Celestun Fishery Refuge Zone 2023 Monitoring Evaluation

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MARISTA

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Abstract

The Celestún Fishery Refuge Zone (FRZ), established in 2019, underwent monitoring efforts in 2023 with the participation of local fishermen, despite challenges posed by the COVID-19 pandemic, which impacted the intended five-year evaluation period. Two methodological approaches—academic monitoring and institutional monitoring—were employed to assess the diversity of the primary commercial species within this FRZ.

The results obtained indicate that, although the type of substrate does not appear to be a determining factor in the distribution of commercially significant species, there is a notable scarcity of biotic structures such as coral reefs and seagrass meadows. Nevertheless, the evaluation of biological diversity through the Shannon-Weaver diversity index shows a high degree of congruence, despite the methodological disparities between the two monitoring approaches.

Furthermore, the outlook for the Celestún FRZ appears promising in terms of growth, recruitment, and biological diversity over a broader temporal scale. Although biomass estimates could not be directly compared between the two monitoring methods due to differences in design and approach, significant improvements in this variable are also anticipated over time. This projection is based on an understanding of ecological processes and population dynamics, as well as the active participation of local fishermen in implementing appropriate protection and management measures for the conservation of this marine ecosystem.

This work summarizes the key findings from the monitoring efforts conducted in the Celestún FRZ in 2023, providing an overview of the current status and future prospects for the management and conservation of this important protected area.

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Introduction

On October 2, 2019, the establishment of the Celestún Fishing Refuge Zone (FRZ) was officially announced through the Official Gazette of the Federation. This initiative was driven by the Federation of Fishing, Aquaculture, and Tourism Services Cooperatives of Celestún S.C. de R.L. de C.V. The FRZ, represented in **Figure 1**, was established in a partial modality as stipulated in the (DOF, 2014). Under this modality, certain commercial activities are authorized, such as octopus fishing during the fishing season using the fishing method known as "*gareteo*" as well as sawfish and mackerel fishing using the "*trolling*" technique. Additionally, tourism activities, such as diving, are permitted on the condition that they do not involve resource extraction.

The Fishing Refuge Zone (FRZ) is located off the coast of Celestún, Yucatán, approximately 8 nautical miles from the shoreline to the nearest vertex. With dimensions of 4 nautical miles in width and 22 nautical miles in length, the FRZ covers an area of 32,400 hectares (**Figure 1**). Its primary objective is the recovery of populations of key commercially important species, including the sea cucumber (*Isostichopus badionotus*), the red octopus (*Octopus maya*), the red grouper (*Epinephelus morio*), and the spiny lobster (Panulirus argus).

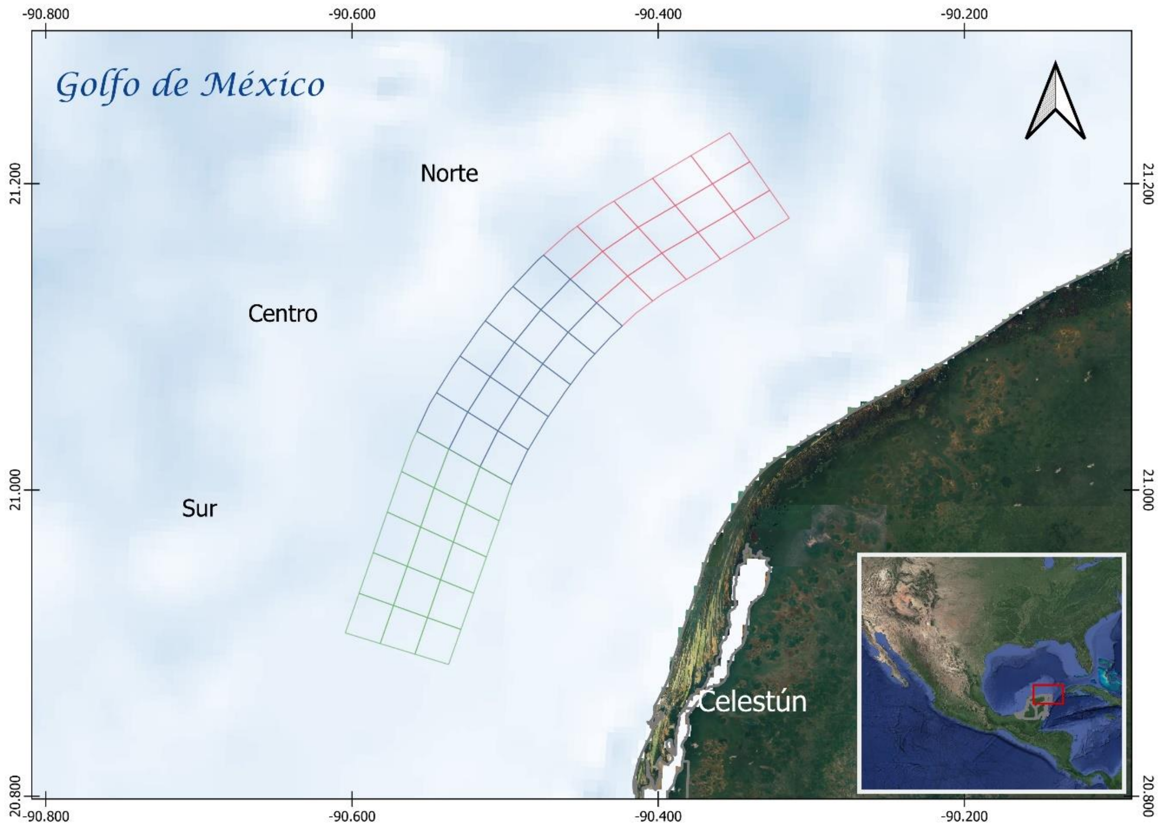

Figure 1. Geographic delimitation of the Celestun Fishing Refuge Zone.

Methods

Underwater biological monitoring

To evaluate the main ecological indicators (richness, biomass, diversity) of the Fishing Refuge Zone (FRZ), two monitoring efforts were conducted during the year 2023. The first monitoring (academic monitoring) took place from August 8 to 10, 2023, and was coordinated by the Universidad Marista de Mérida, with support from the Rufford Foundation, as part of the project "Assessment of Biological and Socioeconomic Effects in a Fishery Refuge Zone in Yucatan, Mexico." On the other hand, the second monitoring (institutional monitoring) was conducted from September 29 to October 2, 2023. It was designed and coordinated by the Mexican Institute of Fisheries and Aquaculture Research (IMIPAS), in collaboration with Community and Biodiversity A.C. (COBI). The details regarding the design and techniques employed in each monitoring effort are presented below.

Academic monitoring

Monitoring design

The monitoring design involved dividing the polygon of the Fishing Refuge Zone (FRZ) into three main zones: North, Central, and South. Each of these regions was further subdivided into 15 cells, resulting in a total of 45 cells throughout the full extent of the polygon. Five monitoring points were established within each main zone of the refuge, designated as "refuge sites" (RS). Additionally, three sites adjacent to the refuge were selected for each main zone, identified as "control sites" (CS). The details of this layout are shown in **Figure 2**.

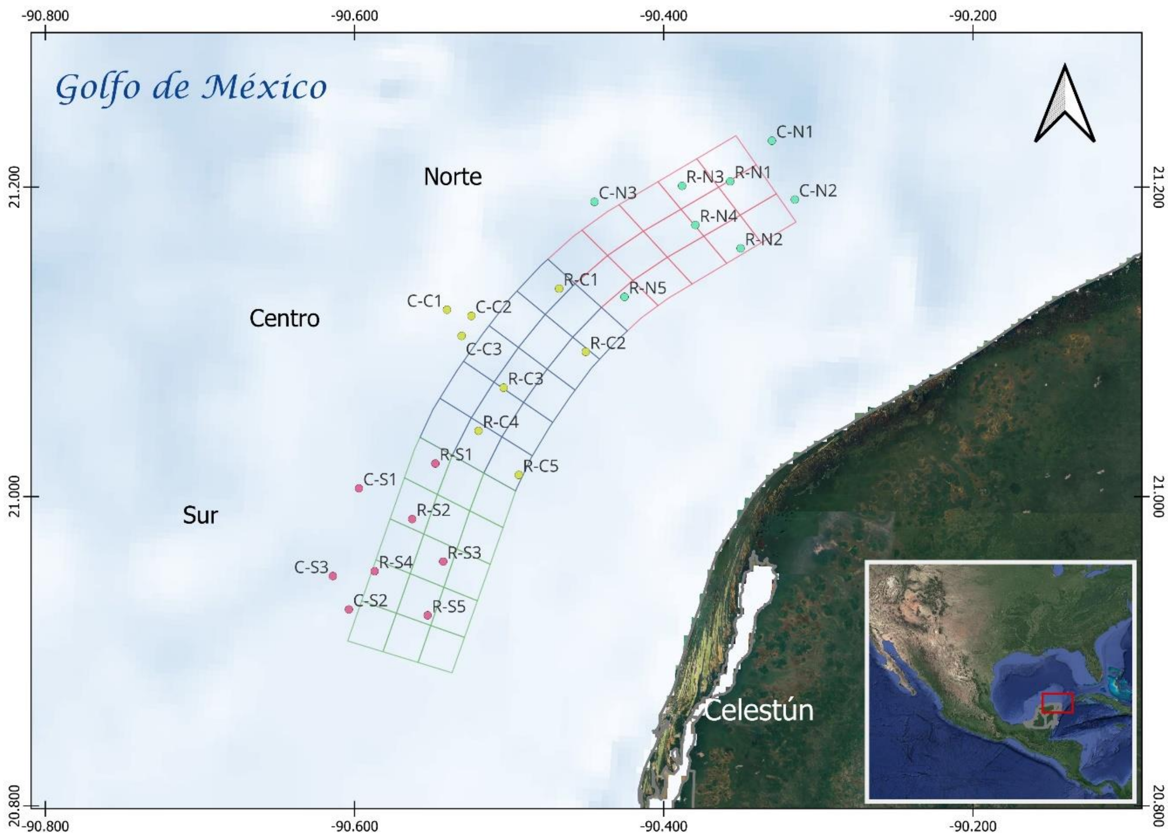

Figure 2. Design of the academic monitoring in the Celestun FRZ.

The points included in the monitoring survey were selected through targeted sampling (Rolim et al., 2019; Amador-Castro et al., 2021). This methodology took into account the empirical knowledge of local fishers, who identified sites with biological potential, such as areas where target and/or associated species aggregate.

Similarly, following the approach of (da Silva et al., 2015), it was ensured that both the sites within the refuge and the control sites shared similar topographic characteristics to facilitate comparisons between them. This resulted in a total of 24 sites evaluated, with 15 located within the polygon of the Fishing Refuge Zone (FRZ) and 9 in the areas adjacent to the polygon.

Monitoring technique

The belt transect technique was employed, based on the monitoring protocol for marine reserves proposed by Hernández-Velasco et al. (2018). This methodology involved deploying a linear belt transect with a length of 30 meters at each sampling site. During the survey, fish observed within an area 2 meters wide, extending from the seabed to a height of 2 meters above it, encompassing the water column, were counted (**Figure 3**). In addition to fish, other ecologically important organisms, invertebrates, and commercially significant benthic species present within the transects were recorded.

Figure 3. Belt transect used in the academic monitoring.

Institutional monitoring

Monitoring design

The design of the institutional monitoring, developed by IMIPAS and COBI, involved collaboration with a variety of institutions, including governmental, academic, and non-governmental organizations (NGOs). These institutions included the Secretariat of Sustainable Fisheries and Aquaculture of Yucatán (SEPASY), the Kanan Kay Alliance, the Universidad Marista de Mérida, and the National Autonomous University of Mexico (UNAM), along with support from the management committee of the Celestún FRZ.

In contrast to the targeted sampling approach used in the academic monitoring, the institutional monitoring adopted a systematic design with a random sampling approach, based on the assumption of a homogeneous distribution (Hernández-Sampieri et al., 2014).

In the design of this monitoring, representativeness across the entire polygon was ensured by examining the three main zones previously mentioned in the academic sampling (North, Central, and South). Four monitoring points were established within each of the main zones of the refuge, maintaining the same nomenclature (RS). Additionally, three points were selected in the adjacent area, with two located in the North zone and one in the South zone, designated as control sites (CS) (**Figure 4**).

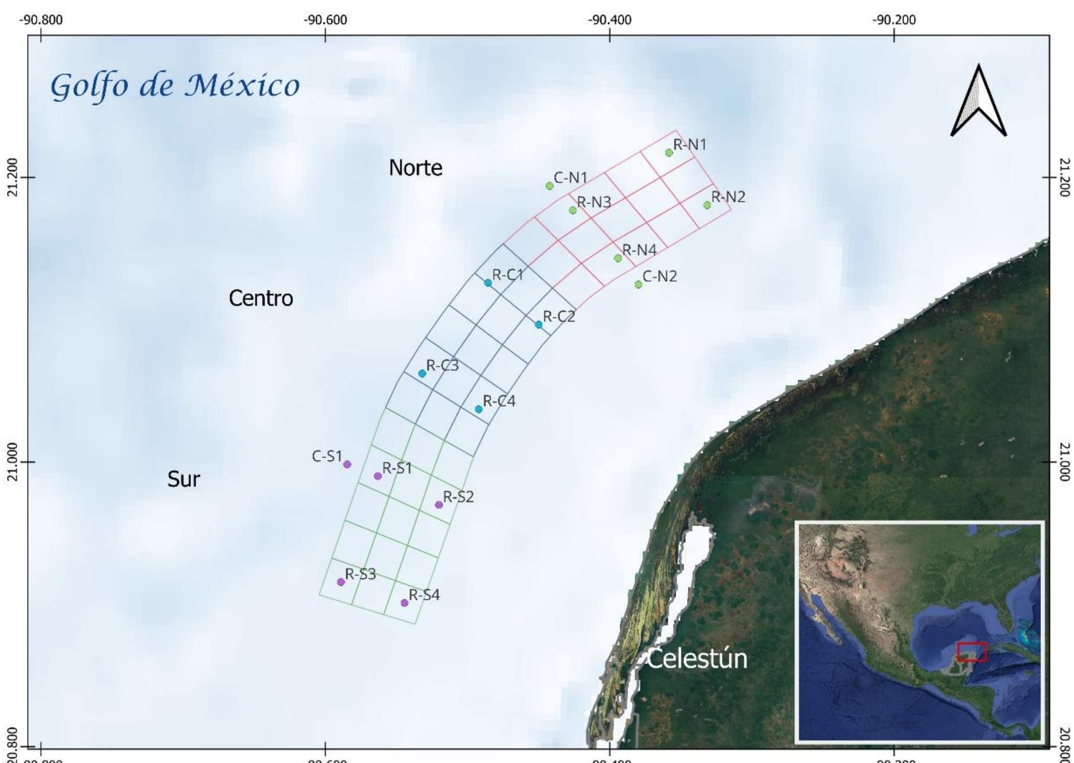

Figure 4. Design of the institutional monitoring in the Celestun FRZ.

This resulted in a total of 15 sites evaluated, with 12 located within the polygon of the FRZ and 3 in the adjacent areas.

Monitoring technique

Similarly, the belt transect technique was employed, based on the monitoring protocol for marine reserves proposed by Hernández-Velasco et al. (2018). This methodology involved deploying 4 linear belt transects, each with a length of 50 meters, at each sampling site. At each site, two pairs of divers conducted the survey at the exact designated point, while the other two pairs of divers conducted the survey at a distance of approximately 800 meters to 1 kilometer from the exact point. During the survey, fish observed within an area 2 meters wide, extending from the seabed to a height of 2 meters above it, encompassing the water column, were counted (**Figure 5**). In addition to fish, other ecologically important organisms, invertebrates, and commercially significant benthic species present within the transects were recorded.

Figure 5. Belt transect used in the institutional monitoring.

Additionally, as a complement at each sampling site, the roving diver technique was applied. This methodology involves recording less frequent commercial species. Under this approach, the diver swims freely for 30 minutes, allowing the recording of various species of commercial fish and invertebrates (**Figure 6**).

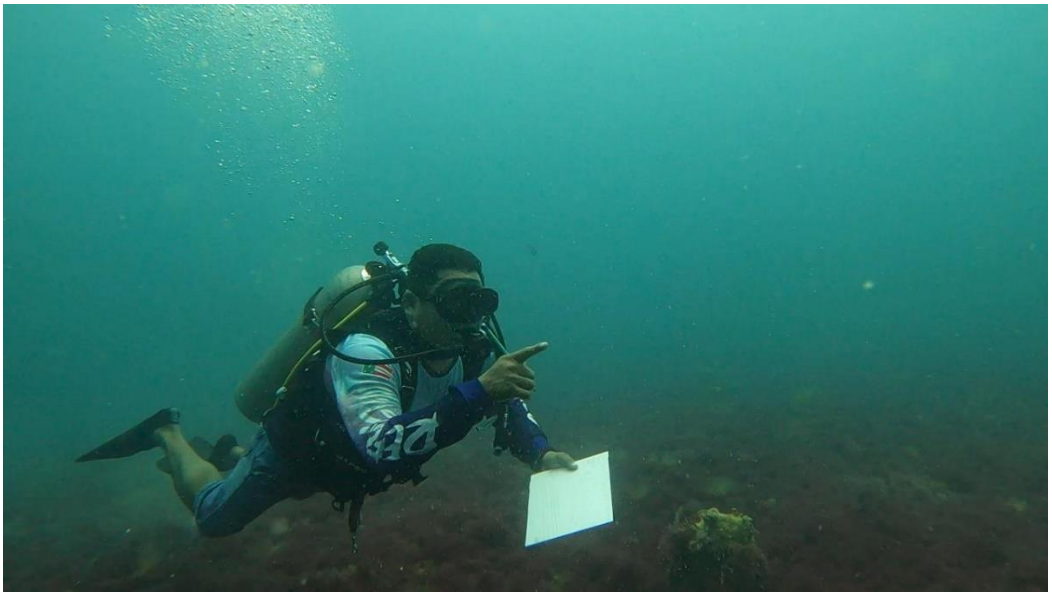

Figure 6. Roving diver technique used in the institutional monitoring.

Finally, the type of seabed was recorded. During each transect, a diver carried out a survey of the seabed coverage, noting the type of substrate present every 50 cm along the entire transect.

Estimation of ecological indicators for commercially important species

The evaluation of various ecological indicators was conducted, including the richness index, biomass estimation, and the Shannon-Weaver diversity index, which exclusively considered commercially important species. The methodology used to calculate each of these indicators was identical for both academic and institutional monitoring. The procedure used to calculate these indicators is detailed below.

Estimation of richness index (S) and rarefaction curve

The richness index and rarefaction curve for commercial fish species and some ecologically important species as indicators of ecosystem health were calculated using the "*vegan*" package in the RStudio platform. Species abundance data were organized into a matrix, where rows represented the different locations or sampling points (RS and CS), and columns represented the various commercial species with their respective abundances.

The richness index represented the count of the total number of unique species present in each sample. The results were expressed as a vector where each element represented the species richness for a specific location, including both RS and CS.

The rarefaction curve calculated the expected species richness for different sample sizes using random sampling without replacement. The rarefaction curve illustrates how the estimated species richness changes as the sample size increases.

The confidence interval (CI) around the rarefaction curve was estimated using the "**bootstrapping**" method. Repeated sampling of the original samples with replacement was performed to obtain multiple estimates of species richness for each sample size. From these estimates, 95% confidence intervals were calculated.

Subsequently, an extrapolation of the rarefaction curve and the CI was performed based on 25 samples for the refuge sites (RS) and 15 samples for the control sites (CS), for both academic and institutional monitoring. This was based on the number of samples conducted for each type of monitoring: 15 samples in RS and 9 samples in CS for academic monitoring, and 12 samples in RS and 3 samples in CS for institutional monitoring.

This extrapolation enabled the estimation of the expected species richness using a common sample size for both areas in each monitoring effort. This facilitated a more precise and equitable comparison between the monitoring points of refuge sites (RS) and control sites (CS). It is important to highlight that this indicator estimation allowed for a comparison between both monitoring efforts based on the sampling effort carried out in each of them.

<u>Estimation of biomass</u>

The individual biomass of the different commercial fish species and some ecologically important species recorded in RS and CS was calculated using the length-weight allometric conversion:

$$W = aLT^{b}$$

where *a* and *b* are species-specific constants, *LT* is the total length in centimeters (cm), and *W* is the weight in grams (g). The length-weight fitting parameters were obtained from FishBase.

<u>Total biomass by species per zone</u>

To calculate the total biomass by species per zone for the RS and CS, the biomass values of each species were summed. These values were then divided by the sampling area to obtain the biomass in (g/m^2). The function is expressed as follows:

$$B(g/m^{2}) = \frac{Total\ biomass\ by\ species\ per\ zone}{area^{2}}$$

In both cases, the standard deviation of the biomass by species per zone was calculated to observe the variability of the biomass among the species present in each zone.

Total biomass by species

To calculate the total biomass by species for the RS and CS, the biomass values of each species were summed. These values were then divided by the total sampling area to obtain the biomass in (g/m²). The function is expressed as follows:

$$B(g/m^2) = \frac{Total\ biomass\ by\ species}{area^2}$$

In both cases, a commercial priority level (1 to 3) was assigned to each species based on the list of commercial species prepared by IMIPAS during the proposal for the establishment of the FRZ. Level 1 species are those considered a priority for conservation based on their commercial, ecological, and cultural value.

Total biomass per zone

To calculate the total biomass by species for the RS and CS, the total biomass values for each species present in each zone were summed. These values were then divided by the sampling area to obtain the biomass in (g/m²). The function is expressed as follows:

$$B(g/m^2) = \frac{Total\ biomass\ per\ zone}{area^2}$$

Statistical analysis of biomass indicator

To evaluate possible significant differences in biomass among the different zones (North, Central, and South), as well as between the refuge sites (RS) and control sites (CS), Shapiro-Wilk normality tests were conducted. These tests were used to verify if the data followed a normal distribution. Once normality of the data was established, parametric tests were applied for the comparison of means in biomass. In cases where the data did not meet the normality assumptions, non-parametric tests were employed.

Subsequently, if significant differences were observed among the main zones, a post hoc Tukey analysis was conducted to identify the specific groups showing significant differences in terms of biomass. This test was applied to gain a more detailed and precise understanding of the differences between the groups, allowing for a comprehensive interpretation of the results obtained.

Regarding the evaluation of possible significant differences in biomass between the zones (North and South) of the institutional monitoring for the control sites (CS), it was not feasible due to the failure to meet the normality requirements of the data distribution. This is because the sample consisted of only 2 observations, which is insufficient to apply the Shapiro-Wilk normality test, as it requires a minimum of 3 observations.

Shannon-Weaver diversity index

Diversity analysis of the different zones (North, Central, and South) in the RS and CS was performed. For this, the Shannon-Weaver diversity index was calculated for each sample. The Shannon index is based on the abundance and diversity of species and was calculated using the following function:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

where *S* is the number of species present in the community and p_i is the proportion of individuals of species *i* with respect to the total in the community.

Statistical analysis of the Shannon-Weaver

To evaluate if there were significant differences in Shannon diversity among the different zones and between the RS and CS, Shapiro-Wilk normality tests were conducted for each zone. If the data followed a normal distribution, parametric tests were performed to compare the means of the Shannon values. If the data did not meet the normality assumptions, non-parametric tests were applied.

Regarding the evaluation of possible significant differences in the Shannon-Weaver index between the zones (North and South) of the institutional monitoring for the control sites (CS), it was not feasible due to the failure to meet the normality requirements of the data distribution. This is because the sample consisted of only 2 observations, which is insufficient to apply the Shapiro-Wilk normality test, as it requires a minimum of 3 observations.

Estimation of the number of invertebrates

In this particular case, the count of invertebrates was included in both monitoring efforts (academic and institutional). Given the short interval of time between the two monitoring efforts, it was assumed that temporality would not affect the recording of invertebrate species observed in the different main zones (North, Central, and South).

Subsequently, the density of invertebrates per hectare (ha) for the different main zones within the refuge was calculated using the following formula:

$$Org/ha = \frac{Number\ of\ invertebrates\ recorded}{area\ (m)^2}$$

This calculation was not performed for the control zones, as this underwater monitoring did not evaluate sampling points in the adjacent area of the Central zone of the FRZ. However, a count of total invertebrate organisms in the CS was possible and is described below.

Finally, a summation of the organism density per hectare recorded in both the RS and CS (excluding the Central zone) was performed to obtain the total number of invertebrates in both the RS and CS.

Benthic substrate type

A frequency distribution of the different types of substrate recorded in each main zone (North, Central, and South) of the FRZ was carried out by registering the substrate type in the various transects.

Results

This section presents the data corresponding to key ecological indicators, including richness, biomass, and diversity, derived from two different types of underwater monitoring: academic monitoring and institutional monitoring. The goal was to collect information since the establishment of the Celestún Fishing Refuge Zone (FRZ) in 2019 and throughout its period of validity. However, due to external circumstances, such as the COVID-19 pandemic, it was not feasible to conduct assessments throughout the entire planned period. Nevertheless, the results obtained during 2023 from both monitoring efforts can be considered as a current characterization of the FRZ, which could be established as a new baseline for future comparisons in upcoming monitoring programs. This is especially relevant in the context of a potential renewal of the FRZ, where increased growth of commercially valuable marine organisms and a rise in ecological diversity over time are anticipated.

Richness (species accumulation curve): academic and institutional monitoring

Regarding the richness index, the analysis of the rarefaction curves derived from two different fish monitoring efforts provided valuable information about the species richness present in both academic and institutional monitoring. Rarefaction curves effectively allow for the comparison of species richness between the two samples, controlling for differences in sampling effort. Below are the results of the rarefaction curves for the two monitoring efforts, both for the refuge zone and the control zone.

With respect to the refuge zone, the first underwater monitoring, conducted by Universidad Marista in alignment with the objectives of this research, showed a sustained upward trend in species richness until approximately 15 individuals were sampled, where it progressively stabilized, indicating that a significant portion of the diversity present in the fish community was sampled (**Figure 7**). In contrast, the monitoring designed by COBI-IMIPAS showed a constant increase in species richness until it reached its plateau around 16 individuals sampled. From this point, the richness remained relatively constant (**Figure 7**).

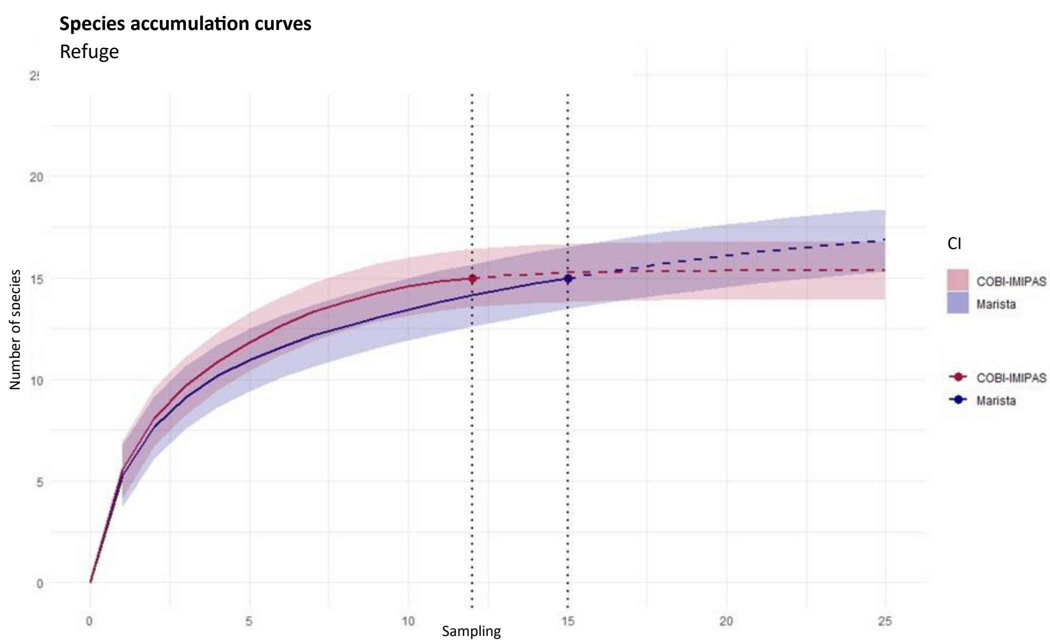

Figure 7. Species accumulation curve for the refuge zone. (Academic monitoring = 15 sampling points; Institutional monitoring = 12 sampling points, Extrapolation to 25 sampling points, CI = 95%).

Overall, both rarefaction curves revealed similar trends in species richness, although the institutional monitoring showed a slight advantage in terms of estimated total species richness. These results suggest that both monitoring efforts capture a significant diversity of fish species in the study region.

Regarding the control zone, the monitoring conducted by Universidad Marista showed a sustained upward trend until approximately 12 individuals were sampled, where it began to stabilize, indicating a significant representation of the diversity of the fish community (**Figure 8**). In contrast, the monitoring designed by COBI-IMIPAS presented a similar pattern, but this curve showed an earlier stabilization, starting at approximately 10 individuals sampled (**Figure 8**).

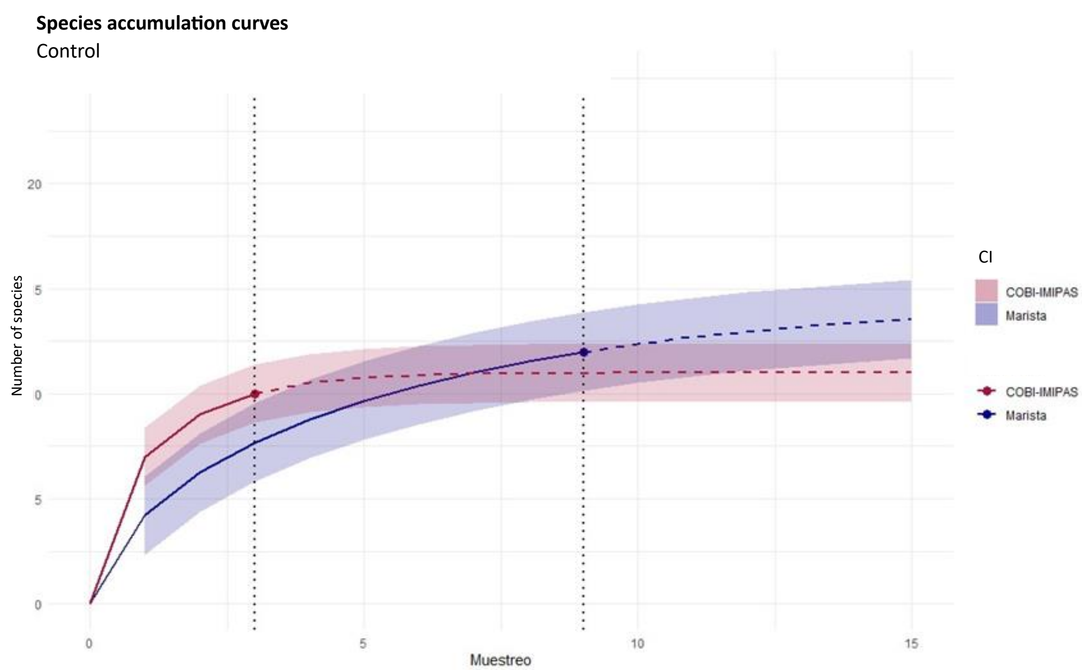

Figure 8. Species accumulation curve for the control zone. (Academic monitoring = 9 sampling points; Institutional monitoring = 3 sampling points, Extrapolation to 15 sampling points, CI = 95%).

In contrast, both curves showed lower estimated species richness values compared to the refuge zone, with 12 species and 10 species respectively for the given sampling effort.

These results suggest that both methodologies capture different representations of fish diversity in the study region. The observed differences may be related to environmental, geographical, or seasonal factors, or to variations in the structure of fish communities between the sampled areas.

Biomass (academic monitoring)

Total biomass by species per zone

The analysis of total biomass by species per zone for the RS showed high variability in terms of biomass among the different zones. Some species exhibited greater presence in certain zones. For example, the coronetfish (*S. dumerii*) and the porgy (*C. calamus*) had greater presence in the Central zone (*Figure 9*). Meanwhile, other species were more evenly distributed among the different zones, such as the yellowtail snapper (*O. chrysurus*) and the hogfish (*L. maximus*) (**Figure 9**).

On the other hand, the species with the highest abundance in terms of biomass concentration among the different zones were the yellowtail snapper (*O. chrysurus*) and the hogfish (*L. maximus*) (**Figure 9**).

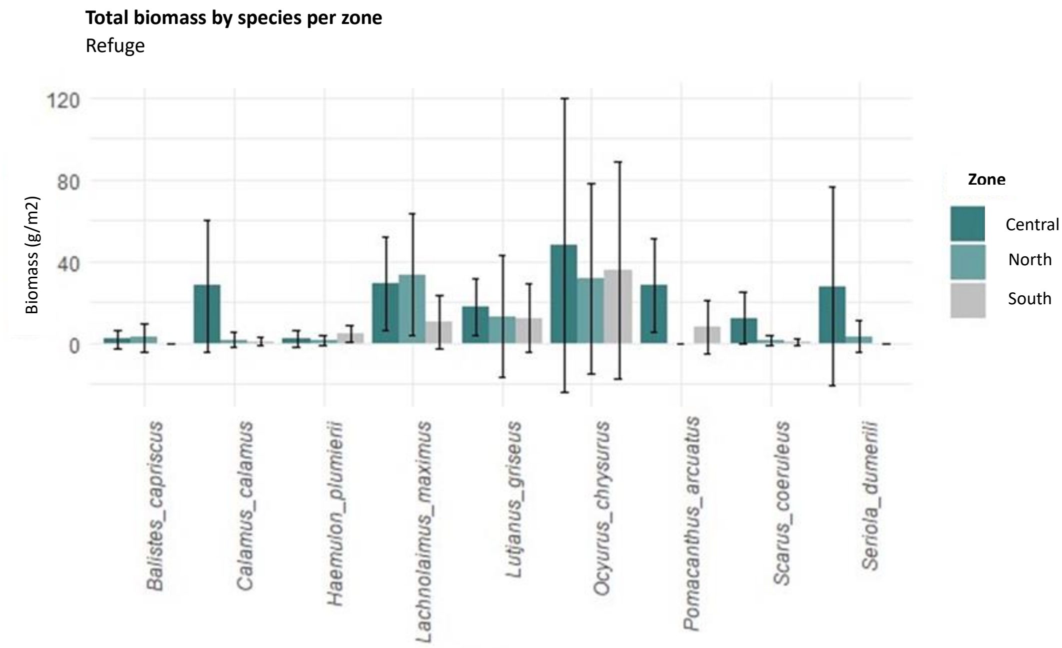

Figure 9. Distribution of total biomass by species per zone within the FRZ in the academic monitoring. (SD ±).

Meanwhile, the biomass distribution for the CS showed a similar pattern to the RS, with high variability among the different zones. Similarly, some species exhibited greater presence in certain zones. For example, the coronetfish (*S. dumerii*) was more prevalent in the Central zone. The species with the highest abundance and concentration in terms of biomass was the hogfish (*L. maximus*) (**Figure 10**).

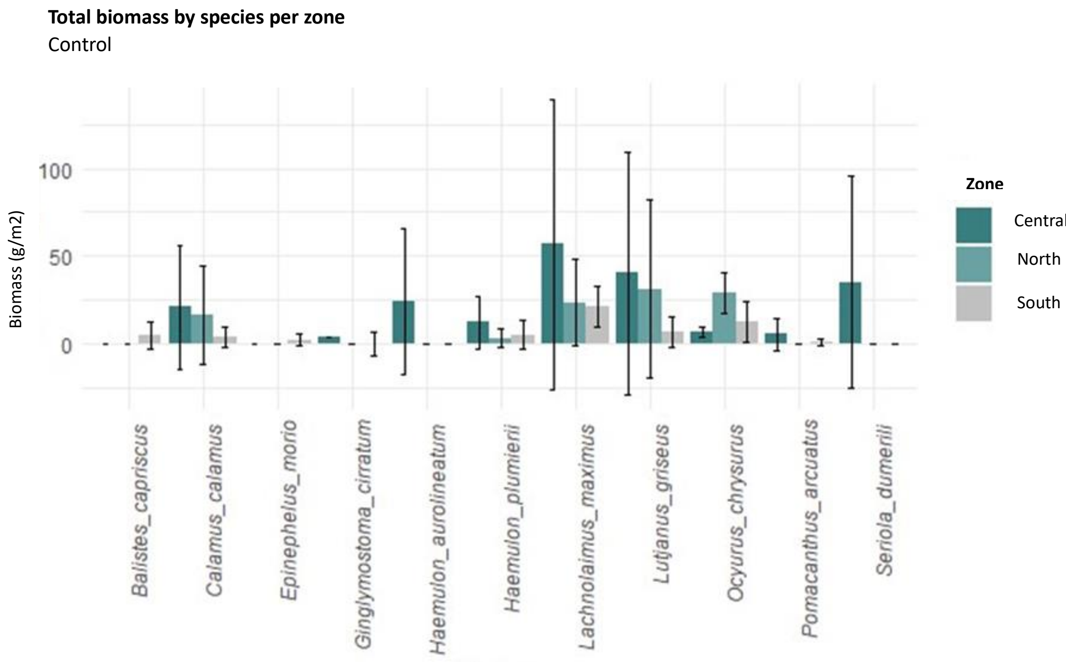

Figure 10. Distribution of total biomass by species per zone in the control zone of the FRZ in the academic monitoring. (SD ±).

Total biomass by species

The analysis of total biomass by species for the RS and CS revealed the distribution of biomass of each species across the different sampled sites. These values result from the summation of the total biomass for each species distributed over the total sampled area. The highest commercial priority species (categorized as level 1) for the RS is the yellowtail snapper (*O. chrysurus*) with approximately 38 g/m² (**Figure 11**). Meanwhile, for the CS, the highest commercial priority species was the hogfish (*L. maximus*) with a biomass concentration of 34 g/m² (**Figure 12**).

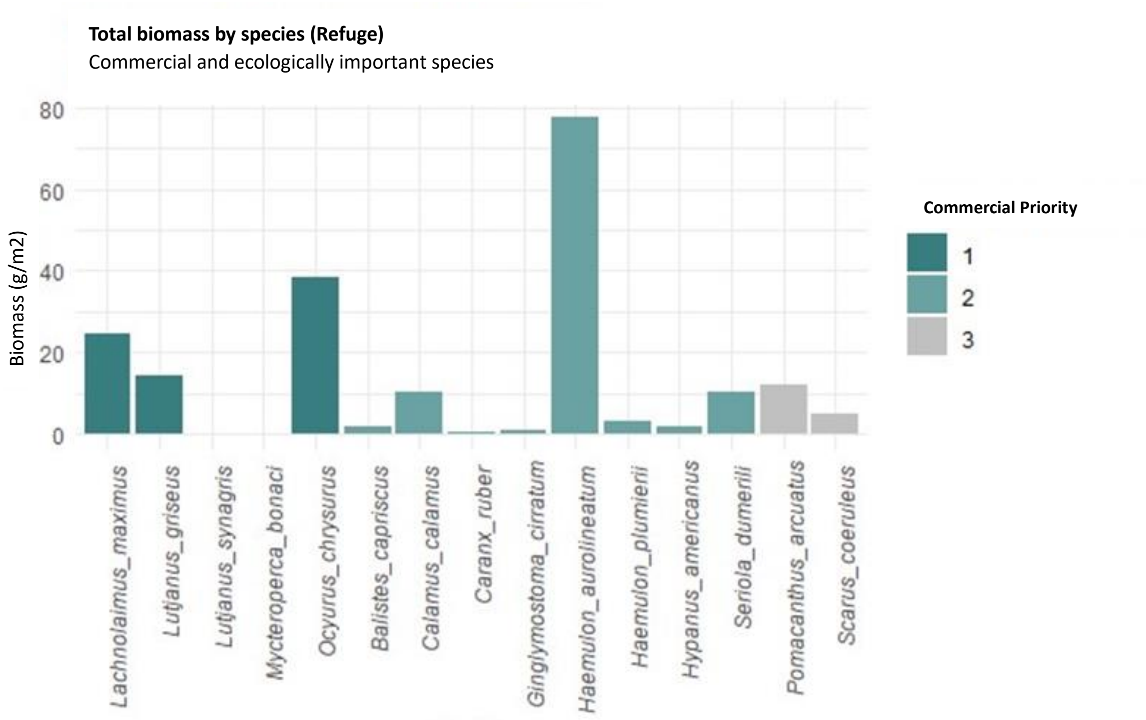

Figure 11. Total biomass by species for the RS under a commercial priority order in the academic monitoring.

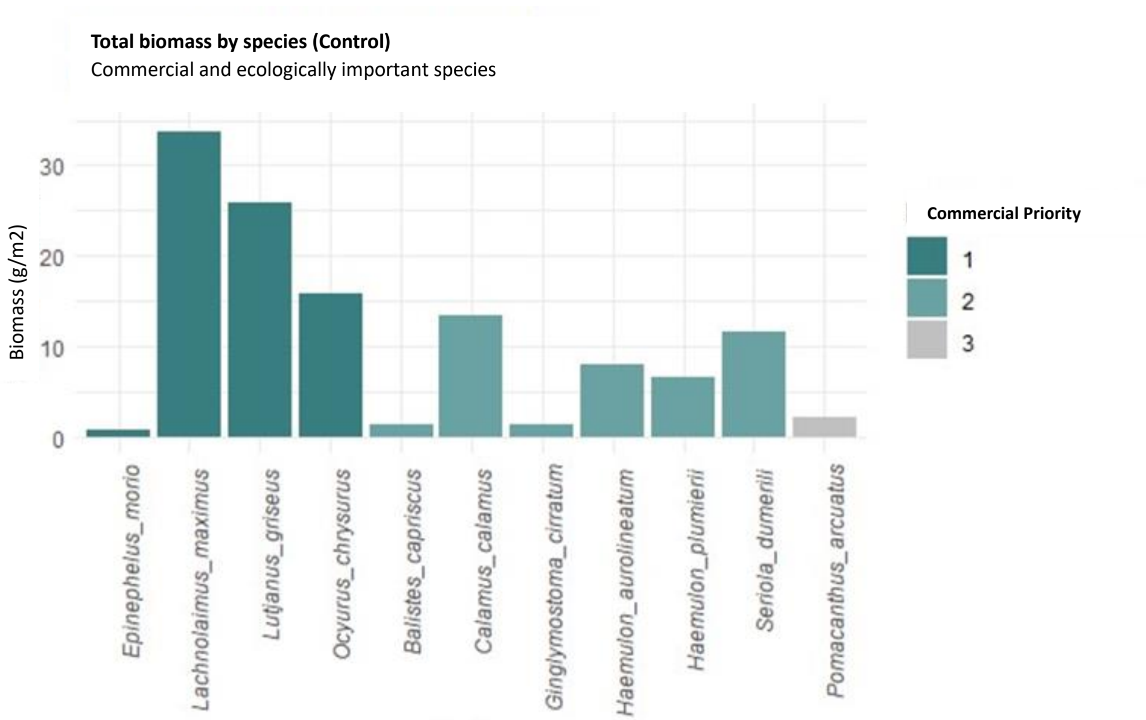

Figure 12. Total biomass by species for the CS under a commercial priority order in the academic monitoring.

Total biomass by zone

The analysis of total biomass by zone for both the RS and CS showed high variability in biomass distribution, with a higher biomass concentration in the Central zone for both RS and CS, with 531 g/m² and 200 g/m² respectively (**Figure 13**; **Figure 14**).

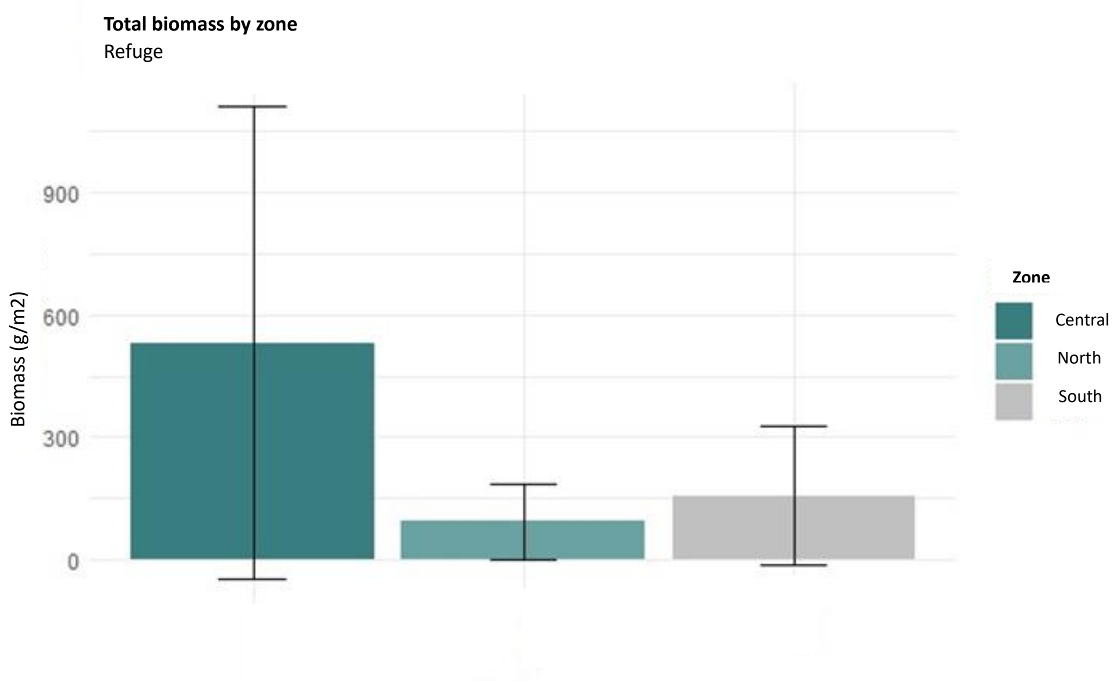

Figure 13. Distribution of total biomass by zone for the RS in the academic monitoring. (SD = ±).

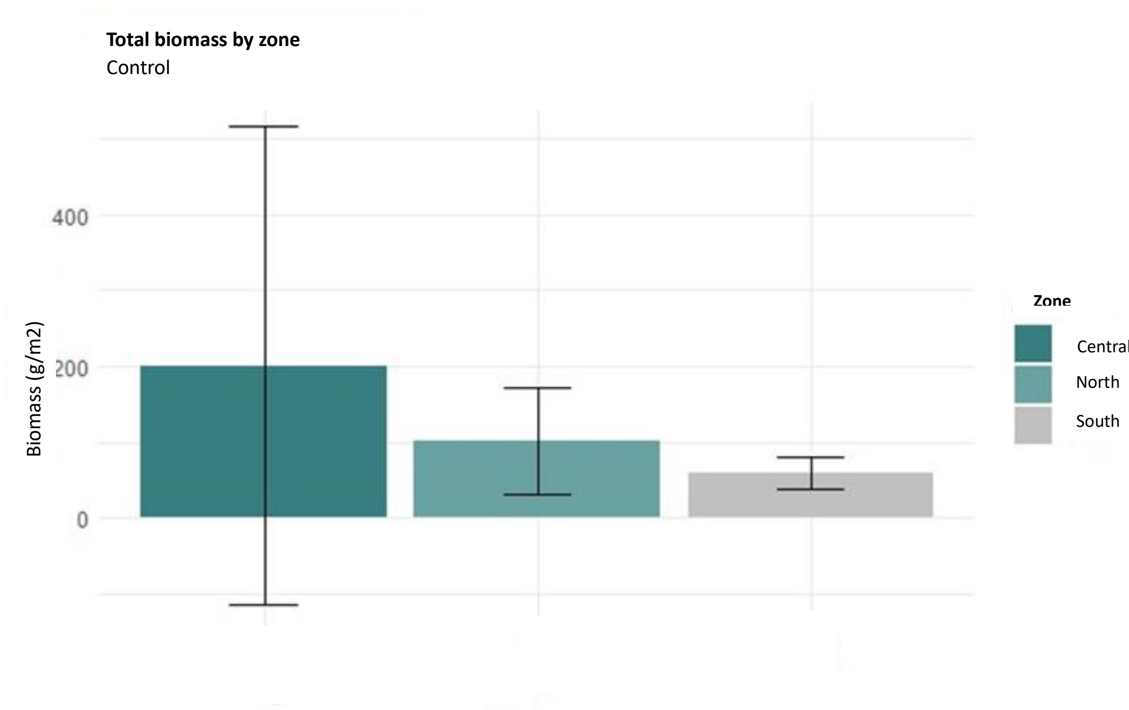

Figura 14. Distribution of total biomass by zone for the CS in the academic monitoring. (SD = ±).

Biomass (institutional monitoring)

Total biomass by species per zone

The analysis of total biomass by species per zone for the RS showed great heterogeneity in terms of biomass among the different zones. Some of the main commercially important species had greater presence in the Central zone. For example, the yellowtail snapper (*O. chrysurus*), the hogfish (*L. maximus*), and the white grunt (*H. plumierii*), with the first two standing out as the species with the highest biomass accumulation among the different zones (**Figure 15**).

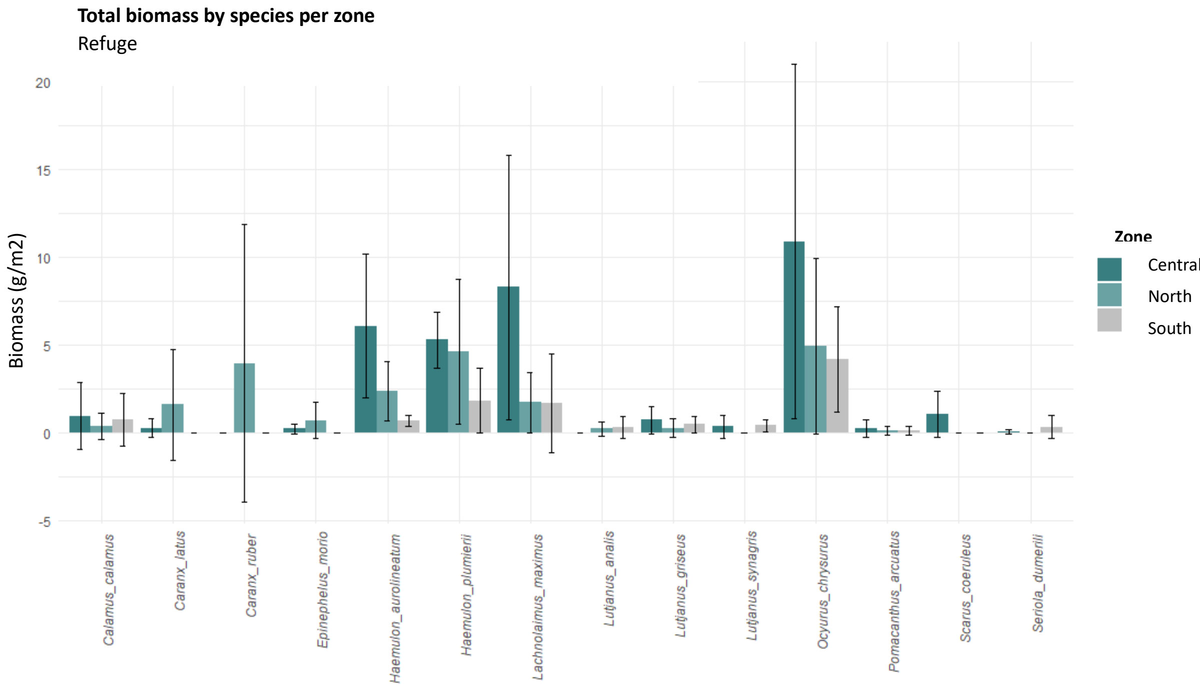

Figure 15. Distribution of total biomass by species per zone within the FRZ in the institutional monitoring. (SD ±).

Meanwhile, the biomass distribution for the CS could only be evaluated in the North and South zones, and a similar pattern to the RS was found, with high variability in biomass for the different species between the two zones. Certain species also showed a greater presence in specific zones. For example, the white grunt (*H. plumierii*) was more prevalent in the South zone, and the gray snapper (*L. griseus*) in the North zone. Additionally, the yellowtail snapper (*O. chrysurus*) stood out as the most abundant and commercially significant species in terms of biomass in both zones (**Figure 16**).

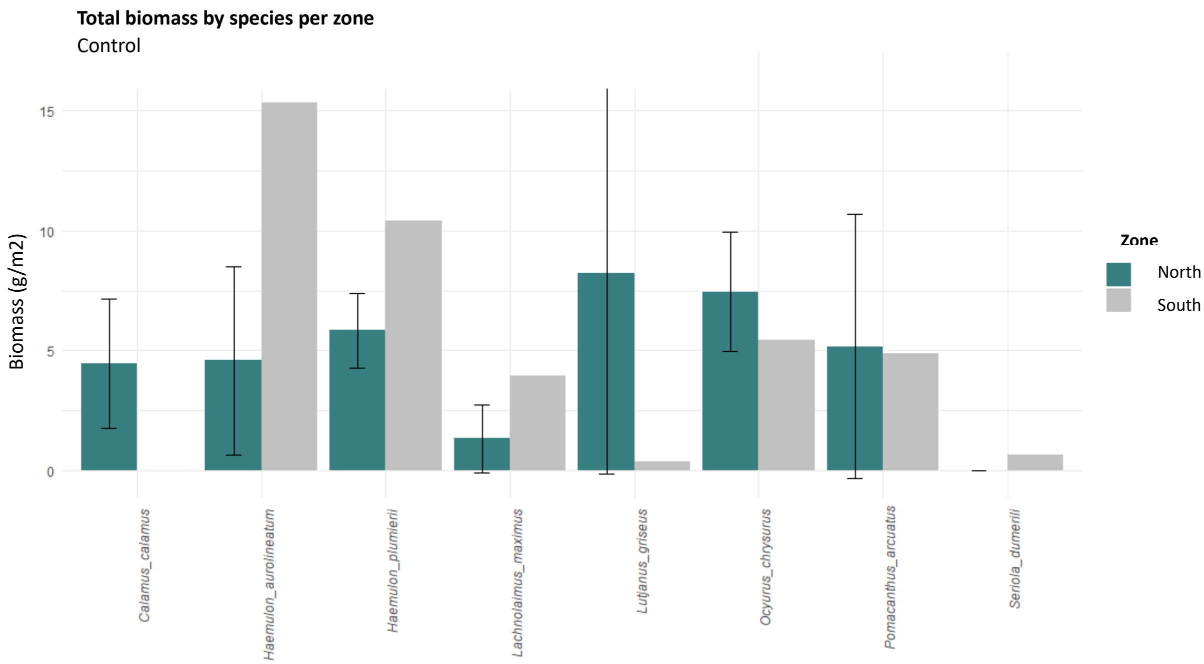

Figure 16. Distribution of total biomass by species per zone in the control zone of the FRZ in the institutional monitoring. (SD ±).

Total biomass by species

The analysis of total biomass by species for the RS and CS revealed the distribution of biomass of each species across the different sampled sites. These values result from the summation of the total biomass for each species distributed over the total sampled area. The highest commercial priority species (categorized as level 1) for the RS is the yellowtail snapper (*O. chrysurus*) with approximately 6.5 g/m² (**Figure 17**). Meanwhile, for the CS, the highest commercial priority species was also the yellowtail snapper (*O. chrysurus*) with a biomass concentration of 6.7 g/m² (**Figure 18**).

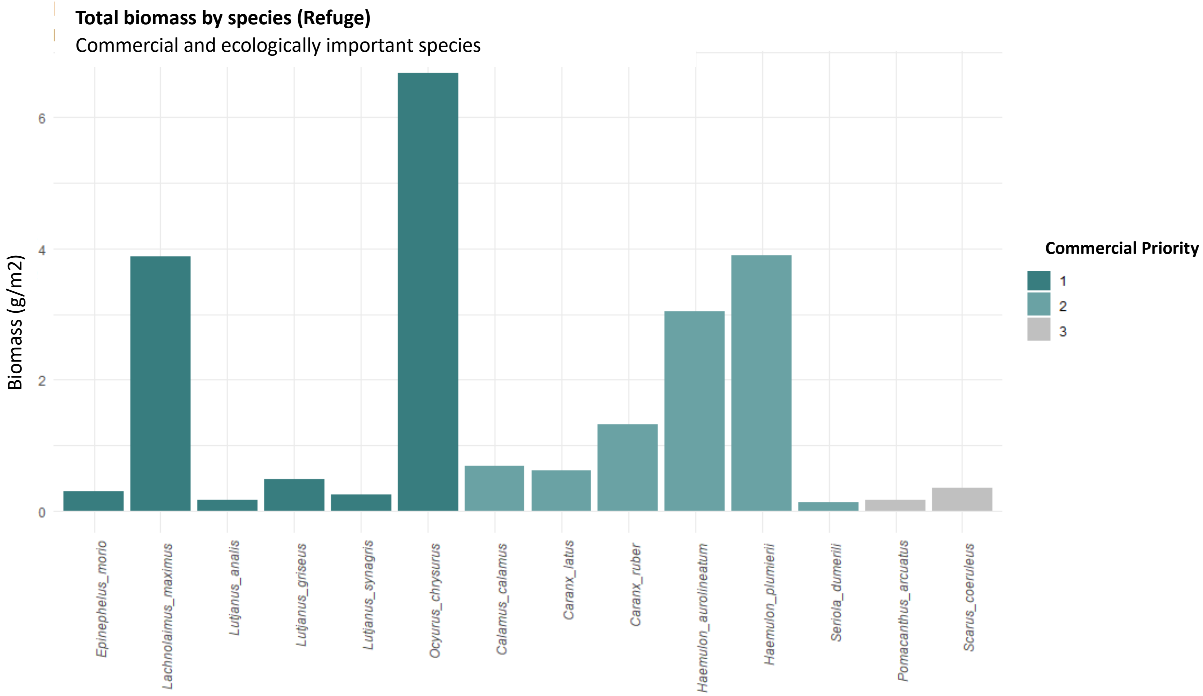

Figure 17. Total biomass by species for the RS under a commercial priority order in the institutional monitoring.

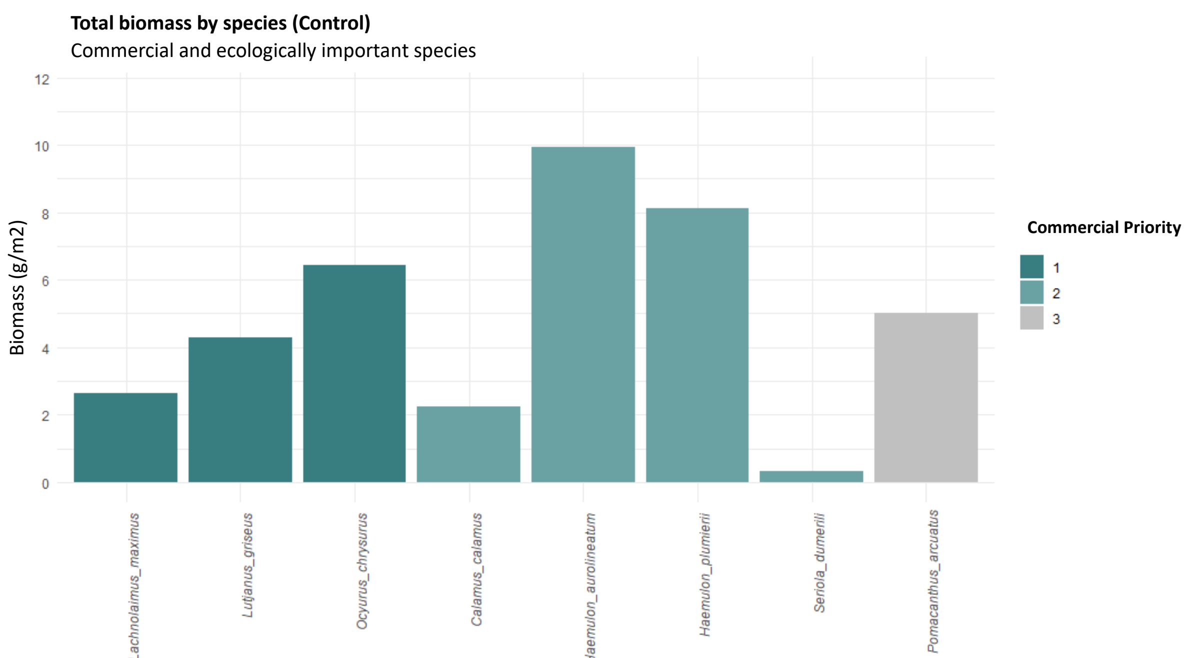

Figure 18. Total biomass by species for the CS under a commercial priority order in the institutional monitoring.

Total biomass by zone

The analysis of total biomass by zone showed a higher concentration in the RS in the Central zone, with 32 g/m² and high variability (**Figure 19**). In contrast, in the CS, the analysis of the North and South zones showed similar values in biomass concentration, ranging between approximately 38 and 42 g/m² (**Figure 20**).

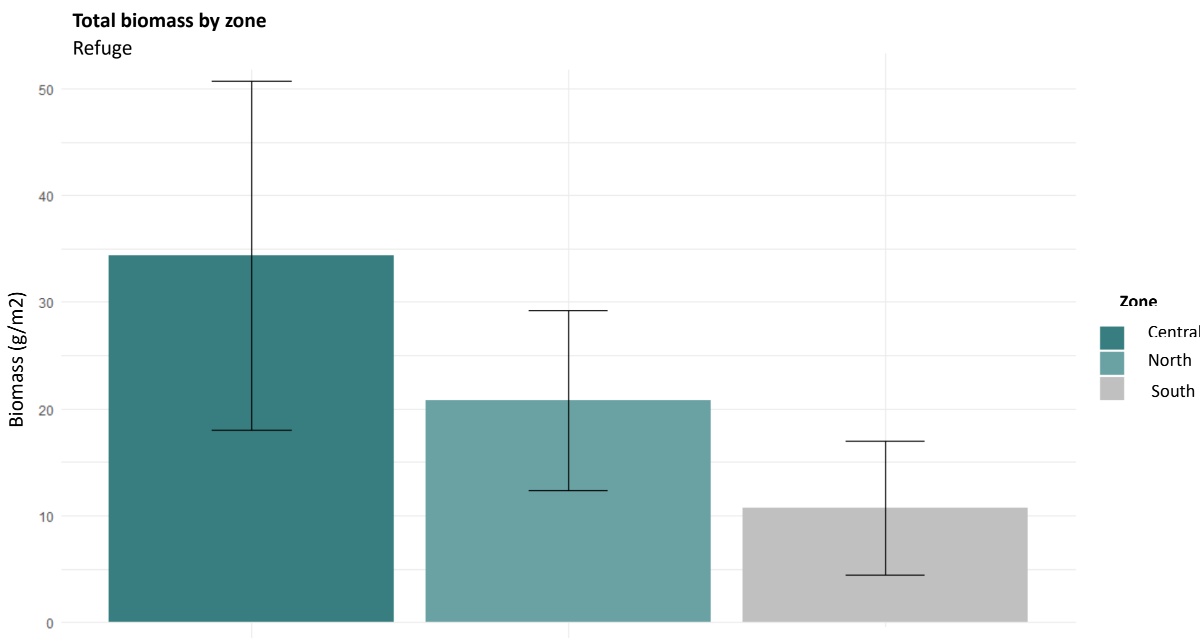

Figure 19. Distribution of total biomass by zone for the RS in the institutional monitoring. (SD = ±).

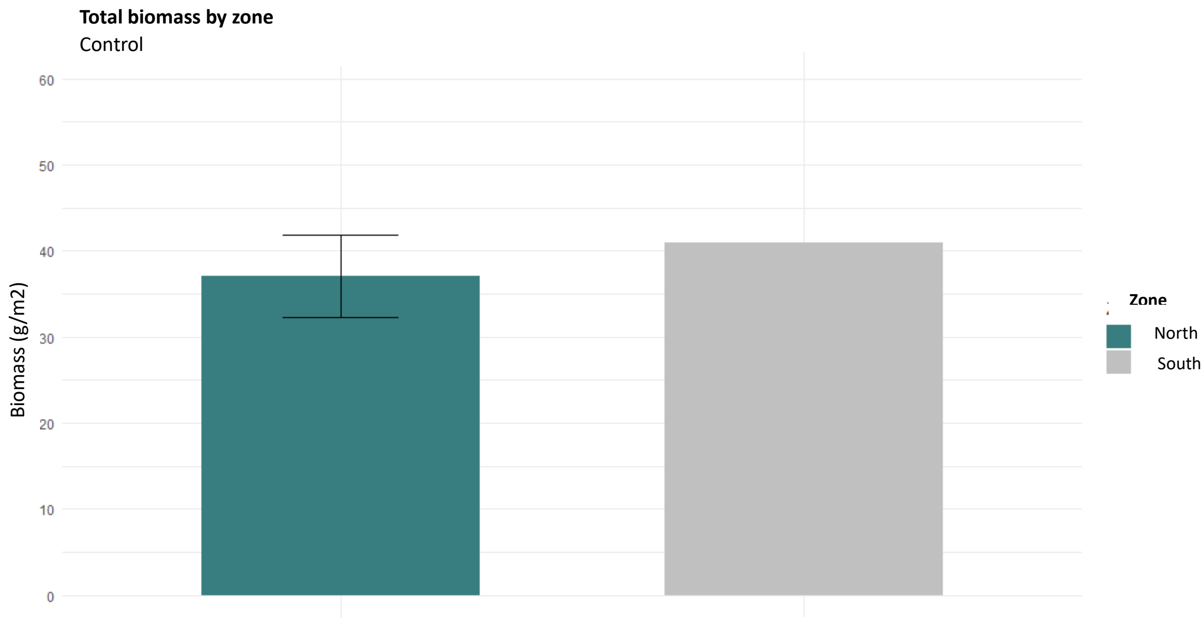

Figure 20. Distribution of total biomass by zone for the CS in the institutional monitoring. (SD = ±).

Shannon-Weaver diversity index (academic monitoring)

Analysis among the different main zones (SR y SC)

The values of the Shannon-Weaver diversity index among the different main zones, both in the RS and CS, revealed a low diversity index (< 2).

The statistical analysis revealed that there were no significant differences in the Shannon-Weaver diversity index among the main zones in the RS (ANOVA, p = 0.65). These results suggest that, although there may be variations in the distribution of the diversity index among the different zones, these differences are not statistically significant (**Figure 21**).

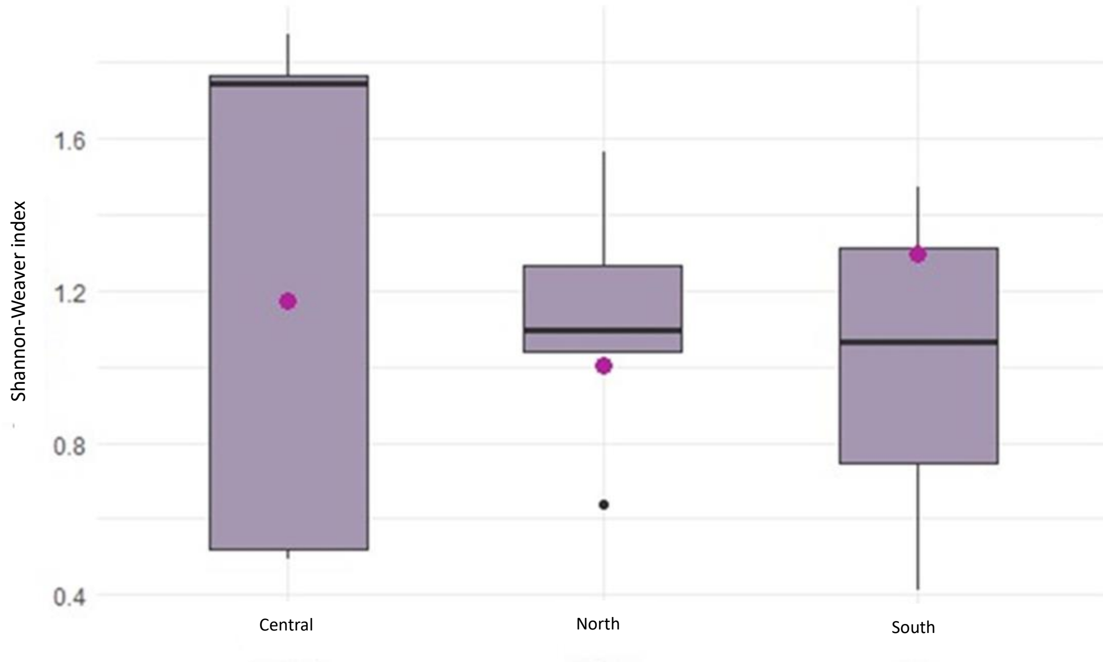

Figure 21. Comparison of the Shannon-Weaver diversity index by zone for the RS in the academic monitoring. (Low diversity < 2; Medium diversity 2 to 3; High diversity > 3).

Similarly, the analysis of the Shannon-Weaver diversity index distribution among the different main zones in the CS revealed that there were no significant differences either (Kruskal-Wallis, $p = 0.65$) (**Figure 22**).

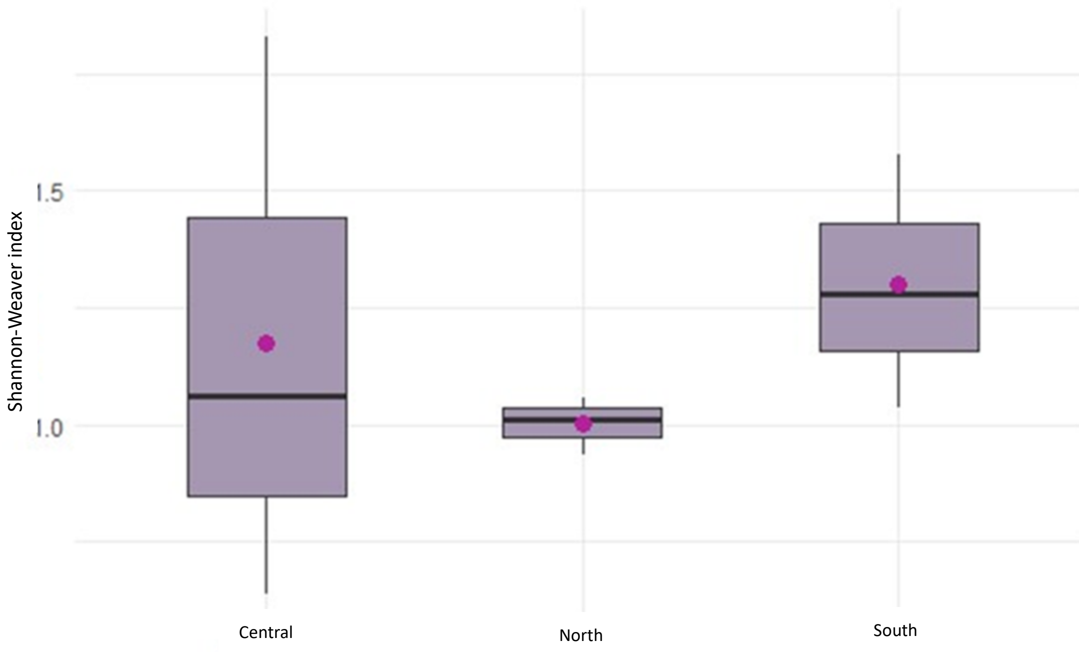

Figure 22. Comparison of the Shannon-Weaver diversity index by zone for the CS in the academic monitoring. (Low diversity < 2; Medium diversity 2 to 3; High diversity > 3).

Analysis of the diversity index between RS and CS

The statistical analysis revealed that there were no significant differences in the Shannon-Weaver index between the RS and CS (ANOVA, $p = 0.89$). These results indicate that, despite the possible variation in the diversity index between the RS and CS, these differences are not statistically significant (**Figure 23**).

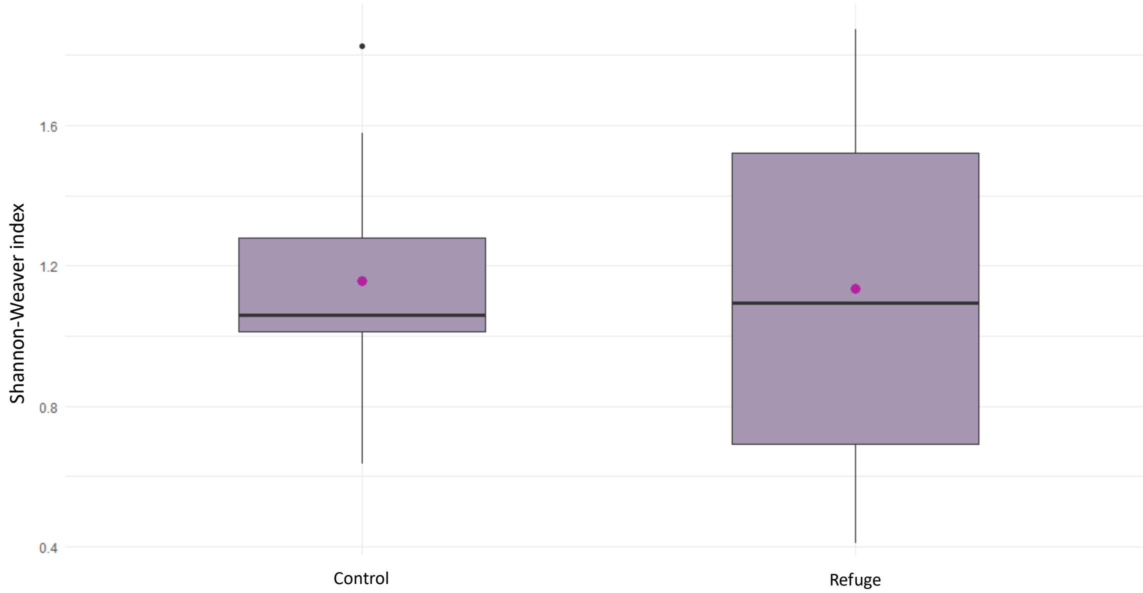

Figure 23. Comparison of the Shannon-Weaver index between the RS and CS in the academic monitoring. (Low diversity < 2; Medium diversity 2 to 3; High diversity > 3).

Shannon-Weaver diversity index (institutional monitoring)

Analysis among the different main zones for RS

The values of the Shannon-Weaver diversity index among the different main zones in both the RS and CS revealed a low diversity index (< 2).

The statistical analysis revealed that there were no significant differences in the Shannon-Weaver diversity index among the main zones in the RS (Kruskal-Wallis, $p = 0.66$). These results suggest that, although there may be variations in the distribution of the diversity index among the different zones, these differences are not statistically significant (**Figure 24**).

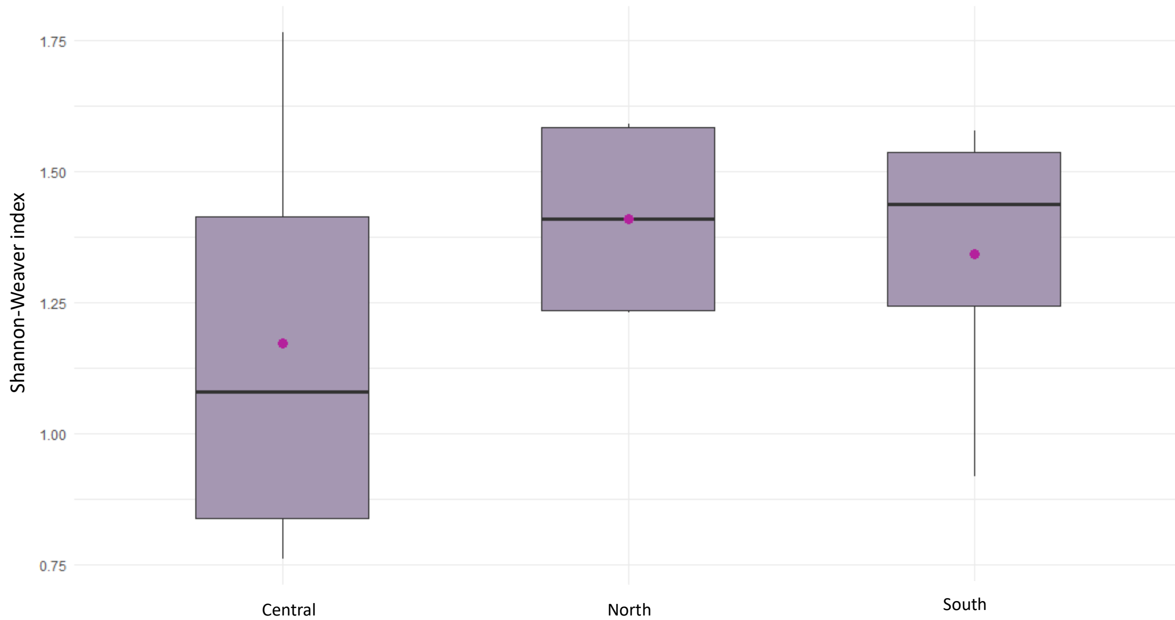

Figure 24. Comparison of the Shannon-Weaver diversity index by zone for the RS in the institutional monitoring. (Low diversity < 2; Medium diversity 2 to 3; High diversity > 3).

The statistical analysis revealed that there were no significant differences in the Shannon-Weaver index between the RS and CS (ANOVA, p = 0.89). These results indicate that, despite the possible variation in the diversity index between the RS and CS, these differences are not statistically significant (**Figure 25**).

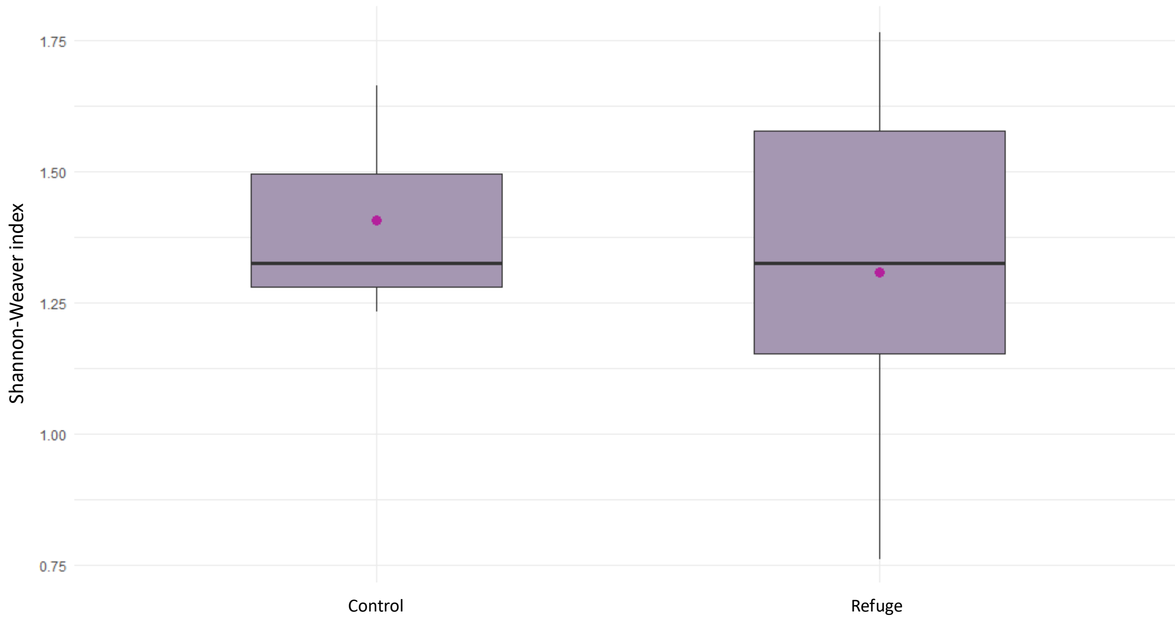

Figure 25. Comparison of the Shannon-Weaver index between the RS and CS in the institutional monitoring. (Low diversity < 2; Medium diversity 2 to 3; High diversity > 3).

Invertebrates

Total record of invertebrates by species

The record of invertebrates (org/ha) by species for the RS and CS revealed the distribution of the number of organisms of each species across the different sampled sites. These values are the result of the total sum of invertebrates for each species distributed over the total sampled area. The highest commercial priority species (categorized as level 1) for the RS and CS was the furry sea cucumber (*A. multifidus*) with approximately 98 and 127 org/ha, respectively (**Figure 26**; **Figure 27**).

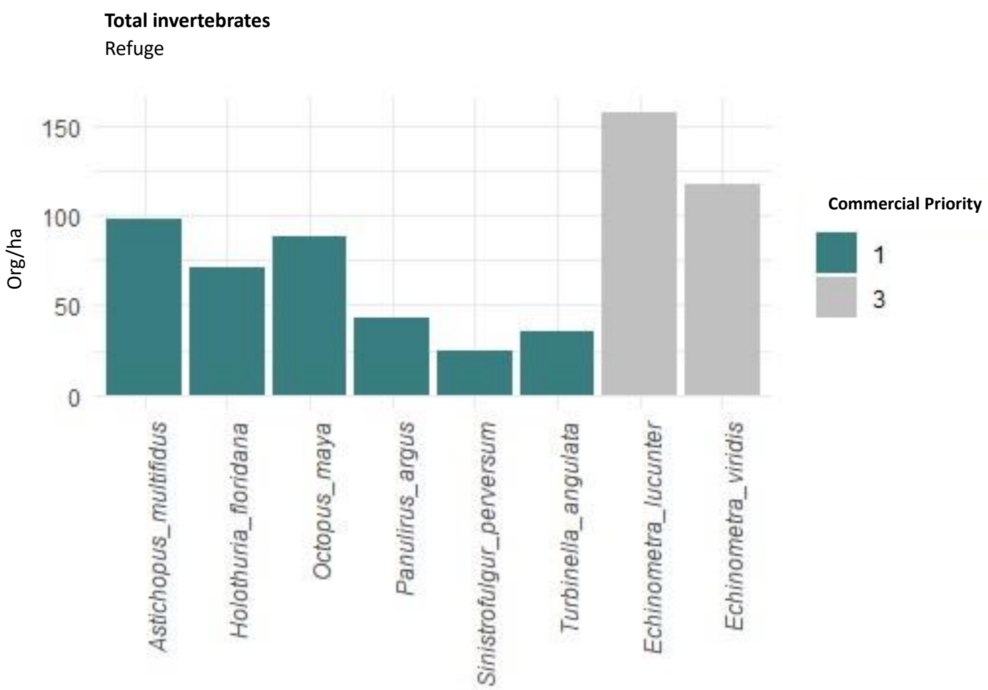

Figure 26. Number of invertebrates per hectare for the RS under a commercial priority order.

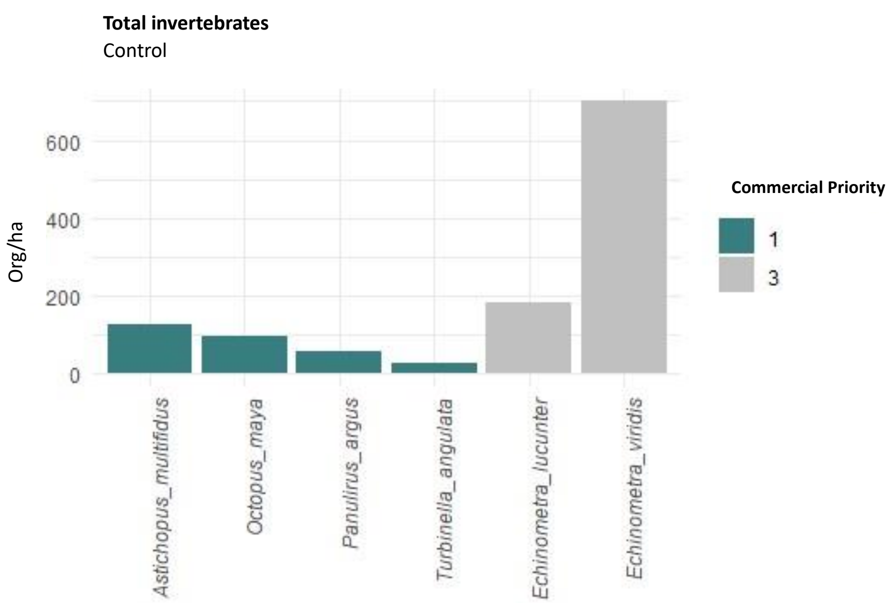

Figure 27. Number of invertebrates per hectare for the CS under a commercial priority order.

Benthic substrate type

The analysis of the distribution of coverage of different types of marine substrate showed a consistent pattern among the different main zones. There was a significant predomínense of sand coverage, followed by green algae coverage in all three study zones (**Figure 28**).

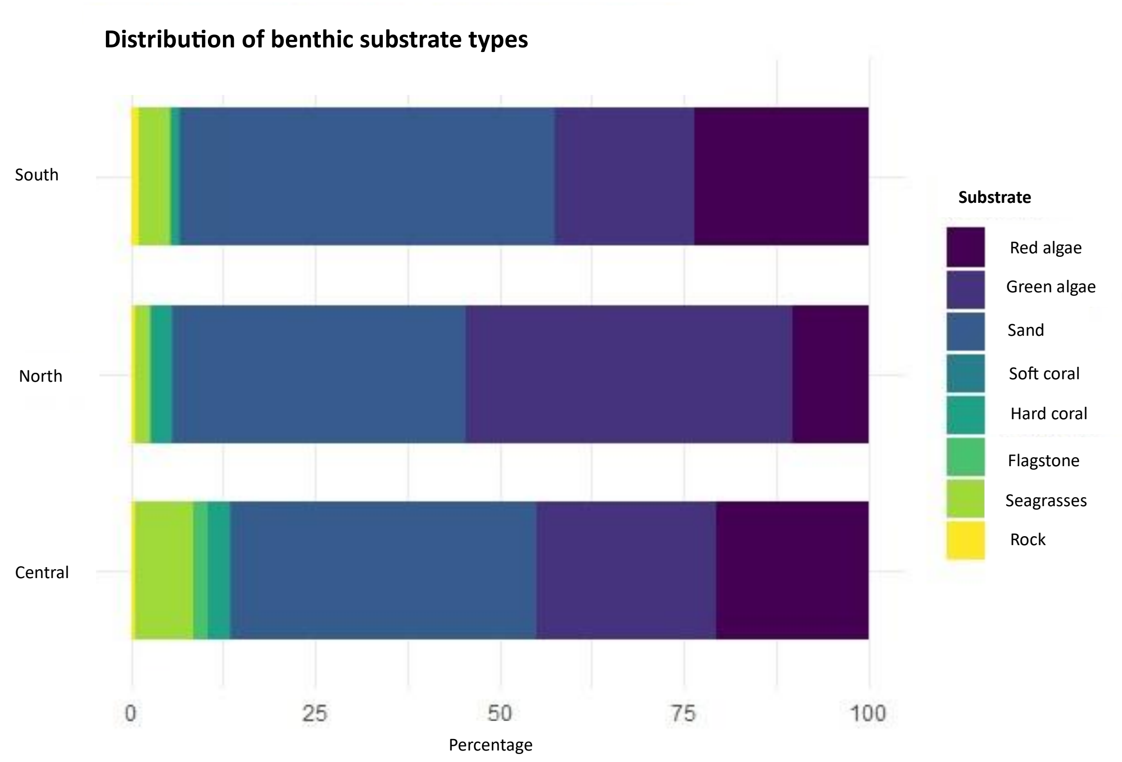

Figure 28. Distribution of benthic substrate types among the different main zones of the FRZ.

Conclusions

- The conclusions drawn from this study highlight the feasibility of two methodological approaches, namely academic monitoring and institutional monitoring, for the continuous assessment of the Celestún Fishing Refuge Zone (FRZ). The use of the species accumulation curve revealed a consistent trend in observing an optimal number of similar organisms in both monitoring methods, directly related to the level of sampling effort applied.
- The comparability of biomass estimates between the two monitoring methods was hindered by disparities in design and approach (targeted versus systematic). Nevertheless, the similarity observed in the values associated with the Shannon-Weaver diversity index in both monitoring efforts is notable. This finding suggests congruence in the assessment of biological diversity despite methodological differences, highlighting the robustness of this index as a reliable measure of biological variability in the study area.
- The analysis indicates that benthic substrate types do not have a determining effect on the distribution of the main commercially important species. Despite the predominance of sandy bottoms in the study area, there is a low presence of biotic structures such as corals or seagrass beds. This suggests that other factors, such as food availability, water temperature, or fishing pressure, may play a more influential role in the distribution and abundance of commercial species in the analyzed marine ecosystem.
- It is anticipated that over a longer temporal scale, there will be significant increases in growth and recruitment parameters, as well as in biological diversity indices within the Fishing Refuge Zone (FRZ). This forecast is based on the understanding of ecological processes and population dynamics that tend to favor the recovery and strengthening of marine ecosystems under appropriate protection and management measures. The extrapolation of these results into the future suggests a promising outlook in terms of the health and sustainability of the marine ecosystem under study.
- The information collected in this study can be interpreted as a baseline, providing a current representation of the ecological characteristics and conditions present in the Celestún Fishing Refuge Zone (FRZ). This dataset serves as a fundamental reference point for future research and assessments, allowing for the monitoring of potential changes in the ecosystem over time and facilitating the implementation of adaptive and effective management strategies for the conservation of this important protected area.

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Appendices

Academic monitoring coordinates

Point	Type	x	y
C-N1	Control	-90.330006	21.230027
C-N2	Control	-90.3152	21.192
C-N3	Control	-90.4448	21.1905
C-C1	Control	-90.540199	21.120799
C-C2	Control	-90.5244	21.1168
C-C3	Control	-90.530699	21.103899
C-S1	Control	-90.597099	21.005299
C-S2	Control	-90.603641	20.927052
C-S3	Control	-90.614011	20.948668
R-N1	Refugio	-90.357001	21.203753
R-N2	Refugio	-90.35025	21.160466
R-N3	Refugio	-90.388122	21.20085
R-N4	Refugio	-90.37953	21.17556
R-N5	Refugio	-90.425351	21.129091
R-C1	Refugio	-90.467616	21.134433
R-C2	Refugio	-90.450457	21.093592
R-C3	Refugio	-90.503536	21.070426
R-C4	Refugio	-90.519766	21.042533
R-C5	Refugio	-90.493755	21.013982
R-S1	Refugio	-90.547683	21.021383
R-S2	Refugio	-90.5627	20.98545
R-S3	Refugio	-90.542649	20.958033
R-S4	Refugio	-90.587	20.951783
R-S5	Refugio	-90.552671	20.923278

Institutional monitoring coordinates

Punto	**Tipo**	**x**	**y**
C-S1	Control	20.998375	-90.584563
C-N2	Control	21.124811	-90.379831
C-N1	Control	21.194116	-90.442206
R-S4	Refugio	20.901046	-90.544233
R-S3	Refugio	20.915672	-90.588934
R-S2	Refugio	20.969944	-90.52002
R-S1	Refugio	20.990116	-90.56296
R-N4	Refugio	21.143248	-90.394123
R-N3	Refugio	21.177028	-90.42593
R-N2	Refugio	21.180642	-90.331432
R-N1	Refugio	21.217394	-90.358205
R-C4	Refugio	21.037186	-90.492065
R-C3	Refugio	21.062241	-90.531802
R-C2	Refugio	21.096601	-90.449925
R-C1	Refugio	21.125908	-90.485517

Photographic evidence

Figure 29. Observation of spiny lobster within the FRZ.

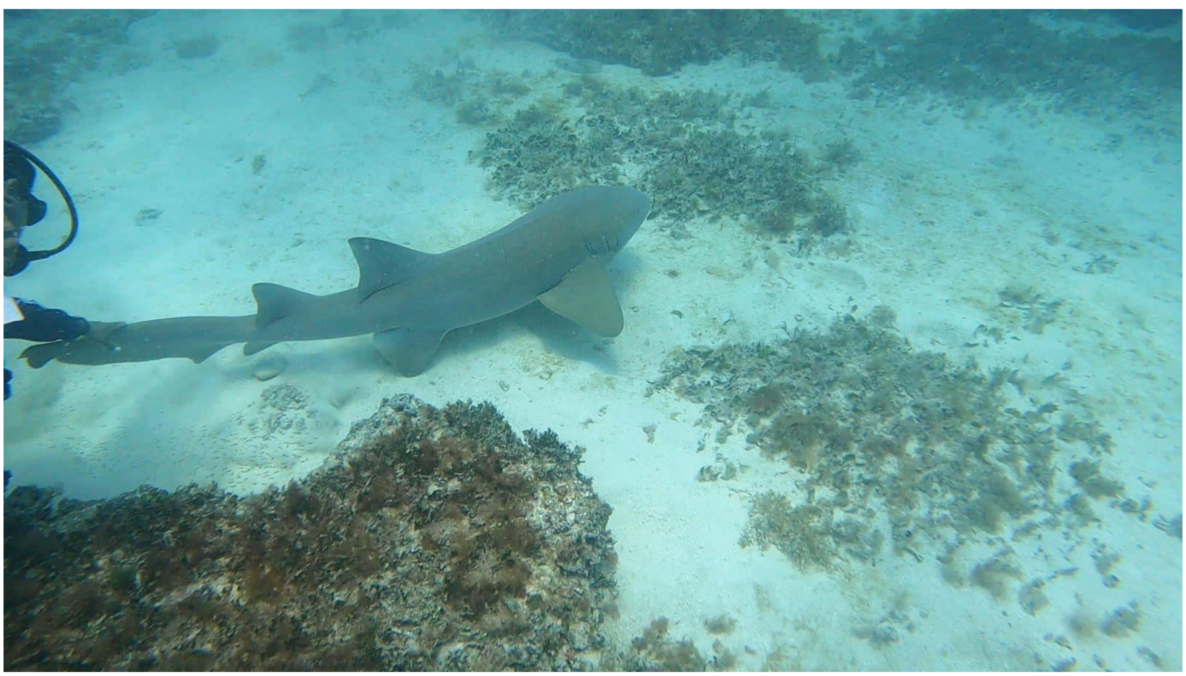

Figure 30. Observation of the nurse shark within the FRZ.

Figure 31. Institutional monitoring group and local fishers from Celestun.

Figure 32. Planning and design of academic monitoring.

Figure 33. Presentation of academic monitoring results to the Celestun FRZ group.

Figure 34. Presentation of academic monitoring results to the Celestun FRZ group.

Figure 35. Observation of gray snapper within the FRZ.

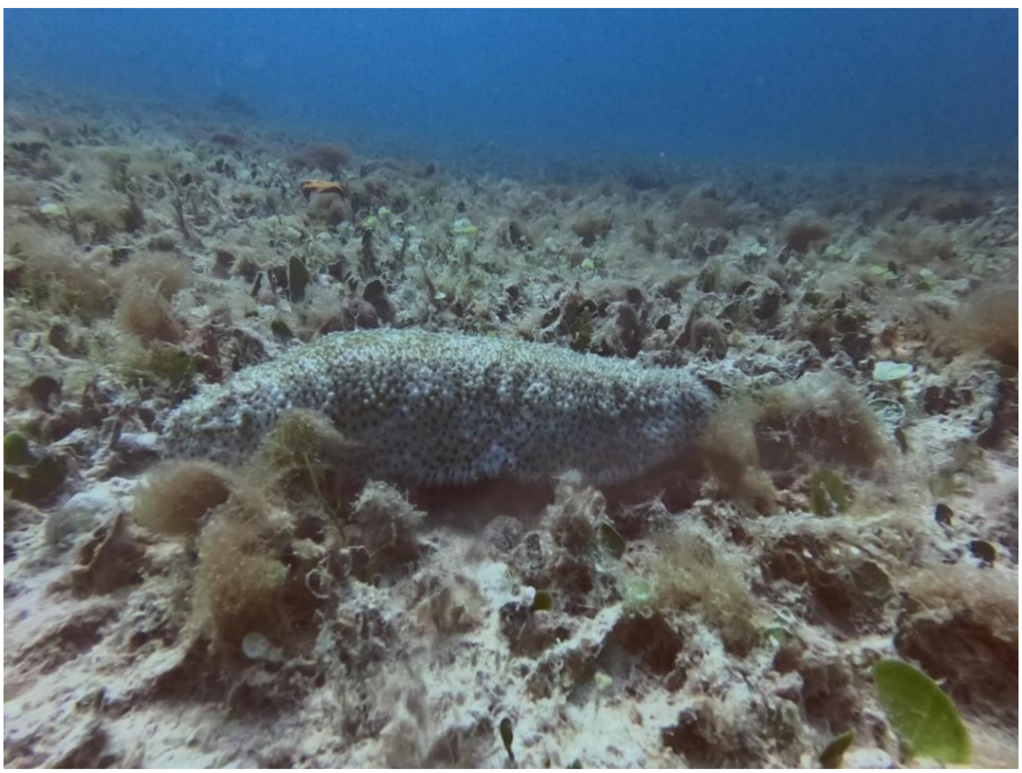

Figure 36. Observation of furry sea cucumber within the FRZ.