Behavioral and Environmental Conditions associated with Shark Attacks on Humans

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To my parents, their endless support made this journey possible.

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Abstract

Sharks, among other large predatory fishes, are declining drastically worldwide, yet numbers of reported shark attacks on humans have tended to increase over time. Considering rapidly increasing coastal populations it is likely that these trends will continue unless humans learn how to interact and coexist with sharks in the coastal environment. The focus of this thesis is to detect behavioral or environmental conditions that may lead to shark attacks. Few previous studies have analyzed a limited number of attacks, often in a regional and anecdotal fashion. Here, I make use of the Global Shark Attack File, a compilation of all confirmed attacks worldwide. Following careful standardization of all available information in a coded data base, I quantify and discuss associated behavioral, geographical and species specific risks of shark attacks. The data revealed 4 major concentrations of shark attacks: the U.S. west coast, the U.S. southeast coast and Caribbean, South Africa, and south and east Australia to Papua New Guinea. Most attacks occurred in the summer months, in mid-to late afternoon. Young males (15-19 yrs) showed highest incidence, correlating with patterns in marine recreation. However, average fatality was highest in infants and above 55 yrs of age. White sharks were responsible for most attacks, but Tiger sharks showed the highest fatality rate. No positive correlation between shark size and inflicted injury was seen, except in Bull sharks. Most attacks were on swimmers, but surfing had by far the greatest average risk of attack (6 per million participants), particularly in the Northern Hemisphere fall and Southern Hemisphere winter. These results give strong support to the hypothesis that Great Whites attack humans mistaken for pinniped prey. I derive 10 simple behavioral rules from these results that may help to minimize the risk of shark attacks on humans.

List of Abbreviations

GIS: Geographic information system
GSAF: Global Shark Attack File

Acknowledgements

First and foremost, I would like to express my sincere gratitude to my supervisor, Dr. Boris Worm. His guidance, patience and devotion were genuinely appreciated. I would also like to thank the Global Shark Attack File, specifically Marie Levine for allowing access to their database. Their dedication and thoroughness to shark conservation is sincerely admirable. Finally, special thanks to Jennifer Milne, of the Dalhousie GIS Centre, for her expertise in Geographic Information Systems.

1.0 Introduction

Historically humans have overexploited large predators on land, with the extinction of large megafuana (Alroy 2001) and currently in the ocean with the removal of predatory fish (Baum *et al.* 2003, Christensen *et al.* 2003, Myers and Worm 2003, Worm *et al.* 2005). Populations and biomass of large predatory fish are declining. Myers and Worm (2003) established the factor-of-10 hypothesis, estimating that only 10% of large predatory fish populations remain from pre-industrial levels. However, 90% declines may still be considered conservative for k-selected species like sharks (Worm and Myers 2005). Fishery management strategies are aimed to sustain target species, and rarely take into consideration sustainability of sensitive bycatch species such as sharks. Elasmobranchs in general are characterized by low fecundity, slow growth, and late age of maturity, making it difficult for shark populations to rebound from overexploitation (Stevens *et al.* 2000). Where detailed data exist, researchers have found population declines of up to 99% in some species (Baum and Myers 2004). The scarcity of pre-industrial population data for sharks combined with the 'shifting baseline' effect make it difficult to calculate the extent of population declines (Baum and Myers 2004). However, generally, within the first 15 years of exploitation, 80% abundance decrease is observed (Myers and Worm 2003). A decline of such magnitude calls for timely conservation efforts, and gives reason for management to reassess fishing strategies.

The ecosystem consequences used by the loss of marine predators such as sharks are largely unknown. However, available evidence suggests significant alteration of ecosystem structure by removing top predators and dominance shifts to lower trophic levels (Pauly *et al.* 1998, Jackson *et al.* 2001, Frank *et al.* 2005). For example, Atlantic cod, *Gadus morhua*, a large predatory fish in the north Atlantic, experienced large population declines in the early 1990s, to the point where a moratorium was introduced (Hutchings and Myers 1994, Myers *et al.* 1996). The depletion of cod stock represents the removal of a large predatory fish from the north Atlantic. Correlating with the depletion of Atlantic cod, snow crab, *Chionocetes opilio*, northern shrimp, *Pandalus borealis,* and American lobster, *Homarus americanu*s, common prey of Atlantic cod, all increased in abundance (Worm and Myers 2003), as did pelagic forage fishes such as capelin (Frank *et al.* 2005). This trend can lead to cascading “ripple effects” across several trophic levels, and alter plankton abundance and nutrient fluxes (Frank *et al.* 2005).

One major concern with regard to top predator removal is the uncertainty. Time lags, from removal to ecosystem consequences can take decades to centuries (Jackson *et al.* 2001, Springer *et al.* 2003). Consequences for removal of top predators on ecosystems are only beginning to be understood. Apex predators do play important regulatory roles in ecosystems and their drastic declines should not be overlooked. Removing large predatory fish creates stress on an ecosystem, increasing the vulnerability. Fishing strategies should take into account the sustainability of sensitive species and their conservational importance ecosystems (Friedlander and DeMartini 2002).

For effective conservation of sharks it is important to understand their behavior, yet, until recently, little reliable information has been available. Their large ranges make many shark species extremely difficult to study. The Great White (or White shark), *Carcharodon carcharias,* is one of the more commonly studied species. Made famous through the movie ‘Jaws’, the Great White (and sharks in general) have been painted as ‘man-eaters’ that pose massive threats to swimmers, divers and surfers. This image is drastically over exaggerated. Although fatal attacks do occur, they are exceptionally rare. Most sharks feed on fish and invertebrates and are harmless to humans unless provoked or threatened. However, larger species of sharks do prey on elasmobranchs, larger teleosts, cetaceans and marine mammals. Much of shark attack debate surrounds the belief that White sharks attack surfers mistaken for pinniped prey (Miller and Collier 1981). Here in I examine quantitative evidence on all confirmed global sharks attacks to examine the possibility of White sharks attacking humans under the assumption they are pinniped prey. I am also testing the hypothesis that larger sharks are more likely to attack or kill a human.

With decreasing population levels of sharks, it is alarming to find that the number of negative human-shark encounters is increasing. Most likely sharks are not selectively attacking humans, but attacks are incidental. With human population levels increasing dramatically in coastal areas, it is likely that shark attacks will continue to occur. This paper is an attempt to discuss the behavioral, environmental, and geographical risks associated with shark attacks. The most dangerous locations and times, both daily and seasonally, will be determined, as well as the degrees of risk by age and gender. Species attack rate will also be analyzed to determine which sharks are most dangerous to humans, and the activities that could potentially elicit various behavioral responses increasing the risk of attack. It is imperative that information on associated risks be made broadly available so humans can safely participate in marine recreation. Education is the window to conservation. Hopefully, this paper can be used to dispel fears and inaccuracies surrounding shark attacks.

2.0 Materials and Methods

The Global Shark Attack File (GSAF hereafter) is dedicated to collecting accurate information on all shark attacks. It is assumed to capture all verified shark attacks (3121 individual attacks), beginning in the year 1500 till 2005. Each recorded attack was issued an identification case number. Data were not entered in a consistent fashion, and using a variety of conflicting formats. A major aim of this thesis was to code the GSAF in a database such it can be summarized and analyzed quantitatively. Data for each case were recorded under appropriate categories, and coded according to specified criteria. Any information that could not be accurately coded or was absent was entered as N/A. Results were presented as summary plots that showed the distribution of attacks in relation to behavioral and environmental variables. Statistical tests were only considered useful where inferences about shark size and injuries were made, in all other cases no statistical inferences were sought, since the data were assumed to represent the entire sample of shark attacks globally.

2.1 Database

Each shark attack was classified according to the time, month, and year the attack occurred. Months were coded from one to twelve. If no month was available, but a season was recorded, data was coded according to the first month of the respective season (Table 1). Years were coded in a four-digit numeral according to the year of reported attacks. Time was coded into hours and minutes according to the 24-hour system. Attacks that took over a minute were coded according to the time the attack began.

Table 1. Coded numerical classification of months and seasons in Northern and Southern Hemisphere.

Month	Numerical Classification	Northern Hemisphere Season	Southern Hemisphere Season
January	1	Winter	Summer
February	2	Winter	Summer
March	3	Winter	Summer
April	4	Spring	Fall
May	5	Spring	Fall
June	6	Spring	Fall
July	7	Summer	Winter
August	8	Summer	Winter
September	9	Summer	Winter
October	10	Fall	Spring
November	11	Fall	Spring
December	12	Fall	Spring

Country, area and location information was entered where available. Area and location were used to infer the latitude and longitude of where the shark attack occurred. Obscure locations, often in developing countries, proved difficult to be assigned accurate latitude and longitudes. Larger, more prominent reference points, that were close in proximity, were utilized if latitude and longitude of an area could not be found. If no reference point could be located, latitude and longitude were coded as N/A. Latitude/longitude was coded in decimal form – negative latitude correlated with the southern hemisphere and a negative longitude equates with a western hemisphere location. Attacks that occurred in the open ocean were not possible to be coded unless coordinates were provided by the source.

Victim activity was recorded by GSAF investigators. Activities were categorized into general activities according to the criteria in Table 2.

Table 2. Criteria for accurately coding general activities during attack.

General Activity	Code	Criteria
Bathing	BTH	Washing animals, people, dishes, clothing
Boating	BTG	Recreational activities in a boat that did not include fishing (i.e kayaking)
Diving	DIV	Includes free diving, scuba, dressed, technical, Hookah, Helmet, and surface supplied oxygen diving
Fishing	FSH	Activities that sought to catch fish or invertebrates
Floating	FLT	With or without a floatation device with no means of propulsion
Handling	HND	Direct human contact with shark, initiated by human
Playing	PLY	Activities associated with splashing, running and jumping in shallow water
Standing	STD	Stationary positions where feet are touching the bottom
Surfing	SRF	Activities, with or without a board, with the intention of riding waves to shore
Swimming	SWM	Surface activities that involved swimming. Includes snorkeling.
Walking	WLK	Walking, wading

Activity in the area of attack corresponded to any activity in the surrounding area that could increase the likelihood of a shark attack. Each activity in the area of attack was coded according to specified criteria (Table 3). Fishing and boating activities were broken down into individual activities (Table 4).

Table 3. Criteria for accurately coding Activity in Area of Attack.

General Activity	Code	Criteria
Dangerous Area	BA	Dangerous areas for recreational use i.e. close to cannery, drop off, etc
Boating	BTG	Activities in a boat that did not include fishing (i.e. kayaking)
Bathing	BTH	Washing animals, people, dishes, clothing
Floating	FLT	Floating with or without a flotation device
Fishing	FSH	Any fishing
Playing	PLY	Activities associated with splashing, running and jumping in shallow water
Recovering Injured Humans	RIH	Aiding person distressed or injured
Diving	DIV	Includes free diving, scuba, dressed, technical, Hookah, Helmet, and surface supplied oxygen diving

Surfing	SRF	Activities, with or without a board, with the intention of riding waves to shore
Swimming	SWM	Surface activities that involved swimming. Includes snorkeling.
Towing	TWG	Being towed by boat or human
Underwater photography	UWP	Photographing underwater not using scuba equipment
Walking	WLK	Walking, wading

Table 4. Fishing and Boating broken into individual Activities.

Fishing Activities	**Code**	**Criteria**
Collecting Fish	CSF	Collecting or carrying dead fish from spear, dynamite or other fishing mechanisms
Fishing	FSH	Any fishing
Invertebrate Fishing	IFSH	Invertebrate fishing while physically in the water i.e. free diving for abalone
Shark Fishing	SHFSH	Big game fishing i.e. sharks, tuna
Spear fishing	SFSH	Free diving, actively hunting fish with a spear gun.
Surf fishing	SFFSH	Fishing where human was fishing while physically standing in the water
Boating Activities	**Code**	**Criteria**
Boating	BTG	Activities in a boat that did not include fishing (i.e. kayaking)
Large Ships	LBT	Large Ships that are not fishing vessels
Shipwreck	SPW	Large boat or airplane disasters, where humans were forced into ocean

Attack records contain age and gender of victims involved in attacks. Humans were coded as F for female and M for male. Age of humans was recorded according to the age at the time of attack.

An attack that resulted in no visible injuries was coded as 0. Minor injuries, coded as 1, were classified as injuries to non-life threatening areas of the body – foot, wrist, arm, calf, and when no parts of the body were significantly injured. Major injuries, coded as 2, were classified as any life-threatening injury - such as those that concern head, chest, thigh, or if any extremity was severed or forced to be amputated. Fatal injuries were coded as 3. A separate category was created for fatal and non-fatal injuries. Any attack that was fatal was coded as F and any attack causing non-fatal injuries were coded as N.

Sharks were classified to species level where possible, according to Compagno, (2005). Attacks by Hammerhead Sharks and Wobbegongs were recorded at the Family level, and dogfish were classified by Order, as no species-specific information was available for these attacks (Table 5). When available, species weight in kilograms, and length in meters were entered into the database. If shark length or weight was recorded as an estimated range, the median between lowest and highest value was used.

Table 5. Shark species code, scientific and common names.

Code	**Common Names**	**Scientific Name**
BLS	Blue Shark	*Prionace glauca*
BSK	Basking Shark	*Cetorhinus maximus*
BTR	Blacktip Reef Shark	*Carcharhinus melanopterus*
BTS	Blacktip Shark	*Carcharhinus limbatus*
BUL	Bull Shark	*Carcharhinus leucas*
BWS	Bronze Whaler Shark	*Carcharhinus brachyurus*
CRP	Carpet Shark	*Orectolobus ornatus*
CRS	Caribean Reef Shark	*Carcharhinus perezi*
DGF	Dogfish Sharks	Order Squaliformes
DGS	Dogshark	*Squalus megalops*
DSK	Dusky Shark	*Carcharhinus obscurus*
GNS	Grey Nurse Shark	*Carcharhinus taurus*
GRF	Grey Reef Shark	*Carcharhinus amblyrhynchos*
GWS	Great white Shark	*Carcharodon carcharias*
HMR	Hammerhead Sharks	Family Sphyrnidae
HRN	Horn Shark	*Heterodontus francisci*
LMN	Lemon Shark	*Negaprion breviostris*
LPD	Leopard Shark	*Triakis semifasciata*
MKO	Mako Shark	*Isurus oxyrinchus*
NRS	Nurse Shark	*Ginglymostoma cirratum*
OWT	Oceanic whitetip Shark	*Carcharhinus longimanus*

PRB	Porbeagle	*Lamna nasus*
SBS	Sandbar Shark	*Carcharhinus plumbeus*
SGS	Sevengill Shark	*Heptranchias perlo*
SLK	Silky Shark	*Carcharhinus falciformis*
SPN	Spinner Shark	*Carcharhinus brevipinna*
TGR	Tiger Shark	*Gaelocerdo cuvier*
WBG	Wobbegong	Family Orectolobidae
WHS	Whale Shark	*Rhiniodon typus*
STS	Silvertip Shark	*Carcharhinus albimarginatus*
BCS	Bamboo catshark	*Chiloscyllium punctatum*
SLM	Salmon Shark	*Lamna ditropis*

Once coding was complete, 10 random case numbers were selected from the original GSAF and cross validated against the completed coded database to check for inconsistencies, which were absent.

Three different chapters were completed to determine: (1) where and when shark attacks most frequently occurred, (2) victims of attacks, and (3) which types of sharks (species, size, and weight) were most likely to attack.

2.2 Spatial and Temporal Distribution of Shark Attacks

Chapter 1 was dedicated to examining spatial and temporal risks associated with shark attacks. Attacks were plotted on a global map to determine any areas with significantly higher risks then others. Data was also separated into Western, Eastern, Northern, and Southern Hemispheres, grouped into 10x10° squares and plotted against the frequency of attack. To establish when attacks occurred month and time of attacks were plotted against frequency. Eastern and Western Hemispheres were not examined, as the seasons are similar in both hemispheres through the year and would not affect the distribution of people entering the ocean. However, Southern and Northern Hemisphere experience opposite seasons, and this would affect the distribution of people using the ocean. Therefore I examined Northern and Southern Hemispheres separately.

2.3 Victims of shark attack

Chapter 2 analyses risks associated with certain activities, ages or gender that may be involved in a shark attack. Different marine activities were suggested to have varying degrees of risks. Total number of attacks for each activity was plotted. To determine current risks, boating, diving, fishing, surfing and swimming had number of attacks per million participants over the last 5 years in the USA calculated. The Great White is commonly assumed to attack surfers mistaken as pinniped prey. However, to my knowledge, no quantitative data has been used to validate this theory. An examination of activity during attack in Northern and Southern Hemisphere by month, for White sharks was undertaken.

Different marine activities were thought to indirectly increase the likelihood of a shark attack in the surrounding area. Activities suspected of promoting a higher risk of shark attack were plotted against the frequency of attack. Fishing and Boating in the area of attack were broken down into individual activities and analyzed.

I asked furthermore whether any age class was at greater risk of attack; ages of humans attacked were plotted, in 5-year categories against the frequency of attack. Severity of attack for each age class was established through calculation of a fatality ratio (Fatal/Non-fatal attacks). The different risks for males and females participating in general activities were examined by calculating a ratio of female to male attacks for each activity.

2.4 Characteristics of Attacking Sharks

Chapter 3 involved the risks of shark attack associated with each species. Varying degrees of risk are assumed to be associated with different species. Attacking species were plotted against frequency of attack to determine which species have the highest probability of attack. Species with the ten highest frequencies of attack had their average injury and ratio of Fatal/Non-Fatal attacks calculated to determine the risk of major injuries or death. Average injury was calculated by summing up the average injuries for all attacks that occurred for a species, divided by the total number of attacks of that species (Table 6). The Fatal/Non-Fatal ratio was calculated by totaling the number of fatal attacks and dividing it by the total number of Non-Fatal attacks. Weight and length of species with the large fatal/non-fatal ratios (Bull, Great White, Mako, Tiger) were plotted against injury inflicted during attack. Regression analysis was used to determine whether there were general trends with size or weight. Species with the 4 highest incidents of attack were plotted on a global map.

Table 6. Example Calculation for Average Injury of Great White Shark and Tiger Shark.

Species	No Injury	Minor Injury	Major Injury	Fatal	Total Injury	Total Attacks	Average Injury
White Shark	58	99	76	89	518	322	1.61
Tiger Shark	8	33	28	40	203	109	1.86

3.0 Results

3.1 Spatial and Temporal Distribution of Shark Attacks

3.1.1 Spatial distribution

Plotting shark attacks globally revealed 4 major areas of concern: The west coast of the United States, the southeastern coast of the United States and Caribbean, South Africa and southern and eastern Australia north to Papua New Guinea. Minor concentrations of attacks were recorded in the Mediterranean Sea, Hawaii, and Southeast Asia (Figure 1).

Western Hemisphere shark attacks (N=1001) were distributed non-randomly. The highest concentration of shark attack, approximately 70%, occurred between 70-80° W and 80-90° W, containing the entire coastline of Florida, portions of the Caribbean Sea, and the Gulf of Mexico. The longitudinal range between 80-90° experienced by far the highest concentration of shark attacks (48%), with 20% of attacks occurring in the neighboring area, between, 70-80°. The west coast of the United States is located between 110-120° and 120-130°. This area combined for 13% of all Western Hemisphere shark attacks. Of the 19 longitudinal ranges, 12 had 2% or fewer shark attacks, with one range, 20-30°, having no shark attacks (Figure 2).

The Eastern Hemisphere recorded a total of 1271 shark attacks. The highest concentration of attacks (43%) occurred in Australia and Papua New Guinea (110-160° E). The largest portions of attack occurred in the 150-160°E and 140-150°E longitude range, with 23% and 15% respectively. Latitudinal ranges between, 10-40°S, spanning all of South Africa and the Mediterranean Sea, reported 34% of all attacks. Remaining ranges had fewer than 3% of all attacks each (Figure 2). All longitude results are available in Table 7.

Table 7. Frequency of shark attacks in Eastern and Western Hemisphere by longitude.

Frequency of Attacks				
Longitude (°)	**Eastern Hemisphere**	**Percent of Attacks**	**Western Hemisphere**	**Percent of Attacks**
0-10	5	0	6	1
10-20	107	8	6	1
20-30	167	13	0	0
30-40	165	13	18	2
40-50	36	3	6	1
50-60	12	1	2	0

60-70	4	0	22	2
70-80	7	1	197	20
80-90	14	1	481	48
90-100	4	0	49	5
100-110	8	1	3	0
110-120	60	5	43	4
120-130	50	4	89	9
130-140	70	6	1	0
140-150	192	15	8	1
150-160	294	23	58	6
160-170	31	2	1	0
170-180	43	3	10	1

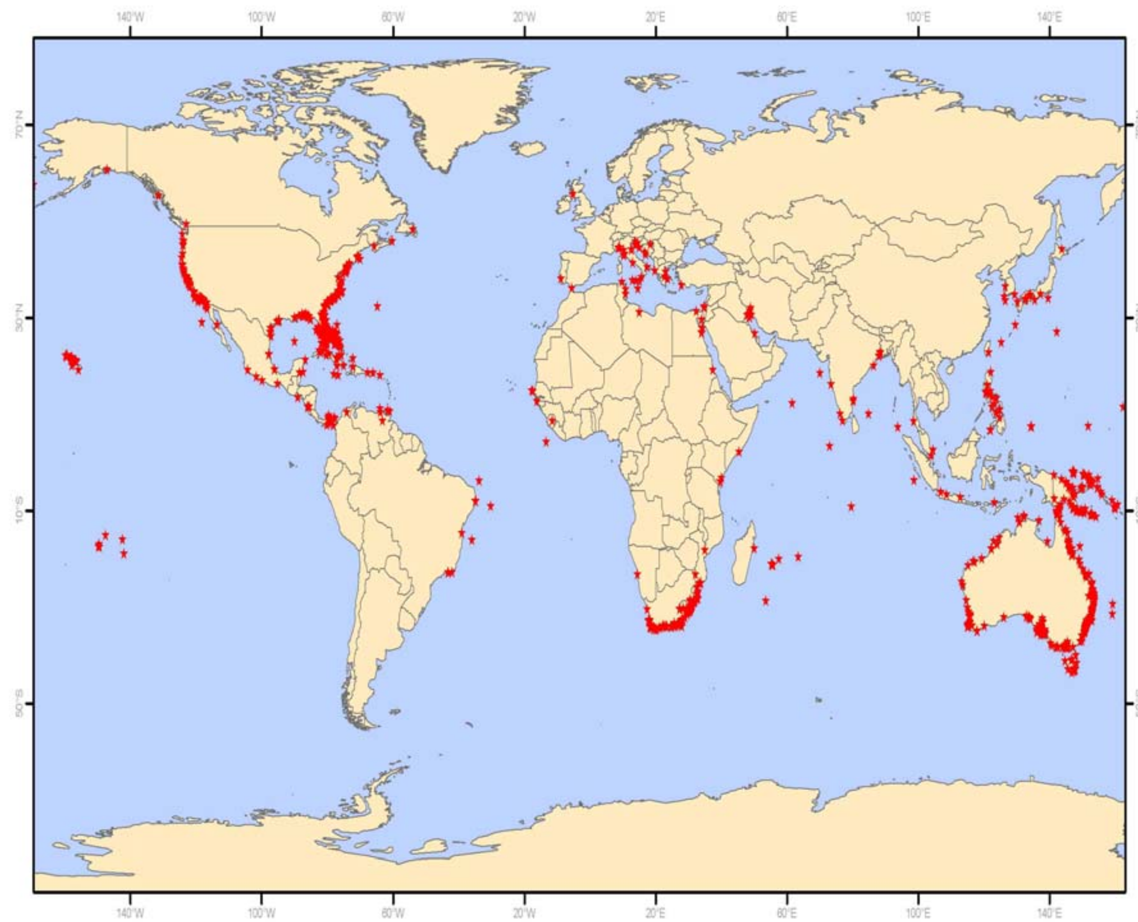

Figure 1. Global positioning of Shark Attacks.

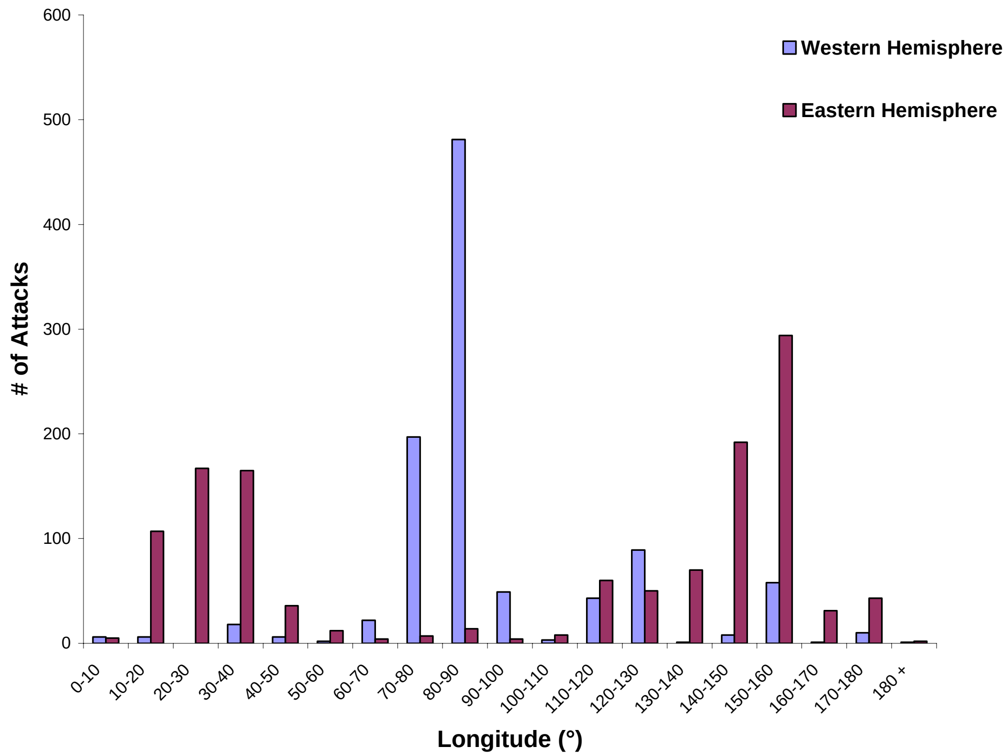

Figure 2. Eastern and Western shark attacks by longitude.

The Southern and Northern Hemispheres had the highest proportions of shark attacks occurring in tropical regions. The Southern Hemisphere (N=1126) had the majority of attacks, 54%, occur between 30-40°S with 606 attacks. The range with the second greatest attacks, 20-30°S, had 220 attacks. The remaining ranges had fewer then 51 attacks and combined for less then 5% of all Southern Hemisphere attacks (Figure 3). Latitude ranges with the highest frequencies of attack encompassed the entire country of South Africa and the majority of Australia's coastline. The Northern Hemisphere had 1151 shark attacks, with the majority, 50%, occurring between 20-30°N. The second highest range, 30-40°N contained the southwest coast of the USA, portions of the east coast of the USA and northern Africa, with 30% of attacks. The remaining ranges each had fewer than 95 attacks and, totaled, combined for 20% of all attacks (Figure 3).

Almost no attacks occurred above 50°N or S. All latitudinal results are available in Table 8.

Table 8. Frequency of shark attacks in Southern and Northern Hemisphere by latitude.

	Frequency of Attacks			
Latitude (°)	Northern Hemisphere	Percent of Attacks	Southern Hemisphere	Percent of Attacks
0-10	46	4	120	11
10-20	95	8	128	11
20-30	578	50	220	20
30-40	345	30	606	54
40-50	81	7	51	5
50+	6	1	1	0

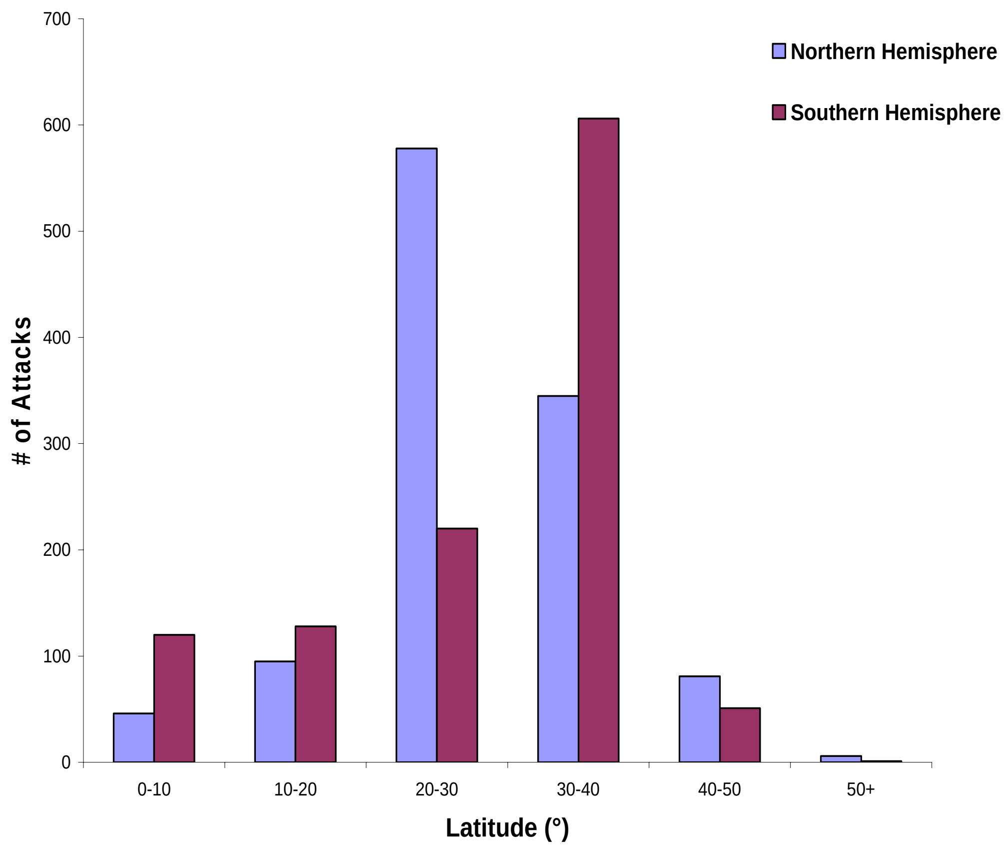

Figure 3. Northern and Southern Hemisphere shark attacks by latitude.

3.1.2 Temporal distribution

The temporal distribution of attacks was also markedly non-random, peaking in the summer and being lowest in winter. The Southern Hemisphere had the greatest number of attacks during the month of January (N=191). August had the fewest shark attacks with 29 (Figure 4). The greatest occurrence of shark attacks occurred during the summer months (N=462). Spring months combined for 278 attacks, fall, 169 and winter, 109 (Figure 5). The Northern Hemisphere had the greatest number of shark attacks during July (N=188). January had the lowest frequency of occurrence with 21 (Figure 6). Summer months combined for the highest number of attacks (N=462), spring had 278, fall, 169 and winter had the least amount of shark attacks with 109 (Figure 7).

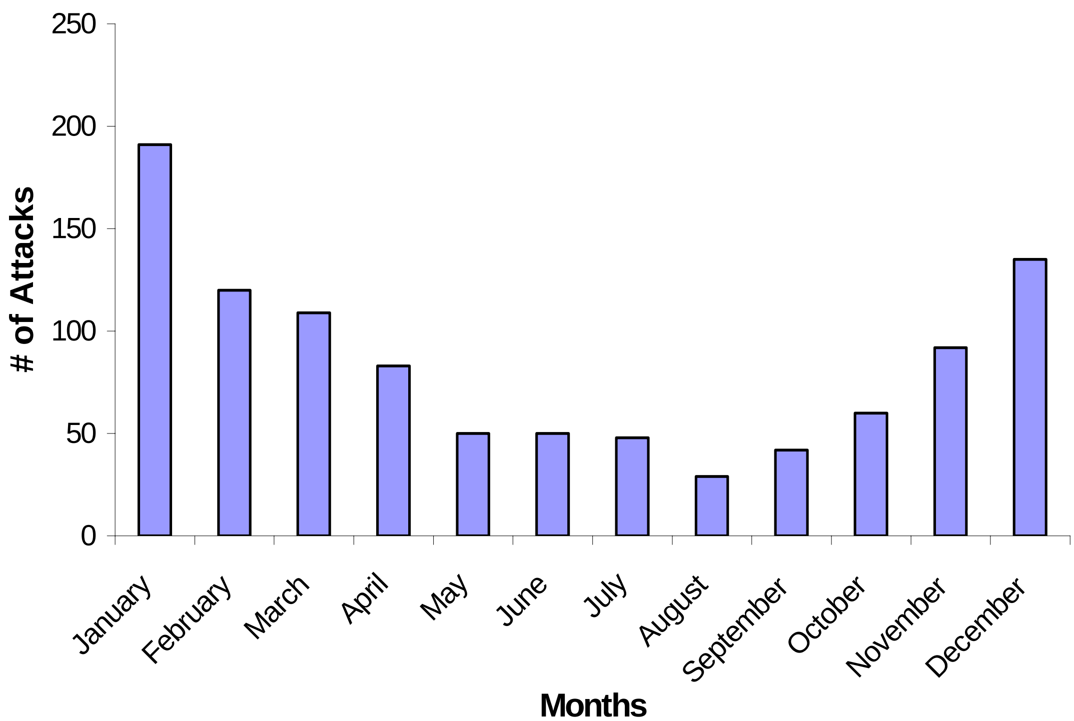

Figure 4. Southern Hemisphere attacks by month.

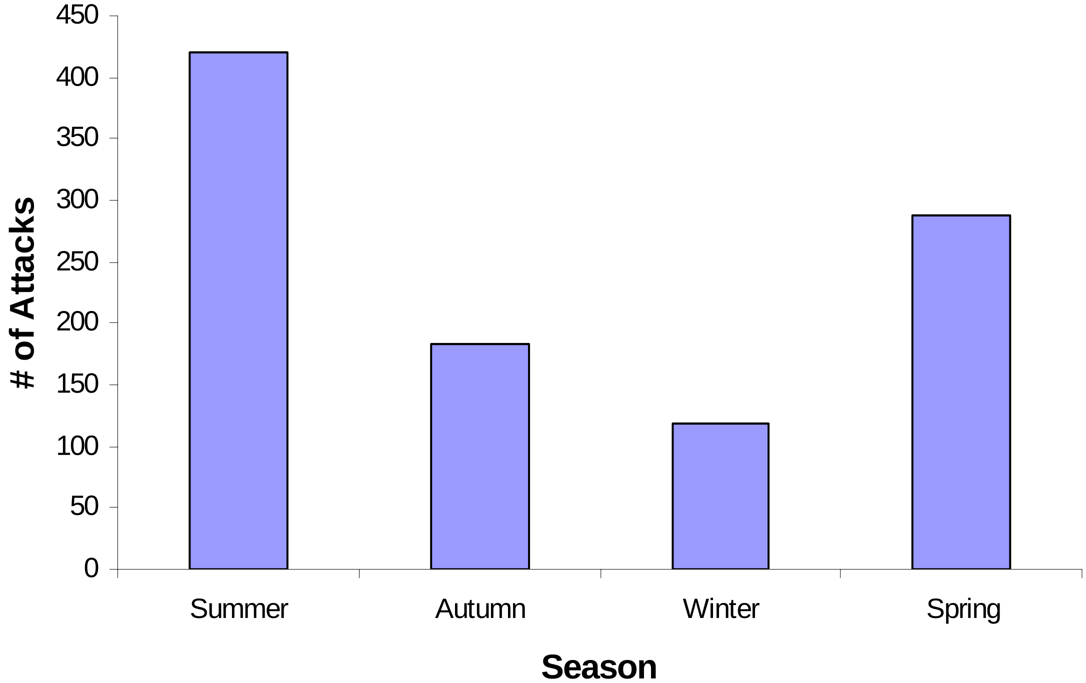

Figure 5. Southern Hemisphere shark attacks by season.

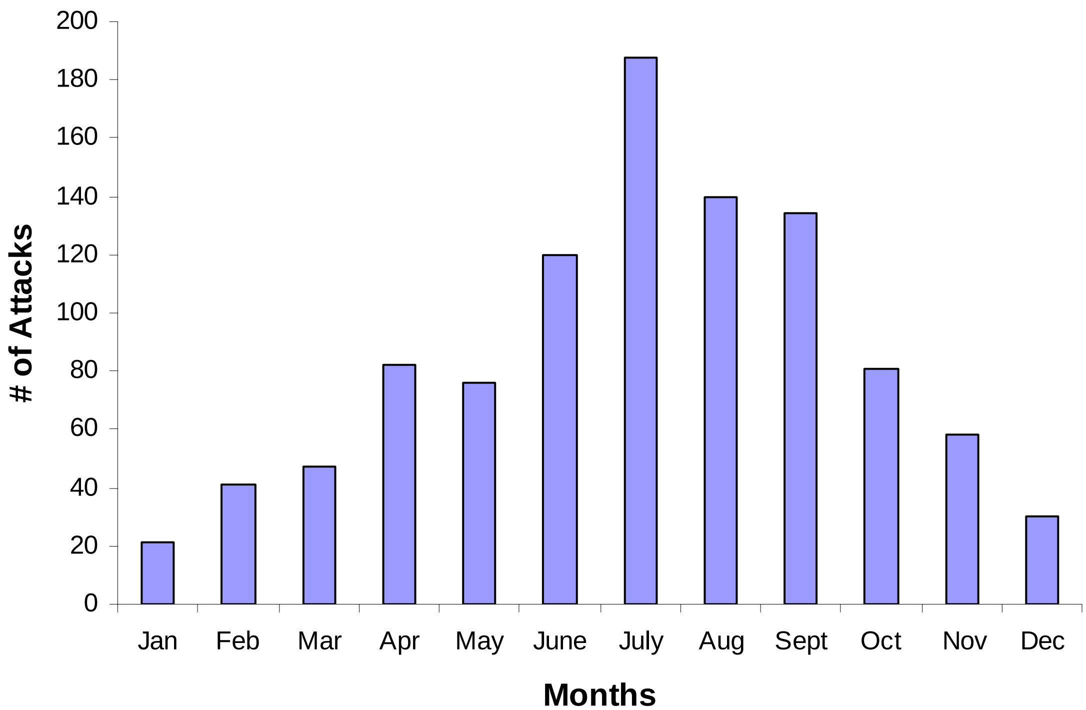

Figure 6. Northern Hemisphere shark attacks by month.

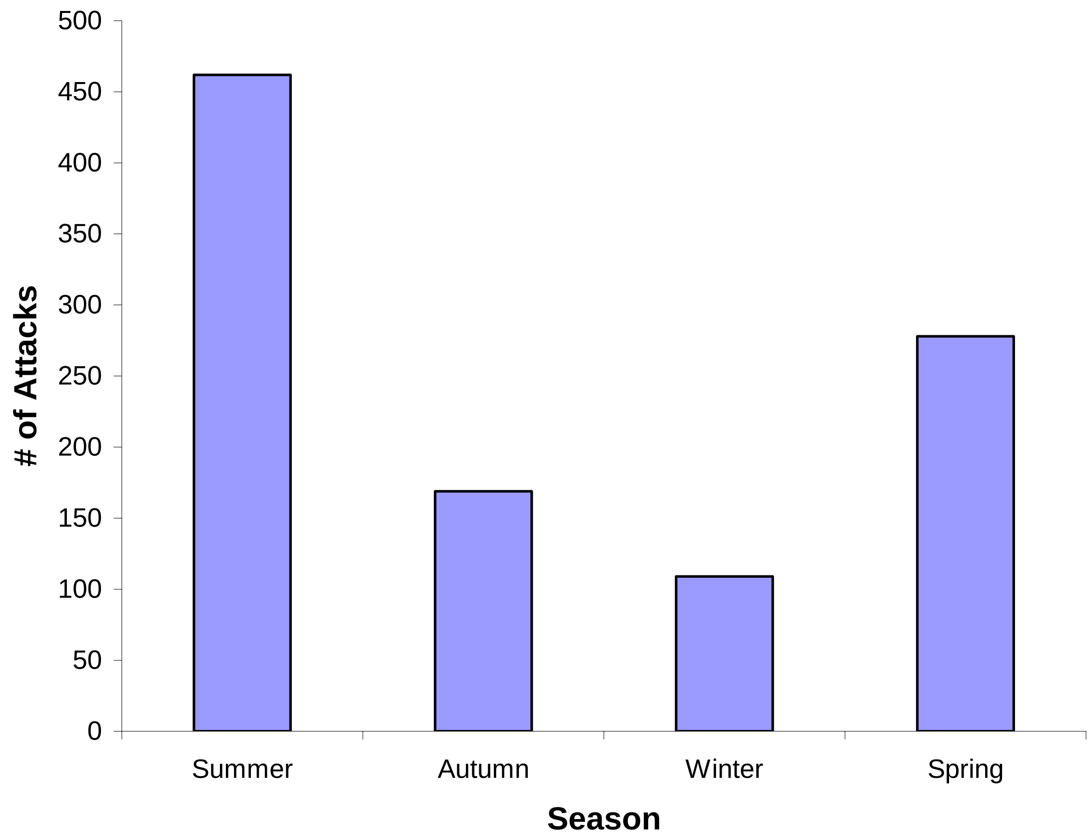

Figure 7. Northern Hemisphere shark attacks by season.

With respect to time of day, attacks in the Southern Hemisphere occurred most frequently in the late afternoon, between 16h00-16h59 (N= 58). At night there were very few attacks; only 9 occurring between 23h00 – 06h00. Daytime attacks were skewed towards late afternoon, containing 55% of shark attacks, compared to 34% in the morning (Figure 8). In the Northern Hemisphere a very similar pattern emerged, but attacks peaked somewhat earlier then the Southern Hemisphere, between 14h00-14h59 with 69 attacks, (Figure 9). The majority of shark attacks, 51%, occurred in the afternoon, while only 37% occurred in the morning hours, 06h00-12h59.

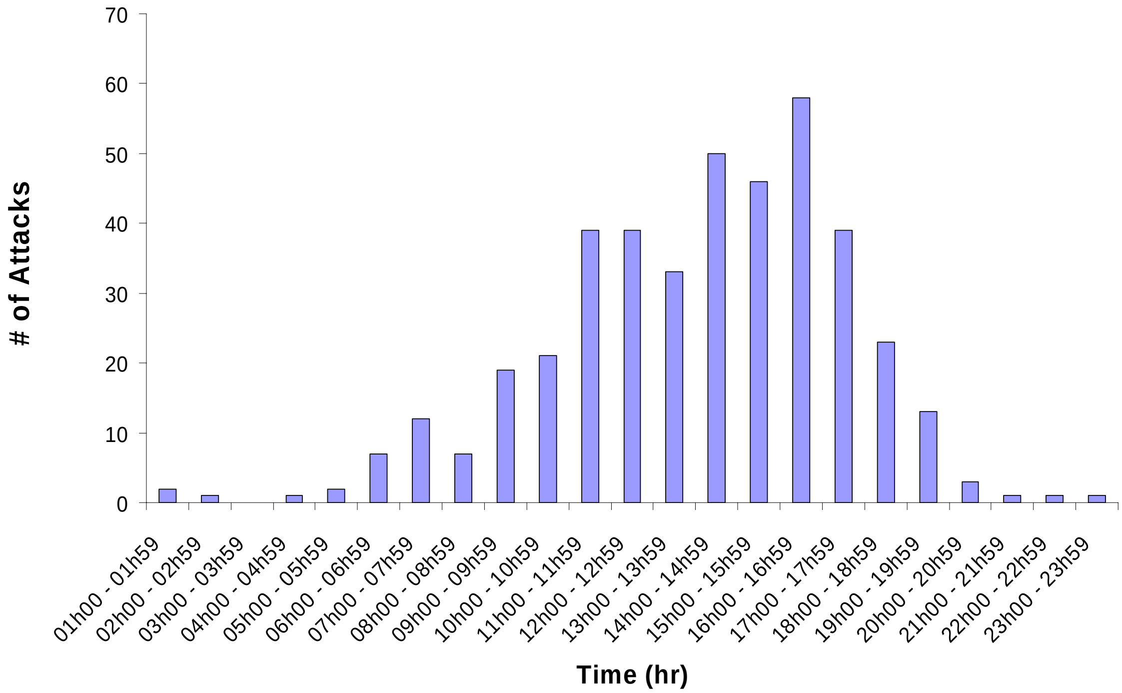

Figure 8. Southern Hemisphere shark attacks by time.

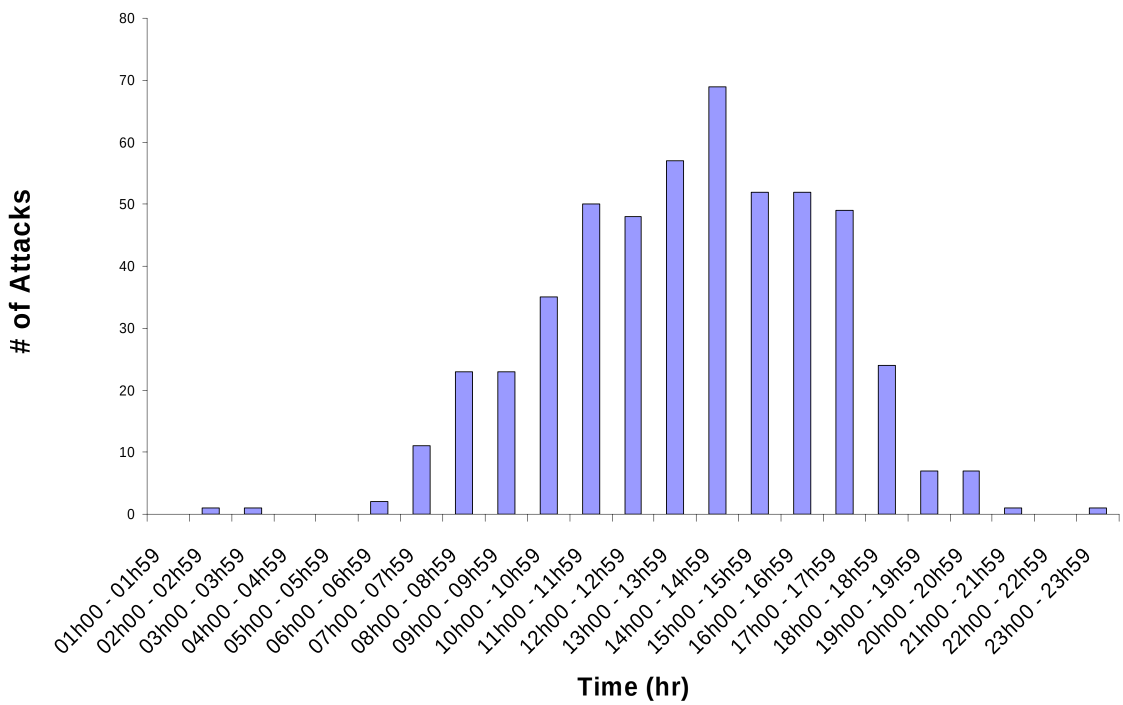

Figure 9. Northern Hemisphere shark attacks by time.

3.2 Characteristics of shark attack victims

Age class plotted against frequency of attacks follows a positively skewed distribution. The peak number of shark attacks occurred on 15-19 year olds with 416 attacks. Age classes older then 15-19 showed a steady decline in shark attacks. The youngest age class, 0-4, had 6 shark attacks, the lowest for any age class (Figure 10).

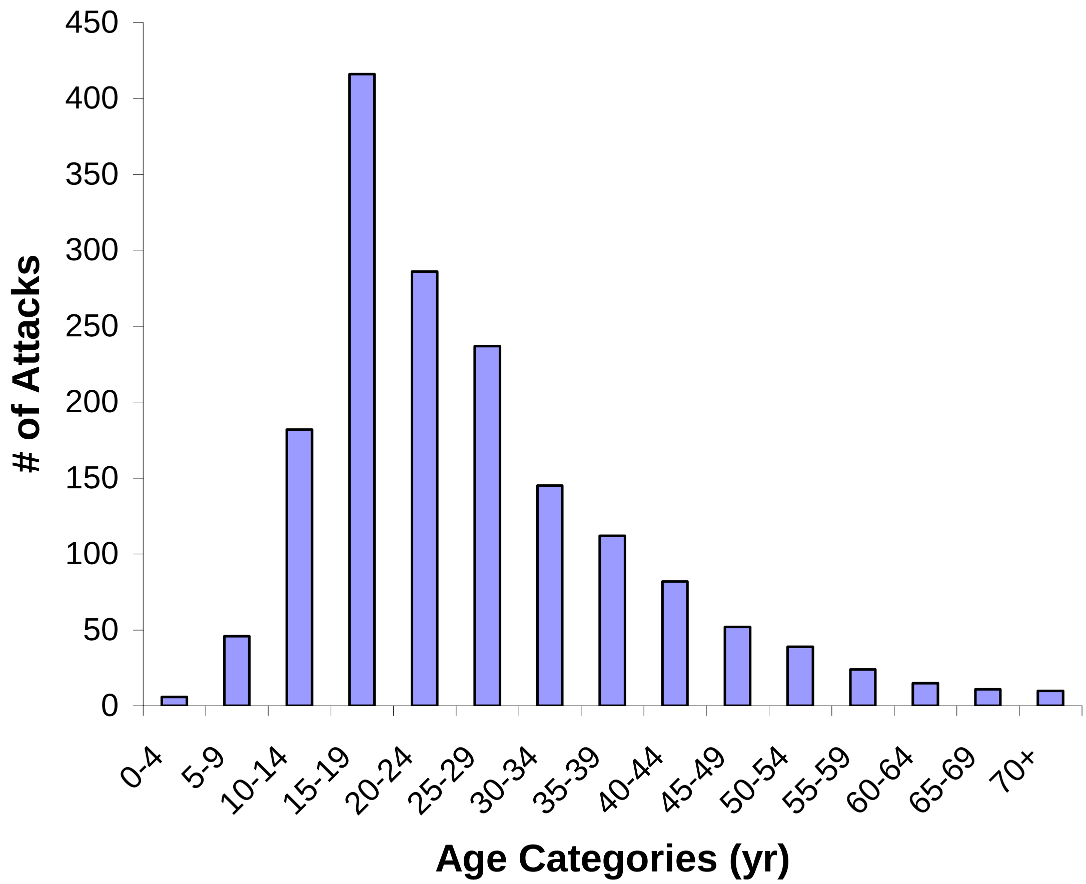

Figure 10. Global shark attacks by Age

Ratios of Fatal to Non-fatal attacks for age classes revealed that infants and small children, 0-4 years of age, had the highest risk of fatality with a ratio of 1.00, or 100% fatal attacks (N=5). Older victims above the age of 55, excluding the 60-64 age class had also higher fatal to non-fatal ratios. Victims between 5-54 years showed no trend, fatality ranged from 0.19 to 0.37 (Figure 11).

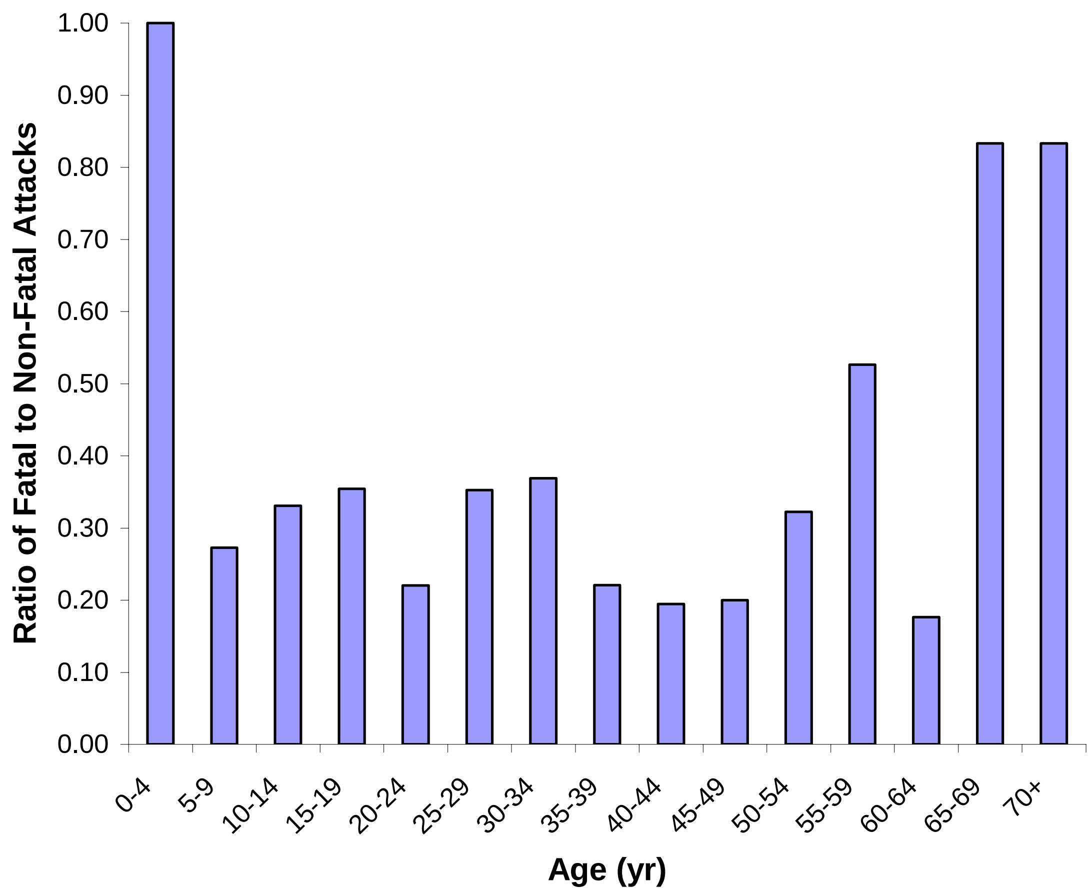

Figure 11. Ratio of Fatal to Non-fatal attacks by age class.

Among activities of the victim, swimming activities had the highest number of shark attacks with 729. Fishing activities had the second highest number of attacks with 569 and surfing activities followed with 564 (Figure 12). However, attacks per million participants over the last 5 years in the USA (the only region where I could find reliable marine recreation demographic data) showed surfing had by far the highest relative risk with 6.376 attacks per million. Remaining activities had much smaller attack ratios of under 0.3 each (Table 9).

Table 9. Attacks per million participants over the last 5 years in the USA.

Activity	# of Attacks	# of Participants (millions)	Attack per million
Surfing	139	21.8	6.376
Swimming	52	333.7	0.156
Fishing	14	113	0.124
Diving	4	14.95	0.268
Boating	1	170.1	0.006

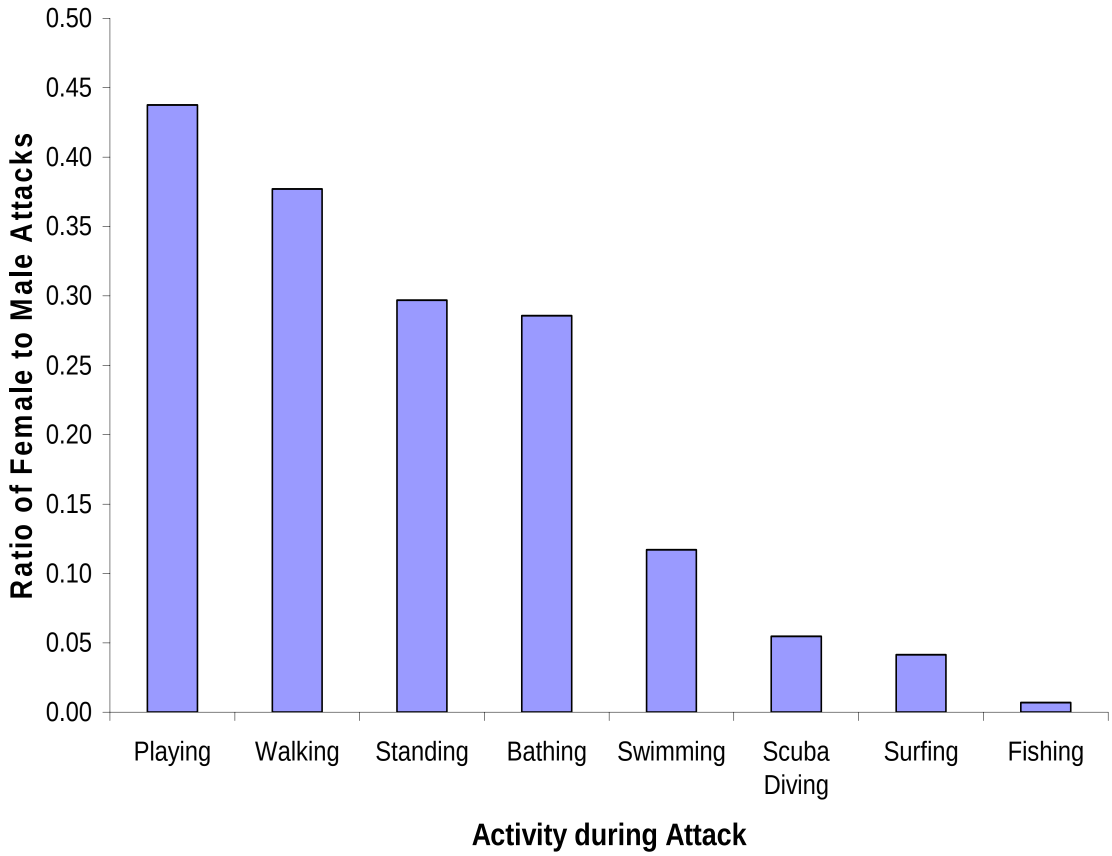

Figure 12. Number of attacks according to activity during attack.

Analysis of people's activities in the area of attack revealed that fishing promoted the highest frequency of shark attacks with 202 and boating second with 119 (Figure 13). Breakdown of fishing in the area of attack into minor categories revealed that invertebrate fishing coincided with the highest number of shark attacks with 85. Collecting and carrying dead fish resulted in 45 attacks, fishing 42 attacks, shark-fishing 24, spear fishing 4 and surf fishing 2 (Figure 14). Boating was broken down into 3 categories. Large Boats resulted in 48 attacks, boating had 40 attacks, and shipwrecked had 31 attacks (Figure 15).

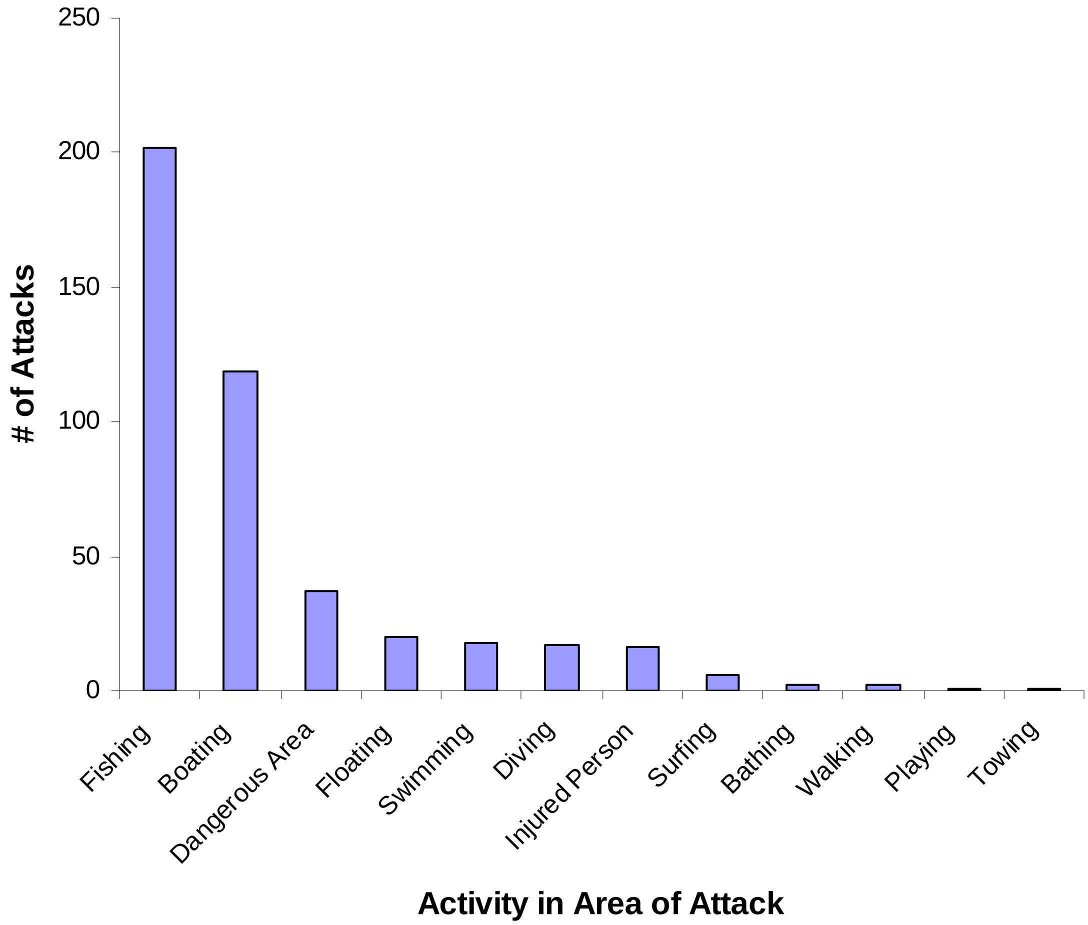

Figure 13. Number of shark attacks according to activity in area of attack.

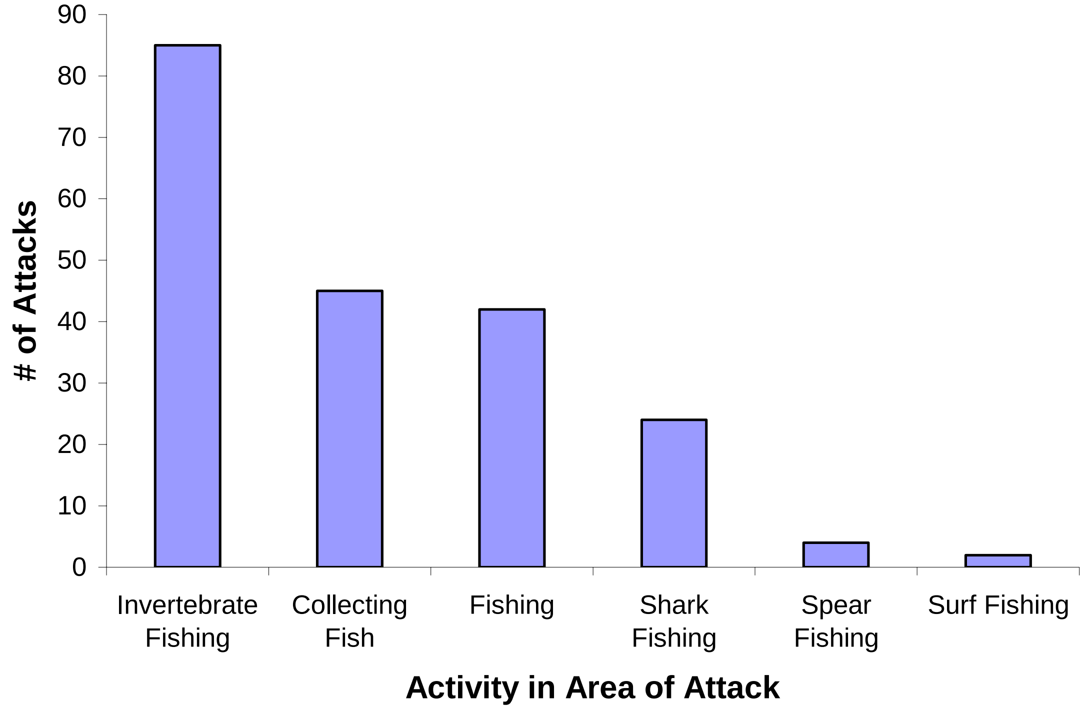

Figure 14. Number of shark attacks according to fishing related activities in the area of attack.

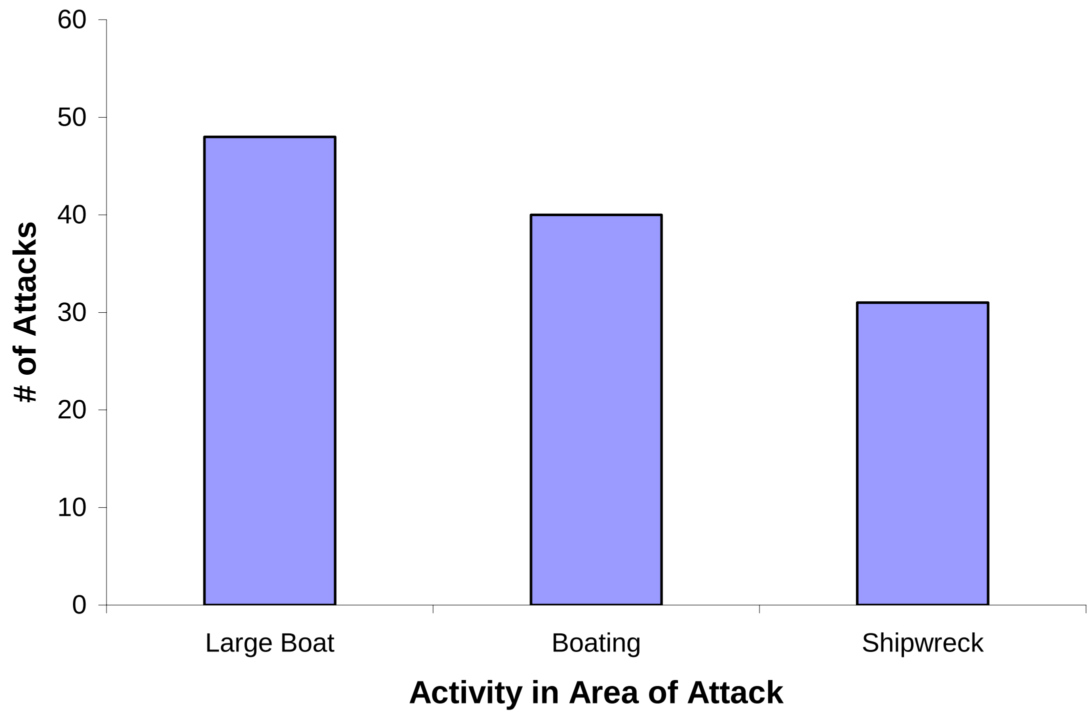

Figure 15. Number of shark attacks according to boating related activities in the area of attack.

Analysis of gender related attacks revealed a surprisingly skewed ratio with 1 attack on females for every 100 attacks on males. Individual ratios for activities during attack were highest for playing with a ratio of 0.44. Activities associated with higher frequency of attacks resulted in low ratios. Surfing, fishing, swimming and scuba diving all had ratios under 0.12 (Figure 16).

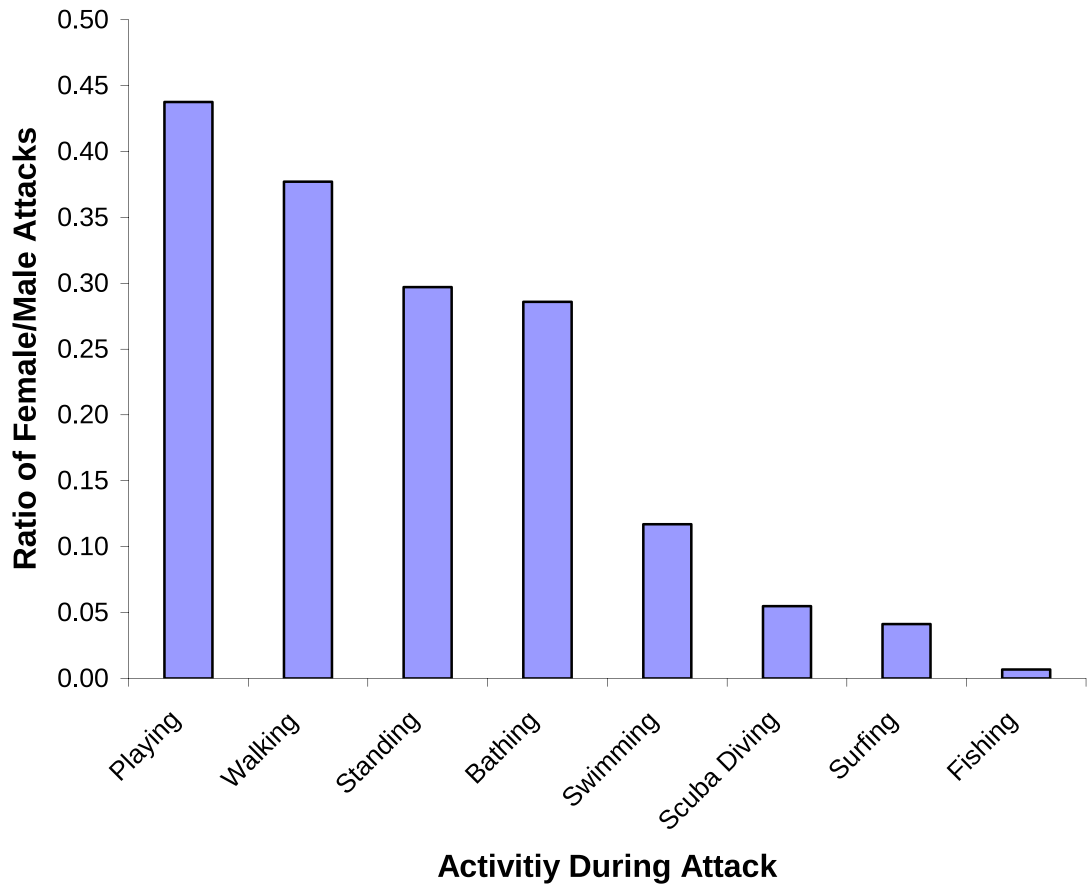

Figure 16. Ratio of fatal to non-fatal shark attacks according to activity during attack.

3.3 Characteristics of attacking sharks

There were at least 29 different species of shark reported to have attacked humans. Great White sharks had the highest occurrence of attacks with 391 (90 fatal, 244 non-fatal, F/N ratio of 0.37) with an average injury score of 1.61. The Tiger shark attacked with less frequency compared to the Great White, but had a higher average injury and fatality ratio (39 fatal, 70 non-fatal, F/N ratio of 0.56) and the highest average injury score of 1.86. The top 10 species of shark in terms of number of attacks are recorded in Table 10.

Table 10. Average Injury, # of fatal and non-fatal attacks, and the ratio of Fatal/Non-fatal for the species of shark with the 10 highest number of shark attacks.

Species	Average	Total # of Attacks	# Of Fatal Attack	# Of Non-Fatal Attacks	Ratio of F/N
Tiger Shark	1.86	109	39	70	0.56
Great White Shark	1.61	334	90	244	0.37
Bull Shark	1.61	83	16	67	0.24
Mako Shark	1.38	29	5	24	0.21
Nurse Shark	1.22	27	0	27	0.00
Blacktip Shark	1.13	23	0	23	0.00
Wobbegong	1.09	22	0	22	0.00
Gray Nurse Shark	0.94	69	1	68	0.01
Hammerhead Sharks	0.92	24	0	24	0.00
Bronze Whaler	0.76	33	1	32	0.03

I tested the hypothesis that larger sharks are more likely to inflict serious injuries. Regression analysis on the size of the attacking shark against injury was performed for the Great White, Tiger, Bull and Mako Shark. These tests resulted in weak correlations throughout, indicating no general relationship between size and injury (Figures 17-21). The Great White had a sample size of N=254 shark attacks with reported shark length and injury. The regression analysis revealed no significant correlation between White shark length and the injury inflicted during an attack (R^2= 0.0004, P=0.75). Similarly, the Tiger (R^2= 0.03, P=0.15, N=67), and Mako shark (R^2= 0.08, P=0.23, N=22) showed no such relationship. The Bull shark (R^2=0.141, P=0.048, N=28) however, showed a marginally significant trend towards more serious injuries with increasing shark size (Figure 22). No correlation was seen between the weight of an attacking shark (all species were pooled) and the average injury of the victim (R^2 of 0.01, N=56) (Figure 23).

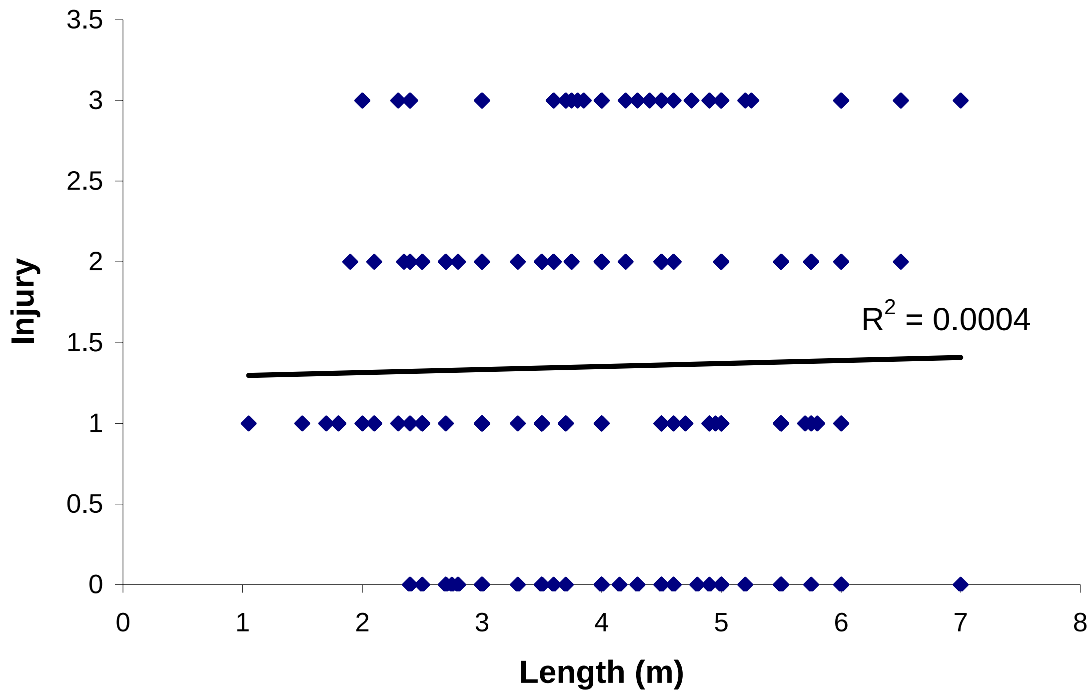

Figure 17. Scatterplot of Great white shark length vs. the injury inflicted during attack.

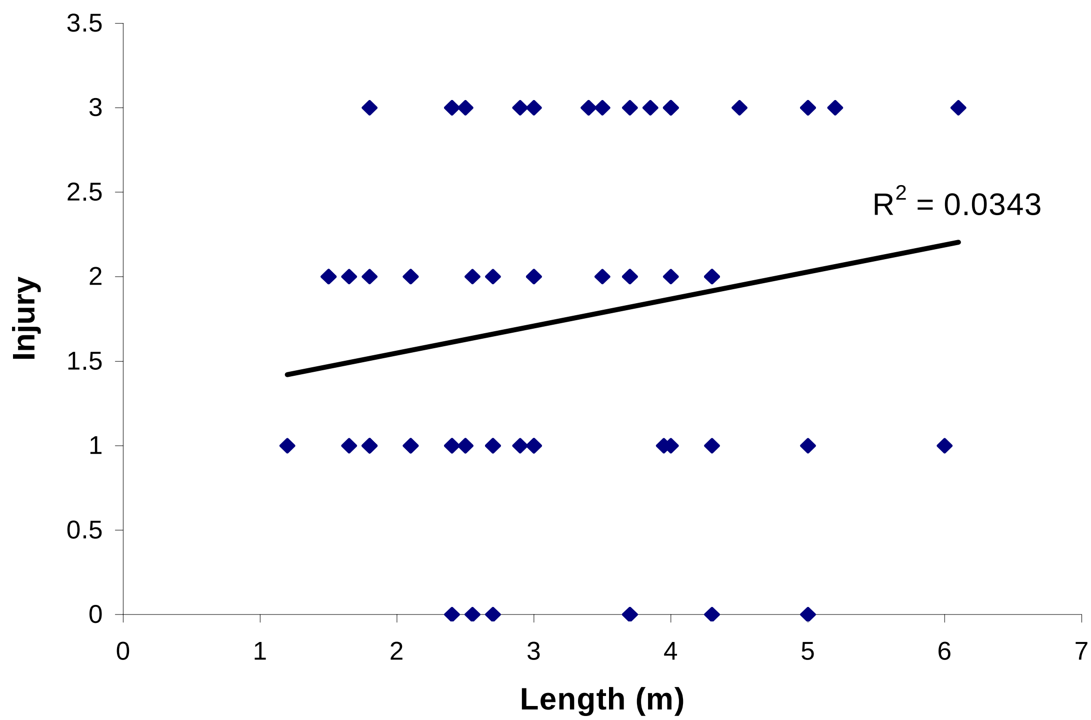

Figure 18. Scatterplot of Tiger shark length vs. the injury inflicted during attack.

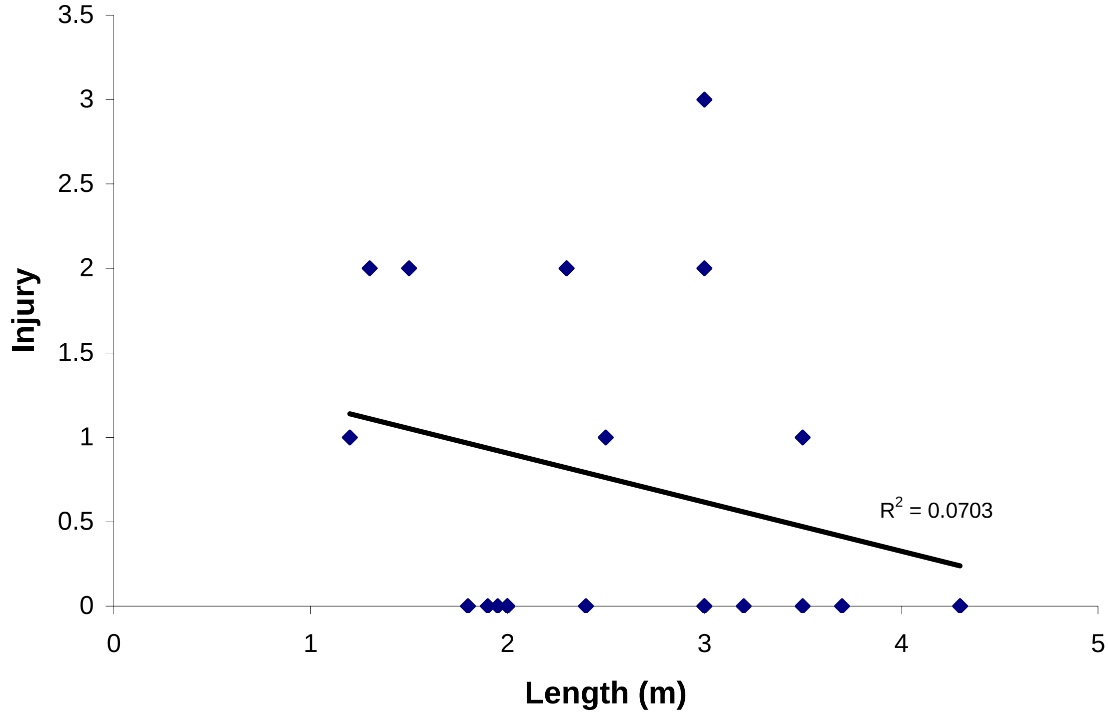

Figure 19. Scatterplot of Mako shark length vs. the injury inflicted during attack.

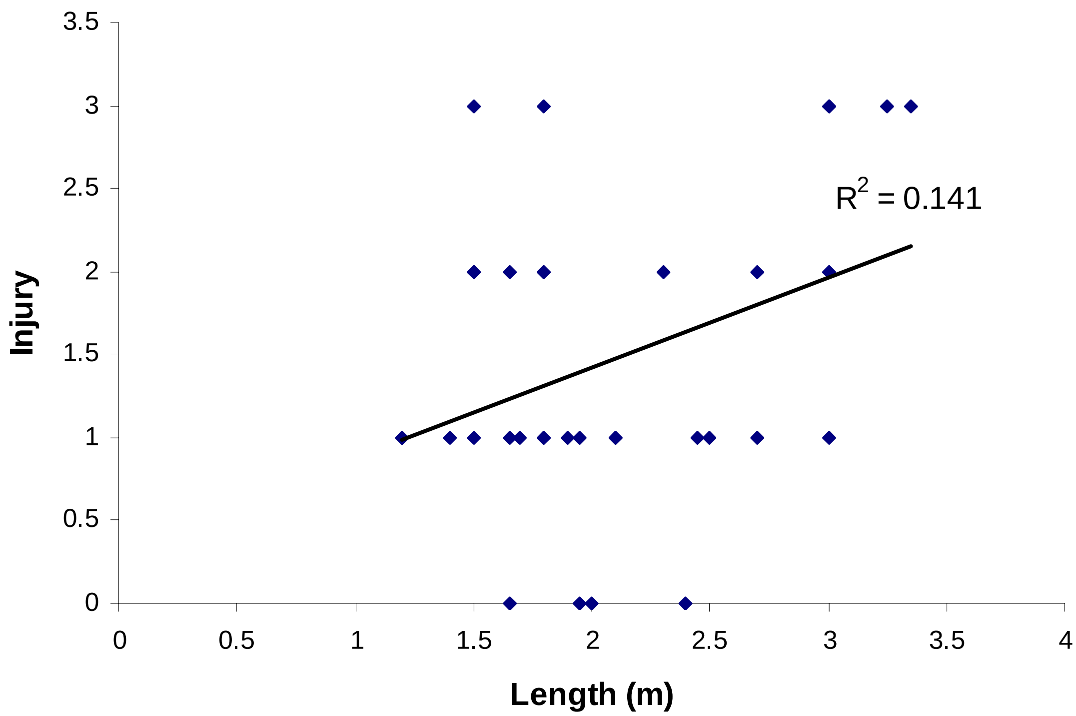

Figure 20. Scatterplot of Bull shark length vs. the injury inflicted during attack.

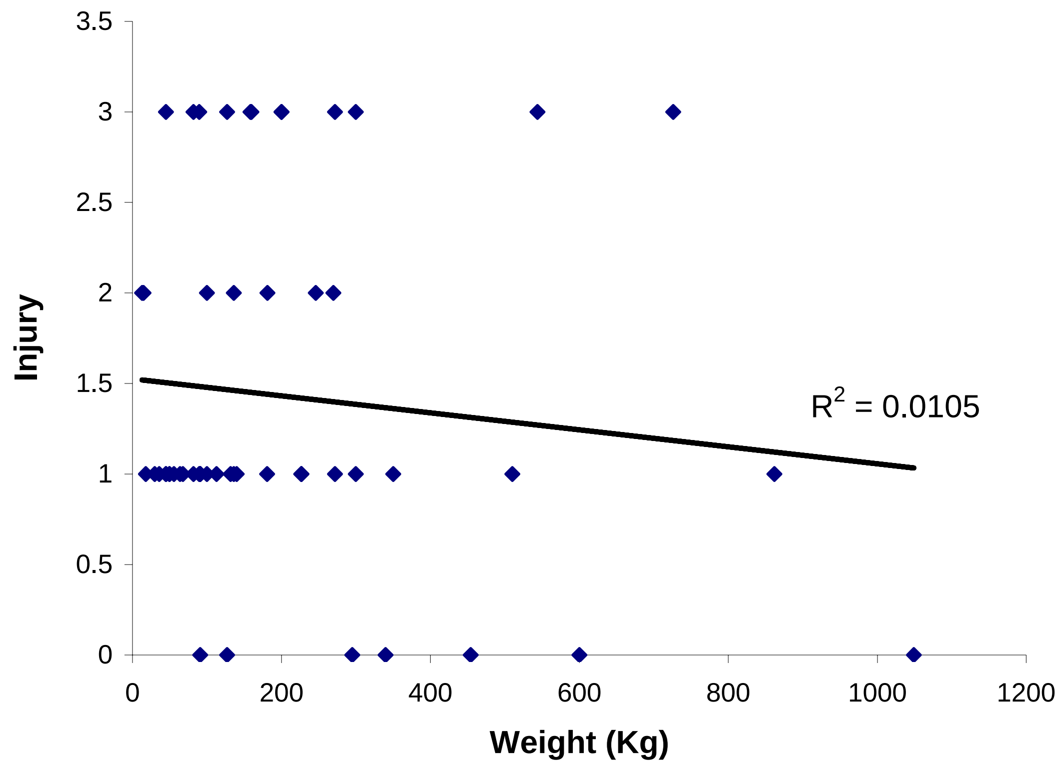

Figure 21. Scatter plot of weight of attacking shark against the injury inflicted during attack.

The Great White had four areas of concentrated attack: the west coast of the USA, the Mediterranean Sea, South Africa and Southern Australia (Figure 22). Results of Great White shark attacks by latitude mirrored these results. The White shark attacked most frequently in the 30-40°S range for both Southern and Northern Hemispheres. In the Southern Hemisphere this mostly concerned South Africa and Southern Australia. In the Northern Hemisphere the west coast of the USA and the southern half of the Mediterranean Seas fall within the 30-40°N range (Figure 23). There is a smaller, but significant concentration of attacks between 40-50°N in the Northern Hemisphere, mostly in the Northern Mediterranean (Figure 24).

Tiger sharks attacked most frequently in 20-30°, 21 attacks or 75% of all Southern Hemisphere Tiger shark attacks, with few attacks occurring in the remaining areas (Figure 24). In the Northern Hemisphere, most Tiger shark attacks occurred between 10-20° (N=13). The second highest range was 20-30° with 11 shark attacks. The remaining areas had few to no shark attacks (Figure 23). Global plotting of Tiger sharks agreed with these results. The coast of northeastern Australia and Florida showed the highest concentration of reported Tiger shark attacks (Figure 22).

The Bull shark had attacked most frequently on the coast of Florida and on the east coast of South Africa (Figure 22). Analysis of attack by latitude depicted the bulk shark attacks concentrating between 30-40° in the Northern Hemisphere with 17 and 20-30° with 15. The remaining ranges had fewer then 2 attacks each, no bull shark attacks occurred north of 50° (Figure 23). Bull shark attacks in the Southern Hemisphere occurred in the 20-30° range with 19 attacks. The remaining ranges had 4 or less Bull shark attacks each, with no attacks occurring south of 40° (Figure 24).

The Gray Nurse shark had only 15% of attacks reported in the Northern Hemisphere, with approximately 90% of the 9 attacks occurring between 30-40°. The only other attack occurred between 20-30° (Figure 23). Northern Hemisphere attacks were isolated in the Western Hemisphere, with all attacks happening on the East coast of the USA. The Southern Hemisphere experienced 84% of nurse shark attacks, 45, in the 30-40° range. The remaining ranges had <16% of attacks each, with 0-10°, 10-20°, and 50°+ having 0 shark attacks. The Gray Nurse shark attacked only 10 times outside the 30-40° range (Figure 24). South Africa had the only concentrated area of attack; the east coast of the USA and Australia showed smaller concentrations of attack (Figure 22).

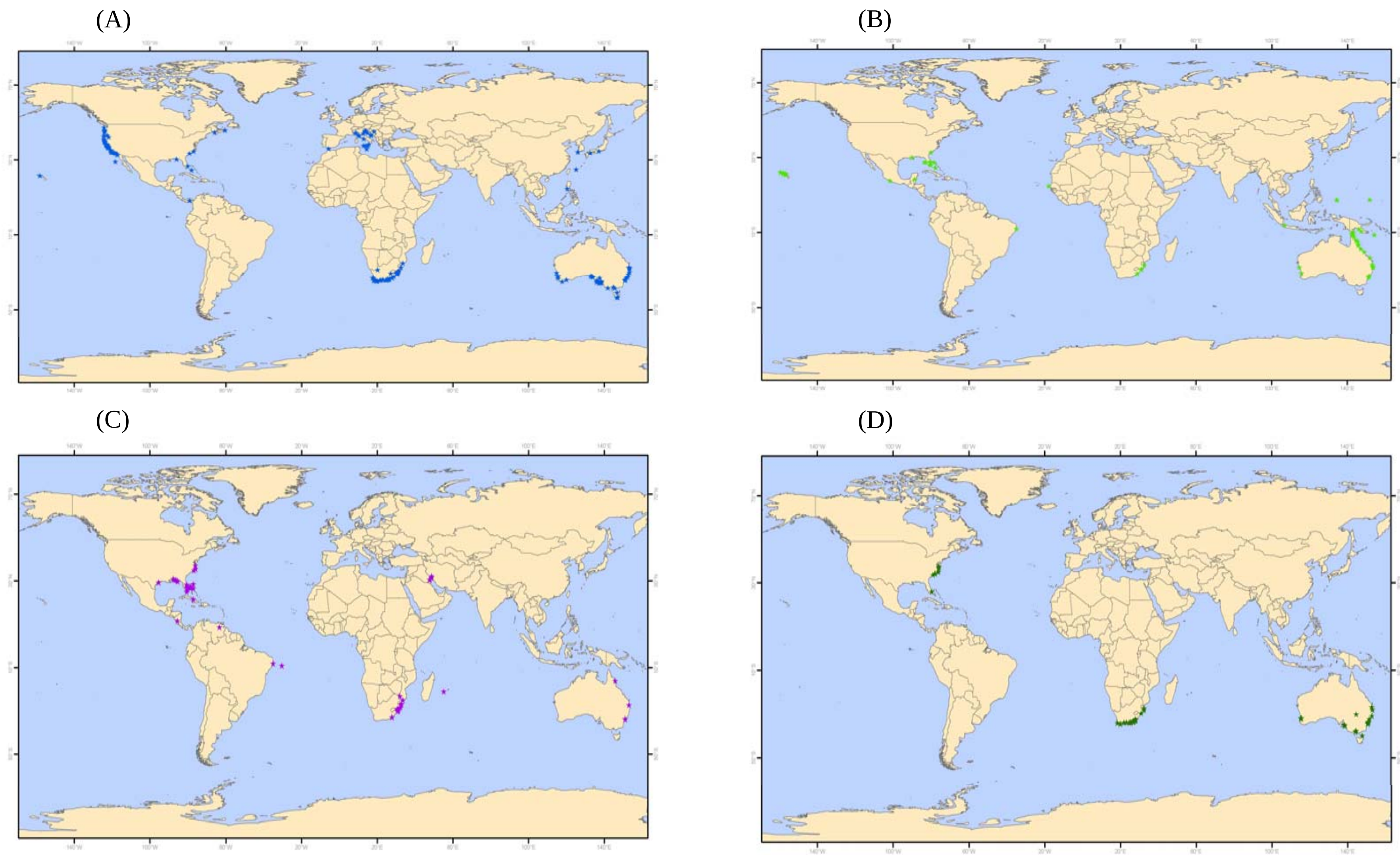

Figure 22. Global Distribution of (A) Great White, (B), Tiger, (C) Bull, and (D) Gray Nurse Shark attacks

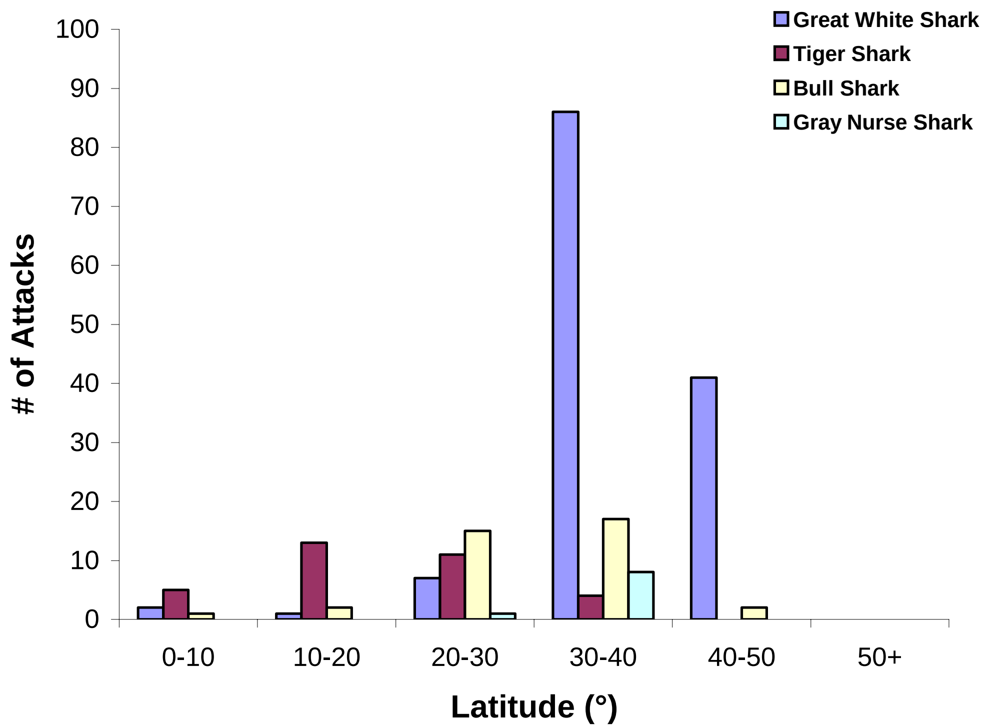

Figure 23. Sharks with the 4 greatest global number of shark attacks by latitude in the Southern Hemisphere.

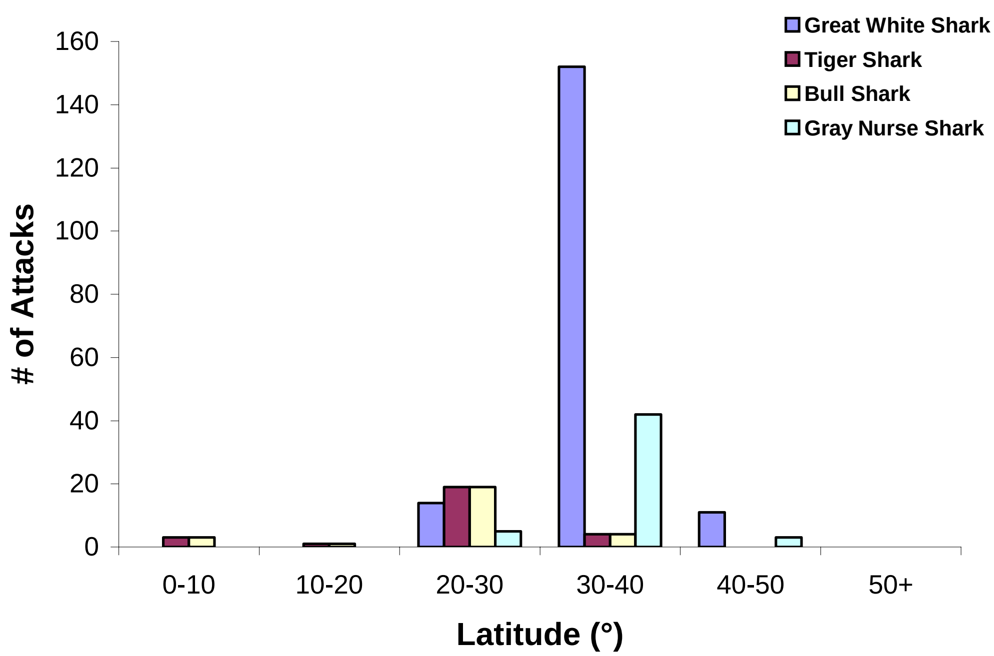

Figure 24. Sharks with the 4 greatest global number of shark attacks by latitude in the Southern Hemisphere.

The Great White shark was the only species with a large enough sample size, which could provide accurate information regarding attacks by month in the Northern and Southern Hemisphere on surfers and swimmers. The Northern Hemisphere had peak attacks on surfers in October and September, with the fewest attacks occurring in July and May. The Southern Hemisphere experienced the greatest number of attacks in the winter months, with the fewest attack occurring in January, March and November. July had the lowest number of attacks (Figure 25). Swimming related attacks in both Northern and Southern Hemispheres had expected attack distributions, based on people's preference to swim in the warm season. Both Hemispheres had higher attack frequencies in summer months and fewer attacks in the winter. Peak attacks occurred in November and February for the Southern Hemisphere and March and July for the Northern Hemisphere (Figure 26).

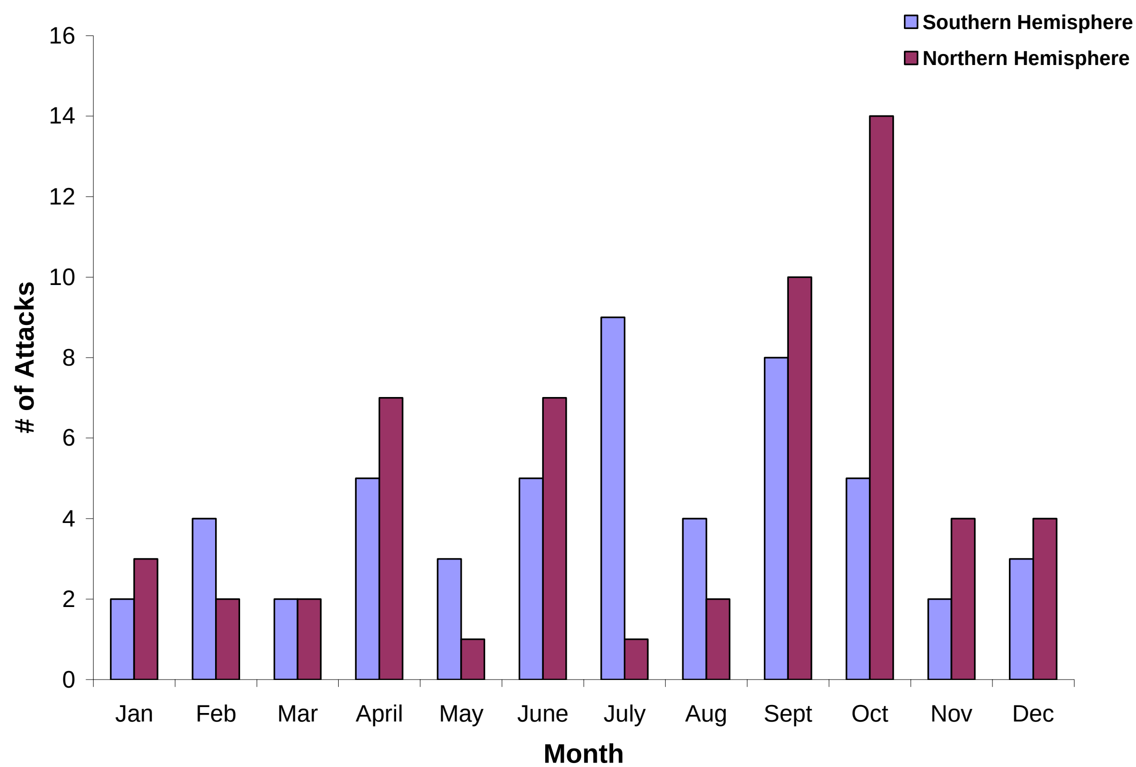

Figure 25. Great White attacks on surfers by month in the Northern and Southern Hemispheres.

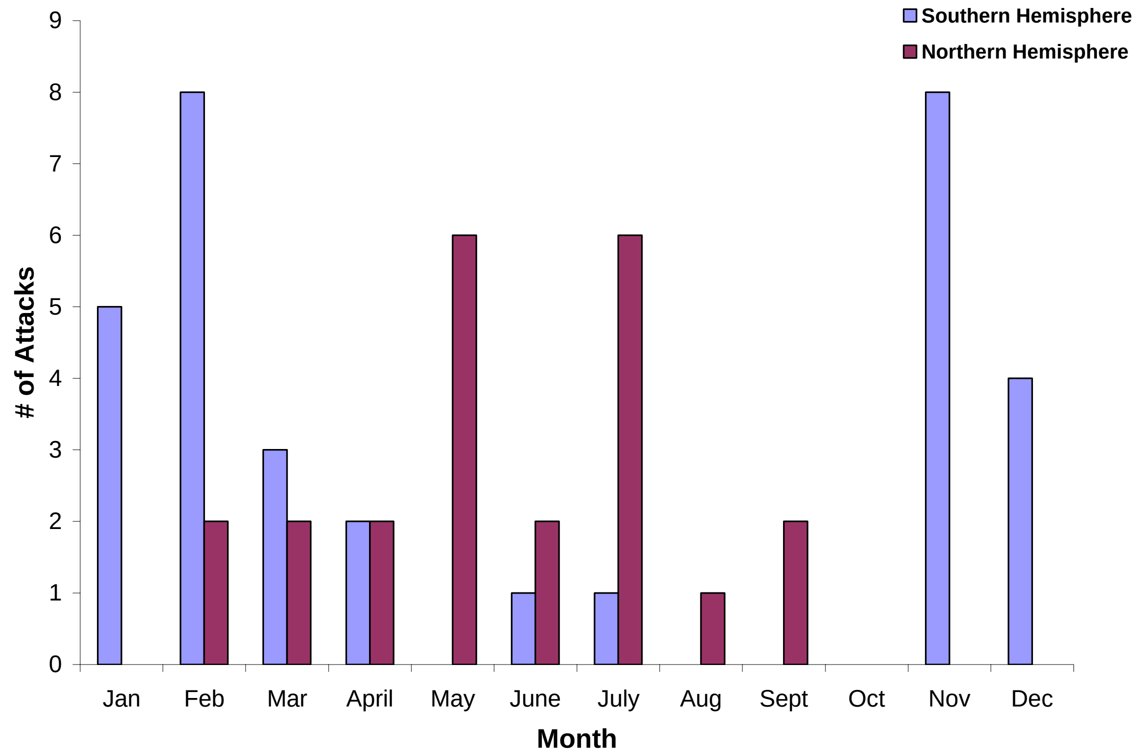

Figure 26. Great White attacks on swimmers by month in the Northern and Southern Hemispheres

4.0 Discussion

The goal of this thesis was to discuss behavioral and environmental risks associated with shark attacks. I analyzed over 3000 shark attacks worldwide and found the majority of attacks were linked to marine recreation participation rates. That is, shark attacks are proportional to the number of people using the ocean. Shark attacks are more attributed to incidental encounters, much like a hiker startles a bear, then sharks actively seeking humans as prey. Only the largest of the predatory fish, the Great White, is suspected of attacking humans under the false assumption they are pinniped prey. Quantitative results to support this theory are discussed. I derived 10 simple behavioral rules that should help swimmers, surfers and divers to minimize the risk of a shark attack.

4.1. General patterns

Analysis of age, gender, daytime and seasonal results suggested that shark attack trends are proportional to marine participation rates. Variation in shark attacks according to gender, age, season and daytime are associated with the variation in marine recreation demographic patterns. For example, assuming males and females use the ocean at a 1:1 ratio, it would be expected that half the attacks would occur on males. However, males are attacked 100 times more often then females, suggesting some factor situates males at a higher risks. Marine recreation demographics illustrate a higher male participation rate, particularly in high-risk activities, such as surfing (Leeworthy 2000, Leeworthy *et al.* 2005). Consequently, males have a higher probability of being attacked, correlating with the observed higher shark attack frequency depicted in the results. Activities such as walking and playing have more equal female to male attack ratios because there is a more even distribution of females and males participating. Surfing, diving and fishing are comprised largely of male participants and as a result the ratio of gender related attacks is very low (Leeworthy 2000, Leeworthy *et al.* 2005).

Seasonality results illustrated similar findings as gender related attacks. Northern and Southern Hemisphere shark attacks were highest during summer months and lowest in winter. Summer months have higher participation rates, mainly because warm weather encourages people to use the ocean. However, in winter months, weather limits some marine recreation activities. Basically, more people are in the water during summer months, increasingly the probability of shark attack.

The proposed hypothesis that shark attacks occur proportionally to the number of people participating in marine recreation did not appear to accurately describe daytime shark attacks. It was assumed that people would use the beach in an approximately normal distribution over the course of a day, with equal attacks occurring in the morning and afternoon. However, results showed both Northern and Southern Hemispheres had the majority of attacks occurring in the afternoon. This was highly unexpected, if anything more attacks in the morning would be expected. For example, the Great White commonly hunts pinniped in the morning hours, with reduced frequency at later daytimes (Martin *et al.* 2005). However, since people do not usually recreate at dusk, but are more likely to stay in the water until late afternoon, this could explain a high rate of encounters at that time. It is possible the assumption of normality was inaccurate and that larger proportions of people use the beach in the afternoon. However, without any daily participation data this cannot be resolved. Until this is available, it is assumed that there is a higher risk of being attacked in the afternoon.

With respect to age of victim, the majority of attacks occurred on 15-19 year olds; with decreasing incidents of attack for older and younger age classes. One possibility is sharks selectively attack teenagers. However, at 15-19 years of age, teenagers have negligible differences from adults in shape and size. Although this is untested, sharks ability to distinguish between younger and older individuals is assumed to be limited, making active selection on the basis of age unlikely. More probable is sharks attack all age classes equally and variances in attacks by age are related to the proportional differences in marine recreation participation. Young adults between the ages of 16-24 have higher participation rates, particularly in activities with higher risk of attack, such as surfing (Leeworthy 2000, Leeworthy *et al.* 2005). Over the last 5 years in the USA, surfing had by far the highest attack rate per million participants. The same pattern was observed for diving, which in the USA had the second highest risk of shark attack over the last 5 years. Conversely, older, 55 + years and younger individuals, 0-9 years, have lower participation rates decreasing the amount of time spent in the ocean, and ultimately the probability of shark attack. Both younger and older generations also have low participation rates in high-risk activities, and tend to engage in low risk activities such as swimming (Leeworthy 2000, Leeworthy *et al.* 2005). Observed high frequencies of attack on 15-19 years can likely be attributed to higher marine participation rates in high-risk activities. Steady declines in frequencies of attack on younger and older individuals are indicative of their increasingly lower marine participation rates in high-risk activities.

Although experiencing fewer attacks overall, ages classes 0-4, 55-59 and above have higher fatality risks. Age classes above 50-54 displayed increased fatality ratios, excluding the 60-64 age class. Older individuals are probably less resilient after an injury then middle-aged people, leading to a higher probability of fatality by shark attack. Only 20 attacks were recorded for people between the ages of 60-64, 3 of which were fatal. The results of this age class could have been skewed by a small sample size. Attacks on children between the ages of 0-4 were always fatal. Infants, specifically, because of their small stature, would be highly susceptible to fatality. Attacks that would leave large, but treatable lacerations to middle-aged humans could be fatal to infants. The results conclude that infants and small children, 0-4 years of age, and anyone above the age of 55 have a higher risk of a fatality if involved in a shark attack.

4.2. Species-specific patterns

With respect to individual species the Great White was responsible for the largest number of attacks. Geographically, these were clustered in 4 major areas: the Western

Coast of the USA, eastern and southern coastline of Australia, South Africa, and the Mediterranean Sea. This was expected as South Africa, Southern and Eastern Australia and the West coast of the USA are known to have large populations of white sharks that prey on local aggregation of pinnipeds (Shaughnessy *et al.* 1995, Goldman and Anderson 1999, Klimley *et al.* 2001, Le Boeuf 2004, Martin *et al.* 2005). Often, White shark attacks on surfers are suggested to result from misidentification (Miller and Collier 1981). Great White sharks spend winter months in a pelagic stage in the Northern Hemisphere. Their arrival to coastal areas during fall months correlate with the return of juvenile northern elephant seals, *Mirounga angustirostris*, from their first foraging trip (Klimley *et al.* 2001, Le Boeuf 2004). During these months, attacks on surfers increase dramatically, even though fall months have decreased participation. This result is mirrored in the Southern Hemisphere with over 40% of attacks occurring in the winter months when White sharks are known to be hunting Cape fur seals, *Arctocephalus pusillus* (Martin *et al.* 2005). Although, the vision of Great Whites is excellent, highly evolved for areas of low light (Gruber and Cohen 1985) it could be that under turbulent surf conditions, misidentification is possible. This is supported by the fact that similar increases in attacks on swimmers are not observed. Only 2 attacks were recorded on swimmers through winter months in the Southern Hemisphere and only 2 in September and October in the Northern Hemisphere. These results confirm that surfers have an increased risk during periods when White sharks search actively for seals and may mistake surfers for prey.

The high frequency of Great White attacks in the Mediterranean Sea was somewhat unexpected as it lacks the characteristic pinniped population observed in the other 3 major attack areas. However, the Mediterranean has been suggested to contain a unique population of White Sharks who feed primarily on cetaceans, chelonians, other elasmobranchs and large teleosts (Morey *et al.* 2003). Historically, the Mediterranean supported large populations of monk seals, *Monachus monachus* as well as other resources that have since been drastically overfished (Panou *et al.* 1993, Gucu *et al.* 2004, Tudela 2004). Closer analysis of attacks in the Mediterranean revealed that most attacks on humans are historical, with the most recent attack occurring in 1987, almost 20 years ago. Recent depletion of white shark populations, and their prey species could explain the historical trend of Mediterranean White shark attacks.

The Great White is the largest predatory fish, considered one of the top marine predators in the ocean. Considering this, the Great White has a moderate average injury of 1.61 and fatality ratio 0.37. Many White shark attacks on humans are characterized by an initial strike, in which the shark then leaves and does not return. The 'bite and spit' hypothesis, attempts to explain the average injury and fatality rate. Great White's attack prey from behind, leaving the area of attack immediately after the initial strike returning later to feed once the animal has died from exsanguinations (McCosker 1985). However, this behavior is observed when White sharks attack larger, more dangerous prey, such as adult elephant seals. Great White's have been observed to attack smaller prey such as sea otters, *Enhydra lutris*, jackass penguins, *Spheniscus demersus*, and sea turtles by non-predatory grasp and release (Simpfendorfer *et al.* 2001). This apparent non-predatory behavior may resemble White shark attack behavior on humans and explain resulting injuries.

The teeth of the White shark are more evolved for pursuing fattier and softer prey, like pinnipeds. When attacking humans, they may experience difficulty with their ‘boniness’, often shattering teeth, and leaving fragments in the bone. More commonly injuries are related to lacerations and have minimal bone damage (Byard *et al.* 2000). However, the Tiger shark, whish feeds primarily on sea turtles (Simpfendorfer et al. 2001), features jaws and dentition evolved to penetrate hard turtle shells. Strong enamel cusps and tooth serrations reduce bite stress and strengthen tooth structure. Combined with a kinetic jaw that allows a row of teeth to project and saw into bone (Witzell 1987), these adaptations make Tiger sharks more dangerous to humans than any other species. Although, Tiger sharks attack less often then Great Whites, on average they inflict more severe injuries, resulting in a 50% fatality rate.

Tiger sharks exhibit a concentration of attacks off the coast of Florida and Northeastern Australia, leading northwards to Papua New Guinea. These areas are associated with large continental shelves with high levels of species richness (Worm *et al.* 2005) - habitats preferred by Tiger shark (Compagno *et al.* 2005). Hawaii showed a small concentration of shark attacks, but had limited longitude / latitude information. The frequency of attack in Hawaii could be underestimated, as Tiger sharks are known to occur frequently around the Hawaiian Islands (Polovina 1984). It is reasonable to assume this area would have a higher risk associated.

Although Bull sharks range globally, attacks on humans are reported mostly off the coast of Florida and the southeastern coast of South Africa. Only few recorded attacks have occurred outside of these areas. Bull sharks were the only species to show a correlation, although marginal, of size of attacking species to injury inflicted during attack. Tentatively, it can be concluded that larger bull sharks may pose a higher risk of inflicting serious injury. Bull sharks are known to have the highest testosterone levels of any species that has been tested so far (Leathermen 2003). High levels of testosterone have been recorded to promote aggressiveness (Rose et al. 1971). What makes Bull sharks most dangerous is its preference for coastal habitats. The Bull shark is commonly found living in surf zones, near wharves, in lagoons, bays, river mouths and even up to 1000's of kilometers upstream in freshwater, where it frequently encounters humans (Compagno *et al.* 2005). Consequently, Bull sharks have the third highest frequency of attack. In fact, it is possible Bull shark attacks occur with greater frequency then previously thought. Attack information with respect to this species is not always accurate. Some observations are from non-experts, where species identification would be problematic, especially under the circumstances of a shark attack. It has been proposed that juvenile Bull sharks, which morphologically resemble Great White sharks and many other whaler sharks (Last & Stevens 1994), may be responsible for a number of attacks that have been quickly attributed to Great Whites (Collier 1992).

The Gray Nurse shark exhibited few attacks in the Northern Hemisphere, found mostly on the northeastern coast of the USA. Attacks with a northern distribution are attributed to reproductive migrations to colder waters in the summer. Animals can be become more aggressive during mating season (Fleming et al. 1993), increasing the probability of attack. Attacks were more frequent in the Southern Hemisphere, specifically in South Africa and Australia. The Gray Nurse is not considered an aggressive species, feeding commonly on smaller fish species (Compagno *et al.* 2005). Historically, the Gray Nurse was reported to be a 'maneater' in the Southern Hemisphere, which led to massive culling of the species by divers and fishermen (Last and Stevens 1994). My results report a single fatality and an average injury of 0.9, below a minor injury rating of 1. The vilification of the Gray Nurse appears to be unwarranted and, consequently, it received the status of a protected species in New South Wales, making it the first elasmobranch in the world to be protected (Last and Stevens 1994). Although having high attack frequencies, the Gray Nurse does not prove to be any significant threat to humans. This species often gulps large breaths of air, leaving them hanging in the water, giving them a very docile appearance (Last and Stevens 1994, Compagno *et al.* 2005). It is possible that many of these attacks were provoked by people stepping on or touching nurse sharks which often appear motionless.

It is important to note that globally, there were only 4 areas with high concentrations of reported attacks: southeastern coast of USA and Caribbean, the Western Coast of the USA, eastern and southern coastline of Australia and Papua New Guinea and South Africa. These areas all had significant frequency of shark attacks and ocean users should be aware when entering the water. Few shark attacks occurred in South America, Africa (excluding South Africa) and southern Asia (Fig. 1). It is likely that there is a shark attack reporting bias towards developed countries compared to a third world country. Alternatively it could be that sharks have declined disproportionally in some waters due to intense historical fisheries (Worm et al. 2005). Also, cultural differences could limit the number of marine recreation users. Probably, a combination of these factors may explain low incidence of shark attacks in some developing countries.

A common feature of species with high fatality ratios and average injuries, excluding the White shark, is opportunistic feeding. Makos, Bulls, Tigers, as well as Oceanic Whitetip and Blue sharks, which have lower incidence of attack but higher average injury rates, are all opportunistic feeders (Compagno *et al.* 2005). Specifically, Mako, Oceanic Whitetip and Blue sharks are pelagic opportunistic feeders, commonly eating items with little nutritional values (Miller and Collier 1981). It is possible that these pelagic species have few opportunities to capture prey and may occasionally see humans as a potential source of prey; however, one would expect a higher fatality rate under these circumstances.

4.3. Patterns of human behavior

Analysis of marine recreation in the area of attack revealed that some activities might elicit behavioral responses from sharks promoting negative human-shark encounters. Often fishing may attract sharks to an area through exposure of baits, injured or dead fish, or chum used to target big fish. For example, Tiger sharks in Western Australia are thought to migrate according to the rock lobster, *Jasus edwardsii*, fishing season. Approximately 150 fishing vessels currently fish for rock lobster, all of which discard wasted bait into the ocean that is consumed by abundant Tiger sharks (Simpfendorfer *et al.* 2001). Areas where invertebrate fishing is present, specifically abalone, are subject to greater risks of shark attack. Many divers unwittingly enter an area to fish abalone that is currently inhabited by a Great White shark and are consequently attacked (Collier 1992). Reasons for the attack are unknown, but sharks have shown territorial displays (Johnson and Nelson 1973, Klimley *et al.* 2001). Abalone fishermen invading these beds could be perceived as intruders and subsequently attacked. Spear fishermen are often attacked because they drag speared fish behind them. The injured fish attract sharks; fishermen are subsequently injured when sharks attempt to take tied fish. Boating had few attacks during the activity, but occurred 119 times in the area of attack. Many of these shark attacks concern shipwrecked boats in WWII. Boats were sunk and humans were forced into the ocean. Sharks commonly follow boats, being attracted by waste and offal. Studies have reported up to 25 Oceanic Whitetip sharks following a single boat (Baum and Myers 2004). Combined with the chaos of a sinking ships and resulting injuries, sharks that were not in the area previously were likely attracted to the area and excited, promoting attack. It is concluded that humans must be selective in their area of marine recreation. Particular regions, times of years, times of day, and activities seem to increases the likelihood of shark attack. This information should be used to minimize risk and promote coexistence of sharks and humans in coastal environments.

5.0 Conclusions

Analysis of 3121 shark attacks worldwide revealed 4 large concentrations of shark attacks, with the remaining attacks sporadically distributed. The southeastern coasts of USA and Caribbean, the Western Coast of the USA, eastern and southern coastline of Australia and Papua New Guinea and South Africa appeared to have much higher risks of shark attack than other areas. Areas north of and south of 50° had limited shark attacks and may pose little threat to humans. Risks in developing countries cannot be confidently resolved because of a possible reporting bias.

Higher attack frequencies on males, in summer months, and on individuals between the ages of 15-19 likely occurred because of increased marine recreation participation, not because of higher inherent risk. However, a marked tend towards attacks in the later afternoon is likely linked to diurnal hunting behavior of sharks. Infants and young children, 0-4, and older individuals, 55 + years were found to be at highest risk of fatality in case of a shark attack. White, Tiger, Mako and Bull sharks were responsible for the large majority of serious attacks, and no correlation between the severity of attack and shark size was found for these species, except for Bull sharks which show a positive trend with size. The White Shark, the largest of all predatory fish was concluded to pose the highest risk to humans. Although White shark attacks have lower fatality rates then those by Tiger sharks, the substantially higher attack frequency warrants the Great White as the most dangerous shark to humans.

Quantitative evidence illustrates behavioral risks associated with an attack. Fishing, had a high frequency of attack, but calculated risks over the last 5 years in the USA suggested a very low attack rate per million participants. However, fishing seemed to promote attacks in the surrounding area, probably through spread of fish blood and offal. Surfers had by far the largest risk of an attack, with over 6 attacks per million participants in the USA over the last 5 years. This rate was higher then those for all other activities (swimming, diving, boating, fishing) combined. Analysis revealed that during times when Great Whites actively search for seals (Northern Hemisphere fall, Southern Hemisphere winter), the probability of attack on surfers drastically increases. To my knowledge it is the first study to quantitatively link increases in shark attacks on surfers in both the Northern and Southern Hemisphere to Great White predatory behavior on seals. The hypothesis that surfers when attacked are mistaken for pinniped prey is supported.

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