The Presence of Great White Sharks: Associations with Environmental Factors

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Abstract

The white shark (*Carcharodon carcharias*) can be regarded as one of the greatest ambush predators on Earth. White sharks have learned the best techniques, places, and times to hunt to maximize their success rate. They are aware of environmental conditions that affect their chances of success. This paper looks at the frequency of white shark sightings compared to wind speeds in Mossel Bay, South Africa and wind’s effect on white shark hunting behavior. The hypothesis is that more sharks will be hunting during high wind speeds because this decreases water visibility and increases swell height, two known environmental factors that aid in ambush predation. Ambush predators like the white shark benefit from poor water visibility and large swells which put their prey at a visual disadvantage. Sharks in Mossel Bay must rely on water visibility more than water depth to conceal their presence because it is relatively shallow thus making wind speed especially important here. This paper aims to serve as a preliminary analysis of wind speed and suggests that more in-depth studies on wind speed be conducted. Future studies that more accurately and consistently record wind speed and other data will be useful in further proving this hypothesis. Beach-goers, policy makers, and the South African government can all stand to benefit from studies like this one that examine shark behavior and aim to determine shark critical habitat.

Introduction

The white shark (*Carcharodon carcharias*) can be regarded as one of the greatest predators on Earth. Ambush predation is highly calculated to give the shark the best chance at capturing its prey. White sharks are particularly picky eaters and are highly specialized to eat a narrow range of prey items (Compagno 2005, Moss 1977). They preferentially eat high fat prey items such as Cape fur seals (*Arctocephalus pusillus pusillus*, Bres 1993) because hunting is so energetically costly (Duncan 2006, Martin et. al. 2005). Thus, wasting energy while searching for prey and hunting, when it is unlikely that the shark would be successful, seems to be a maladaptive trait. Sensory capabilities of the predator and its prey are affected by the environmental conditions under which predation occurs (Ellis 1986) therefore, ambush predators such as white sharks should favor environmental conditions that increase their ability to predate successfully by
hindering their prey (Hammerschlag et. al. 2006, Sundström et al. 2001, Heithaus 2004). It has been shown that attack frequency of white sharks on pinnipeds has increased with swell height and decreased with water clarity (Pyle et al. 1996, Hammerschlag et. al. 2006). Wind speed affects both swell height and water visibility, so in theory, more sharks should be hunting during windy days than on calm days because it creates optimal hunting conditions.

This paper examines the effects of wind speed on white shark hunting behavior and whether more sharks are in search of prey during windier days. This paper is meant to serve as a preliminary analysis. It utilizes datasets that were available from another study. More in-depth analyses should be conducted in the future to solidify these conclusions.

The hypothesis is that more sharks will be hunting during windier days because this decreases water visibility and increases swell height. The purpose of this paper is to examine wind speed which has not been explored extensively in the past. Previous studies have examined shark behavior as a function of sea surface temperature, dissolved oxygen content, tidal height and range, swell height, and salinity (Carlisle and Starr 2009, Hopkins and Cech 2003, Robbins 2007). The few studies that have explored wind speed have not examined it in depth and have compared it to predation success (Hammerschlag et. al. 2006, Martin et. al. 2009), not shark sighting frequency as this paper does.

The previous studies that have examined predator/prey interactions and how environmental factors affect them usually analyzed the percentage of successful predations out of all observed attacks. This paper examines shark sighting frequency regardless if a predation was observed. Choosing to analyze sightings versus predation
success rate removes the bias that hunting white sharks will always attack prey if they see it instead of waiting until the best opportunity presents itself. Most of the sharks observed here approached the boat and the bait but left once they realized that the bait was not a preferred prey item, and that their success rate was low. Observers could also miss predation events which would skew the results. Sharks have been observed bumping unknown objects with their nose to determine what it was instead of attacking it outright (Bres 1993).

Questions to be Answered

There were three main questions that this paper aimed to answer. The first was, can wind speed be used as a reliable indicator that more sharks will be hunting in the area? Answering this question may further prove that water visibility and swell height are important environmental variables. The second question was, what effect does wind have on the hunting behavior of white sharks? Sharks were observed as more aggressive on windier days, but there is not enough data here to answer how it specifically affects their behavior. There is also no way to define aggressive behavior as opposed to calm behavior. This analysis only shows if more sharks were sighted on days above designated wind speeds. Lastly, how can wind be used to help determine critical habitats for white sharks? If wind speed does play a large enough role in determining shark hunting behavior, it could possibly be used to determine critical habitats. Areas that are known to have consistent, strong winds might be ideal places for sharks to hunt and for conservation.
Oceans Research

Oceans Research is a non-governmental organization based in South Africa that conducts research primarily on South African marine mega-fauna and advises various government and non-government groups on marine conservation issues. The Mossel Bay laboratory focuses on five main objectives pertaining to white sharks: population, behavior, physiology, ecology, and socioeconomics. Population data is assessed through photo and genetic-identification. A database of shark dorsal fins has been created by Oceans Research and is being used to catalogue the resident sharks within Mossel Bay and to compare them between other shark sightings in South Africa. Behavioral data is collected through manual tracking which allows a fine scale of detail of the sharks’ movements to be recorded. Physiological data is determined through bite-strength meters and acoustic telemetry. Ecological data is examined through predator-prey relationships between the white sharks and Cape fur seals. Lastly, socioeconomics are studied through the analysis of cage diving in Mossel Bay and proposed and current fish farms in South Africa. The data used for this paper was collected during chum trips when Oceans Research interns would collect photographs of dorsal fins and genetic samples for their population study. Other observations were also made during manual tracking trips. Observations were made by the author while interning at Oceans Research during the months of June and July of 2010.

Methods

Two chum trips were conducted almost daily (excluding weekends) from 2001-2010 at Oceans Research in Mossel Bay. A chum slick consisting of sea water and fish
oil was released into the water constantly during each trip to attract white sharks. A frozen fish head tied to the end of a rope with a buoy attached (Figure 1) was used to coax nearby white sharks to the surface for photo identification. Multiple observers kept track of the nearby sharks simultaneously to avoid double counting of individuals. Trips would last an average of 2.5 hours. The start and end time of the chum trip was recorded which then gave the total time of the trip. The number of sharks observed on each chum trip was then divided by this number to obtain number of sharks per hour. This calculation was done to normalize the number of sharks tested since chum trips lasted various time lengths.

![Figure 1 An example of bait rope handling.](image)

During the chum trips, Oceans Research interns recorded environmental parameters including cloud cover, wind speed, wind direction, and swell height. This environmental data was inconsistently recorded however because interns were more focused on obtaining dorsal fin photographs which is the primary goal of Oceans Research. It is for this reason that this study is meant to serve as a preliminary analysis, though its outcome is still useful.
Interns are only required to work at Oceans Research for a minimum of one month. Therefore, they change on a monthly basis and the new interns must be taught how to accurately collect and enter data based on Oceans Research’s goals. This limited time frame for interns is another reason why there are so much missing data because every month similar mistakes are repeated by the new interns.

Available Datasets

There were four datasets available for this study (Table 1): 2001-2005, 2008, 2009, and 2010. A fifth dataset was created in which all of the available data was combined. The size of the dataset and the amount of missing data in it is a good indicator of how reliable each dataset is and should be considered when looking at the results of this study.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Sample Size (n)</th>
<th>Amount of missing data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001-2005</td>
<td>266 (Mossel Bay only), 796 (Mossel Bay, Gansbaai, and Port Elizabeth)</td>
<td>Low</td>
</tr>
<tr>
<td>2008</td>
<td>223</td>
<td>Medium</td>
</tr>
<tr>
<td>2009</td>
<td>314</td>
<td>High</td>
</tr>
<tr>
<td>2010</td>
<td>67</td>
<td>High</td>
</tr>
<tr>
<td>combined</td>
<td>886</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 1 Available datasets for this study with their sample size and amount of missing data.

The 2001-2005 dataset is large and has little missing data; this observational period is considered a reliable and accurate dataset. It had data not only from Mossel Bay, but from two other ports with notable shark activity, Gansbaai and Port Elizabeth. In the analysis, Mossel Bay was analyzed separately as well as combined with the two other ports. The 2008 dataset is slightly smaller than the 2001-2005 dataset, and there is more missing data, but it is still useful. The 2009 dataset is slightly larger than
the 2008 dataset, but there are many more missing data than the 2008 dataset. Lastly, the 2010 dataset is very small with the most missing data. The last two datasets are highly influenced by the missing data and are much less reliable than the first two datasets.

Testing Wind Speed

The datasets were sorted based on wind speed from low to high. Each dataset was tested three times using a different wind speed cutoff each time. Sharks per hour below the wind speed cutoff were classified as “good weather” and sharks per hour above that wind speed were classified as “bad weather” (see Appendix I for a summary of data). Good and bad weather were entered into two columns into the program Statmost 32 and compared for significance using a Tukey test. A Tukey test was the most appropriate method over a simple t-test because a Tukey test eliminates type I error, which was a very likely possibility given the amount of missing data in the available datasets. Wind speed cutoffs were chosen to be 3 knots, 5 knots, and 8 knots. Wind speeds above 8 knots become more problematic to classify because they were recorded as a broad range. Testing wind speeds higher than 8 knots therefore became impractical because clearly defining each wind speed was more ambiguous. Once each dataset was tested for each wind speed cutoff separately, the data for each year was combined under the three different wind speed cutoffs and tested again to give the fifth dataset. This information was useful because it shows how much influence the missing data had on the individual datasets (See table 2 in Results).

When the wind speed was listed as a range, the median of the range was used to classify the day’s wind speed. Wind speeds were estimated by visual cues such as white
caps on the water’s surface while out on the boat during the chum trip, so ranges were best estimates of the observers on a given day. Therefore, using the median of the range is not assumed to greatly alter their estimations or impact the findings.

The only dataset that presented different bait types was the 2001-2005 dataset. On each chum trip a combination of three different baits were used. It is assumed that there was no difference in shark frequency between bait types during this time period since bait types were used simultaneously. In the other datasets, it is assumed that only one type of bait was used since nothing was recorded.

This analysis is meant to test shark sightings regardless of anchorage point. Testing all of the anchorage points simultaneously gives a good variety of known resting and hunting locations within Mossel Bay. Oceans Research has observed and recorded white shark hunting and resting locations within Mossel Bay during their manual tracking trips. Significant differences between the anchorage points may be due to these various location preferences but that analysis is beyond the scope of this study.

**Missing, Inconsistent, and Incorrect Data**

While there is a significant amount of missing data in the newer datasets, the older, more complete datasets, can be viewed as quite reliable. Not only is missing data a problem with these datasets but inconsistent and incorrect data is as well. For example, the finish time of the chum trip was not always recorded. This missing information made calculating the number of sharks per hour impossible because the total time of the trip was unknown. In one instance, a chum trip was listed as lasting one minute. It can be assumed that the hour was entered incorrectly, but it still renders the information useless
since the correct time is unknown. On several occasions, wind speeds were recorded as
dates (most likely due to the auto format function in Microsoft excel). All of the missing
or incorrect data described above was excluded from the analysis.

Human error when entering and analyzing the data was also a huge issue with
these datasets. When the wind speed was recorded as a range it prevented excel from
sorting the information correctly. This caused the data to be out of order which increased
the effect of human error when copying the datasets from Microsoft excel into
StatMost32. Another issue was that, while the same data was used for each year in the
different wind speed cutoffs, the size of the dataset analyzed in StatMost32 seemed to
vary.

*Anchorage points*

There were six anchorage points in Mossel Bay that showed up in the available
datasets. These were chosen at random at the beginning of each day. They were
anecdotally named Beneke’s Klip (only seen in the 2001-2005 dataset), the Blue Houses,
Hartenbos, Grootbrak, Kleinbrak, and Seal Island (Figure 2).
Results

Table 2 shows the datasets and whether or not there was a significant difference between the number of sharks that were observed during “good weather” versus “bad weather” (p < .05). The size of the 2001-2005 dataset, when only testing data from Mossel Bay, was significantly smaller (Table 1). Testing the Mossel Bay data alone resulted in insignificance for the 5 knot and 8 knot wind speed cutoffs (p-values of .5238 and .3769 respectively). When all three ports were included in the analysis, the 5 knot and 8 knot wind speed cutoffs were significant (Table 2).
The 2009 dataset had a lot of missing data which is most likely why it showed insignificance. In the 2010 dataset, only the 3 knot wind speed cutoff was insignificant. It is unclear at this time if the 5 knot and 8 knot wind speed cutoffs were significant due to the missing data. The two older datasets that showed significance have very low p-values. Low p-values are good evidence that wind speed is a valid parameter to study when interested in environmental conditions that affect white shark hunting behavior.

For the 5 knot cutoff, the combined dataset is close to being significant (p=.0755), despite the inclusion of the 2009 dataset which had a very high p-value. The combined dataset uses all three ports from the 2001-2005 dataset. This insignificance in the combined dataset shows how influential the 2009 dataset is over the other three datasets. This means that the missing data in the 2009 dataset is likely to be the cause of its insignificance.

### Discussion

**Who Will Benefit**

Beach-goers will benefit from this information because wind speed is easy to observe and can serve as a safety measure if they are afraid of encountering a shark.

<table>
<thead>
<tr>
<th></th>
<th>3 knots</th>
<th>5 knots</th>
<th>8 knots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2001-2005</strong></td>
<td>yes-.0344</td>
<td>yes-9.116E-5*</td>
<td>yes-.0011*</td>
</tr>
<tr>
<td><strong>2008</strong></td>
<td>yes-.0012</td>
<td>yes-.0043</td>
<td>yes-.0012</td>
</tr>
<tr>
<td><strong>2009</strong></td>
<td>no-.5109</td>
<td>no-.2295</td>
<td>no-.3167</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>no-.3908</td>
<td>yes-.0055</td>
<td>yes-.0068</td>
</tr>
<tr>
<td><strong>combined</strong></td>
<td>no-.1987</td>
<td>no-.0755</td>
<td>no-.3043</td>
</tr>
</tbody>
</table>

**Table 2** Significance of the datasets with p-values. Significant differences are shown in bold. *This data shows the analysis using all three ports for the 2001-2005 dataset. The analysis of Mossel Bay alone showed no significance p-values: .5238 for 5 knots and .3769 for 8 knots.
Warnings can be displayed at public beaches during particularly windy days to caution beach-goers of the likelihood of encountering a shark. These warnings may be beneficial in South Africa where some of the most popular beaches are also home to many sharks.

Policy makers who are interested in delineating shark critical habitat and creating marine protected areas (MPAs) may also benefit. South Africa would benefit from more MPAs since currently only 15% of their coastline is protected (“Four New Marine Protected Areas” 2004). Globally, it is believed that white shark numbers have decreased as much as 60-95% within the last 50 years (Great White Shark 2007). MPAs have been shown to aid in population recovery (Crowder 2000).

Determining white shark critical habitat is an important initial step towards their conservation. Wind may help determine critical habitat if areas that typically display prolonged periods of strong winds are preferred by white sharks as hunting grounds. These areas could be set aside for conservation purposes and to protect beach-goers.

South Africa’s economy depends largely on the white shark cage diving (WSCD) industry. The South African government may benefit from critical habitat protection if they can profit from having more sharks in their waters. In 2004, more than 26,000 tourists went on WSCD trips. The eight WSCD operators in Gansbaai alone, out of 14 nation-wide, generated an income of almost $4.3 million (USD) over a 12 month period from direct ticket sales (“Draft White Shark Cage Diving Policy and Regulations” 2006).

*Marine Protected Areas in South Africa*

Before 2004, South Africa only had 19 MPAs encompassing 11% of their 3000km coastline (“Four New Marine Protected Areas” 2004). After 2004, the
government created four more MPAs bringing their total to 23 MPAs encompassing 15% of their coastline. South Africa has a zoned MPA system. The three zone types are: controlled zones, restricted zones, and sanctuary zones. Only sanctuary zones are “no-take” which means that no fishing or invasive tourism practices such as cage diving can occur there. “Marine protected areas allow for the conservation of natural environments, while assisting in the management of fisheries by protecting and rebuilding economically important stocks” (“Four New Marine Protected Areas” 2004). This protection means that, while no cage diving can occur within the MPAs, they are still important in supporting a viable stock of sharks outside of the MPAs where cage diving does take place. “No-take” zones in South Africa only account for 9% of their coastline which constitutes only 270km (“Four New Marine Protected Areas” 2004). Figure 3 is a map of South Africa (Google Earth 2010) showing the current MPAs (outlined with white lines), pointed out by the yellow arrows.

Figure 3 Map of South Africa with the marine protected areas pointed out with yellow arrows. Individual MPAs may be hard to discern given the scale of this map.
Related Studies

There have been many related studies on various shark species that correlate environmental conditions to their behavior. A few significant findings are summarized below.

Martin et. al. (2009) noticed that a decrease in stalking depth of white sharks increases the probability of visual detection by seals. This decrease in stalking depth reduces the amount of water between the predator and the prey (which is important to the shark when trying to hide from their prey) as well as the vertical strike distance and thereby the impact energy and the probability of incapacitation. Initial incapacitation is an important component of ambush predation for white sharks. It can save them energy while hunting by preventing them from having to chase down their prey at full speed. Where sharks hunt in Mossel Bay is particularly shallow (Figure 4) because their pinniped prey typically stay close to the shore unless heading out to sea. During tracking trips with Oceans Research, the shark being tracked rarely went in waters deeper than 5-10m (Gennari 2010). Therefore, it seems likely that wind speed plays a predominant role in when sharks hunt in Mossel Bay where they are forced to hunt in shallow water.

Figure 4 A map of Mossel Bay showing water depth in meters.
Shallow water, in the case of Mossel Bay, means that more turbidity is required to help the shark hide. White sharks try to maximize their vertical distance from their prey, up to 30m, to avoid being detected and allow them to build up momentum to launch an attack (Hammerschlag et. al. 2006, Goldman and Anderson 1999). Depths of 30m seem to be the maximum at which a shark can maintain visual contact with their prey at the surface (Goldman and Anderson 1999). Martin et al. (2009) suggested that white sharks have a visual advantage over cape fur seals while stalking them from the sea floor during conditions that affect visibility.

Sharks do not have a specific location where they call home, they are constantly moving to breathe. However, they do have a specific hunting location that they gravitate towards. This preferred hunting location is learned through hunting experience. The shark has found this location to be successful given environmental conditions, competition with other sharks, and availability of prey. Martin et.al. (2009) show that shark hunting patterns are not only non-random, but centered around an optimal “anchor point.” The anchor point is not simply where sharks are likely to encounter the most prey, but also where they have the highest success rates of catching their prey, based on bathymetry and environmental conditions. This behavior may not only be related to spatial and environmental conditions but on a temporal scale as well. Separating feeding bouts by periods of fasting may also be a learned hunting strategy. Klimley et. al (1992) suggested that this might increase the sharks success rate because its pinniped prey may become less vigilant and more vulnerable with time since the last predation.

Martin et. al. (2009) noted that older white sharks exhibit greater predation success rates than younger individuals. Mature white sharks usually remain near a
hunting ground that they have found to be successful and show a limited spatial and temporal range displaying their focused and learned selection of a hunting ground (Martin et. al. 2009, Goldman and Anderson 1999, Sundström et. al. 2001). Younger sharks that are less experienced have larger hunting ranges (i.e. less well-defined anchor points) until they figure out where the prime hunting grounds are. Younger sharks may also have to choose a less than optimal location due to intraspecific competition.

Heithaus, et. al. (2004) discovered that tiger sharks rarely engaged in prolonged high-speed chases, and did not attack prey that were vigilant. Not only must sharks be aware of their surrounding environmental conditions, but the vigilance of their prey as well. Selecting the most vulnerable prey and the easiest target will save energy when hunting. While it is advantageous for a prey to exert as much energy as possible to escape a predation, it is not advantageous for a shark to exert maximum energy (Martin et. al. 2005).

Goldman and Anderson (1999) point out that little is known about the pre- or post-predation stages of shark hunting behavior. These include the stages before a prey is sighted and after a feeding event has concluded. Analyzing wind speed could uncover important information about the pre-predation stage and sharks’ decision making process when choosing when and where to hunt.

Olfaction plays an important role in predatory behavior, especially under conditions of poor water quality and light intensity. Sharks use olfaction as a normal part of predatory behavior and these cues may be the most important factor in detection of prey at a distance (Bres 1993). Demski and Northcutt (1996) found that olfactory bulbs in white sharks comprise 18% of their total brain mass which is more than any other
shark species. This olfactory dominance explains how white sharks can smell large slicks of chum and seal excreta for miles out at sea.

Environmental conditions such as wind speed may influence a shark’s initial choice of habitat. Sharks could have initially been attracted to Mossel Bay by seal excreta that was blown out into the ocean (Hammerschlag et al. 2006, Strong et al. 1992). Once sharks arrived in Mossel Bay, they would have remained there because it is an optimal hunting ground. It has been shown by Hammerschlag et al. (2006) and Martin et al. (2005) that sharks cease to hunt if their predation success rate drops below 40%. If the sharks were less than 40% successful at predation in Mossel Bay, they would have left to find another hunting spot. This shows that Mossel Bay has an optimal combination of prey availability and environmental conditions.

Oceans Research also conducted manual tracking of white sharks which showed more detail on their hunting and resting behavior. Manual tracking allows a finer scale of detail which automated tracking does not provide. This temporal oscillation displays white sharks’ calculated hunting behavior.

**Manual Tracking of White Sharks**

Oceans Research conducts manual tracking of white sharks and has completed several tracking sessions that lasted over 100 hours. It was observed during these tracking trips that once the shark had eaten, it remained near the mouth of the Hartenbos River to rest, away from the Cape fur seal colony on Seal Island (Figure 5). After several days, the shark would travel back towards the seal colony to patrol and wait for an opportunity to feed. The shark typically wouldn’t feed for a few days more, waiting for
the highest probability of predation success. This behavior shows how sharks only feed when necessary, not simply because prey is available or presented to them.

**Summary of Findings**

This preliminary analysis shows that there is a correlation between wind speed and shark presence and that wind speed can be used as a reliable indicator that more sharks will be hunting in the study area. Further studies on different locations would help confirm these findings because this may differ with location, but there is enough evidence here to show that white sharks in Mossel Bay rely somewhat on wind. Higher winds cause more sharks to be in “hunting mode” because it creates optimal hunting conditions for them by aiding their ambush predation technique. Looking at areas that are known to have consistent, strong winds may aid in delineating shark critical habitat. Windy areas that also have seal colonies might be strongly preferred by white sharks and should be
protected for the shark and seals’ sake. Countries like South Africa that depend largely on ecotourism such as white shark cage diving may benefit from more MPAs that protect sharks.

Figure 6 shows a simplified diagram of how wind speed affects shark decision making about hunting. This flowchart serves as a visual summary of this paper’s findings, not as an all-encompassing diagram. Physical surroundings such as wind speed, swell height, water visibility and other environmental factors (such as salinity, dissolved oxygen content etc.) affect this decision, as well as prey density and time since the shark’s last predation. Biological factors such as the age of the shark and the age of its prey also play a role and there are many unknown factors that have yet to be discovered or studied. All of these conditions point to the energy lost during the hunt because they can help reduce this energy cost if they are optimized.

**Figure 6** A flowchart that shows factors that affect shark predation. There are many other environmental factors that play a role here and not all factors that could affect a shark or its prey are shown. This flowchart is meant to serve as a visual explanation of how complex the thought process of a shark might be.
The main reason why there are so many missing data is because Oceans Research doesn’t require environmental conditions to fulfill their purposes. Oceans Research’s photo database is still functional without the environmental conditions or a start and finish time for the chum trip. The analyses given here are still useful as a preliminary approach to studying wind speed as the most complete datasets show significance in their findings.

*Recommendations and Future Studies*

It is recommended that Oceans Research aim to consistently record environmental data because they could simultaneously study environmental conditions that affect shark behavior while collecting photographs for their database. Using an anemometer on every chum trip instead of estimating wind speed would also help them to be more consistent. A more in-depth and precise study of wind speed would help to solidify these findings since these data came from a study not aimed at wind speed.

Related studies on wind could include testing wind direction, or if there is a minimum or maximum wind speed that affects white sharks. Wind direction and its effect on sharks may vary between locations (i.e. Mossel Bay and Gansbaai) but be constant in one place (i.e. sharks prefer winds blowing from the north in Mossel Bay). Perhaps there is a minimum wind speed below which, shark behavior doesn’t change or a maximum wind speed above which their behavior doesn’t change.

A future study on younger sharks compared to more mature sharks might show that younger sharks are less affected by environmental conditions such as wind. Comparing the effect wind speed has on different shark age groups may further prove
that young sharks are less aware of the best hunting conditions and that they learn this hunting technique as they age.

A similar study on environmental conditions could test if certain seasons affect shark sighting frequency since few studies on season have been conducted in the past (Klimley 1992). Season, coupled with wind speed and direction, could give even more insight into temporal shark hunting behavior and where preferred habitats are. Knowing when and where sharks are likely to be hunting could greatly help conservation efforts and beach-goers. The difference between shark sightings and anchorage points could be tested in the future as well.

**Conclusion**

The information presented here on the relationship between wind speed and white shark hunting behavior is useful in understanding the environmental factors that affect sharks. This analysis demonstrates that wind speed plays a role in white shark hunting behavior and is certainly worth studying in more detail. Any institution that wishes to further investigate wind speed could use this analysis when planning a more detailed study.

It has already been proven that other environmental factors including swell height and water visibility affect shark hunting behavior. Studying wind speed more closely could provide new insight into shark behavior and aid the conservation community and beach-goers alike.
Acknowledgements

I would like to thank Oceans Research for providing the data to analyze here and the use of their facilities. The Environmental Internship Fund for providing a substantial amount of financial aid to travel to South Africa. Bill Kirby-Smith for his advice and guidance, Josh Black for editing my work, and Elise Leduc for helping me create a GIS map of Mossel Bay.

The views presented here may not necessarily be shared by Oceans Research.
References


“Four New Marine Protected Areas.” 24 June 2004. 22 Oct. 2010


Appendix I
This chart shows a sample of data from the 2001-2005 dataset. Only columns that were analyzed for this study are shown. Data has been sorted by wind speed so only wind speeds of 1 knot are displayed.

<table>
<thead>
<tr>
<th>Date</th>
<th>Start time</th>
<th>Finish time</th>
<th>Time</th>
<th>Sharks</th>
<th>Sharks/hour</th>
<th>Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/03/2003</td>
<td>10:36</td>
<td>13:45</td>
<td>3.15</td>
<td>2</td>
<td>0.63</td>
<td>1</td>
</tr>
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<td>15:01</td>
<td>5.82</td>
<td>4</td>
<td>0.69</td>
<td>1</td>
</tr>
<tr>
<td>6/03/2003</td>
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<td>1.68</td>
<td>2</td>
<td>1.19</td>
<td>1</td>
</tr>
<tr>
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<td>1.92</td>
<td>6</td>
<td>3.13</td>
<td>1</td>
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<td>14:05</td>
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<td>1</td>
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Appendix II

The following is an example of the 2008 dataset analyzing the 8 knot wind speed cutoff.

---

ColName | Count | Mean   | Std.Dev. | Std.Err.  
---------|-------|--------|----------|-----------
good_weather | 167   | 1.1535 | 1.1059   | 0.0856     
bad_weather  | 56    | 1.7637 | 1.4582   | 0.1949     

---

One-Way ANOVA Table

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Tukey’s Test

Sorted mean:

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Significance Level: 0.05
Degree of Freedom: 221
Variables | Range | Mean Diff | Critical Value | Significant
---|-------|-----------|----------------|----------------|
good_weather Vs. bad_weather | 2      | 0.6103    | 0.3661         | YES

Bartlett Test

Hypothesis:

H0: All group variances are equal.
H1: At least two of the group variances are unequal.

MSS: 1.4478

Group Num | Size | Variance |
----------|------|----------|
1         | 167  | 1.2230   |
2         | 56   | 2.1264   |

Bartlett Chi-Square: 6.8728
Critical Chi-Square: 0.0039
Reject H0.

---

StatMost Report Created by Karen, Duke University