Possible causes of a substantial decline in sightings in South Africa of an ecologically important apex predator, the white shark

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A decline in sightings of a top predator, the white shark (*Carcharadon carcharias*), in South Africa was quantified in order to identify possible causes for this decline. White shark sightings data across 8 years (2011–2018), recorded from a cage-diving vessel in Gansbaai are reported. A significant decline in mean total white shark sightings per boat trip (>6 in 2011 to <1 in 2018) and a 69% reduction in the probability of a sighting were found. Correlating with this decline in sightings is a rise in sightings of sevengill sharks (*Notorynchus cepedianus)* in False Bay and copper sharks (*Carcharhinus brachyurus)* in Gansbaai, as well as substantial ecosystem changes. The effects of lethal conservation measures such as the use of shark nets in KwaZulu-Natal; the direct and indirect effects of overfishing including a reduction in smoothhound (*Mustelus mustelus)* and soupfin (*Galeorhinus galeus*) sharks; and novel predation on white sharks are discussed as possible causative factors for this decline in white shark sightings.

Significance:

- The results of this paper highlight the need to reassess the impact of marine conservation initiatives and fishing practices. Failure to do so could seriously affect ecologically and economically important marine species. This paper reveals a potentially serious decline to the South African white shark population, characterised by a substantial decline in white shark sightings. This decline correlates with the overfishing of prey species, bycatch, the use of lethal gill nets and ecological changes such as the novel presence of orca. Better marine management is required if South Africa wishes to keep a healthy white shark population.

Introduction

Of the more than 1000 species of sharks and rays, approximately half are classified by the International Union for Conservation of Nature (IUCN) as vulnerable, endangered, critically endangered or near threatened.[1] Between 63 million and 273 million sharks, belonging to 61 species, are killed by human activity each year – mainly from legal and illegal fishing operations.[2] The white shark, *Carcharadon carcharias*, is an example of one of these species.[3] White sharks perform important regulatory roles in coastal ecosystems by influencing the structure and function of communities via both direct and indirect predatory effects.[4] Their removal has been shown to cause reductions in marine biodiversity and cause negative trophic cascades.[5] For instance, white sharks control the population of meso-consumers, like Cape fur seals (*Arctocephalus pusillus)*.[6] Without white shark predation, and a reduction in the threat of their predation, the fur seal foraging range has extended, resulting in the removal of refugia for seal prey species[7] which has reduced the populations of economically significant fishery species.[4-6]

White sharks also provide fiscal benefits to the South African economy.[8] For example, the Gansbaai shark cage-diving industry raised USD4.4 million in 2003 and brings an estimated USD2 million into False Bay annually, excluding multiplier effects (e.g. hospitality industry).[9] More recently in Gansbaai, a complete white shark absence for 21 days was predicted to have caused a loss of ZAR1.5–2 million in January 2016.[10] Therefore white sharks are considerably important to South Africa's economy.

Historically, white sharks were exploited by fisheries and are still caught as bycatch.[11] They are also still legally culled despite being granted protected status in South Africa in 1991.[11] For example, from 1976 to 2008, 1073 sharks were killed in shark nets in KwaZulu-Natal.[11] This resulted in a 99% reduction in adult white sharks caught.[11,12] There is also evidence to suggest that the white shark population is declining.[6] For example, at Seal Island in False Bay, an overall non-significant decline in white shark sightings occurred up to 2014 and sightings were the lowest on record during 2016–2018.[9] Given the economic importance of white sharks to the tourism industry and their wider ecological significance, identifying the reasons for this decline in sightings is vital. Data on sightings from 2011 to 2018 in Gansbaai, a white shark hotspot on the Western Cape, were used to determine some of the possible causes of the decline in white sharks in South Africa.[6]

Methods

The data used for this study were collected between January 2011 and December 2018 from an ongoing survey of sightings. Data collection occurred in all months except November 2011, October 2012, January 2016 and June 2018. In total, 92 months of data were analysed. The annual trend in sightings across the 8 years was analysed. Overall, 3010 trips were undertaken and 15 122 shark sightings were documented. In this context, one sighting equates to at least one shark seen within the duration of a trip, and is not the total number of individuals sighted within the trip. Shark sightings per year varied from a peak of 2644 in 2013, and a minimum of 360 in 2018. To control for sampling effort, the total number of shark sightings was divided by the total number of trips (Table 1).

Table 1: The mean(±s.d.) number of white shark sightings per trip per year and the total number of trips

Year	Mean shark sightings per trip	Total number of trips
2011	5.50±3.66	297
2012	7.31±3.63	345
2013	7.21±1.66	412
2014	5.84±2.69	457
2015	4.39±2.76	341
2016	4.73±2.72	424
2017	1.21±1.73	386
2018	0.81±1.04	348

Observations were recorded 9 km southeast of Gansbaai, in the proximity of Dyer Island and Geyser Rock (collectively known as 'shark alley') and at an inshore reef system known as Joubertsdam. A 10.6-m ecotourism cage-diving boat, operated by White Shark Projects, collected all the data used in this project. Trips were conducted up to three times a day, weather permitting. The trips started at 07:00, 10:00 and/or 13:00 and lasted 3 h. Sharks were attracted to the vessel via an olfactory cue of chum consisting of local fish farm discards and by throwing and dragging a tuna head attached to a rope in the water. These cues were provided for the entire duration of every trip.

All statistical analyses were conducted using the statistical software 'R studio 2018'.[13] The distribution of the shark sightings per trip data was bimodal, because some trips had zero sightings. Therefore, a binomial generalised linear model was used to test if the probability of sighting a shark changed per year. This model was tested using an analysis of variance (ANOVA), with a chi-squared test. Then, shark sightings ≥1 were normally distributed, so a linear model was used to investigate if shark sightings per trip ≥1 differed per year. An ANOVA was used to test the significance of this model.

Results

The total reduction in the probability of sighting a shark per trip was 69% over the 8-year period from a maximum of 100±0.0% in 2013 to a minimum of 31±0.48% in 2018 ($X^2_{1,177}=135.6$; $p<0.0001$). From 2011, the mean number of shark sightings decreased by 0.81 sightings per trip each year ($F_{1,141}=14.8$; $p<0.001$) (Figure 1). In total, over eight years, mean white shark sightings per trip declined by 6.5. Initially, mean white shark sightings increased to a peak in 2012 of 7.31±3.63. However, in 2013, a gradual decline in mean white shark sightings per trip began. With the exception of 2016, on average, each year saw a decline of 1.3 white shark sightings per trip. At the end of this study period in 2018, white shark sightings per trip were at a minimum of 0.81±1.04.

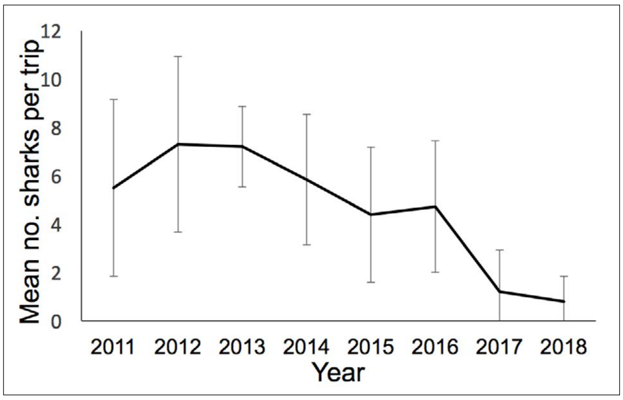

Figure 1: The trend in mean (±s.e.) number of shark sightings per trip, across the 8-year project.

Discussion

The main finding of this research project was that white shark sightings substantially decreased from >6 sharks per trip to <1 shark per trip over the 8-year study period, in a region internationally recognised for its high white shark abundance.[6] A recent project assessing population size using mark-recapture and genetic sampling between 2009 and 2013 concluded that it was reasonable to assume white sharks sampled at Gansbaai were representative of the whole South African population.[6] The aforementioned project estimated that the white shark population consisted of between 353 and 522 individuals, with a small contemporary effective population size of 333.[6] Therefore, if the sightings data in this paper are indicative of a decline in the white shark population, then this population is at serious risk of extinction.

It is likely that direct mortality of white sharks has contributed to the decline in white shark sightings seen here. For example, the KwaZulu-Natal Sharks Board reported that an average of 16.8 white sharks were killed in their nets per year between 2013 and 2017.[14] This number equates to ~84 white sharks killed in total in 5 years.[14] Assuming Andreotti et al.'s[6] population estimate of the South African white shark was accurate, then shark nets were responsible for between ~one-sixth to a ~one-third decline in the white shark population from 2013 to 2017.[6,14] Moreover, white sharks had a mean spatial overlap with fishing effort of 64% (median 65%) in the southwest Indian Ocean and have been shown to swim in the highest-risk zone in all oceans in which they were tracked.[15] In fact, since 2016, two white sharks were reported as bycatch by the South African demersal shark longline (DSL) fishery – one fatally in May 2019.[16] It is likely that the true number of white shark bycatch in South Africa is underreported by the DSL fishery.[17] For example, in 2017, the South African Department of Agriculture, Forestry and Fisheries ran a bycatch assessment experiment from a (DSL) vessel in Algoa Bay.[18] In just one day of operation, three white sharks were caught[18] (Fallows C 2020, written communication, July 25). Moreover, in Australia, white shark bycatch is reported to be six times higher than that in South Africa, with a reported estimated catch of >30 white sharks per year in 2014.[19] Therefore it is likely white sharks are subjected to a high risk of becoming bycatch from longline fishing[16], and might still be killed at unsustainably high levels in KwaZulu-Natal shark nets[14].

Overfishing of white shark prey species could also be a significant contributor to the decline in white sharks in South Africa.[20] Analyses of the stomach contents of 225 white sharks caught between 1978 and 2009[21] and 591 white sharks from 1974 to 1988[22] caught in the KwaZulu-Natal nets, indicated that for ~75% of their lifespan, elasmobranch and teleost prey made up ~60% of their diet. Dusky sharks (*Carcharhinus obscurus)* and small sharks including smoothhound (*Mustelus mustelus)* and soupfin (*Galeorhinus galeus)* sharks were the main prey items.[22] From 2013 to 2017, dusky sharks were also the most commonly caught shark in KwaZulu-Natal nets, with an annual average mortality of 78.6 individuals per year.[14] Due to overfishing, substantial declines in smoothound[23] and soupfin sharks also correlated with the decline in white shark numbers[24]. Following a reallocation of the fishery in 2013, and a fishing effort increase in 2015, the soupfin shark population dropped to ~13% of carrying capacity[23], and the smoothhound population decreased by 30%[24]. Around this time, fishing pressure was strong in False Bay but has now shifted eastwards to near Mossel Bay.[24] Furthermore fishing effort has increased[16] – for example, smoothhound have been fished by the DSL at an extent 1.6–2.2 times higher than that recommended for all South African fisheries, including 17 588 (~123 t) individuals in 2016 and an estimated 23 592 (~165 t) individuals in 2019.[16]

Overfishing has also led to a reduction in pelagic sharks including shortfin mako (*Isurus oxyrinchus)* and blue (*Prionace glauca)* sharks.[25] These sharks are usually preyed upon by a pelagic ecotype of orca (*Orcinus orca)*.[25] In 2017, this type of orca was observed inshore and five liverless white shark carcasses characteristic of orca predation washed up in Gansbaai.[26] Therefore, overfishing may have severely decreased prey stocks, causing orcas to predate on white sharks.[20] In response, white sharks may have temporarily left the Western Cape waters to evade the new predation pressure.[20] A similar response by white sharks to orca predation was documented at the Farallon Islands, USA.[27] This could help explain the sudden drop in white shark sightings from 2017 onwards, but it is likely to have a medium-term effect.[20] White shark sightings started declining in 2013, prior to the arrival of orca.[20] Therefore, whilst significant, orcas cannot fully explain the decrease in white shark sightings.

The decline in white shark sightings also correlated with substantial changes in trophic structure.[19] Notably sevengill sharks (*Notorynchus cepedianus)*[19], and copper sharks (*Carcharhinus brachyurus)* have become prevalent in False Bay and Gansbaai[28]. Furthermore, possibly due to a reduction in white shark predation, the foraging range of the Cape fur seal has extended.[16] This extension has caused a removal of refugia for endangered African penguins (*Spheniscus demersus)* and their prey species.[7,29] Consequently, African penguins must extend their foraging ranges, making them more susceptible to predation.[29] These changes also correlated with a further reduction in bony fish species and may have deleterious consequences on the distribution of kelp forests.[16] Therefore, prioritising white shark conservation could mitigate against the loss of other endangered species, biodiversity and economically important fishery species.

Conclusion

There has been a clear reduction in white shark sightings in Gansbaai – an area that was internationally recognised as having the highest white shark abundance worldwide.[6] More research is needed to quantitatively and qualitatively assess the ecological significance of this decline in white sharks. However, if sightings of white sharks continue to decrease, then there is likely to be a negative effect on the distribution of other coastal species, including a reduction in the biodiversity of South Africa's marine ecosystem.[16] The extent to which white sharks have temporarily disappeared or possibly relocated is still uncertain.[20] Therefore long-term population surveys and monitoring of white shark sightings around the whole South African coastline is required.[15] Yet, despite these uncertainties, there is strong evidence highlighting the negative impacts of a poorly managed DSL fishery.[16] This fishery might be directly and indirectly impacting the white shark population. Given the ecological and economic importance of the white shark to South Africa, and the likelihood that their population has declined severely, better fisheries management is imperative. In addition, there is evidence indicating that the use of shark nets is detrimental to the population of white sharks.[14] Therefore, a re-evaluation of the use of shark nets should be considered to prevent the complete loss of the white shark from South Africa.

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Competing interests

To the best of my knowledge, there are no conflicts of interest to declare.

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