ROCKY REEF
MONITORING PROGRAM

2022 CAMPAIGN

GULF OF CALIFORNIA MARINE PROGRAM
of the INSTITUTE OF THE AMERICAS

CBMC
CENTRO PARA LA BIODIVERSIDAD MARINA Y LA CONSERVACIÓN, A.C.

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego

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Design
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This report is a summary of the research activities completed during 2022 related to the rocky reef ecological monitoring program coordinated by the Gulf of California Marine Program. All data generated through this program are available upon request through dataMares or by contacting Catalina López-Sagástegui (clopez@iamericas.org).

EXECUTIVE SUMMARY

The 2022 rocky reef monitoring campaign included 76 reefs in the Gulf of California where a team of scientists completed 598 transects that covered 78,660 m². This year, the team also recorded 16,500 contact points for invertebrates. A total of 156 species were identified (57 invertebrates; 99 fishes), and the team measured and counted a total of 100,234 organisms (19,425 invertebrates; 80,809 fishes).

Aside from calculating biomass, relative biomass and species richness, data shows how the fish communities throughout the monitored reefs have changed over time. Using these indicators should be done while considering environmental conditions since this allows us to better understand what is happening in these communities. For example, Cabo Pulmo continues to host healthy and stable reef communities, while reefs in La Paz are still in need of stronger protection that allows these communities to recover.

In Loreto, the highest species richness and biomass were recorded; however, looking at the relative biomass we see piscivores make up most of the biomass. This leads us to believe that these reefs, while on a possible path to recovery, may still be displaying signs of overexploitation from fishing. This may also be the case of reefs in San Basilio, where fishing is largely unchecked, and initial signs of ecosystem degradation are becoming apparent.

Determining whether an ecosystem, in this case rocky reefs, is in healthy condition requires us to analyze how ecological indicators have behaved over time as well as the environmental conditions the reefs have been subjected to. This will provide the appropriate context and a better baseline on which to base a health status evaluation.

NUMBER OF ROCKY REEFS 598

NUMBER OF TRANSECTS 76

- Invertebrates 313
- Fish 285
- Contact points (invertebrates) 16,500

NUMBER OF SPECIES IDENTIFIED 156

- Invertebrates 57
- Fish 99

NUMBER OF ORGANISMS COUNTED AND MEASURED 100,234

- Invertebrates 19,425
- Fish 80,809

TOTAL AREA COVERED BY DIVERS:

78,660 M²

(11 SOCCER FIELDS)

TOTAL TIME SPENT UNDERWATER:

160 HOURS

(YOU COULD WATCH THE LORD OF THE RINGS TRILOGY 13 TIMES!)

INTRODUCTION

The rocky reef monitoring program has been one of the main research activities of the Gulf of California Marine Program (GCMP) since 1998. This long-standing collaboration between Scripps Institution of Oceanography (SIO) at the University of California San Diego and Centro para la Biodiversidad Marina y la Conservación A.C. (CBMC) in La Paz, B.C.S., has not only allowed for scientists to track and evaluate the health of rocky reefs in the Gulf of California (GoC), but also provides training and capacity building opportunities for young and early-career scientists. Additionally, over these past 24 years, the countless collaborations with scientists and students from research institutions in Mexico and the United States have resulted in one of the longest time series of ecological data available.

Collected data was analyzed to determine density, richness, biomass and trophic level of fish and macroinvertebrate communities in the surveyed rocky reefs. The resulting database enables scientists to identify ecological patterns in the GoC and quantify changes due to natural and anthropogenic drivers. For example, after 2014's Hurricane Odile, which severely impacted the southern GoC region, we were able to utilize data collected to determine the impact and estimate recovery of the marine ecosystems and their associated biodiversity. The information generated annually also allows GCMP's collaborators to contribute to environmental assessments and, as was the case of Isla Guadalupe, Islas Marías, Revillagigedo, Arrecife Alacranes and Banco Chinchorro, data is shared with CONANP to update marine protected areas' management plans.

Under the leadership of the CBMC, a team of five researchers and four students traveled to five regions in the Southern Gulf of California between September and October of 2022 to dive and record data on fish and invertebrate communities in coastal rocky reefs (Figure 1). The team included scientists from Scripps Institution of Oceanography and the Institute of the Americas, and participating students are currently enrolled at the Universidad Autónoma de Baja California Sur. While the research team continues to analyze data, this report includes initial results and information relevant to our local partners, including CONANP.

ROCKY REEF MONITORING REGIONS AND SITES

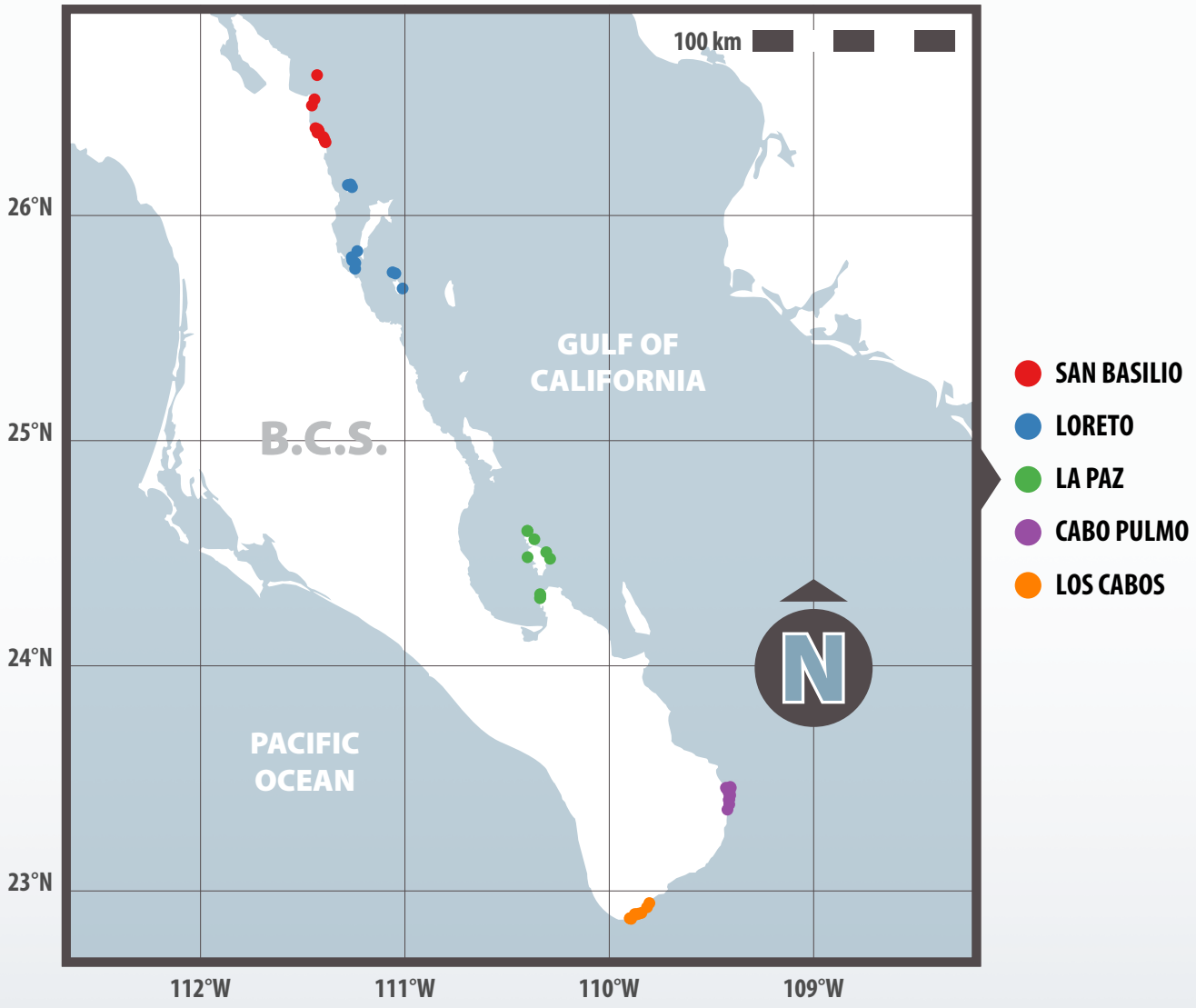

Figure 1. Rocky reefs monitored during the 2022 monitoring season. Reefs are grouped by region based on general ecological characteristics of the marine environment.

ARE ROCKY REEFS HEALTHY OR ARE WE MISSING INFORMATION?

Collecting ecological data enables us to calculate species abundance, richness, density, biomass and relative biomass, which are all critical metrics in determining and tracing reef health throughout time. Richness, a measure of diversity, shows how many different species are present in each surveyed site (Figure 2). The biomass indicator is the total mass of living organisms obtained by combining two variables: the number of individuals present and the size of these individuals, while relative biomass is the comparison of biomass among species or trophic groups[1].

High biomass, richness, and relative biomass (among appropriate groups) reflect a healthy ecosystem. In general terms, the higher these indicators are for piscivorous and carnivorous fish, the healthier we can consider a rocky reef community. If these metrics increase throughout time, we can conclude that ecosystems are thriving, growing, or recovering from any negative impacts. However, if these indicators show a decreasing trend over time, we can assume that the ecosystems are deteriorating or have been altered in some way.

Data from the 2022 monitoring campaign shows that, collectively, reefs in the region of Los Cabos have the lowest fish biomass, followed by rocky reefs in La Paz. The reefs in Loreto reached the highest fish biomass values, with Cabo Pulmo ranking in third place (Figure 3).

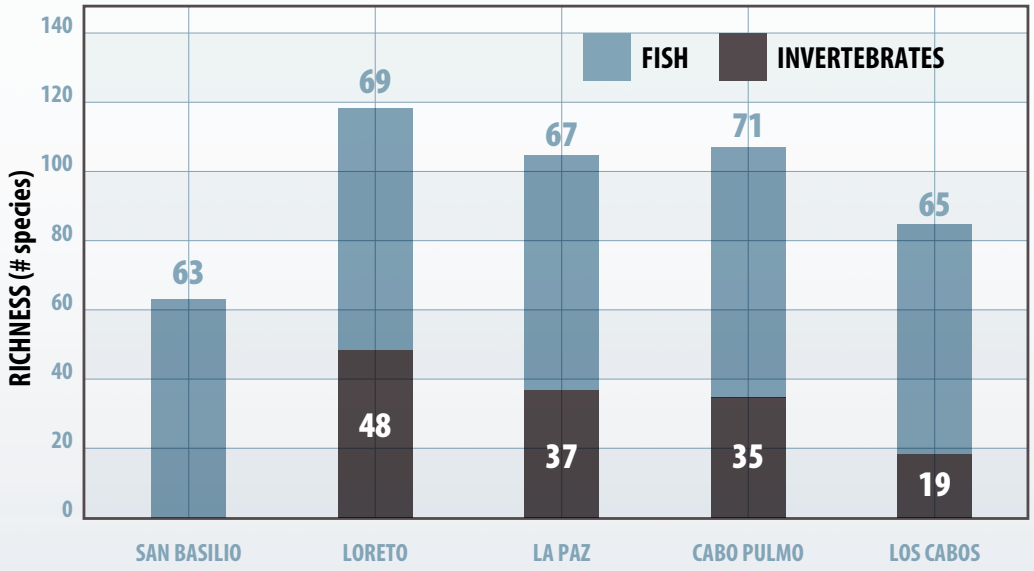

Figure 2. Number of invertebrate and fish species recorded during the 2022 monitoring campaign on rocky reefs in the Gulf of California.

[1] A trophic group is a set of species, that occupy the same position in a food web. Such grouping is based on their diet: piscivorous are apex predator fishes that eat other fishes; carnivorous are fishes that eat other animals but are also prey; herbivorous are fishes that eat prevalently algae; and zooplanctivorous are fishes that feed on plankton in the water column.

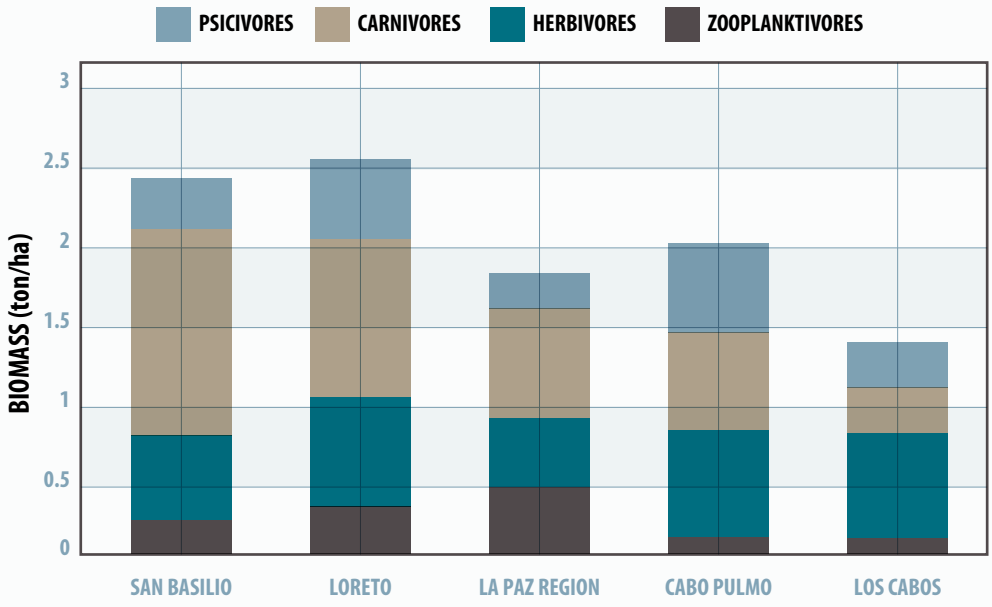

Figure 3. Fish biomass estimates for each trophic group in the regions monitored during the 2022 rocky reef monitoring campaign.

However, looking at overall biomass by itself is not a good indicator to assess the health status of a rocky reef fish community. Properly interpreting the meaning behind the biomass values for the different trophic groups is critical. If we look at which group contributes more to San Basilio's or Loreto's high biomass, it is the carnivore fishes which are not necessarily an indicator of a healthy reef (Aburto et al., 2015). As fishing pressure acts disproportionally on the larger fishes (i.e. Piscivores), a high abundance of carnivores on the reef can be a result of the removal of larger predators that keep the populations of carnivores in check. Conversely, a high proportion of fish biomass of higher trophic groups (Piscivores) can be a sign of low fishing pressure.

Having a large proportion of top predators is a requirement for a reef to be considered "healthy" (Aburto et al., 2015; Graham et al., 2017). For example, Cabo Pulmo's reefs do not have the highest overall biomass levels (Figure 3), but the proportions of the trophic groups making up that biomass (Figure 4) tell a different story. Top predators (piscivorous) are present in more than 20% of Cabo Pulmo's reefs. The reefs in the region of La Paz have, for the most part, very few top predators (Figure 4), which is an indication of continuous fishing pressure on the reef or nearby areas.

In Los Cabos, despite the reefs having no protection (no fully protected areas there), some of them are influenced by an oceanic environment since they are located between different ecoregions made up by the cold California current influence, the warm tropical waters from the south, and the subtropical waters from the Gulf of California. This explains why the biomass at those reefs sometimes shows larger proportion of piscivores which visit these coastal ecosystems from pelagic environments lured by the high productivity of the area.

The large proportion of herbivores in Los Cabos also shows that rocky reefs in this region resemble tropical reefs (like coral reefs) which can be characterized by a higher diversity of herbivores (Graham et al., 2017) that have evolved to graze on several algae species. This differs from the subtropical and semi-temperate reefs found in the inner regions of the Gulf of California where herbivores usually graze on turf algae (Vergés et al., 2014, 2016; Bennett et al., 2015; Favoretto et al., 2022).

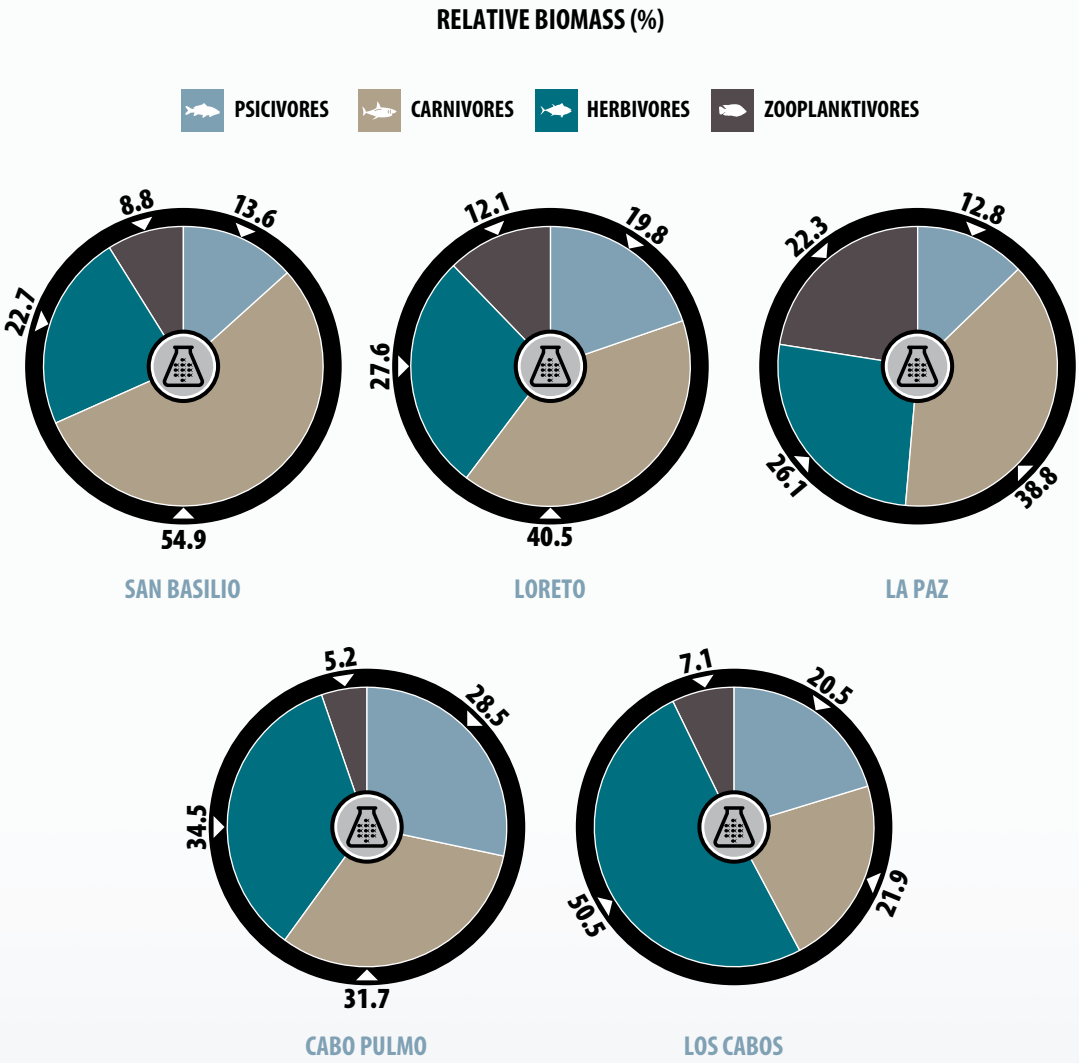

Figure 4. Relative biomass of fish species estimated for each trophic group in each region monitored during the 2022 monitoring season.

The changes in biomass composition over time provides a broad perspective of how a rocky reef community is changing (Figure 5). Cabo Pulmo is the only region showing an overall biomass consistently higher than 2 ton/ha with a large proportion of piscivores after the implementation of the marine reserve in 2007. Two years of low biomass in 2011 and 2013 can be attributed to natural variability, further underlining the importance of contextualizing the trends over time. Rocky reefs in Loreto show stable biomass values, but most of this biomass is made up of carnivorous fishes which, as mentioned here and known in the literature, does not reflect a healthy community status. La Paz is showing a decreasing trend in overall biomass, mostly because of the decrease in piscivore biomass thus suggesting that fishing pressure on the reefs and the surrounding areas is still too high, hindering the reef community's recovery.

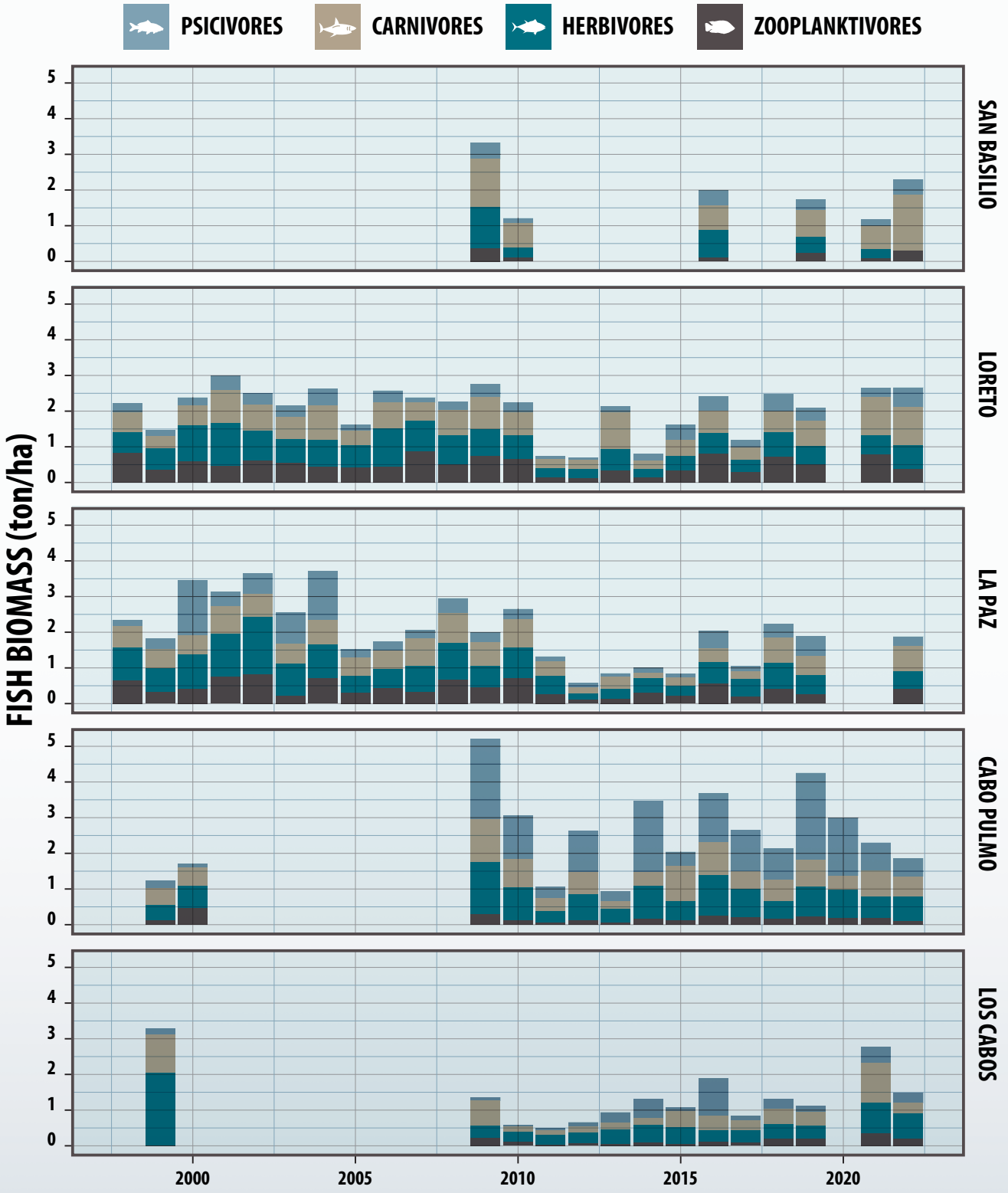

Figure 5. Overall fish biomass recorded over the years in each region divided by trophic groups.

The rocky reefs in the GoC have been under fishing pressure for decades (Sala et al., 2004; Rife et al., 2013b, 2013a; Aburto-Oropeza et al., 2015; Ulate et al., 2018; Giron-Nava et al., 2019), and despite the implementation of Marine Protected Areas (MPAs) only Cabo Pulmo National Park has shown a large recovery of fish biomass (Aburto-Oropeza et al., 2011) as a result of the complete ban of fishing within the boundaries of this MPA. The interpretation of ecological data must be contextualized over time, but also within the current knowledge of the systems. For example, if herbivores fish biomass is increasing, as seen in reefs in La Paz, but biomass in other trophic groups is not increasing proportionately, it is an indication of the system's disequilibrium and should not be seen as a positive conservation outcome.

A healthy fish community has a higher ratio of large predatory fishes (also known as top predators, like sharks or groupers) (Aburto-Oropeza et al., 2015; Graham et al., 2017). Therefore, this is the best indicator to consider when trying to determine if a reef community is on the path to recovery or if it can be considered a healthy one. Knowledge of how a rocky reef community functions was only possible thanks to the spatial and temporal coverage of our monitoring program. Having this large database has shaped and improved our understanding of what healthy rocky reef communities look like, as well as the baselines and other ecological systems we should compare them to (Aburto-Oropeza et al., 2015; Ulate et al., 2018).

HOW IS CLIMATE CHANGE IMPACTING ROCKY REEFS IN THE SOUTHERN GULF OF CALIFORNIA?

Warmer than average conditions in the Gulf of California continue to manifest on the rocky reefs since recently reported (Favoretto et al., 2022) and show no sign of returning to historical minimum (Figure 6A). Southern latitudes are usually ~1 °C warmer than the northern ones, but during the last El Niño, warming and heatwaves homogenized this difference and increased average temperature by more than 1°C. The current warming phase is the longest recorded since 1982 and includes intense marine heatwaves within this warming period. For example, the 2021-2022 period of warming anomaly is as strong and long as the El Niño from 1997, one of the strongest ever recorded (Figure 6A). However, it seems that extreme events were less common in 2022 since only 2 heatwaves were detected (Figure 6B).

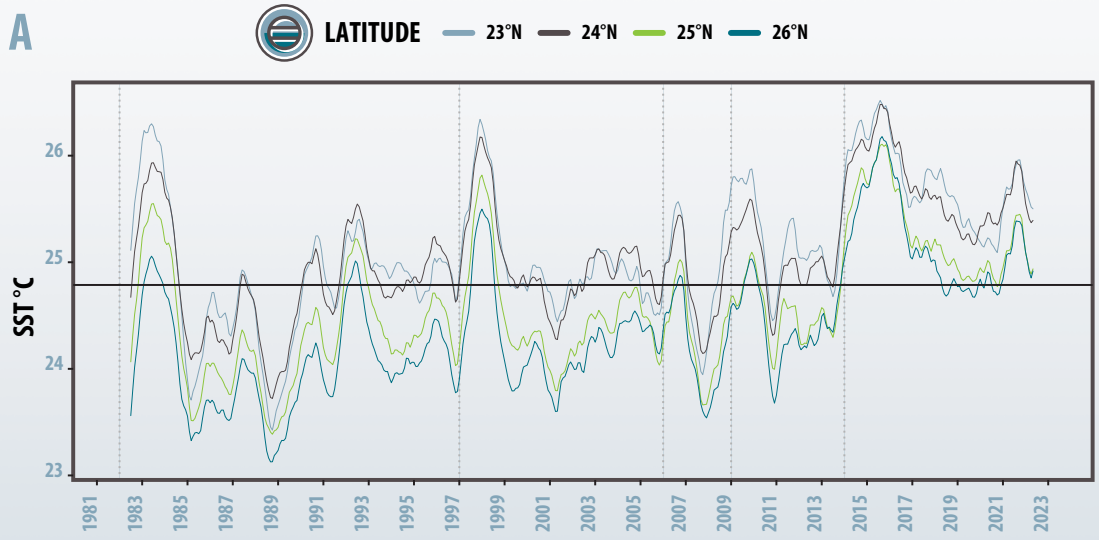

Figure 6. (A) Sea Surface Temperature (SST°C) trend at different latitudinal degrees; the horizontal line represents the historical average.

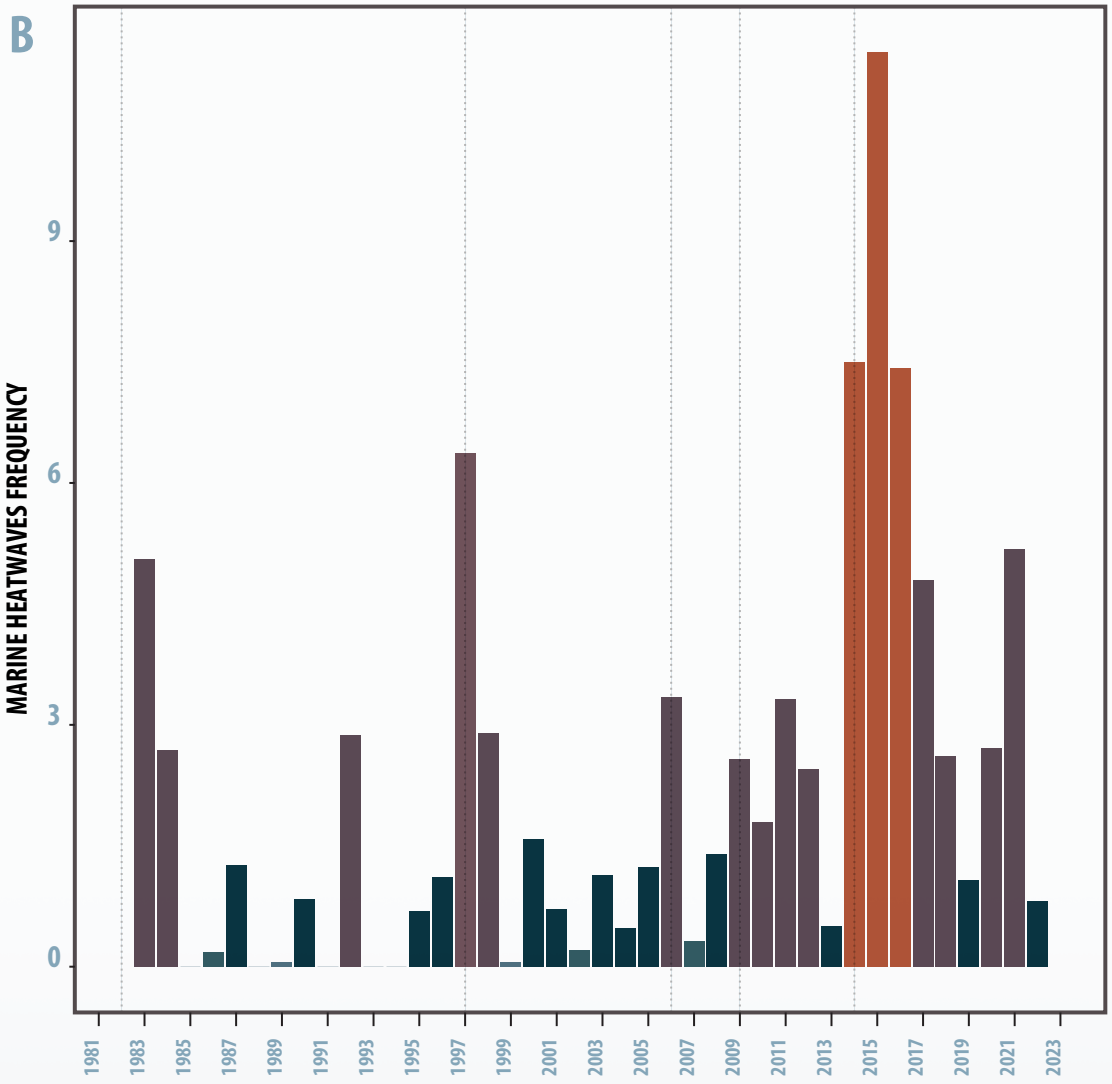

Figure 6. (B) Annual marine heatwave frequency (see methods for details on how heatwaves are calculated). Vertical dashed lines indicate El Niño events on both graphs.

These warming trends have a tropicalization effect on the rocky reefs and the communities that inhabit them. This means that species with temperate affinities are decreasing, while species with tropical affinities, or higher resistance to warming conditions, increase. The latter is the case of stony corals (Hexacorallia), which are limited by the cold temperatures and the Gulf of California is one of the northernmost points of their worldwide distribution (Paz-García et al 2012; Favoretto et al, 2022). Data shows that stony corals are increasing in La Paz and Loreto (Figure 7); both regions belonging to a transitional area between subtropical climatic conditions and more temperate conditions (Favoretto et al., 2022). At the same time, a loss of species with temperate affinities like echinoderms (Asterozoa and Echinozoa) and soft corals (Octocorallia) has been recorded for these same regions (Figure 7).

The tropicalization effect is also reflected by a decreasing trend in species richness, except for the Hexacorallia which show an increase in richness in the region of La Paz. What the data shows is that not only are tropical species increasing in abundance, but there are more species stretching their distribution northward. The overall consequences of tropicalization are still largely unknown and research on other ecosystems like deeper waters and sargassum and macroalgae forests is needed to improve our understanding of the potential impacts tropicalization will bring.

Figure 7. Abundance trends of taxonomic groups recognized as critical ecological indicators for rocky reefs in the Gulf of California (Favoretto et al., 2022; Paz-García et al., 2012; Ulate et al., 2016). Asterozoa are sea stars, Echinozoa are sea urchins, Hexacorallia are stony corals and Octocorallia are soft corals.

IMPACT OF HURRICANE ODILE ON INVERTEBRATE COMMUNITIES - A CASE STUDY.

Rocky reefs in Los Cabos are particularly vulnerable to tropical storms and hurricanes and with the frequency and strength of these events increasing, understanding their impact on reef invertebrate communities is important. Invertebrate epilithic communities[2] have special adaptations allowing them to resist the physical impacts of wave activity. However, when wave strength becomes unbearable, species composition changes as a result from the removal of foundational species[3] and fast-growing pioneering species colonizing the bare rock faster.

After hurricane Odile, which hit Baja California Sur in September 2014, large portions of rocky reefs previously dominated by Octocorals (e.g., *Leptogorgia rigida*) and *Hexacorallia* (e.g., *Pocillopora* spp.) were left bare by the impacts of the waves. After such extensive damage, encrusting polychaetae (or segmented worm) called *Idanthyrsus pennatus* started colonizing large portions of the rock surfaces (Figure 8). For several years, *I. pennatus* remained the dominant species, but recently, coral coverage is starting to slowly increase as *I. pennatus* decreases (Figure 8). This process resembles the vegetational succession process that occurs on bare rock on land and is also indicative of an alternative stable state. Reef communities are constantly changing and adapting to their environment.

As environmental conditions change and considering the impact of climate change, understanding ecological dynamics is crucial if we wish to be successful in conservation and ecosystem restoration efforts. This case study provides insight into coral recovery and the ecological dynamics of the rocky reefs in the Gulf of California.

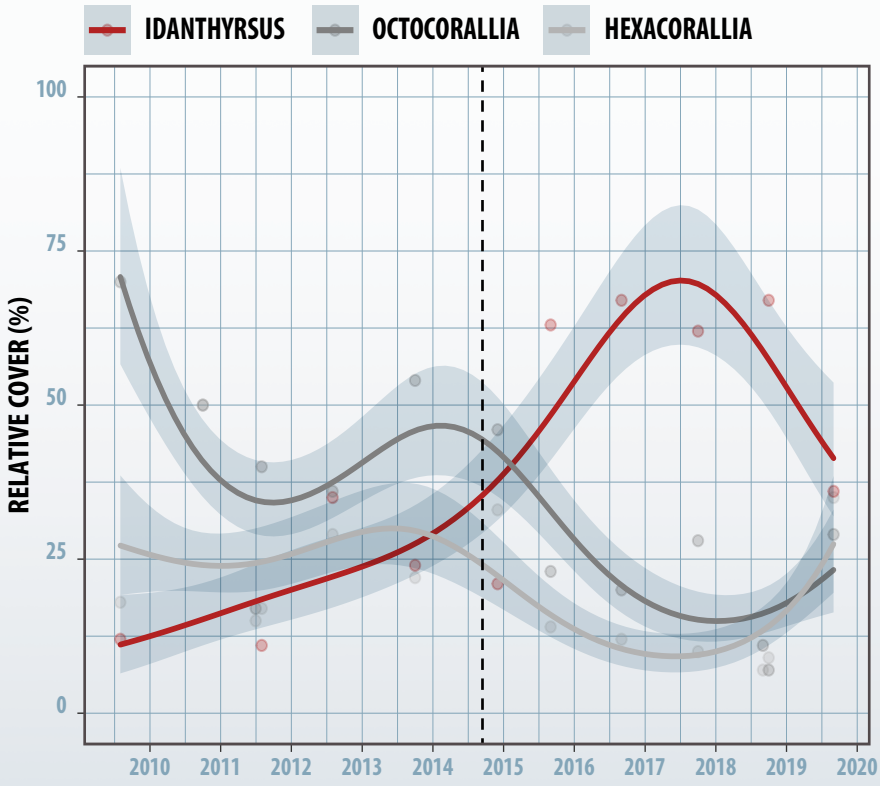

Figure 8. Change in area coverage of dominant species of the rocky reefs in Los Cabos, Baja California Sur, Mexico. *Idanthyrsus pennatus* became dominant after hurricane Odile made landfall in 2014 represented by the vertical black line. Octocorallia and Hexacorallia are soft and stony corals respectively.

[2] This refers to species that grow on the surface of rocks.

[3] In ecology, the foundation species are those that have a strong role in structuring a community, for example, corals, kelps or seagrasses.

METHODS

Temperature data: We retrieved Reynolds optimally interpolated sea surface temperature (OISST) for the southern Gulf of California. The OISST product is a global 0.25x0.25° gridded dataset of Advanced Very High-Resolution Radiometer (AVHRR) derived sea surface temperatures at a daily resolution, from 1982 to 2020. Further in the text, we refer to OISST data as simply SST. The source data is currently available at: https://www.ncdc. noaa.gov/oisst. The code was written in R studio IDE (v.1.4.1717) working on R v.4.1.2. 2.2.

Marine heatwaves events: To detect marine heatwaves events, we calculated our climatological period (the statistical properties of the time series, including the mean, variance, seasonal cycle, and quantiles) over the whole time series. We then detected marine heatwaves from SST daily data within each 0.25° grid (i.e., each pixel). Since the analysis is pixel-based, it is independent of the size of the region bounding box selected. The number and duration of marine heatwaves were calculated as periods of five or more consecutive days when daily SST was greater than the 90th percentile of our climatological threshold based on our time series (Hobday et al, 2016). The marine heatwaves analysis was completed using the R package heatwaveR (Schegel et al., 2018).

Rocky reefs surveys: Fish and macroinvertebrate data collected since 1998 was used in this analysis. This data has been consistently collected using SCUBA assisted underwater surveys with standard methods for visual belt transects. Each diver has undergone training before the surveys consisting of in situ species identification and size and distance estimation. At each site, two-person diving teams swam along 50-m transects, with one observer recording fishes and the other epibenthic macroinvertebrates. Within each site, four transects are positioned at 20 m and four at 5 m depth for a total of eight transects per site. Fish divers counted and estimated the size of all fishes within a five-meter-wide belt along each transect during two passes (250 m^2 total area). Different behavioral groups (mobile species versus territorial species) were surveyed in separate passes to ensure that individuals were only counted once. All macroinvertebrates were counted and identified along 30 m transects with a one-meter-wide belt (30 m^2). Fish total length is estimated to the nearest cm and individual specific lengths are then converted to body weights. The biomass of individual fishes was estimated using the allometric length-weight conversion $W = aTL^b$, where parameters a and b are species-specific constants, TL is the total length in cm, and W is weight in grams. Length-weight fitting parameters were obtained from FishBase15. The cross-product of individual weights and numerical densities was used to estimate biomass by species converted to ton/ha.

Time series analysis: We analyzed time trends in abundance of invertebrates and fish biomass as these are the major indicators to assess rocky reefs' condition. We fitted Generalized Additive Models (GAM) to average abundance and biomass to describe the trends in time. For the Los Cabos before/after hurricane effects we calculated Octocorals, Hexacorallia and Idanthyrsus pennatus cover following the methods described in Ulate et al. (2016) by multiplying abundance per the size estimated underwater of the colonies.

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Field work was coordinated by the Centro para la Biodiversidad Marina y la Conservación, while data analysis is led by the Aburto Lab at Scripps Institution of Oceanography at UC San Diego. The Gulf of California Marine Program at the Institute of the Americas coordinates the binational team of scientists participating in this research program.

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