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The effect of a Marine Protected Area on grouper abundance and biomass: A multi-method comparison

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The effect of a Marine Protected Area on grouper abundance and biomass: A multi-method comparison

A report submitted to the IMAP-MPA project, Barcelona convention, June 2023

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Methods

Study site:

The study was carried out in the *Yam Rosh Hanikra* no-take marine protected area (MPA) (33°04'11"N, 35°05'58"E) and in fished areas south of the MPA border (Figure 1). The MPA covers 10 km^2, stretching 5 km along the shore and 2 km from the shoreline westwards, reaching a maximum depth of 45 m. The MPA was established in 1968; however, effective enforcement of regulations started in 2007 representing a marine environment protected from commercial fishing for an extended period of time. The MPA protects the richest and most diverse fish and invertebrate communities along the Israeli Mediterranean coast (Frid et al. 2022)

. In 2019, *Yam Rosh Hanikra* MPA was significantly expanded to a size of 96 km^2 in order to protect the deep areas of the Achziv underwater canyon.

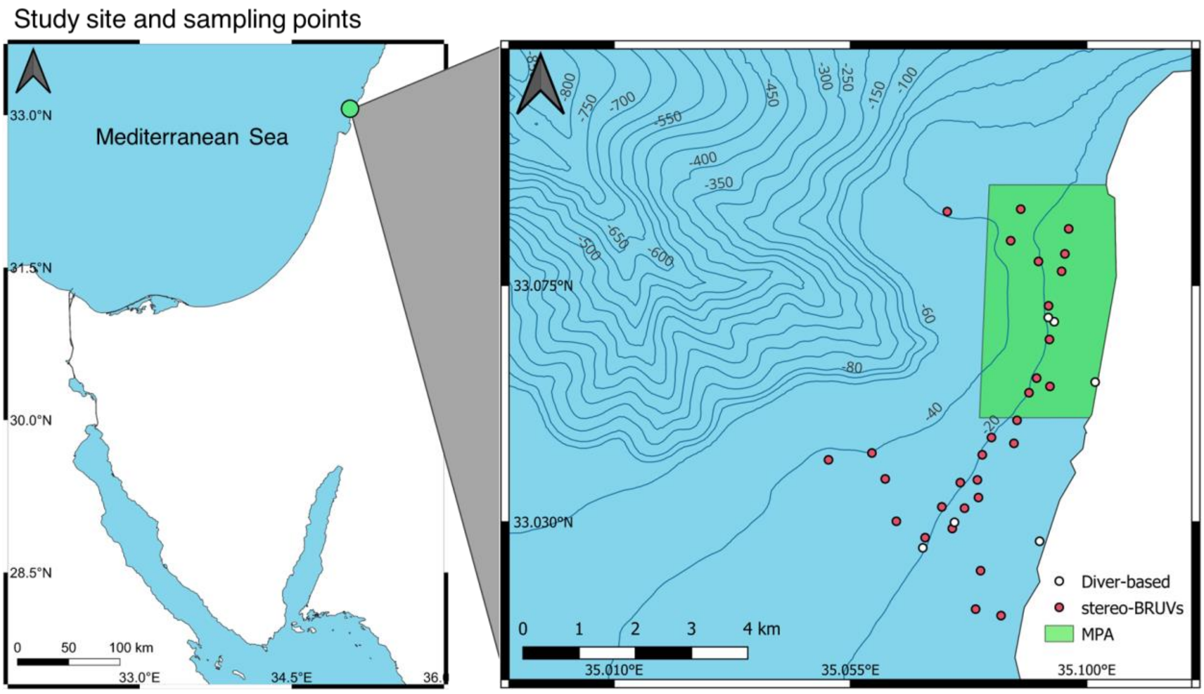

Figure 1. Study site and sampling points. A total of six diver-based locations (CC and OC, white) were used including three within the *Yam Rosh-Hanikra* MPA and three outside its range. Additional 30 stereo-BRUVs samples were used including 11 within the MPA and 19 outside its borders.

Sampling method:

Open and close circuit visual sampling

Surveys were conducted over two consecutive days in November 2023. Fish were sampled using belt transects of 25 x 5m. During the transect, fish were identified to the species level (apart from the *Mugilidae* and *Atherinidae* families, which are challenging to distinguish underwater), counted and their total length was estimated to the closest centimeter. Size was converted to biomass using species-specific Mediterranean-based length-weight relationships ($W = aL^b$) gathered from FishBase (Froese & Pauly 2023).

Habitat variables recorded included: (1) bottom depth, (2) % cover of different substrate types (including rock, sand, rubble, or algae) as estimated every meter along the 25m transect, (3) habitat complexity, estimated qualitatively on a scale of 0 to 5, where 0 is no vertical relief; 1, low and sparse relief; 2, low but widespread relief; 3, moderately complex; 4, very complex with numerous fissures; and 5, exceptionally complex with numerous caves or overhangs (Polunin and Roberts 1993).

Surveys were conducted using two types of diving systems: **regular open circuit (OC)** and **closed circuit (CC)**. To assure potential differences are not due to differences in survey experience, the **CC divers switched to open circuit diving (O-CC)** in the middle of the dive. We were careful to begin with CC and then switch to O-CC so that fish behavior will not be impacted by the OC section of the dive.

Surveys were based on two teams of divers, one OC and one CC. On each dive, these teams surveyed either a MPA site or a control site (areas where fishing is permitted). On each sampling day the teams' survey locations in MPA and control sites were switched between dives. Divers were partially replaced between sampling days.

The paired OC and CC teams entered the water in locations ~100 m apart so that the surveyed habitat is similar while mutual interference is unlikely. On each dive, OC divers performed between 2 and 4 transects (depending on time limitation that differed by depth) and CC divers performed between 4 and 6 transects altogether (including both CC and OC). The number of CC transects in each dive ranged between 3 and 4, and the number of OC transects performed by the same CC divers ranged between 1 and 3 (this variation was due to OC transects both requiring more air and dive safety limitations).

Table 1: Transect numbers across diving systems and depth categories, inside *Yam Rosh Hanikra* MPA and in adjacent control sites. OC represents transects that were conducted using open diving systems, CC represents transects that were conducted using closed-circuit diving systems and CC-O represents transects that were conducted by closed-circuit divers using open diving systems.

Sampling site	Protection	Depth category	OC	CC	CC-O	Total
1	Fished	Shallow	4	3	1	40
2	Fished	Middle	7	6	4	
3	Fished	Deep	5	7	3	
4	MPA	Shallow	4	3	1	38
5	MPA	Middle	6	6	3	
6	MPA	Deep	5	7	3	

On each diving day, each team performed two to three dives at three different depth categories: (1) 20-26 m, (2) 12-18m, (3) 4-6 m. When only two dives were performed, due to sea conditions or logistic constraints, the shallow depth was excluded.

Video surveys

To estimate the level at which the presence of divers influences the abundance, biomass, and occupancy of fish we also compared our results using stereo Baited Remote Underwater Video Surveys (stereo-BRUVs; (Langlois et al. 2020). This method allows the assessment of species relative abundance and accurate length measurements with a reduced observer bias (Harvey and Shortis 1995). Here, we analyzed 30 samples, each comprising a 60-minute video, deployed down to 40 m on rocky reef habitats (Figure 1). To tackle the issue of abundance overestimation (i.e. resampling the same individual that entered and exited the frame several times) we used a conservative index (MaxN; (Priede et al. 1994). MaxN uses the maximum number of individuals within a frame per species for the entire 60-minute video. Samples were collected between November 2019 to July 2022 every three months and during daylight hours (i.e. between an hour after sunrise and an hour before sunset) to avoid possible crepuscular variation in fish assemblages and behavior. To estimate fish biomass, we measured the fork length of individuals, converted it to total length, and then used length-weight conversion coefficients available on rFishBase (Boettiger *et al.* 2012).

Analyses

Diving surveys

For OC transects we used the data recorded by the more experienced observer of the pair. For CC transects we averaged the abundance and biomass between the two observers (unless a single observer was assigned), except when internally comparing between CC and O-CC transects from the same team in which case we used data from both observers. For CC transects, when examining grouper size, we randomly chose a single observer.

To test the effects of protection on grouper size we used a general linear model, and for abundance and biomass we used Generalized Linear Models with a Poisson distribution and Tweedie distribution (power variance = 1.5, log link function), respectively. We used protection (inside MPA vs. control sites) and diving systems (OC vs. CC) as predictors, and tested their interaction. Models assumptions were tested and verified.

To further test the effect of diver disturbance on grouper behavior we compared the observed abundance and biomass (separately) of only dive teams that used both CC and O-CC systems, inside the MPA and in control sites. To do that, we calculated the log-ratio between grouper abundance and biomass observed using CC compared to O-CC on the same site. We then averaged the log-ratio across divers. We used general linear models to examine the effects of protection on the log-ratio of both abundance and biomass. Models assumptions were tested and verified.

Stereo-BRUVs

To test the effect of protection on grouper abundance, and body size we applied Generalized Linear Models (GLM) with Poisson, and Gaussian error distributions respectively using the 'stats' R package (R Core Team 2023). MPA was set as a two-level categorical predictor and

MaxN or body size as the response variables. To test the effect of MPA on grouper biomass we applied a two-sample Wilcoxon test. Here parametric tests such as GLM and two-sample t-tests did not meet the assumptions. To test whether the MPA affects groupers' occurrence we used GLM with binomial error distribution. In this model, we used a two-level response variable (i.e. presence/ absence) and MPA as a two-level categorical predictor. For the GLMs, the Homoscedasticity and non-normality of the residuals were evaluated using the 'simulateResiduals' function from the 'DHARMa' R package (Hartig 2021).

2. Results

Diver-based methods

We present here the results for groupers (combining the three most common species; *Mycteroperca rubra*, *Epinephelus marginatus* and *E. costae*) – fishes of high trophic level that are extremely sensitive to fishing. We found clear evidence for higher groupers abundance (Figure 2A) and biomass (Figure 2B) within the MPA compared to control sites. The difference between OC and CC systems was apparent only at control sites, outside of the MPA, with higher abundance and biomass detected using CC systems (Figure 2). These results largely reflect our expectations, attesting to the value of the MPA, and at the same time emphasizing that CC systems are better at detecting grouper when fishes are wary of fishers (i.e., outside MPAs). These results, including the interaction between protection and OC/CC are comparable to those found in a previous similar study (Lindfield *et al.* 2014).

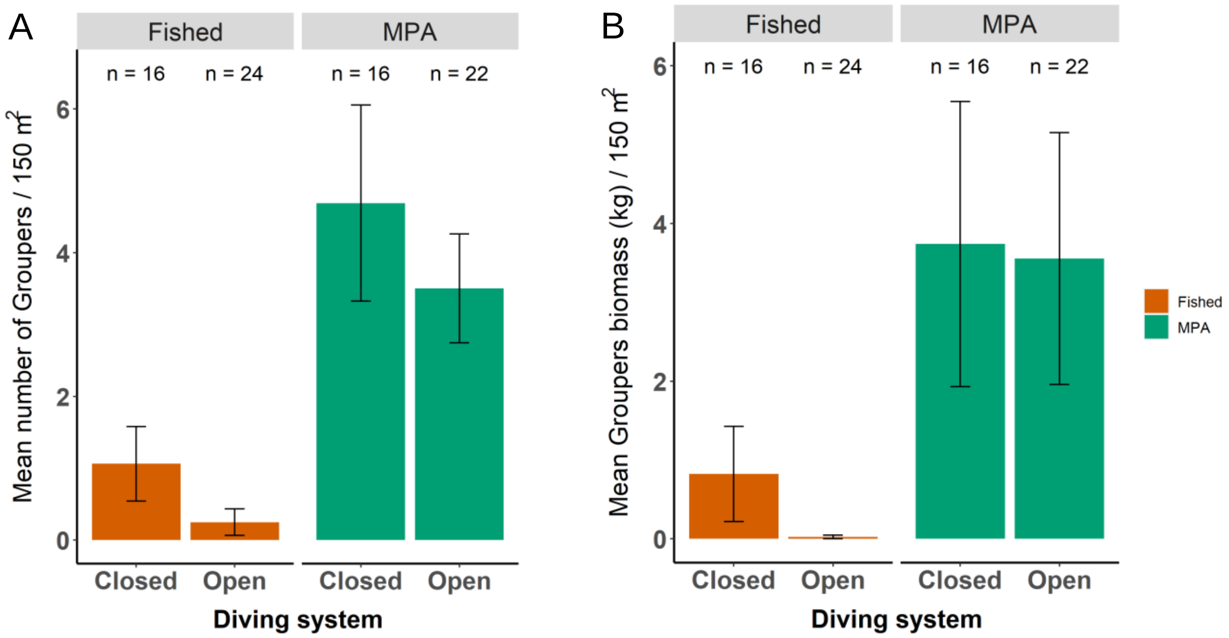

Figure 2. Mean number of groupers (A) and grouper biomass (B) per transect in fished sites (brown) and in *Yam Rosh-Hanikra* MPA (green), using OC and CC systems. Error bars represent 95% CI. *n* represents the number of transects. Protection has a positive and significant effect on grouper abundances ($p < 0.05$), while only a marginal effect was found between the dive systems ($p = 0.07$). The effect of protection on grouper biomass is significant ($p < 0.05$) indicating higher biomass inside the MPA. The effect of the dive system is not significant, while the effect of the dive system alone is

not. For both grouper abundance and biomass, the interaction between MPA and diving system was significant ($p < 0.05$), indicating that the effect of the diving system is only observed in control sites. Thus, fewer groupers are observed outside the MPA when using OC systems compared to CC systems.

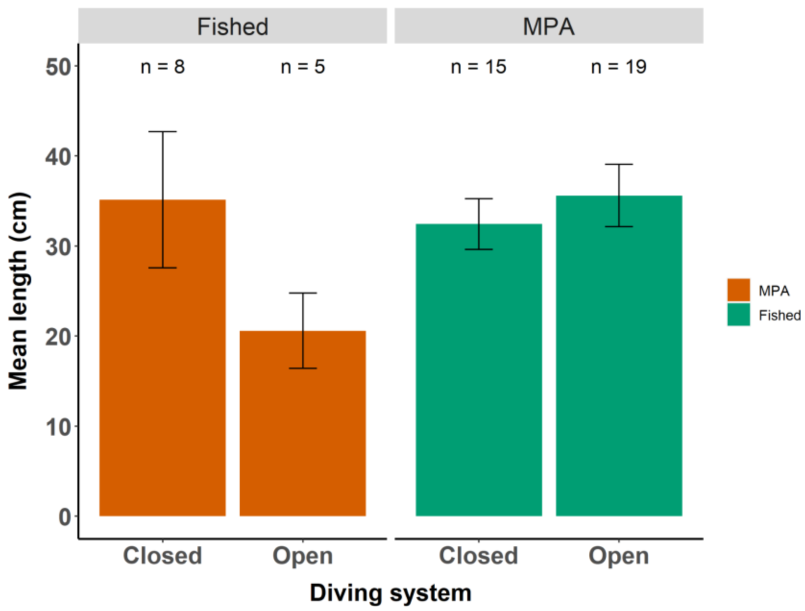

Figure 3: Mean grouper length in fished sites and in *Yam Rosh-Hanikra* MPA, using OC and CC systems. Error bars represent 95% CI. *n* represents the number of transects in which groupers were observed. The interaction between protection and diving system was significant ($p < 0.05$) and indicates that the effect of the diving system is only observed in fished sites. Thus, smaller groupers are observed outside the MPA when using OC systems compared to CC systems.

We further checked the results per diver to assure that these results are not driven by more experienced divers using the CC systems. This was done by comparing the ratio between grouper abundance and biomass when using OC versus CC, per diver. Positive ratios indicate that either more groupers or larger groupers were observed when using the CC. Both the numbers and biomass of groupers were higher per transect when using the CC as indicated by the positive ratios (figure 4). The ratio was higher outside the MPA for biomass ($p < 0.05$) but not for abundance.

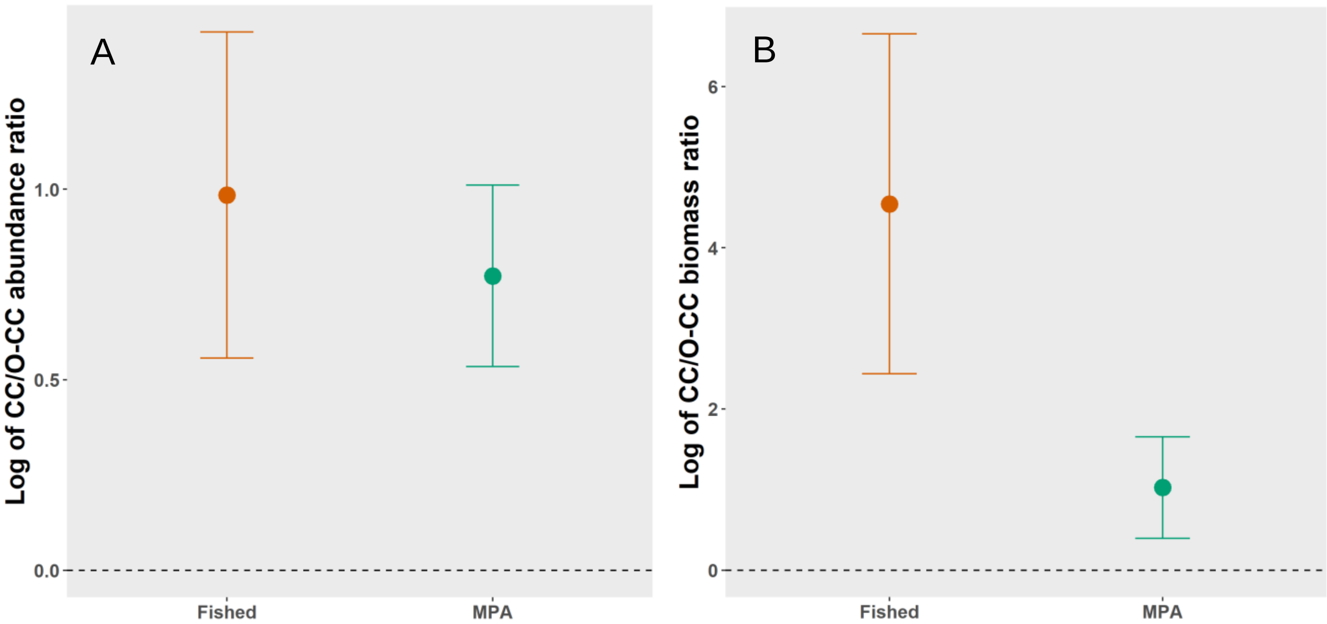

Figure 4. The log ratio of grouper abundances (A) and biomass (B) when using CC versus O-CC systems in fished sites (brown) and in *Yam Rosh-Hanikra* MPA (green). The ratio was calculated for paired CC and O-CC dives, and then averaged across all dive teams. As the ratio increases, more groupers were observed when using CC systems compared to O-CC systems.

stereo-BRUVs

The benefit of MPAs to grouper abundance was also clearly detectable when using the stereo-BRUVS, where the effect of diver avoidance was not expected to be an issue (figure 4). We found moderate evidence that the MPA had a positive effect on groupers' MaxN (GLM: z = 2.295, p = 0.021, Figure 5A). Conversely, we found no evidence that the MPA affects either the occurrence patterns of groupers (GLM: z = 1.582, p = 0.114, Figure 5B), body size (GLM: t = 1.246, p = 0.228, Figure 5C), or biomass (two-sample Wilcoxon test: W = 79, p = 0.25, Figure 5D).

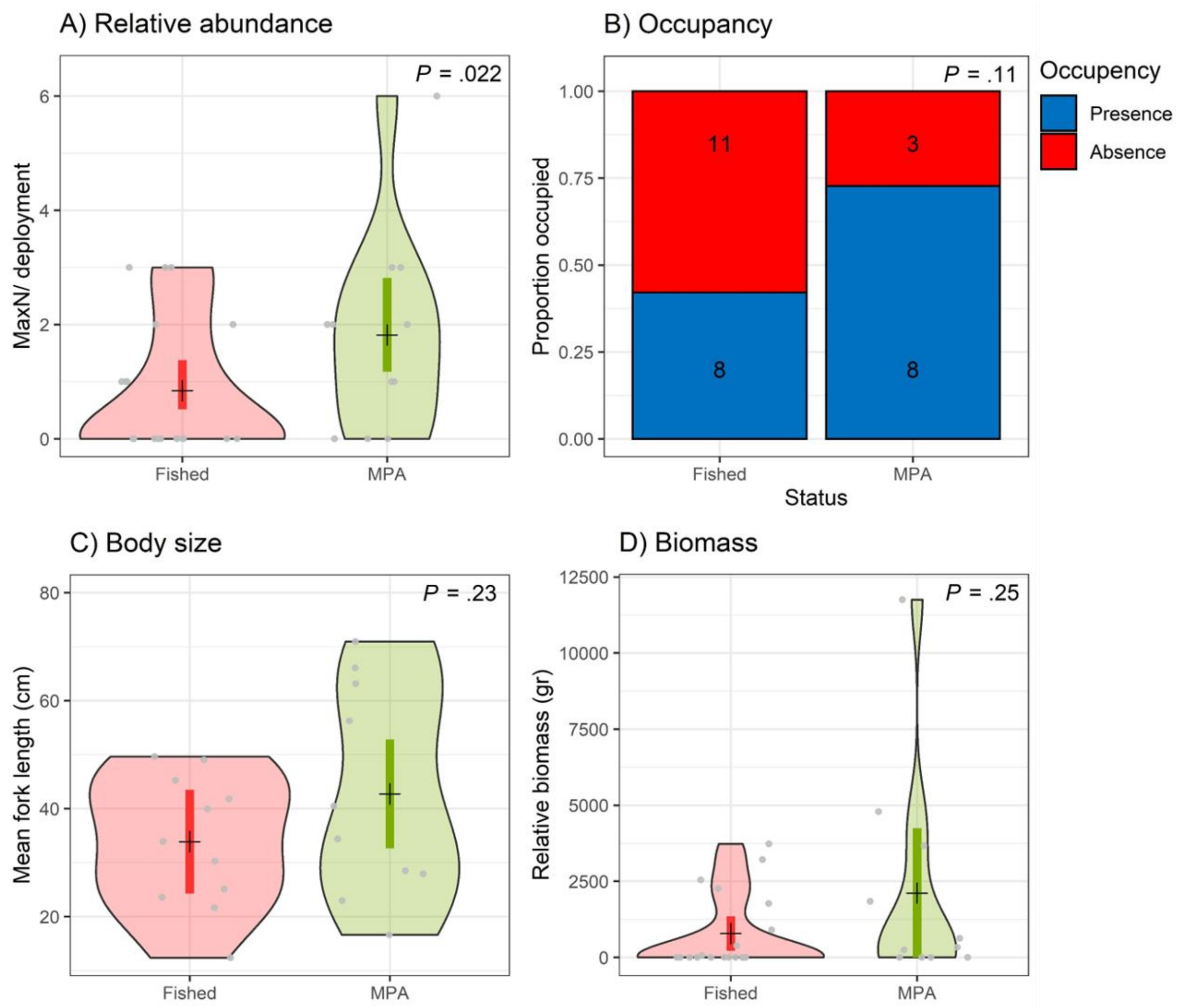

Figure 5. Grouper estimates for fished and protected areas using stereo-BRUVs. A) Relative abundance, B) Occupancy, C) Body size, and D) Relative biomass. In panels A, C, and D, polygons are kernel density estimates, error bars are 95% confidence intervals, and crosses denote the mean values. Each point is a stereo-BRUV deployment. Panel B displays the proportion of samples that recorded groupers within the fished and protected areas. Numbers denote the number of samples. P-values denote the significance level of the effect sizes.

3. Conclusions and recommendations

- We have established a capacity to sample using CC systems in the eastern Mediterranean.
- Using **all** methods, the MPA demonstrated higher abundance of the major target species (groupers). This attests to the benefits of *Yam Rosh-Hanikra* MPA.
- The effect of protection on grouper abundance and biomass is independent of the dive system.
- The results show that CC systems are capable of detecting higher abundance and biomass of the major target species (groupers) relative to OC systems. However, this effect is only significant outside of the MPA.
- The lower biomass observed using the OC diving systems compared to CC systems (outside the MPA) is likely due to larger individuals being more wary of fishing, indicating that our ability to detect such specimens using OC systems is compromised.
- Using CC systems is recommended when logistically possible. However, within the MPA the benefit of using the CC systems is extremely small and not statistically significant.
- We recommend maintaining the use of a combination of stereo-BRUVS and OC systems as the major sampling methods due to reduced operational and logistic costs and to allow sufficient sample sizes (which are limited by trained personnel in CC diving). At the same time, we recommend augmenting these with periodic CC surveys that can be used to calibrate OC results, especially outside of MPAs.

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