The Impact of White Shark (*Carcharodon carcharias*) Sightings and Attacks on Recreational Water Use Patterns in False Bay

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ABSTRACT

White sharks (*Carcharodon carcharias*) are apex predators that play an important role in the structure and functioning of marine ecosystems. However, despite both their ecological importance and threatened conservation status this species is still subject to lethal control to reduce the risks of predation for recreational water users. The Shark Spotter program, pioneered in False Bay, South Africa, proposes a non-lethal alternative to reducing predation risk. This program aims to balance the needs of people with white shark conservation by actively reducing conflict between recreational water users and sharks. In this study I establish the extent of spatial overlap between white sharks and water users at two popular recreational beaches in False Bay (Fish Hoek and Muizenberg), and investigate how shark sightings (accompanied by warning flags and/or a siren) as well as attacks influence water use patterns amongst bathers, surfers and paddlers. In the period from 2006 to 2012, the total number of shark sightings recorded was 531 at Muizenberg and 322 at Fish Hoek, with a notable increase in sightings at both beaches in recent years. Shark sightings were rare in winter increasing into the spring and summer months when recreational use of the inshore was highest. Daily shark sightings peaked at midday to late afternoon at both beaches, coinciding with peak numbers of water users. The response of water users to warnings of shark presence by the Shark Spotters was only found to be significant in cases where the siren was sounded by the shark spotters, and in the absence of a siren warning flags had little impact on average numbers of water users. The occurrence of a fatal shark attack was found to a) increase response of water users to auditory warnings (when the siren is sounded) but not visual warnings (warning flags unaccompanied by a siren); and b) reduce the average number of water users present at both beaches for at least three months following the fatal incident. Annual averages of water users at Muizenberg beach also reflected this pattern, with a general reduction in water use in years with attacks compared to those without. These findings indicate that the Shark Spotter program is effective in mitigating conflict between water users and white sharks through auditory warnings and subsequent beach clearing in the event of a shark sighting; however the lack of response by water users in the absence of a siren and after long periods without an attack remains a challenge to the effectiveness of the program. The large spatial overlap between white sharks and water users, as well as the increasing number of shark sightings at both beaches, emphasises the need for continuous revision and improvement of mitigation strategies to prevent conflict between white sharks and water users in False Bay.

INTRODUCTION

Human-wildlife conflict presents one of the greatest challenges to the effective conservation of wildlife species (Woodroffe et al. 2005; Dickman 2010). Typically the response to this form of conflict is the lethal control of problematic species (Treves and Naughton-Treves 2005), a practice which poses a risk to threatened species as well as the stability and health of natural systems (Woodroffe et al. 2005; Ritchie and Johnson 2009). Top predators are often most at risk to lethal control as these animals pose an indirect threat to human livelihoods through predation on livestock or game animals and a direct threat through rare but fatal attacks (Woodroffe et al. 2005; Berger 2006; Dickman 2010). Furthermore the life history characteristics of many top predators such as slow growth, late age of sexual maturity, low reproductive capacity and low overall abundance has made them particularly vulnerable to extensive lethal control (Musick et al. 2000; Woodroffe 2005).

The field of human-wildlife conflict research seeks to ensure that apex predators persist despite a burgeoning human population (Redpath 2012). This is necessary as the presence of apex predators in both terrestrial and marine ecosystems has been associated with high levels of biodiversity and stability in lower trophic levels (Sergio et al. 2006; Ritchie and Johnson 2009). However in many instances there are challenges to conflict management including unwillingness of certain parties to engage in alternatives to lethal methods, financial limitations, lack of effective protective legislation and negative, sensationalised media coverage of the conflict (Redpath et al. 2012).

White sharks provide a classic example of severe human-wildlife conflict, as attacks on humans often result in serious injury or death. Currently white sharks are protected internationally, being listed as an Appendix II species by the Convention on International Trade in Endangered Species (CITES) and classified as “vulnerable” by the International Union for Conservation of Nature (IUCN) (Fergusson et al, 2009). However like many other shark species, white sharks are highly susceptible to anthropogenic impacts due to their life history traits (Musick et al. 2000). Anthropogenic impacts on white sharks include habitat degradation (due to pollution, development and overexploitation of prey species), continued exploitation by commercial fisheries, primarily for fins (Shivji et al. 2005), as well as incidental by catch by near shore fisheries operating long lines, gill nets, trawls and various other fishing gear (Fergusson et al. 2009).

Limited knowledge on the distribution and movement patterns of white sharks also presents a challenge to effective conservation, as these range from seasonal aggregations in coastal areas (Jorgensen et al. 2010; Anderson et al. 2011; Kock et al. 2013) to large scale coastal and trans-oceanic migrations (Bruce et al. 2006; Domeier and Nasby-Lucas 2008; Jorgensen et al. 2010). This emphasises the need for broad scale, globally-coordinated conservation plans for white sharks.

Arguably the most severe threat to white sharks, however, is the implementation of lethal control methods to mitigate human-shark conflict. White sharks have long been the focus of negative media attention due to rare but severe attacks on humans. In the period from 1876 – 2011 there have been a total of 263 unprovoked white shark attacks recorded worldwide, of which 69 were fatal (ISAF 2012). Although shark attacks are infrequent, shark control programmes have been implemented at a number of major recreational beaches in areas such as Kwazulu Natal South Africa (KZN), as well as Queensland and New South Wales (NSW) in Australia (Dudley 1997). In all three areas, control measures aim to reduce the probability of a shark attack by reducing shark populations through lethal measures (Dudley 1997; Cliff and Dudley 2011). These measures include the use of large-mesh gill nets (used in NSW) and baited "drum lines", or a combination of the two (used in KZN and Queensland) and have been shown to successfully reduce the number of attacks on humans (Dudley 1997).

However, these control methods are costly in terms of their environmental impacts. Not only are gill nets and drum lines reducing the numbers of a protected apex species, they are also highly unselective and result in the by catch of many other species including cetaceans, rays, turtles and a number of harmless shark species (Paterson 1990; Krogh 1996; Cliff and Dudley 2011). Alternative strategies are thus needed to mitigate conflict between water users and sharks without threatening the stability of marine ecosystems and the conservation status of white sharks.

In some areas such as Hong Kong, and recently at Fish Hoek beach in False Bay, South Africa, small-mesh exclusion nets have been implemented, which act as a non-lethal barrier to sharks (Reid et al. 2011; Pollack 2012). However these nets are only effective when deployed in sheltered bays lacking strong currents and wave action (Cliff and Dudley 2011) and are thus not suited to many popular inshore recreational areas that overlap with white shark distribution.

In False Bay a novel community initiative known as the Shark Spotter program has been implemented as an alternative to lethal methods (Kock et al. 2012). The proximity of mountains to popular beaches provides vantage points from which spotters can alert the public to the presence of white sharks in or close to the surf zone using a combination of auditory (sirens) and visual (flags) warnings (Kock et al. 2012).

The Shark Spotter programme thus aims to balance the needs of water users in False Bay with the conservation of sharks by reducing the spatial overlap between people and sharks in the near shore region and hence the probability of an attack (Kock et al. 2012). What is not clear is whether recreational water users are responding appropriately to both the visual and auditory warnings and how the response is varying with time since inception of the project, season and following a predation event. In this project I propose to assess annual, seasonal and hourly patterns in shark sightings in False Bay, and to compare these with recreational water use patterns in the bay. In addition I will assess the response of water users to both visual (different flag colours) and auditory warnings of shark presence and how this varies following an attack.

I predict following from Kock et al. (2013) that the incidence of white shark sightings in the inshore zone will be higher in spring and summer months than in autumn and winter; while the total number of sharks spotted per annum in False Bay is expected to increase over the study years due to improved conservation of white sharks through the use of the shark spotter program (Kock et al. 2012) as well as the establishment of the Table Mountain Marine Protected Area in 2004 (WWF 2009). The high level of residency displayed by white sharks in False Bay (Kock et al. 2013) is expected to result in a localised increase in white shark abundance despite the depressed state of South Africa's overall white shark population (Kock and Johnson 2006; Towner 2013). I further predict that water users will be more risk averse when 1) flags are accompanied by a siren and active beach clearing; 2) immediately after a serious injury or fatality attributed to sharks.

METHODS AND MATERIALS

STUDY SITE

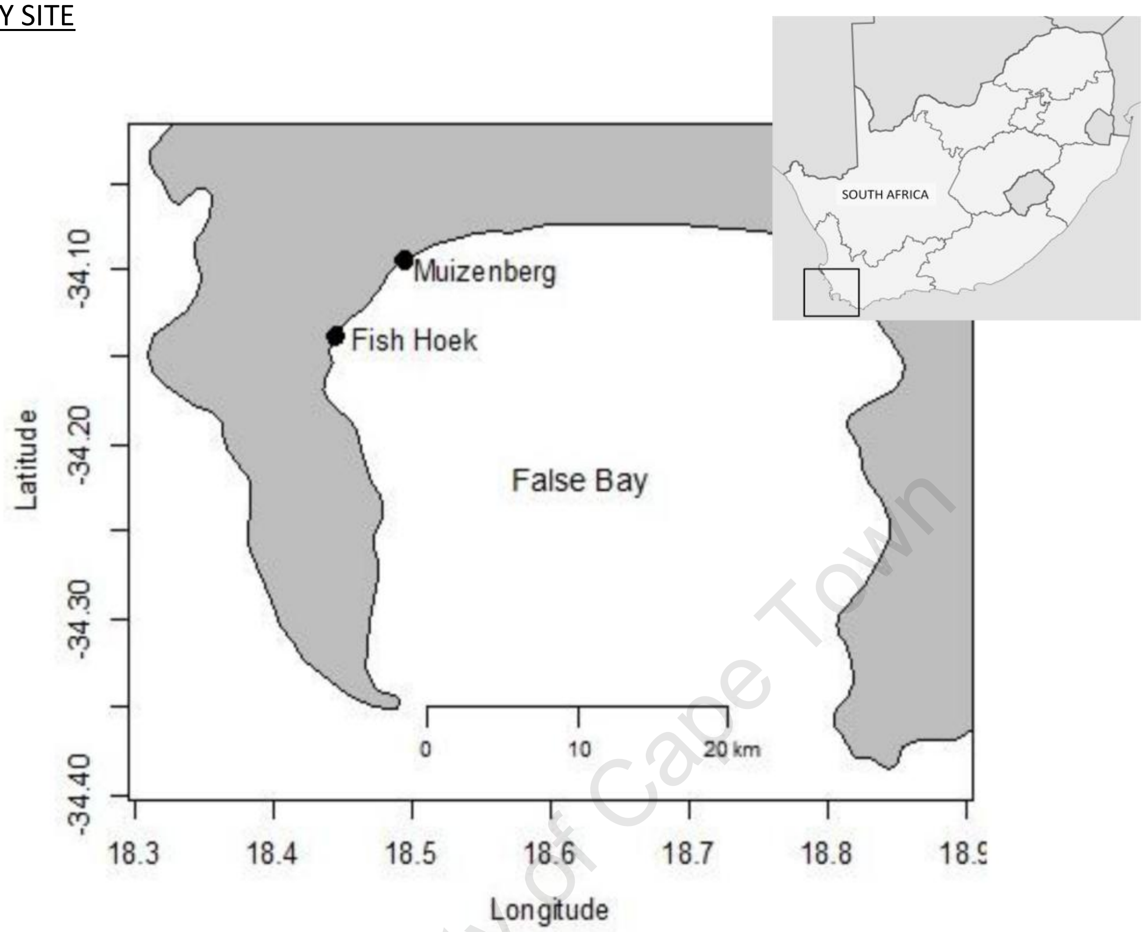


Figure 1: Locations of Muizenberg and Fish Hoek beaches in False Bay, South Africa.

This study focused on two popular recreational beaches in False Bay, namely Fish Hoek and Muizenberg, both of which are frequented by water users such as bathers, surfers/body boarders, and kayakers, and have shark spotters present during daylight hours for 365 days a year (Kock et al. 2012). Spotters make use of vantage points on the mountains (110-120m above sea level at Fish Hoek and 90-100m at Muizenberg) above each beach to detect sharks in the inshore region (Kock et al. 2012). A flag system is used by spotters to warn water users of the potential risk they face when entering the water. The flag system operates as follows (sensu Kock et al. 2012):

Green flag: spotting conditions good – no shark present;

Black flag: spotting conditions poor;

Red flag: High shark alert;

White flag: Shark has been spotted in the surf zone (usually accompanied by a siren).

Two shark attacks, on the 12th of January 2010 and the 28th of September 2011 respectively, have taken place at Fish Hoek since the formal adoption of the Shark Spotter program by the City of Cape Town in 2006. Both attacks involved swimmers, and in the first case the attack was fatal, while the second attack resulted in the loss of the victim's right leg (www.sharkattackfile.info). There has only been a single attack in Muizenberg in the last eight years, which took place on the 13th of August 2006, and was non-fatal, resulting in the loss of the victim's foot (www.sharkattackfile.info).

QUANTIFYING WATER USE AND SHARK SIGHTINGS IN THE INSHORE ZONE

I used data collected by shark spotters on prepared datasheets. Shark spotting is divided into two shifts, the morning shift from 8am to 1pm (7am in summer), and the afternoon shift from 1pm to 6pm (7pm in summer). Spotters entered basic information such as the date, the name of the spotter on each shift, and whether the beach and mountain sirens were functional. Weather conditions were recorded, including temperature (ambient and water), visibility (ambient and water) and wind speed. The number and type of water users (surfers, paddlers and bathers) and the corresponding flag colour were recorded on the hour, every hour of the day. The total number of shark sightings per shift was recorded, and whether the siren was sounded to alert water users to leave the water. Spotters used a diagram to illustrate the position of sharks when sighted and their subsequent movement patterns within the bay. These were recorded as "one way" (unidirectional) movement or "patrolling" behaviour, in which sharks displayed circular movement patterns. Finally, spotters also noted the presence of dolphins, whales and/or trek netters in the bay.

DATA ANALYSES

All analyses were conducted using the statistical package Statistica v11 (2012). Sighting data consisted of a record of all sharks sighted between 2004 and 2012, and the abundance of water users in the hour preceding a sighting versus the hour following a sighting. These data were analysed for Fish Hoek and Muizenberg respectively for the period 2006 – 2012 due to incomplete data on sightings and water user abundance in years prior to 2006. Data on hourly water use and flag colour at each beach were only entered from shark spotting datasheets for 2012 due to time constraints.

Shark Sightings: The total number of shark sightings at each beach was plotted annually in order to investigate variation in the number of sharks sighted on an annual basis as well as to determine any temporal trends. A correlation analysis was then performed to determine if there was a significant correlation between the total number of sightings and year for both beaches. As the data were not normally distributed the Spearman's Rank correlation coefficient was calculated to a 95% confidence level. The total number of sightings per year was then averaged across all study years ($N = 7$) at each beach in order to determine if there was a significant difference in the average number of sightings between the two beaches. As the data were not normally distributed this analysis was performed using a non-parametric Mann Whitney U test to a 95% confidence level.

Patterns of shark sightings and recreational water use: The total number of sightings per month was averaged for the period from 2006 to 2012 in order to determine if there were seasonal trends in shark sightings for each beach respectively. Seasonal patterns in sightings were then compared to patterns of water user abundance for 2012 (the only year in which data was entered on hourly water user abundance) to explore the relative spatial overlap between white sharks and humans on the inshore region of False Bay. For both these analyses a non-parametric Kruskal Wallace ANOVA followed by post hoc comparisons of mean ranks of all pairs of groups was used to determine if there were significant differences among months. Following this the number of sightings recorded when the black versus green flags (representing poor and good visibility respectively) were used each month was plotted for 2012 (the only year with hourly data entered on flag colour), in order to determine if seasonal patterns in shark sightings are as a result of varied visibility across months, or actual variations in shark presence in the inshore zone.

Finally the number of sightings was averaged hourly across all study years ($N = 7$) for each respective beach. A cube root transformation was used to normalise the data and following this a one way ANOVA (followed by a Tukey post hoc test) was used to determine if time of day had a significant impact on average number of shark sightings. The average number of sightings per hour was then compared to hourly patterns in water use at each beach for the year 2012. The impact of time of day on average water user abundance was analysed for each water user group (surfers, paddlers and bathers) per beach using a non-parametric Kruskal Wallace ANOVA followed by post hoc comparisons of mean ranks of all pairs of groups.

Water user response to shark sightings: The response of water users to a shark sighting was measured using a “before/after” approach, in which the number of waters users the hour preceding a sighting was compared to the number present the hour after a sighting. This small time frame was used to allow the exclusion of numerous confounding variables such as variations in weather patterns, season, day of the week, etc. Furthermore, sighting data were only analysed in cases where water users were present prior to a shark sighting, in order to quantify the effect of a sighting on water user abundance. A Mann Whitney U test (to a 95% confidence level) was used to compare the average number of water users before and after a sighting at each beach. The average number of users was also compared when these sightings and the associated flag change were accompanied by a siren or not.

Water user response to attacks: The effect of a fatal attack on the response of recreational water users to shark sightings and both visual and auditory warnings was assessed for both beaches. This was done by comparing the average response of water users to shark sightings (as a comparison of abundance the hour before and after a sighting) in the three months preceding the fatal attack, versus the average response in the three months following an attack. This was done using a Mann Whitney U test at the 95% confidence level. Changes in water user response to sightings before and after a fatal attack were analysed independently for sightings where the siren was sounded versus those in which the siren was not sounded, in order to assess variations in water user response to auditory versus visual warnings.

In addition to this, the average number of water users at each beach prior to a sighting was compared in the months preceding a fatal attack versus the months after a fatal attack in order to determine if recreational water use is reduced by the occurrence of a fatal attack. This was done using a Mann Whitney U test at the 95% confidence level. In order to ensure the observed changes in water use prior to and following a fatal attack were as a result of the attack and not seasonal patterns, the changes in water use over this period were compared for years in which an attack did not occur (2007-2009 and 2012) versus the year a fatal attack occurred (2010) using Mann Whitney U tests to a 95% confidence level.

Finally, water user abundance at Muizenberg beach was averaged on an annual basis for 2006 to 2012 to compare the average number of each water user group (surfers, paddlers and bathers respectively) in years in which attacks did or did not occur. Data from Muizenberg beach were used due to extremely low numbers of sightings recorded in Fish Hoek for certain years, resulting in large standard errors around mean water user abundance. A non-parametric Kruskal-Wallace ANOVA was used to determine if there were significant differences in water user abundance among years as there were insufficient attacks to perform a factorial ANOVA on the impacts of year and attacks respectively on water user abundance.

RESULTS

Shark sightings: The total number of shark sightings recorded at Fish Hoek over the period from 2006 to 2012 was 322, while the total number of sightings at Muizenberg was 531. Shark sightings ranged in length from 1 minute to 300 minutes at Fish Hoek, with an average of 16.40 minutes, while in Muizenberg sighting length ranged from 2 minutes to 115 minutes, with an average of 14.86 minutes.

Shark behaviour was similar at Fish Hoek and Muizenberg, with one-way movement most common (78.8% and 81.0% respectively) and patrolling behaviour rare (21.2% and 18.4% respectively). Finally the percentage of different size classes of sharks sighted differed between beaches: at Fish Hoek most sharks sighted were of medium size (54.2%), followed by large sharks (26.9%) and small sharks (18.9%). At Muizenberg medium sized sharks were again most common (63.2%), followed by small (28.8%) and then large sharks (8%).

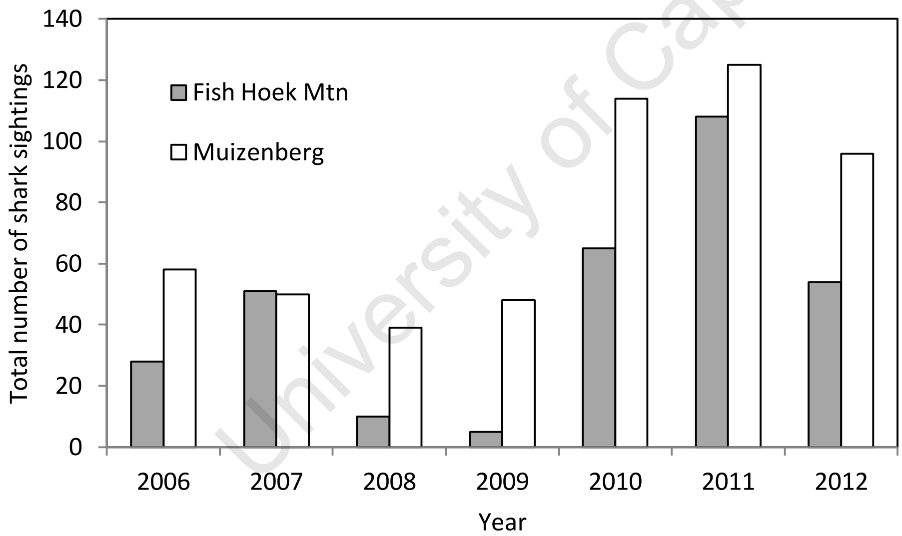


Figure 2: Total number of shark sightings at Muizenberg and Fish Hoek beaches between 2006 and 2012.

The total number of sharks sighted in each of the study years varied between the two beaches and across years with a general trend of more sightings at Muizenberg (except 2007) and more sightings in general for both beaches in the last three years compared to the previous four (Figure 2). There is a significant positive linear correlation ($r = 0.57$, $p < 0.05$) between year and total number of sightings across both beaches.

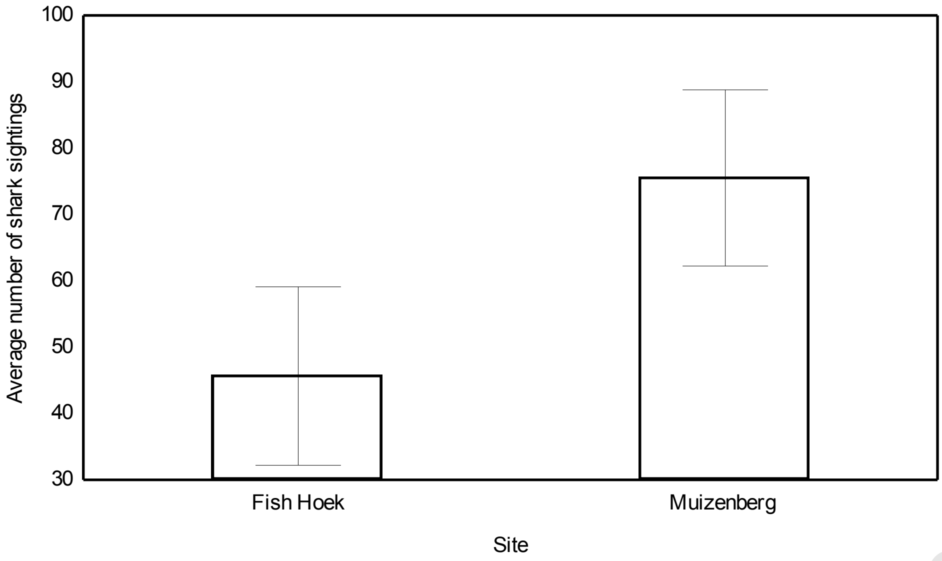


Figure 3: The average (± SE) number of shark sightings at Fish Hoek and Muizenberg beaches across all study years (n = 7).

There was no significant difference (U = 15, n_1 = 7, n_2 = 7, p = 0.26) in the average (± SE) number of annual shark sightings between Fish Hoek (46.0 ± 13.42), and Muizenberg (75.9 ± 13.24) (Figure 3).

Patterns of shark sightings and recreational water use:

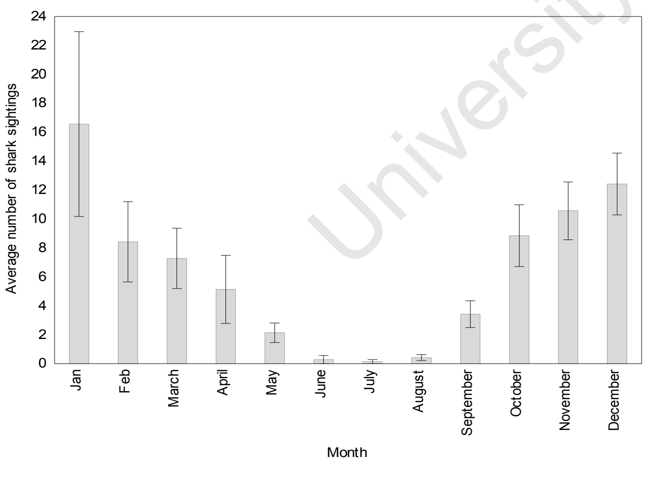


Figure 4.1: Monthly average (±SE) of shark sightings across all study years (N = 7) at Muizenberg beach

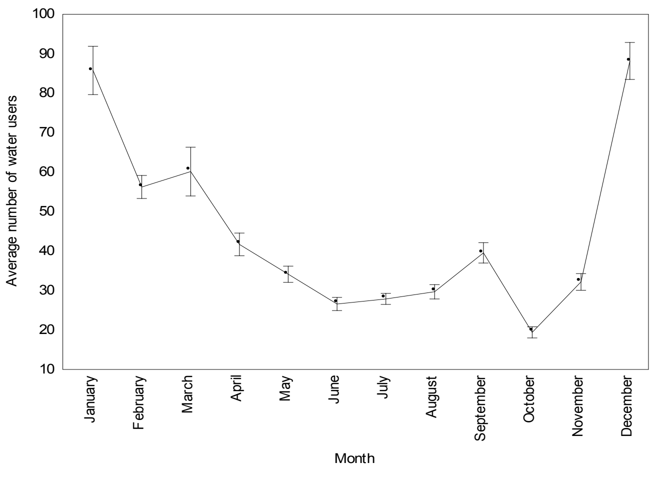


Figure 4.2: Monthly average (±SE) of water users for the year 2012 at Muizenberg beach

The average number of shark sightings differed significantly in the different months (H = 50.36, N = 84, $p < 0.001$, Figure 4.1), with significantly more sharks sighted (Tukey post hoc test: $p < 0.05$) in the summer (Jan, Nov and Dec) than winter (June, July and August).

The average number of water users differed significantly in the different months (H = 538.49, N = 3994, $p < 0.001$, Figure 4.2) with summer months (Jan, Feb and Dec) having a significantly (Tukey post hoc test: $p < 0.001$) higher average number of water users compared to winter months (May, June, July, August).

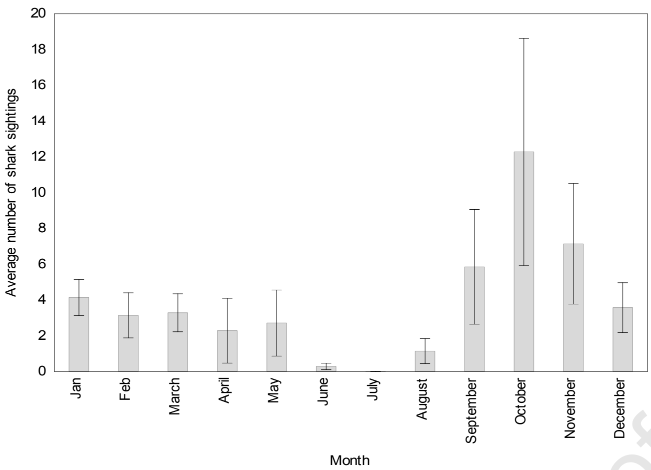


Figure 5.1: Monthly average (±SE) of shark sightings across all study years (N = 7) at Fish Hoek beach

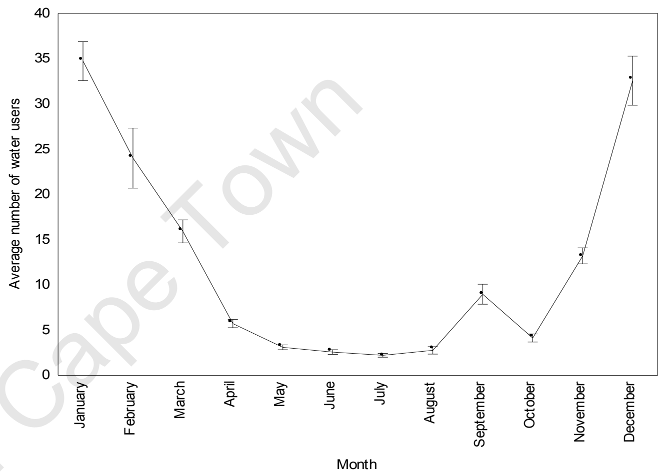


Figure 5.2: Monthly average (±SE) of water users for the year 2012 at Fish Hoek beach

There is significant variation in the average number of sightings in the different months (H = 25.23, N = 84, $p = 0.008$, Figure 5.1) with October having significantly more sightings (Tukey post hoc test: $p = 0.04$) than July.

The average number of water users differs significantly in the different months (H = 1338.94, N = 4117, $p < 0.001$, Figure 5.2), with summer months (January and December) having a significantly higher average (Tukey post hoc test: $p < 0.001$) than winter months (May, June, July and August).

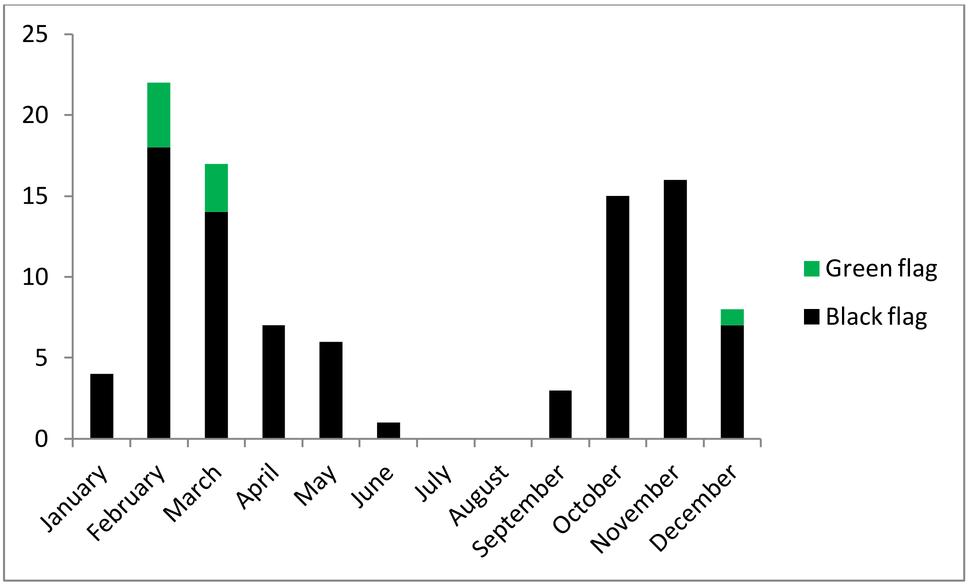


Figure 6.1: The total number of sharks sighted in each month at Muizenberg in 2012 when the flag was either black or green. Black and green bars denote the number of shark sightings that were made when the black versus green flags were flying.

The majority of sightings at Muizenberg in 2012 occurred during the late spring (October, November) and summer (February, March) months (Figure 6.1) and almost all sightings (91.9%) occurred when the black flag was flying relative to the green flag (8.1 %).

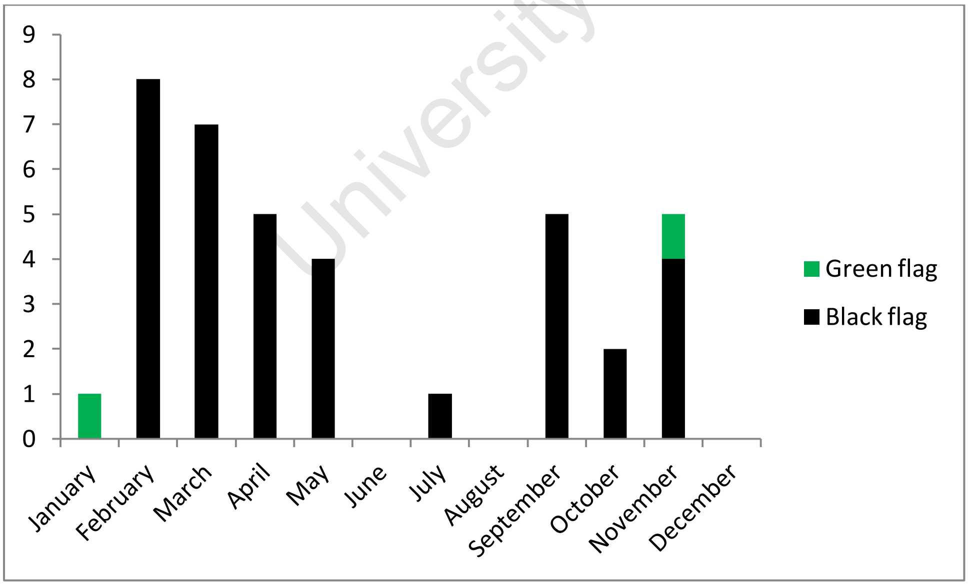


Figure 6.2: The total number of sharks sighted in each month at Fish Hoek in 2012 when the flag was either black or green. Black and green bars denote the number of shark sightings that were made when the black versus green flags were flying.

The majority of shark sightings at Fish Hoek in 2012 occurred during the late summer (February, March) months (Figure 6.2) and almost all sightings (94.7%) occurred when the black flag was flying relative to the green flag (5.3%).

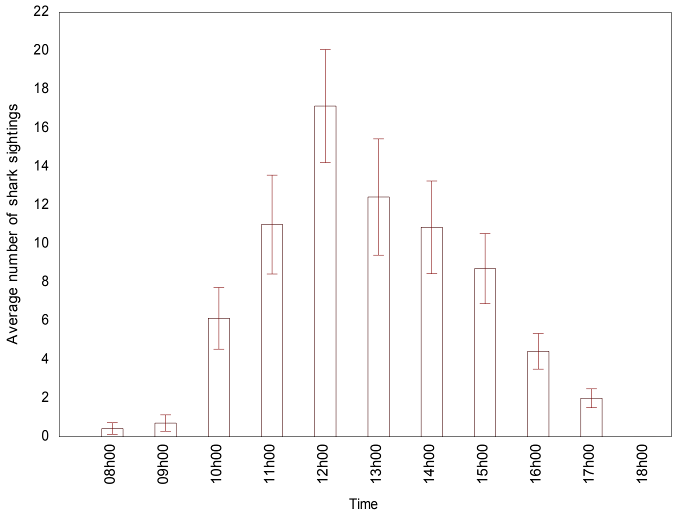


Figure 7.1: Hourly average (±SE) of shark sightings across all study years (N = 7) at Muizenberg beach

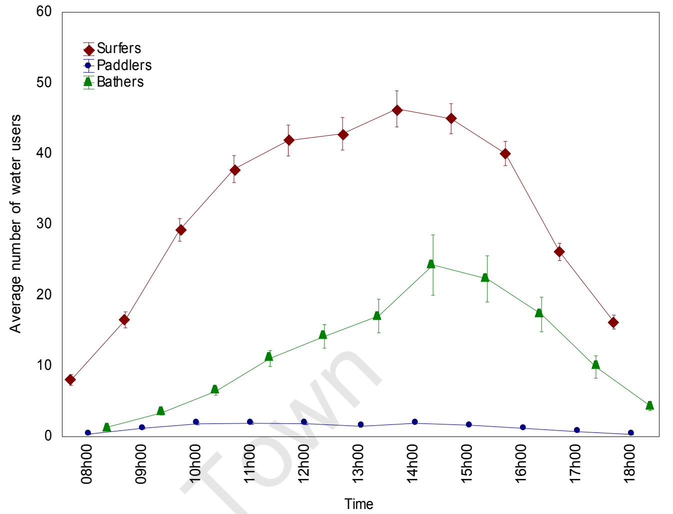


Figure 7.2: Hourly average (±SE) of water users (surfers, paddlers and bathers) for the year 2012 at Muizenberg beach

The average number of sightings differed significantly with time of day ($F = 23.82$, $df = 10$, $p < 0.001$, Figure 7.1), and was significantly higher (Tukey post hoc test: $p < 0.01$) in the hours between 10h00 and 16h00 (with a peak at 12h00) than in the early morning (08h00 and 09h00) and evening (18h00).

The average number of surfers differed significantly with time of day ($H = 845.5$, $N = 3994$, $p < 0.001$, Figure 7.2), and was significantly higher (Tukey post hoc test: $p < 0.05$) in the hours between 11h00 and 16h00 than the morning hours of 08h00 – 10h00 and evening hours of 17h00 and 18h00. There was significant variation in the average number of bathers with time of day ($H = 338.4$, $N = 3994$, $p < 0.001$, Figure 7.2), which was significantly higher (Tukey post hoc test: $p < 0.05$) in the hours between 11h00 to 16h00 than the morning hours of 08h00 and 09h00 and evening hours of 17h00 and 18h00. The average number of paddlers also varied significantly with time of day ($H = 305.6$, $N = 3994$, $p < 0.001$, Figure 7.2), and was significantly lower (Tukey post hoc test: $p < 0.05$) in the early morning (08h00) and late evening (17h00 and 18h00) than the period from 09h00 – 16h00.

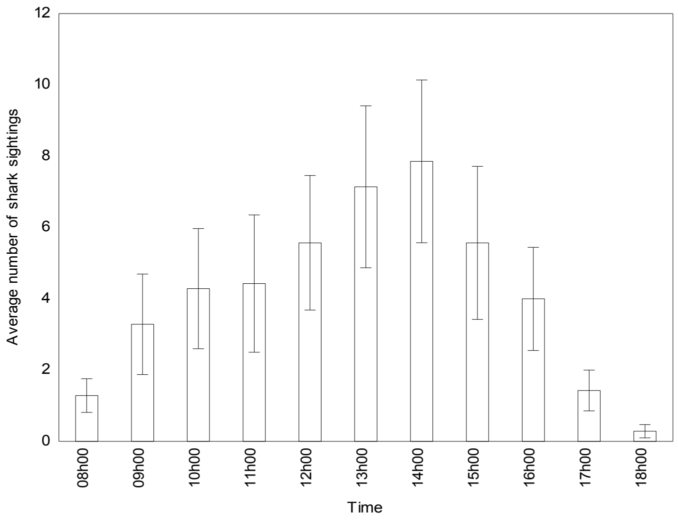


Figure 8.1: Hourly average (±SE) of shark sightings across all study years (N = 7) at Fish Hoek beach

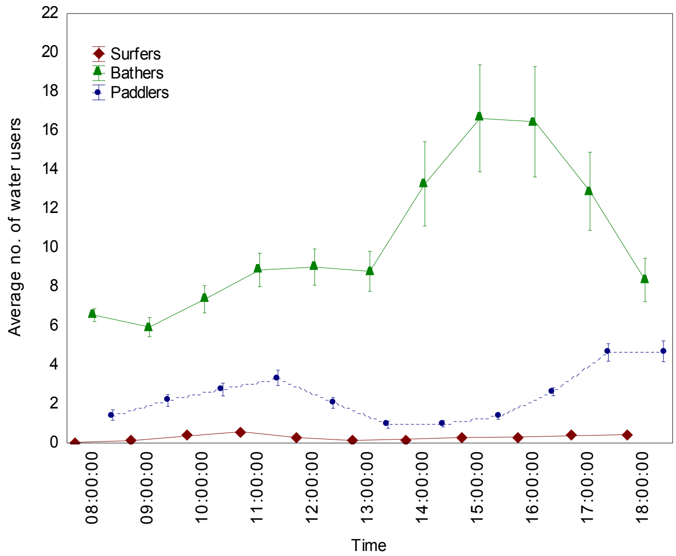


Figure 8.2: Hourly average (±SE) of water users (surfers, paddlers and bathers) for the year 2012 at Fish Hoek beach

The average number of sightings varied significantly with time of day (F = 2.62, df = 10, p = 0.009, Figure 8.1) and was significantly lower (Post hoc Tukey test: p < 0.05) at 18h00 relative to the midday hours of 12h00 – 14h00.

The average number of bathers varied significantly with time of day (H = 113.3, N = 3820, p < 0.001, Figure 8.2), and was significantly higher (Tukey post hoc test: p < 0.05) at 15h00 relative to the morning (08h00), midday (13h00) and evening (18h00). The average number of paddlers also varied significantly with time of day (H = 281.7, N = 3820, p < 0.001, Figure 8.2), and was significantly higher (Tukey post hoc test: p < 0.05) in the morning hours of 10h00 and 11h00 and in the evening hours of 17h00 and 18h00 than the early morning (08h00) and midday hours (12h00 – 14h00). There was significant variation in the average number of surfers with time of day (H = 80.0, N = 3820, p < 0.001, Figure 8.2), however significant differences between hours were not detected by a Tukey post hoc test.

Water user response to shark sightings:

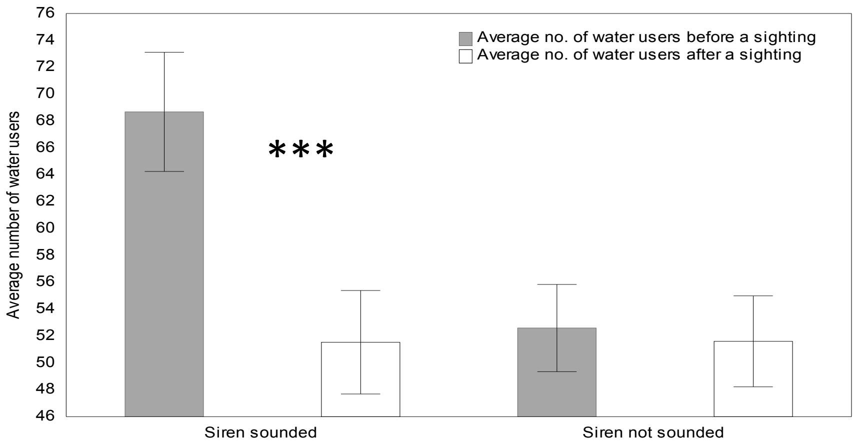


Figure 9: Average (±SE) number of water users across all study years (N = 7) at Muizenberg beach prior to and following a shark sighting when the siren is sounded and not sounded respectively. *** $p < 0.001$.

There is a significant reduction in the average number of water users following a sighting when the siren is sounded ($U = 20910.0$, $N_{before} = 232$, $N_{after} = 232$, $p < 0.001$, Figure 9). However the average number of water users does not change significantly after a sighting when the siren is not sounded ($U = 29770.0$, $N_{before} = 248$, $N_{after} = 248$, $p = 0.269$). There is also a significant difference in the number of water users present prior to a sighting in cases where the siren is sounded versus not sounded ($U = 23706.5$, $N_{yes} = 232$, $N_{no} = 248$, $p < 0.001$).

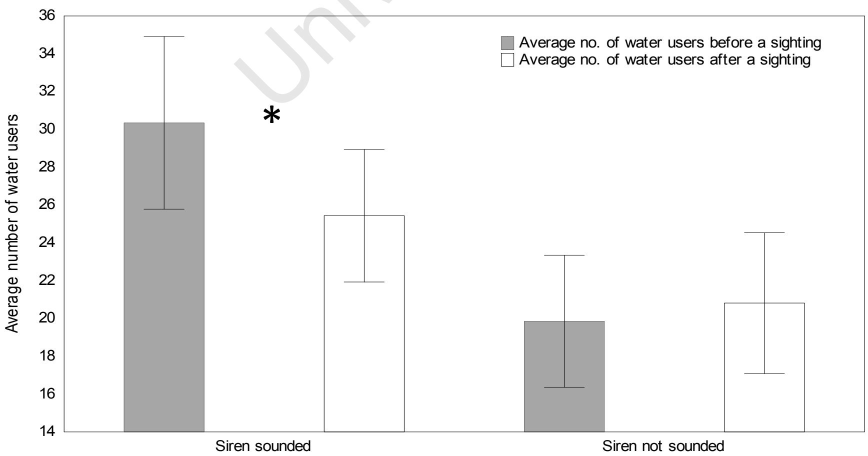
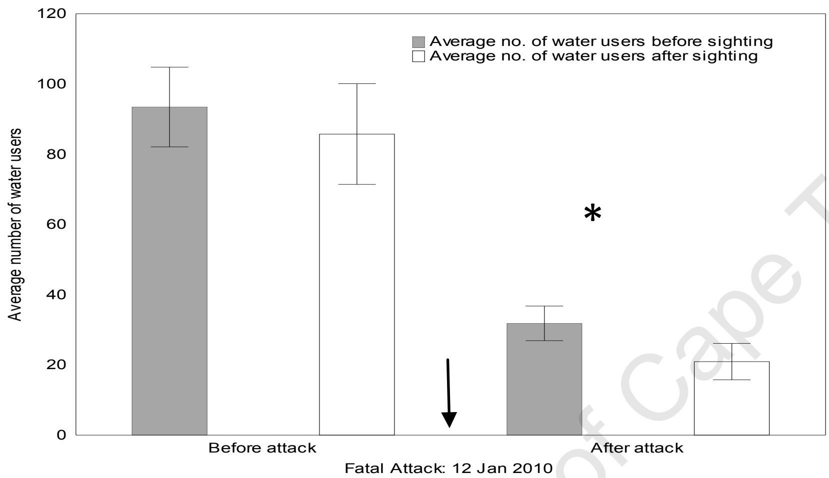


Figure 10: Average (±SE) number of water users across all study years (N = 7) at Fish Hoek beach prior to and following a sighting when the siren is sounded and not sounded respectively. * $p < 0.05$.

There is a significant reduction in water users after a sighting when the siren is sounded (U = 7599.5, N_{before} = 132, N_{after} = 132, p = 0.0365, Figure 10). However the average number of water users does not change significantly after a sighting when the siren is not sounded (U = 356, N_{before} = 27, N_{after} = 27, p = 0.445). There is also no significant difference in the average number of water users present prior to a sighting in cases where siren is sounded versus not sounded (U = 1691.5, N_{yes} = 132, N_{no} = 27, p = 0.680).

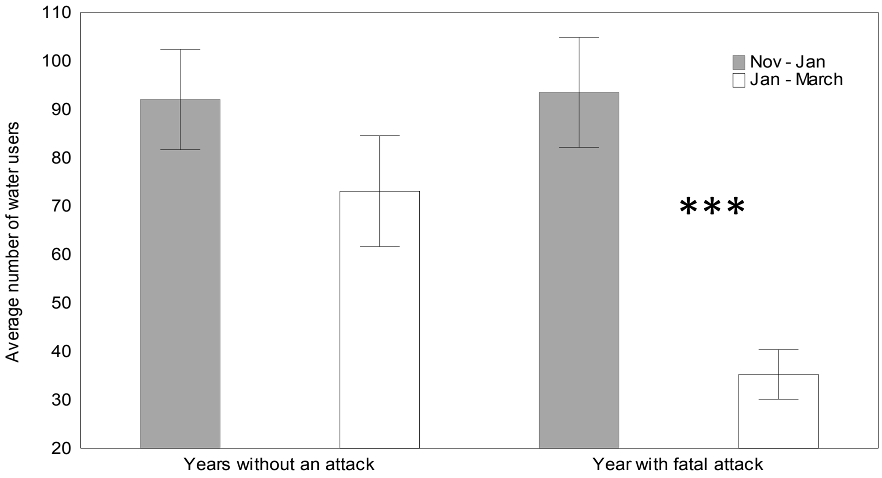
Water user response to attacks:



Siren sounded: Yes

Figure 11.1: Number of water users averaged (±SE) for both Fish Hoek and Muizenberg before and after a shark sighting for the period from 1 November 2009 to 11 January 2010 (Before attack) versus the period from 13 January 2010 to 31 March 2010 (After attack). * $p < 0.05$.

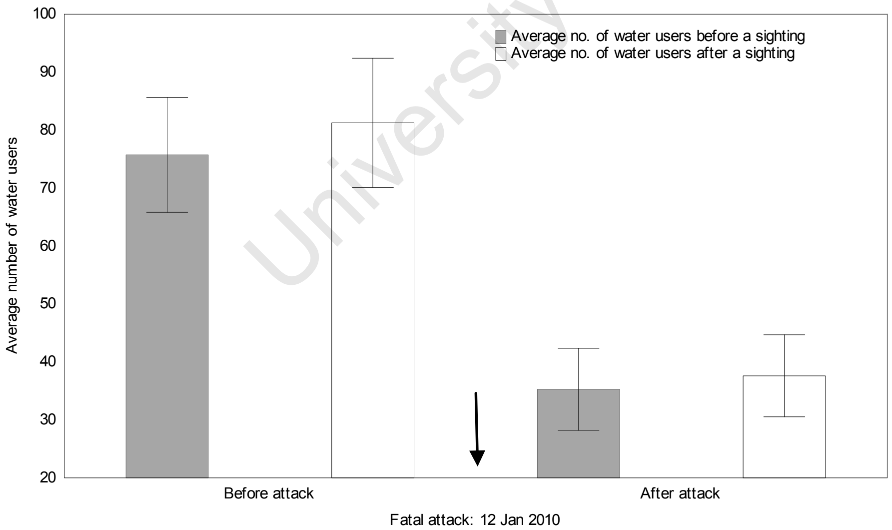
There is no significant reduction in water users after a shark sighting in the period prior to a fatal attack despite the siren being sounded (U = 131.5, N_{before} = 17, N_{after} = 17, p = 0.329, Figure 11.1). However, in the months following a fatal attack there is a significant decrease in water users when the siren is sounded (U = 153.5, N_{before} = 22, N_{after} = 22, p = 0.0184).



Siren sounded: Yes

Figure 11.2: Number of water users averaged (±SE) for both Fish Hoek and Muizenberg for the period from 1 November to 11 January versus the period from 13 January to 31 March, in years without a shark attack versus the year with a fatal attack (2010). * $p < 0.001$.

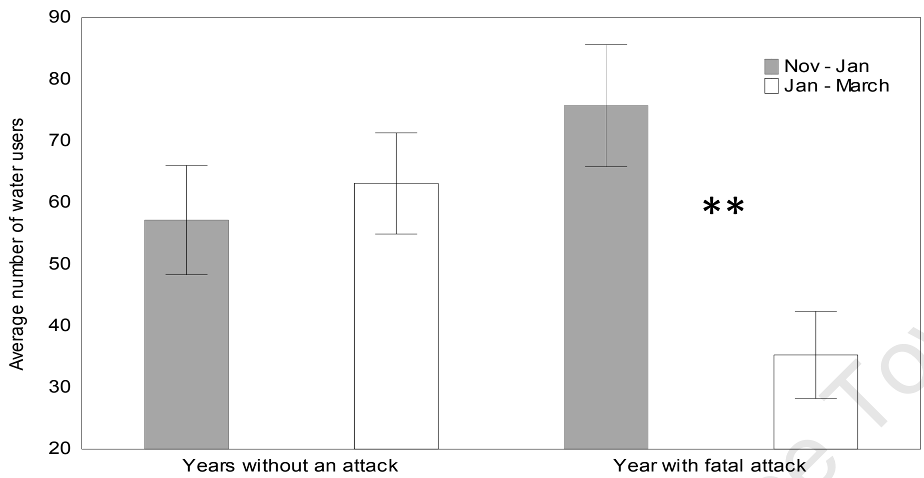
The change in the number of water users during the period 1 November – 11 January versus 13 January – 31 March in years without an attack was not significant ($U = 1175.5$, $N_{Nov\text{-}Jan} = 53$, $N_{Jan\text{-}March} = 56$, $p = 0.0613$), while in 2010 there was a significant decrease in water users over this period ($U = 50.5$, $N_{Nov\text{-}Jan} = 17$, $N_{Jan\text{-}March} = 22$, $p < 0.001$).



Siren sounded: No

Figure 12.1: Number of water users averaged (±SE) for both Fish Hoek and Muizenberg before and after a shark sighting for the period from 1 November 2009 to 11 January 2010 (Before attack) versus the period from 13 January 2010 to 31 March 2010 (After attack) when the siren is not sounded.

There is no significant change in the average number of water users after shark sightings in which the siren was not sounded in the period before a fatal attack (1 November 2009 to 11 January 2010) ($U = 542.0$, $N_{before} = N_{after} = 33$, $p = 0.490$), or in the period following a fatal attack (13 January 2010 to 31 March 2010) ($U = 148.0$, $N_{before} = N_{after} = 18$, $p = 0.335$).



Siren sounded: No

Figure 12.2: Number of water users averaged (±SE) for both Fish Hoek and Muizenberg for the period from 1 November to 11 January versus the period from 13 January to 31 March, in years without a fatal attack versus the year with a fatal attack (2010). ** $p < 0.01$

The change in the number of water users during the period 1 November – 11 January versus 13 January – 31 March in years without an attack was not significant ($U = 999.0$, $N_{Nov\text{-}Jan} = 49$, $N_{Jan\text{-}March} = 48$, $p = 0.204$), while in 2010 there was a significant decrease in water users over this period ($U = 158.5$, $N_{Nov\text{-}Jan} = 33$, $N_{Jan\text{-}March} = 18$, $p = 0.0028$).

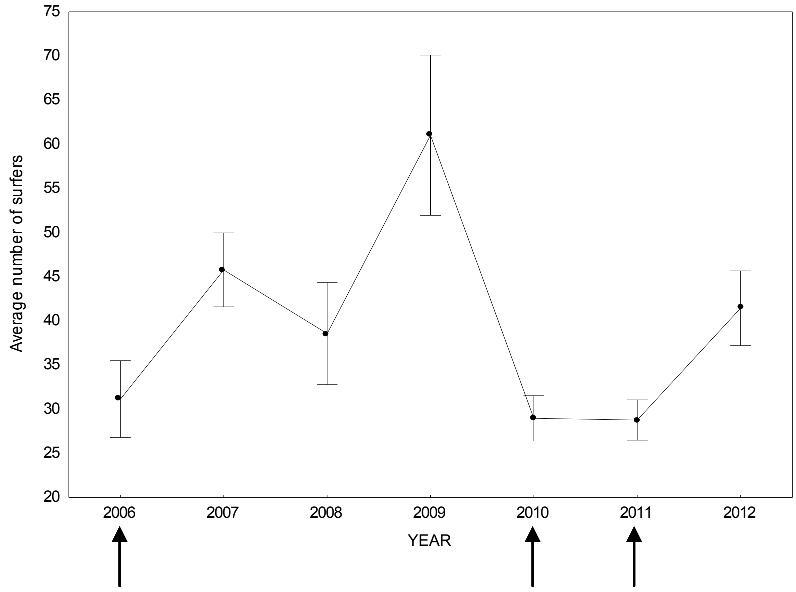


Figure 13.1: Average (±SE) of surfers present at Muizenberg beach between 2006 and 2012. Arrows indicate years in which attacks took place (2006, 2010 and 2011).

The average number of surfers varied significantly in the different years (H = 33.284, N = 510, $p < 0.0001$). The average number of surfers in 2007 and 2009 were significantly higher (Tukey post hoc test: $p < 0.01$) than years in which attacks occurred (2006, 2010, 2011).

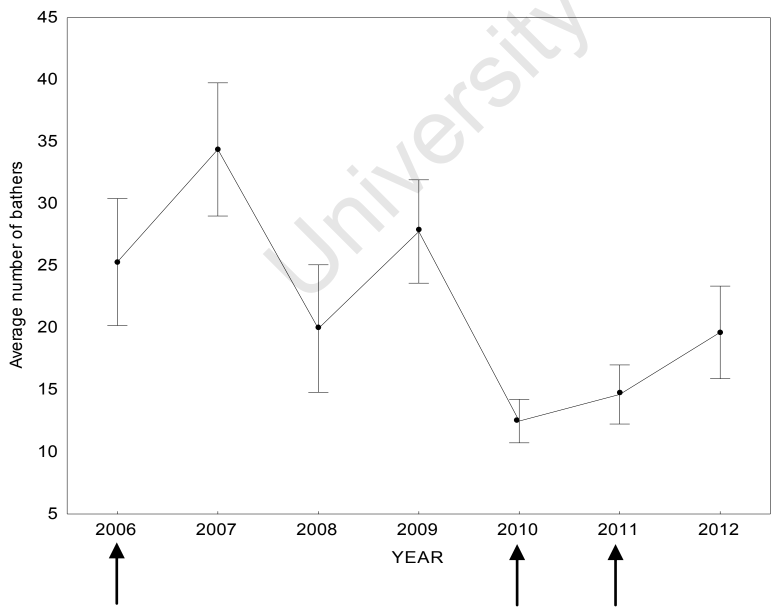


Figure 13.2: Average (±SE) of bathers present at Muizenberg between 2006 and 2012. Arrows indicate years in which attacks took place (2006, 2010 and 2011).

There were significant differences in the average number of bathers in different years (H = 37.923, N = 510, p < 0.001), with the average in 2007 and 2009 significantly higher (Post hoc Tukey test: p < 0.05) than 2010, 2011 and 2012.

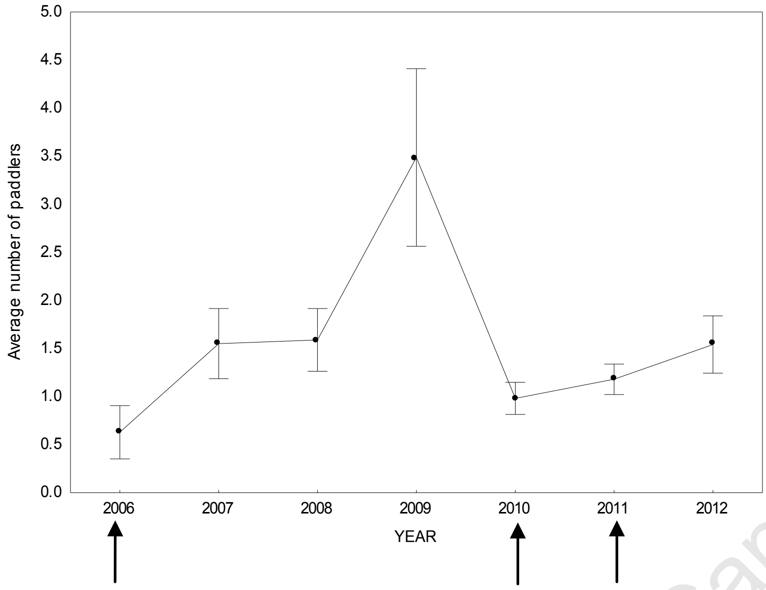


Figure 13.3: Average (±SE) of paddlers present at Muizenberg between 2006 and 2012. Arrows indicate years in which attacks took place (2006, 2010, and 2011).

There were significant differences in the average number of paddlers in the different years (H = 31.189, N = 510, p < 0.001), with 2009 significantly higher (Post hoc Tukey test: p < 0.01) than 2006 and 2010.

DISCUSSION

Number of shark sightings:

According to Kock and Johnson (2006), increases in both shark sightings and attacks in False Bay post 1991 (following the declaration of white sharks as a protected species in South Africa) cannot be used to infer an overall increase in white shark abundance in South Africa. White shark recovery in South Africa was found to be significantly lower than the expected intrinsic rate of population increase, showing that the recovery of the white shark population of South Africa remains depressed (Kock and Johnson 2006). This finding is supported by a recent population estimate for white sharks in South Africa using photo identification and automated software (Towner et al. 2013), which showed that the species has not made a marked recovery since protection in 1991. The increases in sightings in False Bay are thus thought to result from a localised increase by migratory white sharks for this section of the South African coast, although the cause for this preference remains elusive.

Although Muizenberg beach had more shark sightings on average compared to Fish Hoek this difference was not significant and was characterised at both beaches by high inter-annual and seasonal variation. As predicted, the number of shark sightings increased at both beaches during the study period suggesting that the lack of lethal control in False Bay is having a positive impact on overall shark numbers in the region. Alternatively the improved conservation of preferred white shark prey species through the establishment of the Table Mountain MPA may result in more white sharks remaining in the bay for longer and so a greater proportion of sharks in southern African waters may be aggregating in False Bay.

Patterns of shark sightings and recreational water use:

Similar to the findings of Kock et al. (2013) and Weltz et al. (2013) I found that the number of shark sightings peaked during the warmer months at both beaches. Both Kock et al. (2013) and Weltz et al. (2013) suggested that the increased presence of white sharks along the inshore regions of False Bay during spring and summer months reflects an increase in the availability of fish prey species. Although shark sightings were on average more frequent at Muizenberg than Fish Hoek this difference was not significant possibly because of the close proximity of the two beaches (6.4km apart) and the observation that most sharks swam along the coast in a unidirectional manner and hence were likely to be detected at both beaches.

The proportion of sightings that were made when the black versus green flag colours were flying suggests that reduced sightings during winter months is not a result of reduced visibility in winter, but an actual decrease in white shark presence in the inshore zone from May to August. This finding is supported by Kock et al. (2013) who using telemetry showed a marked absence of sharks along the inshore areas during the winter months when the sharks were predominantly found at Seal Island feeding on young of the year cape fur seals.

The summer peak in white sharks on the inshore zone has implications for human-wildlife conflict management, as this corresponds to peaks in water user abundance in False Bay (Herwerden et al. 1989; and figures 4.2 and 5.2, this study). Sightings also varied significantly with time of day, peaking at midday in Muizenberg (Figure 7.1) with reduced sightings in the early morning and evening and significantly higher sightings between 11h00 and 15h00. It is possible that the reduced sightings at dawn and dusk reflect reduced light penetration at these times and hence reduced visibility of surface swimming sharks. This needs to be confirmed through the equivalent of secchi disc surveys from both shark spotter vantage points. Peak shark sightings at Muizenberg beach correspond with peak water use by surfers and bathers in the early to mid-afternoon period (Figure 7.2) and thus there is ample opportunity for conflict. A similar pattern was shown at Fish Hoek, with shark sightings peaking in the early afternoon (Figure 8.1), corresponding with peaks in water use by bathers in the early to mid-afternoon (Figure 8.2). These patterns stress the importance of the shark spotter program in reducing spatial overlap between white sharks and recreational water users during the midday and afternoon peaks.

Water user response to sightings:

At both Muizenberg and Fish Hoek the reduction in water users for the hour after a sighting compared to the hour preceding a sighting was only significant if a siren was sounded to notify water users to the presence of a shark (Figures 9 and 10). This finding illustrates that high risk flags (red and white flags) without an accompanying siren are not sufficient to elicit a response in water users, and hence the siren is an essential component of the program. It was also shown that the number of water users present prior to a sighting differed significantly in cases where the siren was sounded versus not sounded in Muizenberg (Figure 9).

It is possible that the siren may be sounded more readily when there are large numbers of water users present due to the increased area occupied by water users, increasing their proximity to sharks entering the surf zone. Furthermore, spotters may sound the siren more readily when water user abundance is high due to the increased time needed to clear the beach if a shark comes in close proximity to water users.

Water user response to attacks:

Water user response to a siren averaged over both beaches was found to be significantly impacted by the occurrence of a fatal attack. In the months prior to a fatal attack (1 Nov 2009 to 11 Jan 2010) there was no significant reduction in water users after a sighting despite the siren being sounded (Figure 11.1). However in the months following a fatal attack (13 Jan 2010 to 31 March 2010) this behaviour changed, and there was a significant decline in water user abundance in the hour following a sighting accompanied by a siren. This result shows that risk awareness and adherence of water users to shark warnings may decline after extended periods without a shark attack, an observation that illustrates a key challenge to the effectiveness of the shark spotter program. The same analysis was conducted for water user response to sightings in the months preceding and following a fatal attack when the siren was not sounded (Figure 12.1), and it was shown that there was no significant response of water users to a sighting before or following a fatal attack. This shows poor response to warning flags unaccompanied by a siren, even after an attack has occurred. The siren is therefore a key element in alerting water users to the presence of a shark in the inshore zone.

The number of water users present prior to a sighting averaged over both beaches was found to be notably impacted by the occurrence of a fatal attack, with a significant decrease in water user abundance in the months following a fatal attack compared to the preceding months (Figures 11.2 and 12.2). This significant reduction in water users was found to be due to the fatal attack and not due to general patterns in water user abundance with season. This effect was also shown on an annual basis for each water user group (surfers, paddlers, bathers) at Muizenberg beach and in all three cases the year in which a fatal attack occurred (2010) had a significantly lower average number of water users than the preceding year. This shows that the impact of attacks (especially those that are fatal) on water use patterns persists for long periods after an attack, significantly reducing the annual average of water users.

Ultimately these prolonged periods of reduced water use may impact adversely on commercial ventures associated with the recreational use of beaches and this in turn may increase pressure by the public for the authorities to implement lethal control. It is therefore important that the efficacy of the Shark Spotter program be maximised in order to prevent human-shark encounters and the need for lethal control of white sharks in False Bay.

Benefits of the Shark Spotter program:

The Shark Spotter program plays an important role in balancing the needs of recreational water users in False Bay with the conservation of white sharks in the bay. The notable spatial overlap between white sharks and people in the inshore zone of False Bay illustrated by this study would likely result in the need for lethal control of sharks for water user safety if the Shark Spotter program did not actively mitigate conflict between sharks and water users. This effective conservation of white sharks is of particular importance in False Bay as this region is known to have a high proportion of large (>3m) white sharks, and hence may house a significant percentage of South Africa's reproductive stock (Kock and Johnson 2006). Furthermore, data collection by the Shark Spotters provides valuable information on white shark movement and behaviour in the inshore zone and how this varies temporally within False Bay.

Limitations of the Shark Spotter program:

Despite the success of the Shark Spotter program in reducing human-sharks conflicts, there are a number of identified limitations to the Shark Spotter program. The high incidence of "poor visibility" days (denoted by the black flag) due to environmental factors such as wind, cloud cover and rain limit effectiveness of spotting, although sighting data from 2012 indicates that sharks are still frequently spotted in these conditions. Furthermore the program is limited to daylight hours and human error may occur in detecting sharks in the inshore zone, especially if visibility is poor (such as in the early morning and late evening) or spotters are fatigued (Kock et al. 2012). Finally the behavioural response of water users to shark sightings may limit the effectiveness of the program, as shown by the lack of response to flag changes unaccompanied by a siren, as well as reduced response to a siren following long periods without an attack. The attacks in Fish Hoek in both 2010 and 2011 illustrate how human behaviour can limit success in mitigating human wildlife conflict, as in both cases the shark warnings put in place by shark spotters prior to the attacks were ignored by the victims (Oelofse, 2011).

Possible improvements?

According to Kock et al (2012) there are a number of possible improvements that can enhance the effectiveness of the Shark Spotter program, including the use of polarized sun glasses, reduction in shift length for spotters to prevent fatigue, as well as enhanced training of spotters to minimise human errors in sightings. In addition to this, a review of the flag system and better education of water users may be necessary in order to improve response to flag changes unaccompanied by a siren.

Conclusions

Therefore the trends observed in this study highlight the notable spatial overlap between water users and sharks in the inshore zone of False Bay, and the resultant high potential for human wildlife conflict at popular recreational beaches such as Fish Hoek and Muizenberg. The adherence of water users to siren warnings sounded by the Shark Spotters is promising, but lack of response to warning flags needs to be investigated and addressed. Shark attacks are shown to have a negative impact on water use patterns, and likely lead to decreased tolerance of the public towards shark presence in the inshore zone. Improvements to the program to minimise human-shark conflicts are therefore essential.

The limited time frame and numerous confounding variables that had to be excluded in this study restricted the statistical complexity of analyses and hence a more in depth analysis on the available data is recommended. More conclusive results can be drawn from a broader assessment of all beaches at which the Shark Spotter program runs in False Bay with the complete dataset entered on hourly water use and flag colour from 2006 to 2012. Ongoing studies on the spatial use of False Bay by migratory white sharks and possible shifts in distribution of sharks with time will allow further insight into the importance of False Bay as an aggregation site for white sharks, allowing the implementation of more rigid conservation measures for this species in this area.

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