Blaison et al., 2014; Daly et al., 2014; Wetherbee et al., 1994).

Reunion Island is also experiencing human population booms, with a 15% population increase between 2000 and 2009 (compared with 6% in mainland France) (Marie and Rallu, 2012). The rise in population is attributed to natural growth through high birth rate and low death rate, and such high rates of change are beginning to threaten the amount of agricultural land on the island (Marie and Rallu, 2012). Agriculture and food products make up 64% of Reunion Island's export and represent an important component of the island's economy. However, runoff and wastewater are poorly contained, especially with the high prevalence of natural disasters on the island, such as cyclones, which increase the amounts of runoff and, consequently, pesticides and nutrients into the surrounding marine environment (Marie and Rallu, 2012). Environmental pollutants and agricultural and industrial runoff are known to adversely affect fish health (Austin, 1999; Islam and Tanaka, 2004), which in turn may affect the trophic structure and function of local ecosystems.

While no shark species were confidently identified in the five bites in 2011, two of the bites resulted in fatalities, while a third required the victims' leg to be amputated. This leads to the belief that the bites were by larger species, with bull and tiger sharks known to frequent the area.

3.6. *Bahamas*

Unprovoked shark bite in the Bahamas has remained relatively stable over the last 32 years, with incidence levels generally hovering at between 0 and 2 bites per year (Fig. 1). However, these baseline incidence levels have been gradually increasing (from zero to two per year), leading to an increasing slope of 0.05 bites per year. Incidence peaked at five bites in two years (1988, 2013).

Tourism is a major industry in the Bahamas, accounting for 60% of the gross domestic product and shark tourism alone in the Bahamas was reported to generate up to US$80 million annually (Eilperin, 2011; Maljkovic and Côté, 2011). A number of diving operators in the Bahamas offer cageless shark diving and hand-feeding of resident shark populations. In order to protect the lucrative shark diving industry, the Bahamas introduced a ban on all commercial shark fishing in its more than 240,000 square miles of water (with catch and release fishing still permitted) in 2011 (Eilperin, 2011); however, no change in shark bite incidence has been seen since this time.

All five of the shark bites in 1988 and three of the five (60%) bites in 2013 occurred in July, whereas only 10 of the remaining 38 (26%) documented shark bites in the Bahamas occurred in July between 1982 and 2013. Normally, the Atlantic hurricane season extends from June through November, which may limit tourism and recreational water usage. However, there was only one tropical depression at the beginning of June 1988, and no further tropical activity that year until early August. Two tropical storms (Chantal and Dorian) affected the Atlantic in July 2013, but neither hit the Bahamas (LiveScience, 2013). Scarcity of data from 1988 (both in relation to shark bites that year and also environmental data) makes it difficult to analyse what factors may have led to the increased number of annual (and monthly) bites. Historical water quality data from 1988 and the surrounding years are markedly scarce, and the information that is available on regional SSTs is somewhat conflicting. Chollett et al. (Chollett et al., 2012). found that SSTs remained well below average the entire summer of 1988 in northern Bahamas, whereas data extracted from Dennis and Wicklund (1993) show that July SSTs at Lee Stocking Island were no different in 1988 compared with the following four years. However, relatively high temperatures during the summer of 1987 were high enough to lead to coral bleaching events (Dennis and Wicklund, 1993). The loss or declines of reefs would have significant effects on the food chain, as coral reef associated fish serve as important prey for reef sharks (Bellwood et al., 2006; Hilting et al., 2013; Munday et al., 2008). As details of the five bites in 1988 are incomplete, it is unknown where in the Bahamas the bites occurred (i.e. if they all occurred in close proximity and near significant landmarks and/or dive sites, or were spread out through the territory), and what species were responsible for most of the bites. Two of the five bites in 1988 were attributed to Caribbean reef sharks (*Carcharhinus perezii*), and a further two were detailed as 1.5–2.5 m sharks. Caribbean reef sharks are not considered to be relatively dangerous to humans, but are in abundance in the area and are generally the focal species of provisioned cage dives in the Bahamas.

4. General discussion and conclusions

McPhee (2014) identified that there was a consistent, global increase in the number of unprovoked shark bites over a 30 year period (1982–2012). However, while unprovoked shark bite can occur at any time and location where relevant shark species overlap with humans in the water, a feature of the data analysed at the regional hotspots is that a heightened number of bites can occur over a relatively short timeframe. Therefore, we conclude that while a degree of chance would be involved, unprovoked shark bites are not completely random, independent events as suggested by Neff (2014). Rather, they are more likely often influenced by a set of conditions that increase the likelihood of shark-human interaction at a local or regional scale, and these conditions do not necessarily continue to persist consistently through time. This finding is also consistent with the work of Amin et al. (2012), which focussed specifically on unprovoked shark bite in Florida. Conditions include those that potentially change the overall pattern of human water use, as well as those that alter the distribution and abundance of relevant shark species.

In an ideal situation, data would exist at the appropriate temporal and spatial scales that could be used to statistically determine the relative importance of the various factors at each location that may influence the chance of an unprovoked shark bite occurring. However, such data is not available for all the relevant factors, and will not be available for a significant period of time (if at all), and cannot be back calculated. For example, it is not currently possible to back calculate with certainty the size of white shark (or any other species) populations to determine the influence of population size on the frequency of unprovoked bites over the period examined in this paper. The spatial distribution of shark populations and their prey can also not be back calculated, although the use of acoustic tagging and tracking of sharks and some prey species (e.g. pinnipeds) may provide important information on this in the future. In terms of habitat destruction or modification, while a strong causative link from published material exists between unprovoked shark bites and a single very large development – the Suape Port in Brazil, time series data on the destruction or modification of coastal habitats do not exist, and such impacts are often the results of a cumulative number of smaller developments, where information overall is scant. While it is acknowledged that ours is not a definitive approach to determine the causality of shark bite occurrence, it nonetheless contributes substantially to a better understanding of the phenomenon.

4.1. Human population

A single person entering an open waterway (natural or artificial) enables the chance of an unprovoked shark bite, and each additional person who enters the water further increases the likelihood. The world population has been increasing, and coastal regions are prime locations for both residence and tourism (Hall, 2001; Honey and Krantz, 2007; Neumann et al., 2015). Consequently, increases in population and tourism will doubtlessly lead to more people in the water and increased shark-human interaction. Further, the advent of new and increasing popularity in water sports (and associated technologies) will increase the number of people using the waterways, and also change the pattern of use. West (2011) reported a 418% increase in PADI (Professional Association of Diving Instructors)-registered SCUBA divers over the years of 1990 to 2008, and the development and improvement in wetsuit technology has allowed humans to enter the water in more locations and over the entire year, whereas prior to this technology, water usage would have been limited or greatly restricted by temperature (West, 2011). Additionally, new sports, such as kite surfing, have emerged, which have resulted in water users more frequently utilising additional coastal areas (e.g. inter-reefal areas) for leisure activities (Clua et al., 2014). This paper has generally supported the increase in human population, and by extension, the increase in water users as being a factor that contributes substantially to the trend of unprovoked shark bite. However, additional factors need to be considered in terms of explaining the inter-annual variation in unprovoked shark bite at the regional hotspots examined.

4.2. Environmental conditions, climate variability and water quality

Climate variability can influence a number of factors relevant to sharks, including the distribution of sharks and their prey (Chin et al., 2010; Perry et al., 2005), and this may influence the number of unprovoked bites that occur if distribution shifts lead to greater overlap with areas utilised by humans. Important climate variables include SST, freshwater runoff, turbidity, and currents and circulation patterns (Afonso et al., 2014; Chin et al., 2010; Ortega et al., 2009; Weltz et al., 2013). These factors will not only affect shark homeostasis, but also their habitats and prey availability (Chin et al., 2010). Altered water circulation and currents result in disruptions to upwelling patterns of nutrient rich water, which drives productivity and prey availability at all levels of the food chain (Chin et al., 2010). The substantial increase in the number of shark bites occurring over a relatively small stretch of coastline in South Africa during 1998 correlated with warm SSTs in the western Indian Ocean and decreased rainfall in the southern part of Africa. How such a temperature anomaly impacted the specific location where unprovoked shark bites occurred relative to other parts of adjacent coast cannot be determined, but does warrant further investigative work aimed at understanding the influence of the currents and circulation patterns on the distribution of sharks and their movements. Matich and Heithaus (2012) found that a 12 day cold snap (air temperature) in south Florida was enough to completely eradicate a system with a typical year-round bull shark population for upwards of four months. The population was then rebuilt from young of the year neonates, with no juvenile sharks returning to the area, suggesting entire cohorts had relocated entirely (Matich and Heithaus, 2012).

Water quality may also influence the distribution of sharks (and their prey), and this is particularly the case for the bull shark. Runoff from rainfall alters normal fidelity patterns of bull sharks, and can result in sharks congregating and feeding in coastal areas and adjacent to rivers (Werry, 2010). Human impacts on water quality (e.g. sewage discharge) are widespread and may alter the food chain (Lotze et al., 2006). Furthermore, nutrient-rich water, which is increasingly globally, and particularly in river mouths downstream of high fertiliser use areas, influences eutrophication and phytoplankton blooms and negatively impacts water quality (Rabalais et al., 2009). Nutrient loads have been found to be directly proportional to fish density, until a threshold is reached (Breitburg et al., 2009; Rabalais et al., 2009), subsequently altering local trophic interaction, and potentially drawing in predators that would not normally be in the area. Furthermore, increased nutrient load limits light and decreases water transparency, reducing the ability of visually-mediated predators (Breitburg et al., 2009), although creating feeding conditions suited to the sensory biology of bull sharks (Lisney, 2004). Agricultural runoff and aquaculture effluent (nutrients) is anecdotally implicated in the increasing number of unprovoked shark bite at Reunion Island, but there is an absence of relevant water quality data to demonstrate with any certainty that this is the case. Nonetheless, it is a plausible contributor.

Climate change is expected to have the greatest impact on coastal and estuarine species (Chin et al., 2010), which encompasses the species that are most commonly implicated in shark-human interaction. Increasing temperatures could lead to range expansion for certain species (Chin et al., 2010; Perry et al., 2005), with sharks species previously absent potentially immigrating to waterways utilised by humans. Increased temperatures may also lead to more of the growing human population spending more time in the water (Morgan and Ozanne-Smith, 2013), as was suspected to be a factor leading to the increased incidence of shark bite in Australia in 2009.

4.3. Coastal development

Coastal development can affect habitat quality, disrupt the properties and circulation of water and the connectivity of coastal habitats, the timing and volumes of freshwater flow, and create barriers restricting or altering movement (Chin et al., 2010; Waycott et al., 2007). As seen in Recife, coastal development and infrastructure can have major environmental implications on the distribution of sharks, and this can flow on to the number of unprovoked shark bites. Unprovoked shark bite was virtually unheard of in Recife prior to the construction and operation of the Suape Port; however, due to environmental changes displacing local shark species and the presence of increased shipping activity, Recife is now renowned for having one of the highest rates of shark bites per unit area in the world (Hazin et al., 2013). The environmental assessment of coastal development projects should consider the displacement of relevant shark species and the potential change in the probability of unprovoked shark bite when such developments are in areas where potentially dangerous species frequent. Similarly, the majority of shark bites at Volusia County (Florida, US), dubbed the “shark attack capitol of the world” (Amin et al., 2012) are on surfers at The Point at Ponce Inlet Jetty, which has such favourable conditions due to dredging and man-made rock jetties (which are also heavily used by fisherman, thus adding bait to the water) (Burgess et al., 2010).

4.4. Communication and technological advances

As with the ISAF, improvements in communication between relevant parties can manifest as disproportionate increases in shark bite incidence. Similarly, it should be expected that the rapid development of technology and the ability for immediate, world-wide information dissemination will present as increases in shark-human interaction. Before the advent of the internet and social media, records of global shark bite incidence would have been much more inconspicuous (particularly when only minor injuries occurred), and, therefore, run a much higher risk of being missed and not included in databases. With advances in communication, it is expected that shark bite databases will become more complete and robust. Advances in communication, progress in education of the general public (in relation to both shark bite reporting and species identification) and the development of information sharing modalities should be taken into consideration and acknowledged when assessing long-term shark bite statistics. However, as developments such as these are rarely delineated events in time (i.e. increase in funding to the ISAF), but more often continuous developments (such as ongoing public education and continuously developing technology), isolating and quantifying advances in communication from other shark bite factors is not possible.

4.5. Changes in prey abundance

Historical legislation and management plans may also have an impact on shark bite incidence. Continuously evolving policies exist around the globe to permit, limit, prohibit or restrict a wide variety of fishing and collection practices, and this, in combination with other anthropogenic factors, has the potential to modify species presence and population dynamics. Animals such as New Zealand fur seals and humpback whales were harvested to near extinction along the coasts of Australia in the 19th and 20th centuries, respectively (Bruce et al., 2014; Campbell et al., 2014). However, with the introduction of legislation to protect these species, populations are recovering to the point of nearing population carrying capacities (Campbell et al., 2014; Noad, 2011). Both of these species present valuable food sources for large sharks, such as white sharks (Fallows et al., 2013; Hussey et al., 2012), and increases in prey can be reflected in the abundance of predators at a regional or local scale (Brown et al., 2010; Klimley et al., 2001; Skomal et al., 2012). The increased incidence of unprovoked shark bite in WA attributed to white sharks correlates with the increasing abundance of humpback whales, as well as increases in population size and geographic range of pinnipeds within WA (McPhee, 2014; Sprivulis, 2014). Investigation on trends in the presence of teleost species and their abundance around shark bite hotspots is also warranted.

4.6. Abundance of sharks

Stock assessment of sharks remains an imperfect science, with all current estimates acknowledging limitations to study design based on incomplete data sets, wide-ranging movement and species preference for migration versus site fidelity (or a combination of the two), transient populations, low population numbers and capture heterogeneity (Burgess et al., 2014; Chapple et al., 2011; Holmes et al., 2012; Powers et al., 2013; Towner et al., 2013). Additionally, intraspecific population trends are variable across a global scale (i.e. tiger sharks (Afonso et al., 2014; Carlson et al., 2012; Dudley and Simpendorfer, 2006; Holmes et al., 2012; Reid et al., 2011)). Although certain populations of potentially dangerous sharks have been reported as increasing (tiger sharks off KwaZulu-Natal (Dudley and Simpendorfer, 2006), and white sharks in southeast Australia (Reid et al., 2011)), many of the most recent studies on shark population numbers are estimating stable or decreasing trends. This includes white sharks in California (US)

(Lowe et al., 2012), South Africa (Towner et al., 2013) and the NW Pacific Ocean (Christiansen et al., 2014) and tiger sharks in Recife (Afonso et al., 2014), across their Australian range (Holmes et al., 2012; Reid et al., 2011), and in the NW Atlantic Ocean (Carlson et al., 2012). Based on these studies, it remains highly unlikely that the global trend of increasing shark bite is the result of increasing shark numbers, especially given only 2.7% of bites off of South Africa are attributed to tiger sharks and 15% of bites by white sharks in southeast Australia.

Recent studies are also pointing to a trend in decreasing body size of white (Kock and Johnson, 2006; Reid et al., 2011), tiger (Powers et al., 2013; Reid et al., 2011) and bull sharks (Powers et al., 2013) in South Africa, southeast Australia and the Gulf of Mexico during the 20th century. This could lead to changing behavioural patterns of shark species that pose threats to humans. White sharks are known to show ontogenetic variation in prey preference (Fallows et al., 2013), and decreasing shark size may result in behavioural shifts that could lead to an increased proportion of white shark populations frequenting inshore areas to predate on smaller prey items.

4.7. *Management of shark-human interaction*

Management of shark-human interaction needs to be rational, proactive and adaptive based on new scientific information on the sharks themselves, as well as new mitigation technologies and approaches. Given the highly emotive nature of unprovoked shark bite, this is a challenge, but an important challenge that needs to be met to ensure that the actual risk to humans is clearly communicated to the public, while the needs of shark conservation are also met. The effective management of shark-human interaction will need to take into consideration a number of different factors. These include human population and waterway usage, water quality and environmental conditions, local ecosystem composition and dynamics, accurate and detailed communication of shark bite incidence to relevant authorities and through the media, and current and recent species management legislation and practices. Ongoing strategies that can be continuously re-evaluated to meet changing environmental conditions and shark prevalence and distribution are best placed to effectively mitigate the risk posed.

4.8. *Management overview and conclusions*

Unprovoked shark bite incidents have the widest geographic human-wildlife interaction footprint, and represent a complex challenge for those tasked with understanding, managing and mitigating the hazard, including environmental managers, scientists and policymakers (Neff, 2012). Unprovoked shark bite represents a low probability, but a vivid and potentially high consequence risk, with substantial emotional and psychological repercussions. Consequently, effective shark bite management needs to begin with the management of human behaviour and perception. The historical approach in a number of jurisdictions of culling sharks is no longer socially acceptable and is equivocal in its actual effectiveness at reducing the risk posed and placating the fear (Gibbs and Warren, 2014, 2015; Meeuwig, 2014; Simpfendorfer et al., 2011). The human fear of shark bite is amplified by emotion, as opposed to reason, leading to an unrealistic impression of the likelihood of occurrence (Neff, 2012). This fear can lead to disproportionate overreactions by the public following individual incidents, a lack of trust in political leaders in charge during the event, and consequently, an overreaction of policy makers ("action bias") who try to avoid political unrest from natural crises (Neff, 2012; Sunstein and Zeckhauser, 2011). The recent, but now ceased, shark cull in WA (Australia) perfectly represents a contemporary example of action bias relating to shark-human interaction.

Education is essential to help relieve some of the unjustified fear, and therefore, the most effective management priority should be more proactive dissemination of accurate information about sharks and realistic risk assessment of water usage in relation to unprovoked shark bite. This information should be developed as a collaborative effort between scientists, policy makers and conservation groups and disseminated through beach safety education for audiences of all levels, popular media channels, and also from trusted political figures. As individual species are known to show preferences for certain environmental variables and prey, an understanding of attractive and unattractive conditions can lead to forewarning of heightened potential prevalence of dangerous shark species in an area at a certain time. The Shark Spotters program implemented in South Africa represents a system where information on the distribution of sharks and beach conditions is collected and used to provide real-time information on the risk posed at patrolled locations, which is communicated to the general public by way of coloured flags that represent the level of risk at the time (Kock et al., 2012; Weltz et al., 2013).

The concurrent ongoing study of sharks is also necessary input for shark-human management programs. Further research is needed on a broad range of topics, including general biology, ecology, ecosystem composition, sharks' roles within the ecosystem and individual species' responses to changing environmental conditions (Simpfendorfer et al., 2011). This research then needs to be further communicated to environmental managers, policy makers, conservation groups, within the scientific community, industry groups and to the wider community (Simpfendorfer et al., 2011). Positive perception of sharks has been correlated to a greater percentage of sharks released by fishers in good condition (Lynch et al., 2010). Extrapolating this scenario to a broader scale could lead to further public, and consequently, political support for the development of proactive, conservative shark-human mitigation programs, if human perception can change to better incorporate an understanding of the biology and ecology of sharks, and their role in marine ecosystems.

Through the analysis of shark bites in six locations with high bite prevalence, a variety of factors have been identified that may draw sharks to certain locations or alter traditional behavioural patterns of these animals. These include changed or anomalous water and environmental parameters, changed prey prevalence and/or abundance, and natural or anthropogenic changes to environmental conditions due to natural disasters or new coastal development. Therefore, these factors should be continuously assessed through developed management plans to maximise the effectiveness and ensure that these plans continue to provide the best protection for both humans and sharks within natural waterways.

References

Adigun, B., 2015. Rise in Shark Attacks Scares Tourists Away from Paradise Isle of Reunion. Express. Northern and Shell Media Publications.

Afonso, A.S., 2013. Bioecology and Movement Patterns of Sharks off Recife, Brazil: Applications in the Mitigation of Shark Attack Hazard. Faculdade de Ciências e Tecnologia. UNIVERSIDADE do ALGARVE, Faro, p. 295.

Afonso, A.S., Andrade, H.A., Hazin, F.H.V., 2014. Structure and dynamics of the shark assemblage off Recife, northeastern Brazil. PLoS One 9, e102369. http://dx.doi.org/10.1371/journal.pone.0102369.

Amin, R., Ritter, E., Kennedy, P., 2012. A geospatial analysis of shark attack rates for the east coast of Florida:1994–2009. Mar. Freshw. Behav. Physiol. 45, 185–198. http://dx.doi.org/10.1080/10236244.2012.715742.

Aubrey, C., Snelson Jr., F., 2007. Life history of spinner shark in Florida waters. In: McCandless, C.T., Kohler, N.E., Pratt Jr., H.L. (Eds.), Shark Nursery Grounds of the Gulf of Mexico and the East Coast Waters of the United States. American Fisheries Society, Bethesda, pp. 175–189.

Austin, B., 1999. The effects of pollution on fish health. J. Appl. Microbiol. 85, 234S–242S.

Australian Bureau of Statistics, 2010. Coastal Development. Measures of Australia's Progress. Canberra. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1370.0~2010~Chapter~Coastal%20development%20(6.4.4.1) (Accessed 10 October 2014).

Australian Bureau of Statistics, 2014. International Movements — 2013-14. http://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbyCatalogue/6DC2530C5C286824CA257E9900173469?OpenDocument (Accessed 10 September 2014).

Bellwood, D.R., Hoey, A.S., Ackerman, J.L., Depczynski, M., 2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. Glob. Change Biol. 12, 1587–1594.

Bigot, L., Conand, C., Amouroux, J.M., Frouin, P., Bruggemann, H., Gremare, A., 2006. Effects of industrial outfalls on tropical macrobenthic sediment communities in Reunion Island (Southwest Indian Ocean). Mar. Pollut. Bull. 52, 865–880.

Blaison, A., Jaquemet, S., Guyomard, D., Van Grevelynghe, G., Gazzo, T., Perry, C., Cliff, G., Landron, F., Soria, M., 2014. New Insight in Seasonal Patterns and Reproductive Biology of Tiger and Bull Sharks in Reunion Island, Western Indian Ocean. Sharks International, Durban, p. 22.

Bonfil, R., Meÿer, M., Scholl, M.C., Johnson, R., O'Brien, S., Oosthuizen, H., Swanson, S., Kotze, D., Paterson, M., 2005. Transoceanic migration, spatial dynamics, and population linkages of white sharks. Science 310, 100–103. http://dx.doi.org/10.1126/science.1114898.

Brazier, W., Nel, R., Cliff, G., Dudley, S., 2012. Impact of protective shark nets on sea turtles in KwaZulu- Natal, South Africa, 1981–2008. Afr. J. Mar. Sci. 34, 249–257.

Breitburg, D.L., Hondorp, D.W., Davias, L.A., Diaz, R.J., 2009. Hypoxia, nitrogen and fisheries: Integrating effects across local and global landscapes. Annu. Rev. Mar. Sci. 1, 329–349.

Brown, A.C., Lee, D.E., Bradley, R.W., Anderson, S., 2010. Dynamics of White Shark Predation on Pinnipeds in California: effects of Prey Abundance. Copeia 2, 232–238.

Bruce, B., Stevens, J., Malcolm, H., 2006. Movements and swimming behaviour of white sharks (Carcharodon carcharias) in Australian waters. Mar. Biol. 150, 161–172.

Bruce, E., Albright, L., Sheehan, S., Blewitt, M., 2014. Distribution patterns of migrating humpback whales (*Megaptera novaeangliae*) in Jervis Bay, Australia: a spatial analysis using geographical citizen science data. Appl. Geogr. 54, 83–95.

Bureau of Meteorology, 2015. Western Australia Tropical Cyclone Season Summary 2008-09. Australian Government. http://www.bom.gov.au/cyclone/history/wa/2009.shtml (Accessed 03 May 2015).

Burgess, G.H., 2014. ISAF 2013 Worldwide Shark Attack Summary International Shark Attack File, Florida Museum of Natural History, University of Florida. http://www.flmnh.ufl.edu/fish/sharks/isaf/2013summary.html (Accessed 09 October 2014).

Burgess, G.H., Bruce, B.D., Cailliet, G.M., Goldman, K.J., Grubbs, R.D., Lowe, C.G., MacNeil, M.A., Mollet, H.F., Weng, K.C., O'Sullivan, J.B., 2014. A Re-Evaluation of the Size of the White Shark (*Carcharodon carcharias*) Population off California, USA. PLoS One 9, e98078. http://dx.doi.org/10.1371/journal.pone.0098078.

Burgess, G.H., Buch, R.H., Carvalho, F., Garner, B.A., Walker, C.J., 2010. Factors contributing to shark attacks on humans: a Volusia county, Florida, case study. In: Carrier, J.C., Musick, J.A., Heithaus, M.R. (Eds.), Sharks and Their Relatives II: Biodiversity, Adaptive Physiology, and Conservation. CRC Press, Boca Raton, pp. 541–566.

Caldicott, D.G.E., Mahajani, R., Kuhn, M., 2001. The anatomy of a shark attack: a case report and review of the literature. Injury 32, 445–453.

Campbell, R., Holley, D., Collins, P., Armstrong, S., 2014. Changes in the abundance and distribution of the New Zealand fur seal (*Arctocephalus forsteri*) in Western Australia: are they approaching carrying capacity? Austr J. Zool. 62, 261–267.

Carlson, J.K., Hale, L.F., Morgan, A., Burgess, G., 2012. Relative abundance and size of coastal sharks derived from commercial shark longline catch and effort data. J. Fish. Biol. 80, 1749–1764. http://dx.doi.org/10.1111/j.1095-8649.2011.03193.x.

Chapple, T.K., Jorgensen, S.J., Anderson, S.D., Kanive, P.E., Klimley, A.P., Botsford, L.W., Block, B.A., 2011. A first estimate of white shark, *Carcharodon carcharias*, abundance off Central California. Biol. Lett. 7, 581–583. http://dx.doi.org/10.1098/rsbl.2011.0124.

Chin, A., Kyne, P.M., Walker, T.I., McAuley, R.B., 2010. An integrated risk assessment for climate change: analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. Glob. Change Biol. 16, 1936–1953.

Chollett, I., Müller-Karger, F.E., Heron, S.F., Skirving, W., Mumby, P.J., 2012. Seasonal and spatial heterogeneity of recent sea surface temperature trends in the Caribbean Sea and southeast Gulf of Mexico. Mar. Pollut. Bull. 64, 956–965.

Christiansen, H.M., Lin, V., Tanaka, S., Velikanov, A., Mollet, H.F., Wintner, S.P., Fordham, S.V., Fisk, A.T., Hussey, N.E., 2014. The Last Frontier: Catch Records of White Sharks (*Carcharodon carcharias*) in the Northwest Pacific Ocean. PLoS one 9, e94407. http://dx.doi.org/10.1371/journal.pone.0094407.

Clua, E., Bescond, P.-M., Reid, D., 2014. Fatal attack by a juvenile tiger shark, Galeocerdo cuvier, on a kitesurfer in New Caledonia (South Pacific). J. Forensic Leg. Med. 25, 67–70. http://dx.doi.org/10.1016/j.jflm.2014.04.005.

Comas, M.E., 2012. Volusia Beach Water Cleaner than Most in Florida, Report Says (Orlando Sentinel).

Crossley, R., Collins, C.M., Sutton, S.G., Huveneers, C., 2014. Public perception and understanding of shark attack mitigation measures in Australia. Hum. Dimens. Wildl. 19, 154–165. http://dx.doi.org/10.1080/1087/1209.2014.844289.

Daly, R., Smale, M.J., Cowley, P.D., Froneman, P.W., 2014. Residency patterns and migration dynamics of adult bull sharks (*Carcharhinus leucas*) on the East Coast of Southern Africa. PLoS One 9, e109357. http://dx.doi.org/10.1371/journal.pone.0109357.

Dennis, G.D., Wicklund, R.I., 1993. In: The Relationship between Environmental Factors and Coral Bleaching at Lee Stocking Island, Bahamas in 1990. Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History. University of Miami, Florida, pp. 167–173.

Dias, D., Peron, J., 2011. The rise of sustainable urban development on reunion island. Ecocity World Summit 21. Montreal.

Dudley, S.F.J., 1997. A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). Ocean. Coast Manag. 34, 1–27. http://dx.doi.org/10.1016/S0964-5691(96)00061-0.

Dudley, S.F.J., Cliff, G., 2010. Shark control: methods, efficacy, and ecological impacts. In: Carrier, J.C., Musick, J.A., Heithaus, M.R. (Eds.), Sharks and Their Relatives II: Biodiversity, Adaptive Physiology, and Conservation. CRC Press, Boca Raton, pp. 567–592.

Dudley, S.F.J., Simpendorfer, C.A., 2006. Population status of 14 shark species caught in the protective gillnets off Kwa-Zulu-Natal beaches, South Africa, 1978-2003. Mar. Freshw. Res. 57, 225–240.

Eilperin, J., 2011. Bahamas Bans Commercial Shark Fishing (Wahington Post).

Fallows, C., Gallagher, A., Hammerschlag, N., 2013. White sharks (*Carcharodon carcharias*) scavenging on whales and its potential role in further shaping the ecology of an apex predator. PLoS one 8, e60797.

FAOSTAT, 2014. Population. Food and Agriculture Organization of the United Nations Statistics Division.

Gibbs, L., Warren, A., 2014. WA Shark Cull Season Ends, and Ocean Users Don't Want it to Return. The Conversation 30 April, 1–3.

Gibbs, L., Warren, A., 2015. Transforming shark hazard policy: learning from ocean-users and shark encounter in Western Australia. Mar. Policy 58, 116–124. http://dx.doi.org/10.1016/j.marpol.2015.04.014.

Gribble, N.A., McPherson, G., Lane, B., 1998. Effect of the Queensland Shark Control Program on non-target species:whale, dugong, turtle and dolphin: a review. Mar. Freshw. Res. 49, 645–651.

Hall, C.M., 2001. Trends in ocean and coastal tourism: the end of the last frontier? Ocean. Coast Manag. 44, 601–618. http://dx.doi.org/10.1016/s0964-5691(01)00071-0.

Hazin, F.H.V., Afonso, A.S., 2014. A green strategy for shark attack mitigation off Recife, Brazil. Anim. Conserv. 17, 287–296. http://dx.doi.org/10.1111/acv.12096.

Hazin, F.H.V., Afonso, A.S., De Castilho, P.C., Ferreira, L.C., Rocha, B.C.L.M., 2013. Regional movements of the tiger shark, *Galeocerdo cuvier*, off northeastern Brazil: inferences regarding shark attack hazard. Ann. Braz. Acad. Sci. 85, 1053–1062.

Hazin, F.H.V., Burgess, G.H., Carvalho, F.C., 2008. A Shark attack outbreak off Recife, Pernambuco, Brazil: 1992–2006. Bull. Mar. Sci. 82, 199–212.

Hilting, A.K., Currin, C.A., Kosaki, R.K., 2013. Evidence for benthic primary production support of an apex predator–dominated coral reef food web. Mar. Biol. 160, 1681–1695. http://dx.doi.org/10.1007/s00227-013-2220-x.

Holmes, B.J., Pepperell, J.G., Griffiths, S.P., Jaine, F.R.A., Tibbetts, I.R., Bennett, M.B., 2014. Tiger shark (*Galeocerdo cuvier*) movement patterns and habitat use determined by satellite tagging in eastern Australian waters. Mar. Biol. 161, 2645–2658. http://dx.doi.org/10.1007/s00227-014-2536-1.

Holmes, B.J., Sumpton, W.D., Mayer, D.G., Tibbetts, I.R., Neil, D.T., Bennett, M.B., 2012. Declining trends in annual catch rates of the tiger shark (*Galeocerdo cuvier*) in Queensland, Australia. Fish. Res. 129–130, 38–45. http://dx.doi.org/10.1016/j.fishres.2012.06.005.

Honey, M., Krantz, D., 2007. Global Trends in Coastal Tourism. Cent. Ecotourism Sustain. Dev. 140.

Hussey, N.E., McCann, H.M., Cliff, G., Dudley, S.F.J., Wintner, S.P., Fisk, A.T., 2012. Size-based analysis of diet and trophic position of the white shark, Carcharodon carcharias, in South African waters. In: Domeier, M.L. (Ed.), Global Perspectives on the Biology and Life History of the White Shark. CRC Press, Boca Raton, pp. 27–50.

International Shark Attack File. Florida Museum of Natural History, University of Florida. https://www.flmnh.ufl.edu/fish/isaf/home (Accessed 10 July 2015).

Islam, M.S., Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Mar. Pollut. Bull. 48, 624–649. http://dx.doi.org/10.1016/j.marpolbul.2003.12.004.

Jewell, O.J.D., Johnson, R.L., Gennari, E., Bester, M.N., 2013. Fine scale movements and activity areas of white sharks (*Carcharodon carcharias*) in Mossel Bay, South Africa. Environ. Biol. Fishes 96, 881–894. http://dx.doi.org/10.1007/s10641-012-0084-4.

Kim, S.L., Tinker, M.T., Estes, J.A., Koch, P.L., 2012. Ontogenetic and Among-Individual Variation in Foraging Strategies of Northeast Pacific White Sharks Based on Stable Isotope Analysis. PLoS One 7, e45068.

Kingsford, M.J., Welch, D.J., 2007. The vulnerability of pelagic ecosystems in the Great Barrier Reef to climate change. In: Johnson, J.E., Marshall, P.A. (Eds.), Climate Change and the Great Barrier Reef: a Vulnerability Assessment. Great Barrier Reef Marine Park Authority, Townsville, pp. 555–592.

Klimley, A.P., Le Boeuf, B.J., Cantara, K.M., Richert, J.E., Davis, S.F., Van Sommeran, S., Kelly, J.T., 2001. The hunting strategy of white sharks (*Carcharodon carcharias*) near a seal colony. Mar. Biol. 138, 617–636.

Kock, A., Johnson, R., 2006. White shark abundance: not a causative factor in numbers of shark bite incidents. In: Nel, D.C., Peschak, T.P. (Eds.), Finding a Balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa. WWF South Africa Report Series pp. Annexure1 1–19.

Kock, A., Titley, S., Petersen, W., Sikweyiya, M., Tsotsobe, S., Colenbrander, D., Gold, H., Oelofse, G., 2012. Shark spotters: a pioneering shark safety program in Cape Town, South Africa. In: Domeier, M.L. (Ed.), Global Perspectives on the Biology and Life History of the White Shark. Taylor & Francis, Boca Raton, pp. 447–466.

Koening, M.L., Leca, E.E., Neumann-Leitao, S., de Macedo, S.J., 2003. Impacts of the construction of the Port of Suape on phytoplankton on the Ipojuca River Estuary (Pernambuco-Brazil). Braz Arch. Biol. Technol. 46, 73–81.

Krogh, M., Reid, D., 1996. Bycatch in the protective shark meshing programme off south-eastern New South Wales. Biol. Conserv. 77, 219–226.

Lisney, T., 2004. Neuroethology and Vision in Elasmobranchs. School of Biomedical Sciences. University of Queensland, St. Lucia.

LiveScience, Hurricane Season, 2013. Storm Coverage [cited 2014 09 October]; Available: http://www.livescience.com/36983-hurricane-season-2013.html.

Long, D., Jones, R., 1996. White shark predation and scavenging on cetaceans in the eastern North Pacific Ocean. In: Klimley, A.P., Ainley, D.G. (Eds.), Great White Sharks: the Biology of *Carcharodon carcharias*. Academic Press, San Diego, pp. 293–307.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion, degredation, and recovery potential of estuaries and coastal seas. Science 312, 1806.

Lowe, C.G., Blasius, M.E., Jarvis, E.T., Mason, T.J., Goodmanlowe, G.D., O'Sullivan, J.B., 2012. Historic fishery interactions with white sharks in the Southern California bight. In: Domeier, M.L. (Ed.), Global Perspectives on the Biology and Life History of the White Shark. CRC Press, Boca Raton, FL, USA, pp. 169–185.

Lynch, A.M.J., Sutton, S.G., Simpfendorfer, C.A., 2010. Implications of recreational fishing for elasmobranch conservation in the Great Barrier Reef Marine Park. Aquat. Conserv. – Mar. Freshw. Ecosyst. 20, 312–318. http://dx.doi.org/10.1002/AQC.1056.

Maguire, G.S., Miller, K.K., Weston, M.A., Young, K., 2011. Being beside the seaside: Beach use and preferences among coastal residents of south-eastern Australia. Ocean. Coast Manag. 54, 781–788.

Maljkovic, A., Côté, I.M., 2011. Effects of tourism-related provisioning on the trophic signatures and movement patterns of an apex predator, the Caribbean reef shark. Biol. Conserv. 144, 859–865.

Marie, C., Rallu, J., 2012. Demographic and Migration Trends in the Outermost Regions: Impacts on Territorial, Social and Territorial Cohesion? Executive Summary – Reunion Island. European Commission, Directorate General for Regional Policy, pp. 1–16.

Matich, P., Heithaus, M.R., 2012. Effects of an extreme temperature event on the behavior and age structure of an estuarine top predator, Carcharhinus leucas. Mar. Ecol. Prog. Ser. 447, 165–178. http://dx.doi.org/10.3354/meps09497.

McPhee, D., 2014. Unprovoked shark bites: are they becoming more prevalent? Coast Manag. 42, 478–492.

Meeuwig, J.J., 2014. Has Queensland Really Saved Lives by Killing Thousands of Sharks? the Conversation. The Conversation Media Group.

Meeuwig, J.J., Ferreira, L.C., 2014. Moving beyond lethal programs for shark hazard mitigation. Anim. Conserv. 17, 297–298. http://dx.doi.org/10.1111/acv.12154.

Morgan, D., Ozanne-Smith, J., 2013. Identification of observed factors that predict bather water-immersions at beaches. Ocean. Coast Manag. 84, 180–183.

Mull, J., 2013. Reunion Island Bans Surfing (Surfer).

Mull, J., 2015. Testing the Water. Surfer Magazine. The Enthusiast Network.

Munday, P.L., Jones, G.P., Pratchett, M.S., Williams, A.J., 2008. Climate change and the future for coral reef fishes. Fish. Fish. 9, 261–285.

Murtugudde, R., McCreary Jr., J.P., Busalacchi, A.J., 2000. Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997-1998. J. Geophys Res. 105, 3295–3306.

Myrick, J.G., Evans, S.D., 2014. Do PSAs Take a Bite Out of Shark Week? The Effects of Juxtaposing Environmental Messages With Violent Images of Shark Attacks. Sci. Commun. 36, 544–569.

National Climate Centre, 2009. The Exceptional January-February 2009 Heatwave in Southeastern Australia. Bureau of Meteorology, Melbourne, pp. 1–11.

Neff, C., 2012. Australian beach safety and the politics of shark attacks. Coast Manag. 40, 88–106. http://dx.doi.org/10.1080/08920753.2011.639867.

Neff, C., 2014. Human Perceptions and Attitudes towards Sharks: Examining the Predator Policy Paradox. Routledge, Abingdon.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J., 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding - a global assessment. PLoS One 10, e0118571. http://dx.doi.org/10.1371/journal.pone.0118571.

Noad, M.J., 2011. Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). J. Cetacean Res. Manag. 243–252, 1561-0713.

Ortega, L.A., Heupel, M.R., Van Beynen, P., Motta, P.J., 2009. Movement patterns and water quality preferences of juvenile bull sharks (*Carcharhinus leucas*) in a Florida estuary. Environ. Biol. Fish. 84, 361–373. http://dx.doi.org/10.1007/s10641-009-9442-2.

Paschoa, C., 2013. Environmental Consequences of the Suape Port Complex. Marine Technology News. http://www.marinetechnologynews.com/blogs/environmental-consequences-of-the-suape-port-complex-700402 (Accessed 02 March 2015).

Paterson, R.A., 1990. Effects of long-term anti-shark measures on target and non-target species in Queensland, Australia. Biol. Conserv. 52, 147–159.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. Science 308, 1912–1915.

Powers, S.P., Fodrie, F.J., Scyphers, S.B., Drymon, J.M., Shipp, R.L., Stunz, G.W., 2013. Gulf-Wide Decreases in the Size of Large Coastal Sharks Documented by Generations of Fishermen. Mar. Coast Fish. 5, 93–102.

Rabalais, N.N., Turner, R.E., Diaz, R.J., Justic, D., 2009. Global change and eutrophication of coastal waters. ICES J. Mar. Sci. 66, 1528–1537.

Reid, D.D., Robbins, W.D., Peddemors, V.M., 2011. Decadal trends in shark catches and effort from the New South Wales, Australia, Shark Meshing Program 1950-2010. Mar. Freshw. Res. 62, 676–693.

Rolland, M., De Melo, E.H., Vieira, É.L.R., De Oliveira, M.C.A., De França Caldas, A., 2012. Environmental conditions associated with shark attacks against humans: a case report about territoriality. Am. J. Foren. Med. Pathol. 33, 265–267.

Ropelewski, C., 1999. The Great El Niño of 1997 and 1998: impacts on precipitation and temperature. Consequences 5, 17–25.

Sawers, R., 2012. The Beautiful Brazilian Beaches Plagued by Shark Attacks. World News TV.

SBS, 2014. Inside La Réunion's Shark Cull: Why the Locals Want Them Dead.

Simpfendorfer, C.A., Heupel, M.R., White, W.T., Dulvy, N.K., 2011. The importance of research and public opinion to conservation management of sharks and rays: a synthesis. Mar. Freshw. Res. 62, 518–527.

Skomal, G.B., Chisholm, J., Correia, S.J., 2012. Implications of increasing pinniped populations on the diet and abundance of white sharks off the coast of Massachusetts. In: Domeier, M.L. (Ed.), Global Perspectives on the Biology and Life History of the White Shark. CRC Press, Boca Raton, pp. 405–418.

Smith, S.K., Cody, S., 2015. Trends in Florida's Population Growth, 2000 to 2012. Florida Data at Your Fingertips. Bureau of Economic and Business Research. University of Florida, Gainsville.

Sprivulis, P., 2014. Western Australia coastal shark bites: A risk assessment. Aust. Med. J. 7, 137–142.

Stewart, R., 2015. Reunion shark attacks scare surfers and tourists from beaches. Telegraph. Date of online article: 23 April 2015, (Telegraph Media Group Limited).

Sunstein, C.R., Zeckhauser, R., 2011. Overreaction to fearsome risks. Environ. Resour. Econ. 48, 435–449. http://dx.doi.org/10.1007/s10640-010-9449-3.

Tourism Australia, 2014. Short Term International Arrivals Soar to New Levels. Quarterly Market Update. Tourism Australia, pp. 1–15.

Towner, A.V., Wcisel, M.A., Reisinger, R.R., Edwards, D., Jewell, O.J.D., 2013. Gauging the threat: the first population estimate for white sharks in South Africa using photo identification and automated software. PLoS One 8, e66035. http://dx.doi.org/10.1371/journal.pone.0066035.

United States Census Bureau, 2015. State and County QuickFacts. http://quickfacts.census.gov/qfd/states/12000.html (Accessed 23 July 2015).

Van Grevelynghe, G., 2000. Shark attacks in La Reunion Island (southwestern Indian Ocean). In: Seret, B., Sire, J.Y. (Eds.), 3rd Meeting of the European Elasmobranch Association, Boulogne Sur Mer, pp. 73–81.

VISIT FLORIDA Research, http://www.visitfloridamediablog.com/home/florida-facts/research/(Accessed 01 October 2015).

Waycott, M., Collier, C., McMahon, K., Ralph, P., McKenzie, L., Udy, J., Grech, A., 2007. Vulnerability of seagrasses in the Great Barrier Reef to climate change. In: Johnson, J.E., Marshall, P.A. (Eds.), Climate Change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, pp. 193–235. Townsville.

Wcisel, M., O'Riain, M.J., de Vos, A., Chivell, W., 2015. The role of refugia in reducing predation risk for Cape fur seals by white sharks. Behav. Ecol. Sociobiol. 69, 127–138. http://dx.doi.org/10.1007/s00265-014-1825-5.

Weltz, K., Kock, A.A., Winker, H., Attwood, C., Sikweyiya, M., 2013. The influence of environmental variables on the presence of white sharks, *Carcharodon carcharias* at two popular Cape Town bathing beaches: A generalized additive mixed model. PLoS one 8, e68554. http://dx.doi.org/10.1371/journal.pone.0068554.

Werry, J.M., 2010. Habitat Ecology of the Bull Shark, *Carcharhinus Leucas*, on Urban Coasts in Eastern Queensland, Australia. School of Environment. Griffith University, Gold Coast.

Werry, J.M., Lee, S.Y., Lemckert, C.J., Otway, N.M., 2012. Natural or artificial? habitat-use by the bull shark, *Carcharhinus leucas*. PLoS One 7, e49796. http://dx.doi.org/10.1371/journal.pone.0049796.

West, J.G., 2011. Changing patterns of shark attacks in Australian waters. Mar. Freshw. Res. 62, 744–754.

Wetherbee, B.M., Lowe, C.G., Crow, G.L., 1994. A review of shark control in Hawaii with recommendations for future research. Pac Sci. 48, 95–115.

Woolgar, J.D., Cliff, G., 2001. Shark attack: Review of 86 consecutive cases. J. Trauma-Inj. Infect. Crit. Care 50, 887–891.