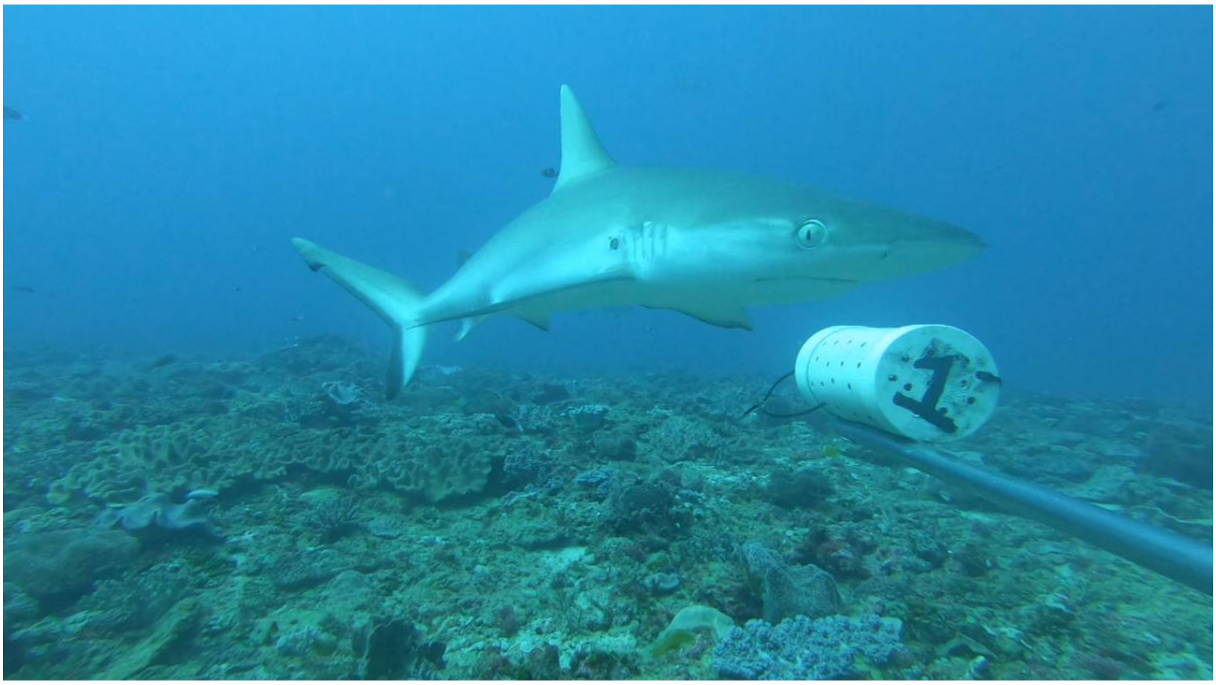
DEPARTMENT OF MARINE SCIENCES

ASSESSING THE INFLUENCE OF A SUBMARINE CANYON ON ELASMOBRANCH DIVERSITY AND ABUNDANCE WITH BAITED REMOTE UNDERWATER VIDEO SYSTEMS (BRUVS) AND MACHINE-LEARNING METHODS



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Abstract

Understanding habitat use and the influence of topographic features is important for the conservation of a species, but also the entire ecosystem. Submarine canyons remain a rather undiscovered feature of the oceans of the world despite there being more than 8500 worldwide. The canyon effect is referring to the topographic features of canyons that can cause oceanographic phenomena such as upwelling, which tend to benefit lower trophic levels and therefore cause a bottom-up increase in species abundance and diversity. Elasmobranch (sharks and rays) populations worldwide suffer from overexploitation and stock declines, where 37% of sharks and rays are threatened with extinction as a result. This study aims to assess the influence of the Wright Canyon in the iSimangaliso Wetland Park Marine Protected Area on elasmobranch species diversity and abundance, along with establishing if machine-learning methods can be used for large-scale assessments in ecology and conservation. A total of 48 baited remote underwater video systems (BRUVS) were randomly deployed south of the Wright Canyon and in a control site, referred to as Non-Canyon, over the course of four days. All videos were manually analysed to retain the MaxN, and also run through the object detection model that was trained to recognise six of the total ten manually observed species. Despite the assumption that the canyon would inhabit more elasmobranchs, results showed no significant difference in the relative abundance between the two areas. This was probably caused by elasmobranchs' wide home ranges, a small sample size or the fact that the canyon effect is not seen in higher trophic levels since they are very mobile. Machine-learning methods have great potential for large-scale studies to reduce analysing time and enhance the conservation potential of the decreasing numbers of elasmobranchs worldwide.

Keywords Submarine canyons · elasmobranchs · species diversity · abundance · BRUVS · machine-learning methods · iSimangaliso Wetland Park · South Africa

Influence of a submarine canyon on elasmobranch diversity and abundance

Elasmobranchs (sharks and rays) around the world are threatened by a number of factors, with fishing being one of them. A large amount is trapped in nets as bycatch from fishing of other species and as a result, 37% of shark and ray species are threatened with extinction. To

protect these species, knowledge about abundance, diversity and habitat preferences is crucial.

Submarine canyons are underwater valleys that join the continental shelves with the deep sea. These topographic features have a big influence on the ecosystems in and around them due to oceanographic factors, called the canyon effect. This study compared the abundance and diversity of elasmobranchs from a site south of the Wright Canyon in the iSimangaliso Wetland Park Marine Protected Area in South Africa with a Non-Canyon control site north of the canyon. Baited Remote Underwater Video Systems (BRUVS) were used to collect 48 videos of 60 minutes each on four different occasions, which were analysed manually and by a trained object detection model. No significant differences in abundance were observed between the Canyon and Non-Canyon. The cause of this is believed to be because sharks and rays range vast distances naturally, which therefore wouldn't show a difference when comparing two areas relatively close to each other. These animals may not be affected by a possible canyon effect due to their wide home ranges. Another cause could be that a larger sample size is needed to assess this question further. In this study, object detection models were trained with artificial intelligence to recognise six species of elasmobranchs which performed well when tested on video stills and videos including these species. If more data were to be collected, machine-learning methods would be a great tool to scale up data collection to reduce the time of analysis of these videos that can be used to enhance the conservation effort and work to hinder the decreasing numbers of elasmobranchs worldwide.

Introduction

The Anthropocene is a new geological age driven by the impact of centuries of human activities (Dulvy et al. 2021). The ocean and its biodiversity have been affected by, and are still threatened by human activities indirectly through climate change and directly via habitat modification, overfishing, hunting and as bycatch (Pimm et al. 2014). Elasmobranch (sharks and rays) populations specifically have suffered from overexploitation and stock declines, where 37% of sharks and rays are threatened with extinction as a result (Bakker et al. 2017, IUCN 2023). Slow reproduction, very long gestation periods, slow growth and late maturing are all key factors that contribute to this (O'Shea et al. 2013, Dulvy et al. 2014). However, for most species, even the most basic ecological information is lacking to evaluate the extinction risk of the species, which led to 46.8% (449 species) of sharks, skates and rays being listed as

'Data Deficient' in the first global IUCN Red List of Threatened Species assessment published in 2014 (Dulvy et al. 2014; Buckley et al. 2018). To protect these species from extinction, more data is needed to monitor and assess their current state.

One of the most common approaches to gathering fundamental ecological information about elasmobranch populations, mainly sharks, is through scientific longline surveys (Brooks et al. 2011). The number of sharks caught per hook per hour is the unit used for relative abundance, which can be derived from the catch per unit effort (CPUE) calculations (Kessel et al. 2016). Because sharks reach maturity at a late age, have low fecundity and low resilience to exploitation from fisheries, this method that increases physical trauma and psychological stress with possible post-release mortality should be replaced with non-invasive, non-destructive methods in all cases possible (Schindler et al. 2002, Brooks et al. 2011). Using baited remote underwater video systems (BRUVS) has been proven successful in identifying population-level changes in response to various stressors including overfishing, habitat destruction and climate change, along with providing fast and reliable population data that is crucial for the conservation of elasmobranchs (Bruns & Henderson 2020). BRUVS are beneficial for bigger animals like elasmobranchs since it's not size selective like the hooks used on the scientific longline surveys, and they can be replicated in varying habitats and at any depth (Brooks et al. 2011). BRUVS are excellent tools for the monitoring and management of the conservation of ecosystems, but also for studies of community structure and elasmobranch diversity (Harvey et al. 2021).

Monitoring biodiversity and the environment is crucial for understanding and managing the changes that occur in different habitats and ecosystems, especially in the ocean (Palumbi et al. 2009). To scale up such monitoring, object detection models are a great tool to shorten the time of analysis. When machine-learning models are trained with representative images to recognise the species, they can efficiently identify large numbers of underwater recordings which are not possible to analyse manually (Anton et al. 2021). However, the performance of object detection models depends on the amount and quality of the data used for training and image quality. The contrast between the objects and the background along with visibility in the water column also influences the performance and accuracy of the model, which can limit it to certain areas and/or habitats.

Submarine canyons are steep-sided valleys that connect the continental shelf with the deep sea and act as the main way of transportation for nutrients, organic matter, sediments and litter (Amaro et al. 2016). In 2014, Harris et al. mapped more than 8500 submarine canyons globally, and these topographic features have recently received a more extensive research focus due to their ecological importance. An increased species diversity is predicted in complex heterogeneous ecosystems that offer more niches (Kovalenko et al. 2012).
"The canyon effect" is a widely known phenomenon that implies that the topographic features of submarine canyons create upwelling and downwelling events which is a key factor in these regions having increased biological productivity and diversity that benefits all levels of the food chain (Allen & Durrieu de Madron 2009, Moors-Murphy 2014). Studies have shown that shelf-break canyons often enhance local concentrations of lower trophic levels such as plankton and fish (Allen et al. 2001). Submarine canyons have a great impact on the surrounding ecosystems because of their highly variable seascape that enables many different niches and contributes to physical oceanographic processes including upwelling of nutrient-rich water (Demopoulos et al. 2017).

South Africa's east coast is defined by the Agulhas current: a fast-flowing, warm south-westerly current that follows the coast (Beckley & Leis 2000). It is the main oceanographic factor in the iSimangaliso Wetland Park since it is fully formed in this area, around 27°S (Lutjeharms 2006). Since 1999, the iSimangaliso Wetland Park Marine Protected Area (MPA) has been South Africa's only UNESCO marine World Heritage Site, and the second biggest one in the country after Kruger National Park (https://www.isimangaliso.com). The discovery of coelacanths (*Latimeria chalumnae*) in the submarine canyons of iSimangaliso Wetland Park MPA in 2000 has led to a lot of attention and research being directed towards this area since (Hissmann et al. 2006). The MPA has 23 mapped submarine canyons and the biggest one is the Wright canyon, reaching a depth of below 700m (Ramsay & Miller 2006). The head of the Wright Canyon in the iSimangaliso Wetland Park is cooler than the surrounding water year-round, which historic data from temperature sensors located at the head of the canyon have shown. The southward flow of the Agulhas Current has been a contributing aspect to these sharp decreases in temperature occurring around the canyon head, indicating that upwelling events happen regularly (Schleyer et al. 2018). Rautenbach et al. (2023) found that upwelling in this area is caused by two to five cyclonic eddies annually, either directly or through contact with anticyclonic eddies that push water off the shelf at their trailing side.

The study aims to test a non-invasive method to sample elasmobranch diversity and relative abundance data and use this data to compare different areas surrounding the deepest canyon in the iSimangaliso Wetland Park. The Wright canyon is located on the border of the Sodwana Dive Restricted Zone (SDRZ), which is protected as fishing is only allowed outside of the zone. This canyon is a highly productive area with upwelling of nutrient-rich water. An assessment and comparison of the impact on the elasmobranch diversity and relative abundance from the canyon could lead to the discovery of a new elasmobranch hotspot in need of further protection, along with clarification of preferred areas and/or different habitats for certain species.

Given the hypothesis that the canyon effect will have an impact on, and reveal a higher number of elasmobranch abundance and diversity in the Canyon area, I asked the following questions: 1.) How are elasmobranch abundance and diversity affected by the Wright canyon in the iSimangaliso Wetland Park Marine Protected Area? And 2.) Can automated monitoring of elasmobranchs with cameras and machine learning be used for large-scale assessments in ecology and conservation?

Methods

Study area

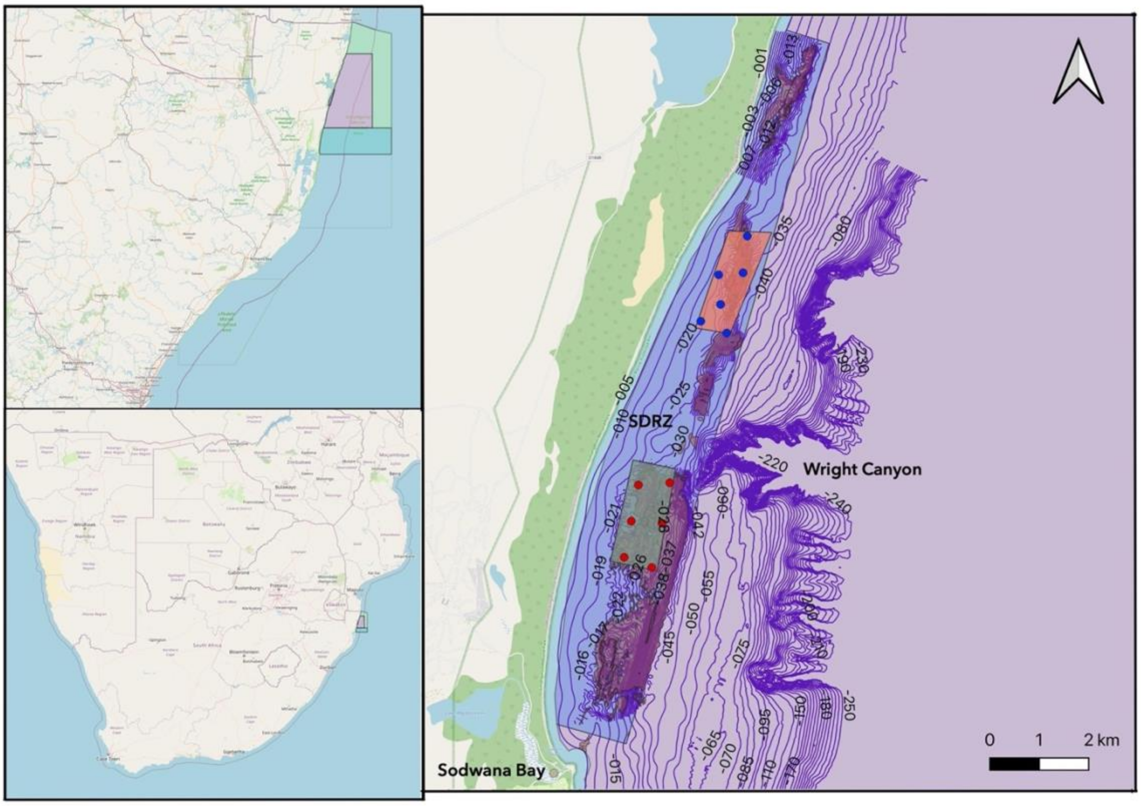

Figure 1 Map of the study area, iSimangaliso Wetland Park Marine Protected Area outside of Sodwana Bay, KwaZulu-Natal, South Africa with two blocks including the randomized points for BRUVS drop sites. The red points in the green polygon represent the canyon study site and the blue points in the orange polygon represent the non-canyon study site. The blue coastal area represents the Sodwana Dive Restricted Zone (SDRZ), and the light purple area is the iSimangaliso Offshore Controlled Pelagic Line-fishing Zone North (IOCPLZN). Reefs are displayed in darker purple inside the SDRZ. Made in QGIS.

Sodwana Bay is located in the KwaZulu-Natal province along South Africa's north-eastern coastline. It is situated by the second largest protected area in South Africa - the iSimangaliso Wetland Park. Of the coast is the 10 700km^2 iSimangaliso Marine Protected Area (MPA), a popular Scuba diving and sport fishing destination influenced by the warm nutrient-rich waters of the Agulhas current. The Wright Canyon is the biggest one out of the 23 mapped submarine canyons existing in the MPA (Ramsay & Miller 2006). With a start depth of around 40m, Wright Canyon is a large and mature canyon located around 2 km from the coast with a narrow head (Nyawo 2020). Over a distance of 500 m, Wright Canyon descends from 50 to

250 m. It is located in the iSimangaliso Offshore Controlled Pelagic Line-fishing zone North (IOCPLZN), just on the border to the Sodwana Dive Restricted Zone (SDRZ), with the 1.1 km wide head that cuts the edge of the shelf close to the shore and facing popular diving reefs (Figure 1). The SDRZ was enforced in 2019, meaning no fishing has been legal within this area since then.

Data collection

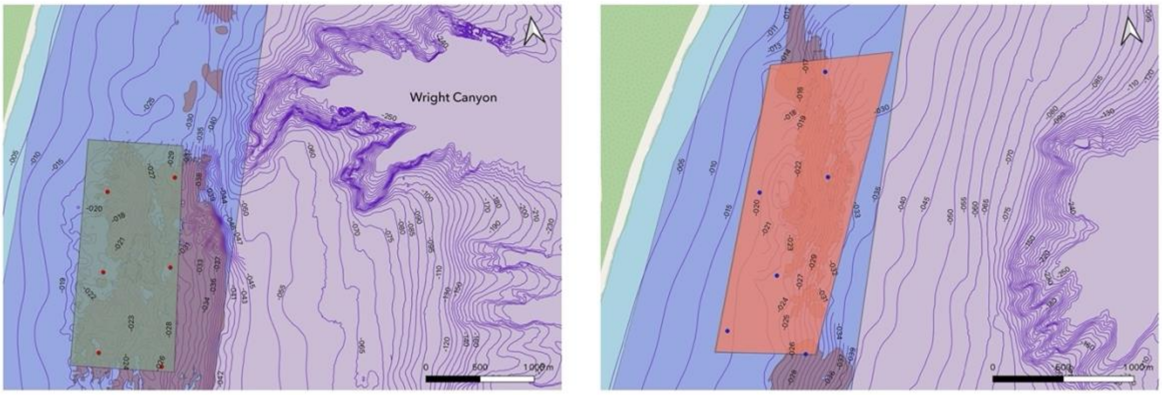

Figure 2 Maps of the Canyon and Non-Canyon sites with all six randomly selected waypoints in polygons. The Canyon site is just south of the rim of the Wright Canyon, and the Non-Canyon site is north of the Wright Canyon in the iSimangaliso Wetland Park, South Africa. Made in QGIS.

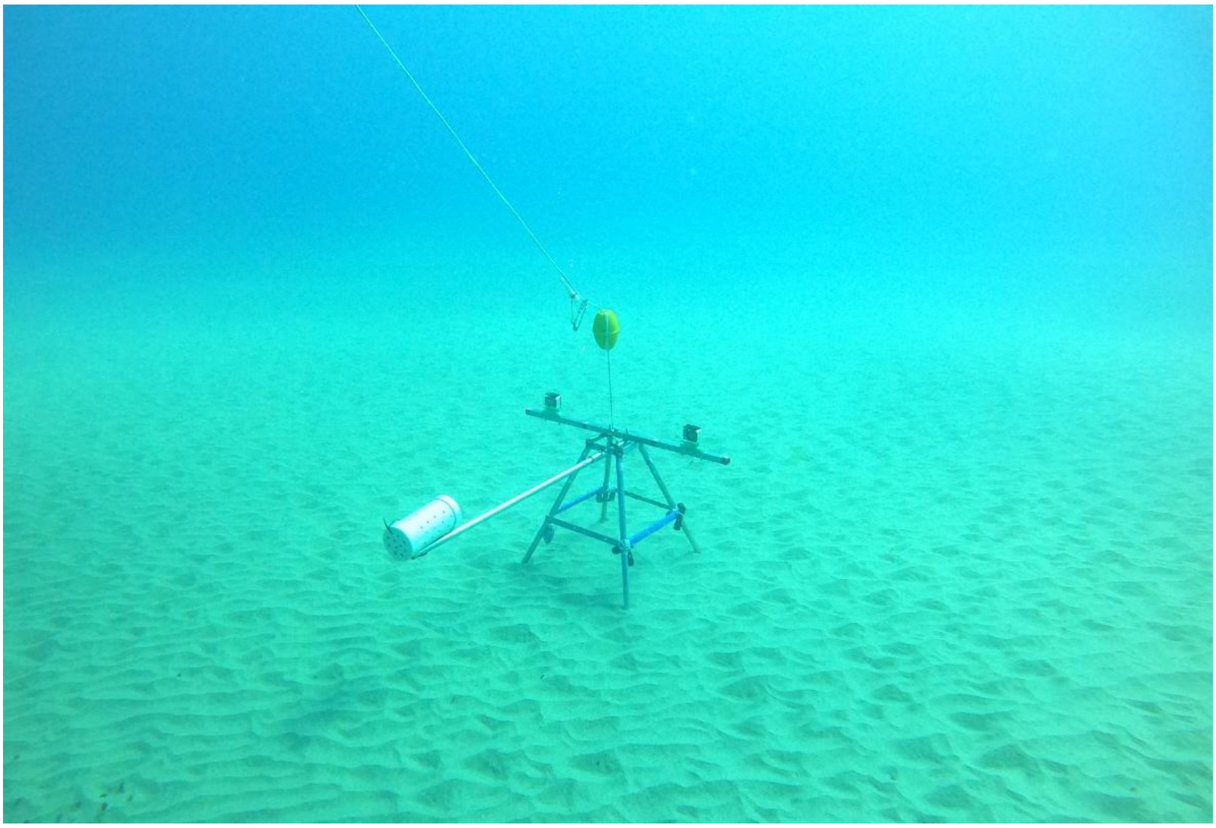

Figure 3 Picture of the stereo-BRUVS used for this project. Picture by Sharklife Conservation Group.

Since 2020, Sharklife Conservation Group has been deploying over 700 baited remote underwater video systems (BRUVS) in the iSimangaliso Marine Protected Area for elasmobranch assessment, understanding and conservation. For this project, sampling was conducted in March 2023 where twelve stereo-BRUVS were deployed a day on four different occasions. Six waypoints were randomly selected within a polygon using the 'Random points in polygons' tool in QGIS (QGIS Development Team 2023) of the area just south of the Wright canyon (Figure 2), where the canyon is expected to have the most impact. In the same way, six other waypoints were randomly selected within a polygon in QGIS north of the Wright canyon (Figure 2), which is an area where the canyon is believed to have less impact. Both polygons were formed around reefs in the depth range of approximately 20-30 m, and there were more than 3,2 km between the most northern point of the Canyon site to the most southern point of the Non-Canyon site (Figures 1 and 2). To prevent bait plumes from overlapping and reduce the possibility of elasmobranchs travelling between BRUVS drop sites during the sampling period, all waypoints were spaced apart by a minimum of 500 meters. BRUVS were deployed at depths between 17.5-29m by freediving. The BRUVS stand consisted of two GoPro high-definition cameras on each end of a 1.1 meter long metal bar, with the cameras being 63 cm apart and with a buoy line connected (Figure 3). A bait box, mounted on a 120 cm long metal pole, was attached to each BRUV stand containing 1 kg of sardines in each 26x11.5 cm box. The BRUVS were soaked for a little longer than an hour, but only one hour of recording was used for the analysis. At each site, a Garmin eTREX 10 GPS was deployed to record the speed and direction of the surface current. The date, time in, time out, area, zone, sea surface temperature (SST), bottom surface temperature (BST), vertical visibility and coordinates were also registered at each site. The substrate type was determined by looking at what was in the frame of the recorded video and then categorising each substrate type into one of six different categories: Sand, Sand Inundated Reef (more than 30% sand), Patchy-reef Low, Patchy-reef High, Reef Low and Reef High. The swell was registered from Windguru (https://www.windguru.cz/). The SST was registered with a transducer connected to the Lowrance hook reveal 7.55 boat chart, and the BST is recorded with temperature loggers using the Maxim-1 wire software (http://www.ibuttonlink.com/products/maxim-1-wire-viewer). A total of 48 BRUVS were collected, 24 BRUVS at each site.

Manual video analysis

To compare the observations collected by BRUVS from the canyon site with those outside the canyon, each BRUV video was analysed manually by assessing each elasmobranch sighting by identifying the lowest taxonomic level. The maximum number of individuals seen at once (i.e., in one frame) was used to determine the relative abundance of each species found (MaxN). This was used to look at the species diversity and the relative abundance to compare these between the sites.

Machine learning analysis

The object detection model was created by using the existing Koster Sea Observatory (KSO) platform (Anton et al. 2021), which was trained to recognise six different species of elasmobranchs: Grey Reef Shark (*Carcharhinus amblyrhynchos*), Tiger Shark (*Galeocerdo cuvier*), Silvertip Shark (*Carcharhinus albimarginatus*), Humans Whaler Shark (*Carcharhinus humani*), White Spotted Wedgefish (*Rhynchobatus australiae*) and *Himantura* sp. The model was trained using 316 still photos of the video material collected for this project where each species was marked with different coloured boxes to tell the model which species were in the photo. The number of photos was slightly different for each species depending on how many sightings were available. All species had around 50 pictures apart from Silvertip Shark which only had one sighting and therefore only 26 pictures (Figure 5). The model was trained in Weights & Biases (https://wandb.ai/site) by an expert from KSO where 80% of the photos were used for training (Figure 6) and the remaining 20% was used to test and verify the model. The already manually analysed videos recorded from the BRUVS were subsequently run to test the accuracy of the model.

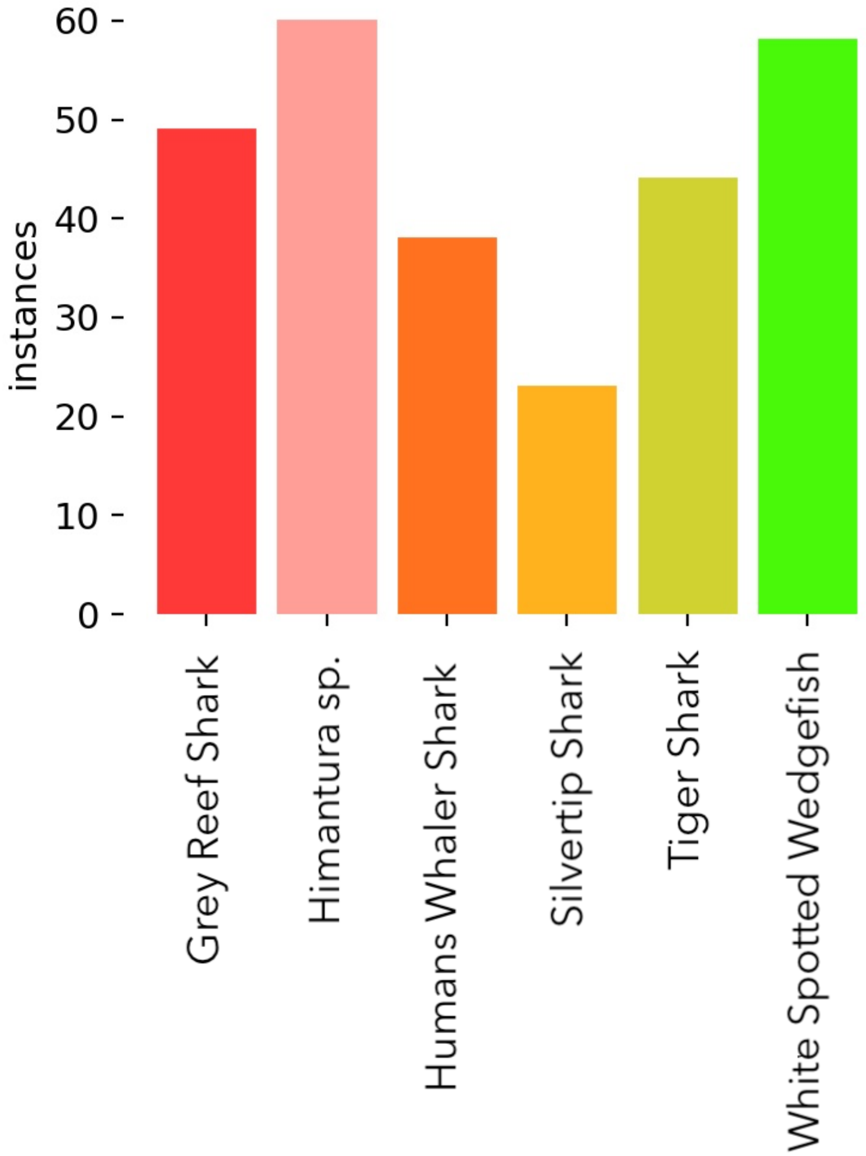

Figure 5 The number of still pictures for each of the six species that was used to train the model to recognise them. These species had the most sightings, or a fewer number but longer sighting where the individual stayed in the frame for a longer time or came back repeatably. Since there was only one

sighting of a Silvertip Shark (*Carcharhinus albimarginatus*), fewer pictures were taken of that sighting and therefore used to train the model.

Figure 6 Example pictures of the training of the model where the coloured boxes frame the elasmobranch in the picture and name the species, with a confidence value that varies between 0-1. This value describes the probability of the observation being true, i.e., how sure the model is of the observation being that specific species of elasmobranch.

An independent t-test with unequal variances was done in Microsoft Excel to compare the statistical significance in the relative abundance of all elasmobranch sightings in the two different sites – Canyon and Non-Canyon, as well as for sharks and rays respectively.

Results

Data analysis

During the period of study, a total of 22 sightings (MaxN) were recorded in the Canyon, representing six different species (Table 1). In comparison, a total of 35 sightings (MaxN) were recorded in the Non-Canyon consisting of eight different species (Table 1).

Table 1 Summary of data collected during the period of study from both sites, including the total number of sightings as well as all individual sightings based on MaxN.

Species sightings	Canyon	Non-Canyon
Grey Reef Shark (*Carcharhinus amblyrhynchos*)	14	7
Humans Whaler Shark (*Carcharhinus humani*)	4	8
Silvertip Shark (*Carcharhinus albimarginatus*)	0	1
Tiger Shark (*Galeocerdo cuvier*)	1	1
Whitetip Reef Shark (*Triaenodon obesus*)	1	0
White Spotted Wedgefish (*Rhynchobatus australiae*)	1	4
Blotched Fantail Ray (*Taeniurops meyeni*)	1	0
Himantura sp.	0	6
Jenkins Stingray (*Pateobatis jenkinsii*)	0	4
Pink Whipray (*Himantura fai*)	0	1
Unidentified Rays	0	3
Total sightings (MaxN)	22	35
Total species diversity	6	8

Table 2 An independent t-test comparing the statistical significance in the relative abundance of all elasmobranch sightings in the two different sites – Canyon and Non-Canyon.

t-Test: Two-Sample Assuming Unequal Variances	Canyon	Non-Canyon
Mean	0,9167	1,4583
Variance	0,5145	1,3025
Test statistic	-1,9686	
df	39	
P(T<=t) two-tail	0,0561	

Table 3 An independent t-test comparing the statistical significance in the relative abundance of shark sightings in the two different sites – Canyon and Non-Canyon.

t-Test: Two-Sample Assuming Unequal Variances	Canyon	Non-Canyon
Mean	0,8333	0,7083
Variance	0,5797	0,9112
Test statistic	0,5015	
df	44	

P(T<=t) two-tail	0,6185	

Table 4 An independent t-test comparing the statistical significance in the relative abundance of ray sightings in the two different sites – Canyon and Non-Canyon.

t-Test: Two-Sample Assuming Unequal Variances	Canyon	Non-Canyon
Mean	0,0833	0,75
Variance	0,0797	0,8043
Test statistic	-3,4736	
df	28	
P(T<=t) two-tail	0,0017	

There is no significant difference in the relative abundance of elasmobranchs (p = 0,0561) between the Canyon and Non-Canyon sites (Table 2). Figure 7 compares the species diversity between the two sites, showing that the diversity differs with the two more species in the Non-Canyon, as well as somewhat more evenly distributed numbers of relative abundance when it comes to the count of sightings of different species. In the Canyon site, most sightings were of Grey Reef Sharks (*Carcharhinus amblyrhynchos*) which represented 63,6% of all sightings and 70% of all shark sightings at this site (Figure 7). In comparison, Grey Reef Sharks (*C. amblyrhynchos*) only represented 41,2% of all shark sightings and 20% of all sightings in the Non-Canyon site (Figure 7). The Humans Whaler Shark (*Carcharhinus humani*) was sighted twice as many times in the Non-Canyon compared to the Canyon site (Table 2). Both sites had one sighting each of a Tiger Shark (*Galeocerdo cuvier*), as well as one sighting of a Whitetip Reef Shark (*Triaenodon obesus*) in the Canyon and one Silvertip Shark (*Carcharhinus albimarginatus*) in the Non-Canyon (Figure 7). The total number of species of sharks sighted in both sites was the same (4), and there was no significant difference in the relative abundance of sharks between the two sites (p = 0,6185) (Table 3). 54% of the sharks recorded were sighted in the Canyon.

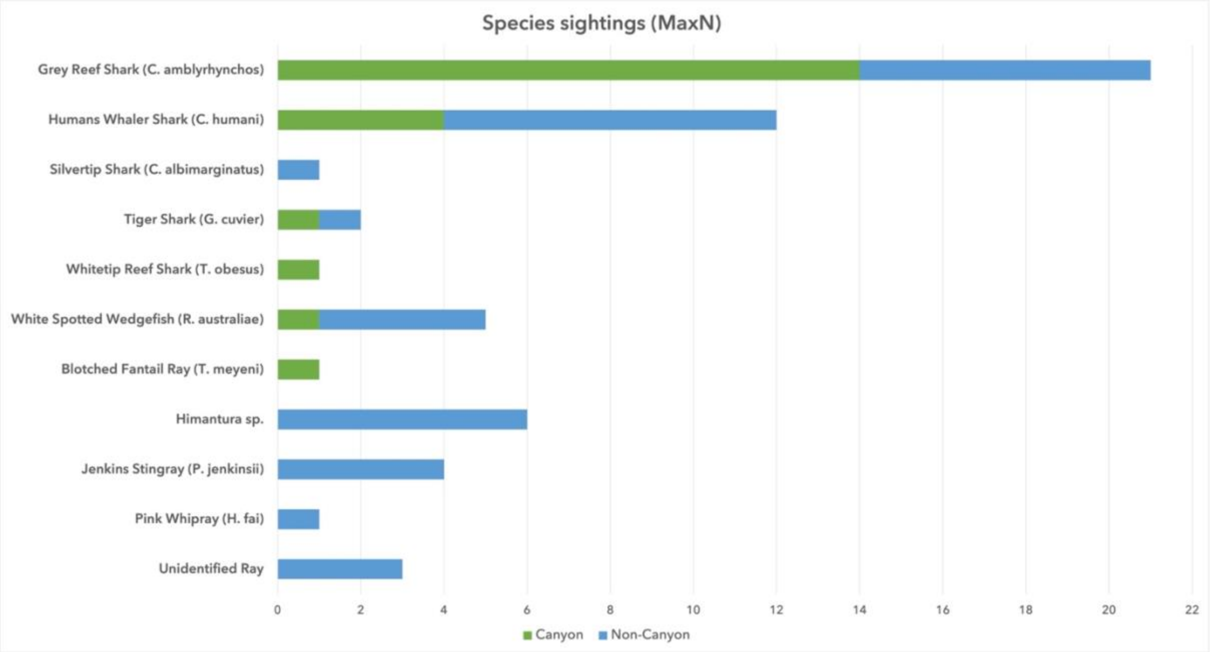

Figure 7 Elasmobranch species diversity in both Canyon and Non-Canyon sites. The total number of sightings (MaxN) in the Canyon was 22 and six different species were observed. The majority of these sightings were of the Grey Reef Shark (*Carcharhinus amblyrhynchos*) which had 14 individual sightings. In the Non-Canyon, the total number of sightings (MaxN) was 35, with eight different species observed at this site. There was no significant difference in relative abundance between the two sites (p = 0,0561). The canyon is shown in green bars and Non-Canyon in blue bars.

The number of rays differed significantly when comparing the two sites (p = 0,0017) (Table 4). Of the total number of rays recorded, 90% were in the Non-Canyon. Figure 7 shows that the Non-Canyon has a way higher number of sightings (18) compared to the two sightings of rays in the Canyon site. The species diversity was also higher with four different identified species in the Non-Canyon and only two different species in the Canyon (Figure 7). Three more rays were observed in the Non-Canyon but were unable to be identified, hence categorising them as “Unidentified Ray” and not counting them in species diversity.

There was a lot of variation among the substrate type (Appendix 1), both within both sites but also between the two sites. The Canyon had more different substrates, where the majority was Sand Inundated Reef (29.2%) followed by Reef Low (25%) and equally as many Sand BRUVS as Reef High (16.7%). Patchy-high reef represented 8.3% and Patchy-low reef was 4.1%. In the Non-Canyon site, the majority of BRUVS were on Sand (54.2%) which was a lot higher compared to the Canyon site. Reef Low was the same as in the Canyon (25%) and Sand

Inundated Reef was a little bit less (20.8%). There were no BRUVS with Patch-reef High, Patch-reef Low and Reef High in the Non-Canyon site.

Model analysis

The model's ability to detect the different species and separate them from false positives (FP), such as fish or other elasmobranchs is shown in the Precision curve (Figure 8), where a higher precision value means more elasmobranchs are detected with less FP. The Recall curve (Figure 8) shows the model’s ability to avoid false negatives (FN), like missing observations, where a high recall value means that more observations have been detected. The F1-Confidence curve (Figure 9) shows the relationship between the Precision and the Recall curve. The confidence value that varies between 0-1 describes the probability of the observation being true, i.e., how sure the model is of the observation being that specific species of elasmobranch.
The model performs well with a confidence value of 0.4-0.8 where both recall and precision values are above 0.9 (Figure 9).

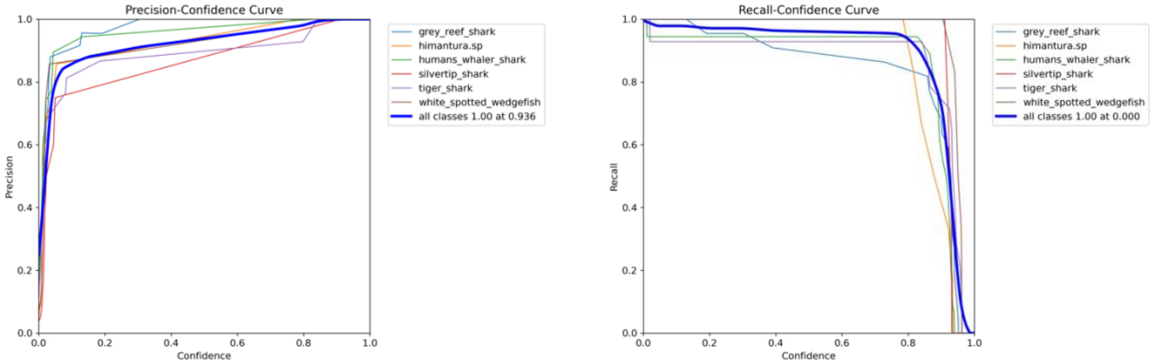

Figure 8 Precision-confidence curve showing the model's ability to detect the different species and separate them from false positives (FP), such as fish or other elasmobranchs. A higher precision value means more elasmobranchs are detected with less FP. The Recall-confidence curve shows the model’s ability to avoid false negatives (FN), like missing observations, where a high recall value means that more observations have been detected.

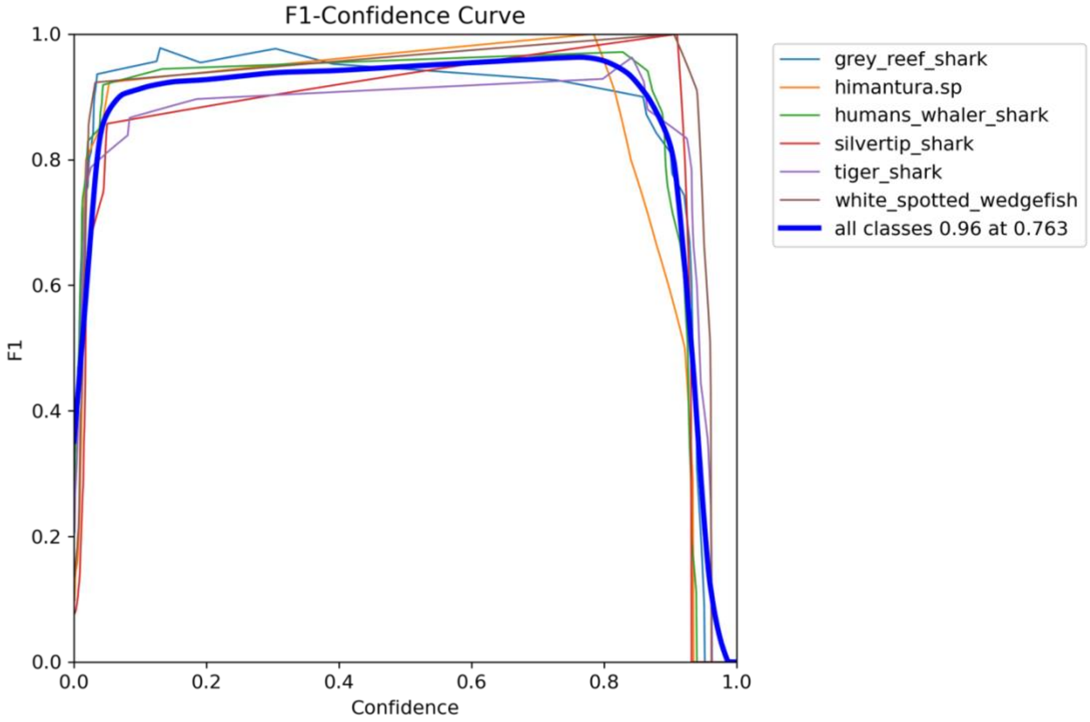

Figure 9 F1-Confidence curve showing the relationship between the Precision and the Recall curve. The model's ability to detect the different species and separate them from false positives (FP), such as fish or other elasmobranchs of a precision curve is compared to the recall curve which shows the model's ability to avoid false negatives (FN) like missing observations.

Discussion

Observations during this study indicate that the canyon effect might not have an influence higher up in the food chain on predators such as sharks and rays. The expected higher abundance and diversity of the canyon were not observed in the results of this study (Table 1). Even though the difference in relative abundance between the two sites weren't statistically significant (p = 0,0561), it was very adjacent (Table 2). This is most likely due to the fact that the rays differed significantly between the Canyon and Non-Canyon site when compared separately (p = 0,0017) (Table 3), since the sharks did not show any significant differences when compared on its own (p = 0,6185) (Table 4). However, this does not indicate that a canyon effect was observed since the Non-Canyon, being the control site of this study, had more sightings of elasmobranchs.

Although, a so-called "canyon effect" was observed by Nyawo (2020) in the Wright Canyon with a significantly higher total abundance of fish and different fish assemblage structures.

These results may be an outcome of the wind- and eddy-driven upwelling that occurs over the canyon that could benefit fish by profiting lower trophic levels, and therefore explain the higher total abundance of fish (Rautenbach et al. 2023). Sharks are expected to stick around areas with a higher abundance of food. Yet, this pattern is not observed in this study which can be explained by the fact that sharks can range widely and tend to move outside of smaller defined areas like the ones this study focused on (Holland et al. 1999). On the other hand, sharks' migration patterns are species-specific and can also depend on many parameters other than food supply. Schlaff et al. (2014) looked at the impact of changes in abiotic factors on shark and ray movements. Prey density and availability along with predator avoidance was linked to abiotic parameters including temperature, salinity, dissolved oxygen, tide, photoperiod, barometric pressure and pH, which together influenced their movements (Schlaff et al. 2014).

Another factor potentially influencing the non-significant results of any effect or impact from the Canyon on elasmobranch abundance and diversity could be the small sample size. A greater sampling effort with stereo-BRUVS would improve and strengthen the results. This could be done by dropping BRUVS surrounding the entire canyon head for the canyon site and choosing a control site (Non-Canyon) further away but with the same bathymetry and substrate type. For future studies, or to develop this study further, machine-learning methods could help increase the sample size of a study like this from 24 to 240 samples per site by speeding up and simplifying the video analysis and thereby helping reveal potential distribution patterns across the seabed topography. Using BRUVS and machine learning methods is therefore a good way to assess large-scale changes and monitoring for ecology and conservation purposes.

The BRUVS data collected can also be used to compare future BRUVS data to address historical changes in species diversity and relative abundance, in the same area or compared to other areas. It can also be accessed to collect additional information subsequently, along with being utilized for management actions and as a resource of educational material (Harvey et al. 2021).

Complementing data like biomass measurements could also be calculated as a supplement to the abundance and diversity data. This could determine whether the size of all individuals differs between the two sites. The collection of oceanographic data may also help enhance the study, where measurements of productivity would help determine if there were upwelling events during the sampling period with enhanced chlorophyll *a*.

Since a higher percentage of reef substrate was observed in the Canyon site (Appendix 1), the number of reef sharks was expected to be higher, along with the number of rays being lower. This was seen in the results of this study, as the number of Grey Reef Sharks (*C. amblyrhyncos*) was twice as high and a Whitetip Reef Shark (*T. obesus*) was observed, along with the number of rays being way less (10% of the total amount) than in the Non-Canyon site. This is supported by Bond et al. (2012) showing that Caribbean Reef Sharks (*Carcharhinus perezii*) exhibit high site fidelity, implicating that reef sharks tend to have smaller ranges. However, Chapman et al. (2005) discovered that while Grey Reef Sharks (*C. amblyrhyncos*) in an atoll in the Pacific exhibited a daily site fidelity, sharks of similar sizes on the surrounding ocean reefs travelled tens of kilometres along the atoll's edges over a similar period of time. Varying results for varying species, but also for the same species in different areas indicate that, as previously stated, many factors contribute to the ranges of sharks.

As benthic predators, rays of the family Dasyatidae prefer and are usually found on sand as they use it to make pits while foraging and also to hide from predation (O'Shea et al. 2013). In this study, more sand substrate was found in the Non-Canyon site (Appendix 1) which explains why the majority of rays also were found in this area (Table 1). Conversely, the two sightings of rays in the Canyon area were both found on reef, even though there were several BRUVS with sand substrate in the canyon too. This could be a coincidence or caused by lower predator abundance as Sherman et al. (2020) observed with smaller benthic rays that were sighted less often with higher abundances of predators, although this is not supported by the results of this study.

As seen in Figures 8 and 9, the object detection model performs well in recognising the six species of elasmobranchs that it was trained on. To further evolve the model, more species can be added for recognition which would enable larger data sets to be analysed with it. This could develop biodiversity monitoring and conservation work by having more species, with longer time periods and in larger regions. In the iSimangaliso Wetland Park MPA, such upscaling would imply less time spent on analysing data. However, just like Anton et al. (2021)

state, storing and archiving such large sample volumes of videos is a difficulty that needs to be addressed for this future upscaling and developments to happen.

The effectiveness of no-take marine reserves in protecting larger animals like sharks and rays, and thus whether they will be effective for the conservation of these frequently heavily exploited species, remains highly uncertain because sharks can range widely (Chapman et al. 2005). As a result, no-take marine reserves will always be limited in size when it comes to the protection of these mobile, long-lived species (Chapman et al. 2005). However, no-take marine reserves can still be very efficient in the protection of sharks and rays if they protect the most crucial life stages, where BRUVS is a great tool to find out how to maximise the effectiveness where it is most needed in these marine reserves (Knip et al. 2012). MacNeil et al. (2020) also showed that nations with shark sanctuaries had a higher relative abundance than nations without sanctuaries, hence the benefit of having these areas rather than not having any.

Difficulties encountered during the study include one BRUVS being pulled up 6 minutes too early due to human error. There was also a malfunction in one of the two cameras of one BRUVS, where that camera did not record and therefore video material is only available from one camera on this site. However, since no biomass calculations were made for this study, no information was lost due to this.

In conclusion, the Wright Canyon does not have a direct impact or effect on the elasmobranch abundance and diversity according to this study. However, similar studies are important to assess habitat preferences and movements, and to collect data for more accurate abundance estimations of elasmobranchs. Studies of a larger scale are also needed to enhance the conservation potential of the decreasing numbers of elasmobranchs worldwide. With continued overfishing being the main threat, the establishment of marine no-take reserves and other protected areas is crucial to prevent further elasmobranch declines (Bornatowski et al. 2014, MacNeil et al. 2020). To monitor these areas, the use of machine-learning methods is a great tool to ease and shorten the data analyses of large sample sizes to favour conservation work.

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References

- Allen, SE et al. 2001, ‘Physical and biological processes over a submarine canyon during an upwelling event’, Canadian Journal of Fisheries and Aquatic Sciences, vol. 58, no. 4, pp. 671–684.
- Allen, SE & Durrieu de Madron, X 2009, ‘A review of the role of submarine canyons in deep-ocean exchange with the shelf’, Ocean Science, vol. 5, no. 4, pp. 607–620.
- Amaro, T et al. 2016, ‘The Whittard Canyon – A case study of submarine canyon processes’, Progress in Oceanography, vol. 146, pp. 38–57.
- Anton, V et al. 2021, ‘An open-source, citizen science and machine learning approach to analyse subsea movies’, Biodiversity Data Journal, vol. 9.
- Bakker, J et al. 2017, ‘Environmental DNA reveals tropical shark diversity in contrasting levels of anthropogenic impact’, Scientific Reports 2017 7:1, vol. 7, no. 1, pp. 1–11, viewed 4 January 2023, <https://www.nature.com/articles/s41598-017-17150-2>.
- Beckley, LE & Leis, JM 2000, ‘Occurrence of tuna and mackerel larvae (Family: Scombridae) off the east coast of South Africa’, Marine and Freshwater Research, vol. 51, no. 8, pp. 777–782, viewed 8 May 2023, <https://www.publish.csiro.au/mf/mf00044>.

- Bond, ME et al. 2012, ‘Reef Sharks Exhibit Site-Fidelity and Higher Relative Abundance in Marine Reserves on the Mesoamerican Barrier Reef’, PLOS ONE, vol. 7, no. 3, p. e32983, viewed 8 March 2023, <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0032983>.
- Bornatowski, H, Braga, RR, & Vitule, JRS 2014, ‘Threats to sharks in a developing country: The need for effective simple conservation measures’, Natureza & Conservação, vol. 12, no. 1, pp. 11–18.
- Brooks, EJ et al. 2011, ‘Validating the use of baited remote underwater video surveys for assessing the diversity, distribution and abundance of sharks in the Bahamas’, Endangered Species Research, vol. 13, no. 3, pp. 231–243, viewed 7 March 2023, <https://www.int-res.com/abstracts/esr/v13/n3/p231-243/>.
- Bruns, S & Henderson, AC 2020, ‘A baited remote underwater video system (BRUVS) assessment of elasmobranch diversity and abundance on the eastern Caicos Bank (Turks and Caicos Islands); an environment in transition’, Environmental Biology of Fishes, vol. 103, no. 9, pp. 1001–1012, viewed 12 October 2022, <https://link.springer.com/article/10.1007/s10641-020-01004-4>.
- Buckley, KA et al. 2018, ‘Sustainability of threatened species displayed in public aquaria, with a case study of Australian sharks and rays’, Reviews in Fish Biology and Fisheries, vol. 28, no. 1, pp. 137–151.
- Chapman, DD et al. 2005, ‘Marine Reserve Design and Evaluation Using Automated Acoustic Telemetry: A Case-study Involving Coral Reef-associated Sharks in the Mesoamerican Caribbean’, Marine Technology Society Journal, vol. 39, no. 1, pp. 42–55.
- Demopoulos, A et al. 2017, ‘Food-web dynamics and isotopic niches in deep-sea communities residing in a submarine canyon and on the adjacent open slopes’, Marine Ecology Progress Series, vol. 578, pp. 19–33.
- Dulvy, NK et al. 2014, ‘Extinction risk and conservation of the world’s sharks and rays’, eLife, vol. 3.
- Dulvy, NK et al. 2021, ‘Overfishing drives over one-third of all sharks and rays toward a global extinction crisis’, Current Biology, vol. 31, no. 21, pp. 4773-4787.e8.

- Harvey, ES et al. 2021, ‘The BRUVs workshop – An Australia-wide synthesis of baited remote underwater video data to answer broad-scale ecological questions about fish, sharks and rays’, Marine Policy, vol. 127, p. 104430.
- Hissmann, K et al. 2006, ‘The South African coelacanths - an account of what is known after three submersible expeditions: coelacanth research’, South African Journal of Science, vol. 102, no. 9, pp. 491–500.
- Holland, KN et al. 1999, ‘Movements of tiger sharks (Galeocerdo cuvier) in coastal Hawaiian waters’, Marine Biology, vol. 134, no. 4, pp. 665–673.
- IUCN 2023, The IUCN Red List Of Threatened Species, 2022, p. Version 2022.2.
- Kessel, ST et al. 2016, ‘Three decades of longlining in Bimini, Bahamas, reveals long-term trends in lemon shark Negaprion brevirostris (Carcharhinidae) catch per unit effort’, Journal of Fish Biology, vol. 88, no. 6, pp. 2144–2156.
- Knip, DM, Heupel, MR, & Simpfendorfer, CA 2012, ‘Evaluating marine protected areas for the conservation of tropical coastal sharks’, Biological Conservation, vol. 148, no. 1, pp. 200–209.
- Lutjeharms, JRE 2006, ‘The ocean environment off southeastern Africa: a review: coelacanth research.’, South African Journal of Science, vol. 102, no. 9, pp. 419–426.
- MacNeil, MA et al. 2020, ‘Global status and conservation potential of reef sharks’, Nature, vol. 583, no. 7818, pp. 801–806.
- Moors-Murphy, HB 2014, ‘Submarine canyons as important habitat for cetaceans, with special reference to the Gully: A review’, Deep Sea Research Part II: Topical Studies in Oceanography, vol. 104, pp. 6–19.
- Nyawo, MAJ-R 2020, Do submarine canyons influence the structure and diversity of benthic fish assemblages on the continental shelf edge?Master, Rhodes University, Makhanda, viewed 22 May 2023, <https://commons.ru.ac.za/vital/access/services/Download/vital:41462/SOURCE1>.
- O’Shea, OR et al. 2013, ‘Dietary partitioning by five sympatric species of stingray (Dasyatidae) on coral reefs’, Journal of Fish Biology, vol. 82, no. 6, pp. 1805–1820.
- Palumbi, SR et al. 2009, ‘Managing for ocean biodiversity to sustain marine ecosystem services’, Frontiers in Ecology and the Environment, vol. 7, no. 4, pp. 204–211.
- Pimm, SL et al. 2014, ‘The biodiversity of species and their rates of extinction, distribution, and protection’, Science, vol. 344, no. 6187.

- QGIS Development Team 2023, QGIS Geographic Information System, https://www.qgis.org/.
- Ramsay, PJ & Miller, WR 2006, ‘Marine geophysical technology used to define coelacanth habitats on the KwaZulu-Natal shelf, South Africa : coelacanth research’, South African Journal of Science, vol. 102, no. 9, pp. 427–434.
- Rautenbach, G et al. 2023, ‘Wind- and eddy-driven upwelling over submarine canyons inshore of the northern Agulhas Current’, African Journal of Marine Science, vol. 45, no. 1, pp. 1–14.
- Schindler, DE et al. 2002, ‘Sharks and Tunas: Fisheries impacts on predators with contrasting life histories’, Ecological Applications, vol. 12, no. 3, pp. 735–748, viewed 11 May 2023, <https://doi.org/10.1890/1051-0761(2002)012[0735:SATFIO]2.0.CO;2>.
- Schlaff, AM, Heupel, MR, & Simpfendorfer, CA 2014, ‘Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review’, Reviews in Fish Biology and Fisheries, vol. 24, no. 4, pp. 1089–1103.
- Schleyer, MH et al. 2018, ‘What can South African reefs tell us about the future of high-latitude coral systems?’, Marine Pollution Bulletin, vol. 136, pp. 491–507.
- Sherman, C et al. 2020, ‘When sharks are away, rays will play: effects of top predator removal in coral reef ecosystems’, Marine Ecology Progress Series, vol. 641, pp. 145–157.

Appendix

Appendix 1 BRUVS deployment data with coordinates, depth and substrate type of each drop. Substrate type was categorised by looking at the collected video material and assessing the bottom in the categories of Sand, Sand Inundated Reef (more than 30% sand), Patchy-reef Low, Patchy-reef High, Reef Low and Reef High.

BRUVS	Longitude (E)	Latitude (S)	Depth (m)	Substrate type
CB01_14.03.2023	32,69534	-27,50437	24.3	Reef High
CB02_14.03.2023	32,6914	-27,49572	21.0	Sand
CB03_14.03.2023	32,68994	-27,50249	20.7	Patchy-reef Low
CB04_14.03.2023	32,69777	-27,49617	28.2	Sand Inundated Reef
CB05_14.03.2023	32,69303	-27,48936	17.5	Reef High
CB06_14.03.2023	32,6992	-27,48906	28.0	Reef Low
NCB01_14.03.2023	32,70552	-27,48906	24.0	Sand Inundated Reef
NCB02_14.03.2023	32,7105	-27,46191	29.0	Sand
NCB03_14.03.2023	32,70956	-27,45677	22.6	Sand Inundated Reef
NCB04_14.03.2023	32,70941	-27,45133	20.0	Sand
NCB05_14.03.2023	32,71418	-27,45124	26.7	Sand Inundated Reef
NCB06_14.03.2023	32,7147	-27,44461	19.0	Sand
CB01_15.03.2023	32,69533	-27,50423	25.0	Reef High
CB02_15.03.2023	32,68997	-27,50224	20.7	Sand Inundated Reef
CB03_15.03.2023	32,69154	-27,49588	21.0	Sand
CB04_15.03.2023	32,69755	-27,49616	28.7	Reef Low
CB05_15.03.2023	32,69309	-27,48936	17.8	Sand Inundated Reef
CB06_15.03.2023	32,69941	-27,48895	27.7	Reef Low
NCB01_15.03.2023	32,70524	-27,45996	20.0	Reef Low
NCB02_15.03.2023	32,71065	-27,46187	27.0	Sand
NCB03_15.03.2023	32,70948	-27,45631	22.7	Sand Inundated Reef
NCB04_15.03.2023	32,70931	-27,45119	20.0	Sand
NCB05_15.03.2023	32,71415	-27,45099	27.0	Reef Low
NCB06_15.03.2023	32,71483	-27,44433	20.0	Sand
CB01_16.03.2023	32,69554	-27,50457	24.0	Patchy-reef High
CB02_16.03.2023	32,68971	-27,50226	21.0	Sand Inundated Reef
CB03_16.03.2023	32,69122	-27,49599	21.0	Sand
CB04_16.03.2023	32,69749	-27,49663	28.5	Reef Low
CB05_16.03.2023	32,6928	-27,48935	19.3	Sand Inundated Reef
CB06_16.03.2023	32,69917	-27,4892	28.0	Reef Low
NCB01_16.03.2023	32,71033	-27,46223	27.0	Reef Low
NCB02_16.03.2023	32,70529	-27,4596	19.5	Sand
NCB03_16.03.2023	32,7098	-27,45674	23.3	Sand Inundated Reef
NCB04_16.03.2023	32,70895	-27,45113	18.7	Sand
NCB05_16.03.2023	32,71422	-27,45144	27.1	Reef Low
NCB06_16.03.2023	32,71479	-27,44445	19.7	Sand
CB01_23.03.2023	32,69538	-27,50484	23.2	Patchy-reef High
CB02_23.03.2023	32,68985	-27,50185	19.2	Sand Inundated Reef
CB03_23.03.2023	32,69155	-27,4955	20.3	Sand
CB04_23.03.2023	32,69735	-27,49641	27.0	Reef High
CB05_23.03.2023	32,69268	-27,48922	17.5	Sand Inundated Reef
CB06_23.03.2023	32,69889	-27,48914	26.1	Reef Low
NCB01_23.03.2023	32,71049	-27,46248	27.0	Reef Low
NCB02_23.03.2023	32,70556	-27,45903	18.6	Sand
NCB03_23.03.2023	32,71011	-27,45644	21.0	Sand
NCB04_23.03.2023	32,7094	-27,451	18.0	Sand
NCB05_23.03.2023	32,71449	-27,45075	26.0	Reef Low
NCB06_23.03.2023	32,71488	-27,44449	19.7	Sand