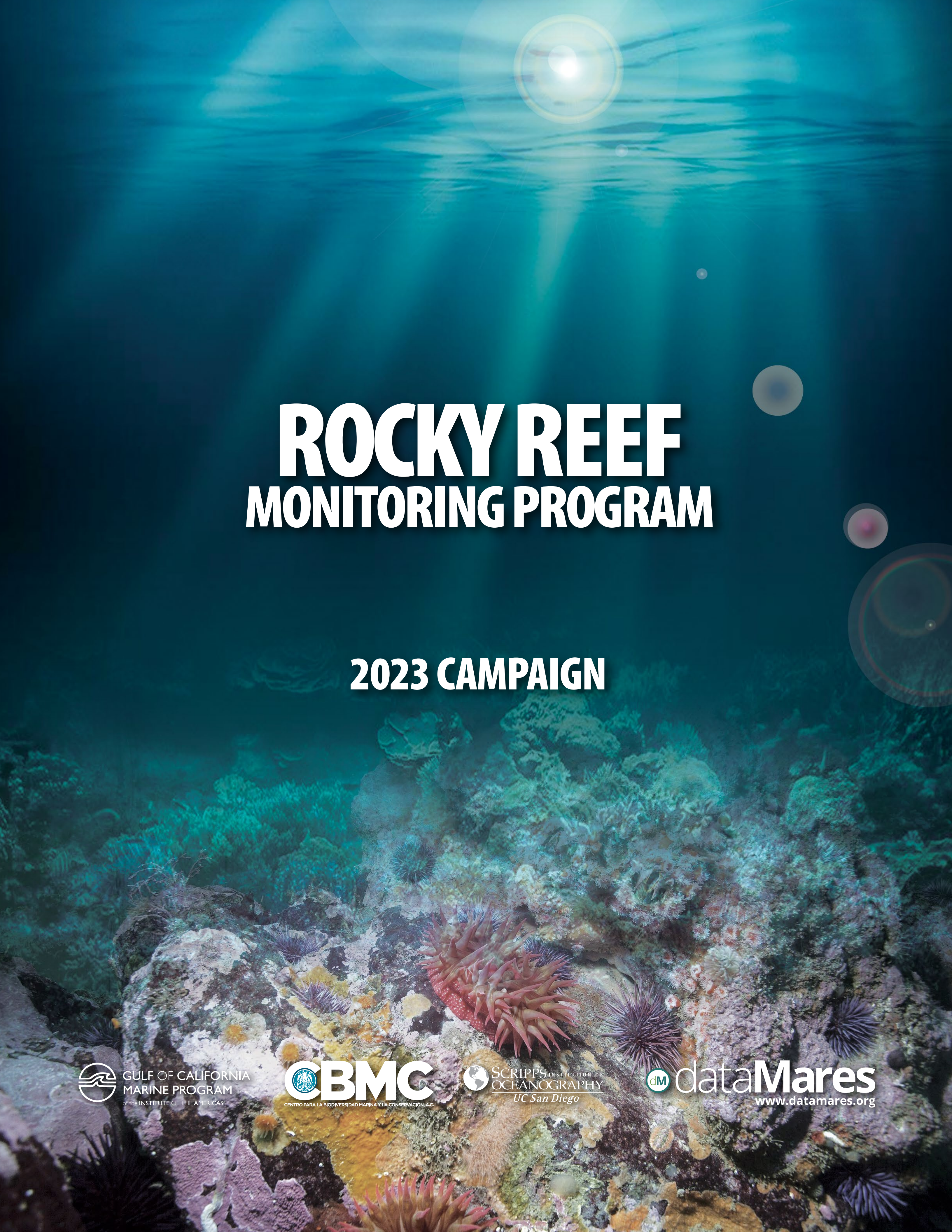
# ROCKY REEF
## MONITORING PROGRAM



## 2023 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**
dataMares

**JANUARY 2024**

This report is a summary of the research activities 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).

# 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 collaborative effort bring together scientists, early career professionals and students from research institutions sand conservation organizations from the United States and Mexico. Under the leadership of Dr. Octavio Aburto from Scripps Institution of Oceanography (SIO) at the University of California San Diego, and the support of the Centro para la Biodiversidad Marina y la Conservación A.C. (CBMC) in La Paz, B.C.S., the annual field work campaigns have allowed scientists to track and evaluate the health of rocky reefs in the Gulf of California, while providing capacity building opportunities for young and early-career scientists.

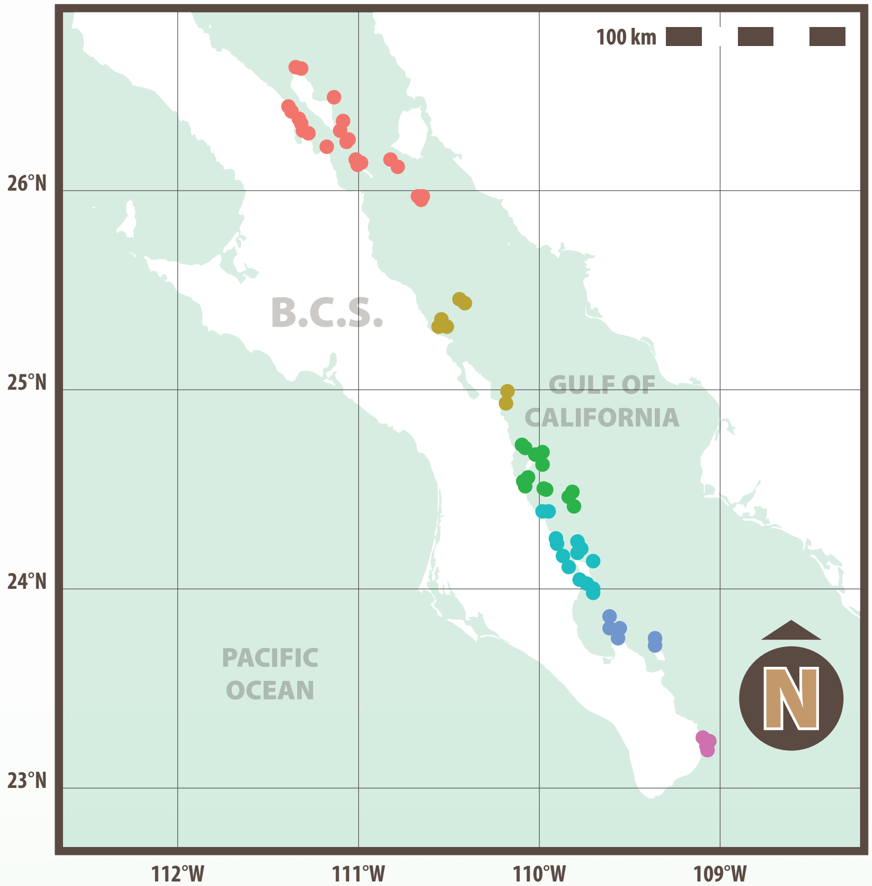
The Ecological Monitoring Program was established back in 1998 when a group of scientists and students from SIO, the Birch Aquarium at Scripps and the Universidad Autónoma de Baja California Sur (UABCS) set out to study coastal rocky reefs along the Gulf of California with the objective of increasing our knowledge and understanding of these underwater ecosystems. By collecting data on species composition, abundance, trophic level, size and other ecological indicators, this small group of scientists began building a knowledge baseline for invertebrate and fish communities on rocky reefs. During these 25 years of uninterrupted work, the program has evolved to give space for new collaborators, ideas, research hypotheses, methodologies and tools that allow us to reach unexplored ecosystems and collect more data.

Perhaps the biggest benefit resulting from the longest-running monitoring program is that it provides the necessary information for environmental assessments and improves our collective understanding of the marine ecosystems that sustain local and regional economies in the region. Over the years, the information we have generated has been used in studies that evaluate environmental threats and conservation challenges and helps monitor changes due to natural and anthropogenic drivers. Furthermore, this program has provided training and networking opportunities for students and early-career scientists looking to gain hands-on experience as they decide their path forward in their academic and professional careers.

To celebrate the 25th anniversary of the rocky reef monitoring program, a group of 10 scientists, 3 photographers and 8 students boarded a ship to recreate the original monitoring campaign from 1998. For 30 days, the team documented the state of rocky reef communities, explored deep and pelagic ecosystems using the latest technology, studied blue carbon ecosystems along the coastline, and collected photographic and video material along the way. This report includes some of the most relevant findings from 2023 and an overview of what this research program has accomplished in its first 25 years of existence.

# ROCKY REEF MONITORING REGIONS AND SITES

The 2023 monitoring campaign included 83 rocky reefs that have been monitored. Sites are grouped by region based on general ecological characteristics.




**NUMBER OF ROCKY REEFS**
**83**

**NUMBER OF TRANSECTS**
**1128**

INVERTEBRATES
564

FISH
564

**TOTAL AREA SURVEYED**
**142,800 m²**

**TOTAL TIME SPENT UNDERWATER**
**131 HOURS/SCIENTIST**

**CONTACT POINTS**
**720,280**

INVERTEBRATE SPECIES
102

**NUMBER OF SPECIES IDENTIFIED**
**255**

INVERTEBRATES
128

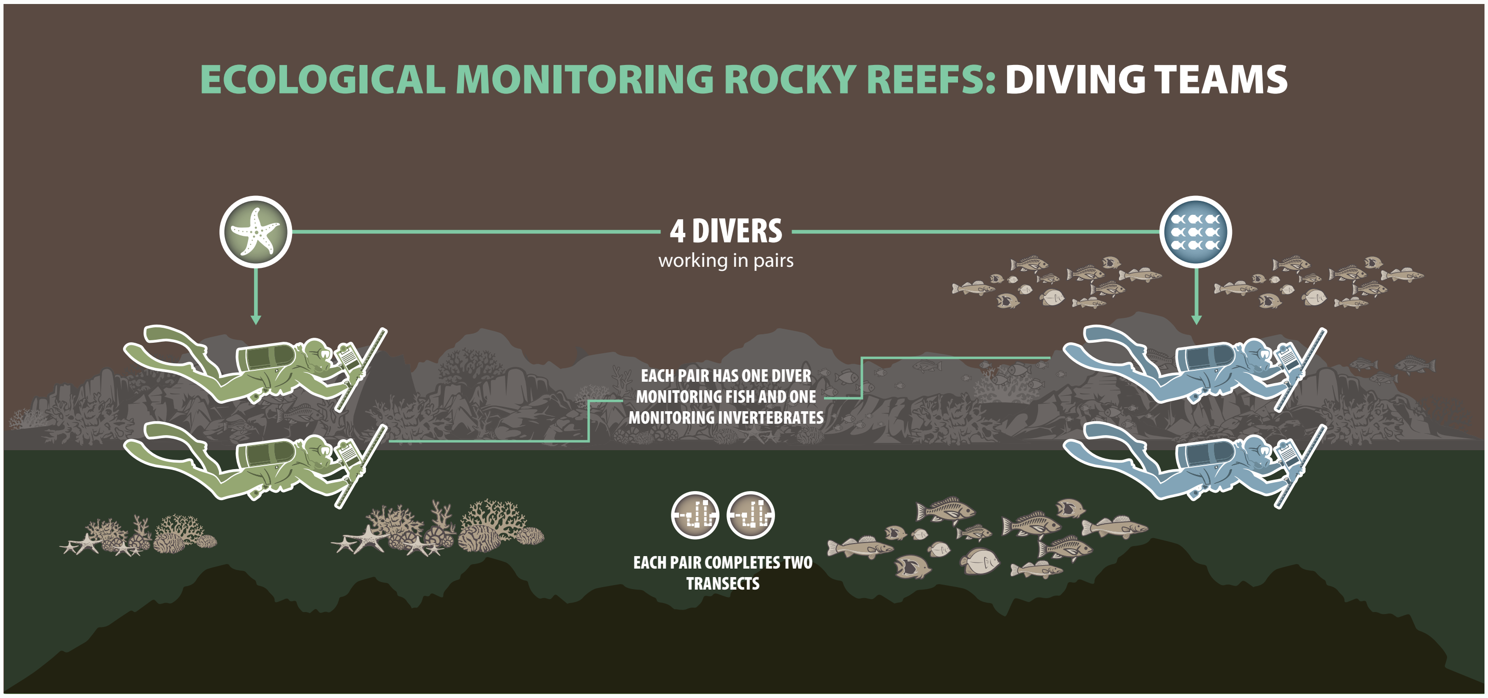
FISH
127

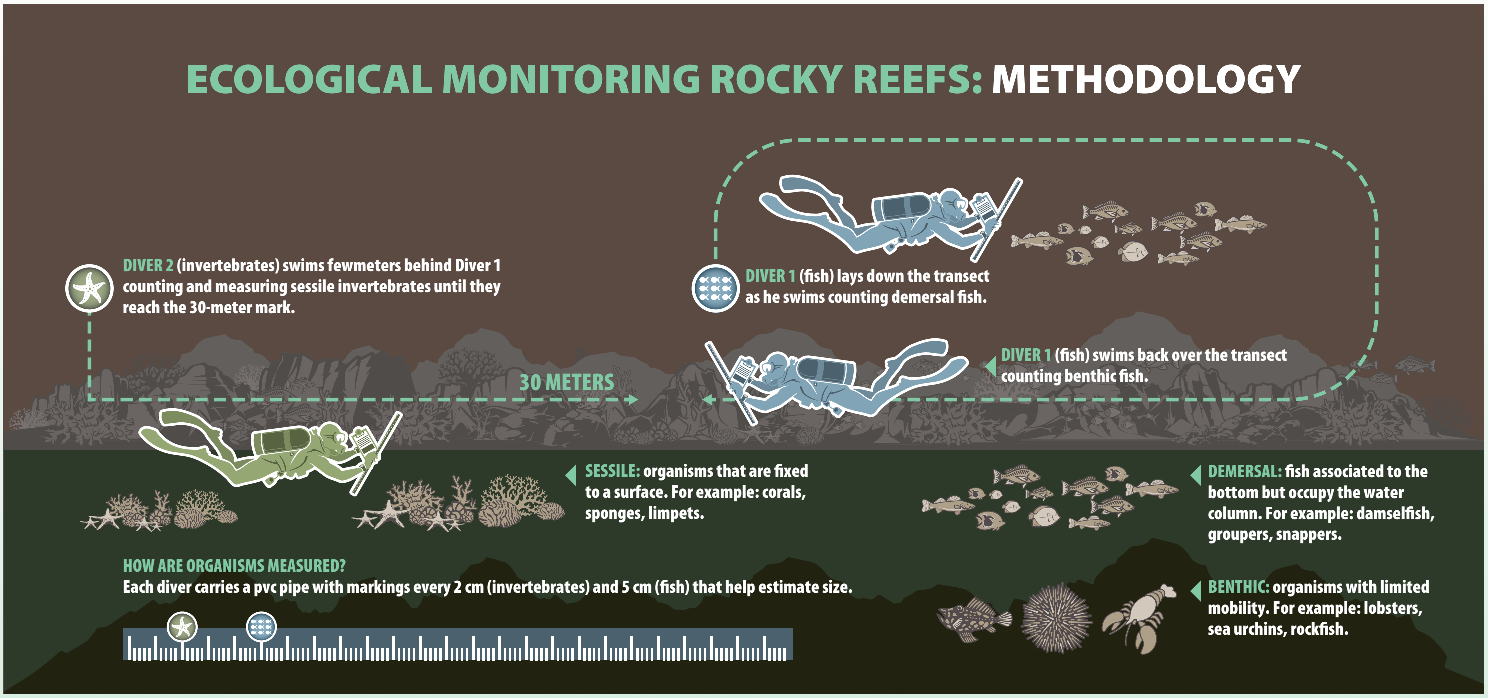
**NUMBER OF ORGANISMS COUNTED AND MEASURED**
**131,146**

INVERTEBRATES
50,616

FISH
80,530

Divers follow the monitoring methodology established 25 years ago (Rodríguez et al., 2014) which includes two pairs or researchers monitoring each site. Each team includes one diver focusing on surveying fish, while the other one focuses on invertebrates.



# MONITORING ECOSYSTEM HEALTH IN ROCKY REEFS

Species abundance, richness, biomass and relative biomass are some of the metrics we use to assess a reef's health throughout time. One way to measure diversity is through species richness since it shows the number of different species that are present in each site that is surveyed (Figure 1). However, we must consider additional metrics to assess the health of an ecosystem, like biomass and relative biomass, which we only calculate for fish. Biomass refers to the total mass of living organisms and is calculated by combining two variables: number of individuals and their size (Figure 2). Relative biomass is the comparison of biomass among trophic groups (piscivorous, carnivorous, herbivorous and zooplanctivorous) (Figure 3).

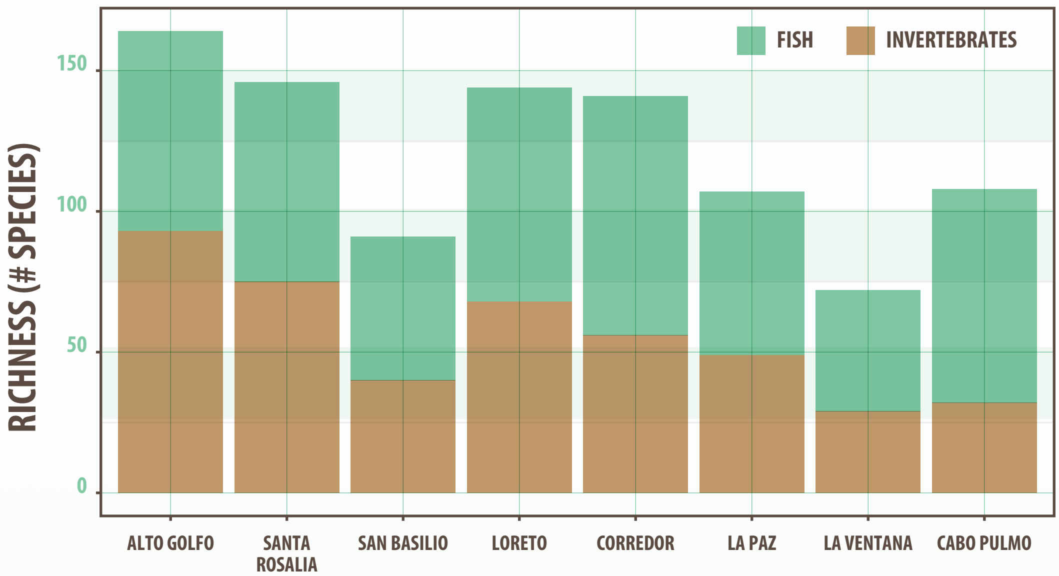



**Figure 1. Number of invertebrate and fish species recorded during 2023.**

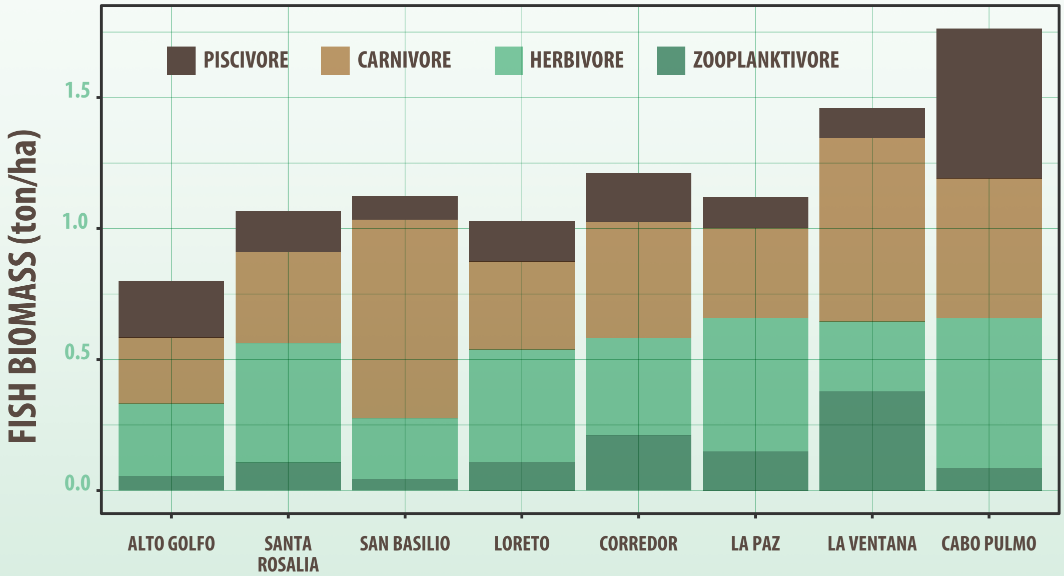



**Figure 2. Estimates of fish biomass for each trophic group for each region.**

The higher the biomass and richness recorded for an ecosystem, the healthier we can consider it to be as these two variables indicate that an ecosystem can function properly. If these metrics increase or are maintained throughout time, we can conclude that ecosystems are thriving, growing, or actively recovering from any negative impacts. However, if these indicators show a decreasing trend over time, we can assume that the ecosystem is deteriorating or has been altered in some way. The data collected in 2023 shows that both richness and biomass have remained similar which, while a positive sign, we must look closer to get a more complete view of what is happening.

Relative biomass estimates provide insight into ecosystem function by showing each trophic group's contribution to biomass (Figure 3). In a healthy ecosystem, we expect to see a large proportion of top predators (piscivores) in comparison to lower trophic levels (Aburto et al., 2015; Graham et al., 2017). For example, in San Basilio and La Ventana, carnivores contribute most of the biomass, however these are areas where fishing pressure seems to be acting disproportionally on the larger fishes. This high abundance of carnivores can be a result of the removal of larger predators (i.e. Piscivores) that keep carnivore populations in check. Conversely, a high proportion of fish biomass of higher trophic groups (Piscivores) can be a sign of low fishing pressure as seen for Cabo Pulmo.

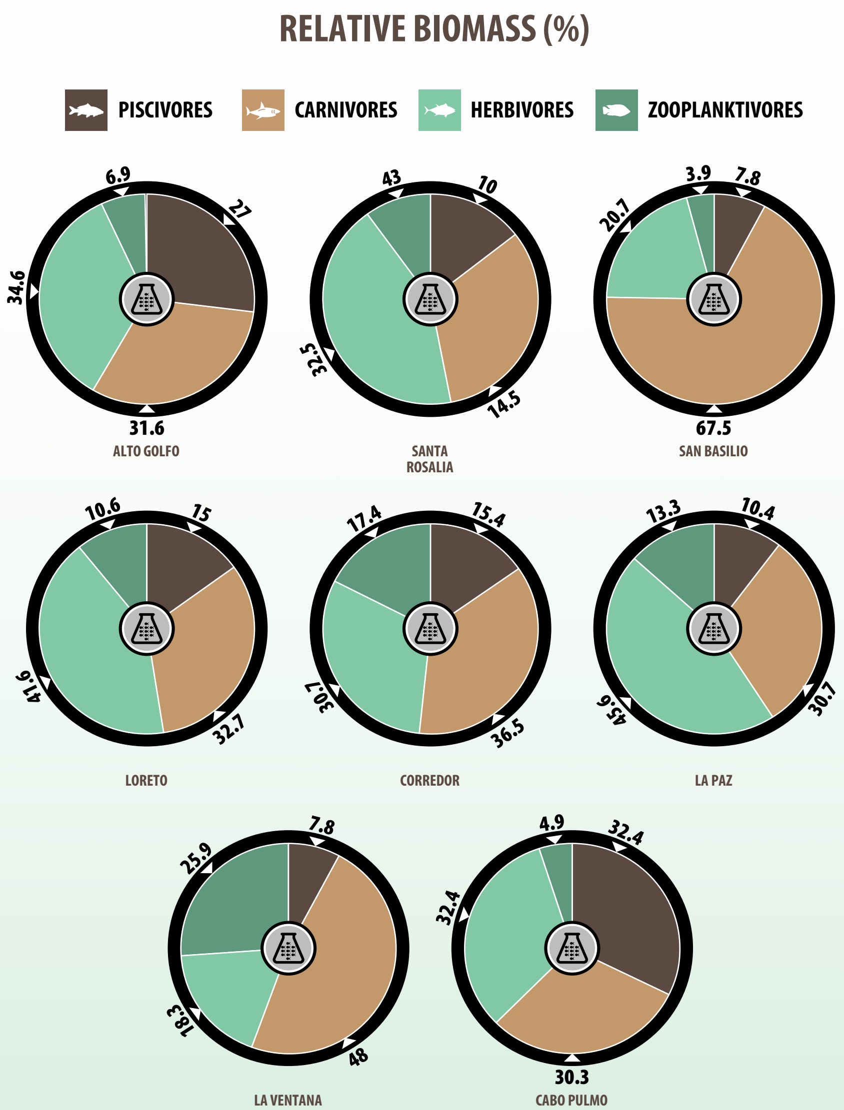



**Figure 3. Fish relative biomass of each trophic group in the regions monitored during the 2022 rocky reef monitoring campaign.**

Using the data collected in the 25 years of monitoring allows us to assess how biomass has changed over time since these changes are usually a reflection of broad-scale phenomena and/or stressors (Figure 4). Cabo Pulmo, the only area where fishing is not permitted, continues to be the only region consistently showing a large proportion of piscivores on its reefs, while those in Corredor and La Paz seem to be missing their top predators, suggesting that fishing pressure may be too high. Data from Loreto shows consistent levels of biomass, but little predator biomass compared to other trophic levels, which can also be interpreted as the result of consistent fishing pressure. The low biomass recorded in 2011 and 2013 can be attributed to natural variability throughout the Gulf of California.

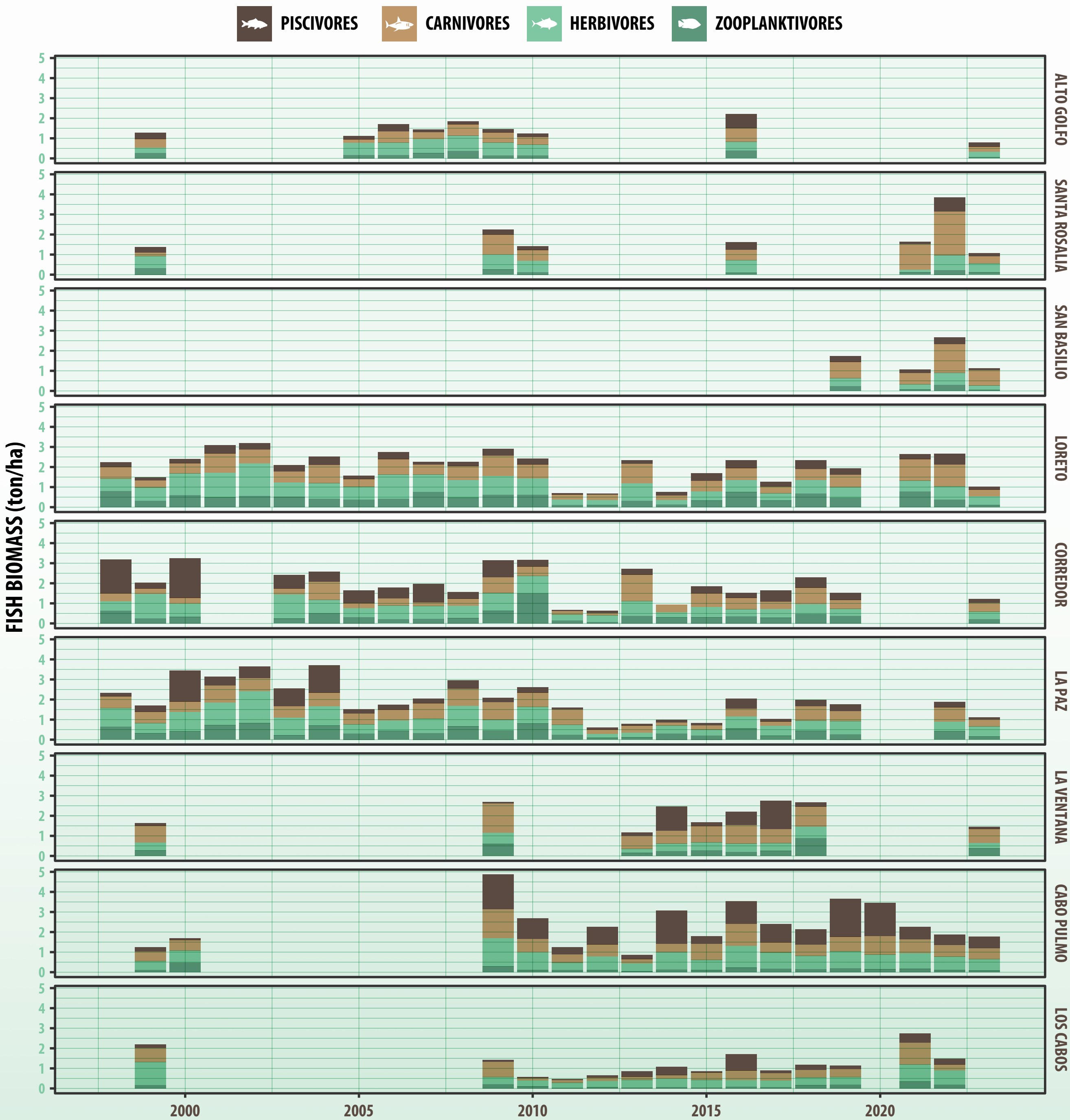



**Figure 4. Fish biomass recorded over the years for the surveyed regions. Cabo Pulmo was the only region surveyed during 2020 after obtaining special permits to operate during the COVID-19 pandemic.**

# CLIMATE CHANGE AND ROCKY REEFS IN THE GULF OF CALIFORNIA

Marine heatwaves (MHWs) are extended periods of elevated sea surface temperatures which are increasingly recognized as critical drivers of ecological change with significant implications under climate change paradigms (Wernberg et al., 2013). These thermal anomalies can lead to substantial biological alterations in marine ecosystems, notably within coastal regions characterized by rich biodiversity and intricate ecological networks (Filbee-Dexter et al., 2020). Favoretto et al. (2022) highlight the role of MHWs in accelerating the tropicalization of rocky reefs, suggesting that these thermal events are fostering the dominance of warm-water-adapted species over their temperate counterparts, thereby catalyzing ecological homogenization across distinct climatic zones. The year 2023 witnessed multiple MHWs on the Gulf of California's rocky reefs (Figure 5).

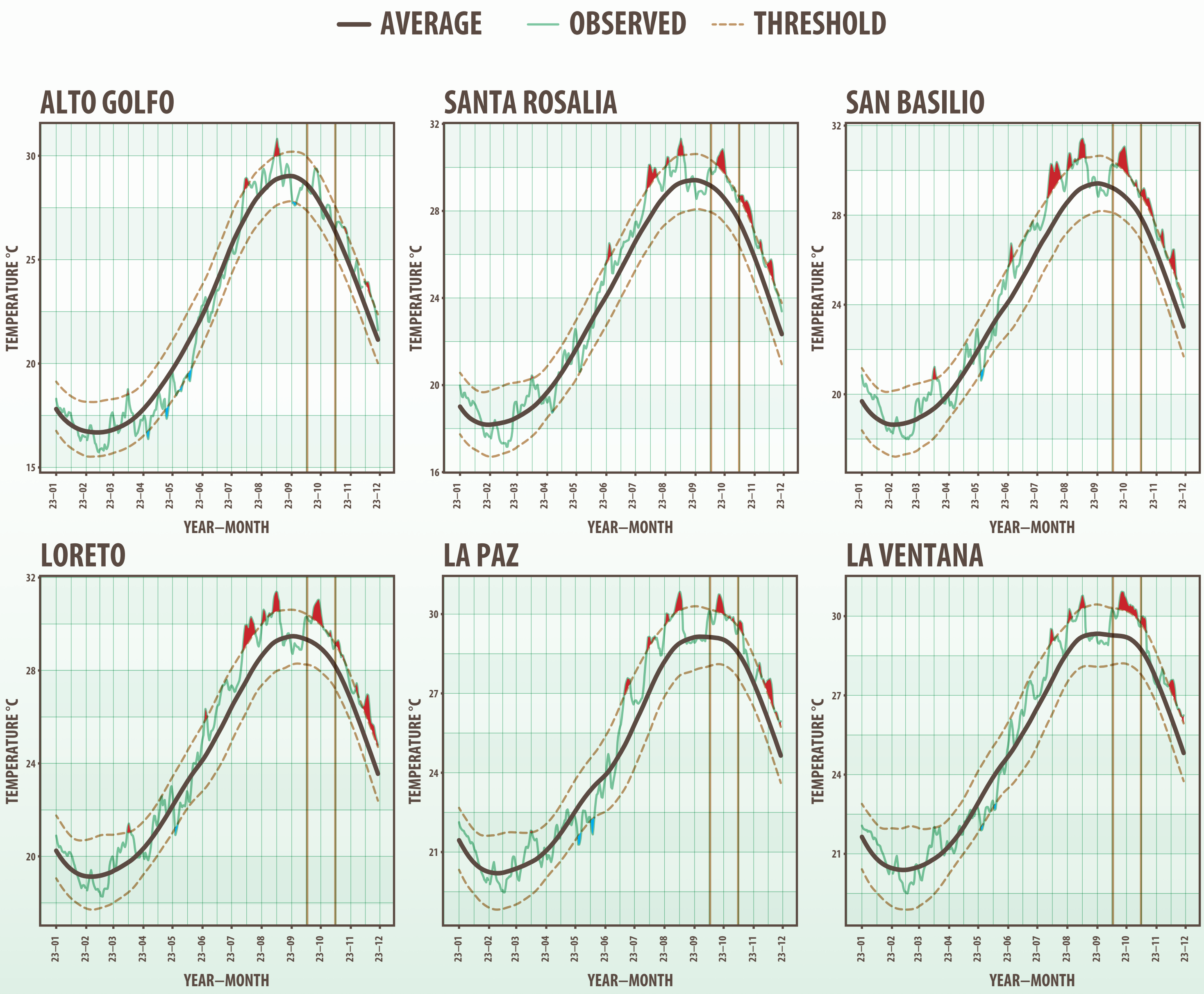



**Figure 5. Marine heatwaves detected during 2023. The dark brown line represents the average climatological condition of the area, the dashed brown lines represent the 95th and 10th percentile thresholds that define extreme heat and cold events, respectively. The green line is the observed temperature obtained by satellite remote sensing. Days that recorded temperature above or below the threshold are shaded in green or blue, indicating heatwaves or cold spells, respectively. Finally, the two vertical lines represent the dates of our cruise expedition in 2023.**

While marine heatwaves are typically monitored using surface temperature sensors (Reynolds et al., 2007), new findings highlight complex thermal behaviors beyond surface layers, including temperature anomalies, that can remain undetected (Wyatt et al., 2023; Zhang et al., 2023). During the 2023 monitoring campaign, we observed a MHW event across 30 reefs spanning 6 degrees of latitude, and we conducted an analysis of the the water column temperature profiles before, during and after the event. This revealed significant thermal alterations, especially beyond 20 meters depth, where the thermal anomalies were more intense (Figure 6). This ongoing analysis shows an increase in anomalies with depth, suggesting that MHWs may have a profound impact on deeper reefs, potentially leading to the redistribution of species and to adverse effects on species adapted to stable thermal conditions (Bates et al., 2018).

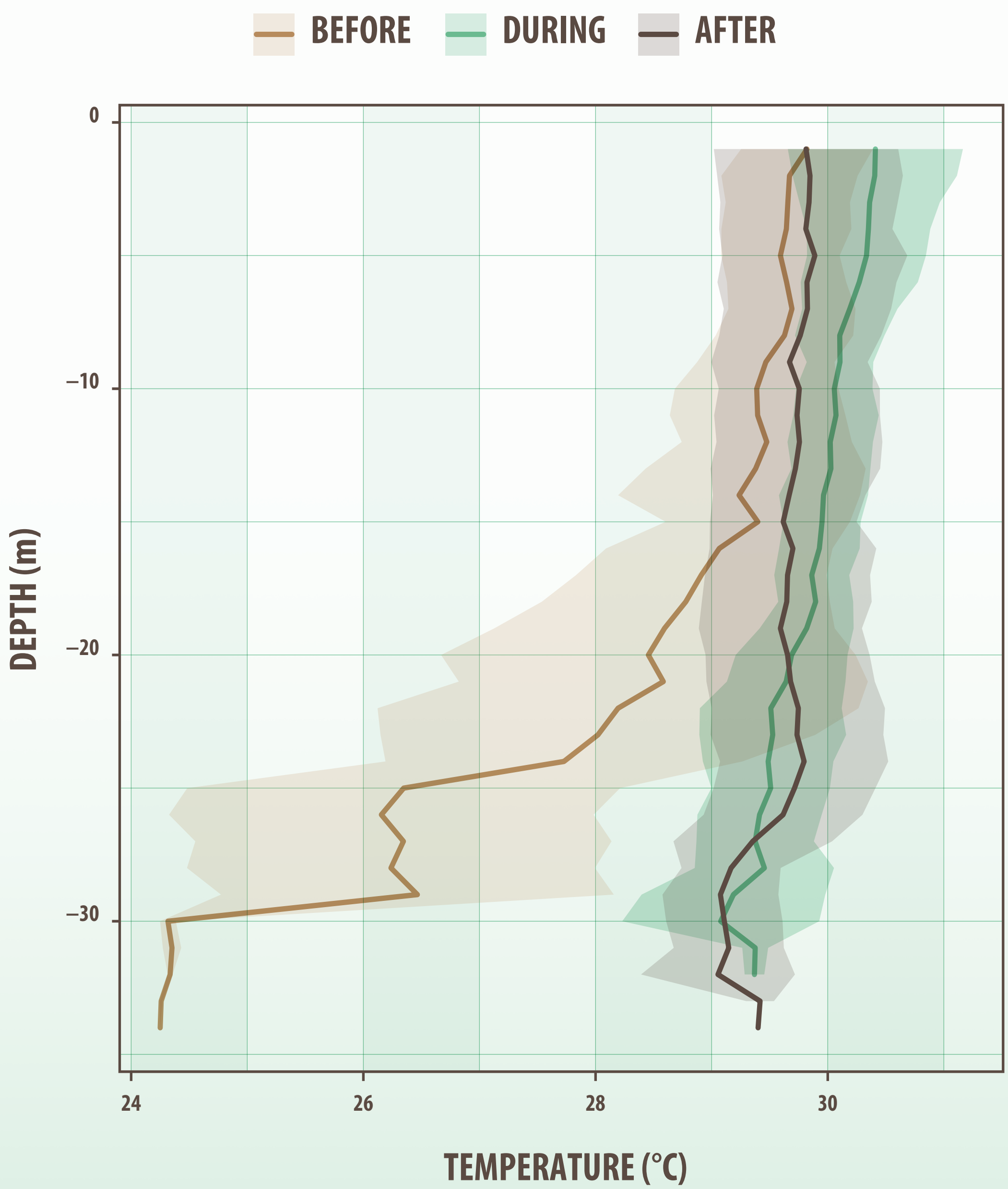



**Figure 6. Variations in water column temperature profiles before (brown), during (green), and after (dark brown) a marine heatwave event. Shaded areas represent the variation of the profiles within each state.**

# METHODS

**Rocky reefs temperature profile data:** We collected temperature profiles of rocky reefs using diving computers equipped with an integrated thermometer. This device recorded the temperature continuously during each dive. To maintain consistency, all dives were conducted at similar times each day, specifically around 07:00, 09:00, 11:00, and 15:00 hours. Post-dive, we extracted the data and processed it into a structured dataset. Initially recorded in Kelvin, the temperature measurements were converted to degrees Celsius, while depth was recorded in meters. All dives consistently exceeded depths of 20 meters. The data collection was part of a liveaboard expedition from September 16, 2023, to October 15, 2023. For analytical purposes, we categorized dive sites by latitudinal degree to serve as a neutral proxy for baseline environmental variations among sites in the Gulf of California, in alignment with the oceanographic marine sectors delineated by Favoretto et al. (2022).

**Surface Temperature Data:** We obtained Reynolds Optimum Interpolation Sea Surface Temperature (OISST) data specific to the Gulf of California. The OISST dataset is a global compilation of sea surface temperatures, gridded at 0.25° × 0.25° intervals, derived from the Advanced Very High-Resolution Radiometer (AVHRR) with a daily temporal resolution spanning from 1982 to 2020. Hereafter, we refer to the OISST data as SST for brevity. The dataset is accessible at the National Centers for Environmental Information (NCEI) website: https://www.ncdc.noaa.gov/oisst. The analytical code was developed using the RStudio Integrated Development Environment (IDE), running on R version 4.3.2.

**Marine Heatwave Events:** To identify marine heatwave events, we first intersected the coordinates of the rocky reefs to the 0.25° grid cell of the OISST data. For each site we established a climatological baseline, computing the statistical characteristics of the time series, which included the mean, variance, seasonal patterns, and quantiles, over the entire dataset. Detection of marine heatwaves was conducted on the SST daily dataset within each. Marine heatwave occurrences and durations were quantified as sequences lasting at least five consecutive days where the daily SST exceeded the 90th percentile of the climatological threshold, derived from our time series, as described by (Hobday et al., 2016). This analysis of marine heatwaves was performed utilizing the R package heatwaveR (Schlegel and Smit, 2018). methods described in Ulate et al. (2016) by multiplying abundance per the size estimated underwater of the colonies.

## ACKNOWLEDGEMENTS

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Field work and cruise logistics were coordinated by the Centro para la Biodiversidad Marina y la Conservación and 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 research stemming from this program.

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