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Evidence of cascading ecosystem effects following the loss of white sharks from False Bay, South Africa

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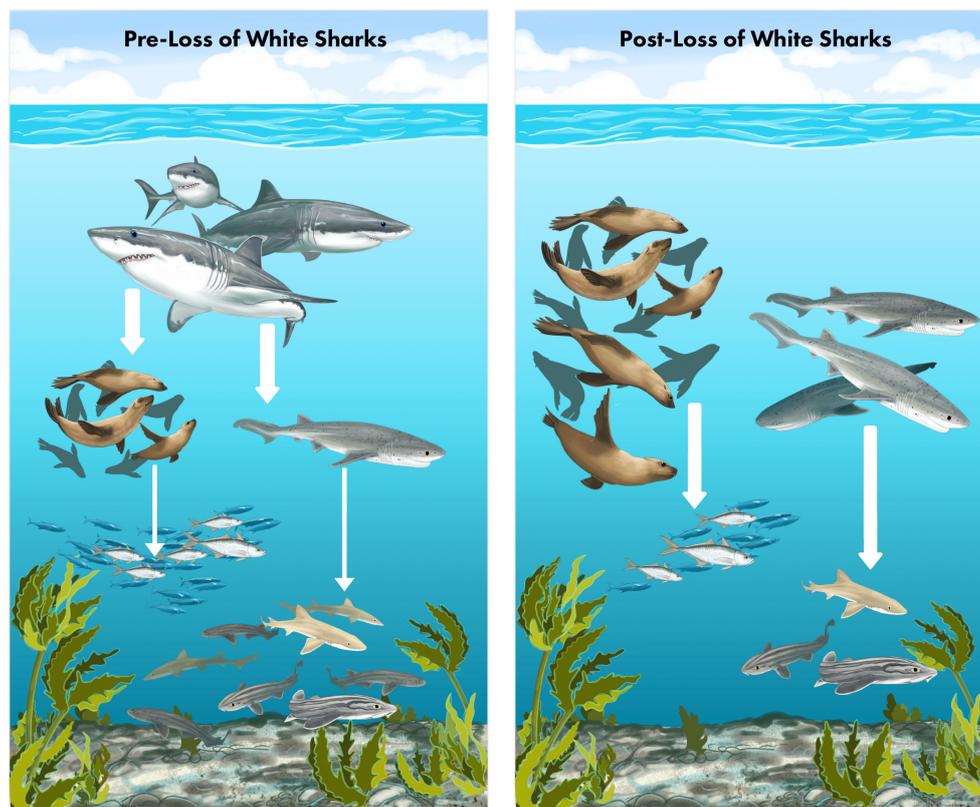
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Introduction

Top predators can affect the density (Creel and Winnie, 2005), physiology (Leach and Taylor, 1977; Woodley and Peterson, 2003), and behavior (Werner et al., 1983) of prey. Such direct impacts on prey may indirectly impact multiple trophic levels (Ripple et al., 2001; Croll et al., 2005; Hammerschlag et al., 2019). Apex predators are among the most threatened species globally, experiencing widespread global population declines (Ripple et al., 2014). Accordingly, this has led to a growing concern for and need to understand the associated ecological consequences of apex predator loss on food webs (Estes et al., 2011).

Sharks are upper-level predators in virtually all marine environments (Cortes, 1999). Research has shown that spatial and temporal variations in shark presence has the potential to alter the abundance and behavior of their prey, indirectly impacting habitat structure (reviewed by Dedman et al., 2024). For example, on a Fijian coral reef, Rasher et al. (2017) found that differences in topography and tidal state created patches of reef that varied spatially and temporally in shark presence. At locations and times where shark encounter rates were high, herbivorous fish reduced grazing activity. This predator-driven alteration to fish behavior created spatial refuges for seaweed from grazing, resulting in higher seaweed biomass (Rasher et al., 2017). In light of global shark population declines from overfishing, understanding and predicting the consequences of shark loss on ecosystems been identified as a research priority (Jorgensen et al., 2022; Dedman et al., 2024). However, empirical evidence of the ecological impacts of large shark declines on prey populations in the wild are limited (Ruppert et al., 2013; Barley et al., 2017a; Barley et al., 2017b, Hammerschlag et al., 2018, Hammerschlag et al., 2019, Hammerschlag et al., 2022) and may be context-dependent (Sandin et al., 2022). For example, on the great barrier reef, Desbiens et al. (2021) did not find an impact of shark density on either density or biomass of teleost mesopredators and prey; instead, many functional groups, including sharks, were more associated with environmental drivers. Moreover, evidence for indirect cascading ecosystem effects of shark removals across multiple trophic levels is scarce (Ferretti et al., 2010; Myers et al., 2007). These knowledge gaps likely stem from the methodological,



GRAPHICAL ABSTRACT

This study provides empirical evidence of a trophic cascade following the loss of white sharks (*Carcharodon carcharias*) from False Bay, South Africa. Arrow thickness represents the relative strength of top-down predation effects (thicker arrows indicate stronger effects, thinner arrows indicate weaker effects). **Left Panel:** Historically, white sharks occupied the apex of the food web, preying on Cape fur seals (*Arctocephalus pusillus pusillus*) and both competing with and feeding on sevengill sharks (*Notorynchus cepedianus*). Seals primarily preyed on schooling fishes, while sevengill sharks primarily preyed on benthic sharks. **Right Panel:** Following the decline and eventual disappearance of white sharks from False Bay, both seals and sevengill sharks have increased in relative abundance, coinciding with declines in small fish that seals feed on and smaller sharks that sevengills prey upon. Illustration by Kelly Quinn / Canvas of the Wild.

logistical, and financial challenges of conducting experimental research on large, highly mobile predators in vast marine environments (Hammerschlag, 2019).

Here we evaluated a unique dataset collected as part of a 20+ year monitoring program from False Bay, South Africa, which documented the decline and ultimate disappearance of white sharks (*Carcharodon carcharias*) from the system (Hammerschlag et al., 2019, Hammerschlag et al., 2022). While the exact reason behind the loss of white sharks from False Bay is unclear (Gennari et al., 2024), known removals of white sharks by the KwaZulu-Natal Sharks Board's lethal shark control program are high enough to drive regional population declines (Bowly et al., 2022). Although not yet recorded from False Bay, instances of white shark mortality due to specialized shark-eating orcas (*Orcinus orca*) have been documented elsewhere along the coastline (Towner et al., 2022), likely contributing to the decline (Gennari et al., 2024).

In False Bay, standardized boat-based surveys of white shark sightings at Seal Island occurred between 2000–2020 providing a metric of relative abundance over time based on the number of individual white sharks sighted per hour of observational effort (Skubel et al., 2018; Hammerschlag et al., 2019). The overall trend in the relative abundance of white sharks was relatively stable in the

first fifteen years of monitoring; however, their relative abundance began to precipitously decline after 2015, leading to a complete disappearance of white sharks from the standardized surveys since mid-2018 (Hammerschlag et al., 2022). This rapid decline and subsequent loss of white sharks from False Bay coincided with rapid behavioral and physiological response in their prey, Cape fur seals (*Arctocephalus pusillus pusillus*), including reductions in seal stress levels and increasing seal rafting distances from Seal Island, a behavior that would have rendered seals vulnerable to shark attack (Hammerschlag et al., 2022). The loss of white sharks from False Bay also coincided with the novel emergence of sevengill sharks (*Notorynchus cepedianus*) in boat-based surveys at Seal Island (Hammerschlag et al., 2019). Historically, this large-bodied shark would have been an important prey of and competitor with white sharks in False Bay.

Based on ecological theory, here we investigated for potential trophic cascades resulting from the rapid decline and loss of white sharks in the system. Given established predator-prey dynamics in False Bay, we hypothesized that the loss of white sharks in the system would coincide with increases in the relative abundances of Cape fur seals and sevengill sharks, which in turn would be associated with decreases in the relative abundances of their prey,

such as small pelagic fishes in the case of seals and smaller benthic sharks in the case of sevengill sharks.

Methods

Study site

Located off South Africa, False Bay is nearly 1000 km² (Pfaff et al., 2019; Figure 1). Historically, white sharks could be found year-round in False Bay, spending more time within inshore areas during warmer months, while during colder months spending relatively more time patrolling the waters surrounding Seal Island, a rocky outcrop situated 10 km off the Bay's northern shoreline (Kock et al., 2013). Seal Island may be inhabited by as many as 60,000 Cape fur seals that were targeted prey of white sharks during colder months, whereas white sharks more time within inshore areas during warmer months (Kock et al., 2013), presumably to increase foraging on large teleosts and elasmobranchs, such as sevengill sharks (Martin et al., 2005; Kock et al., 2013).

Boat-based surveys at Seal Island

Between 2000 and 2020, shark relative abundance at Seal Island was monitored from standardized boat-based observation surveys (details in Hammerschlag et al., 2019). While surveys occurred year-round, most observations occurred during colder months (May through September) (Hammerschlag et al., 2006; Fallows et al., 2012). During boat-based surveys, sharks were attracted to the boat using a line baited with fish and/or a seal decoy. Individual sharks were identified based on a combination of visual markers, including unique scarring, presence/absence of claspers, and

individual variation in pigmentation patterns on the gill flaps, pelvic fins, and caudal fins. The duration of each baited survey was recorded, along with the number of different individual sharks observed during this period. Using these data, the number of different individual sharks observed per hour of baited survey was calculated as a metric of shark relative abundance (Hammerschlag et al., 2019). We used these data to calculate annual means of shark relative abundance at Seal Island, as well as overall means in the period prior to and following the decline of white sharks from False Bay (2000–2015 vs 2016–2020, i.e. pre-loss vs post-loss period).

Seal sightings

Sightings data of Cape fur seals in False Bay were derived from the Global Biodiversity Information Facility (GBIF) database (Telenius, 2011). Only geo-referenced occurrences deriving from 'Human Observation' and those occurring within or along the coastline of False Bay were selected, producing reports on Cape fur seal sightings by location and date. The majority of these GBIF data were derived from the iNaturalist citizen science application. Because few reports included the number of individual seals observed at a given time, we focused our analysis on the number of reports of seal sightings, rather than the number of seals observed across reports. The number of visitors to False Bay are likely to influence the number of seal sightings reported to iNaturalist and GBIF (i.e., more visitors equates to more reports). To address this, we obtained data on the number of visitors to the Cape Point Nature Reserve, which spans the western shoreline of False Bay. These data were derived from Wesgro Research (<http://www.wesgro.co.za/>) sourced from South African Tourism and Table Mountain National Park. While visitor data from the Cape Point Nature Reserve may underestimate the total number of visitors to False Bay, it serves as a reliable relative proxy as

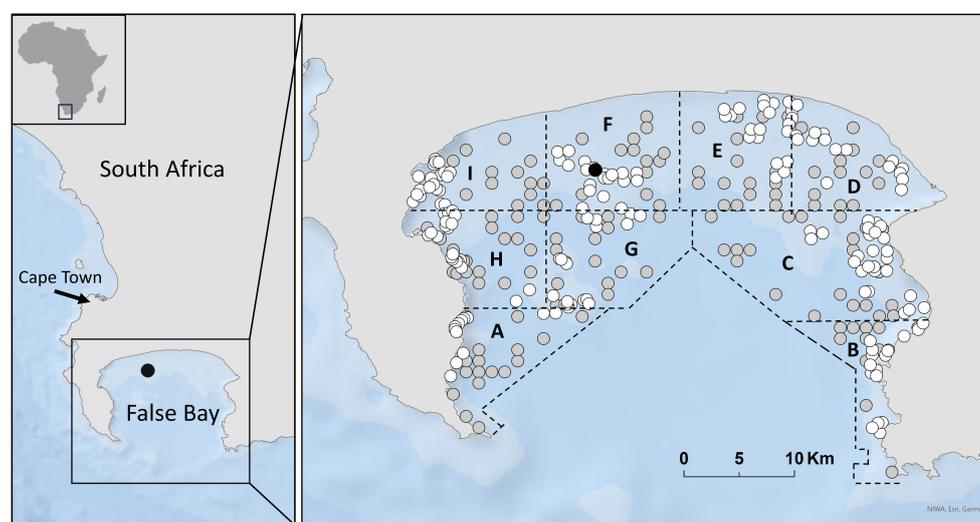


FIGURE 1

False Bay, South Africa. Seal Island is located with a black circle; white and grey circles represent Baited Remote Video Station (BRUVS) sampling sites in the pre-loss (white circles; 2012) and post-loss (grey circles; 2020/21) periods. Sampling zones are labelled (A–I).

the number of visitors to the Cape Point Nature Reserve will scale with the number of visitors to False Bay. It also stands to reason that individuals visiting a nature reserve would be more likely to report natural observations of wildlife to citizen science databases, such as those used here. Thus, to evaluate if sightings of seals have increased over time, we calculated the annual number of seal reports to GBIF divided by the number of annual visitors to the Cape Point Nature Reserve as a standardized proxy of relative seal occurrence in False Bay over time and space. Visitor data were only available beginning 2009, therefore we focused on data from 2009 to 2022. To also evaluate if the spatial distribution of seal sightings has changed across the width of False Bay over time, we calculated the annual longitudinal range in reported seal sightings by subtracting the minimum and maximum longitudinal value of reported seal sightings by year. We then plotted the longitudinal degree range of seal sightings annually, from 2009 to 2022.

Baited remote underwater video stations

BRUVS were deployed in False Bay in both the pre-loss and post-loss period using the same methods and equipment of De Vos et al. (2015a). Each BRUVS consisted of a GoPro HD camera fixed to a metal base, facing a perforated PVC bait canister (130 mm × 110 mm with 10 mm perforations). The bait-facing camera was positioned 1 m away from the bait canister, which was filled with 1 kg of chopped sardine (*Sardinops sagax*). For deployments, BRUVS were lowered to the seafloor via a retrievable float line and left for at least 65 minutes. The footage retained for analysis was standardized to 60 minutes, starting from the moment the BRUVS settled on the seafloor (De Vos et al., 2015a).

As outlined in De Vos et al. (2015a) False Bay was divided into nine sampling zones, each encompassing a range of depths and habitats to facilitate deployment of BRUVS (Figure 1). BRUVS were deployed in depths of 5 to 50 m, as visibility was compromised in shallower depths due to turbulence and insufficient light at deeper depths. Deployment site selection followed a random stratified design to ensure that each zone, depth range, and habitat type was sampled during winter and summer of both periods. The number of deployments chosen for each zone was proportional to the size of the zone, with fifty percent of deployments within each zone allocated to reef and sand, respectively (see De Vos et al., 2015a for more details). The minimum distance between daily sampling sites was restricted to a minimum of 250 m, but averaged 500 m, to permit statistical independence of deployments (Cappo et al., 2001, Cappo et al., 2003) and to reduce the chance of overlapping bait plumes (Bernard and Götz, 2012).

Between June and December of 2012, 173 BRUVS were deployed in False Bay (summer = 85, winter=88), comprising pre-loss period sampling (Figure 1). Between July 2020 and February 2021, 150 BRUVS were deployed (summer=82, winter=68), comprising post-loss period sampling (Figure 1). Videos from each deployment were analyzed for MaxN, which is the maximum number of individuals of the given species in any single frame for the duration of the 60-minute video at a site (Albano et al., 2021). This provided a value of

MaxN per hour for each deployment that was then averaged across samples, providing a metric of relative abundance (Cappo et al., 2001, Cappo et al., 2003).

While BRUVS tend to under-sample larger-bodied shark species (Santana-Garcon et al., 2014; Albano et al., 2021), possibly due to the type and amount of bait used (1 kg of sardines), any white sharks or sevengill sharks recorded on the BRUVS were analyzed for MaxN as a means of independently corroborating patterns found in the boat-based surveys. We primarily used BRUVS data to examine for changes in relative abundance of important prey for seals and sevengill sharks. Based on David (1987) and Huisamen et al. (2012), important prey for seals that were also detected on our BRUVS was Cape horse mackerel (*Trachurus capensis*). Based on Ebert (1991) important prey for sevengill sharks in the region that were also detected in our BRUVS were pyjama catsharks (*Poroderma africanum*) and smoothhound sharks (*Mustelus mustelus*).

For these focal prey species, we tested for potential differences between periods in MaxN by fitting a zero-inflated Generalized Linear Mixed Model (GLMM) using the R package 'glmmTMB' (Brooks et al., 2017). Since previous work in False Bay by De Vos et al. (2015a) revealed differences in the seasonal occurrence of these lower-trophic level species (Cape horse mackerel and smoothhound shark = summer; pyjama catshark = winter) as well as habitat preferences for two of the species (smoothhound sharks = sand, pyjama catsharks = reef), we modelled individual counts in the form of MaxN as a function of the period (pre-loss vs post-loss of white sharks), sampling season (summer vs winter) and sampling habitat (reef vs sand), including an interaction between period and season. We incorporated sampling zone as a random effect in our models to account for any potential spatial effects and variability on occurrences of the focal prey species. See the Supplementary File 1 for additional details about the GLMMs.

Additionally, from each sampling method (boat-based surveys, seal sightings, BRUVS), we calculated percent change and percent difference in average metric values between periods using the following formulas:

$$\% \text{ change} = [V_2 - V_1/V_1] \times 100$$

$$\% \text{ difference} = [V_2 - V_1/((V_2 + V_1/2))] \times 100$$

where V_1 and V_2 are the average value of relative abundance for given species in the pre-loss versus post-loss period. Analyses, calculations, and plots were completed using R Version 4.2.2 (R Core Team, 2024).

Results and discussion

Between 2000 and 2015 (hereafter the pre-loss period), white shark relative abundance in boat-based surveys averaged 1.64 ± 0.03 (mean \pm se) shark sightings per hour, whereas between 2016 to 2020 (hereafter as the post-loss period), white shark relative abundance declined to 0.3 ± 0.02 per hour (Figures 2, 3), representing a 82% decrease and -138% difference between periods (Figure 4). No white sharks were sighted in False Bay since August 2018. While BRUVS likely under sampled white sharks, results from our deployments throughout False Bay mirrored those from the boat-based surveys at

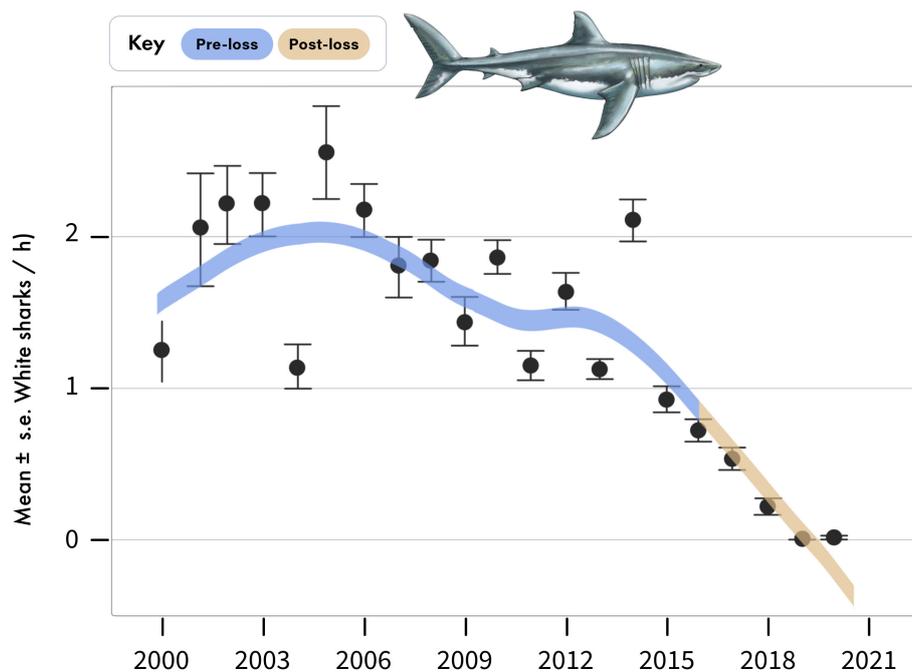


FIGURE 2

Annual sightings of white sharks during standardized boat-based surveys at Seal Island, in False Bay. Data are mean \pm standard error of white shark sightings per hour averaged across sampling days for each year.

Seal Island (Figure 3). Specifically, while only three white sharks were detected on 323 BRUVS, these only occurred in the pre-loss period (2012), with no detections of white sharks on BRUVS deployment in the post-loss period (2020/21; Figure 3).

Coinciding with the decline of white sharks, seal observations reported from False Bay have increased over the same period (Figure 5), growing from a mean of 10.52 ± 2.27 reported seal sightings per million visitors to the area during the pre-loss period to 65.21 ± 32.55 in the post-loss period (Figure 5), representing a 520% increase and a 144% difference between periods (Figure 4). Of note, both visitor numbers at the Cape Point Nature Reserve and reported seal sightings dipped in 2020, likely due to Covid-19 lockdowns and associated restrictions on movement, which would likely curtail outdoor activities (Supplementary File 2, Supplementary Figure S1). However, in 2021, despite continued low visitation to the nature reserve, reported seal sightings reached a peak (Supplementary File 2, Supplementary Figure S1). This discrepancy may be explained by a relaxation of lockdown restrictions, which enabled more localized outdoor activities and associated wildlife observations, while few people still avoided public spaces, like the Cape Point Nature Reserve (Supplementary File 2, Supplementary Figure S1). In addition to increases in the frequency of reported seal sightings in the post-loss period, the spatial extent of reported seal sightings has expanded across the width of False Bay (Figure 5). For example, all reported seal sightings spanned only 0.045 degrees of longitude (4.14 km) in 2016, but increased to 0.426 degrees of longitude (39.18 km) in 2019, an increase of 846%. Notably, both the number of reported seal sightings and the spatial extent of these sightings were consistently relatively low for years, until the documented onset

of white shark decline, after which values began to rapidly increase (Figure 5, Supplementary File 2, Supplementary Figure S1).

Cape fur seals in the region primarily feed on small pelagic fishes, such as anchovies (*Engraulis encrasicolus*) and to a lesser extent Cape horse mackerel. While anchovies were not detected in our BRUVS, Cape horse mackerel were. Cape horse mackerel have been found to be among the most abundant fish species detected in BRUVS studies within our study region (e.g. Roberson et al., 2015). Coinciding with changes in seal sightings between periods, we detected a reduction in the relative abundance of Cape horse mackerel on our BRUVS (Figure 3), a 22% decrease and -33% difference between the pre- and post-loss periods (Figure 4). This reduction occurred primarily in the summer, when Cape horse mackerel were historically most abundant in False Bay (De Vos, 2021). Their summer relative abundance declined from a mean MaxN of 24.62 ± 0.54 in the pre-loss period to 13.05 ± 0.4 during the post-loss period, representing a 44% decline and -61% difference (Figure 3, 4). This decline emerged as statistically significant in the zero-inflated GLMM (Supplementary Table S1, Supplementary Table S2, Supplementary Table S3), where a strong interaction between period and season was detected (Wald $X^2 = 8.71$, $p = 0.003$). As Cape horse mackerel are prey of seals in False Bay (David, 1987), these findings are consistent with a trophic cascade arising from predation release on seals due to the loss of white sharks; a pattern in agreement with previously demonstrated changes in seal behaviors and reductions in seal physiological stress levels associated with the declines of white sharks in False Bay (Hammerschlag et al., 2022).

Sevengill sharks were not observed in boat-based surveys at Seal Island in the pre-loss period, but averaged 0.96 ± 0.03 sightings per

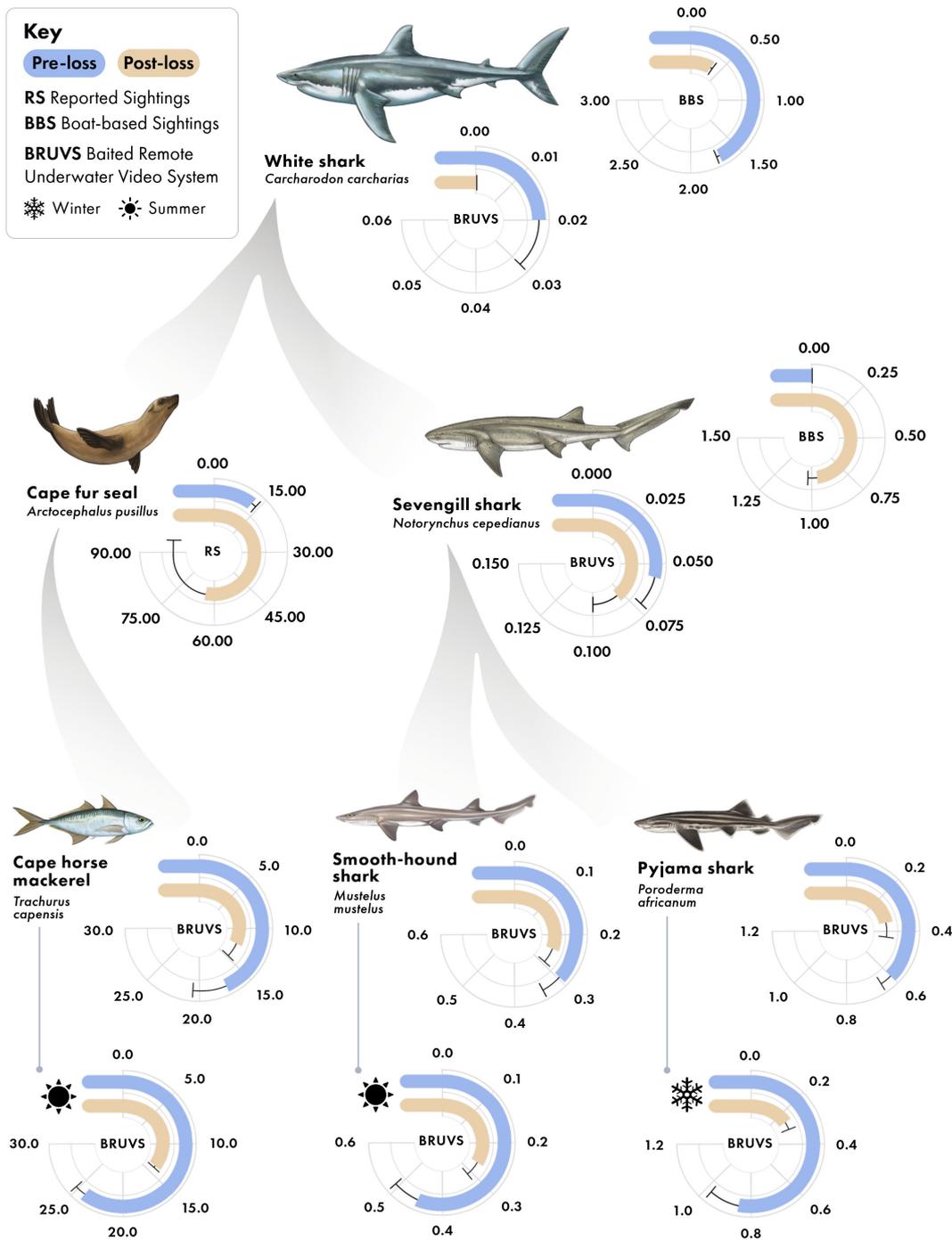
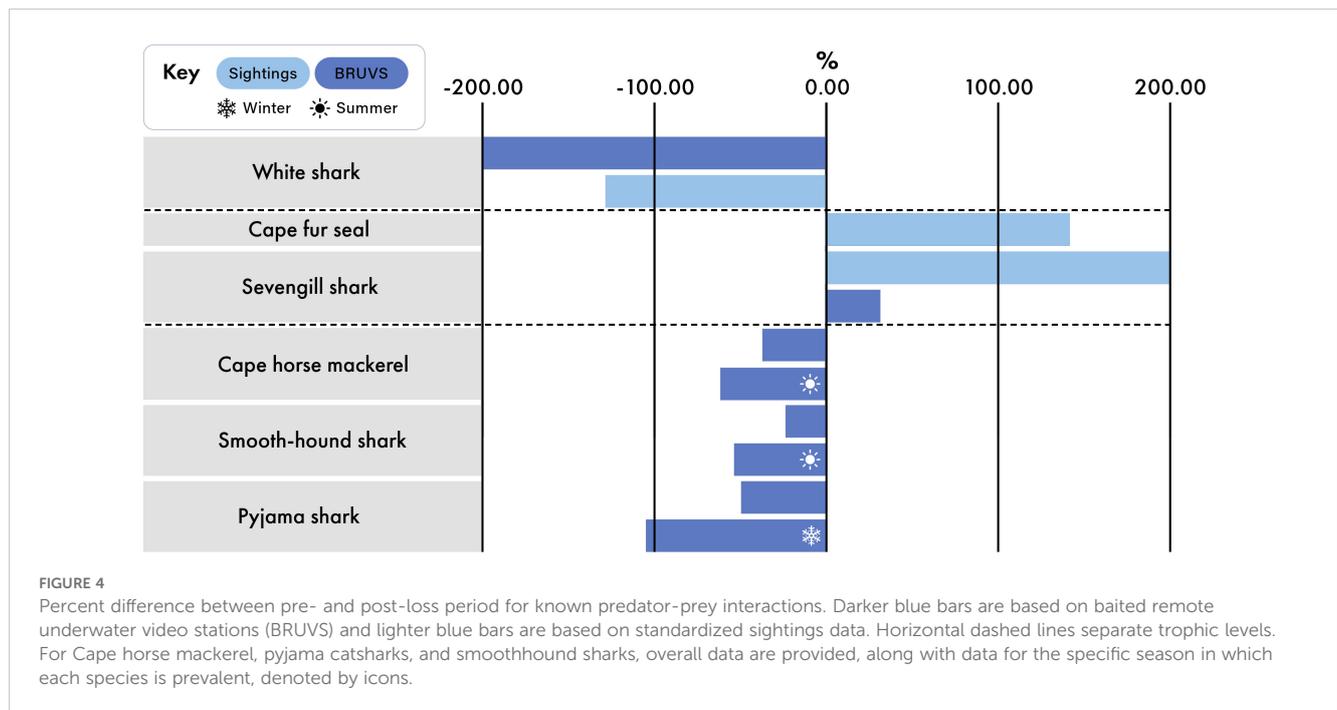


FIGURE 3
 Predator-prey interactions in False Bay, South Africa, with average specie-specific relative abundance values between periods (pre-loss and post-loss of white sharks). Sampling methods producing each radial plot are indicated. Values in radial plots are mean \pm standard error; for RS, data are the annual number of Cape fur seal sightings reported in False Bay, per million visitors to the Cape Point Nature Reserve; for BBS, data are the number of individual sharks observed per hour of baited survey; for BRUVS, data are the average MaxN (maximum number of individuals of the given species in any one frame for the duration of the 60-minute sampling video). For Cape horse mackerel, pyjama catsharks, and smoothhound sharks, overall data are provided, along with data for the specific season in which each species is prevalent, denoted by icons.

hour following the decline of white sharks from the system (Figure 6). Similarly, the relative abundance of sevengill sharks detected on BRUVS was consistent with the findings from the boat-based data (Figure 3). For two important prey species of sevengill sharks detected in our BRUVS (pyjama catsharks and smoothhound

sharks), we found reductions in relative abundance that fell by 40% and 21%, respectively, between periods, a -50% and -23% difference (Figures 3, 4). Similar to the findings for Cape horse mackerel, declines for both species primarily occurred in one particular season: winter for pyjama catshark and summer for smoothhound.



For pyjama catsharks, winter relative abundance declined from 0.86 ± 0.10 in the pre-loss period to a mean of 0.24 ± 0.06 during the post-loss period (Figure 3), representing a 72% decline and -113% difference between periods (Figure 4). This decline also emerged as statistically significant in the GLMM (Supplementary Table S1, Supplementary Table S2, Supplementary Table S3), where a strong interaction between period and season was detected (Wald $X^2 = 9.70$, $p = 0.002$). For smoothhound sharks, their summer relative abundance declined from 0.45 ± 0.07 in the pre-loss period to 0.26 ± 0.06 during the post-loss period (Figure 3), representing a 42% decline and -54% difference between periods (Figure 4). The interaction between period and season did not emerge as statistically significant in the GLMM for smoothhound (Wald $X^2 = 2.01$, $p = 0.156$), although contrast analysis indicates a potentially relevant change for the species during the summer (Supplementary Table S1, Supplementary Table S2, Supplementary Table S3).

The three prey species – Cape horse mackerel, pyjama catsharks, and smoothhounds – are known to exhibit seasonal differences in their occupancy of False Bay (De Vos et al., 2015a; De Vos, 2021). Interestingly, we primarily detected declines between periods in the seasons in which these species were historically more abundant in False Bay. It is thus possible that their predators (seals and sevengill sharks) are primarily targeting these prey species during the seasons in which their prey are most abundant. Accordingly, predation pressure would vary seasonally as would be the expected responses by prey, which would explain our results. Such patterns have been found in other predator-prey systems. For example, experiments with predatory birds and artificial lizards in tropical savanna woodlands have revealed higher predation by birds during the wet season driven by increased prey availability, not by increased predators (Nordberg and Schwarzkopf, 2019). Moreover, observations of big cats in Kenya showed that seasonal changes in prey abundance influenced predation; lion (*Panthera leo*) and cheetah (*Acinonyx*

jubatus) switched their hunting focus to wildebeest (*Connochaetes taurinus*) during seasons of increased wildebeest abundance (Vettorazzi et al., 2022).

We note that changes in species relative abundance found here following the loss of white sharks are likely not exclusively or primarily due to alterations in consumer-induced mortality; but rather, are also a result of behavioral adjustments associated with alterations to predation risk. Prey will typically reduce risk of predation by increasing refuge use and/or reducing conspicuous foraging behavior (Werner et al., 1983) as has been documented in the case of white sharks and seals (e.g. De Vos et al., 2015b; De Vos et al., 2015c). According, we suspect that increases in species relative abundance patterns are also driven by increased foraging behavior and/or decreased refuging in the post-loss period associated with predation release. We suspect that given the relatively short time span over which white sharks were lost from False Bay, the observed changes across trophic levels are likely driven more by changes in antipredatory behavior.

The trophic cascade hypothesis posits that the magnitude of top-down effects of predators are strongest at trophic levels immediately below them; but, diminish successively down the food web (Shurin et al., 2002; Ripple and Beschta, 2004; Borer et al., 2005). Our findings were consistent with this ecological pattern (Figure 4), with the largest magnitude in relative differences between pre- and post-loss periods recorded in seals and sevengill sharks, with a relatively lesser magnitude in relative differences seen in lower trophic levels.

Limitations and alternative hypotheses

A limitation of any correlative study in the wild is that our results could be driven by confounding factors including fishing, pollution, invasive species, climate change, and natural stochastic

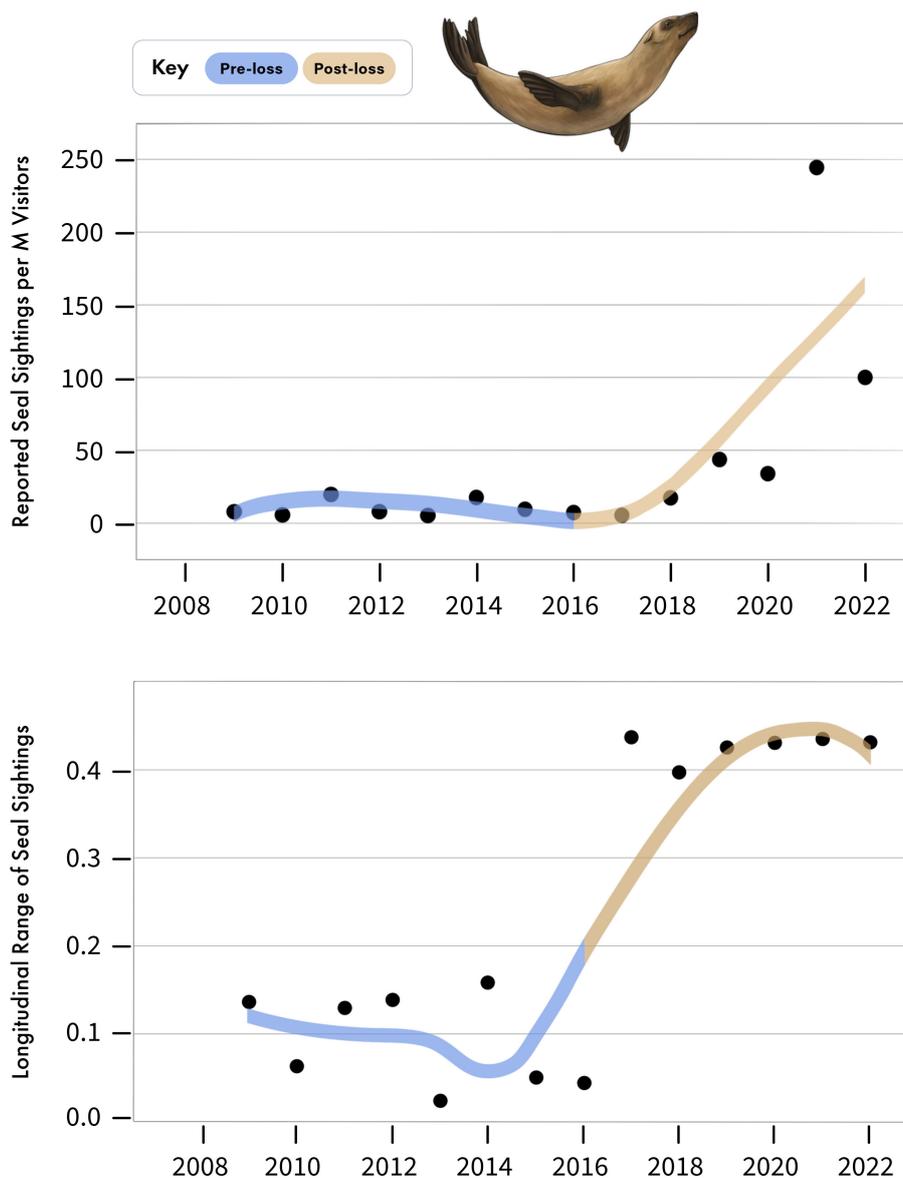
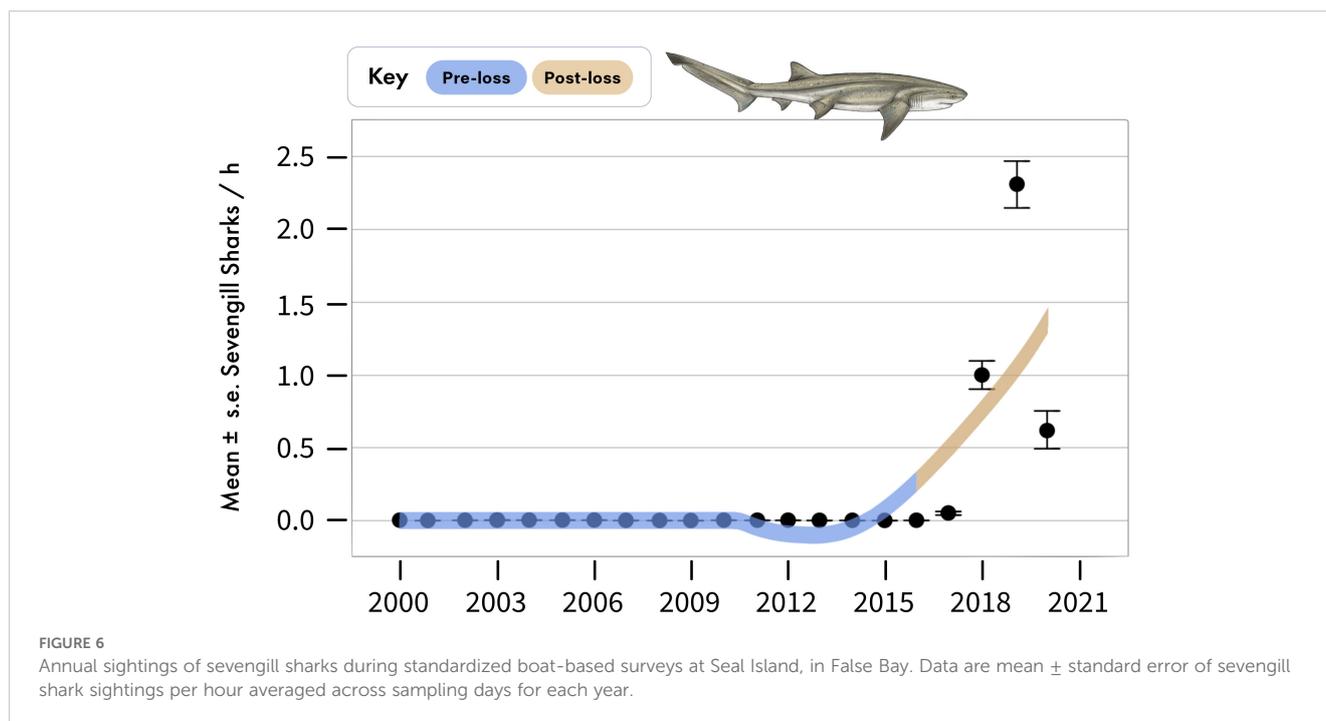


FIGURE 5 (Above) Annual number of Cape fur seal sightings reported in False Bay in GBIF, per million visitors to the Cape Point Nature Reserve. (Below) Longitudinal range, in degrees, of seal sightings reported annually to GBIF. Note that 0.1 degrees longitude is equivalent to approximately 9.2 km.

processes. However, for the species evaluated here, we found patterns that were inconsistent with long-term population trajectories in the region that we believe would otherwise confound our results. For example, we documented a marked increase in the frequency and spatial scale of seal sightings in the post-loss period, despite the seal population in False Bay having been on a declining trajectory since the late 1990s (Kirman et al., 2013). We realize that seal sightings data are dependent on reporting via citizen science applications, like iNaturalist, that have likely become more accessible due to smartphones in more recent decades. However, the number of smartphone users have steadily increased since 2009 (Sandesara et al., 2022), which is inconsistent with the patterns of reported seal sightings

documented here, which only began to rapidly increase following the loss of white shark from False Bay after 2017.

While we documented a concurrent decrease in the relative abundance of Cape horse mackerel during the post-loss period, a recent assessment indicated that the stock status of this species for the South African coastline is optimal and that spawning biomass are well above Maximum Sustainable Yield, with commercial catch per unit effort index of abundance in 2018 at its highest on record in South Africa (DEFF, 2020), a pattern inconsistent with the decrease documented in our BRUVS in the post-loss period. A comprehensive study of fisheries data from False Bay, reported no clear temporal trends in relative abundance for sevengills or pyjama catsharks between 1897 and 2011, whereas significant increases



were found for smoothhounds (Best et al., 2013). Although these time series precede our study, those reported long-term trends differ considerably in magnitude and direction from the changes between periods found for these species in the present study. That said, for smoothhound sharks, fisheries data suggest a regional population decline (da Silva et al., 2019). So, local declines due to increased predation are likely exacerbated by regional population declines from overfishing.

While False Bay has experienced significant coastal development over the past 30 years with associated increases in pollution that has likely had lethal and sublethal impacts on varying species (Pfaff et al., 2019), this is unlikely to have caused the observed inverse patterns in relative abundance and frequency at successively lower trophic levels. Since the 1980s, False Bay has also experienced increased upwelling and cooling, which has led to nutrient enrichment of the bay and subsequent increases in kelp, rock lobsters, seabirds, pelagic fish, and several invasive species (Pfaff et al., 2019). While these changes have likely had bottom-up ecosystem impacts in False Bay, these impacts predate our study by several decades and would likely have already largely stabilized prior to the study period.

Temperature is a major driver of fish behavior and could contribute in some way to changes in the relative abundance of the observed species. However, changes in temperature between the periods would not be expected to drive the observed inverse patterns in relative abundance of predators and prey at successively lower trophic levels. While study results are most parsimoniously explained by the loss of white sharks from False Bay, a major limitation of this study is that for species evaluated using BRUVS, we only have two sampling periods, and cannot account for potential changes in detection probabilities. While

confidence in our results was strengthened by incorporating multiple datasets for some species (e.g. sevengill sharks), the availability of other fisheries-dependent or independent data that would corroborate patterns for other species (e.g. horse mackerel) are currently unavailable. Accordingly, future work would benefit from additional sampling over time.

Summary

The decline in white sharks that occurred in False Bay within a long-term monitoring program has provided an unparalleled opportunity to gain preliminary insights into ecological changes in the wild due to the loss of a marine apex predator. The documented changes in relative abundance patterns between periods matched with expectations of a trophic cascade caused by the loss of top-down predation from white sharks. This has included increases in species that were historically important prey of white sharks and in turn, decreases in abundances of their prey. Future work at this site would benefit from understanding if and how community structure and function may have been altered and the extent to which they will continue to change through time. While impacts of apex predator declines are difficult to detect in the wild, especially in marine environments, they are likely more widespread than recognized given the pace and extent of apex predator declines globally.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by University of Miami Institutional Care and Animal Use Committee. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

NH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. YH: Data curation, Formal analysis, Investigation, Writing – review & editing. CF: Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. TC: Formal analysis, Supervision, Writing – review & editing.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2025.1530362/full#supplementary-material>

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