"Investing in Seychelles' blue future"

Deep Blue Grant Fund

Investigating the marine predator community around Aldabra to assess connectivity between shallow and deep sea ecosystems and the effectiveness of the Aldabra marine zonation strategy

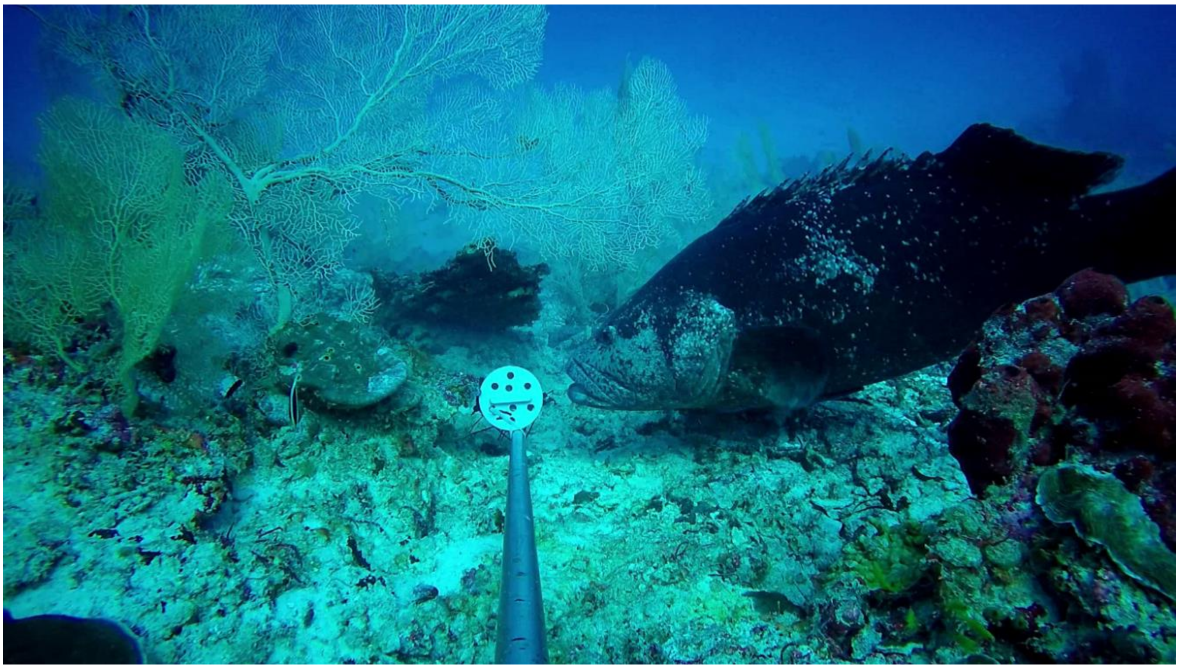

Figure 1: A giant grouper (Epinephelus lanceolatus) seen during the baited underwater remote video surveys on Aldabra ©SIF, 2019

Project lead: Jennifer Appoo

Project partner: Seychelles Islands Foundation

Report type: Scientific report

Date: March 2020

Project context:

- The Deep Blue Grants Fund is a partnership between the Seychelles Conservation and Climate Adaptation Trust ('SeyCCAT') and Nekton Oxford Deep Ocean Research Institute ('Nekton'). This partnership was developed to provide a mechanism to fund Seychellois researchers to conduct innovative deep-sea research in Seychelles and participate in the Seychelles Nekton First Descent Deep Ocean Expedition 2019.
- The Seychelles Nekton Deep Ocean Expedition is a partnership between Seychelles and Nekton to undertake pioneering research, capacity development and public engagement to support the implementation of Seychelles Marine Spatial Plan and the sustainable development of the Blue Economy. The First Descent expedition took place in March and April 2019 and surveyed around Aldabra Atoll.
- The project leader Jennifer Appoo was successful in securing funds of SCR 247,080 for the above-mentioned project with the Seychelles Islands Foundation (SIF; research agreement A40). The project leader participated in the Nekton Deep Ocean Expedition around Aldabra Atoll in March 2019 and was also awarded the Africa-Oxford Nekton Marine Science visiting fellowship in July-August 2019.
- This project was funded by SEYCCAT and Nekton. SIF contributed co-financing to the project through support of the project implementation.
- Project timeline: January – December 2019.

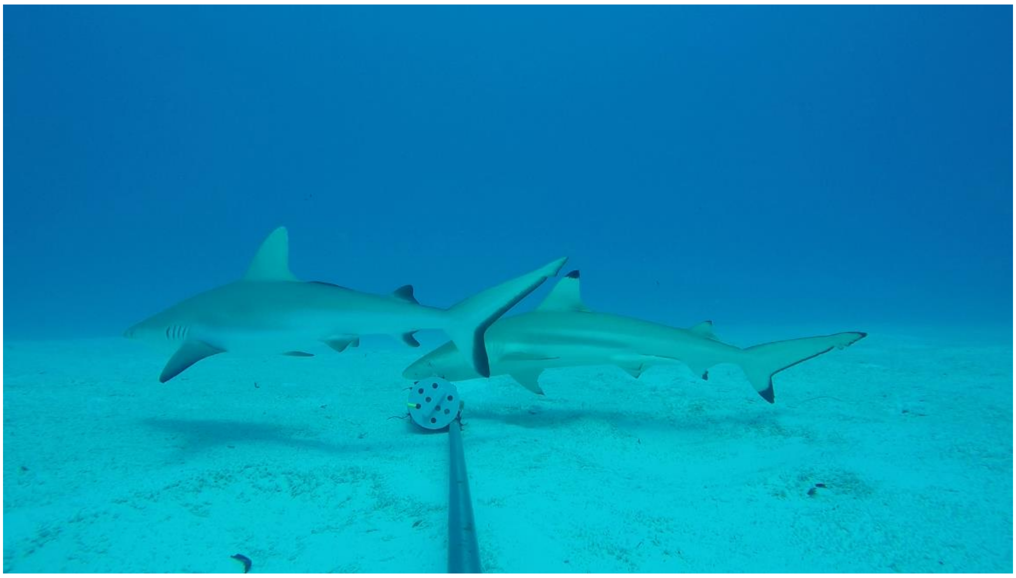

Figure 2: Sharks seen during the baited underwater remote video surveys on Aldabra ©SIF, 2019

Scientific report submitted to Seychelles Islands Foundation, Seychelles' Conservation and Climate Adaptation Trust and the Nekton Foundation.

Prepared by: Jennifer Appoo, March 2020.

Summary

Aldabra supports one of the most abundant and intact marine predator communities in the Seychelles archipelago. Marine predators such as sharks and large groupers are key indicators of marine ecosystem health. Around Aldabra these species are monitored through Baited Remote Underwater Video (BRUV) surveys down to a depth of 50m. Aldabra's near-shore marine area has been subject to a zoning plan since 2016 to regulate human activities around the atoll. The zoning strategy delimits three management zones, namely the Conservation zone (CZ), the Tourism zone (TZ) and the Food Security Zone (FSZ) with new fishing regulations. BRUV surveys are used to monitor the effectiveness of these zones and sampling has been implemented annually since 2017. This sampling has been challenged by multiple issues since its inception, hindering the progress of the monitoring to varying degrees.

In March 2019, the Seychelles' Nekton First Descent Deep Sea expedition explored for the first time the deep-sea communities around Aldabra down to 250m. Through the SeyCCAT-Nekton deep blue grants fund, this research project was set up to combine the Aldabra BRUV and Nekton datasets and establish a baseline of marine predators around Aldabra from the shallow to the deep sea and assess levels of connectivity. Moreover, it aimed to provide technical support to the BRUV research programme on Aldabra, and through analysis of the BRUV dataset collected over the years, assess the effectiveness of the marine zoning plan.

BRUV sampling was successful in 2017 and partially successful in 2018 and 2019 on Aldabra. Only 2017 and 2019 BRUV datasets had comparable samples and were used for analysis. Marine predators showed a general increase in abundance from 2017 to 2019. This increase was found to be statistically significant for groupers in CZ. Sharks indicated higher abundances in FSZ during both years but this was not found to be statistically significant. The results indicate a rapid recovery of groupers following fishing restrictions. The effect of the new fishing regulations on sharks are less direct as the species were never extracted.

During the Seychelles' Nekton First Descent deep-sea expedition, sampling of predators through the use of baited drop-camera systems was not successful and an overview of the fish community was obtained using stereo-video surveys. This dataset was not directly comparable with the BRUV dataset but allowed for the first time a look at the marine communities thriving beyond 50m down to 250m on Aldabra. The expedition detected the presence of a sixgill shark, a first record for Aldabra of this deep-sea species.

This research grant has been successful in supporting the Aldabra BRUV monitoring programme by increasing the technical capacity and improving implementation of BRUV surveys. The project has also supported the analysis of the Aldabra BRUV dataset and explored the effectiveness of the management zones. Continuation of BRUV sampling is encouraged as it enables the monitoring or rare, threatened, keystone species. The baseline results provided in this report will be beneficial to continue monitoring the effectiveness of the zoning plan over the long-term. Further scientific expeditions are also encouraged in unexplored marine areas to continue documenting Aldabra's impressive biological diversity.

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Abbreviations

ARM	Aldabra Reef Monitoring
BRUV	Baited Remote Underwater Video surveys
CZ	Conservation Zone
FSZ	Food Security Zone
MPA	Marine Protected Area
ROV	Remotely Operated Vehicle
RUV	Remote Underwater Video surveys
SIF	Seychelles Islands Foundation
SEYCCAT	Seychelles' Conservation and Climate Adaptation Trust
TZ	Tourism Zone

1. Introduction

Aldabra has the highest diversity and abundance of top marine predators in the southern Seychelles (Friedlander *et al.* 2015) due to decades of strict protection. As top predators, sharks and large groupers are key ecological indicator species for monitoring conservation efforts and success on Aldabra. Moreover, some of these species have large depth ranges during their lifetime, playing a role in connectivity between shallow and deep waters. Through the Aldabra Reef Monitoring (ARM) programme, the fish community is monitored with the use of Baited Remote Underwater Video (BRUV) systems. BRUV surveys are aimed at assessing fish community assemblages around the atoll and allow the monitoring of large diver-shy species such as sharks and groupers which are seldom detected during underwater visual censuses. However, the BRUV surveys are limited to shallow waters (< 50m) and very little is known about the communities beyond this depth.

Aldabra was designated a Special Nature Reserve in 1969 and a UNESCO World Heritage site in 1982. A closely monitored and carefully managed subsistence fishery operates around the atoll to enable the continued presence of the scientific research station in this remote and irregularly accessible location. Fishing operates under the condition that the level and method of fishing is sustainable and does not impact on the protected area's outstanding universal values (SIF, 2016). The small subsistence fishery has been in operation for several decades and fish catch data has been collected and monitored since the mid-1990s. The 2016 Aldabra management plan introduced a new marine zonation strategy within the near-shore of Aldabra's Marine Protected Area (MPA). The area was zoned according to three levels of management, (1) tourism zones (TZ) where tourism activities are allowed; (2) food security zones (FSZ) where subsistence fishing is allowed; and (3) conservation or no take zones (CZ) where all activities are prohibited. Observance of these zones were instigated in September 2016, along with prohibitions on fishing of large groupers (shark fishing has always been prohibited). Annual BRUV surveys were identified as a method to assess the impacts of localised subsistence fishing on Aldabra's fish community (i.e. effectiveness of the zones) and to develop adaptive management strategies to mitigate any negative impacts. Since 2017, BRUV surveys have been conducted on Aldabra with varying success. The surveys has encountered several logistical, technical, methodological and capacity issues, exacerbated by the remoteness of the atoll, leading to incomplete datasets that have not been analysed in depth.

Aldabra's deep-sea communities were explored for the first time in March 2019 during the Seychelles' Nekton First Descent Deep Sea expedition. The expedition was a unique opportunity for the fish and benthic community to be investigated down to a maximum depth of 250m using video surveys. In parallel, this grant was secured with three main aims; (i) to combine the BRUV and Nekton expedition datasets and undertake analysis to obtain a comprehensive baseline of the marine predator community around Aldabra from the shallow to the deep sea. This will also identify the depth ranges of these species providing an indication on the levels of connectivity between shallow and deep-sea ecosystems around the atoll; (ii) to source additional equipment to improve the BRUV sampling strategy on Aldabra and enhance capacity; and (iii) to compare the marine predator assemblage between the management zones over the years using data collected from BRUV surveys to determine the effectiveness of the Aldabra marine zoning strategy.

This report gives the results of the analysis of the Aldabra BRUV dataset and gives an overview of the Nekton expedition results. The report focuses on three main research questions:

1. What is the abundance, diversity and distribution of marine predators around Aldabra from 0 to 250m?
2. What is the level of connectivity between the shallow and deep-sea areas for marine predator species around Aldabra i.e. depth ranges?
3. What is the effect of Aldabra's zoning plan on predator assemblage and is the plan effective i.e. is there a higher abundance and diversity of marine predators in no-take zones?

Overall, this research project seeks to contribute to strengthening marine research, conservation and management efforts of Aldabra. This type of zoning strategy within an MPA is the first in Seychelles and if proven successful, it represents a model example for ocean governance, especially fisheries management for other areas in Seychelles.

2. Methodology

2.1. SIF BRUV surveys

BRUV systems are based on the principle of estimating the relative abundance of fish species attracted into a camera's field of view by using bait. It involves deployment of rigs which consist of an underwater camera and a bait canister attached to a tripod frame. The frame is in turn attached to a rope and a surface buoy enabling deployment and collection of the equipment. Rigs are left on the sea floor to record for one hour using GoPro cameras and then retrieved. The videos are downloaded and the footage is analysed visually, recording and counting the fish species seen. A detailed description of the equipment design and methodology employed by SIF is given in the Aldabra BRUV monitoring protocol.

2.1.1. Sampling locations

BRUV/RUV surveys on Aldabra are designed to be implemented in 12 sampling blocks consisting of four replicates of the three different management zones (conservation zones, food security zones and tourism zones) (Annex 1a). Two monitoring plans have been developed; annual BRUV survey take place in blocks 1−6 (only conservation and food security zones); and five-yearly survey using RUVs and BRUVs in blocks 1−12, covering all three management zones. Furthermore, the sampling design is stratified by depth (shallow 0−10m, medium 10−20m and deep 20–50m) and encompasses a variety of reef habitats (reefs, sand, seagrass, algal reefs).

Each of the 60 survey sites has an allocated GPS point which ensures the deployment of the rigs at the same area each year (referred to as "Original" points). These were chosen at random with a minimum of 300m distance between points (Annex 1b). The exact location of where to sample is determined in the field depending on weather and sea conditions, in favour of representing the different depth ranges and as close to the "Original" points as possible. A new GPS waypoint is taken at the location of each deployment.

BRUV surveys were conducted around Aldabra in 2017, 2018 and 2019 following the annual sampling plan (blocks 1–6, sites 1–30). In 2017, the surveys panned over three months due to the boat being used for other work activities; 24 videos were collected in March and six videos in May. In 2018, BRUV surveys were conducted in March but due to issues with the boat only 10 sites were sampled, of which only 9 deployments were successful. In 2019, BRUV surveys were conducted in January but limited bait enabled only 18 sites to be sampled with 17 successful deployments. For meaningful comparison, data from only the 17 sites successfully sampled in both 2017 and 2019 will be used for this study. **Figure 3** shows the locations of the 17 sites and see **Annex 2** for the full GPS points.

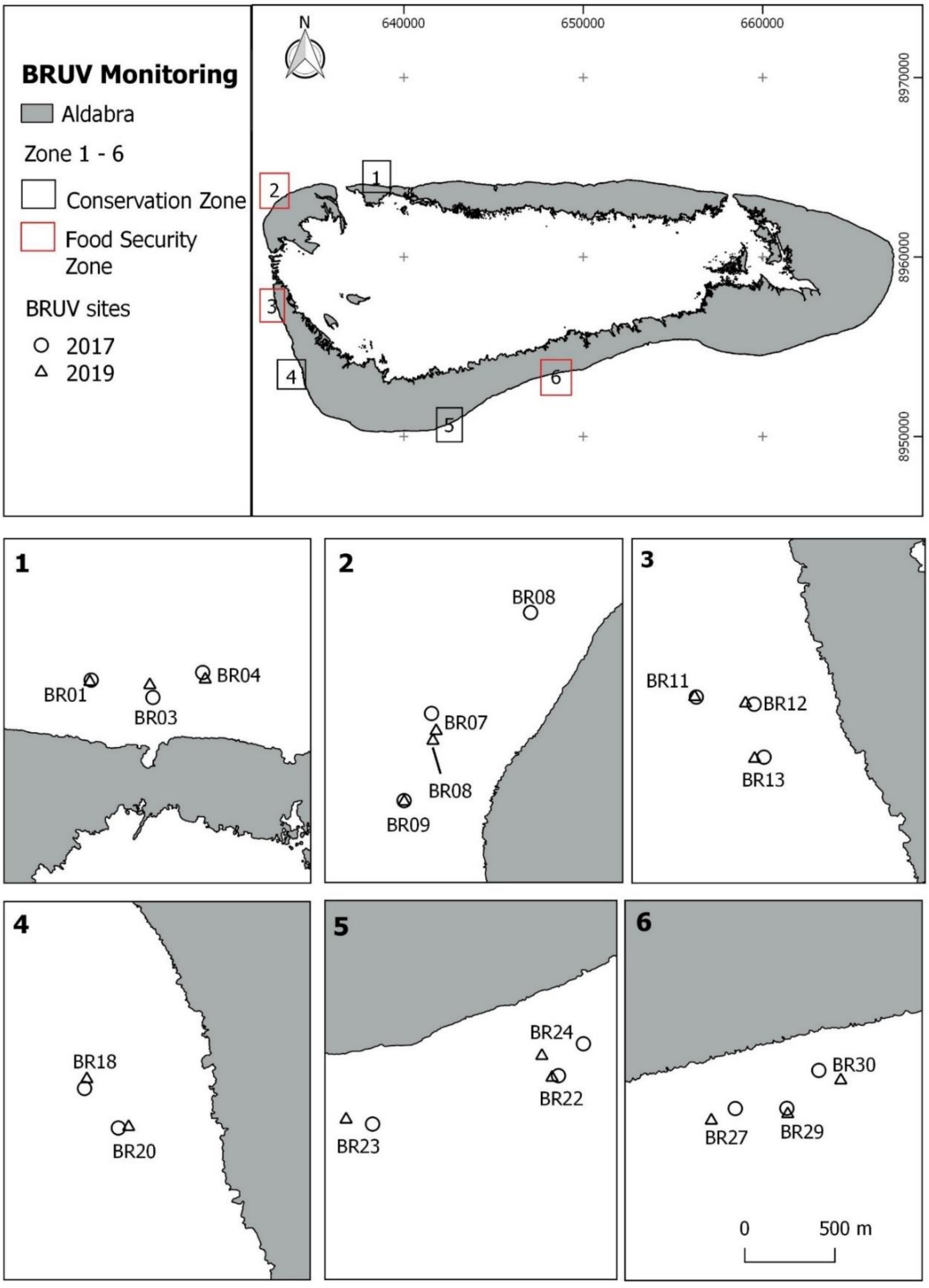


Figure 3: Location of the BRUV sampling stations for this study in 2017 and 2019.

2.1.2. BRUV sessions conducted

One BRUV session refers to one outing on a boat. SIF possesses three BRUV rigs allowing the sampling of three sites simultaneously. **Table 1** gives the participants of the 2017, 2018 and 2019 BRUV surveys and **Table 2** gives the details of each session conducted during the surveys over the three years. Bait consisted of offal collected from the Aldabra subsistence fishery from a variety of fish including trevally, kingfish, barracuda, spangled emperor, twin-spot red snapper and green jobfish.

Table 1: SIF staff who participated in the 2017, 2018 and 2019 BRUV surveys on Aldabra.

March – May 2017	
Survey leader	April Burt (AJB)
Survey assistant	Anna Koester (AK), Jennifer Appoo (JA), Ronny Marie (RM), Ella Nancy (EN), Marvin Roseline (MR), Lee-roy Estrale (LE), Rosie Gordon (RG), Adam Mitchel (AM), Reza Moustache (ReM), Jean-Yves Payet (JYP)
Skipper	Jude Brice (JB), Joel Bonne (JBo), Landis Baker (LB)
January 2018	
Survey leader	Cheryl Sanchez (CS)
Survey assistant	Anna Koester (AK), Jennifer Appoo (JA), Ronny Marie (RM)
Skipper	Joel Bonne (JBo)
January 2019	
Survey leader	Cheryl Sanchez (CS)
Survey assistant	Anna Koester (AK), Jake Letori (JL), Ronny Marie (RM), Jessica Moumou (JM)
Skipper	Jilani Suleman (JS)

Table 2: Details of BRUV sessions conducted in 2017, 2018 and 2019 on Aldabra.

Date (DD.MM.YY)	Zone	Sites visited (# valid BRUV videos)	Participants	Comments
06.03.17	6	26 – 30 (2)	AJB, JB, AK, RM, LB	Sites 26, 27, 29 not useable: rig drags or flipped over.
09.03.17	4	17, 18, 20 (3)	AK, RM, RG, ReM, LB	
10.03.17	3, 4	11 – 16 (6)	AK, RM, RG, AM, LB	
14.03.17	2, 4, 5, 6	6, 8, 10, 19, 21 - 27, 29 (10)	AK, MR, JYP, LB	Sites 10 and 25 not useable: rig flipped over.

17.03.17	2	7, 9, 10 (3)	AK, RM, ReM, JBo	
04.05.17	1	1-5 +extra 1 (4)	JA, JB, EN, JBo	Two sites failed. An extra station was added to site 1 (named site 1.5) because one station was missed in Zone 5 (site 25).
05.05.17	1	2, 4 (2)	JA, EN, RM, JBo	
22.03.18	5, 6	21-30 (9)	AK, JA, RM, JBo	Site 30: Gopro flooded but BRUV redone. Site 26: rig flipped but BRUV redone. Site 24: only 38 min recorded and BRUV not redone.
23.01.19	5, 6	22, 23, 24, 27, 29, 30 (6)	AK, JL, JM, RM, JS	Rig flipped on site 24 and had to be redone.
24.01.19	1, 2, 3, 4	1, 3, 4, 7, 8, 9, 11, 12, 13, 18, 19, 20 (9)	AK, JL, JM, RM, JS	Rig moves at site 11, rig flipped at sites 20 and 19.
26.01.19	3, 4	11, 20 (2)	AK, JL, JM, RM, JS	

2.1.3. BRUV video analysis

The BRUV videos were analysed using VLC software for a period of 60 minutes starting when the rig settles on the substrate. Each new fish species that enters the camera's field of view is identified and recorded including the time at which it is first seen. The same species is only recorded again (and the time) if the number of individuals of that species exceed the last highest recording for that species in the same video. This gives the maximum abundance (MaxN) of the species. The BRUV video analysis involves documenting all species on the target list outlined in the Aldabra BRUV protocol Annex 4. All videos were analysed by the same person (JA).

For the purposes of this project, data for only marine predators consisting of sharks (*Elasmobranchii*) and groupers (*Serranidae*) will be used. The video analysis for this group of fish were verified by a second person Matt Waller (MW) for the 2019 videos.

2.1.4. Statistical analysis

For this study, the sampling design consisted of three factors: zone type (two levels, fixed: protected vs fished), depth (three levels, fixed: shallow 0−10m, medium 10−20m and deep 20–50m) and site (fixed: nested in zone type and depth: three sites at each depth). There were 17 comparable samples for the years 2017 and 2019.

Data were not normally distributed, and could not be transformed to achieve normality. Statistical significance of differences of average MaxN was tested using Wilcoxon rank sum test for variation between year and zone type, Kruskal-Wallis test for variation between year and depth and a generalised linear model for variation between depth and zone type. The number of species was used to compare differences in species richness and the Shannon-Weiner diversity index was used to compare differences in species assemblage. This index takes into account relative abundances of the different species to characterise species diversity.

2.2. Nekton expedition stereo-video surveys

Surveys around Aldabra during the Seychelles-Nekton First Descent Deep Sea expedition were conducted between 17th and 28th March 2019. The predator community was planned to be assessed using a baited drop-camera system but the methodology was not successful. To fill in the gap, information was obtained from stereo-video surveys conducted using multiple methods including SCUBA, mini-ROV (Remotely Operated Vehicle) and submersible dives to give a general overview of the fish and benthic community.

At 10m depth, surveys were conducted by divers using SCUBA. Three 100m stereo-video transects for fish (forward facing) and benthic cover (downward facing) were completed parallel to shore with at least 20m between each 100m transect. For each stereo-video system, two Paralenz cameras were attached to a metal frame and swum along the transects around 0.5m above the reef by a diver. Only one site was successfully surveyed by SCUBA. The survey then switched to using MiniROV using the same methodology.

For depths > 30m, the submersible *Kensington Deep* was used (**Figure 4**). At each site, the submersible conducted three 250m transects using three pairs of stereo Paralenz cameras attached to submersible (downward, forward and sideways). The transect consisted of the submersible facing the wall and drifting with the current maintaining a constant direction and altitude from the seafloor between 1-2 m. A recorder noted the start and end times and distance travelled of each dive. For full details of the methodologies please see the Seychelles Nekton expedition cruise report (*in prep*).

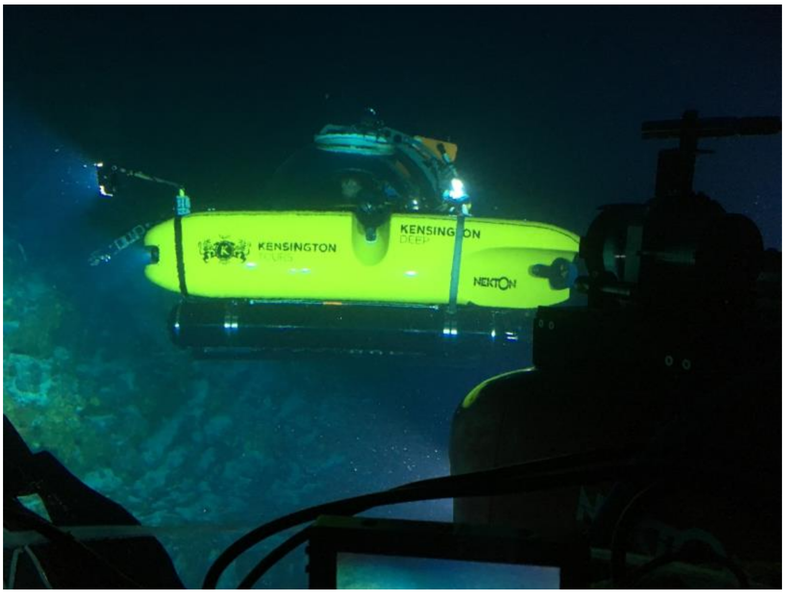


Figure 4: The submersible Kensington Deep used to survey the benthic and fish community during the Seychelles Nekton Deep Ocean Expedition in March-April 2019.

2.2.1. Sampling locations

A total of 13 dives were successful in collecting stereo-video data at two locations on Aldabra (**Figure 5**). The start and end GPS points of each dive is given in **Annex 3**.

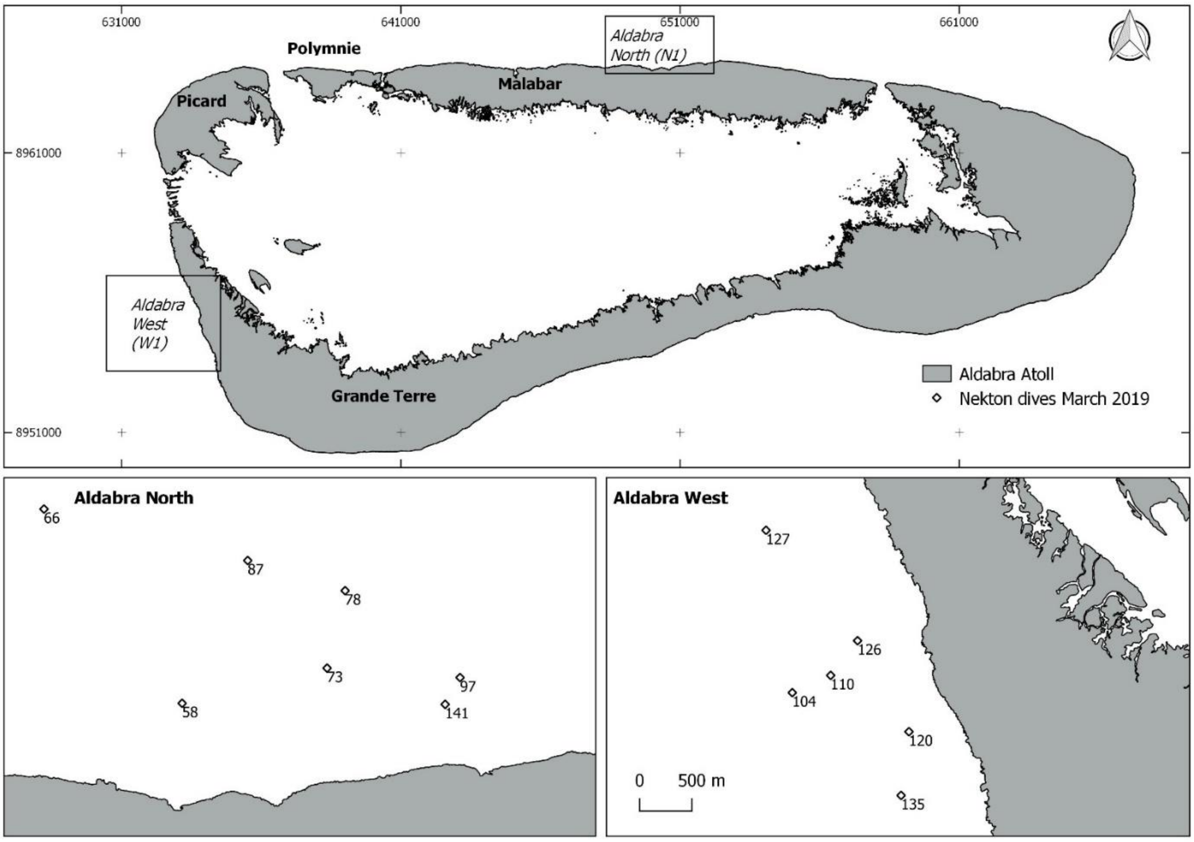


Figure 5: Location of the start of stereo-video transects conducted during Nekton Expedition in March 2019

2.2.2. Stereo-video transects conducted

Tables 3 and **4** below gives the details of the survey sessions conducted around Aldabra and the recorders involved.

Table 3: Members who participated in the collection of stereo-videos around Aldabra during the Seychelles' Nekton Deep Sea Expedition 2019

March 2019	
Survey leader	Dr Lucy Woodall (LW)
Recorders	Dr Paris Stefanoudis (PS), Prof Louise Allcock (LA), Jennifer Appoo (JA), Clara Belmont (CB), Dr Kaveh Samimi-Namin (KS), Oliver Steed (OS), Molly Rivers (MR), Sheena Talma (ST), Rowana Walton (RW)
Submersible pilots	Robert Carmichael (RC), Randy Holt (RH)
SCUBA/ Mini-ROV pilot	Nick Neiss (NN)

Table 4: Details of stereo-video transect conducted around Aldabra during the Seychelles' Nekton Deep Sea Expedition 2019

Date	Dive number	Gear used	Transect depth (m)	# transects conducted (# valid videos)	Recorder
Aldabra North (N1)					
17-03-19	058	Submersible	100	2 (2)	PS
18-03-19	066	SCUBA	10	3 (3)	-
19-03-19	073	Submersible	250	2 (2)	MR
20-03-19	078	Submersible	60	3 (3)	OS
21-03-19	087	Submersible	250, 120	3 (2; 1 at 250m and 1 at 120m)	MR
22-03-19	097	Submersible	30	3 (3)	KS
28-03-19	141	Submersible	60	3	ST
Aldabra West (W1)					
23-03-19	104	Submersible	30	3	LA
24-03-19	110	Submersible	120	3	PS
25-03-19	120	Mini-ROV	10	3	RW
26-03-19	126	Mini-ROV	30	3	RW
26-03-19	127	Submersible	250	3	JA
27-03-19	135	Submersible	60	3	CB

2.2.3. Stereo-video analysis

The stereo-videos were analysed by the Nekton team and the main types of fish families and benthic communities encountered along the transect at each depth were identified and recorded. These data will undergo further analysis by the Nekton team.

3. Results

3.1. BRUV surveys

3.1.1. Marine predator abundance

Predators were recorded on 88% of the BRUV videos in 2017 and on all videos in 2019. A total of 113 individuals were recorded in 2017 (sharks n = 36, groupers n = 77) and 147 individuals were sighted in 2019 (sharks n = 56, groupers n = 91). Overall, the average relative abundance of predators was slightly higher in 2019 with a mean MaxN of 1.55 ± 0.07 predators/hour (mean ± SE) compared to 1.38 ± 0.07 predators/hour (mean ± SE) in 2017. When looking at the two families separately, similar trends were observed with both shark (1.40 ± 0.09 shark/hour, mean ± SE, n = 40) and grouper abundances slightly higher in 2019 (1.65 ± 0.1 grouper/hour, mean ± SE, n = 55), as opposed to 1.33 ± 0.09 sharks/hour (mean ± SE, n = 27) and 1.4 ± 0.08 grouper/hour (mean ± SE, n = 55) recorded in 2017 (**Figure 6**).

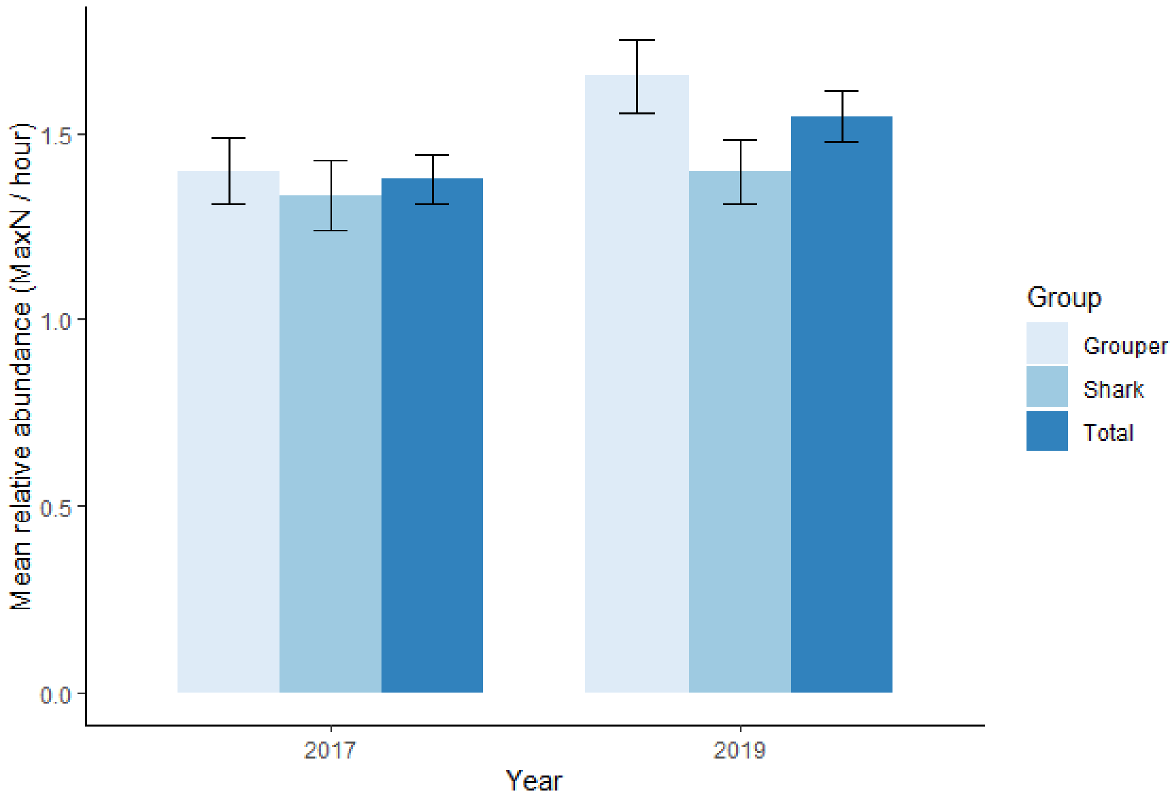


Figure 6: Mean relative abundance (MaxN per 60 minute deployment ± SE) of marine predators in 2017 and 2019 on Aldabra.

<u>Variation between year and zone type</u>

Average abundances of predators were higher in both conservation and food security zones in 2019 compared to 2017. In 2019, average abundances were slightly lower in CZ 1.52 ± 0.1 (mean ± SE, n = 42) than in FSZ 1.56 ± 0.09 (mean ± SE, n = 53) (**Figure 7**). The average abundance of predators between the two zones were not significantly different within both years (2017: Wilcoxon rank sum test, W = 724, n = 82, p = 0.51; 2019: Wilcoxon rank sum test, W = 1068.5, n = 95, p = 0.71). There were also no significant difference in average abundances between 2017 and 2019 for both zones (CZ: Wilcoxon rank sum test, W = 523, n = 72, p = 0.15; FSZ: Wilcoxon rank sum test, W = 1189.5, n = 105, p = 0.17).

When looking at groupers and sharks separately, they followed the same observations with higher average MaxN/hour in both zones in 2019 than in 2017 (**Figure 7**). In 2017 the average abundance of groupers were lower in CZ (1.36 ± 0.14, mean ± SE, n = 22) than in FSZ (1.42 ± 0.12, mean ± SE, n = 33) but this trend reversed in 2019 with higher average grouper abundances recorded in the CZ (1.7 ± 0.14, mean ± SE, n = 24) than in FSZ (1.61 ± 0.14, mean ± SE, n = 31). The average abundances were not significantly different between CZ and FSZ in 2017 and in 2019 (2017: Wilcoxon rank sum test, W = 343, n = 55, p = 0.68; 2019: Wilcoxon rank sum test, W = 410.5, n = 55, p = 0.47). However, when looking at differences between 2017 and 2019, grouper abundance was significantly higher in CZ in 2019 (Wilcoxon rank sum test, W = 182, n = 46, p = 0.04), while for FSZ the difference between the two years were not significant (Wilcoxon rank sum test, W = 439, n = 64, p = 0.27).

For sharks, the average abundance is consistently lower in CZ than in FSZ for both 2017 (CZ: 1.25 ± 0.16, mean ± SE, n = 8; FSZ: 1.36 ± 0.11, mean ± SE, n = 19) and 2019 (CZ: 1.26 ± 0.13, mean ± SE, n = 19; FSZ: 1.46 ± 0.1, mean ± SE, n = 24). The difference is however not significant between the zones for each year (2017: Wilcoxon rank sum test, W = 67, n = 27, p = 0.58; 2019: Wilcoxon rank sum test, W = 177, n = 40, p = 0.14). Likewise, difference in average abundances between 2017 and 2019 were non-significant for both zones (CZ: Wilcoxon rank sum test, W = 73, n = 26, p = 0.97; FSZ: Wilcoxon rank sum test, W = 181.5, n = 41, p = 0.41).

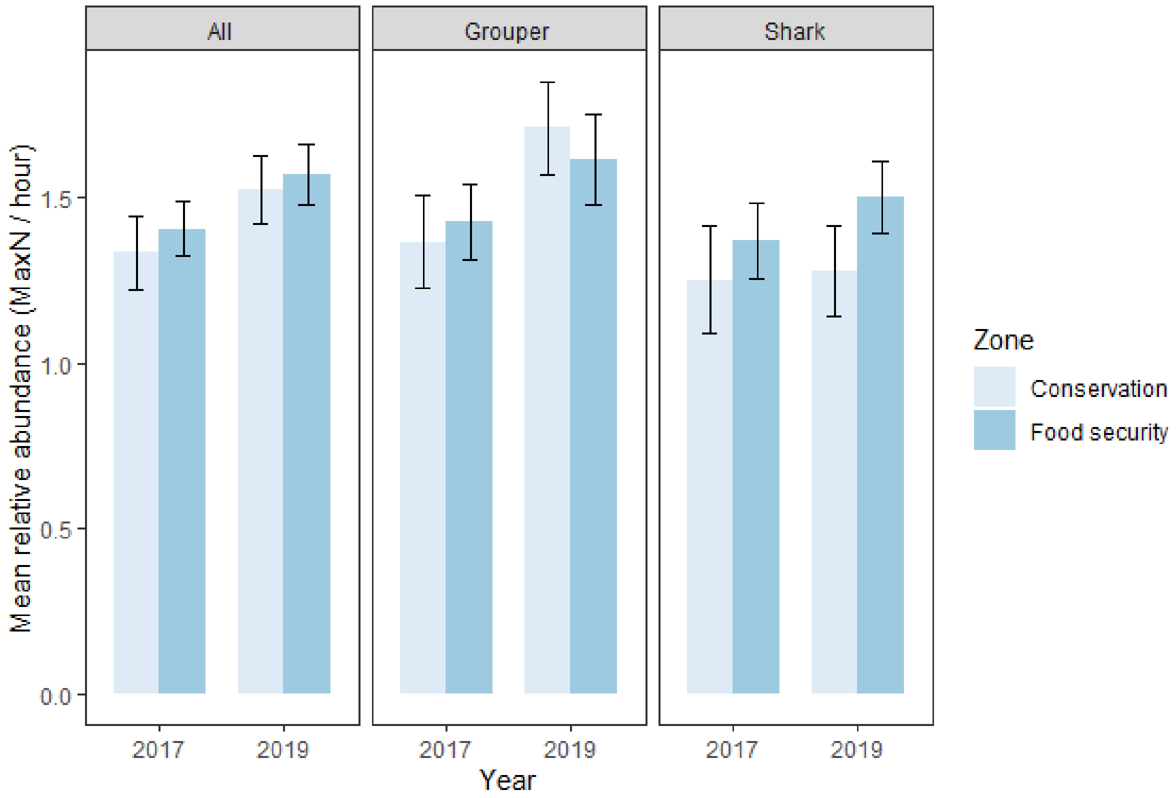


Figure 7: Mean relative abundance (MaxN per 60 minute deployment ± SE) of marine predators in each zone in 2017 and 2019 on Aldabra.

<u>Variation between year and depth</u>

In 2017, the mean abundance of predators was higher at deep sites with an average MaxN/hour of 1.6 ± 0.22 (mean ± SE, n = 10). In contrast, in 2019 mean abundance of predators was higher at shallow sites (average MaxN/hour 1.64 ± 0.12, mean ± SE, n = 36) (**Figure 8**). Differences among the depths were not significantly different within both years (2017: Kruskal-Wallis test, χ^2 = 1.79, df = 2, p = 0.41; 2019: Kruskal-Wallis test, χ^2 = 1.23, df = 2, p = 0.54). Moreover, no depths showed a significant difference in abundances between 2017 and 2019.

Similar observations were made for groupers and sharks separately with non-significant differences in average abundances between the depths within and between the two years. The exception is for grouper which showed a significant increase in abundances at shallow sites between 2017 (1.34 ± 0.11, mean ± SE, n = 26) and 2019 (1.77 ± 0.16, mean ± SE, n = 22; Kruskal-Wallis test, χ^2 = 5.01, df = 1, p = 0.02).

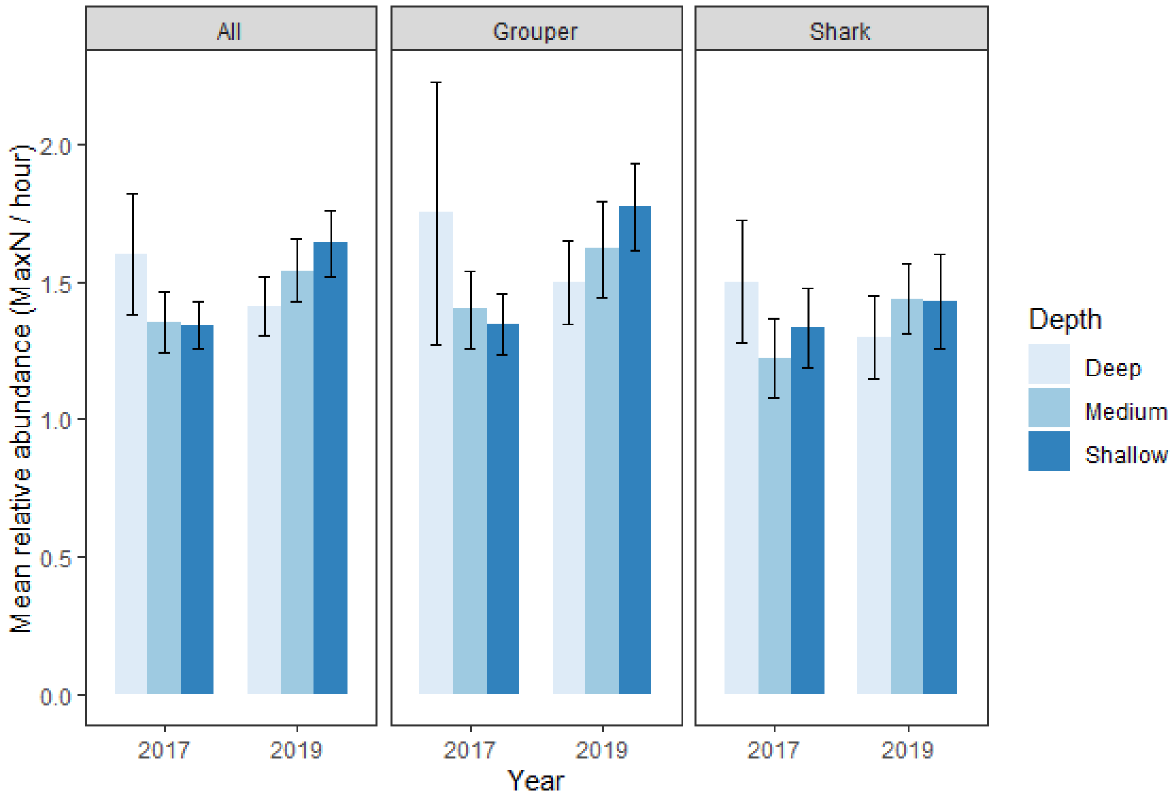


Figure 8: Mean relative abundance (MaxN per 60 minute deployment ± SE) of marine predators in each depth range in 2017 and 2019 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.

<u>Variation between depth and zone type</u>

In 2017, the relative abundance of predators in CZ and FSZ were higher at deep sites (CZ: 1.5 ± 0.34, mean ± SE, n = 6; FSZ: 1.75 ± 0.25, mean ± SE, n = 4), while in 2019 abundances were higher at shallow sites for both zones (CZ: 1.69 ± 0.17, mean ± SE, n = 13; FSZ: 1.6 ± 0.16, mean ± SE, n = 23) (**Figure 9**).

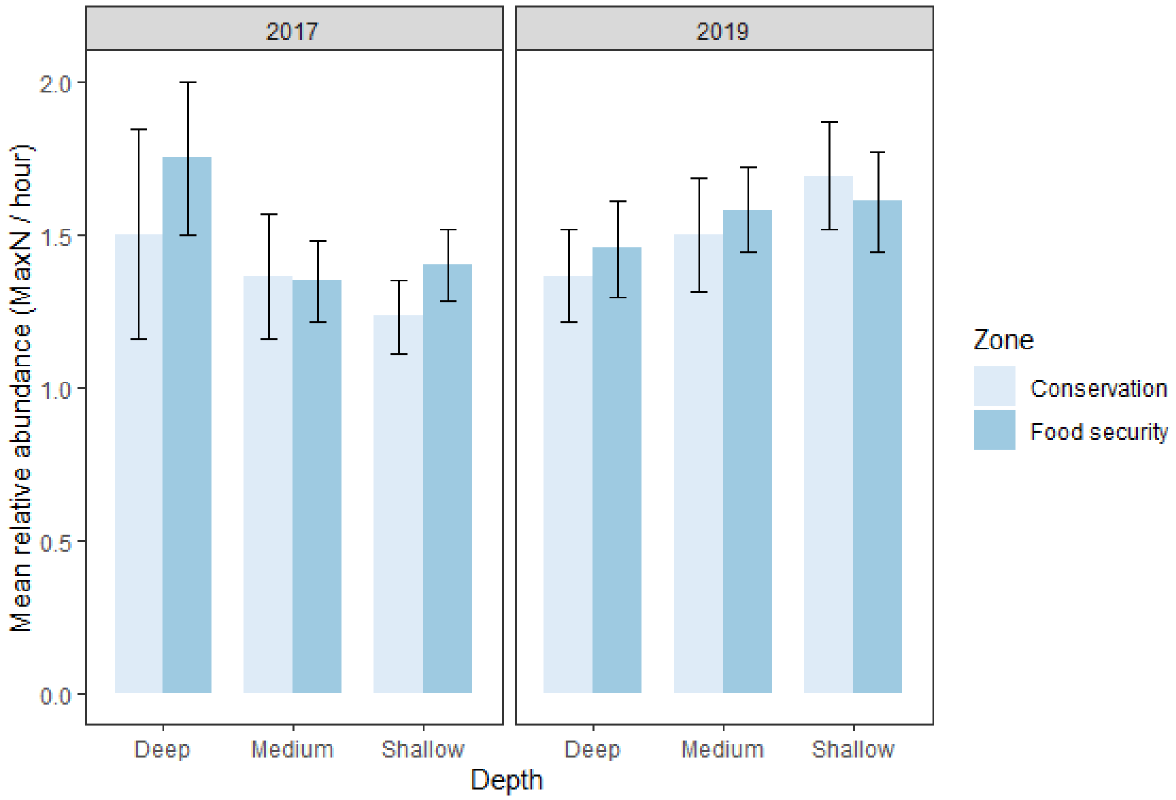
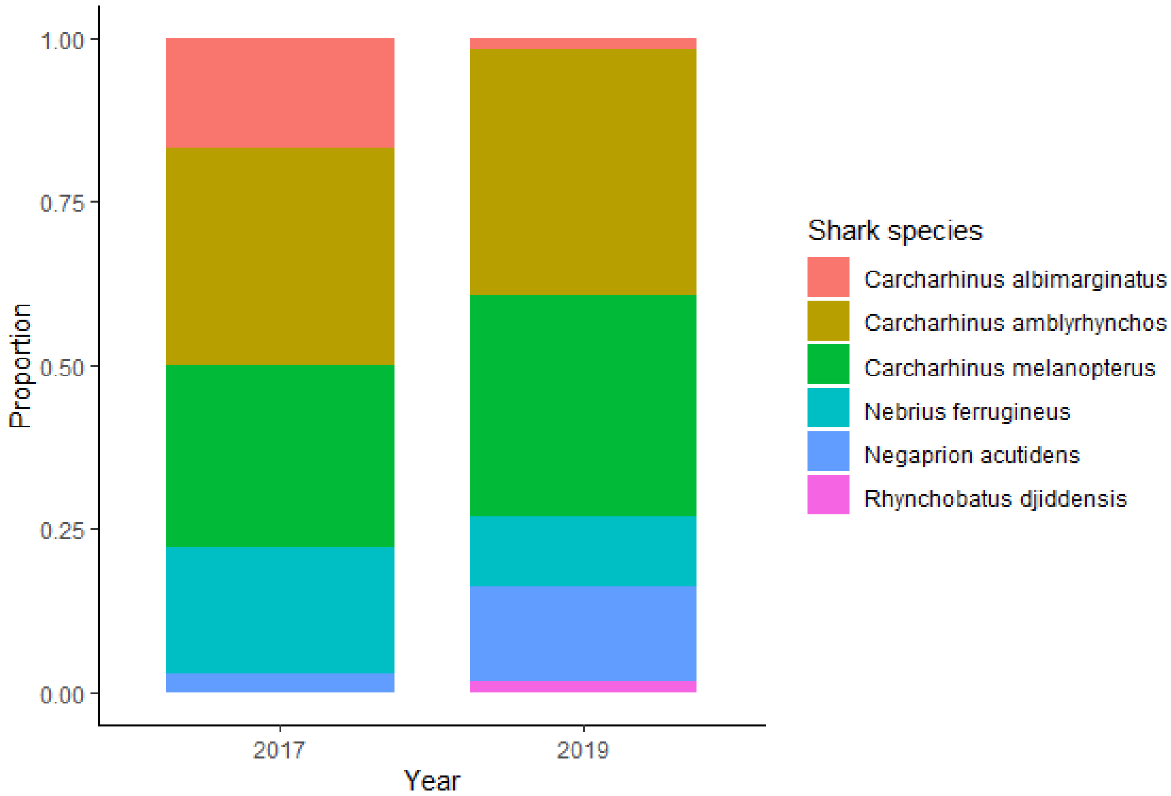


Figure 9: Mean relative abundance (MaxN per 60 minute deployment ± SE) of marine predators in each zone and depth range in 2017 and 2019 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.

3.1.2. Community composition

In 2017, 21 marine predator species were recorded (sharks n = 5, grouper n = 16) and in 2019, 19 species were seen (shark n = 6, grouper n = 13). The overall mean Shannon-Weiner diversity index was similar for 2017 (H' = 0.49 ± 0.04) and 2019 (H' = 0.5 ± 0.04).

In both years, the most abundant shark seen was the grey reef shark *Carcharhinus amblyrhynchos* with a total of 12 individuals recorded in 2017 and 21 individuals in 2019. The grey reef shark appeared in 58% of videos in 2017 and 82% of videos in 2019. The most abundant grouper sighted was the yellow-edged lyretail grouper *Variola louti* with a total of 14 individuals seen in 2017 and 25 individuals in 2019. The yellow-edged lyretail grouper was sighted in 58% and 70% of videos in 2017 and 2019 respectively. **Figure 10** shows the proportion of shark and grouper species seen in both years.



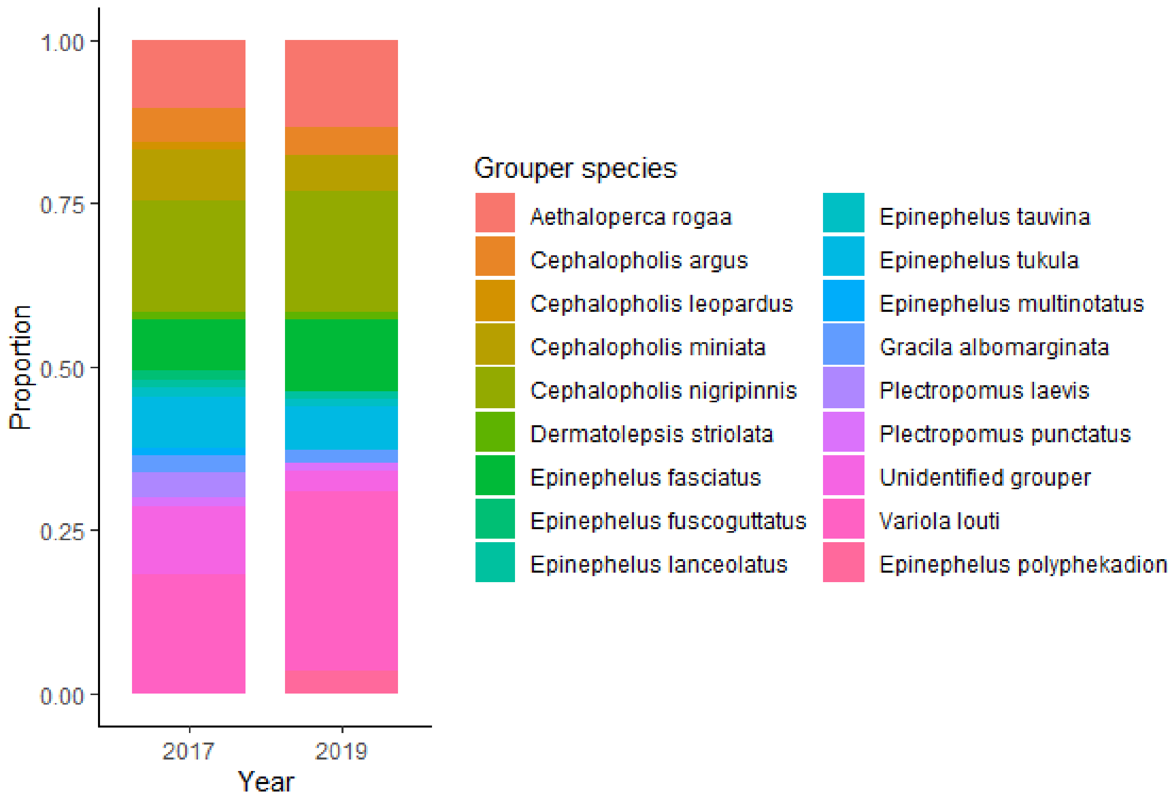


Figure 10: Proportion of sharks (top) and groupers (bottom) recorded on BRUVs on Aldabra in 2017 and 2019.

When looking at variations between the zones, in both years there were more species recorded in FSZ (2017: n = 18, 2019: n = 19) than CZ (2017: CZ n = 17, 2019: n = 13). The mean Shannon-Weiner index for 2017 was slightly higher in FSZ (H' = 0.54 ± 0.04) than CZ (H' = 0.41 ± 0.06). In 2019, the mean index was quite similar for both zones (CZ: H' = 0.52 ± 0.06; FSZ: H' = 0.5 ± 0.06). **Annex 4** shows the average abundance of each species recorded in each zone and year.

For variations with depth, in 2017 shallow zones recorded more species (n = 16), followed by medium (n = 15), and deep zones (n = 8). Whereas in 2019, the medium depth sites recorded more species (n = 15), followed by deep (n = 13) and shallow zones (n = 12). The mean Shannon-Weiner Index for the th ree depths were quite close for 2017 (shallow: H' = 0.51 ± 0.07, medium: H' = 0.49 ± 0.09, deep: H' = 0 .47 ± 0.05). In 2019, the index was higher for shallow sites (H' = 0.55 ± 0.07) than medium (H' = 0.53 ± 0.05) and deep sites (H' = 0.43 ± 0.09). **Annex 5** shows the average abundance of each species seen at each depth range and year.

3.1.3. Distribution

In 2017 higher abundances were recorded in zone 3 (1.53 ± 0.15, mean ± SE, n = 17) followed by zone 5 (1.44 ± 0.24, n = 9) whereas in 2019 more predators were recorded in zone 6 (1.9 ± 0.35, mean ± SE, n = 9) followed by zone 5 (1.57 ± 0.13, mean ± SE, n = 21). Average abundances increased in all zones in 2019 except zone 3 and 4 (**Figure 11**).

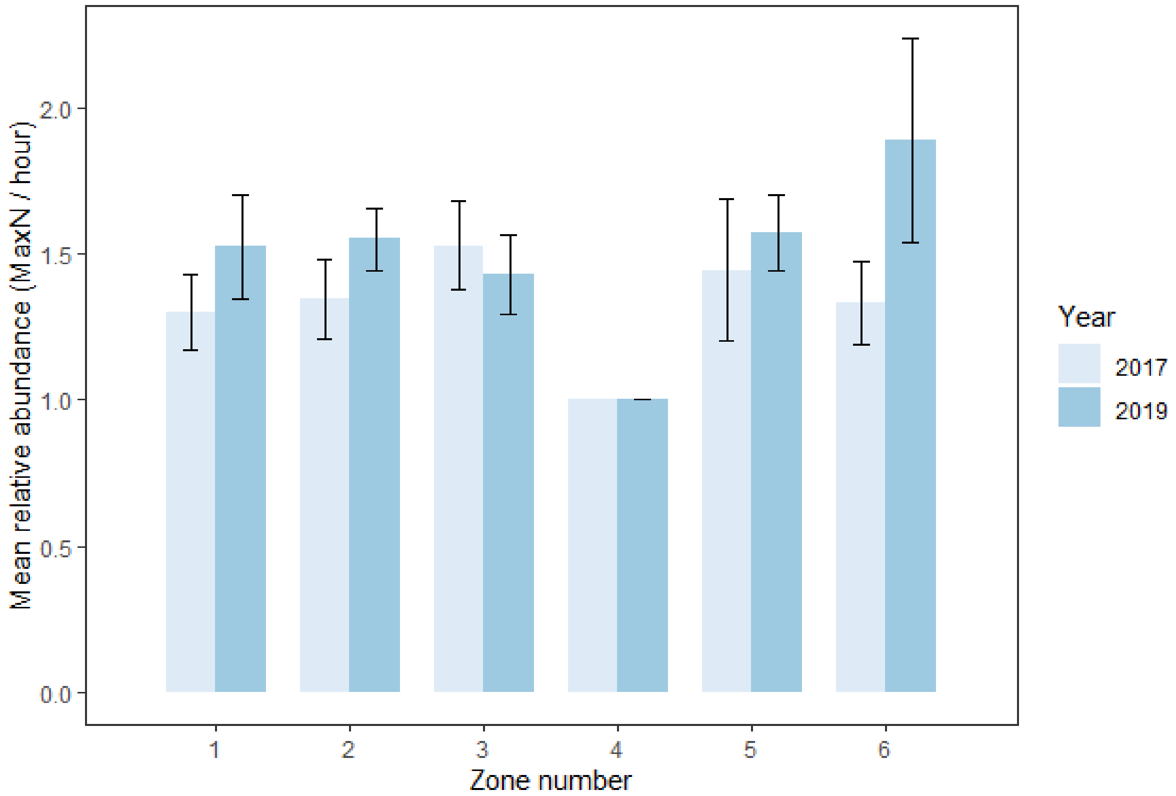


Figure 11: Mean relative abundance (MaxN per 60 minute deployment ± SE) of marine predators at each zone number in 2017 and 2019 on Aldabra

3.2. Nekton expedition surveys

The paragraphs below are an excerpt from the Seychelles' Nekton expedition cruise report (*in prep*) and gives a general overview of the benthic and fish community recorded on the stereo-video surveys at each depth and study site on Aldabra.

Aldabra North

10 m

Gentle sloping reef at 10m characterized by the hard coral *Heliopora* and the green calcareous algae *Halimeda*. Overall, low coverage of hard corals with patches of rubble and sand in between. Reef slopes into sand at between 15-20m. Small basslets and damselfish were common, but of note was the high abundance of large predatory fish (Serranidae, Lutjanidae, Lethrinidae, and reef sharks).

30 m

Steep sloping reef with high complexity covered mostly in hard coral and very few sandy patches in between. The reef supported a diverse suite of coral species, dominated by the scleractinian *Pachyseris* and large sea fans (Subergorgiidae). High abundance of reef fish consisting of fusiliers (e.g. large schools of *Pterocaesio tile*), butterflyfish (Chaetodontidae), angelfish (Pomacanthidae), soldierfish (Myripristinae), snappers (Lutjanidae), groupers (Epinephelinae), trevallies (Carangidae) and barracuda (Sphyraenidae).

60 m

Steep rock wall which descends to a gentle to medium sloping bottom. Substrate was covered by a thin sediment veneer with some patches of exposed bedrock. The base of the wall was dominated by large sea fans, and types of black coral. Several schools of fish were spotted consisting of sweetlips (Haemulidae), snappers (Lutjanidae) and trevallies (Carangidae). Other types of fish included groupers (Epinephelinae), butterflyfish (Chaetodontidae) and pufferfish (Tetraodontidae).

120 m

Steep slopes with rocky outcrops and occasional patches of sand; with numerous overhangs, caves and small crevices. There was a good selection of soft corals, dominated by white whip corals (*Viminella*), several types of sea fans from Ellisellidae and Plexauridae families, black corals and occasionally fleshy corals (Alcyoniidae). Several of the small fish such as basslets (*Pseudanthias*), soldierfish (Myripristinae) and squirrelfish (Holocentrinae) were commonly associated with corals and were found seeking refuge in crevices when the submersible was in close proximity. Other larger fish such as trevallies (Carangidae) and groupers (Epinephelinae) were also occasionally found roaming at that depth. From those, potato groupers (*Epinephelus tukula*) were by far the most inquisitive of all. One spotted moray eel (*Gymnothorax* sp.) was also observed at this depth.

250 m

Medium to steep slopes with rocky outcrops often covered by a thin layer of sand; with occasional few sandy patches in between. Barren landscape, often covered by dead seagrass fragments (*Thalassodendron*), and a few sea urchins and sea stars. Very few fish seen.

Drop-cam

Before failing, the drop-cam managed to record the sighting of a sixgill shark (*Hexanchus griseus*) at 300m depth at this site (**Figure 12**).

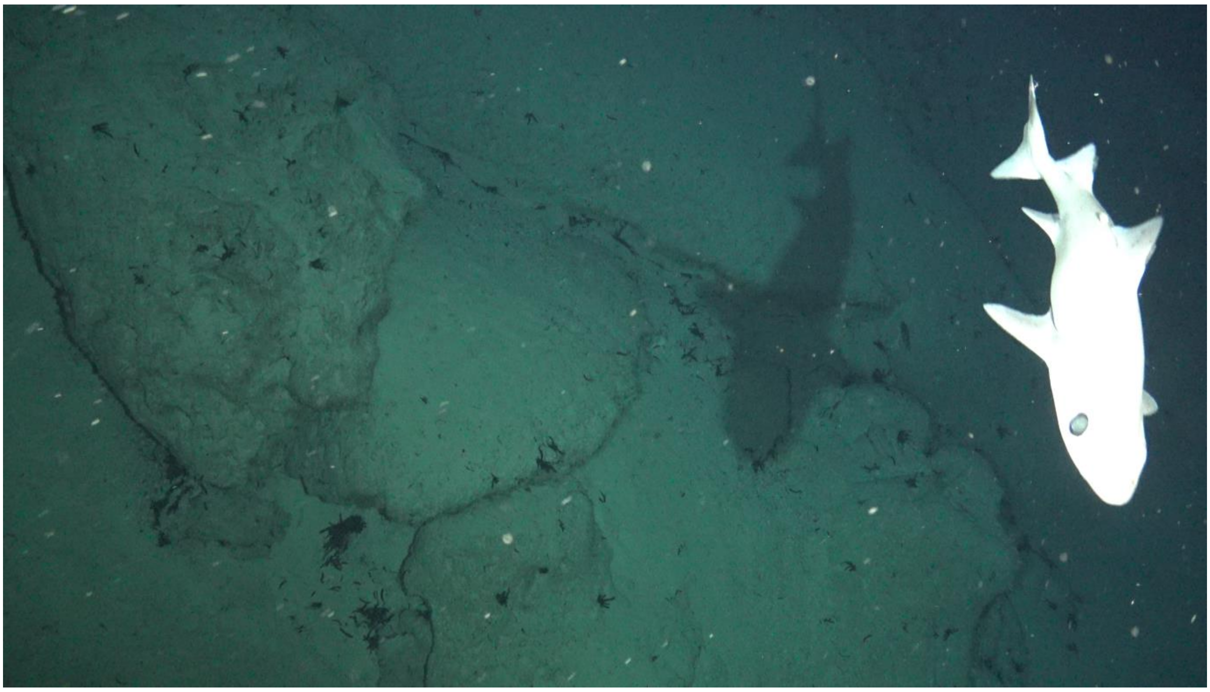


Figure 12: Sixgill shark sighted on Aldabra in March 2019 at 300m on the drop-cam ©Nekton.

Aldabra West

10 m

Shallow flat reef that graduates into seagrass beds (*Thalassodendron*) at the reef crest (around 3-4m). Reef at 10m dominated by *Porites* spp., *Favites* and members of the Lobophyliidae (*Lobophyliia* and *Symphyllia*). Signs of the impact of the 2016 coral bleaching event were still evident. With high stocks of large predatory fish (Serranidae, Lutjanidae, Lethrinidae, and reef sharks).

30 m

Sandy habitat, in the form of a thin sediment veneer overlaying bedrock, with several patches of exposed bedrock providing suitable habitat for corals and encrusting organisms. Benthic communities comprise a mixture of hard corals (e.g. *Porites, Physogyra* and *Turbinaria*), sponges (*Theonella* and *Spheciospongia* spp.), sea fans and other soft corals (Nephtheidae). Incredible diversity of fish some of which include surgeonfish (Acanthuridae), blue-fin trevallies (*Caranx melamphygus*), butterflyfish (Chaetodontidae) and triggerfish (Ballistidae).

60 m

Large sandy expanses with rocky outcrops. In one of the dives, exposed bedrock was more common. Overall, fish and corals were sparse above sandy habitats but much more common when hard substratum was available. Common types of fish included small basslets (Serranidae), surgeonfish (Acanthuridae), triggerfish (Ballistidae), and larger pelagic aggregations of blue-fin trevallies (*Caranx melamphygus*), snappers (Lutjanidae) and sweetlips (Haemulidae). In particular, a large school of bengal snappers (*L. kasmira*) was notable in one of the dives. Benthic communities comprised several types of sea fans, sea whips and other branching corals (Ellisellidae), a variety of encrusting sponges (yellow, orange, red and green morphotypes), some tube sponges, and crinoids. Very occasionally, some encrusting scleractinian colonies were observed.

120 m

Similar to Aldabra N1, habitat topography at this depth comprised steep slopes with rocky outcrops, often overlaid by thin sediment layers. Abundance of small overhangs and crevices, provided habitat for many cryptobenthic fish. Coral communities were dominated by red, soft, fleshy corals (*Litophyton*) as well as white whip corals of *Viminella*. White cup sponges were also quite common. Large predatory fish such as sharks, including a silvertip reef shark (*Carcharhinus albimarginatus*), and potato groupers (*Epinephelus tukula*) were occasionally spotted during the dives.

250 m

Extensive thin sedimented layers covering bedrock with frequent large boulder-like features. Due to little available exposed substratum very few encrusting organisms were observed, and benthic fauna was dominated by white Stylasterids, sea urchins and bryozoans. Some black corals and large ophiuroids, the latter located on a large overhangs, were also spotted. Several dead fragments of seagrass populating the seafloor. Very few fish observed at this depth.

4. Discussion

This research project investigates Aldabra's marine predator community and the effectiveness of the marine zonation strategy through analysis of BRUV data collected on Aldabra from 2017 to 2019. It also provides an overview of deep-sea communities recorded around Aldabra during the Seychelles' Nekton deep-sea expedition in March 2019.

The analysis for this project was focussed around three main research questions. We have detailed the abundance, diversity and distribution of marine predators from 0 to 50m around Aldabra. From 2017 to 2019, we observed a general increase in the average abundance of marine predators around the atoll, although this is not statistically significant. We have also explored the effect of Aldabra's zoning plan and found that CZ have in general higher predator abundance. Groupers recorded a significant increase in average abundance in CZ in 2019 compared to 2017 indicating that this group of fish can undergo rapid recovery following fishing restrictions. On the other hand, shark abundances were consistently higher in FSZ in both years. Sharks depredation during subsistence fishing is common around Aldabra and they may be constantly attracted to the FSZ for these purposes. It is important to note that the effect of fishing restrictions on sharks are less direct than on groupers since they were not extracted on Aldabra even before the zoning were put in place. We did not manage to answer our third question on the depth ranges of sharks and groupers around Aldabra. The stereo-video surveys conducted during the Nekton expedition is unfortunately not directly comparable with the Aldabra BRUV surveys which uses bait to attract predators to the camera's field of view. Our analysis is therefore limited to 50m.

Overall, the project has been successful in achieving two of its main aims. The BRUV surveys on Aldabra faced many challenges in its first years of implementation. Despite this and the very time-demanding analysis, BRUVs allows us to monitor keystone, rare and threatened marine species which are not surveyed in any other research programme on Aldabra. The additional survey equipment sourced through this project will greatly enhance the technical capacity of the Aldabra team to continue and improve implementation of subsequent BRUV surveys. A bigger sample size will increase the robustness of the analysis. Secondly, the project has enabled the analysis of the Aldabra BRUV dataset and explored the effectiveness of the management zones. Although the success of the zoning strategy may seem too early to tell, periodic reviews are essential to prevent accumulation of large datasets, to refine methods and to address recurring issues in the sampling strategy. We have successfully obtained a baseline for marine predators in the different zones and this can be used to continue monitoring the effectiveness of the zoning plan over the long-term. We did not manage to meet the first aim of the project which involved combining the BRUV and Nekton datasets to assess connectivity between shallow and deep areas. Nevertheless, the stereo-video surveys collected during the Seychelles' Nekton First Descent expedition has enabled for the first time a look into the deep sea areas of Aldabra (down to 250m) and provided very valuable information on the communities that thrive in the deep. For example, the sighting of the sixgill shark is the first record of that species on the atoll. This deep-sea predator is quite unique and bears six gill slits which is unlike other shark species that have five gill slits.

Our results add to previous BRUV research work conducted on Aldabra (Haupt 2019). Our study could be improved to obtain a more meaningful analysis of the zoning effectiveness. For example, including environmental variables such as water temperature, turbidity, moon phase, and time of survey, type of bait, etc., could provide insight on predator numbers seen. Furthermore, including the subsistence fisheries dataset could provide information on the type and amount of fish extracted, the most common location of fishing and the success rate of releases of large groupers. Taking into account the criteria for locations of the different zones could also provide more context to the results. Moreover, including other fish communities in the analysis such as corallivores and herbivores could infer on spill-over effects of the CZ. The results obtained in this project can be compared with other BRUV surveys being implemented in other protected and non-protected areas across Seychelles such as Alphonse, Curieuse, North and Denis Islands to assess effectiveness of fisheries management strategies across the Seychelles. Finally, when information from Nekton's stereo-video surveys are available it can be used to gain a better idea on deep reef faunas including predatory fish as well as other fish communities not typically observed on BRUVs.

This research grant has been hugely beneficial to support continuation of the marine research programme on Aldabra. We encourage further support for more science-based projects and more expeditions into unexplored marine areas to fathom Aldabra's impressive biodiversity and provide evidence of successful conservation efforts on this unique UNESCO World Heritage Site.

5. Acknowledgements

This research project was funded by the Seychelles' Conservation and Climate Adaptation Trust and supported by the Nekton Foundation and the Seychelles Islands Foundation. The project leader also benefited from the AfOx Nekton-Marine Science fellowship by the Africa-Oxford Initiative. Thank you to all the participants who assisted with the data collection for the BRUV surveys and the Nekton deep-sea expedition. Thank you to SIF Head Office who provided administrative and logistics support for the project. Thank you to Dr Lucy Woodall and Dr Paris Stefanoudis for their valuable scientific advice, to Dr Phillip Haupt for advice on statistics and to Dr Frauke Fleischer-Dogley, Dr Nancy Bunbury, Cheryl Sanchez and Matthew Waller for their reviews and assistance in the drafting of this report.

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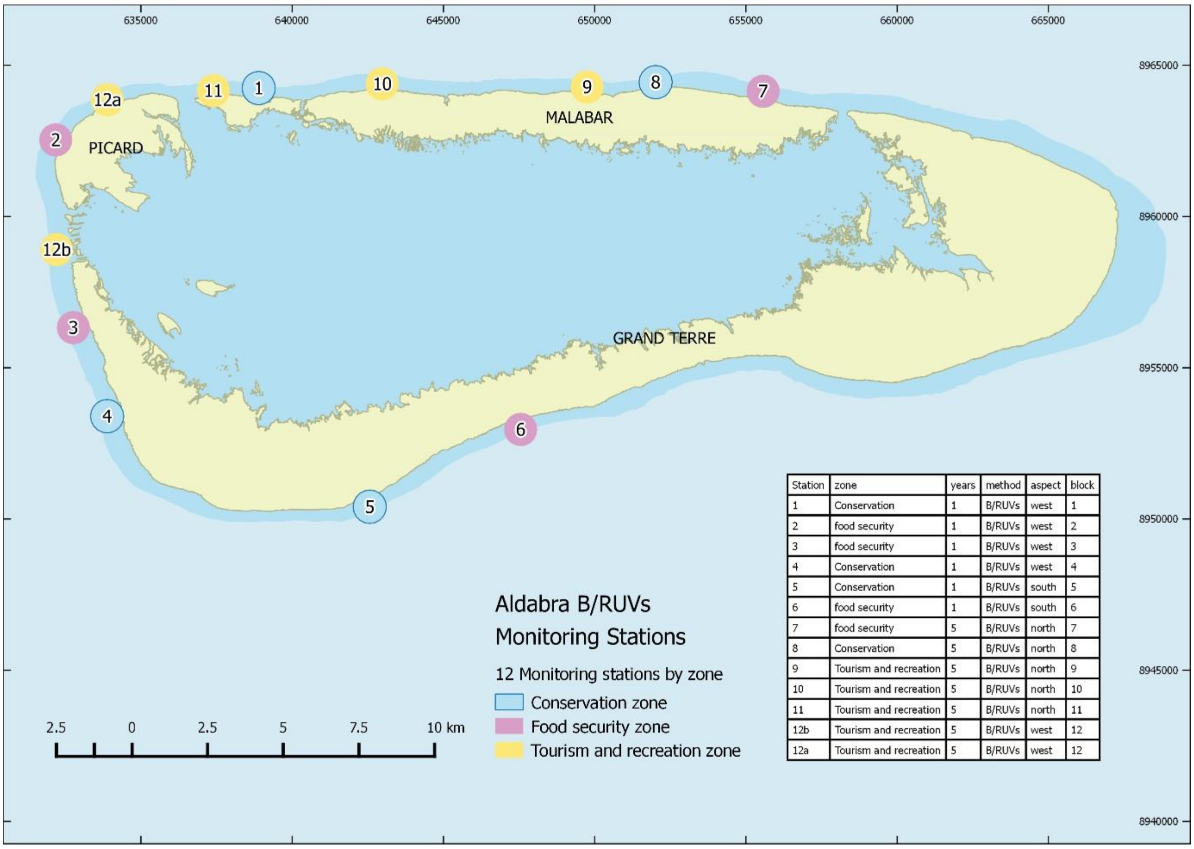
7. Annexes

Annex 1a: Aldabra B/RUV monitoring stations as per the management zones



Station	zone	years	method	aspect	block
1	Conservation	1	B/RUVs	west	1
2	food security	1	B/RUVs	west	2
3	food security	1	B/RUVs	west	3
4	Conservation	1	B/RUVs	west	4
5	Conservation	1	B/RUVs	south	5
6	food security	1	B/RUVs	south	6
7	food security	5	B/RUVs	north	7
8	Conservation	5	B/RUVs	north	8
9	Tourism and recreation	5	B/RUVs	north	9
10	Tourism and recreation	5	B/RUVs	north	10
11	Tourism and recreation	5	B/RUVs	north	11
12b	Tourism and recreation	5	B/RUVs	west	12
12a	Tourism and recreation	5	B/RUVs	west	12

Figure 13: Aldabra B/RUV monitoring stations. Zones 1 – 6 are set out to be surveyed annually via BRUV, zones 7 – 12 are set out to be surveyed every 5 years with a combination of BRUV and RUV (extracted from Aldabra BRUV Monitoring protocol).

Annex 1b: Aldabra B/RUV monitoring sites as per the management zones

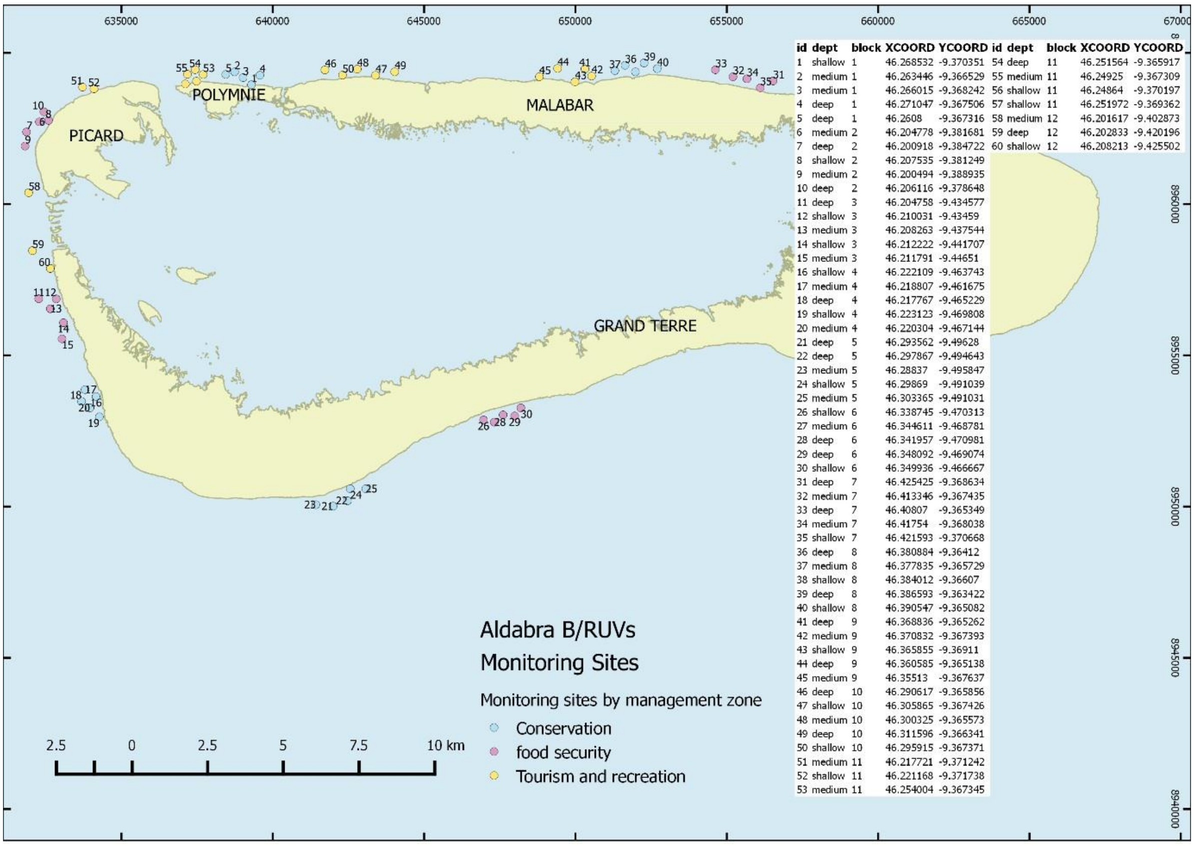


Figure 14: Aldabra B/RUV monitoring sites (Original). Sites 1 – 30 (annually) cover zones 1 – 6, sites 31 – 60 (every 5 years) cover zones 7 – 12 (extracted from Aldabra BRUV Monitoring protocol).

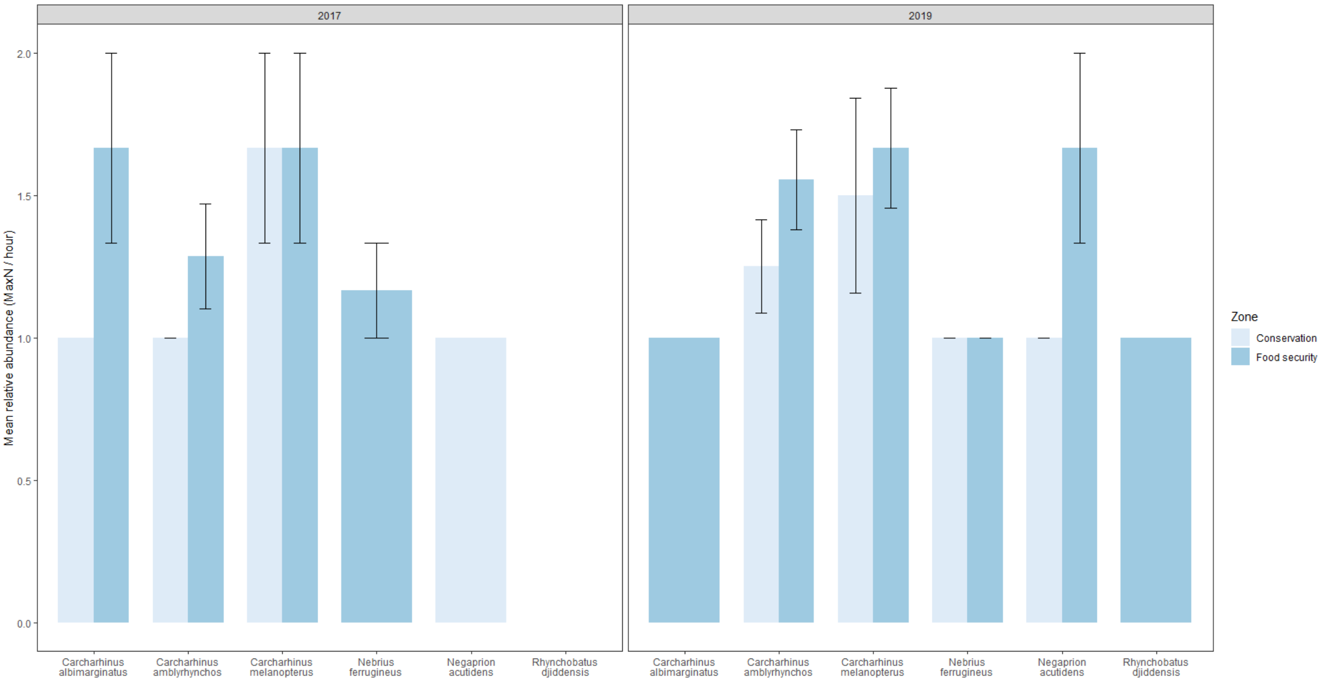
Annex 2: GPS points of Aldabra BRUV survey locations in 2017 and 2019

Zone	Site	Waypoint name	Latitude	Longitude	Zone	Site	Waypoint name	Latitude	Longitude
2017									
1	1.5	BR1.5-17	-9.36739	46.25787	3	15	BR15-17	-9.44774	46.21151
1	1	BR1-17	-9.36844	46.26837	4	16	BR16-17	-9.46396	46.21998
1	2	BR2-17	-9.36749	46.26309	4	17	BR17-17	-9.46173	46.21791
1	3	BR3-17	-9.36758	46.26525	4	18	BR18-17	-9.46582	46.21765
1	4	BR4-17	-9.36718	46.27088	4	19	BR19-17	-9.47008	46.22077
1	5	BR5-17	-9.36681	46.25968	4	20	BR20-17	-9.4678	46.21937
2	6	BR6-17	-9.38044	46.20429	5	21	BR21-17	-9.49623	46.29413
2	7	BR7-17	-9.38392	46.20099	5	22	BR22-17	-9.49457	46.29821
2	8	BR8-17	-9.37885	46.20597	5	23	BR23-17	-9.49704	46.28879
2	9	BR9-17	-9.38829	46.19962	5	24	BR24-17	-9.49296	46.29947
2	10	BR10-17	-9.37794	46.20604	6	26	BR25-17	-9.47051	46.34092
3	11	BR11-17	-9.43466	46.20484	6	27	BR27-17	-9.46887	46.34547
3	12	BR12-17	-9.43501	46.20776	6	28	BR28-17	-9.47113	46.34189
3	13	BR13-17	-9.43766	46.20827	6	29	BR29-17	-9.46885	46.34808
3	14	BR14-17	-9.44379	46.21047	6	30	BR30-17	-9.46694	46.34969
2019									
1	1	BR1-19	-9.367813	46.26821	4	18	BR18-19	-9.465347	46.21776
1	3	BR3-19	-9.367667	46.26518	4	20	BR20-19	-9.467744	46.21989
1	4	BR4-19	-9.367525	46.27101	4	22	BR22-19	-9.494667	46.29789
2	7	BR7-19	-9.384793	46.20123	5	23	BR23-19	-9.496813	46.28745
2	8	BR8-19	-9.385281	46.20106	5	24	BR24-19	-9.493574	46.29737
2	9	BR9-19	-9.388333	46.19962	5	27	BR27-19	-9.469475	46.34426
3	11	BR11-19	-9.434653	46.20476	6	29	BR29-19	-9.469138	46.34812
3	12	BR12-19	-9.434969	46.20733	6	30	BR30-19	-9.467432	46.3508
3	13	BR13-19	-9.43774	46.20779	6				

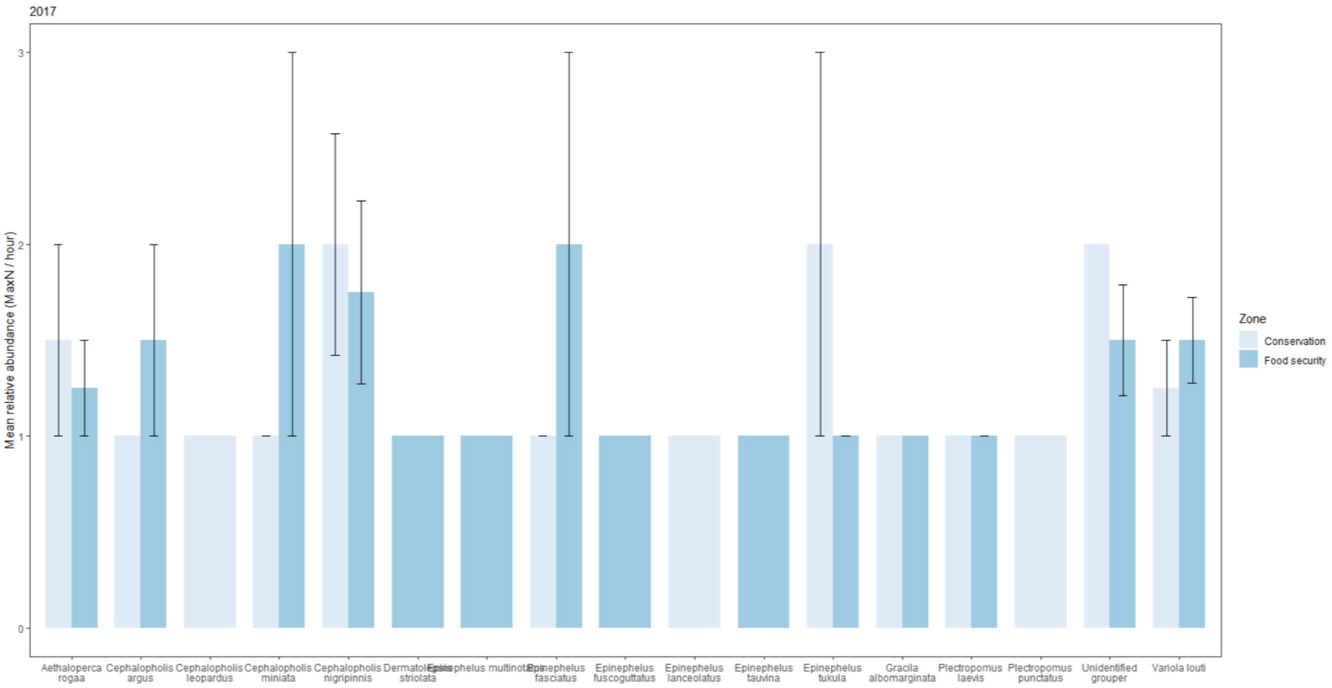
Annex 3: GPS points of stereo-video transects conducted during the Seychelles' Nekton expedition March 2019

	Dive	Transect start		Transect end	
		Latitude	Longitude	Latitude	Longitude
Aldabra North (N1)	058	-9.36417	46.36617	-9.364	46.37283
	066	-9.35333	46.35833	-9.52	46.35833
	073	-9.36217	46.37433	-9.36217	46.37433
	078	-9.35783	46.37533	-9.35783	46.37533
	087	-9.35617	46.36983	-9.35617	46.36983
	097	-9.36267	46.38183	-9.36267	46.38183
	141	-9.36417	46.381	-9.36417	46.381
Aldabra West (W1)	104	-9.45633	46.20717	-9.45633	46.20717
	110	-9.45483	46.2105	-9.45633	46.20717
	120	-9.45967	46.21733	-9.4575	46.2165
	126	-9.45183	46.21283	-9.4485	46.21217
	127	-9.44233	46.20483	-9.44233	46.20483
	135	-9.46517	46.21667	-9.46517	46.21667

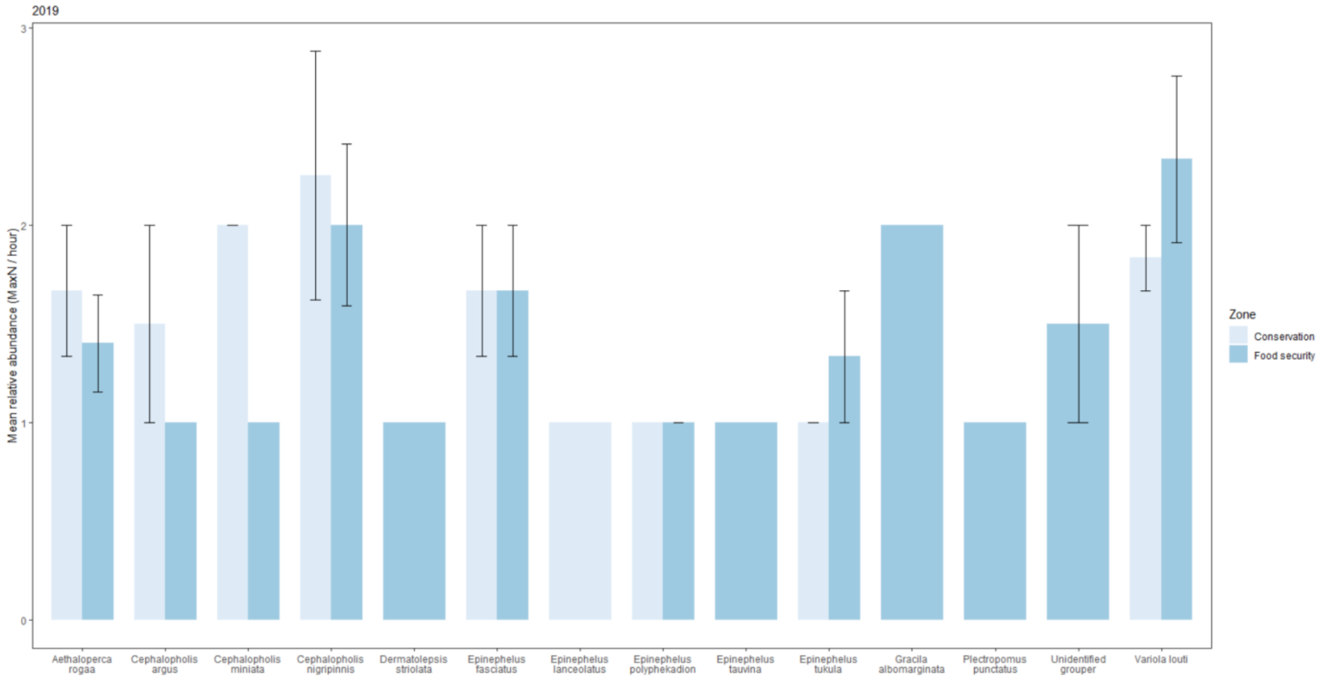
Annex 4: Abundances of each species in each zone in 2017 and 2019



Mean relative abundance (MaxN per 60 minute deployment ± SE) of each shark species in each zone in 2017 and 2019 on Aldabra.



Mean relative abundance (MaxN per 60 minute deployment ± SE) of each grouper species in each zone in 2017 on Aldabra.



Mean relative abundance (MaxN per 60 minute deployment ± SE) of each grouper species in each zone in 2019 on Aldabra.

Annex 5: Abundances of each species at each depth range in 2017 and 2019

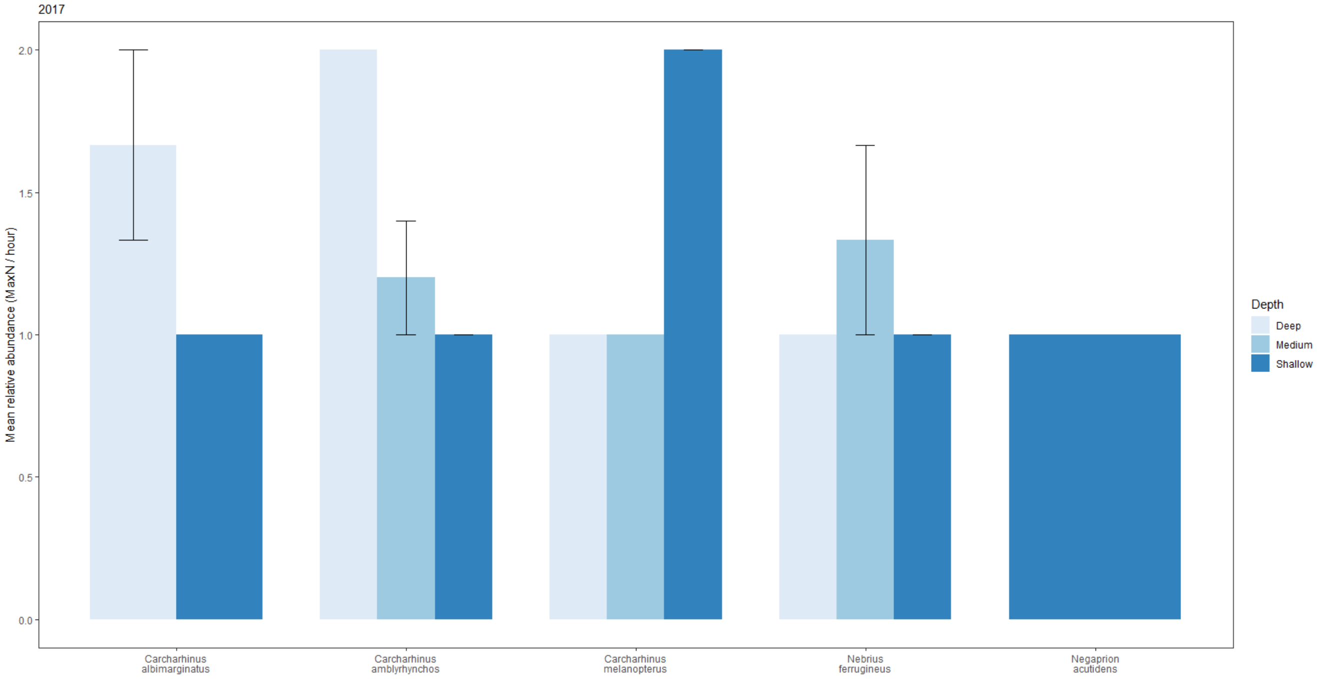


Figure 15: Mean relative abundance (MaxN per 60 minute deployment ± SE) of sharks at each depth range in 2017 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.

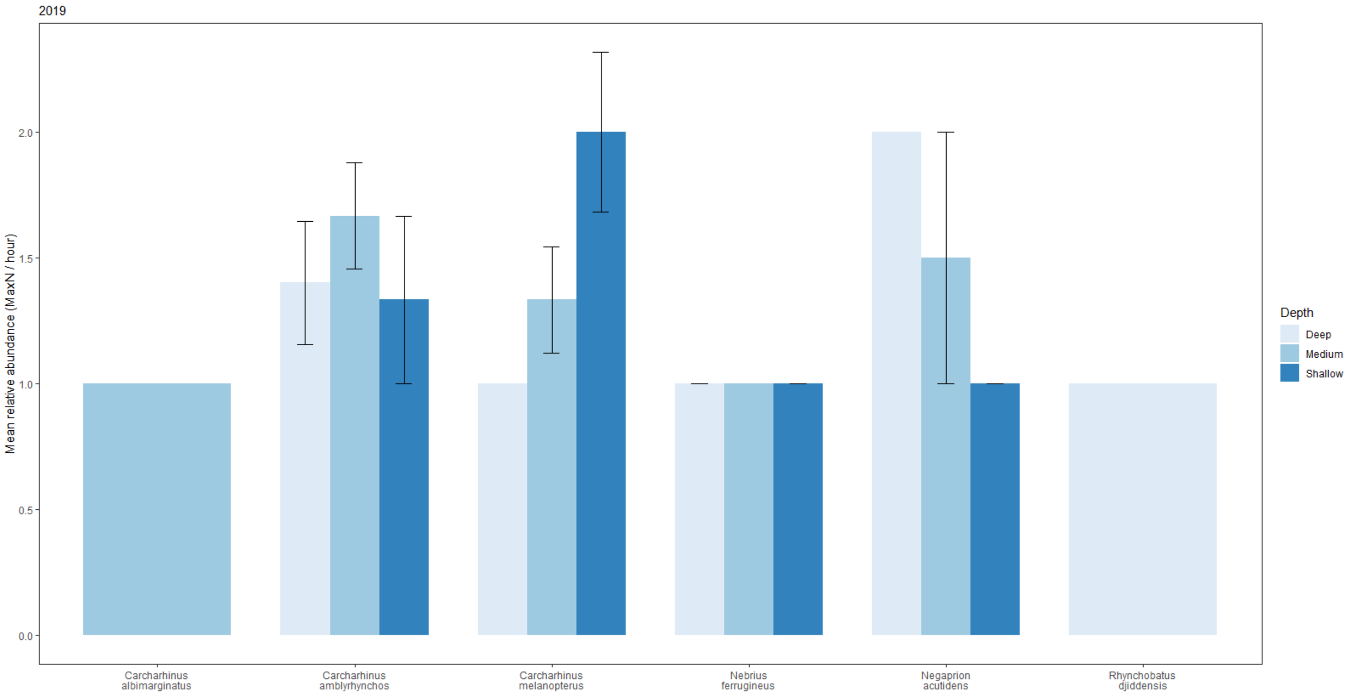


Figure 16: Mean relative abundance (MaxN per 60 minute deployment ± SE) of sharks at each depth range in 2019 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.

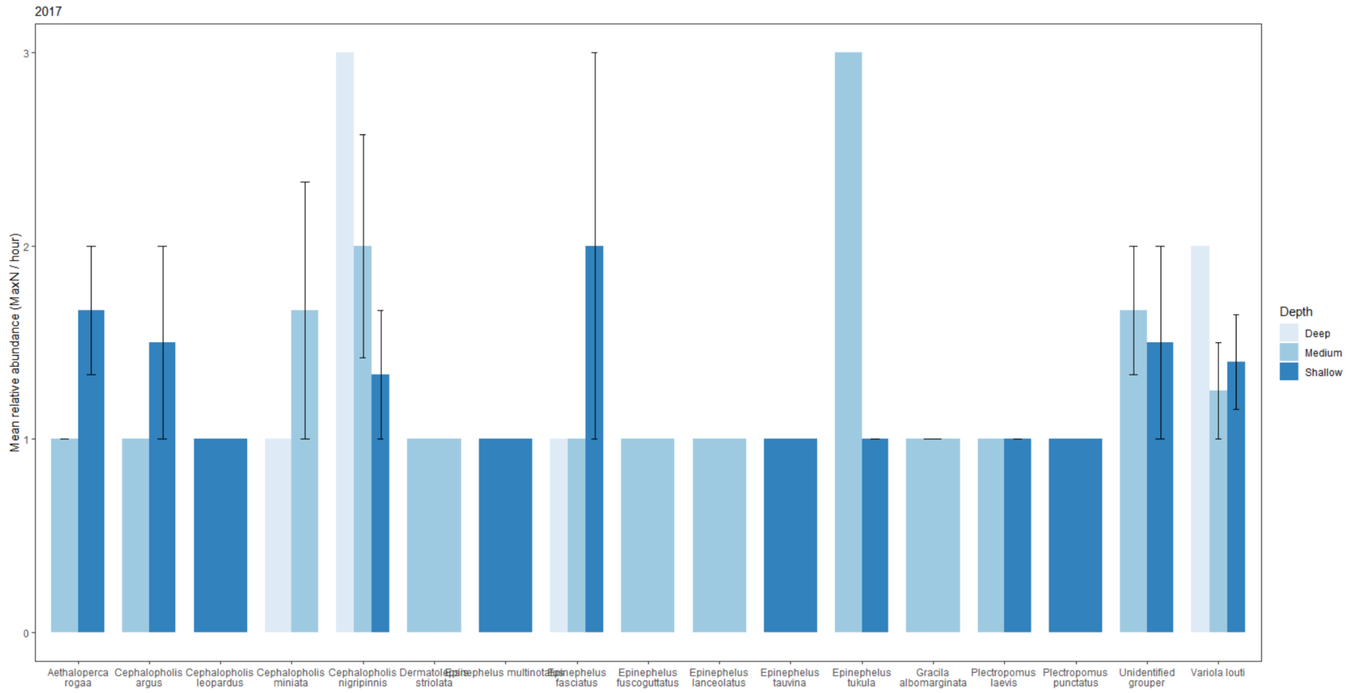


Figure 17: Mean relative abundance (MaxN per 60 minute deployment ± SE) of groupers at each depth range in 2017 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.

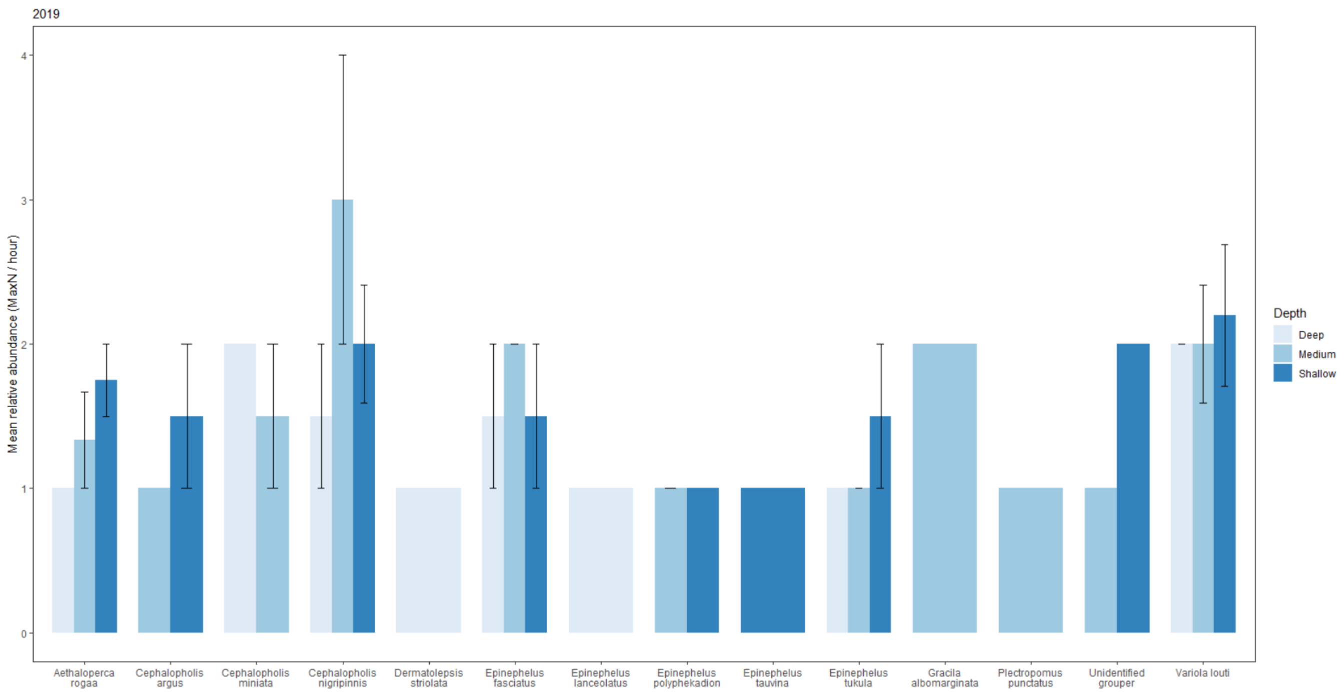


Figure 18: Mean relative abundance (MaxN per 60 minute deployment ± SE) of groupers at each depth range in 2019 on Aldabra. Shallow = 0-10m, Medium = 10-20m, Deep = 20-50m.