White Shark abundance: not a causative factor in numbers of shark bite incidents

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Abstract

Since the late 1990's the presence of white sharks in the False Bay region has become increasingly conspicuous. Not only has increased numbers of sightings been reported, but there has also been a localised spate of shark bite incidents on beaches along the Cape Peninsula. This paper reviews existing evidence regarding the status and behaviour of False Bay's white shark population.

Key findings of this review:

- The maximum rate of population growth is unique to every species and is termed 'intrinsic rate of population growth'. White sharks are K-selected species with life-history traits similar to those of mammals (large body size, slow growth, development of few young). Thus, their intrinsic rate of population growth is slow (4.0 – 11.9 % per annum). The maximum abundance of white sharks is ultimately limited by the

availability of resources, and is termed its ‘carrying capacity’. Thus, white shark numbers in South Africa cannot increase either quickly or indefinitely.

- White shark abundance and population trends are scarce throughout their range. Evidence from global hotspots suggests low abundance, compared to sympatric shark species. Declines in numbers have been identified in the NW Atlantic, Australia and the USA. There are no global examples of an increase in abundance.

- In South Africa, the most reliable population trend information is provided by the Catch per Unit Effort (CPUE) from the protective gillnets in KwaZulu-Natal. Initially, the CPUE declined rapidly, but this decline has stabilised (1978 – 2003). Splitting CPUE data into 'pre 1991' and 'post 1991' (1991 being the year protective legislation was introduced) reveals that protection may have stabilized the population or even contributed to a slight rise in numbers. Prior to 1991, the number of sharks in the nets decreased by 1.3 % per annum, yet, following protection there appears to by a 1.6 % annual increase in capture rate. Yet, significant interannual variation means a degree of caution must be appreciated when interpreting these trends.

- Evidence illustrates that the actual recovery rate (population growth rate) of white sharks following protection appears slower than what the population is capable of (i.e. 4.0 - 11.9 % per annum). This apparent discrepancy may be caused by any one of a number of possibilities. Namely, (a) the presence of fewer than expected sexually mature females (b) human induced mortality being greater than we currently estimate or (c) South Africa’s white shark population approaching its carrying capacity. There is currently not enough information available on this species’ population status to either confirm or reject these possibilities.

- We need to appreciate the limitations and possibilities for region specific trends, but in the absence of any contradictory evidence, our most responsible approach is to accept that the long-term KZN trends can be used to infer regions specific trends, including False Bay.

- On a large spatial scale, white sharks move freely to and from False Bay, they undergo coastal migrations along South Africa’s entire coast and are capable of transoceanic migrations. Thus, at present, the best evidence suggests that changes in the capture rate of white sharks in bather protection nets will probably be mirrored on localised scales. As such, it is improbable that an increase in white shark abundance within False Bay would not be reflected on a national scale (e.g. capture rate in the bather protection nets). No such increase has been observed.

- The white shark population within False Bay consists of the highest ratio of large white sharks (ca 350 – 500 cm total length) of those areas studied in South Africa (incl: KZN beach netting, Mossel Bay and Gansbaai). Anecdotal evidence and eye-witness accounts suggest shark bites on humans are primarily instigated by 'large' white sharks, thus particular attention must be paid to mitigating shark bite incidents in False Bay. The importance of sharks in False Bay must also be acknowledged and appreciated, as False Bay may house a large percentage of South Africa's reproductive stock.

- White sharks are present at seal colonies along the Western Cape primarily during the winter months, whilst during the summer month's white sharks are observed near shore (e.g. adjacent to swimming beaches). This seasonal change in habitat use is not unique to False Bay, as this pattern is observed in Gansbaai, Mossel Bay and as far a field as California. It is highly unlikely that this behavioural pattern has only recently developed in white sharks residing in False Bay.

- Alternative possibilities to account for an increase in sightings in Muizenberg and Fish Hoek are that the distribution of white sharks within False Bay has changed (Chris Fallows, pers.com). Changes in distribution have been recorded for other shark species (e.g. bull sharks, blue sharks), but unfortunately no reliable historical data is available to compare present day white shark distribution to historical data. The current research program in False Bay indicates that white sharks use the entire bay, from Gordon's Bay all along the coast to Cape Point. Long term monitoring within False Bay will be a crucial step in determining the possibility of future changes in distribution.

  Furthermore, the reported increase in sightings may be caused by (a) the increasing profile of the white sharks along South Africa's Western Cape, (b) the increase in human vigilance towards spotting the presence of white sharks, and (c) change in the behaviour of human water users. Such an acute rise in sightings cannot be accounted for by the increase in the numbers of white sharks present.

- False Bay hosts a relatively high ratio of large white sharks that may potentially come into contact with human water users, particularly in summer months. However, based on the best evidence available, the population's status and composition has not changed markedly since protection in 1991. Thus, it is improbable that an increase in shark numbers is behind the recent spate of shark bite incidents.

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1. Introduction

Since the late 1990's the presence of white sharks (*Carcharodon carcharias*) in the False Bay region has become increasingly conspicuous. Not only have kayakers, surfers and law enforcements officials on local beaches, reported increased numbers of sightings but there has also been a localised spate of shark bite incidents on beaches along the Cape Peninsula. Many people are under the impression that since the 1991 protective legislation, prohibiting the capture and killing of white sharks, the number of white sharks has grown considerably and that this is a causative factor behind the recent spate of shark bite incidents. A counter argument is that the substantial increase in the number of water users is the major contributing factor in the rise in shark bite incidents, and shark sightings have increased as a direct result of increased awareness and vigilance. The aim of this paper is to review the status of the white shark population in South Africa and even more locally, within False Bay, and assess the implications for water users. We will use the most recent information available to evaluate factors such as white shark population growth, local and global population trends, spatial and temporal patterns within False Bay.

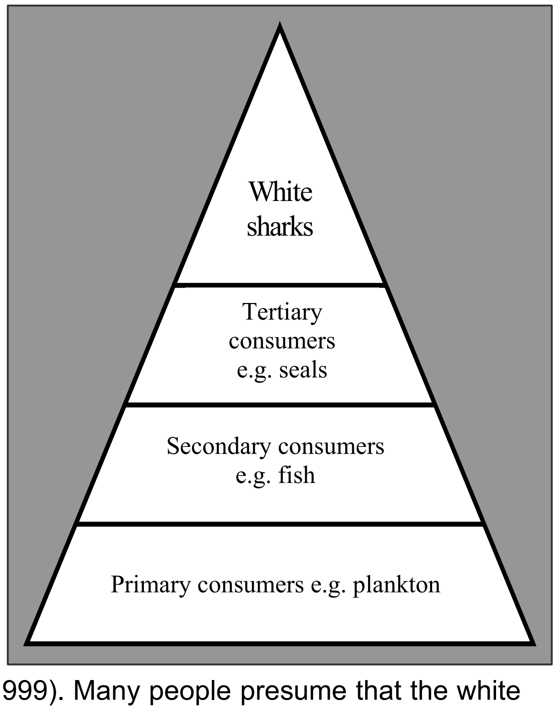
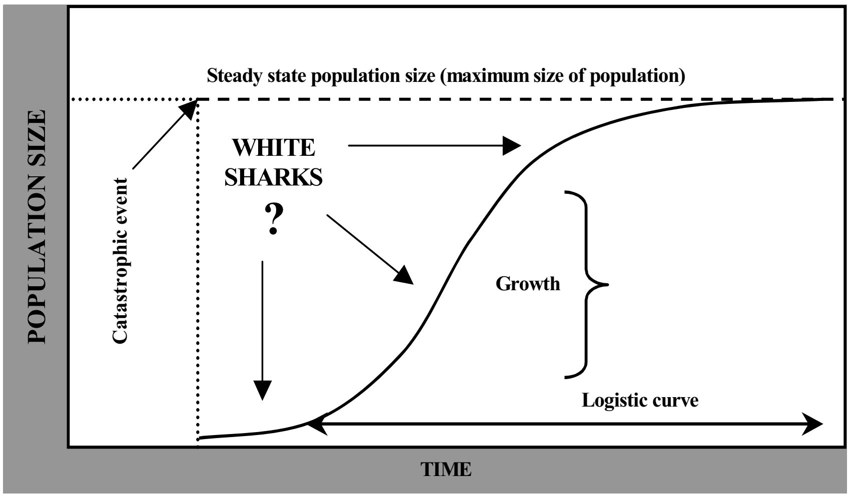


Figure 1. White sharks occupy the highest trophic levels (+ 4.5) in marine ecosystems and their populations are relatively small, compared to lower trophic level populations.

2. What governs the size of a population?

White sharks are apex predators, occupying the highest trophic levels in marine eco-systems (Fig. 1), thus their population density (relative to lower trophic levels) is consequently low (Cortes 1999). Many people presume that the white shark population can increase rapidly and indefinitely, however, this is not the case. No population can grow indefinitely, as resources (e.g. food, space) are limiting factors. Such an 'upper ceiling' for a given population is termed its 'carrying capacity'. In addition, different species have different rates of potential population increase. Let us explore a logistic model of population growth. This model starts with an undisturbed population inhabiting a constant environment for a long period of time (Fig. 2) (taken from Hoenig & Gruber 1990). The population has reached an equilibrium state, with the recruitment number (immigration and births) equal to the number of individuals lost to the population (i.e. deaths and emigration), and thus the size of the population remains constant. However, what happens to this population when an outside force, such as exploitation (e.g. fishing), results in a significant reduction in the size of the population? In a healthy and uncrowded environment, with no resource limitations, population growth may approach an exponential curve, based on the species potential intrinsic growth rate, but as the population increases, resources become limiting and the population growth rate reduces and approaches zero (e.g. the populations carrying capacity).

Figure 2. Population growth as predicted by a logistic growth model. The fundamental problem is that we are unsure of where the South African white shark population is along this curve.



Each species also has its own intrinsic growth rate (innate ability to increase the size of their populations). However, it’s very difficult to measure this rate of increase, especially on wild populations, but it’s evident that species that grow fast, produce lots of young and that are short-lived are able to increase their populations relatively rapidly. Conversely, sharks have life-history traits, which are more comparable to mammals and the ability to increase the size of their populations is slow (Hoenig & Gruber 1990, Smith *et al*. 1998). These life-history traits include large body size, slow growth, late maturity, low natural mortality, the development of few well-developed young and long longevity (Table 1). Due to these life-history traits, white shark populations are poor at resisting population decimation from consumptive exploitation, and following decimation are slow to recover to their former abundance (Smith *et al*. 1998).

Table 1. Estimated life-history parameters for white sharks (Compagno 1997, Smith *et al*. 1998, Dudley & Simpfendorfer 2006).

Maximum size (cm)	640
Size at birth (cm)	109 – 165
Size at maturity (cm)	450 – 500 (female); 350 – 410 (male)
Age at maturity (years)	12 – 14 (females); 9 – 10 (males)
Longevity (years)	23 – 36 (even estimations of up to 60)
Gestation period	Uncertain (possibly 12 months or longer)
Reproductive periodicity	Uncertain (probably 2 or 3 years)
Litter size	2 – 10 pups / litter
Intrinsic annual rate of population increase	0.04 – 0.119

Although measures on the rate of population increase are difficult, they have been estimated for a few shark species, including white sharks. The maximum rate of population increase (r) for white sharks has been estimated to be in the range between 4 and 11.9% per annum. The most conservative of these estimates was Smith *et al*. (1998) who calculated r as between 4 – 5.6 % per annum, less conservative was Mollet & Cailliet (2002) with an estimate of 7.8 % per annum and lastly, Dudley & Simpfendorfer (2006) calculated the most optimistic growth rate at 11.9 % per annum. Within the context of these biological constraints, we can gain insight into temporal population trends in False Bay, South Africa and worldwide.

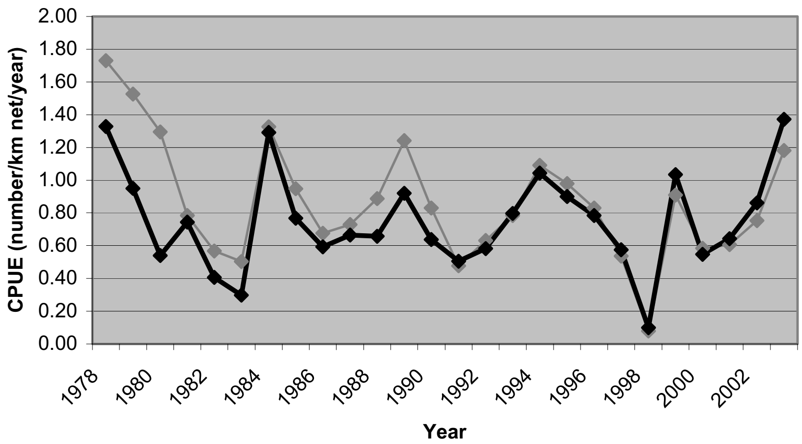
3. Abundance and population trends

To date, there are no published estimates of global white shark abundance and very little abundance trends from areas where they regularly occur. This is due to the fact that white sharks are inherently rare and elusive, they migrate between and within continents, and sighting rates vary considerably between years. Complex ontogenic (changes with age) and sex biased behavioural patterns further complicate attempts to produce robust population estimates. Here we review the existing data on a local and global scale.

Globally, populations of white sharks have been severely reduced in most regions where they occur (Walker 1998). The most dramatic and rapid decline that has been reported comes from the NW Atlantic. In total 6087 white sharks were caught during a 14 year period in over 200 000 pelagic longlining sets, compared to 23 071 thresher sharks, 1 044 788 blue sharks and 60 402 hammerhead sharks. Porbeagle sharks (829 in 8 years) and oceanic white tips (8 526 in 14 years) were also rare. It's estimated that the population of white sharks may have decreased by up to 79 % since 1986, with no catches reported in some areas since the 1990's (Baum *et al*. 2003). A rapid decline was also observed for other large shark species, like hammerheads (89 %), tiger sharks (65 %), thresher sharks (80 %), blue (60 %) and oceanic white tip (70 %). Furthermore, the study predicts that these severe declining trends may be reflective of a global phenomenon due to the intense fisheries taking place in all our oceans targeting many of the same species (Baum *et al*. 2003). Although Burgess *et al*. 2006 believes some of the results of this study to be exaggerated; they do acknowledge that there is more than likely a large decline. Australia has also experienced declines in white shark numbers over time as is evident by a decline in CPUE (catch per unit effort) by the protective gill netting programs (Reid & Krough 1992) and by game fishing catch statistics in SE Australia (Pepperell 1992). Declines have also been reported for eastern USA (Casey & Pratt 1985) and California (Pyle *et al*. 1996). Thus, available global evidence indicates that white sharks are relatively rare, as predicted by their life-history traits, and that their populations are declining, even in areas where they are protected.

In South Africa, white sharks were legislatively protected in 1991, the inaugural country to follow this route (Compagno 1991). This decision was a pre-emptive measure based on the fact that (a) white shark populations were declining in many regions internationally where they occur, (b) their life-history strategy predicts that they are vulnerable to over exploitation and (c) it was strongly suspected that the South African population was declining due to the high demand for white shark jaws as trophies locally and internationally (Compagno 1991). The aim of this legislation was to ensure that the white shark population was protected from over exploitation and it was hoped that it would re-cover over time. So what has happened since then? We looked at available sources of information to determine the current situation.

Figure 3. Annual CPUE of white sharks caught in the bather protection program along the KwaZulu Natal coast between 1878 and 2003 for all installations excluding Richard's Bay, Mzamba, and the months of June and July (black line). The effects of the sardine run in winter months are illustrated for the CPUE for all installations (except Richards Bay) in all months (grey line). (Source: Dudley and Simpfendorfer 2006).



As previously stated, there is very little information available on the status of white shark populations, however, the most reliable long-term data on white shark abundance in South Africa comes from sharks caught in the protective gillnets off the coast of Kwa-Zulu Natal. The CPUE offers information on temporal trends in South Africa's white shark population (Cliff *et al*. 1989). Cliff and Dudley 1992 reported substantial declines in the CPUE of white sharks between the mid 1960's and mid 1970's, but the decline has not persisted and catches of white sharks in the nets have stabilized from 1978 – 2003 (Fig. 3) (Dudley and Simpfendorfer 2006). Interestingly, splitting Dudley and Simpfendorfer's (2006) data into 'pre 1991' and 'post 1991' (1991 being the year protective legislation was introduced) does, however, reveal that protection may be having a positive effect on the number of white sharks. Prior to 1991, the number of sharks in the nets decreased by 1.3 % per annum, yet, following protection there appears to by a 1.6 % annual increase in capture rate. The interannual variation in this data does, however, lesson the robustness of these trends. Converse to the possibility of a slight increase is the discovery of the continual decline in the mean size of female white sharks caught in the nets since 1978, which may be indicative of a decline in this segment of the population (Dudley & Simpfendorfer 2006). Most importantly though is that there is no evidence of a 'leap' in white shark abundance.

White shark abundance in South Africa

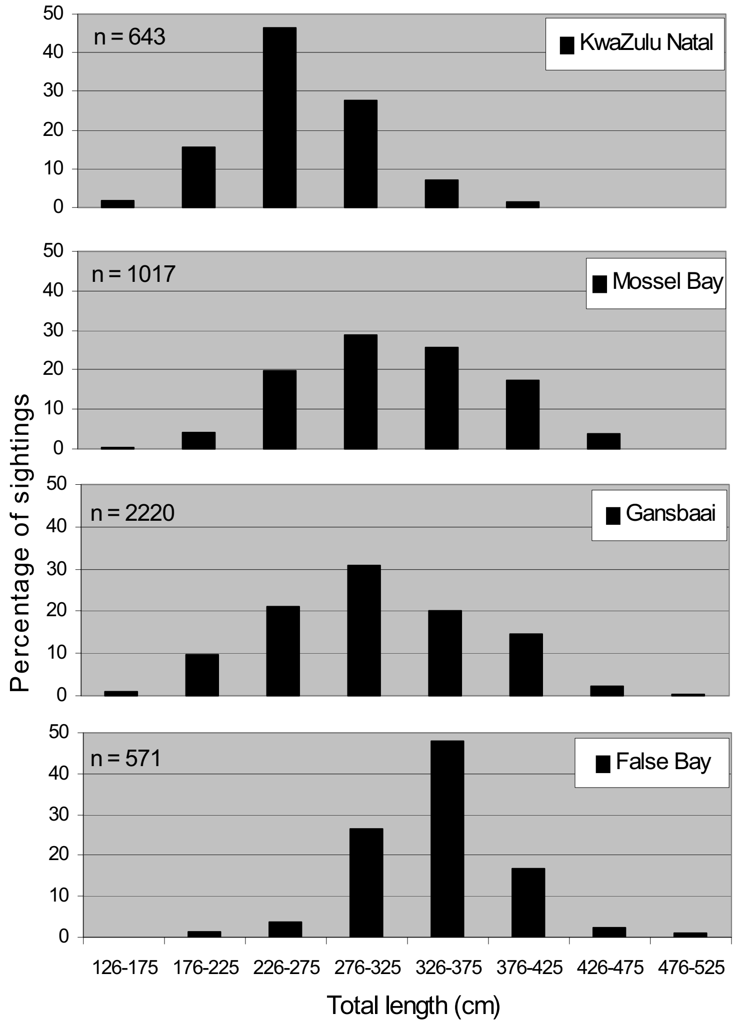
Research at three sites along the western Cape has so far gathered preliminary information on the minimum number of white sharks recorded in these areas. In Mossel Bay a minimum number of 198 individual white sharks sighted between 2001 and 2005. This number is established from successfully identifying 70.25 % of the 1104 white shark sightings made from the research vessel. In Gansbaai a researcher has identified over 1200 individual sharks between 1998 and 2005 (Michael Scholl pers. com.). In False Bay a minimum of 128 have been identified (2004 – 2005). To date, these estimates don't provide the answers we are looking for in explaining changes in shark bite rates and are still preliminary. However they do give us good baseline data to investigate future changes in distribution, abundance and behaviour for each area.

Marking individual white sharks (via tagging or photographic identification) can enable population estimates to be made based on the ratio of marked individuals in latter surveys (e.g. jolly-seber, Petersen techniques). This technique was used in 1996 by Cliff *et al*. 1996 on a small data set to estimate the white shark population between Richard's Bay (KwaZulu-Natal) to Struis Bay (western Cape) at circa 1279 individuals. There are currently two large-scale telemetry (acoustic tagging) projects operational in False Bay and Mossel Bay, which when completed will be able to provide more robust estimates on the white shark population. Additionally, a long-term identification project run in Gansbaai will similarly yield information on the abundance of the white sharks in South Africa.

4. False Bay's white shark population - can it act independently?

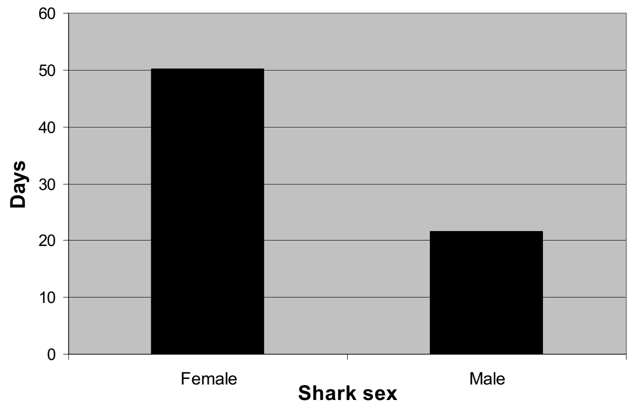
Based on our knowledge of movement of individual white sharks, can abundance trends in False Bay act independently from trends observed elsewhere in the country? Telemetry studies offer extensive evidence that white sharks within South Africa regularly move between areas (e.g. False Bay, Gansbaai, Mossel Bay, KZN), and thus do not represent an isolated population (Johnson *et al.* in review). Furthermore, genetic and satellite tracking results suggest that the 'South African' white shark population may form part of a 'global' white shark population, with linkages between South Africa, Australia and New Zealand (Pardini *et al.* 2001, Bonfil *et al*. 2005). Genetic evidence links South African male white sharks with Australia and New Zealand (Pardini *et al*. 2001), while satellite tracking data recently revealed that females of the species are capable of transoceanic return migrations between South Africa and Australia (Bonfil *et al.* 2005). In the broadest sense, this kind of information tells us that any change in the abundance of white sharks in South Africa will probably occur ubiquitously and be observed throughout the various areas where we scientifically observe white sharks.

Figure 4. Size ratio of white sharks at four areas along South Africa's coast. Dudley & Simpfendorfer (2006) source for KwaZulu Natal data, PCL to TL conversion (Mollet & Cailliet 1996).



What complicates this simple assumption is that males and females, small and large sharks may behave differently to one another. To illustrate this point we compared the size distribution of white sharks sighted in four areas. Namely, False Bay, Gansbaai, Mossel Bay, and sharks captured in the KZN bather protection nets (Fig. 4). It becomes obvious that False Bay, and to a lesser extent, Gansbaai, hosts the largest proportion of 'large' white sharks in the areas studied, conversely very few large sharks are sighted in the area of the KZN shark nets (no sexually mature female white sharks have ever been captured in the bather protection nets). The authors believe that the high proportion of large sharks in the False Bay region is due to the abundance and accessibility of Cape fur seals. Larger white sharks prey more frequently on marine mammals compared to smaller white sharks and this evidently affects their distribution throughout South Africa. A similar discrepancy in behaviour exists when comparing the residency patterns of male and female white sharks at the various study areas. At Mossel Bay, male white sharks display low site fidelity and often move in an out of the study area quickly. Alternatively, a number of females, particularly large females, display high site fidelity and remain resident in the study area for a number of months (Fig. 5).

Figure 5. Mean number of days resident at Mossel Bay of 71 (58 female, 13 male) white sharks following attachment with RCODE acoustic transmitters



With this kind of information available, must we accept or reject the proposition that a 'geographically specific' change in abundance could occur in False Bay that would not be detected in other parts of South Africa, for example in the catch rates of the KZN sharks nets? The KZN sharks nets capture very few sharks over 350 cm TL (Dudley and Simpfendorfer 2006), even though they are capable of catching sharks as large as 450 cm (Geremy Cliff pers. com.), this may be because these large sharks occur primarily in the Western Cape in waters adjacent to seal islands, although alternative explanations, such as large sharks not frequenting nearshore KZN waters, are also possible. Subsequently, there is a slight possibility that there may be a localized (Western Cape region) increase in the number of large white sharks, and that this increase would not be reflected by catch rate data from KZN. Two points of caution must be made to contextualise this previous hypothesis. Firstly, white sharks' life history means that the recruitment into the population is strongly linked to the parental stock. That is, if the presence of large sexually mature white sharks in the Cape region were significantly increasing, this would be proportionally reflected in the annual recruitment of juvenile white sharks into the population, this in turn would be reflected in the catch rate of the bather protection nets. Such a trend has not been observed.

Secondly, the purpose of South Africa initiating protective legislation was the realization of the inherent vulnerability of white sharks to human exploitation. Female white sharks mature at between 12 and 15 years (ca 4.8 m total length), thus, in the presence of human induced mortality, very few will reach age of reproduction. The goal of protection is to ensure a sustainable population; this can only be met if a viable adult population exists. Our results highlight the importance of False Bay in housing such an adult population, and also cast doubt on the current existence of a healthy adult population. Thus, we need to appreciate the limitations and possibilities for region specific trends, but in the absence of any contradictory evidence, our most responsible approach is to accept that the long-term KZN trends can be used to infer region specific trends, including False Bay. Using the aforementioned evidence, it is unlikely that absolute numbers of white sharks have increased considerably in South Africa and as such False Bay.

5. Behaviour of White sharks in False Bay

In the last *ca* two years, white shark sightings have been reported to be increasing in areas such as Muizenberg and Fish Hoek, with many statements by residents saying, “never before have they seen white sharks in these areas”, “white sharks occurring close to beaches is a unique situation”. Research has shown that white sharks are seasonally present at Seal Island, False Bay (Fig. 6). Sharks are most abundant from May – September, when they prey on young of the year Cape fur seals (Kock 2002). In general, towards the end of August the sharks are less abundant around the island and most sharks leave the island completely by October (Fig. 6).

Figure 6. White sharks are seasonally (winter) abundant at seal colonies in the western Cape.

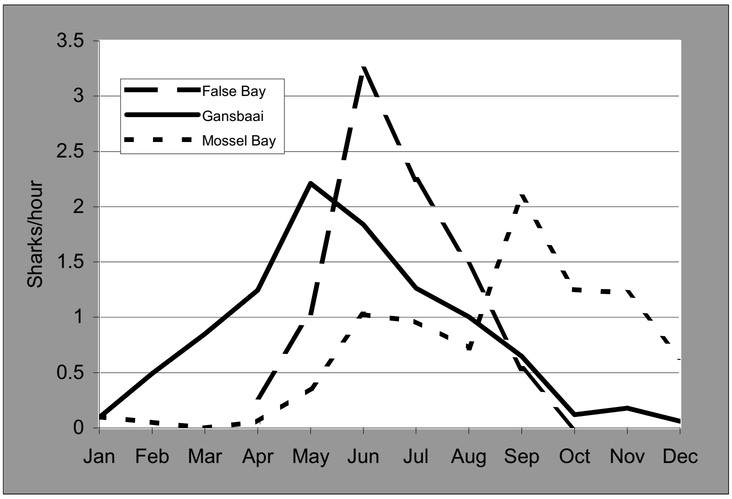
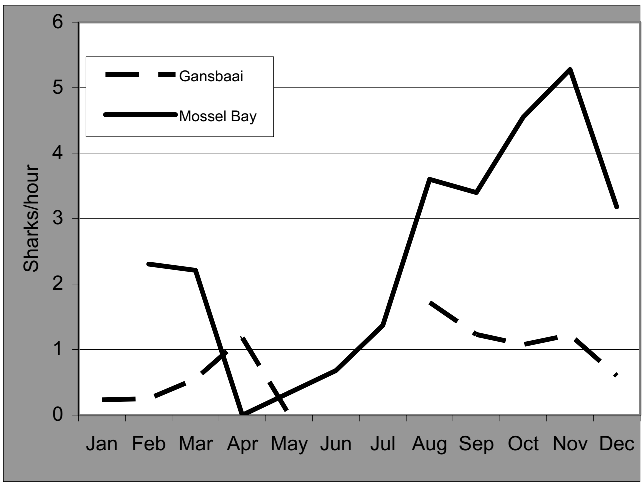
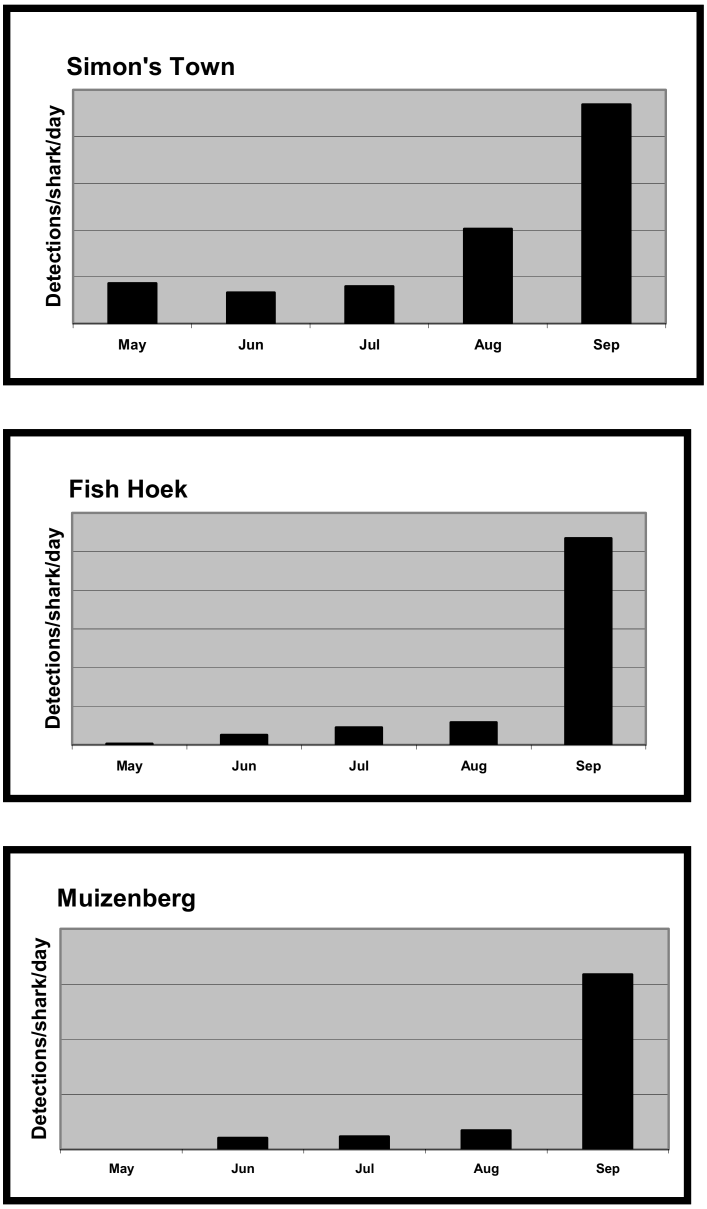


Figure 7. White sharks are seasonally abundant (Spring-summer) near inshore areas at Gansbaai and Mossel Bay (Grootbrak).



Corresponding to this trend is an increase in the number of sharks recorded on monitors located close inshore in areas such as Muizenberg, Fish Hoek and Simon's Town (Fig. 8). What is important to note with regards to this seasonal change in habitat use is the history of it. Reports from military personal during aerial activities over False Bay in the 1960's and 1970's tell of large numbers of white sharks spotted just behind the breakers from Macassar to Muizenberg (Justin Menge pers. com.). Historically, when white sharks were hunted for trophies during big game fishing tournaments, most sharks caught in False Bay were caught near-shore in areas such as Strandfontein and Macassar (Johan Vosloo pers. com). Additionally, such a seasonal pattern and their occurrence near inshore areas have been observed in Gansbaai since 1998 (Fig. 6, 7) and have also been observed in Mossel Bay (Fig. 6, 7). Thus, claims that this behaviour (white sharks occurring inshore close to beaches) is unique to False Bay and only recent in their appearance are erroneous.

Figure 8. Preliminary data illustrating the seasonal change in behaviour at selected inshore areas in False Bay.



6. So where is the population and what is going to happen in the future?

The central questions of this paper are: "what has happened to the white shark population since protection? What is going to happen in the future? And what does this mean for human water users?" To answer this we have collated all-available theoretical and recorded data to produce estimates in the localized (False Bay) abundance of white sharks over time. Taken into account are various measured and calculated parameters that contribute to population growth (Table 2). However, limitations in the data supplied to this estimate should be appreciated due to reasons outlined previously (e.g. limited data availability, localized changes in distribution etc.). As such, these results should be observed with caution, and be considered as indicators of what may have, and could happen within False Bay.

The most reliable data concerning relative trends in white shark numbers within South Africa stems from captures in bather protection nets. The most recent evidence, suggests that following protection the number of sharks has either remained stable or increased at a rate of 1.6 % per annum (Table 2). If these changes are in fact representative of the change in abundance within False Bay, then we would expect abundance to change by a factor of between 0.00 and 0.31 in the 15 years following protection. Between, 2004 - 2005 a minimum of 128 sharks was identified to occur within False Bay, all in the waters adjacent to Seal Island. The actual number may, however, (1) vary considerably throughout the year as sharks move in and out of the bay, and (2) be larger as a number of sharks were not successfully photographed during the ongoing study. Yet, conceptually, the estimated factors of increase (0.00 - 0.31) would suggest optimistically that since protection, white shark numbers in False Bay might have climbed by 26, from 102 to the current 128.

Table 2. Parameters utilized in localized population growth concept model. SA = South Africa, FB = False Bay, Var = variable, (model enables various entries).

Parameter	**Value**			**Source**
SA population estimate	1279 (1993)			Cliff *et al*. 1996
FB minimum population number	128 (2004 - 2005)			Kock (unpub. data)
Intrinsic growth rate	4.0 - 5.6% per annum			Smith *et al*. (1998)
	7.8% per annum			Mollet and Caillet 2002
	11.9% per annum			Dudley & Simpfendorfer 2006
Population carrying capacity	Var.			
	Pre 91	91 - 06	Post 06	
Observed population growth	-0.013	0.016	Na	Dudley & Simpfendorfer 2006
Mortality (nets)	ca 35.9	ca 30.9	Var.	Dudley & Simpfendorfer 2006
Mortality (fishing)	ca 50	ca 0	Var.	Cliff *et al.* 1996
Mortality (unaccounted for)	Var.	Var.	Var.	
False Bay shark bite number	8	12	Na	Cliff (S.A. Shark attack file), Levine 1996

Ultimately, can this information identify whether changes in the white shark population is the major driving force behind the rate of shark bite incidents in False Bay? To assess this we made the following assumptions. (1) The likelihood of a shark to bite a human that it encounters is constant over time, (2) that human water users are temporally constant and thus encounter likelihood is directly proportional to white shark numbers, (3) relative trends in KZN bather protection nets are indicative of changes in abundance in False Bay. Accepting these assumptions, we would then expect the relative shark bite rate in False Bay to roughly mirror the relative abundance of white sharks. Between 1970 and 1990 (pre - protection period), shark bite rate in the False Bay / Cape Peninsula region averaged 0.38 shark bites per annum (1970 - 1990) (Cliff pers. com., Levine 1996). Following protection, shark bite rate has steadily increased and averaged 0.80 shark bites per annum (1991 - 2005) (Cliff et al. 2006, in review). Effectively, shark bite rate has increased by a factor of 2.13 since white sharks were protected in 1991. During the corresponding 15 - year period, our estimate optimally predicts that white shark abundance has changed by a factor of 0.31 from circa 102 sharks to circa 128 sharks. Thus, even appreciating the limitations of data and the cautious nature of our proposed estimate, the potential increase in shark abundance fails spectacularly to explain the recent rise in shark bite rate.

The major limitation to the above assessment is that it does not take into consideration changes in distribution of white sharks within South Africa. Thus, despite evidence that the population is relatively stable throughout South Africa, a greater percentage of the population may be occurring in False Bay waters. It is hoped that future analysis of photographic identification records and long term monitoring of movement patterns will offer some insight into the behavior and movement of individual sharks throughout South Africa.

A major cause of interest, however, is the discrepancy between the apparent rate of change measured by KZN sharks nets and the intrinsic rate of population increase that white sharks are capable of. Following protection white shark numbers should increase at near their intrinsic rate of population increase and move towards the population's theoretical carrying capacity. However, if there is significant difference between the expected population growth and the measured population growth than additional influence(s) must be limiting the recovery of white sharks. Such influences could be (a) resources becoming limited, (b) the rarity of mature sharks means a lower than expected ability to produce recruits, or (c) that human induced mortality is greater than we estimate. The fact that measured temporal trends in white sharks abundance are far below the expected trends suggests that South Africa’s white shark population remain depressed. As such, concerns raised in 1991 that lead to protective legislation being initiated remain valid, and the white shark population remains vulnerable to overexploitation, from practices such as, targeted culling or extension of bather protection nets to the Western Cape.

7. Alternative explanations

Although this papers’ scope does not include in-depth examination of alternative causes driving shark bite rate we feel that it is pertinent to at least introduce the subject. We have shown without a doubt that the shark bite rate cannot be explained by an increase in shark abundance. Similarly, neither can the acute rise in sightings, thus alternative factors have to be involved.

Increase in water users

Studies of human water use in the Cape region have concluded that the number of people using False Bay for swimming, surfing, kayaking and other beach/water activities increases substantially each year (Prochazka and Kruger 2001). Additionally it was found that the average density of people using 11 beaches around the Cape Peninsula more than doubled over the last circa 30 years. Studies have shown that an increase in beach usage closely mirrors adjacent population increase as well as increasing residential developments (Glassom & McLachlan 1989, De Ruyck *et al*. 1995; Prochazka & Kruger 2001). There is therefore no doubt that that since 1991 the number of people using False Bay for various water activities has increased dramatically and will continue to do so as the population continues growing. The authors believe this substantial increase in water users (particularly of activities in which humans become vulnerable to encountering white sharks, such as surfing and paddle skiing) needs to be examined more closely and, believe it will more than likely be realised as the driving force behind shark bite frequency. Expectantly, this will be explored further in the subsequent review on this topic.

Increased awareness

Since the spate of shark bite incidents in the Cape Peninsula region people have become increasingly aware of the presence of white sharks, largely due to the media. Furthermore people are more vigilant towards spotting for white sharks, especially in the Muizenberg and Fish Hoek region. Current research clearly shows that white sharks are distributed throughout False Bay (authors unpublished data). Preliminary information indicates that Simon’s Town has relatively high levels of shark activity (higher than most sites at Muizenberg or Fish Hoek) (Fig. 10), and although they are spotted here occasionally, the sighting rate at Fish Hoek and Muizenberg is considerably higher. Sharks also regularly occur along the eastern shores of False Bay (Gordon’s Bay and Koeël Bay), but sightings are rare in this area. Similarly the sighting rate at beaches, like at Mossel Bay and Gansbaai, where white sharks frequently swim within a few 100 meters of beach users, is low. The authors contribute these low sighting rates to a decrease in vigilance and unawareness in these areas, in addition to few high vantage points (unlike False Bay), which would facilitate spotting sharks, not a decrease in the number of sharks.

8. Conclusions

The original premise of this paper was set to describe temporal trends in the abundance and behaviour of white sharks in False Bay. Speculation exists claiming a dramatic rise in the sightings of white sharks, and that this in turn is a driving factor behind the recent spate of shark bites in the False Bay region. Although some evidence exists suggesting that False Bay is dominated by a restricted sector of South Africa's white shark population (namely a high ratio of large female sharks), most evidence suggests that the population should be considered open. As such, increases and decreases in numbers would be reflected ubiquitously in all regions of South Africa. Despite limitations in available data, current indications suggest that since protection, South Africa's white shark population has remained stable or possibly increased slightly (circa 1.6 % per annum), and clearly is not increasing at its potential intrinsic rates of increase (i.e. 4.0 - 11.9 % per annum). This provides a strong argument that other factors are contributing to retarding the population’s recovery. Such factors may include (a) a skewed population structure with fewer than expected sexually mature females, thereby hampering recruitment, (b) the population is already approaching its natural carrying capacity, or (c) human induced mortality (sharks nets and unaccounted fishing) is having a greater impact than we calculate. A secondary possibility to explain the reported sighting increase is that the behaviour of white sharks within the bay has altered, and sharks are spending progressively more time inshore where they can potentially encounter humans. We illustrate that white sharks naturally occur near shore, that this behaviour pattern is wide spread nationally and internationally, and that it has most likely occurred for numerous years. As such, the most plausible explanation for the apparent increase in sightings is the public’s increase in awareness of white shark presence and subsequent increased vigilance.

Historical data confirms a conspicuous presence of white sharks in the False Bay region during years preceding protection, yet shark bite rate was markedly low. More recently, the recent spate of shark bite incidents (post 1997) cannot be explained by an increase in white shark numbers due to the population's inability to expand sufficiently quickly. Our most optimistic estimation for abundance increase since protection (factor of 0.28 - 0.31) dramatically fails to explain the jump in shark bite rate observed since protection (factor 2.13). As such, alternative explanations are required to explain the recent spate of shark bite incidents.

9. Recommendations

- Utilize mark-recapture models, using telemetry or photo-identification methodology, to determine absolute abundance of white sharks
- Continue monitoring white shark movement and behavioural patterns to (1) identify possible future changes in distribution within False Bay and possibly on a larger scale, (2) identify ‘hotspot’ areas and times of year of white shark presence within False Bay, (3) identify site-fidelity and residency patterns within False Bay, (4) identify factors driving behavioural patterns identified
- Recognise that False Bay provides an essential habitat for white sharks in South Africa and due to hosting a relatively large proportion of adult (sexually mature) white sharks, it may be particularly important for sustaining a healthy white shark population.
- Recognise that invasive management solutions for white sharks occurring in False Bay is likely to have negative ramifications for white shark numbers nationally and possibly internationally

- Support development and ratification of non-invasive management policies premised on co-existence of humans and white sharks in the False Bay region

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