TECHNICAL REPORT 3327
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Farallon de Medinilla 2022 Coral Reef Survey

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

Coral reef surveys were conducted at Farallon de Medinilla (FDM) August 14–19, 2022 by Naval Information Warfare Center (NIWC) Pacific Scientific Diving Services (SDS) to satisfy requirements of the Mariana Islands Training and Testing Area Biological Opinion (MITT BO) issued by the National Marine Fisheries Service in 2020 (NMFS 2020). This report fulfills portions of Terms and Conditions (T&C) 2b and 2c of the 2020 MITT BO (NMFS 2020). T&C 2b includes the requirement for the Navy to "provide reports of any observed in-water effects (e.g., crater size, observed mortality) to corals resulting from detonations of high-explosive ordnance as they are discovered...during coral reef surveys..." T&C 2c states "The Navy shall, no less than once every five years, survey coral reef habitat around FDM within 30 m of water depth. These surveys will be structured to confirm presence or absence and abundance of Endangered Species act (ESA)-listed corals and to assess general trends in coral reef species composition, percent coral coverage, and condition (disease, predators, extent of breakage, etc.)." The primary objectives of the 2022 field survey were to quantify the abundance and location around the island of ESA-listed corals, quantify coral reef health (percent cover of living coral, coral species composition, and coral condition), and compile observations of ordnance impacts. Secondary objectives were to record incidental observations of any other ESA-listed species encountered while fulfilling the primary objectives.

Surveys were conducted in all habitat types around the island, including collection of approximately 1,050 photoquadrats on 73 transects and 615 representative photos in the survey area. Corals in photoquadrat images were identified to the lowest taxonomic level with a reasonable degree of confidence. However, coral identification in photographs, particularly in biodiverse locations, such as FDM, is less certain than methods including destructive sampling. These challenges are described further in the report. Corals from 32 genera were identified in photoquadrats for this reporting effort.

A total of 16 colonies identified as the ESA-listed coral Acropora globiceps were observed: 10 colonies were captured in photoquadrat images (0.12% of all enumerated coral colonies), and an additional 6 colonies were captured in other representative photographs. In addition, a total of 27 colonies believed to be the ESA-listed coral Acropora retusa were observed during the 2022 survey: 10 colonies were captured in photoquadrat images (0.12% of all enumerated coral colonies), and an additional 17 colonies were captured in representative photographs. A. retusa has not previously been positively identified at FDM, although it is included in the range of this coral. This evidence indicates that ESA listed corals are present, but relatively rare, in waters <30 m depth around FDM. In 2017, some colonies were identified as one of three potentially new (undescribed to science) species of Acropora corals and there were an additional 11 species of Acropora that were considered unique but could not be identified. In 2022, only one coral colony was identified as possibly being a new species, and two others were identified as one of the previously unknown corals. In 2022, other Acropora corals which may have been unidentified or thought to be new species in 2017, were identified to known species. This is possibly because those are the correct identifications and possibly because without expert taxonomist input, it is not feasible even for generally trained coral reef scientists to determine that a species is different enough that it is undescribed, a hybrid, or a new range record, for example.

There was a mild coral bleaching event underway at FDM during the 2022 survey, which was caused by regional anomalously warm sea surface temperatures. On average, 64.1% of corals analyzed exhibited some form of bleaching, but only 5.6% were completely bleached (compared with 47.8% of colonies during the 2017 survey). Observations of broken, diseased and recently dead corals were rare (comprising ~0.1% of the corals analyzed). However, only 37.4% of corals analyzed were considered “healthy”, and 41.1% of living corals appeared to be actively being overgrown by other organisms, usually sponges or turf algae.

There was insufficient evidence of any adverse impacts to the coral from training, including the use of high-explosive bombs. Only two relatively fresh ordnance items were observed. All other ordnance encountered was historical. No impacts attributable to ordnance (e.g., craters, fresh scars near ordnance) were observed anywhere around the island. As noted in all previous marine surveys at FDM (e.g., Smith and Marx, 2016), a substantial percentage of all ordnance items supported scleractinian coral growth on the actual ordnance items.

ACRONYMS

ANU	Authorized for Navy use
CNMI	Commonwealth of the Northern Mariana Islands
COMPACFLT	Commander Pacific Fleet
COTS	Crown-of-Thorns starfish
DoD	Department of Defense
DoN	Department of the Navy
DPS	Distinct Population Segments
DPV	Diver Propulsion Vehicle
EOD	Explosive Ordnance Disposal
ESA	Endangered Species Act
FDM	Farallon de Medinilla
FTF	Fishery Target Fishes
GPS	Geographic Position System
Km	kilometers
MTT BO	Mariana Islands Training and Testing Area Biological Opinion
NIWC	Naval Information Warfare Center Pacific
NMEA	National Marine Electronics Association
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
SDS	Scientific Diving Services
T&C	Terms and Conditions
USFWS	U.S. Fish and Wildlife Service

Note: Use of scientific nomenclature follows international standards for binomial nomenclature designating genus and species in italics. Once introduced, the genus is frequently abbreviated to the single letter (e.g., *acropora globiceps* becomes *a. Globiceps*). When the species is unknown, the organism will be listed by genus with spp. at the end.

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1. INTRODUCTION

Farallon de Medinilla (FDM) is an uninhabited island in the Mariana Archipelago in the western Pacific Ocean. The island is approximately 2.8 kilometers (km) long and is located 278 km north of Guam. FDM has been used by the Department of Defense (DoD) as a live and inert range since 1971. Commander Pacific Fleet (COMPACFLT) funded an initial survey in 1997 and 13 annual marine ecological surveys of nearshore marine resources at FDM between 1999 and 2012 (no survey was perfhereormed in 2011) in support of environmental compliance for the Mariana Islands. The subsequent survey after 2012 was completed in 2017, which was the first survey conducted since 20 species of coral were listed under the Endangered Species Act (ESA) in 2014 (79 FR 53851). The 1999–2004 surveys were completed by a Navy contractor, a representative from the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS) and the Commonwealth of the Northern Mariana Islands (CNMI). In 2004, a decision to utilize an all-Navy team for further studies was made due to safety and liability concerns associated with the presence of unexploded ordnance near FDM. All surveys between 2005–2017 were performed by the same Navy scientist/divers; the 2022 survey included one of the same scientist/divers that conducted the 2005–2017 surveys. Explosive Ordnance Disposal (EOD) Detachment Marianas provided dive support and explosive safety oversight for all surveys. The 2022 FDM survey was conducted to satisfy requirements of the Mariana Islands Testing and Training Biological Opinion (MITT BO; NMFS 2020). The survey was designed to obtain data to address the following goals, in order of priority:

1. Presence and abundance of ESA-listed corals [G1]
2. Percent coral coverage [G2]
3. Coral species composition [G3]
4. Coral condition (e.g., disease, predators, extent of breakage) [G4]
5. Any in water effects (e.g., crater size, observed mortality) to corals from high-explosive bombs [G5]
6. Incidental observations of other ESA-listed species (scalloped hammerhead sharks, marine mammals, sea turtles) [G6]

Currents and wave conditions at FDM can be extreme, particularly on the eastern side of the island and the southern tip. In addition, the time allowed for the marine survey was restricted to a short window during which the range was closed. To accommodate the challenging oceanographic and logistical conditions for this survey, the SDS team worked with COMPACFLT to design an appropriate survey protocol to gather quantitative data needed to address the goals above and satisfy the MITT BO (NMFS 2020) requirements. The approved survey plan (NIWC Pacific 2021) focused on collecting scaled and geo-referenced photographs of coral-bearing substrates within each habitat in the vicinity of FDM that supports corals in order to assess specie compositions and coral conditions, and conduct directed searches for ESA-listed corals, which were the regulatory driver for this survey. Given the very limited dive time possible in the 20-30 m depth range, photoquadrats and directed search protocols were restricted to <20 m depths, while video was primarily collected between 20–30 m depths, using diver propulsion vehicles to allow the divers to maximize the area surveyed. Regions dominated by unconsolidated sediment were not surveyed. This survey methodology was similar to the 2017 survey, and both were significantly different from earlier surveys at FDM in that the focus of the more recent surveys was on collecting quantitative and georeferenced data.

As noted, a key element of this survey was to assess scleractinian corals of all taxa. Emphasis was placed upon identifying and geo-locating specimens of the scleractinian corals listed as threatened, which have been recorded from the Mariana Archipelago (no Endangered scleractinian corals have been recorded in the region). Within the archipelago, four species were confirmed and recognized as present by the National Oceanic and Atmospheric Administration (NOAA): *Acropora globiceps*, *Acropora retusa*, *Acropora speciosa*, and *Seriatopora aculeata* (Fenner and Burdick 2016). Of these, previous field surveys identified only *A. globiceps* as being present at FDM (Belt Collins Hawaii, 2001, 2003; The Environmental Company 2004, 2005; Carilli et al. 2018) as well as Tinian and Pagan (Tetra Tech 2014) and Guam (Brainard et al. 2011). *A. retusa* was tentatively identified at other islands within CNMI (Fenner and Burdick 2016), and identified in Guam (HDR 2011, Fenner and Burdick 2016). *A. speciosa* (HDR 2011, Fenner and Burdick 2016) and *S. aculeata* (Brainard et al. 2011, Fenner and Burdick 2016) was recorded from Guam, but not from any other islands in the Mariana Archipelago (Fenner and Burdick 2016). Due to the need to further clarify the presence or absence of threatened corals at FDM, the investigators specifically searched for the occurrence of these four species (Figure 1).

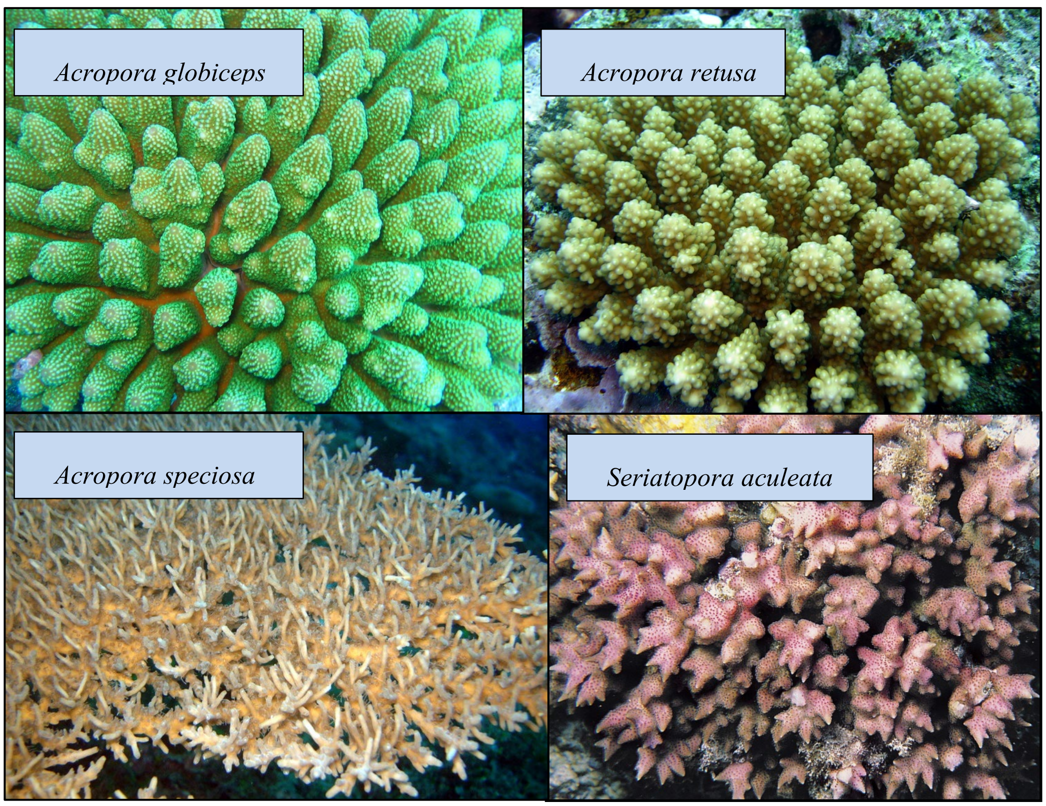

Figure 1: ESA-listed corals previously observed or thought to possibly occur at FDM. All *Acropora* images were created and copyrighted by Douglas Fenner. *Seriotopora* image credit: Australian Institute for Marine Science Coral Fact Sheets (http://coral.aims.gov.au/).

2. METHODS

2.1 DATA COLLECTION

A NIWC Pacific scientist and NIWC Pacific military diver completed different but complementary underwater tasks to address the survey goals, described in detail in the 2021 FDM survey plan (NIWC Pacific 2021) and field implementation plan (NIWC Pacific 2022). Dive locations selected provided comprehensive island coverage to re-survey prior areas from the 2017 survey, which included collecting observations and video from the 20-30 m depth range, and targeting areas with the most threatened coral species. Dive surveys were conducted at a range of depths from 25-100 feet to capture diverse habitats, and were conducted primarily in previously defined Habitat types 2-5 (Figure 4; Appendix A).

Since the Navy started conducting surveys at FDM, it was determined that diver propulsion vehicles (DPVs) were a necessity in order to circumnavigate the island and cover all designated zones of the bombing range. The Suex NEROX MOD1 DPV is on the authorized for Navy use (ANU) list, and was used by the Navy dive team for the 2022 survey (Figure 2). An onboard navigation system was pre-programmed for each deep dive utilizing the DPVs, with waypoints collected from the 2017 survey inputted as the start and end points, to assist with the goal to re-survey similar sections of the seafloor around the island as during the 2017 survey.

Figure 2: Navy diver using a DPV during the 2022 FDM survey.

The in-water tasks completed by the NIWC Pacific divers are listed in Table 1.

Table 1: Tasks performed during 2022 FDM survey dives by each scientific diver. EOD divers also assisted with observations of mobile ESA-listed species and ordnance impacts.

Task	Survey goal	Diver 1	Diver 2
Directed search for ESA-listed corals Colonies encountered photographed & georeferenced.	G1		**X**
Collection of photoquadrat imagery (to allow ESA-listed corals to be enumerated from georeferenced photoquadrats).	G1	**X**	
Assessment of percentage of coral-bearing substrate in each habitat, based on landscape photographs and notes taken during dives.	G2		**X**
Assessment of percentage of coral on said coral-bearing substrate in each habitat, based on landscape photographs and notes taken during dives.	G2		**X**
Collection of photoquadrat imagery (to allow assessment of coral species composition, via post-fieldwork analysis of georeferenced photoquadrats).	G3	**X**	
Coral condition via assessment of field notes and landscape photos, as well as collection of photoquadrat imagery (to allow post-fieldwork analysis of georeferenced photoquadrats).	G4	**X**	**X**
In-water impacts from training catalogued via notes and photographs when encountered incidentally.	G5	**X**	**X**
Other ESA-listed species catalogued via notes and photographs when encountered incidentally.	G6	**X**	**X**

Diver 1 was primarily tasked with collecting photoquadrat images [to accomplish G1, G3, G4]. Because of the rough sea conditions common at FDM, standard photoquadrat methods (placement of PVC frame on substrate prior to photography, or PVC frame attachment to underwater camera) were determined to be unsuitable while developing the survey plan, so therefore not used. Instead, the underwater camera was fitted with a 37” metal monopod to set the perpendicular offset distance for acquiring a standard set of scaled images (Figure 3). Photoquadrats collected using the monopod produced an image footprint (benthic substrate within the image frame when the camera was oriented parallel with the sea floor) of 1.5 x 1.0 m based on camera parameters and offset distance. The standard sizing of these photoquadrat images allow measurement of individual coral colonies within the image frame using various software applications, which supports future analysis and research. Appendix B includes metadata related to photoquadrat imagery collection.

Figure 3: Diver 1 collecting a photoquadrat image using a monopod.

Diver 2 completed in-situ assessment of coral cover [G2] and collected landscape photographs to support this goal. Diver 2 also photographed possible threatened corals encountered during directed search efforts [G1], and additional photographs of individual corals, ordnance [G5], and other organisms including possible other ESA-listed species [G6]. Of note, Diver 2's coral photographs were not collected for coral species abundance analysis.

2.2 SITE-LEVEL OBSERVATIONS

The percentages of potentially coral-bearing substrate (i.e., hardbottom) and coral occupying said coral-bearing substrate, were subjectively assessed and recorded during the dives [G2, G4] by Diver 2. Additional, potential coral health indicators, which Diver 2 searched for during the dives include: a) excess mucus production (Stafford-Smith and Ormond 1992; Wild et al. 2005); b) coral disease, e.g. Black or White Band Disease; c) infestation by the coral barnacle *Cantellius* spp.; d) predation from Crown-of-Thorns starfish (COTS), gastropod corallivores (e.g. *Drupella* spp.), and parrotfish; e) apparent damage from fish traps, nets, anchors, fishing line or spears; g) evidence of sediment accumulation; and h) evidence of high levels of macro-bioeroders, shown by Cooper (2008) to be indicative of reduced water quality.

In addition, all divers collected photographic and/or written notes regarding "any observed in-water effects (e.g., crater size, observed mortality) to corals resulting from detonations of high-explosive bombs as they were discovered incidental to routine operations or during coral reef surveys to confirm or to help revise assumptions on the effects of high-explosive bombs to corals at various depths," [G5] as required by the MITT BO.

Assessing training-related, in-water effects were key elements in the 2017 and 2022 surveys as well as with previous surveys. Divers collected metrics on the following characteristics to assess in-water effects from military training:

1. Fresh, un-colonized craters, pits or peels
2. Fresh/cracked, broken or fragmented coral or sea floor rocks
3. Freshly derived terrestrial rock fragments or boulders
4. Fresh intact ordnance and the condition of such ordnance (e.g., badly bent, gouged, etc.)
5. Fresh ordnance fragments
6. Old ordnance
7. Old ordnance fragments

Objects, such as ordnance or rock, introduced to the marine environment quickly became colonized by marine organisms. These organisms increase in density and size, and changes in community structure from pioneering to climax species occur through time (e.g., Bailey-Brock 1989). In this study, "fresh" and "old" ordnance items were differentiated as such: Fresh ordnance contained little to no marine biological growth or contained only a bacterial film covering the surface. Fresh rock similarly contained little to no marine biological growth, or had terrestrial vegetation still attached. Old objects support an abundance of naturally occurring benthic flora or fauna, such as algal turf, crustose calcareous algae, coral, tube worms, bryozoans, etc., indicative of having been submerged and/or exposed for several months to many years. Depending on the degree of development and the type of species involved, it is possible to determine that some ordnance items have been submerged for many years.

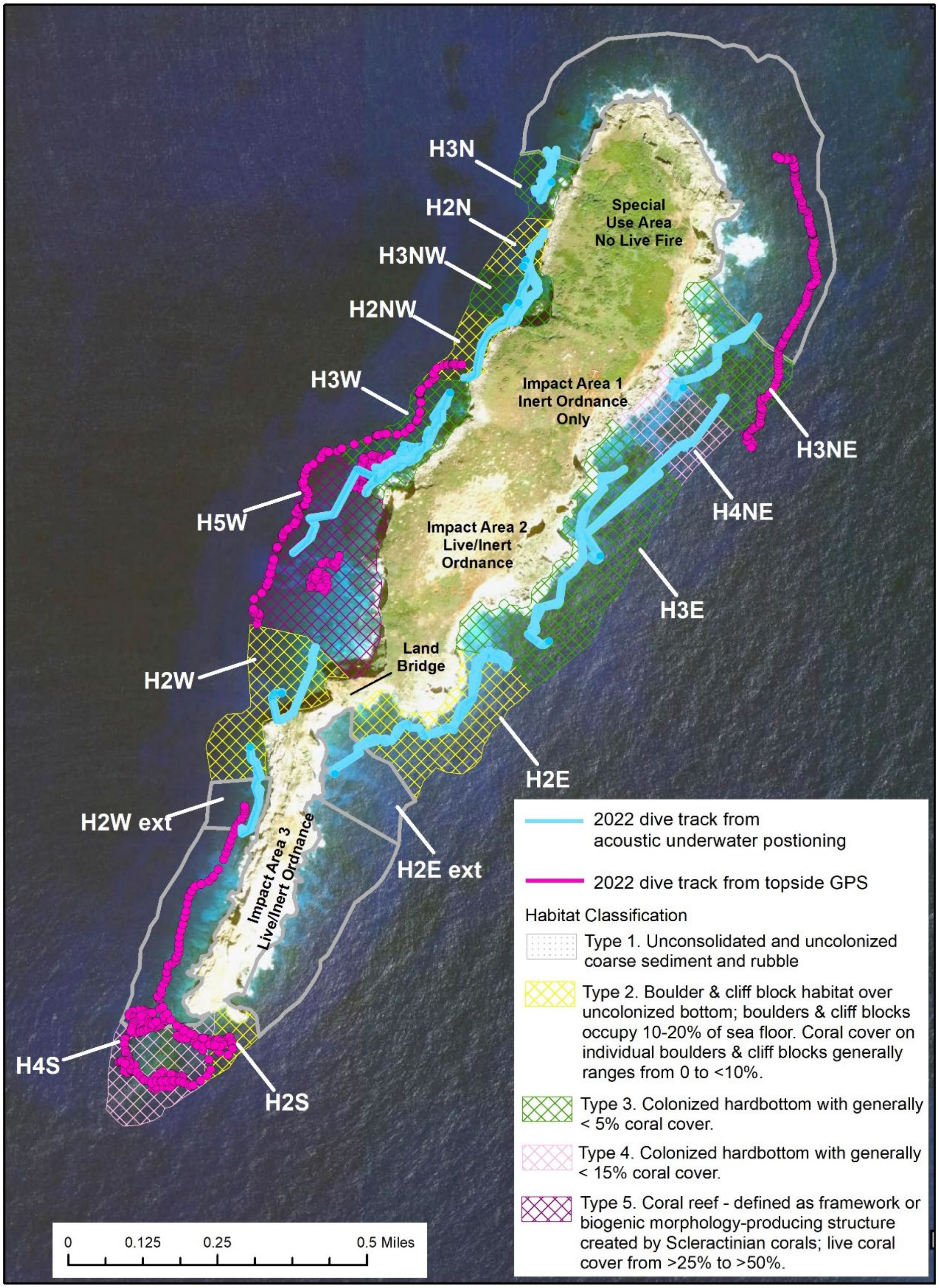

Figure 4: Map of FDM with approximate locations of different habitat types and defined based on historical coral cover (See Habitat Classification Key). Light blue lines were plotted from Latitude/Longitude positions of divers obtained by the SeaTrac underwater acoustic positioning system at two-second intervals showing total area surveyed in 2022.

All divers noted other ESA-listed species observed from the surface or underwater or heard underwater while completing the above tasks [G6]. Within the Mariana Archipelago, three fish species and four sea turtle species had been recorded from the archipelago and may use the waters around FDM and were listed under the ESA at the time of the 2022 survey. These species are:

1. Scalloped hammerhead shark (*Sphyrna lewini*): NOAA divided this species into six Distinct Population Segments (DPS). The Mariana Archipelago is located within the Indo-West Pacific DPS and the scalloped hammerheads in this DPS were classified as threatened under ESA. This species has never been sighted or reported from FDM (Smith and Marx 2016, Carilli et al. 2018).
2. Oceanic whitetip shark (*Carcharhinus longimanus*): NOAA listed this species as threatened throughout its range. This species was not recorded at FDM.
3. Giant manta ray (*Manta birostris*): NOAA listed this species as threatened throughout its range. This species was not recorded at FDM.
4. Five species of sea turtles were recorded within the Mariana Archipelago. However, only two species were recorded by FDM (Smith and Marx 2016): the green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*). Both species were sub-divided into DPSs. The Mariana Islands' turtle populations fall within the Central West Pacific DPS, where both species are listed as endangered. Two other nearby DPSs for the green sea turtle (East Indian-West Pacific DPS and Central North Pacific DPS) are listed as threatened. Individuals from each of these nearby DPSs are believed to be present within the Mariana Archipelago occasionally (G. Balazs, personal communication 2016).

2.3 GEOREFERENCING

Each diver wore an acoustic transponder allowing the diver's relative position (range and bearing) from the boat to be tracked. A topside computer and specialized software (PinPoint, by SeaTrac) was used to convert their relative position into real-world coordinates (latitude and longitude) during the dives using boat positions from a directional geographic position system (GPS) mounted on the dive vessel. Diver tracks were recorded in a proprietary file format by the PinPoint software, and then later converted into National Marine Electronics Association (NMEA) format files. A handheld Garmin Montana GPS was also used to track the position of the dive vessel during the dives (which followed the divers at a safe distance), and to collect waypoints marking times when the divers were essentially co-located with the boat. In addition, Diver 2 wore a dive computer with GPS functionality providing the surface position of the diver at the end of each dive.

For unknown reasons during this survey, the diver's beacons were not functioning and overall neither beacon provided as many position fixes back to the topside system as during the prior 2017 survey and other recent uses of the system. This led to relatively sparse diver positions available to georeference photographs. Photographs taken by the divers were georeferenced to their real-world locations by matching the timestamp of the photographs to the timestamp of their dive positions, using the computer program HoudahGeo. When using the original sparse diver-tracks, the georeferencing approach led to multiple diver photographs being assigned the same position, which was not correct. To improve georeferencing, more realistic diver tracks were created by first filling in likely approximate positions for one or both divers by assigning locations and timestamps from either (a) the more-communicative SeaTrac beacon, (b) the dive boat GPS, (c) the end-of dive dive-computer GPS, and/or (d) map interpretation from all spatial data sources so there were approximate positions that spanned the entire length of each dive. This was completed in Geographic Information Systems (GIS) using ArcGIS and GoogleEarth software with input from the project team, who provided the most realistic dive track from the existing position data. Then, additional estimated time-stamped positions were interpolated along each dive track, adding points once every second between each recorded position, to improve photo geolocation and prevent unrealistic photo clustering. This method assumed that divers swam at a constant rate and in a straight line between each recorded position over relatively short segments (e.g., several to tens of meters and minutes) where position data was sparse. This method provided more realistic time-stamp matching-based positions for each of the collected underwater photographs. Geographic positions were written into each photograph's exchangeable image file (EXIF) metadata tags using HoudahGeo software and digitally printed at the bottom of each photograph JPEG image using MATLAB software.

2.4 IMAGE ANALYSIS FOR CORAL IDENTIFICATION AND CORAL HEALTH ASSESSMENT

All images were initially reviewed and characterized to different extents based on the types of photographs collected. To the maximum extent possible, all coral species captured in the photoquadrats and other photographs were identified to species level.

In photoquadrat images, all scleractinian coral colonies that could theoretically be identified were annotated with a number. Subsequently, a NIWC Pacific analyst identified each annotated colony to the lowest possible taxonomic level. Coral identification proceeded by the analyst comparing each numbered coral in the photoquadrat to coral references and guides, including the FDM Coral Species Representative Photograph document that was prepared with the assistance of coral taxonomy expert Dr. Doug Fenner (2017 FDM survey photographs), Veron, et al. (2016), and other publications. Taxa names, health codes and identification notes were then recorded in Excel workbooks and organized by dive and transect numbers. When the analyst was uncertain of an identification, this was indicated in the workbook. A second NIWC Pacific scientist then reviewed the initial identifications focusing on flagged entries to assist in confirming or correcting identifications.

In addition to taxonomic identifications, each colony was assigned a health code when possible to denote bleaching, disease and damage, and to indicate if the colony looked like it was being actively overgrown by other organisms (Table 2). Note: photoquadrats were not randomly distributed within each surveyed habitat. They were collected in locations that included living corals and the diver assigned to collect photoquadrat images assessed as being representative of the habitat. This representative survey design prompted the more comprehensive identification of all corals on all photoquadrats (rather than selecting random points for identification on each image). This additional effort also produced a rich dataset for future analyses of coral morphological diversity, coral composition and health by coral size, class and relationship of these characteristics with environmental and spatial drivers at FDM.

Table 2: Coral health codes used for photoquadrat analysis.

Health code	Meaning
H	Healthy
B	Bleached (100%)
M	Mottled or partially bleached
P	Pale
D	Diseased
Br	Broken
De	Dead (recently dead)
O	Part of living coral is being overgrown by algae, sponge, etc.

Excel workbooks were used to compile coral IDs by day, dive, transect and photoquadrat number. Because taxa names were keyed to photoquadrat numbers and coral ID numbers, other team members were able to compare, discuss specific specimens, and update identifications in the identification workbooks. In some cases, photoquadrat images included marking numbers that were not associated with a coral; these data points were entered with “XX” in the identification and health assessment spaces. Finally, the entire dataset was compiled into a master workbook.

2.5 CORAL COVER ASSESSMENT

All coral cover observations from 2017 (Carilli et al. 2018) and previous surveys were recorded by the same NIWC Pacific SDS diver; however, that individual retired prior to the 2022 effort. To ensure that coral cover around FDM [G2] was quantified for the 2022 survey using similar protocols as prior efforts, georeferenced landscape photographs were analyzed from the same general sites and depths in both the 2022 and 2017 surveys by three different NIWC Pacific scientists and compared between one another and with in-water site assessment data collected during these surveys. This allowed the NIWC Pacific scientists completing the 2022 survey, data analysis and reporting, to calibrate and normalize site level assessment and reporting to ensure that the same information reported herein can be more directly compared to prior surveys, despite the change in personnel completing this portion of the analysis for the 2022 survey.

While many different types of substrate exist at FDM (including sand, rubble, bare rock, rock colonized by living corals, rock colonized by turf or macroalgae, etc.,) in prior surveys only two general categories of substrate were recorded and reported: 1) overall percent of the benthos comprised of unconsolidated material (sand and rubble) and thus unsuitable as coral habitat, and 2) the percent of the benthos comprised of stable rock that could potentially provide suitable coral habitat (not considering the nuances of this, such as whether a given rock surface was colonized with fleshy algae which could impede coral settlement, or was crustose coralline algae which could enhance coral settlement, for example). The characterization of benthic substrate (rock vs. unconsolidated material) is an important factor to consider in assessing the overall percent of living coral, because in some areas around FDM, suitable stable rock habitat is absent or sparse, and therefore can in some cases partly or largely explain relatively low coral cover when considered on a site-wide scale. Therefore, for this and prior surveys, both the percent of the benthos at a site that is comprised of stable rock (i.e., is not unconsolidated) is reported, as is the percent of that stable rock substrate that is currently colonized by living corals.

2.6 CORAL IDENTIFICATION CHALLENGES

Coral species identification presents many challenges. Coral taxonomy has historically been based almost entirely on skeletal morphology until recently when the results of DNA sequencing studies have led the authors of those studies to group coral species in different ways into genera and families. For example, molecular evidence discussed in Budd et al. (2012) led those authors to suggest that the genus *Montastraea* should be split into three different genera: *Montastraea, Orbicella,* and *Phymastrea*.

As noted above, classical coral taxonomy and identification is primarily based upon morphological characteristics of coral skeletons, not living coral tissue characteristics (for example, tissue color is a poor indicator as it can vary widely within a species or even a single colony). A variety of morphological features of coral skeletons are useful for taxonomy and identification, ranging from overall colony shape to microscopic details of the skeletons. Colony shape is almost always visible for living corals underwater, but microscopic details are sometimes not. Coral tissues are thin for most species, so that some of the larger features of coral skeletons (such as the number, size, and shape of the septa, and whether the thecal walls are fused or distinct) can be seen underwater and in clear, close photographs. One benefit of coral identification in the field is whole colonies can be seen, while in skeleton collections, often only fragments of colonies are available. Further, large numbers of colonies can be seen by divers in situ, which helps in the assessment of variation. In skeleton collections only a tiny fraction of colonies will be represented, even when many fragments are sampled. However, the most reliable coral identifications are based on skeleton examination under a dissecting microscope.

Underwater photographs provide evidence that can be examined after dives have been completed and provide an archive of information from a particular time point that can be re-examined. Photograph quality, however, varies widely from a coral identification standpoint, from excellent to essentially useless. Because features of corals span the size range from entire colonies (cm – m) to microscopic (<mm), photographs of a whole colony as well as sharp macroscopic images are very helpful in positive coral species identification. Lighting of coral photographs is also important; if images saturate under very bright conditions, no skeletal details can be seen, making identification difficult. When corals are bleached, as were some of the corals during the survey reported (and many corals during the previous 2017 survey), identification is much more difficult because small features of coral skeletons often cannot be discerned either in the water or in pictures.

Even within a species, corals are highly variable at all spatial scales, from the smallest microscopic spine to colony-scale variability between individuals across a reef. Within-species variability becomes even greater over larger geographic distances. In this study, the range of survey goals to be met precluded focusing substantial effort on taking the best possible photographs of living corals for subsequent reliable identification, and instead focused on collecting larger numbers of representative photographs spanning as much of the island habitat as possible. Furthermore, coral tissue or skeleton samples could not be collected, and in-water work and imagery analysis could not be completed by a coral taxonomist. Therefore, this study seeks to apply the best science possible to determine coral taxonomic identifications using the available photographs and references described above, noting that identifications presented vary in certitude. Some photographs were suitable for confident certainty of identifications (especially for very distinct species, such as *Herpolitha limax*), but in some instances, even the genus of colonies could not be identified, even tentatively (these entries were coded as "NP", meaning not possible to identify). For the 2017 FDM survey, a coral taxonomist (Doug Fenner) provided his expertise to identify representative photographs of species encountered, primarily to create a species key used to identify other corals in photoquadrats during that survey and the 2022 survey. Dr. Fenner also assisted in identifying photos presumed as ESA-listed corals by the project team. For the 2022 survey, coral reef subject matter experts completed identifications, but those scientists were not trained taxonomists and therefore their ability to determine that a given coral was undescribed (or a hybrid and not named species) was more limited than the 2017 survey. For future survey efforts, if more certainty in species identification is desired, additional resources and different methods can be applied.

2.7 SPECIES LIST COMPILATION

After image analysis work was completed, a coral taxa list was compiled and refined. This list includes all genus and species names assigned to taxa in this 2022 analysis, representing a partial list of coral taxa in the study area (Appendix C). In addition, coral taxon nomenclature was reviewed, and names were updated to reflect taxonomic changes that have occurred since the earlier surveys that identified coral species at FDM. In addition, Veron et al. (2016) was reviewed to determine whether corals identified during the 2022 or prior surveys are recognized as occurring within the Marianas Archipelago; in several cases, mostly from the 2001-2004 surveys, corals at FDM were identified as a species that is not currently recognized as occurring in this area.

2.8 DATA ANALYSIS

Pivot tables were used for summary analysis in Excel following final data compilation and review of the master dataset. Percent cover of potential coral-bearing substrate and percent coral cover were assessed based on the landscape photos taken during the 2022 survey. Potential coral-bearing substrate was defined as any area that was comprised of hard substrate (i.e., rock or framework building coral reef). In several cases, hard substrate was often covered by a thin layer of sand or algal matter, (see diver notes in Table 3). To minimize the potential impact of individual subjective analysis, three NIWC Pacific scientists analyzed landscape photos from seven different dives (three from 2017 and four from 2022 that occurred in the same general habitat location and depth in both 2017 and 2022). It was found that their results for percent hard substrate and coral cover were not significantly different (95% confidence interval) for each dive; therefore, a single NIWC scientist analyzed the remaining landscape photos for 2022. Percent coverage of potentially coral-bearing substrate (rock) and percent coverage of coral are summarized in Table 3 for comparison between habitat subareas, habitats and years (2022 survey vs. 2017 and historic results). Additionally, the 2017 reanalyzed dives are shown in Table 3 for comparison to the hard substrate and percent coral values that were reported based solely on in-situ assessment and diver notes.

For each habitat type, proportions (based on number of occurrences) of corals were computed to assess community composition. This same analysis was conducted for coral condition. Coral composition and health summaries are presented as bar and pie charts respectively.

Diversity indices (Shannon Index, H and the Simpson Index, D) were calculated to further explore coral community variation between habitats. The Shannon Index (H) is a measure of biodiversity that is based on the weighted geometric mean of the proportional abundances of the species in the community and is calculated as:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the proportion of individuals belonging to the i^{th} species (or taxa) in the dataset of interest. A high value of H indicates a diverse and equally distributed community, while a lower value indicates a less diverse and less evenly distributed community. A value of 0 indicates a community with just one species. The Simpson Index (D) also accounts for the abundance and evenness of species present in the community and is calculated as:

$$D = \sum_{i=1}^{S} p_i^2$$

Values of D range between 0 and 1, with 0 being infinite diversity and 1 being no diversity. The Simpson Index is often expressed as 1-D, with numbers close to 1 representing high diversity.

For the 2022 survey, photoquadrat dives were completed at a variety of depths (which averaged approximately 25, 30, 35, 40, 45, 50, 55, and 60 feet below the surface) across the island to ensure broad coverage. Data from specific depth strata were generally not sufficiently large to analyze separately, but general observations were made of variability in coral community and coral health as a function of depth.

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3. RESULTS

Surveys were conducted in all habitat types around the island, including the collection of approximately 1,050 photoquadrats on 73 transects and 615 representative photos in the survey area. The 2022 survey collected 40% more photoquadrat images compared to the 2017 survey (750 photoquadrats from 50 transects were collected in 2017). Habitat descriptions and representative photographs are presented in Appendix B.

3.1 [G1] ESA-LISTED CORALS

Identification of corals to species in the Indo-Pacific is inherently challenging because of high diversity and variables within-species morphology, which occurs between genetically different individuals (as it does in all animal species) and under different physical regimes (Fenner and Burdick, 2016). The most secure identification of corals requires skeleton samples, which were not available for this study; next best are high-quality paired underwater photographs of whole colonies and close-ups, which were not available in most cases. When corals were bleached, pale or very small numbers of polyps were visible, identification was much more difficult and tentative. In addition, it is possible that some corals at FDM represent new, undescribed species or hybrids, or unusual morphologies of named species that may look similar to other species. Accurate taxonomic identification was completed to the best degree possible, and results presented represent plausible identifications but should be interpreted with a degree of caution.

A total of 16 colonies of corals were identified as *Acropora globiceps* in the 2022 FDM imagery; 10 colonies in photoquadrat images and 6 from additional photos. Several examples are shown in Figure 5. In addition, a total of 24 colonies were tentatively identified as *A. retusa*; 10 in photoquadrat images and 14 in other photos (note, some individual colonies were captured in multiple images). An example of one colony identified as *A. retusa*, along with an image of *A. retusa* from Veron et al. (2016) is shown in Figure 6. A small number of other similar-looking Acroporid corals were also identified in photoquadrat images: 4 colonies were believed to be *A. gemmifera,* 2 were identified as *A. humilis,* and 1 colony was identified as *A. monticulosa* and *A. digitifera*. The corals identified as the ESA-listed species *A. globiceps* and tentatively as *A. retusa* were observed at several locations around the island (Figure 7).

Figure 5: Colonies of the ESA-listed coral, *Acropora globiceps,* captured by Diver 2 during the directed search effort for ESA-listed corals [as part of G1]. Original photographs slightly cropped for clarity here.

Figure 6: Example (left) of potential ESA-listed *Acropora retusa* colony captured by Diver 2, compared with (right) a photo of *A. retusa* from Corals of the World.

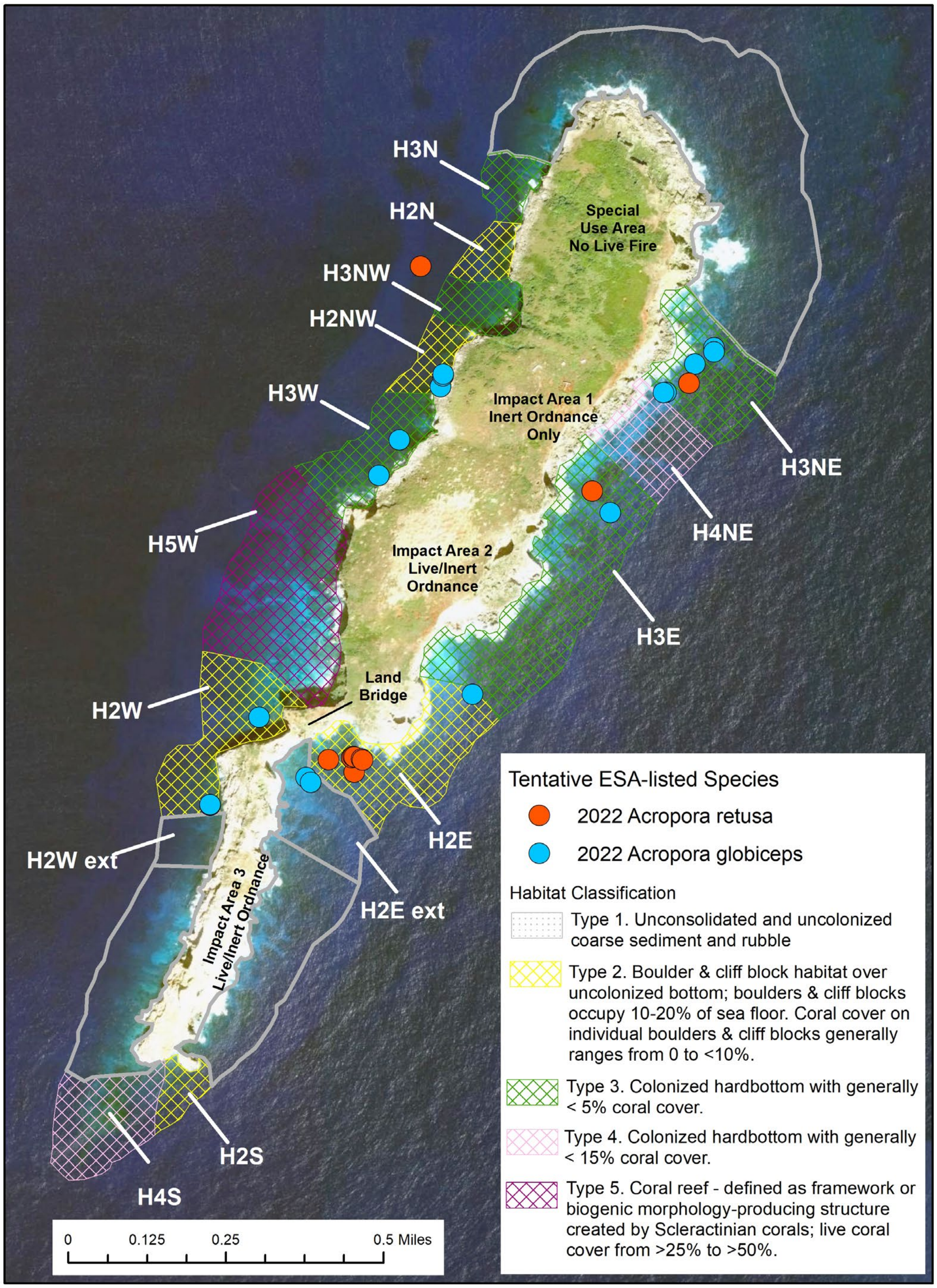

Figure 7: Map of FDM showing locations of corals identified in this study as ESA-listed species.

In 2017, a number of specimens of an unidentified *Acropora* sp., closely resembling *A. globiceps* were seen in both the photoquadrats and representative/general photos. Dr. Doug Fenner completed a meticulous inspection of those photos and compared these with specimens from Samoa, Tonga, Fiji and CNMI, and concluded that those colonies may represent a new species, closely resembling *A. globiceps*, but differing in important distinguishing characteristics. The 2022 survey did not employ an outside coral taxonomist. The NIWC Pacific scientists, considered coral SMEs but not taxonomists per se, tasked with completing this work identified these and all other coral colonies in imagery to the best of their abilities. However, it is possible that some of the identifications are incorrect, particularly if there are corals at FDM from new undescribed species.

Features that are usually the most helpful in *Acropora* sp. identification are colony shape, length and shape of branches, shapes and sizes of radial (side) corallites, and the size of the axial corallite (at the end of the branch). The last two of these three features can only be accurately observed under a dissecting microscope, but sometimes can be differentiated underwater or from clear photographs. Literature specifying and illustrating these features for named species are necessary for identification, and where possible original descriptions and type specimens should be supplemented by more recent observations with improved techniques and those that capture a range of morphologies. Morphologies of specimens within the same species can vary greatly due to genetic and environmental factors. Energy levels (i.e., surge, current, storm frequency), water clarity and light levels are generally considered the most important factors; however, predators, disease, pollutants, sea temperature, sex, etc., can also result in morphological variation. For FDM, the dynamic conditions that include a high-wave energy environment and frequent and severe storms are believed to be the most important factors that influence morphological variance. Also, any particular colony cannot be assumed to be a named species, and it may be good practice to resist applying species names to colonies that look a bit different since this may represent a new species.

No *Acropora speciosa* or *Seriatopora aculeata* specimens were seen, and none have ever been reported during the previous 15 surveys. One colony of the coral *Pavona* cf. *diffluens* was identified in photoquadrat imagery. *P. diffluens* is ESA-listed in the Indian Ocean and Red Sea. However, neither NOAA, nor J.E.N Veron recognize its presence within the Marianas Archipelago (Veron 2000, Fenner and Burdick 2016) and it is not ESA listed in the Pacific Ocean. Randall (2003) reported *P. diffluens* from Guam, but as with the corals identified during the 2017 survey and 2022 as *Pavona* cf. *diffluens* at FDM, this could be a different species that resembles *P. diffluens*.

In summation, 16 colonies of the ESA-listed coral species *Acropora globiceps* (10 in photoquadrat imagery) and 24 colonies tentatively identified as the ESA-listed *Acropora retusa* (10 in photoquadrat imagery) were identified based on morphological characteristics assessed in photographs collected during the 2022 survey. Assuming all identifications are accurate, colonies of each of these species numerically comprise ~0.1% of the total coral community at FDM.

3.2 [G2] PERCENT CORAL COVERAGE

Habitat types around FDM were previously defined by compiling semi-quantitative data acquired from multiple previous surveys by SDS divers at FDM. Habitats were divided into six primary types described in SSC Pacific 2017a and presented in Figure 4 and Appendix A, based on the percentage of the benthos comprised of rock and/or coral, and the general amount of living coral growing on these hard surfaces. There was no apparent change, addition or deletion to these six types observed during the 2017 survey. The basic habitat types and distribution remained largely unchanged in the opinion of the biologists who conducted all surveys since 2005. The general habitat types are described here, and overall observations from 2022 regarding the percent of the benthos comprised of hard bottom (vs. unconsolidated material such as sand and rubble), and the percent of hard bottom currently colonized by living coral, is presented.

Type 1 habitat is comprised of unconsolidated and uncolonized sediment and rubble with generally no coral. Type 6 habitat is comprised of cliff faces, rock, and sediment at the water's edge exposed to very high energy and with almost no coral (0-2%). Because these habitats were unlikely to contain ESA corals, they were generally not targeted for survey in 2022 (or 2017). However, some of the dives included areas previously identified as Type 1 habitat either as part of a dive segment that transitioned to/from Type 1 habitat or as an opportunistic verification/validation of the habitat type.

Type 2 habitat (H2) was originally defined as being comprised of cliff blocks and boulders scattered across sediment. Based on previous survey data, these blocks made up 10-20% of the seafloor and hosted 0-10% coral cover; thus, across the entire area, coral cover would be estimated at approximately 0-2%. The threatened coral *Acropora globiceps* was field-identified prior to the 2017 survey on some of these blocks. During the 2017 survey, the single confirmed specimen of *A. globiceps* as well as the other possible *A. globiceps* colonies were observed in this habitat type. During the 2022 survey, *A. globiceps c*olonies as well as colonies tentatively identified as the ESA-listed coral *Acropora retusa* were identified in H2 but were also identified in other habitat types as well. In 2022, the H2 habitat areas surveyed had on average much higher hardbottom, with a midpoint of 87.5% hardbottom (+- 12.5%) and had less coral than in 2017, with approximately 10% (+-9%) coral growing on that hardbottom (Table 3).

Type 3 and Type 4 habitats (H3 and H4) were originally defined as colonized hardbottoms with 0-5% and 5-15% coral cover, respectively. Type 5 habitat (H5) was defined as 100% hardbottom and occurs in only one relatively small region on the southwest side of FDM. A small area within H5 (approximately 500m x 250m) was defined as being comprised of true coral reef, with live coral cover ranging from more than 25% to over 50% and growing on dead coral framework.

Percent coverage of coral-bearing substrate (i.e., rock) and percent coverage of coral observed in 2022, 2017, and historically is presented in Table 3 with summaries by habitat subarea (e.g., H2N, H2NW, etc.) and habitat type (H2, H3, etc.; see Figure 4). As in 2017, coral cover encountered in 2022 was highly variable between and within habitat types, so estimates of total coral cover in the different habitat types should be considered rough estimates. As described in the 2017 FDM coral reef survey report, a habitat map such as that produced previously (Figure 4) based only on 2017 observations would have resulted in combining H3 and H4 into one habitat type, but the habitat map produced previously was still considered largely accurate. The 2022 survey results were similar to 2017, in that the coverage of hardbottom was similar between the surveyed H3 and H4 habitat areas, although H4 had somewhat less living coral than H3 (the opposite of the original definition used to delineate these habitat types).

During 2017 and 2022, fewer dives were made than in previous years, and they generally covered less area due to different requirements for these surveys (e.g., georeferenced photo-documentation and deeper survey depths in 2022). However, sampling distribution was comprehensive around the island in 2022, which included dives between 20-30 meters due to the 2020 BO requirement to survey to that depth (NMFS 2020). Depths of up to 31 m were surveyed during the 2005-2012 events (Smith et al. 2013). Different locations and depths surveyed were affected by the sea state, survey goals and requirements for dive safety, such as completing the deepest dive of the day first. Therefore, directly comparing observations between time periods is somewhat problematic. In the 2022 analysis (in which landscape photographs taken from the same sites and depths in 2017 and 2022 were re-analyzed), and suggested in the 2017 FDM survey report, additional time comparing previous trip photographs and notes could strengthen the authors' ability to detect and quantify changes between surveys and should be included during planning of any future surveys.

Table 3: Percent coverage of coral-bearing substrate (rock) and percent coverage of coral on rock.

Surveys	**2022**		**2017**		**Prior years**		
Habitat Type Subarea	**% Rock**	**% Coral on rock**	**% Rock**	**% Coral on rock**	**% Rock**	**% Coral on rock**	**Notes**
H2N	92-100%	1-4%	20-35%	<10-50%	10-20%	0-10%	**2022: Bare rocks with gentler slope, *Leptastrea purpurea*. *Porites* massive dominant. *Padina* dominant alga. Some coral species with possible diseases (images: 231/232). Lots of boulders with bare rock. Coarse rock and pebbles, many large boulders, and wall faces, old *Pocillopora damicorni* and *P. eyedouxi* mortality.** 2017: This area was extremely variable; several individual bedrock 'spurs' had >50% coral cover; *P. meandrina* complex was dominant & virtually 100% were severely bleached. However, there were large areas of hard substrate w/<10% coral cover. Overall, there was a dramatic increase in coral cover here vs. previous surveys. This area used to support substantial soft coral (*Lobophyton* sp. + *Sinularia* sp.) few were seen 2017.
H2NW	86-100%	3-13%	10-20%	10-25%	10-20%	0-10%	**2022: Grottos in wall face east, boulders to the north and west. *P. lobata* dominant in most areas, except some small regions where *Porites rus* is dominant. Old mortality of *Pocillopora eyedouxi*, lots of boulders and course sand/rock** 2017: 10% up to 25% in some cases; more corals than in previous surveys; > 2/3 of colonies bleached; most *Porites* massive corals were either not bleached, or only slightly pale.
H2W	75-90%	7-19%	10-20% (Re-calibrated from 2017 landscape photos: 76-94%)	<5-20% (Re-calibrated from 2017 landscape photos: 9-23%)	10-20%	0-10%	**2022: Sand and bare rock with sand. 10% old mortality (*Leptastrea purpurea*). Sand/shell hash. South face has wall with waves breaking at surface. Several juvenile *Tridacna* giant clams. Steep drop offs/radical slope** 2017: Highly variable sea floor cover; > 2/3 of colonies bleached; *Porites* massive corals were either not bleached, or only slightly pale.
H2S	Not recorded		10-20%	≤5%	10-20%	0-10%	

H2E	80-92%	6-15%	10-20%	0-10%	10-20%	0-10%	**2022: Highly variable landscape. Large sections of rock with sand and strips of coarse sand/small rocks between. Also, large area of rock covered with sand and algae. Sand valleys with small boulders. Change in % coral and % cover of rock mid dive. *P. lobata* dominant.** 2017: Area included many old (3-5 yrs) dead *P. meandrina* (complex) colonies; bleaching was severe for living *Pocillopora* colonies.
H2 (midpoint ±range interval)	**87.5 ±12.5%**	**10 ±9%**	**22.5 ±12.5%**	**25±25%**	**15± 5%**	**5±5%**	
H3N	70-90%	3-10%	85% (Re-calibrated from 2017 landscape photos: 78-95%)	<5-25% (Re-calibrated from 2017 landscape photos: 22-42%)	≥85%	<5%	**2022: Large area of soft coral on west site. Lots of bare rock and sand. Some large boulders in sand. Old mortality of *Pocillopora damicornis* and *P eyedouxi*. *P. eyedouxi* breakage from rock impact, likely occurred between 2017-2022. Soft and Stony corals later in the dive, bottom drops off near the end of the dive. *Halimeda* dominant alga** 2017: Coral cover highly variable; similar stretches during dive ranged from <5% to >25%.
H3NW	63-83%	7-24%	80%	<5-10%	≥80%	<5%	**2022: Boulders and bare rock. Huge area of 1 species of *Goniopora sp.* coral. Boulders and coarse rock/pebbles later on in dive. *Padina* prevalent. Old *P. damicornis* mortality near end of dive.** 2017: Coral cover generally < 5%; some limited areas had 10-15% coral.
H3W	71-95%	5-20%	80%	<5%	≥80%	<5%	**2022: Loose rock, sand with occasional boulders. *Porites lobata* dominant. Big boulders later in the dive. Coral healthy, no bleaching. Day 4 dive 2: shows lots of rock covered with sand and boulders.** 2017: Less diversity, more partial mortality and bleaching. This area previously supported extensive soft coral; almost none sighted. *P. meandrina* complex and *Leptastrea purpurea* were the dominant corals based upon frequency of occurrence.
H3E	Not recorded		≥70%	5%	≥70%	<5%	**2022: Coarse rock/sand with rock bed. *Favites* dominant. Wide sand ripples with boulders. Only photoquads taken.**

							Zero percent coral at deeper area where coarse rock/sand is prevalent. Extremely strong current throughout dive. 2017: With a few small exceptions, coral cover ~5% on suitable substrate. Appeared to be more *P. eydouxi* on this dive than any other; most were either healthy, or just slightly pale; *P. meandrina* complex and *Acropora* sp. were severely (>2/3) bleached.
H3NE	47-76%	1-3%	50-70%	5-20%	≥50-70%	<5%	**2022: Large boulders supporting coral. Rest of the area is a wide swath of coarse sand and bare rock, with intermixed big boulders. Day 6 dive 1 shows mostly sand and *Padina* algae in between coral.** 2017: Overall coral cover est. ~5% of potentially colonizable sea floor; some boulders & ledges had 20% coral cover. This part of the island has highly variable habitats that grade into one another.
H3 (midpoint ±range interval)	**71 ±24%**	**12.5 ±11.5%**	**67.5 ±17.5%**	**15±10%**	**67.5 ±17.5%**	**<5%**	
H4S	Not recorded		80%	15%	≥80%	<15%	**2022: Extremely strong sea state and current. Rock face with sand slopes. Could not stay on location long due to conditions.** 2017: ~15% live coral, w/ >2/3 colonies bleached; additional ~15% of sea floor = dead *P. meandrina* complex corals; appear to have been dead 3-5 years; could be the massively infected *P. meandrina* corals from the *Cantellus* barnacle infestation in 2012. Abundant new *Pocillopora* recruits (3-7 cm), but all 100% bleached. Between 50-70 ft coral cover reduced to 5-10%; below 65-70 ft, nearly all rubble w/<5% coral.
H4NE	51-81%	3-10%	100% (Re-calibrated from 2017 landscape photos: 36-67%)	5-10% (Re-calibrated from 2017 landscape photos: 15-29%)	100%	<15%	**2022: Mostly sand and *Padina* algae in between coral. Sand valleys with boulders, and rock ridges. Coarse sand/rock slope with boulders.** 2017: Many coral colonies bleached.

H4 (midpoint ±range interval)	**66 ±15%**	**6.5 ±3.5%**	**90±10%**	**10±5%**	**90± 10%**	**<15%**	
H5W (H5)	85-98%	12-32%	100%	40-65%	100%	>25 to >50%	2022: **Bare rock with some sand, *P. lobata* dominant and coral healthy on Dive 1 Day 2 track. Lots of old mortality of *P. lobata* on Day 3 Dive 1 track (South to North). *P. rus* dominant** 2017: Highest coral diversity of any area; many massive *Porites* corals >200 cm in maximum dimension that showed little or no bleaching. Some massive *Porites* corals were bleached, diseased, overgrown with sponges. *P. meandrina* complex was severely bleached. Overall coral cover ~40%, but some sections of up to 500 m^2 had ~65% coral cover.

3.3 [G3] CORAL SPECIES COMPOSITION

Corals from 32 genera were identified in the photoquadrat images collected in 2022 (Appendix C). A total of 7.8% of coral colonies annotated in the photoquadrat imagery were not identified to species or genus. These colonies were captured at the edges of photographs and were either too blurry, bleached, washed out or were very small and included a few corallites. When this occurred, these issues made it impossible to identify colonies in these photographs. Approximately 94 unique taxa of corals were either positively identified or recognized as individual species but not able to be identified below genus level (Appendix C). To allow for all 2022 photoquadrat images to be analyzed, NIWC Pacific scientists chose not to differentiate the more common massive *Porites* species (*Porites lobata, Porites lutea, Porites evermanni,* possibly other similar looking species) for this survey, referring to all of these species as "*Porites* massive".

Several new tentative species observations were made from the 2022 imagery for corals that have not previously been recorded at FDM. This includes *Acropora retusa* (described above), as well as *Acropora monticulosa*, although only one colony was identified as the latter species. In addition, there were 6 colonies in photoquadrats identified as most likely being *Alveopora minuta*, 15 colonies that were likely *Porites deformis*, and two colonies of *Psammocora nierstraszi*. In 2017, all *Cyphastrea* corals were identified as *Cyphastrea* unknown; however, on review of the *Cyphastrea* species recognized in the Marianas Archipelago in 2022, it is believed that all or nearly all *Cyphastrea* colonies are most likely *Cyphastrea ocellina*, based on the size and spacing of the corallites. Other *Cyphastrea* species previously recorded at FDM were not observed in the 2022 imagery. As noted earlier, it is difficult to make confirmed identifications of coral from photographs, and a taxonomist did not review the photographs or this report. Thus, all identifications should be used cautiously.

There were also several cryptic, large polyp corals that were identified from the 2022 imagery. One colony was identified as the solitary coral *Cycloseris costulata*, and two were thought to be *Parascolymia australis.* Five colonies were also tentatively identified as *Echinophyllia tarae*; this coral was recently described from French Polynesia (Benzoni 2013) and has not been previously identified in the Marianas Archipelago. Other new species of lobophylliid corals have also been recently described in the Indian and Pacific Oceans (Arrigoni et al. 2016, 2019), suggesting that this species at FDM may be either a new distribution record or a different species. These are distinct looking colonies that did not look similar to any other species recognized as occurring in the Marianas.

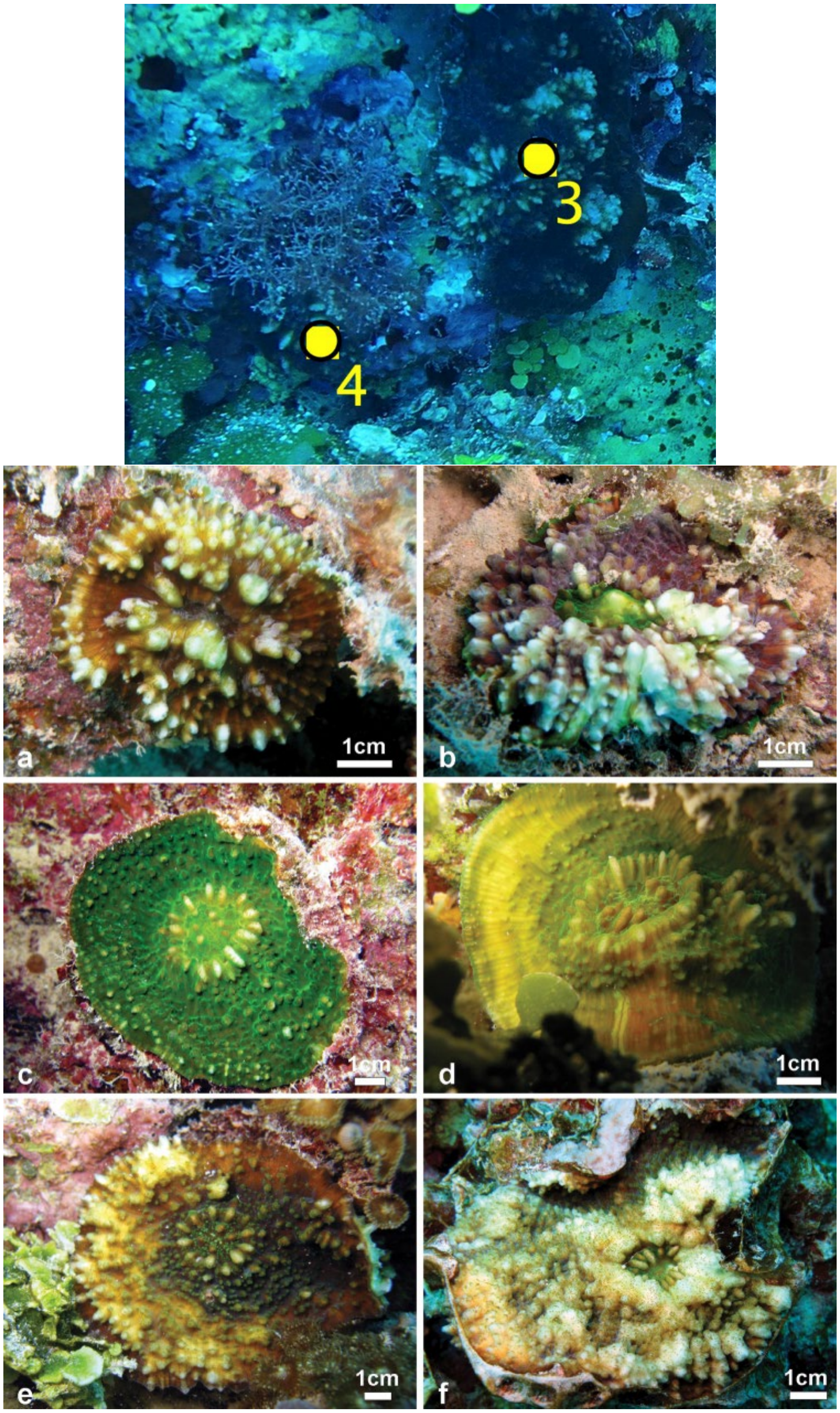

Figure 8: (Left) Coral colonies tentatively identified as *Echinophyllia tarae* from the 2022 FDM photoquadrat imagery compared with (right) photographs of *E. tarae* from the paper describing the species (Benzoni 2013).

Favid-type corals are common at FDM and diverse morphologically. Extra effort was made to differentiate and identify these species from the 2022 imagery. The science team believes one colony in the photoquadrat imagery was *Favia danae*, two were *Favia helianthoides*, 18 were *Favites flexuosa*, 49 were *Acanthastrea regularis,* and 16 were *Phymastrea colemani*; all of which are species not previously identified at FDM, but recognized to occur in the Marianas Archipelago (Veron et al. 2016). Additional colonies were identified as *Favia favus*, *Favia speciosa*, *Favites abdita*, and *Favites russelli*, which were identified at FDM during earlier surveys, but not in 2017. Several of the unknown *Favia* and *Favites* identifications may have been these previously identified species or the newly identified species. Some colonies were still identified as one of the unknown categories used in 2017 because the imagery was not clear enough to provide better identifications, and the colonies looked most similar to representative images of those species in the 2017 species representative photograph document compiled and delivered along with the 2017 FDM survey report.

Each habitat surrounding FDM (Figure 4) was comprised of slightly different coral communities (Figure 9). For instance, Habitat H5 and H4 were dominated by massive *Porites sp.* colonies, while Habitat H2 and H3 had larger numbers of *Leptastrea purpurea*. Habitat H5 also had the highest abundances of *Pavona chiriquensis, Turbinaria stellutata,* and *Goniopora somaliensis,* compared to other habitats. Habitat H4 had the most *Pocillopora eydouxi* coral colonies and the highest frequency of juvenile *Pocillopora* corals in 2017. Habitat H2 had relatively lower abundance of massive *Porites* and *Astreopora myriophthalama* colonies compared to other habitats. In 2017, *Pocillopora meandrina* colonies were numerically the first, second, or third-most abundant species in all habitats; however, in 2022, *P. meandrina* was only the 12th most common coral species at FDM. In all habitats, individual species of *Acropora* corals were comparably rare, and Acroporids comprised between ~0.3-1.4% of the community in all habitats, a reduction from ~2-8% in 2017. Note that these calculations are based on counts of coral colonies and do not consider colony sizes. If sizes were included, benthic cover could be computed, and the community composition would appear differently weighted compared to the frequency-based abundances presented here.

Coral diversity is moderately high for all habitats, with Habitat 5 exhibiting slightly higher diversity compared to the other habitats based on the Shannon and Simpson indices (Table 4). Note, several coral IDs represent multiple species (e.g., groups such as *Porites* massive and *Pocillopora* juvenile taxonomic groups used here). Thus, species richness and subsequently-derived diversity indices calculated in this study may underestimate the true species diversity at FDM. This is consistent with the comparatively larger numbers of coral species recorded during earlier surveys (2004-2007) at FDM.

Table 4: Coral community diversity indices by habitat and overall, from 2022 survey.

Habitat	2	3	4	5	Overall
Shannon-Weiner index	2.57	2.56	2.39	2.89	2.70
Simpson's Diversity index	0.83	0.84	0.85	0.90	0.86

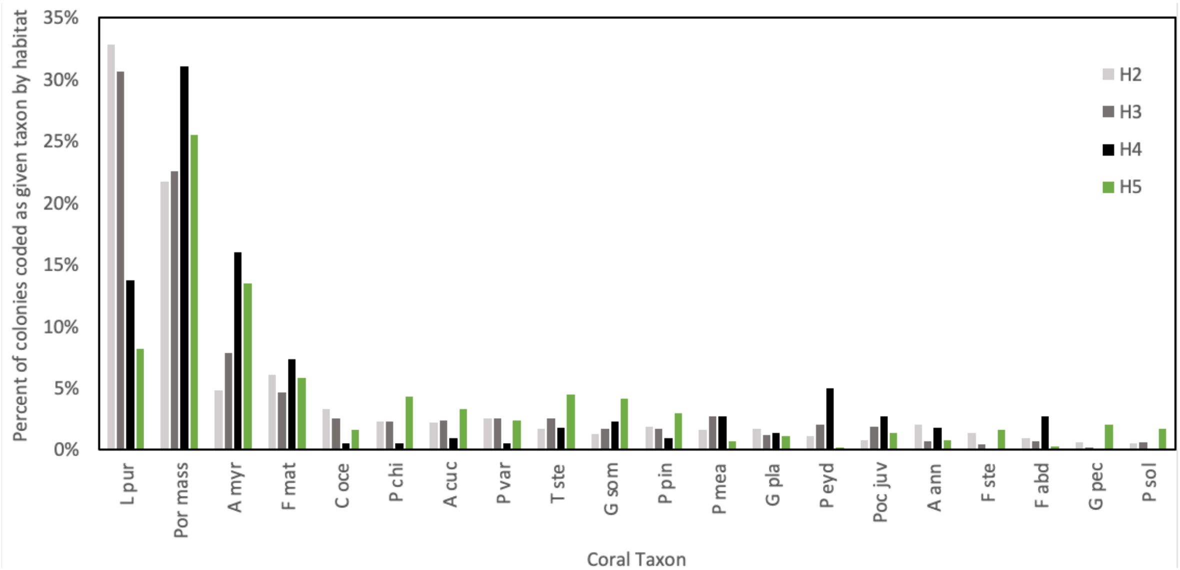

Figure 9: Coral community composition from 2022 for each major habitat type assessed, based on coral colony counts for the 20 most common scleractinian coral taxa (for visual clarity). The y-axis represents percent coral counts for all identified colonies within a habitat. The x-axis displays the coral taxon identified in this study for each habitat type, using shorthand codes. See Appendix C for coral codes.

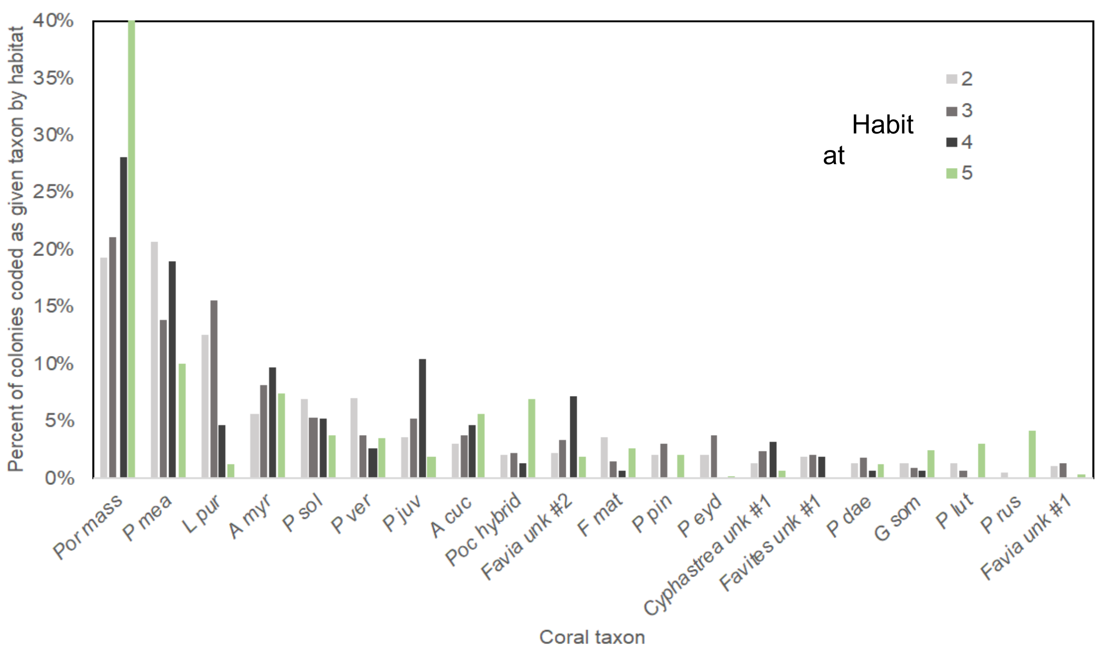

Figure 10: Coral community composition from 2017 for each major habitat type assessed, based on coral colony counts for the 20 most common scleractinian coral taxa (for visual clarity). The y-axis represents percent coral counts for all identified colonies within a habitat. The x-axis displays the coral taxon identified in this study for each habitat type, using shorthand codes.

3.4 [G4] CORAL CONDITION

Corals surrounding FDM experienced a mild bleaching event during the 2022 survey, as predicted by Coral Reef Watch (Figure 11). The 2022 FDM survey was conducted when corals experienced a 4-degree heating week (DHW) of heat stress, triggering a “bleaching warning” for the area. The 2017 FDM survey was performed when corals experienced 14 DHW of heat stress, far beyond the 8 DHW threshold that defines coral bleaching “alert level 2”, which typically results in significant coral mortality.

On average across the island, 5.6% of coral colonies analyzed in photoquadrats were completely bleached (Table 5, Figure 12, Figure 13). Many colonies that were not completely bleached were partially bleached (mottled, 19.5%) or pale (39.1%). Overall, 64.2% of corals around the island for which a condition was determined clearly exhibited some form of bleaching (Table 5). Note, it is possible that many colonies recorded as healthy were actually pale, but it was difficult to determine whether a colony was pale or healthy without healthy reference colonies against which to compare each taxon.

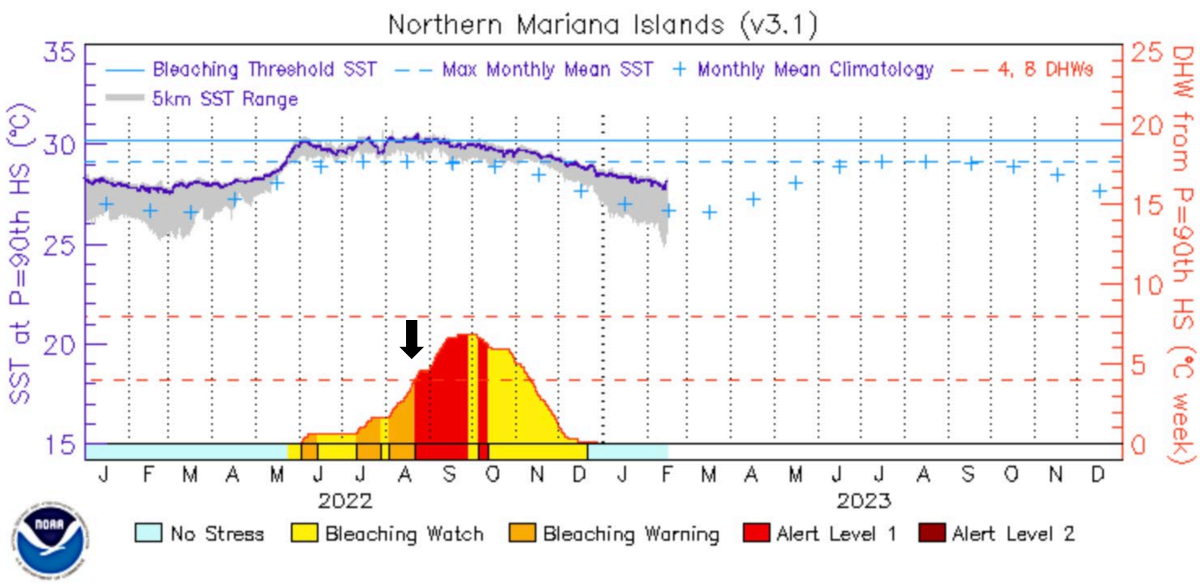

Figure 11: Sea surface temperature (SST, blue line) estimated from satellite data, as well as calculated heat stress expressed in DHWs (red line and colored shading) at the Northern Mariana Islands “virtual station.” The arrow denotes the approximate time of the 2022 FDM survey.

Table 5: Results of coral condition analyses for each habitat.

Coral condition	**H2**	**H3**	**H4**	**H5**	***FDM***
Bleached	4.5%	5%	5.9%	9.9%	*5.6%*
Mottled	19.9%	20.5%	24.3%	15.1%	*19.5%*
Pale	39.7%	38.9%	42.8%	37.3%	*39.1%*
Some Bleaching	*64.1%*	*64.4%*	*73%*	*62.3%*	*642%*
Diseased/Recent dead	0.1%	0.1%	0%	0.1%	*0.1%*
Broken	0%	0.03%	0%	0%	*0.01%*
Healthy	35.8%	35.5%	27%	37.6%	*35.7%*
Number of colonies keyed for condition	3213	3015	222	1248	*7698*

- Percentages in each column represent the percentage of corals observed under that condition category in the photoquadrats, averaged across all transects from each habitat. The "some bleaching" category is the sum of corals considered bleached, mottled, or pale in each habitat, while the FDM column presents the average across all colonies surveyed around the island.

Figure 12: Top: Landscape images from H5W showing extensive coral bleaching in 2017 and large numbers of *Pocilloporid* corals. Bottom: Low bleaching of corals in 2022, but with fewer living *Pocilloporid* corals. Several standing dead *Pocilloporid* corals are circled.

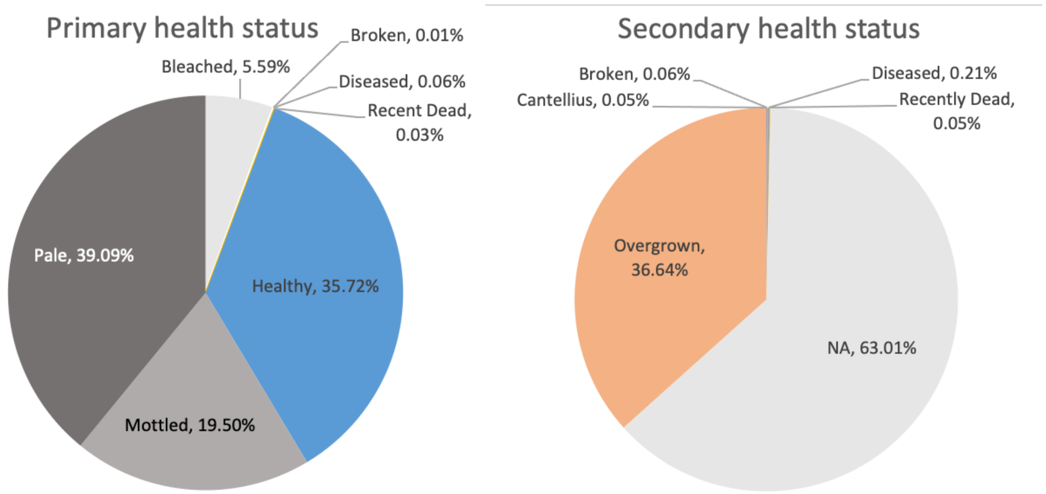

Figure 13: (Left) Summary of primary health status and (right) secondary health status of coral colony recorded.

Out of the 20 most commonly-enumerated coral taxa in photoquadrats, *Goniastrea pectinata* exhibited the highest frequency of complete bleaching at 48%. *G. pectinata, Astreopora cucullata, Astreopora myriophthalama, Cyphastrea ocellata, Turbinaria stellata,* and *Favites abdita* all exhibited the most frequent signs of heat stress, with >90% of these coral colonies appearing either fully bleached, pale, or mottled. In contrast, *Pocillopora eydouxi, Goniopora somaliensis,* and *Pavona chiriquensis* appeared the least heat-stressed, with ≥50% of colonies labelled as healthy.

Only a few coral fragments were observed (Figure 14). No ordnance, nor signature signs of ordnance impacts, such as craters were observed near these fragments. The 2017 survey produced the same results. This suggests that the breakage may have been caused by the high-wave energy environment surrounding the island or other natural impacts, and not from training activities.

Figure 14: Representative observation of coral breakage (photoquadrat P1040476). The yellow dots were placed to number all coral colonies for identification. This allowed multiple scientists to refer directly to the same coral colony for identification confirmation.

Very little disease was observed with only 0.3% of colonies in the photoquadrats exhibiting an unidentified disease (the same level as the 2017 survey). Little to no excess mucous production was observed in the remaining coral colonies that were not bleached.

In 2017, there were a few areas approximately 2 to 3 m^2 each that contained remnants of what appeared to be fossilized gray coral colonies. The authors believe this was caused by overgrowth of the coral-killing sponge, *Terpios hoshinota*. An example patch is shown in Figure 15. This sponge was not observed in similarly large areas in 2022. However, more than a third of corals enumerated in photoquadrats were actively overgrown by other types of sponges and algae, including turf algae in 2022 (Figure 13, Figure 16). Competition for space is a known phenomenon on coral reefs, but studies suggest that corals are increasingly losing out to other space competitors. This makes it difficult for new coral recruits to settle and recover coral communities after catastrophic events, such as mass bleaching (e.g., Sandin and McNamara 2012, Olinger et al. 2021). Out of the 20 most commonly-enumerated coral taxa in photoquadrats, *Pocillopora eydouxi* was also the least commonly observed to have other organisms actively overgrowing the living colony (0.93%). *Leptastrea purpurea* (86.46%), *Astrea annuligera* (75.76%), and *Pavona varians* (52.2%) were the most commonly-observed taxa actively overgrown (Figure 16).

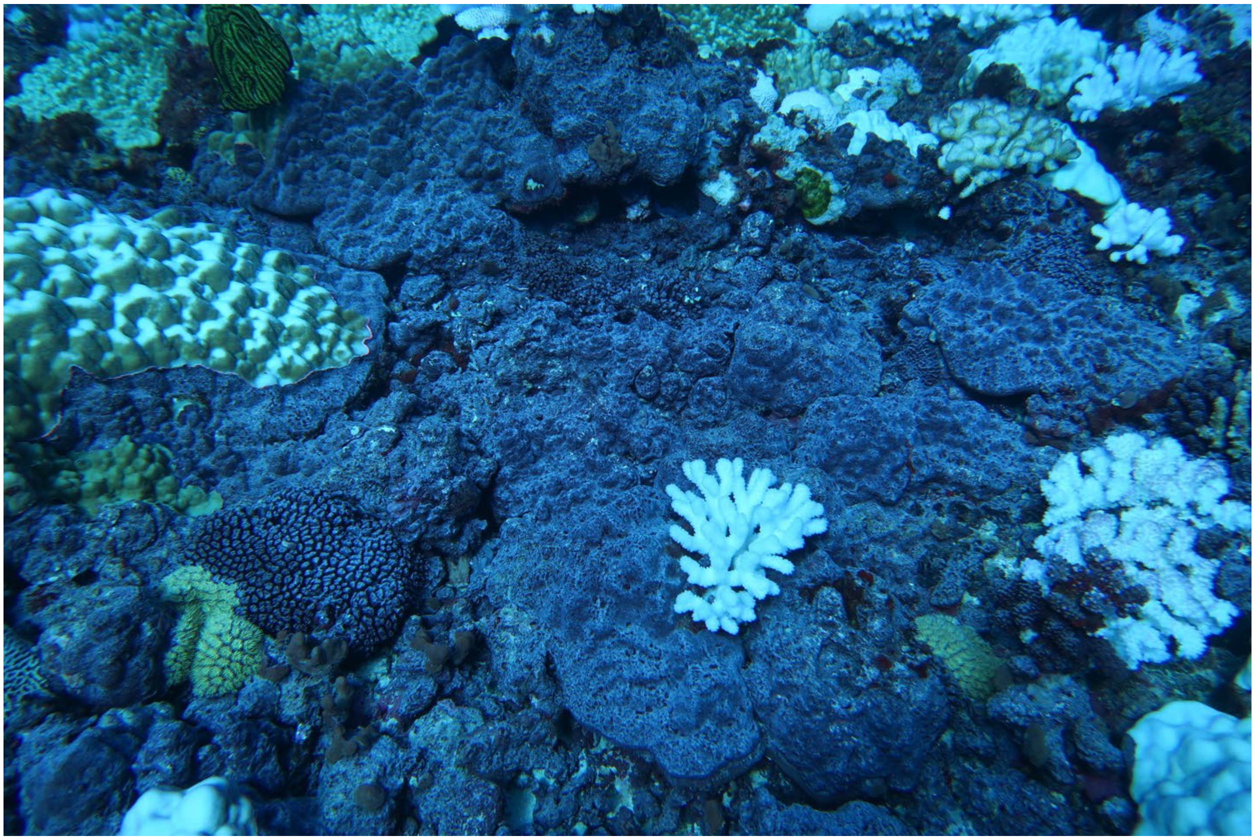

Figure 15: Photoquadrat from 2017 displays likely coral overgrowth by the sponge, *Terpios hoshinota* (gray surfaces). The massive Porites colony (left edge of the photograph) shows two flanks where the sponge started to grow up over the living, but bleached coral.

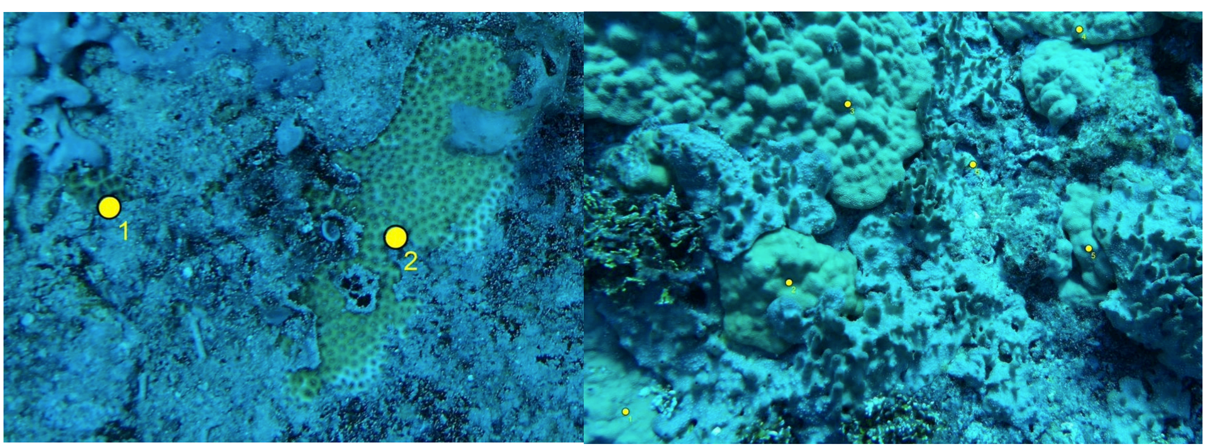

Figure 16: Example of corals actively overgrown by sponges and turf algae in 2022.

3.5 OTHER OBSERVATIONS

Turf algae and macroalgae (especially *Padina spp.*) were the dominant functional algal groups during the 2022 survey. This differs from the 2017 survey in which turf and crustose coralline algae (CCA) appeared as the dominant functional algal groups. During the 2022 survey, CCA was not as frequently observed. The calcareous green algae *Halimeda sp.* was also abundant in some areas.

No fish, crab or lobster traps were sighted. No nets, or net fragments, fishing line or spears were observed. No Crown-of-Thorns starfish were sighted on any of the dives, and no evidence of COTs predation was observed. Some parrotfish bite marks were observed, particularly on massive *Porites* colonies. Unusual macro-bioeroder activity was not noted, nor were high numbers of gastropod corallivores. Four colonies of *Pocillopora* were observed to have some coral barnacle (*Cantellius* sp.) living in some branches, but not at high levels that would be considered an infestation. These other observations were compiled opportunistically; a focused effort to quantify these factors was not conducted.

3.6 [G5] IN-WATER EFFECTS OF TRAINING

The majority of observed ordnance items were large bombs and/or were qualified as "old" based on the abundance of encrusting marine life (72.6% and 97.6%, respectively; Table 6, Appendix E). Only two fresh ordnance items were observed – one was a 50-caliber brass cartridge case, which was also the only small item observed, and the other was a large bomb marked "empty". All other items were bombs, rockets or fragments thereof. The most commonly sighted bombs were MK 81 and MK 82s in the 250 to 500-lb. range. Most (90.3%) of the ordnance items appeared to be intact (did not break apart, but may have been distorted or scarred). The rest were broken open or comprised of fragments of material (Table 6, Appendix E). In all cases, no visual evidence of disturbance (e.g., craters, etc.) to the surrounding marine life was apparent; the bombs or fragments were lying on the bottom and covered in algae, corals, and other organisms. The ordnance items would be indistinguishable from the surrounding benthic community if their shapes were not distinctive.

During dive 12 on 17 August 2022, the team observed pock marks indicative of strafing from machine gun fire (Figure 17). This did not appear to have a negative impact to the marine environment, especially considering that occurred in a high-wave energy area with little to no coral cover.

Figure 17: Landscape image of shallow rock surface showing pock marks that could be indicative of machine gun fire.

Table 6: Summary of details of ordnance observed and photographed by Divers 1 and 2. Georeferenced images of each item are included in the data submitted along with this report. Further details are included in Appendix E.

	Size of ordnance				Condition of ordnance			
	Large	Medium	Small	Fragment	Fresh	Old	Intact	Broken
Sum	61	12	1	10	2	80	65	7
Percentage	72.6%	14.3%	1.2%	11.9%	2.4%	97.6%	90.3%	9.7%

The vast majority of ordnance items observed during the 2022 and 2017 surveys were old. The entire island was not circumnavigated, but the perceived absence of newer items may be significant. Ordnance appears to have accumulated in the waters around FDM relatively slow with few new ordnance items entering the water (via a miss or falling off the island) during a given training event. Figure 18 illustrates typical old ordnance items observed during the 2022 FDM survey, and Figure 19 presents a map of observed and photographed ordnance items.

Figure 18: Representative examples of ordnance observed at FDM in 2022. (Left) a bomb and (right) a rocket.

There was little evidence of any adverse impacts to the coral from the training activities. No blast pits or damaged corals underneath or in proximity to ordnance items were observed. As noted by Smith and Marx (2016), and Carilli et al. (2018), many of the ordnance items present on the sea floor were bent, twisted or scarred in such a manner that it is believed they first hit the island and then ricocheted or were eroded off. That scenario was the unanimous opinion of all EOD technicians on all prior surveys. It was based on the type of damage (bending, deep gouges in the bomb cases, etc.) that the ordnance displayed. Given the lack of observed impacts, such as craters, and that most items observed underwater were intact. This suggests that most if not all of the ordnance items that missed or fell off the island were inert.

Many of the ordnance items supported coral growth, although no new coral recruits were observed on ordnance during the 2022 survey. Many items had probably been submerged for more than 10 years, based upon the size of the coral colonies growing on them. Corals in proximity to the ordnance items did not show any obvious signs of additional stress compared to other corals further from ordnance; this result was qualitatively assessed.

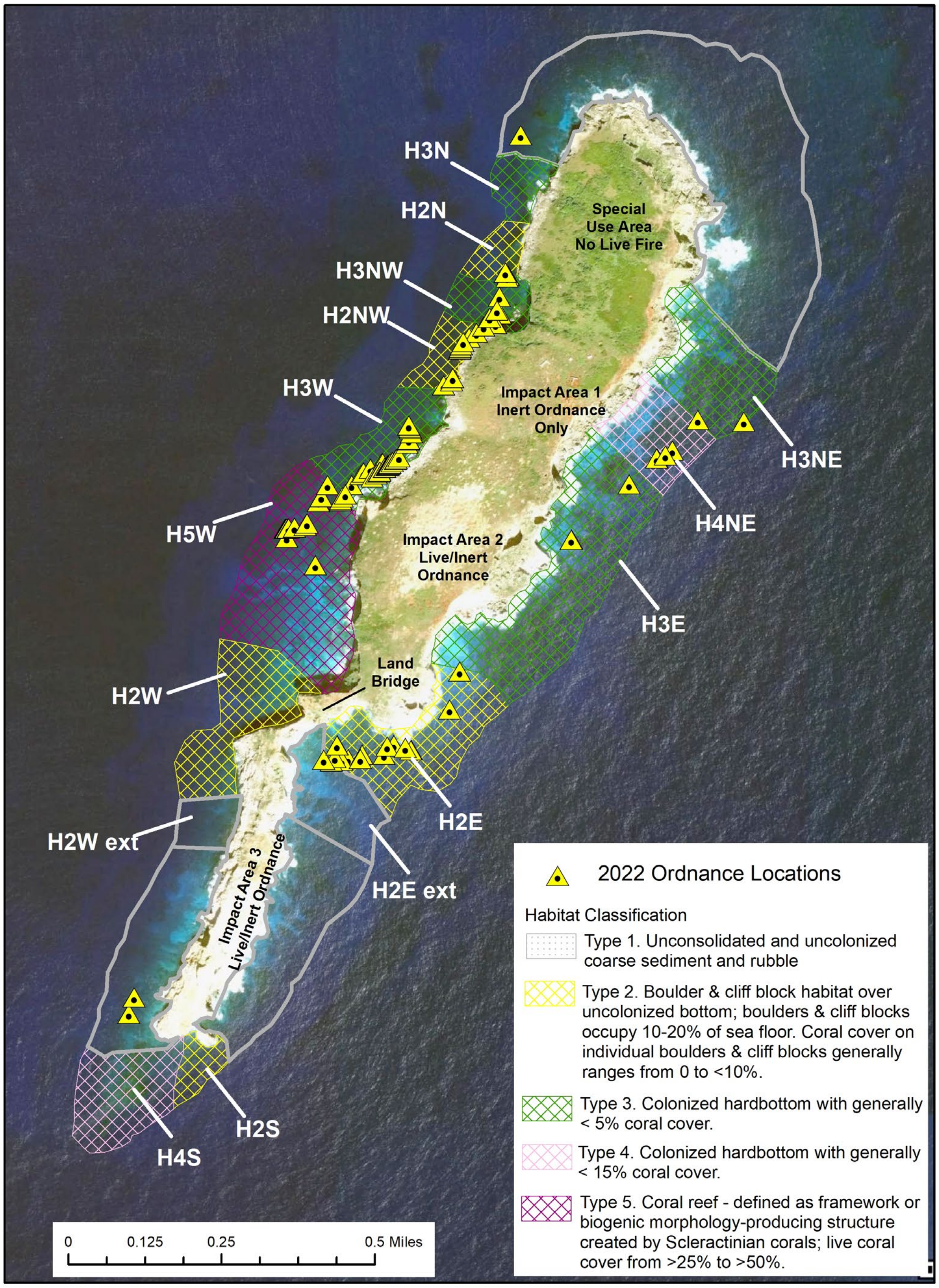

Figure 19: Map of locations of georeferenced photos of observed ordnance.

3.7 [G6] INCIDENTAL OBSERVATIONS OF ESA-LISTED SPECIES

No marine mammals were sighted underwater or from the surface during the 2022 FDM survey, with the exception of a pod of spinner dolphins (*Stenella longirostris*) that were seen on the surface as the dive team traversed back to the Chomorro support vessel after dive 18 on 19 August 2022.

Unlike previous surveys, no sea turtles were observed at any time during the survey.

No Scalloped hammerhead sharks (*Sphyrna lewini*) were sighted. No other hammerhead species were sighted, and no hammerhead species have ever been recorded at FDM.

The ESA-listed, giant manta ray (*Manta birostris*) and the oceanic whitetip shark (*Carcharhinus longimanus*) were not sighted during the 2022 survey, and none were observed during any of the 15 previous marine surveys. Rays were seen on the surface at the end of dive 2, site H2W, on 14 August 2022, but they were too far away to identify to species. During dive 3 at site H5W on the same day, a spotted eagle ray with a wingspan of about four to five feet was seen at approximately 35 fsw (Figure 20). On 15 August during dive 6 at site H2N, three spotted eagle rays were observed. They had wingspans varying from three- to- five-feet wide.

Figure 20: Spotted Eagle Ray observed during the 2022 marine resource survey.

On 16 August during dive 8 at site H3N, a manta ray (probably a reef manta ray) was observed as well as what was tentatively identified as a black tip reef shark of about six- to- seven-feet in length. Both were too far away to photo-document. A gray reef shark was observed on 17 August during dive 12 at site H4S (Figure 21). On 18 August during Dive 15 at site H3NE, a seven-foot nurse shark and a three-foot manta ray (again most likely a reef manta ray) was observed at approximately 40 fsw. They were too far away to take discernible photographs. On 18 August during Dive 16, a small porcupine ray of about three feet in width was observed (Figure 21).

Figure 21: (Left) Gray reef shark and (right) porcupine ray observed at FDM in 2022.

Several small specimens of some of the ESA-listing Candidate species of Giant clams (*Tridacna gigas* and *T. squamosa*) were observed during this survey, as was *T. maxima* (Figure 22). *T. gigas, T. maxima* and *T. squamosa* species have been observed during previous surveys conducted by SDS scientists. The 2001-2004 surveys conducted by other scientists list observations of *Tridacna maxima* and *T. squamosa*, but not *T. gigas* (Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). Counts of giant clams were not included in the scope of work for this project.

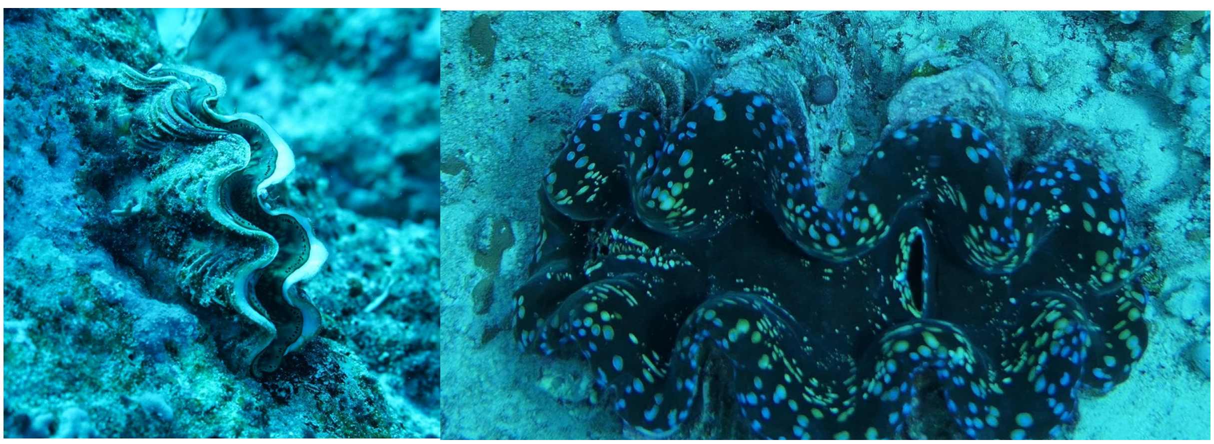

Figure 22: (Left) Example of *Tridacna maxima* observed during survey, showing closely-packed “scutes” on the asymmetrical, embedded shell, and small “eyes” and protuberances on the edge of the mantle. (Right) Example of *Tridacna squamosa* observed during survey, showing very large “scutes” on the symmetrical shell and tentacles on the incurrent siphon.

3.8 OBSERVATIONS FROM DEEP DIVES

In accordance with the Navy diving manual and in compliance with Navy diving operations, the deepest dive is normally planned as the first dive of each day. The first DPV deep dive of the survey was conducted on 15 August 2022. This was on dive day 2 at site H3W, Waypoint 21. The maximum depth was 100 fsw for 25 minutes. The average depth was 83fsw. Visibility was approximately 100 feet, which dictated the average depth in the water column that afforded the scientific team the best location to collect video, make observations and take notes that would cover 10 to 20 feet above and below the maximum planned depth. Maximum water temperature was 84.2°F at the surface, with a slight thermocline decreasing the temperature to 80°F at the maximum depth. A series of videos utilizing GoPro Hero 10 cameras mounted on the DPVs were obtained and labeled GH010108, GH020108, GH030108, and GH040108 respectively.

As the team descended, there was 80% coral cover which was reduced to 50% at six minutes into the dive. For the duration of the dive, percent coral cover varied from 80% to less than 1%. Bottom types varied, including up to 99% sand, 99% sand/rock, 90% bare hard bottom, and 99% of the seafloor covered by small rocks. Metal debris was observed periodically and varied in size and shape including what appeared to be a 2-foot-long rod and a rectangular-shaped piece of metal that may have served as some type of cover. Four pieces of ordnance were observed during the dive, including bombs and one missile that appeared to impact the seafloor and remained approximately vertical. *Pocillopora meandrina* or *eydouxi* (or a possible hybrid) was growing on the tailfins of the missile and appeared healthy. Massive *Porites* colonies (probably comprising multiple species) was the dominant coral taxon in some areas, but there were large areas where there was a mix of taxa with no single dominant species. Occasionally, there were large schools of small fish but only one large tuna was observed during the entire dive.

The second DPV deep dive was conducted on 18 August 2022. This was dive day 5, and occurred on the north end of the island, starting at Waypoint 12. The maximum depth was 98 fsw for 25 minutes, with the average depth being 80 fsw. Visibility was approximately 120 feet. Maximum water temperature was 86°F at the surface, with a slight thermocline of 84.2°F at the bottom. Video footage from the GoPro cameras were labeled G010126, GH020106, and GH030126.

Upon descent, the dive team observed mostly small rock, sporadic coral of about 5% cover, and some long, narrow swaths of sand. The maximum coral cover observed covered about 60% of the bottom at 4 minutes and 45 seconds into the dive. Throughout the dive, several very large colonies of massive *Porites spp.* were seen, ranging in size from two to three meters, as well as several large *Pocillopora eydouxi* colonies. The bottom type varied from up to 90% sand, 90% sand/rock, 75% hard bottom and up to 90% of the seafloor consisting of small rock only. No debris was sighted at any time during the dive. One minute into the video segment labeled GH 020126, a semi-circle of small rocks was observed. It is not known how this was formed, but EOD analyzed the video and confirmed it was not due to any ordnance impacts. Periodically, small schools of small-sized fish were observed along with one barracuda seen at two different occasions. Only three pieces of ordnance were seen during this dive, with one bomb supporting three *Pocillopora meandrina* colonies on it.

3.9 OTHER OBSERVATIONS

The following is a partial list of fish species observed during the 2022 survey:

Pacific ladyfish *Elops affinis*
Checkerboard wrasse *Halichoeres hortulanus*
Various triggerfish
Giant trevally *Caranx ignobilis*
Bluefin trevally *Caranx melampygus*
Peacock grouper *Cephalopholis argus*
Bluespine unicornfish *Naso unicornis*
Smallspotted dart *Trachinotus baillonii*
Pacific steephead parrotfish *Chlorurus microrhinos*

Black and white snapper *Macolor macularis*
Lionfish *Pterois volitans*
Bluestripe snapper *Lutjanus kasmira*
Barracuda *Sphyraena argentea*
Longface emperor *Lethrinus olivaceus*
Princess damsel *Pomacentrus vaiuli*
Moorish idol *Zanclus cornutus*

Since NIWC Pacific SDS divers began FDM surveys in 2004, they have noticed a gradual decline in the number and size of fish. Based on 2022 observations, this appears to be a continuing trend, with further decreasing numbers of fish. Fish continue to behave in such a way that is indicative of spearfishing pressure, maintaining distance or immediately swimming away from the divers, as was observed in 2017. The behavior of fishery target fishes (FTF) has been shown to be indicative of spearfishing pressure (Feary et al. 2011, Pavlowich 2017).

As noted in Smith and Marx (2016), between 2005 and 2012, and the 2017 FDM report (Carilli et al. 2018), FTF around FDM had become much more wary around divers. During the 2017 survey effort, key species from a number of different families, including Twinspot snapper (*Lutjanus bohar*), Peacock grouper (*Cephalophilis argus*), Lyretail grouper (*Variola louti*), Redlipped parrotfish (*Scarus rubroviolaceus*), Tan-faced parrotfish (*Chlorurus frontalis*), Goldman's sweetlips (*Plectorhinchus goldmanni*), and Yellowsaddle goatfish (*Parupeneus cyclostomus*), were observed to be extremely shy and quickly fled at a diver's approach. Rigorous quantitative counts of these fishes were not made, but the authors subjectively estimated that their total numbers were less than half of what had been assessed in the last fish assessment prior to the 2017 survey (2012, reported in Smith and Marx 2016). For some species, the decline was even greater. This apparent reduction was confined to near-shore FTF, such as the species listed above. Near-shore Non-FTF, such as the Arc-Eyed hawkfish (*Paracirrhites arcatus*) and Black-Blotched stingray (*Taeniura meyeni*) did not show any changes in behavior or reduction in numbers in 2017 Figure 23 and Figure 24 illustrate an FTF and Non-FTFs photographed during the 2022 survey.

The data from the 2022 survey were insufficient to draw broad patterns regarding fish presence. Overall, it appears that the abundance of fishes, FTF and non-FTF, have declined relative to previous surveys. The relationship between reef health and fish abundance and diversity is complex and bidirectional (Feary et al. 2007; Zamani and Madduppa 2011; Dwita and Widjoyo 2022). Fish communities are highly spatially and temporally variable, particularly for schooling fishes, which tend to either be entirely absent or present in large numbers. However, the overall apparent absence of large fish around FDM on the transects conducted, even given the limitations on the amount and methodology of data collected in this survey, is concerning. In contrast, during the 2004 and 2005 surveys, we observed numerous fish such as large parrotfish, wrasse and snappers that were abundant compared to locations such as Guam. During those surveys, four species of sharks were also sighted. The most common sighted was the blackfin shark (*Carcharhinus limbatus*), followed by the gray reef shark (*C. amblyrhynchos*), as well as single sightings of the reef whitetip shark (*Triaenodon obesus*) and the tawny nurse shark (*Nebrius ferrugineus)*. Additionally, SDS divers observed large Napoleon Wrasse (*Cheilinus undulatus*), which are on the International Union for Conservation of Nature (IUCN) red list, and were two meters in length during those surveys. These and other earlier observations indicated that FDM was acting as a defacto marine reserve for fishes (Smith and Marx 2016), but more recent observations in 2017 and 2022 suggest that this may no longer hold true.

Figure 23: Fishery Target Species (left) Giant Trevally (*Caranx ignobilis*) and (right) barracuda (*Sphyraena argentea*).

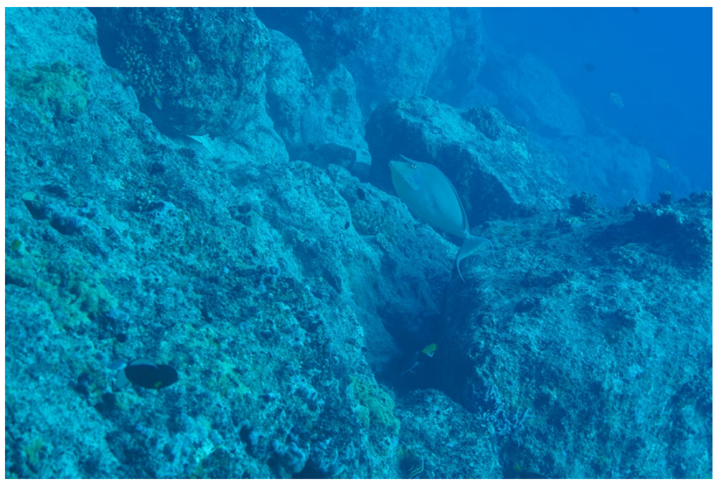

Figure 24: Near shore Non-Fishery Target species: Bluespine unicornfish (*Naso unicornis*), as well as triggerfish, butterflyfish, and other small reef fish.

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4. DISCUSSION

4.1 [G1] ESA-LISTED CORALS

In the 2003 and 2004 surveys, the ESA-listed coral *Acropora globiceps* was recorded on two individual dives as being “rare” (<5 colonies). In addition, corals that look very similar to *A. globiceps*: *A. gemmifera* and *A. humilis*, were recorded as being rare or occasional (5-15 colonies on a dive; Belt Collins 2001, 2003; The Environmental Company 2004, 2005). During the 2017 survey, only one *A. globiceps* colony was positively identified, while seven other colonies were thought to possibly be *A. globiceps*. However, no *A. gemmifera* or *A. humilis* were identified. In addition, no prior surveys identified the ESA-listed coral *Acropora retusa* or any other ESA listed corals at FDM.

During the 2022 survey, 10 colonies of *A. globiceps* were recorded in photoquadrat images and six colonies were recorded in other photographs. In addition, 10 colonies tentatively identified as *A. retusa* were recorded in photoquadrats, and 14 colonies were recorded in other photographs. Some example images of the colonies tentatively identified as *A. retusa* are included in Figure 25. *A. retusa* is similar in appearance to *A. globiceps*, but the branches of *A. globiceps* are neater and more rounded. *A. retusa* has relatively indistinct axial corallites and radial corallites that are appressed (meaning one side is embedded in the branch, as opposed to sticking out like a tube from the sides of the branches), branches are short, and colonies tend to form flat plates (Veron et al. 2016). The corals identified as *A. retusa* at FDM might represent a hybrid of other *Acropora spp.* corals or a new, undescribed species, but appear most similar to *A. retusa,* out of the *Acropora* corals that are recognized in the Marianas Archipelago (Veron et al. 2016).

Figure 25: Examples of coral colonies tentatively identified as *Acropora retusa*, a Threatened coral has not previously been recorded at FDM.

In addition, four colonies of *A. gemmifera* and two colonies of *A. humilis* were identified in photoquadrat images; additional *A. humilis* colonies were also captured in other photographs. Examples of colonies identified as *A. humilis and A. gemmifera* from this 2022 survey are shown in Figure 26. *A. humilis* looks similar to *A. globiceps*, but has relatively longer digitate branches and a large distinct axial corallite. *A. humilis* has radial corallites that generally occur in rows and has small branchlets or incipient axial corallites near the base of main branches (Veron et al. 2016). *A. gemmifera* can also appear similar to *A. globiceps,* but has a distinct (smaller than *A. humilis*) axial corallite, and radial corallites that become larger closer to the base of branches, which are short and wide (Veron et al. 2016). The lack of *A. humilis* and *A. gemmifera* corals identified during the 2017 survey, compared to earlier surveys, and the new observations recorded as potentially *A. retusa* could be interpreted as an actual decline or increase, respectively, of those species at FDM. It is more likely that this is an apparent result caused by differing survey methodologies or locations, or observer error in species identifications during one or more surveys. Note: the 2022 FDM survey collected and analyzed 40% more photoquadrat images of corals than the 2017 survey, increasing the chances of capturing rare species. Earlier surveys (2001-2004) collected coral species data in the field instead of collecting photographs for later identification and archival purposes, so it is not possible to assess the accuracy of those field identifications. However, several species of corals identified during earlier surveys and not observed again are not recognized as occurring in the Marianas Archipelago by Veron et al. (2016; Appendix C). Additionally, the strong bleaching event in 2017 resulted in many coral colony features being washed out in photographs, making identifications very challenging. As discussed above, generally all field- or photography-based identifications must be considered tentative, as they do not involve sampling and microscope analysis of skeletons; all identifications presented here were completed to the best of the ability of the NIWC Pacific team.

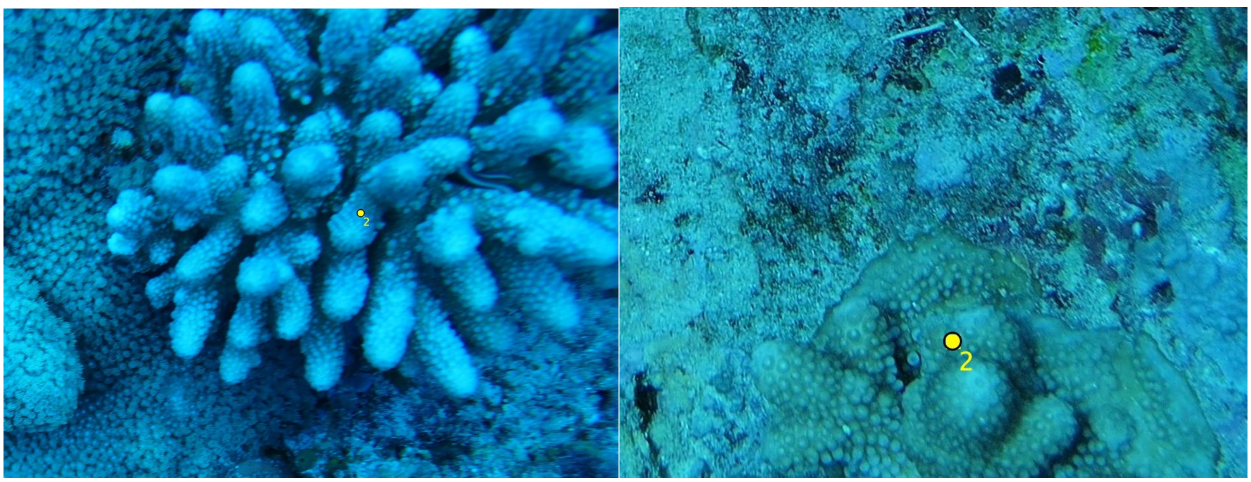

Figure 26: Examples of coral colonies from the 2022 survey identified as (left) *Acropora humilis* (cropped from photoquadrat image P1050330) and (right) *A. gemmifera* (cropped from photoquadrat image P1040326).

4.2 [G2] PERCENT CORAL COVERAGE

A coral coverage/habitat type map was created for consultation purposes (DoN 2016) by Stephen Smith. This was based on his observations between 2005 and 2012 (as reported in various documents) including Smith and Marx (2016), and as stated in the 2017 FDM survey report. The map is still considered relatively accurate, although habitat boundaries grade into one another and should be considered approximate. There is only one area around FDM (habitat area H5W) where corals are sufficiently dense to create an actual coral reef with substrate comprised of old coral skeletons (Figure 4). In other areas around the island corals are found growing on rock, but even in areas with relatively high coral cover, the coral densities are too sparse to be morphological-framework building reefs in the classical sense. In habitat types, H3, and H4, coral cover on hard substrates appears to have remained relatively consistent to the 2017 survey, with midpoints of the range in living coral cover of 12.5% and 6.5% in 2022, respectively, compared to 15% and 10% in 2017 (Table 3). In 2017, habitat type H2 and H3 both had higher coral coverage (~25% and ~15%, respectively) than historical observations (5% and <5%, respectively; Table 3). In habitat type H2, coral cover in 2022 appeared lower than in 2017, at ~10% vs. ~25% (Table 3). In habitat type H5, coral cover remained the highest around the island (~25% in general), but had also decreased since the 2017 survey. Reduction in live coral cover most likely occurred because of the severe bleaching event in 2017. This was apparent as well as a change in coral community composition, which is described further below.

Some huge colonies of massive *Porites* corals remain at deeper depths of ~80 to 100 feet (Figure 27). The 2017 FDM survey report stated one author who completed coral reef surveys at FDM since 2004 believed that the quantity of these sizable colonies had decreased. This was based on the observations of boulder-like formations that had little to no coral growing on them in 2017. It was presumed those formations were large massive *Porites* colonies in the past. While quantitative coral data were not collected below ~70 feet water depth in 2022 (or 2017), qualitatively, the large *Porites* colonies observed at deep depths appeared healthy in the 2022 deep dive videos. Some coral research suggests that deep reefs (often referred to as mesophotic reefs) may offer refuge to corals during bleaching events (e.g., Baird et al. 2018, Pérez-Rosales et al. 2021), but other studies have found that depth did not offer refuge during bleaching (e.g., Neal et al. 2014, Frade et al. 2018). Considering that these deep, large *Porites* colonies do not appear to have suffered significant partial mortality associated with the 2017 bleaching event, as was observed in many shallow colonies, at FDM depth may indeed provide a climate refuge to corals.

Figure 27: Example screenshots from videos collected during deep dives (~100 feet depth) showing large massive *Porites* corals likely to be several hundred years old.

4.3 [G3] CORAL SPECIES COMPOSITION

Species lists of corals observed were prepared during the FDM surveys completed prior to 2005 and in 2017. Surveys completed between 2005–2012 focused on collecting data related to potential ordnance impacts, fin fish, the health and general condition of corals at the level of order (Scleractinia, *Millepora*, etc.). Additionally, they focused on counts and measurements of a select group of coral species judged to be the most abundant and a list of coral families and genera observed (Smith and Marx 2009). Therefore, the 2005-2012 surveys did not collect data on coral species composition, although they did include observations on the most abundant coral genera and species. However, it should be noted, preparing species lists and quantifying coral species composition were not key objectives during earlier surveys prior to 2005. The primary objective of those surveys was to look for and assess potential ordnance impacts.

Direct comparisons of species occurrences from earlier surveys conducted between 2001-2004 (Appendix C; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005), the 2017 survey, and the 2022 survey is challenging because of changes in coral taxonomy. There are inherent challenges in identifying corals to species in this highly biodiverse part of the world and changing methods over time. The coral species list compiled includes some higher-level taxonomic identifications, such as juvenile *Pocillopora* sp. and *Porites* massive identifications, which themselves almost certainly include more than one species, and possibly additional species than identified by any of the previous surveys. Here, we assume that the category *Porites* massive includes at least five individual coral species (likely *P. lobata, P. lutea, P. evermanni, P. australiensis,* and possibly examples of *P. solida* that were not differentiated). The species list from the 2017 survey was comprised of 84 unique categories/species from 26 genera. Surveys completed between 2001-2004 included 107 species from 36 genera (Appendix C; each subsequent annual survey between 2001-2004 recorded an additional ~5-7 species not recorded previously; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). The species list from the 2022 survey includes 95 individual coral taxa (including higher level groups, such as *Porites* massive) from 32 genera. Some of the species observed during the 2017 and 2022 surveys were not recorded during prior surveys; likewise, some of the species recorded previously were not recorded in later surveys. This apparent discrepancy has many potential underlying causes, including, but not limited to, taxonomic errors in one or more surveys, changes in the coral community with time, or differences in survey locations/depths.

As previsouly noted, the assessment of coral species composition at FDM presents many challenges. These challenges include, but are not limited to: 1) coral taxonomy itself is in a state of flux because of conflicts between genetic investigations and traditional morphological criteria, 2) the methodology employed here cannot distinguish coral species with the highest level of confidence (as would be possible were sampling conducted, for example), and 3) the island hosts a large number and diversity of corals that can be challenging to differentiate *in situ* or from photographs. However, despite this uncertainty, some general conclusions can be drawn from the survey data.

Smith and Marx (2009) reported that *Pocillopora* was the dominant scleractinian coral genus at FDM in general, while *Porites* genera corals were particularly abundant in the area of the island containing habitat H5. The 2017 survey was somewhat consistent with these findings. *Porites spp*. dominated habitat H5 in 2017 (46.4% of all identified colonies in habitat H5 in photoquadrats were *Porites*, mostly massive species). However, on an island-wide scale, using number of colonies as a metric, *Porites spp.* colonies were dominant in 2017 as well, followed by *Pocillopora meandrina* (13.8% of all colonies island-wide were *P. meandrina*). *Pocillopora spp*. overall comprised 26.9% of all coral colonies around the island. This suggested that *Pocillopora spp.* corals had reduced in density between past surveys at FDM and the 2017 survey. The 2022 survey results indicate that massive *Porites* colonies remained dominant in Habitats H4 and H5 in 2022, and were observed in 2017, but decreased by more than 15% in relative numbers in Habitat H5, from 46.5% of enumerated corals in 2017 to 30.9% in 2022. *Pocillopora* corals have continued to decline in all habitats at FDM. Overall, *Pocillopora spp.* comprised just 5.7% of identified coral colonies island-wide in 2022, most likely as a result of mortality associated with regional bleaching events. The largest change was in Habitat H2, which experienced a reduction of over 26% in *Pocillopora* corals, from 30.9% of enumerated colonies in 2017 to just 4.3% in 2022.

In all Habitats, but particularly Habitats H2 and H3, *Leptastrea,* particularly *L. Purpurea,* increased in numerical frequency. *L. purpurea* increased from the third most common coral in 2017 to the first most common coral enumerated in 2022 photoquadrats in Habitats H2 and H3. *Astreopora spp.* corals generally remained at a similar level of abundance between 2017 and 2022 in Habitats H2 and H3, but increased by almost 5% in Habitats H4 and H5. Habitat H5 also saw increasing relative abundances of *Pavona spp.* and *Turbinaria stellutata* coral colonies of over 4% between 2017 and 2022.

One important caveat to interpreting the observed changes in coral community composition relates to the unique methodology used for the surveys at FDM. Many coral surveys are completed using random sampling approaches, including line intercept surveys, using a transect tape to survey the same area of seafloor and identifying all taxa (including, but not limited to corals) under the tape at given intervals. Other approaches include collecting random photoquadrats and then identifying the taxa that occur under randomly-placed points in the images. These approaches can provide more direct measures of the percent of the benthos covered by living coral overall and/or by a given coral taxon. In contrast, the methods used here were developed to minimize underwater time while maximizing the ability to capture the breadth of coral taxa that occur at FDM, but the photoquadrat analysis does not take into account the size of individual coral colonies. For example, one *L. purpurea* colony identified in the imagery could occupy just ~10 cm^2 of space, while one massive *Porites sp*. colony 1 m across could occupy ~10,000 cm^2, but these would be enumerated in the same way in our dataset. The landscape-scale percent cover assessments [G2] are intended to address at least some of this discrepancy, but the methodology is important to keep in mind when interpreting the changes in coral species composition.

The loss of *Pocillopora* corals at FDM does not, however, appear to simply reflect methodology bias – indeed visual observations at the landscape scale clearly showed that *Pocillopora* corals were much less abundant in 2022 than in prior surveys. Some other changes in numerical abundance, in particular for *L. purpurea*, *Astreopora spp.,* and *Turbinaria stellutata,* however, are likely a result of partial mortality of previously larger, continuous coral colonies that has resulted in many small fragments of coral colonies that are operationally now distinct colonies. An example is shown in Figure 28, where points 1, 8 and 9 are located on colonies of *Astreopora myriophthalama* and points 4, 6, and 7 are located on colonies of a massive *Porites sp.* that had been almost certainly a single contiguous colony in the past. A dead *Pocillopora* colony is visible in the upper left.

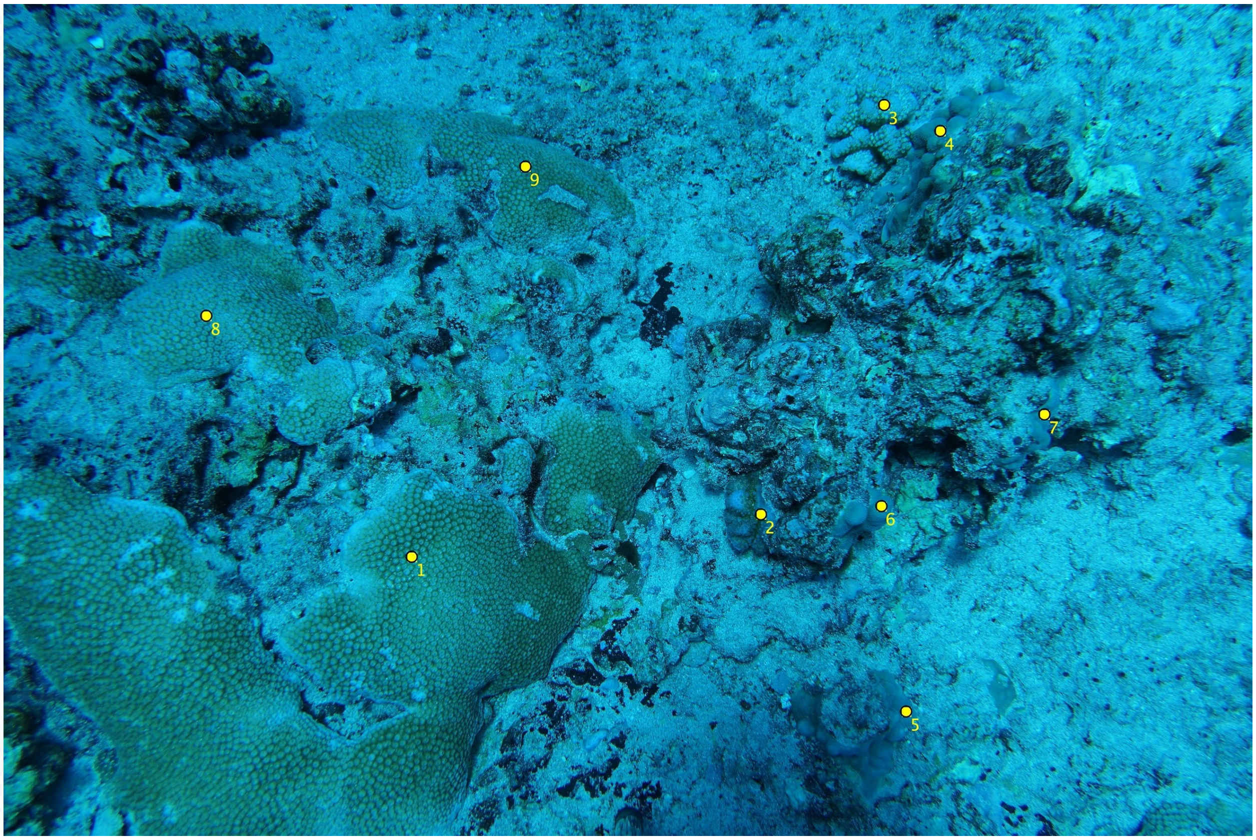

Figure 28: Example photoquadrat image showing that partial mortality of previously large coral colonies, resulting in multiple independent fragments of colonies.

Overall, the FDM coral community appears to be comprised of a larger number of smaller colonies/fragments of previously larger contiguous colonies in 2022, compared to 2017. This is evident when comparing the number of colonies marked and identified in both surveys. Both surveys used the same type of camera and monopod to capture photoquadrat images, such that the footprint of each photograph is essentially equal (although there is some variability related to some photos likely not being captured perfectly nadir to the benthos, and the uneven surface of the benthos itself). In 2022, the average and median number of marked coral colonies in the photoquadrats was 8.2 and 8, respectively, compared to 5.6 and 5 in the 2017 photoquadrats. The value for 2022 is likely underestimated because in some cases, a group of several small fragments of the same coral species was marked with a single point to allow all of the photoquadrats to be analyzed in the available time to complete this project instead of marking every individual fragment (Figure 29).

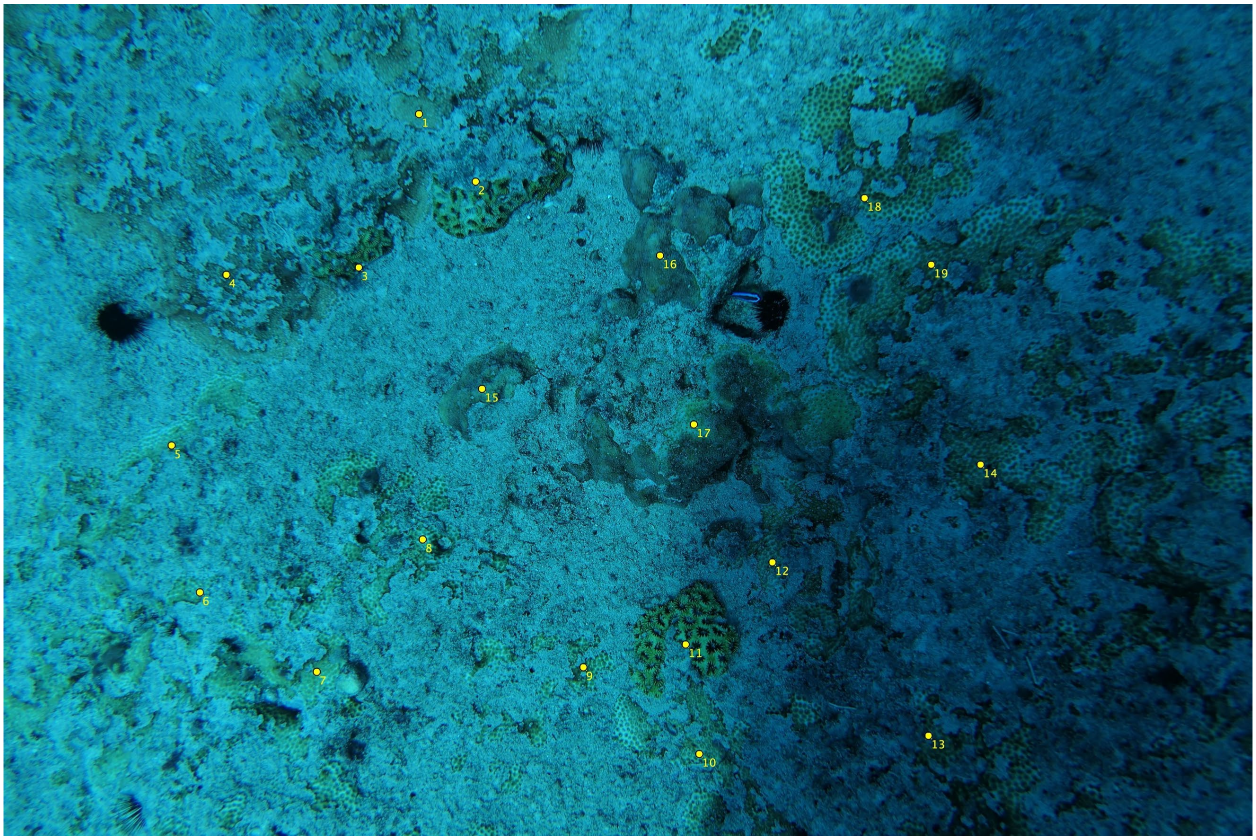

Figure 29: Example photoquadrat in which every small coral colony fragment that is disconnected from other fragments of the same species were not individually marked, for efficiency.

4.4 [G4] CORAL CONDITION

Overall, coral condition of living corals observed during the 2022 survey was better than during the 2017 survey; more corals in the photoquadrats were scored as Healthy (35.7% in 2022 vs. 22% in 2017), and many fewer corals were scored as 100% bleached (5.6% in 2022 vs. 47.8% in 2017). However, more corals were scored as mottled (19.5% in 2022 vs. 10.1% in 2017) and pale (39.1% in 2022 vs. 19.4%), indicating that most of the corals at FDM were heat-stressed during the 2022 survey, although not as severely as during the 2017 survey.

An earlier bleaching event occurred at FDM that was observed during surveys as well in 2007. This regional bleaching event was characterized by heat stress that extended from southern Japan through the Mariana Archipelago and south at least as far as the Republic of Palau. At FDM, some, but not all, scleractinian corals showed slight to severe bleaching during the FDM survey that occurred during that regional bleaching event. However, surveys completed the following year (2008) showed a subjectively very high degree of recovery (Smith and Marx 2016).

Between 2012 and the next FDM survey that occurred in 2017, the island experienced three years (2013, 2014, and 2017) of accumulated heat stress that warranted Alert Level 2 from NOAA's Coral Reef Watch (Figure 30). This level of heat stress is expected to cause "severe, widespread bleaching and significant coral mortality". In addition, the region experienced heat stress that reached Alert Level 1 (in which "significant bleaching is expected within a few weeks of the alert") in 2016. The 2017 FDM survey was conducted approximately 2/3 of the way through that year's Alert Level 2 time period. It was notable that only a small number of recently dead corals were observed at that time, and that some corals did not display signs of bleaching (overall, approximately 22% of corals appeared healthy in 2017). The 2016 heat stress event may have actually helped "prime" the corals at FDM for the 2017 bleaching event, potentially leading to less drastic results (e.g., Hackerott et al. 2021). Since the 2017 survey, there was only one additional year (2020) where heat stress accumulated to Alert Level 2, and this was sustained for a much shorter time period than in 2014 and 2017 (Figure 30).

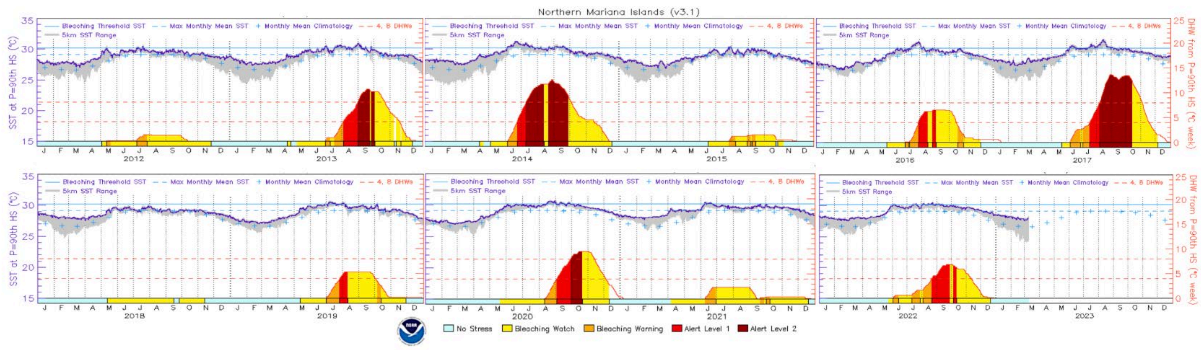

Figure 30: Compilation of accumulated heat stress between January 2012 – February 2023 in the Northern Marianas Islands (from Coral Reef Watch).

In our FDM 2017 survey report (Carilli et al. 2018), we predicted that it was likely that at least some corals would survive the 2017 bleaching event, although significant mortality of *Acroporid* and *Pocilloporid* corals, which had the highest rates of bleaching, was expected. It is not well established how long corals can survive in a bleached state without dying. This is largely because it depends strongly on the energy (fat) reserves of individual corals, the ability of corals to increase feeding on zooplankton while bleached, and other stressors, such as disease (e.g., Brandt and McManus 2009). In contrast to the *Acroporid* and *Pocilloporid* corals, *Porites rus*, *Favia* spp. and *Favites* spp. corals were the least bleached in 2017. A shift in community composition towards more of these stress-tolerant, "weedy" species was expected under a changing climate that causes more bleaching events (Darling et al. 2013), and this was expected to occur at FDM.

Out of the top 20 most abundant coral categories, *P. meandrina* (second most abundant) and juvenile *Pocillopora* sp. (seventh most abundant) corals suffered the most severe bleaching in 2017, with an estimated 94% of colonies completely bleached. *Pocillopora* sp. corals (*P. meandrina, P. verrucosa*, juvenile *Pocillopora*, and *Pocillopora* hybrid #1) were also the only corals recorded in photoquadrat images from 2017 that were recently dead as evidenced by a light covering of cyanobacteria on the white skeleton. Similary, 84% and 91% of corals from the fourth and eighth most abundant coral taxa, *Astreopora myriophthalama* and *A. cucullata* exhibited complete bleaching in 2017. In contrast, 93% of *Porites rus* corals (nineteenth most abundant) and 82% and 81% of *Favites* unknown #2 and *Favia* unknown #2 (fifteenth and tenth most abundant, respectively) were scored as healthy in 2017.

Pocillopora eydouxi specimens showed less bleaching than the *P. meandrina/verrucosa/elegans* complex in 2017. Many colonies of *P. eydouxi* showed little or no signs of bleaching (17% were classified as healthy, 57% bleached), even those located next to severely bleached members of the *P. meandrina/verrucosa/elegans* complex (2% classified as healthy, 84-95% bleached). This same pattern was observed during the 2007 bleaching event (Smith and Marx 2009), and could be related to different *Symbiodinium* clades hosted by each species (eg. Sampayo et al. 2008), or differences in physiology between species that affect susceptibility to heat stress (eg. Baird et al. 2009). The same pattern was observed in 2022, with 50% of *P. eydouxi* specimens categorized as healthy and only 0.9% of colonies bleached, compared to just 29% of *P. meandrina* colonies categorized as healthy and 6.2% bleached.

Some changes in community composition appear to have occurred at FDM and some loss of live coral cover appears to have occurred, particularly in habitat types H2 and H5 (see section G2). This was likely in part in response to the severe 2017 bleaching event. However, not all of the 2017 predictions were borne out: while significant numbers of *Pocillopora* corals have clearly died since the 2017 survey. Some of these corals are still alive, and there has not been a significant change in the relative abundance of *Acropora* colonies: *Acropora* colonies were reduced between 2017 and 2022 by just 0.2-1.8% in Habitats H2, H3, and H5, and actually increased by 0.4% in Habitat H4. *Porites rus* colonies, which have been seen to almost completely take over in some locations as a result of combined heat stress and other local human impacts (e.g., Donner and Carilli 2019) did not increase in relative frequency at FDM between 2017 and 2022. That species represented approximately 0.8% and 0.6% of corals enumerated in 2017 and 2022, respectively.

In prior survey years, coral condition was assessed as generally good-excellent. The exceptions to this were significant breakage after Typhoon TingTing passed over FDM in 2004, a bleaching event in 2007 that killed approximately 15% of the *Pocilloporid* corals, and an infestation of the coral barnacle *Cantellius* sp. in 2012. Subsequent surveys showed that coral recovered from Typhoon TingTing in 2004 and the bleaching event in 2007. This was evident from the survey observations after those occurrences that showed nearly all corals observed as healthy, including *Pocilloporids*. The 2017 survey did not detect any of the coral barnacles (*Cantellius* sp.), but observed many dead *Pocillopora* colonies around the southern portion of the island where the infestation had been the worst, suggesting these corals may have died as a result of this infestation. The 2022 survey observed 4 *Pocillopora* colonies (2 *P. eydouxi* and 2 *P. meandrina*) with *Cantellius* infesting a few of the branches. Therefore, while mortality associated with bleaching is the most likely reason for the loss of *Pocillopora* corals at FDM, *Cantellius* infestation could be a contributing factor.

The sponge *Terpios hoshinota* has been a problem in Guam and caused much alarm when it was first identified; however, more recent work shows that the sponge does not always win against corals it attempts to overgrow (Wang et al. 2012). It is unclear whether this sponge is invasive or native to Guam and the CNMI. Several patches of *T. hoshinota* were observed during the 2017 survey, but none were observed during the 2022 survey. However, other types of sponges were observed overgrowing living corals during the FDM survey. The occurrence of this was not quantified during prior surveys, but it appeared unusually common in the 2022 imagery to the NIWC Pacific photoquadrat analyst, and so the frequency of overgrowth of living corals by other organisms was tracked for the 2022 photoquadrat imagery. Overgrowth was highest in Habitat type H2 (42.2% of corals) and lowest in Habitat type H5 (13.9% of corals). Overgrowth was also generally lowest for upright branching corals such as *Acropora spp.* and *Pocillopora spp.* (1.9% and 2.6% of colonies, respectively), and highest for encrusting corals such as *Leptastrea spp.* (86.3% of colonies), *Astrea spp*. (66.7% of colonies), and *Acanthastrea* (65.5% of colonies). Many colonies of Favids were also being overgrown (44% of *Favia* and 38.3% of *Favites* corals).

4.5 [G5] TRAINING IMPACTS

Between 1997-2003, no significant impacts that could be tied to bombing activities were reported in marine habitats around FDM. In 2004, obvious damage (e.g., branch breakage) was observed that was initially postulated to be partly related to increased bombing activities that year, but was subsequently believed to have probably resulted from the direct passage of Typhoon TingTing over the island. In 2007 and 2008, one 9 m^2 and one 1 m^2 patch of disturbance was observed from bomb detonations. In other years, bombing impacts were even less significant. Overall, prior surveys have concluded that range activities had little discernible impact on the surrounding marine communities at FDM (Smith and Marx 2016).

The 2017 survey found little evidence that training affected coral communities at FDM. Only three relatively fresh ordnance items were observed. Blast pits, craters, or significant areas of coral breakage were not observed. The ordnance observed during the 2017 survey was almost exclusively old, encrusted in marine life, and was not having any discernable impact to surrounding communities. Similar findings were concluded for the 2022 survey. Two fresh ordnance items were observed. There were no blast pits, craters, or significant areas of coral breakage. Approximately 98% of ordnance observed was old and showed no discernable impact to the surrounding marine communities.

4.6 [G6] OTHER ESA-LISTED SPECIES

No other ESA-listed species were observed during the FDM 2022 survey aside from the corals described above. During past surveys, sea turtles were observed, but none were observed during the 2022 survey, either underwater or at the surface. Under the ESA, the Giant Manta ray (*Manta birostris*) and the oceanic whitetip shark (*Carcharhinus longimanus*) have been listed as threatened since the 2017 survey (February 21 and March 1, 2018, respectively). Neither species has ever been sighted at FDM and were not observed in 2022.

Seven species of Giant clam (*Tridacna* spp. and *Hippopus* spp.) are listed as candidate species under the ESA (90 day finding published June 26, 2017). Three of those species have been observed at FDM: *Tridacna gigas (*observations by authors and personal communication with experts), *T. squamosa* (Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005), and *T. maxima* (Carilli et al. 2018). Two other species (*Hippopus hippopus* and *Tridacna derasa*) did exist in the Northern Mariana Islands and Guam; those species may be extinct there due to fishing (Teitelbaum and Friedman 2008) and have not been recorded at FDM. A restocking program for *T. gigas, T. derasa*, and *H. hippopus* in the Northern Mariana Islands was started in 1986 by the Department of Lands and Natural Resources, and another for *T. derasa*, *T. gigas*, and *T. squamosa* was started in 1982 by the Department of Agriculture in Guam (Teitelbaum and Friedman 2008). Photoquadrat images taken during the 2017 and 2022 benthic surveys were all georeferenced and watermarked. Although geographically locating, counting, sizing, and identifying giant clams is beyond the scope of work for this report, those archived photographs could be analyzed at a later date if desired.

Observed impacts associated with range and training activities are de minimis to the fish and reef communities, however, significant long-term impacts have been observed associated with climatological effects, such as warming events causing bleaching and commercial/subsistence fishing. With limited access to FDM because of range operations, the island has served as a de facto nature protection area, surveys prior to 2012 commonly recorded high numbers and large sizes of FTF around the island. Increased fishing pressures during range closures have had a significant impact on the numbers and diversity of observed fishes. Specifically, Smith and Marx (2016), and Carilli et al. (2018), noted that FDM has become subject to increasing pressure from commercial and subsistence spearfishermen. Because the island is small, the near shore fishes are vulnerable to over exploitation. In 2017 and 2022, over exploitation appeared to have taken place for many of the species of FTF since the prior fish surveys in 2012. Crew members of the support ship used in 2017 also revealed that FDM is routinely visited by commercial and subsistence spearfishermen who market their catches in Saipan and even Guam.

It is to be expected that a decrease in percent coral cover will occur a posteriori of a regional bleaching event like the one in 2017, and this was observed in two of the four surveyed habitat types (H2 and H5). *Pocillopora meandrina* and *P. damicornis* appeared to suffer the most from the bleaching with high rates of bleaching in 2017 and loss of living colonies of these species in 2022. *P. eyedouxi* was also impacted by the bleaching event in 2017, but appeared to have fared better, particularly at the deeper depths. The type and abundance of *Symbiodinium* algae occurring within each coral species may have been a determining factor. For example, Al-Sofyani and Floos (2013) have shown that *P. verrucosa* has more flexibility as it relates to temperature fluctuation compared to *P. damicornis*. Their thermal tolerances differ based on the algal genotypes associated with the two coral species. Large and healthy massive *Porites* corals were also observed between 20-30 m depths during the 2022 survey with little to no evidence of any partial mortality associated with the 2017 bleaching event, in contrast to evidence of partial mortality at shallower depths. This suggests that deeper areas at FDM may provide a refuge to corals during future marine heatwaves, which are predicted to increase in frequency due to global climate change.

4.7 ACKNOWLEDGEMENTS

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LTJG Anthony Simonte

EODCS Theodore Baranek

EOD1 Drew Patterson

EODCS Bryan Clark

NDC Brian Ledyard

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REFERENCES

Arrigoni, R., Berumen, M.L., Chen, C.A., Terraneo, T.I., Baird, A.H., Payri, C. and Benzoni, F., 2016. Species delimitation in the reef coral genera *Echinophyllia* and *Oxypora* (Scleractinia, Lobophylliidae) with a description of two new species. *Molecular Phylogenetics and Evolution*, 105, pp.146-159.

Arrigoni, R., Berumen, M.L., Stolarski, J., Terraneo, T.I. and Benzoni, F., 2019. Uncovering hidden coral diversity: a new cryptic lobophylliid scleractinian from the Indian Ocean. *Cladistics*, 35(3), pp.301-328.

Bailey-Brock, J. H., 1989. Fouling community development on an artificial reef in Hawaiian waters. *Bulletin of Marine Science*, *44*(2): 580-591.

Baird, A.H., Bhagooli, R., Ralph, P.J. and Takahashi, S., 2009. Coral bleaching: the role of the host. *Trends in Ecology & Evolution*, 24(1): 16-20.

Baird, A.H., Madin, J.S., Álvarez-Noriega, M., Fontoura, L., Kerry, J.T., Kuo, C.Y., Precoda, K., Torres-Pulliza, D., Woods, R.M., Zawada, K.J. and Hughes, T.P., 2018. A decline in bleaching suggests that depth can provide a refuge from global warming in most coral taxa. *Marine Ecology Progress Series*, 603, pp.257-264.

Belt Collins Hawaii, 2001. Year 2001 Assessment of Marine and Fisheries Resources, Farallon de Medinilla, Commonwealth of the Northern Mariana Islands. Final Report prepared for the Department of the U.S. Navy, November 2001. Contract No. N62742-99-D-1807.

Belt Collins Hawaii, 2003. Year 2002 Assessment of Marine and Fisheries Resources, Farallon de Medinilla, Commonwealth of the Northern Mariana Islands. Final Report prepared for the Department of the U.S. Navy, February 2003. Contract No. N62742-99-D-1807.

Benzoni, F., 2013. *Echinophyllia tarae* sp. n.(Cnidaria, Anthozoa, Scleractinia), a new reef coral species from the Gambier Islands, French Polynesia. *ZooKeys*, (318), p.59.

Brainard, R.E., C. Birkeland, C.M. Eakin, P. McElhany, M.W. Miller, M. Patterson, and G.A. Piniak. 2011. Status review report of 82 candidate coral species petitioned under the U.S. Endangered Species Act. *U.S. Department of Commerce, NOAA Technical Memorandum, NOAA-TM-NMFS-PIFSC-27, 530 p. + 1 Appendix.*

Brandt, M.E. and McManus, J.W., 2009. Disease incidence is related to bleaching extent in reef-building corals. *Ecology*, 90(10), pp.2859-2867.

Budd, A.F., Fukami, H., Smith, N.D. and Knowlton, N., 2012. Taxonomic classification of the reef coral family Mussidae (Cnidaria: Anthozoa: Scleractinia). *Zoological Journal of the Linnean Society*, *166*(3): 465-529.

Carilli J., Smith S.E., Marx Jr. D., and Bolick L., 2018. Farallon de Medinilla 2017 Coral Reef Survey Report. Prepared for U.S. Pacific Fleet. 55 pp. Space and Naval Warfare Systems Center Pacific Technical Report #TBD.

Cooper, T.F., et al., 2008. Temporal dynamics in coral bioindicators for water quality on

coastal reefs of the Great Barrier Reef. *Marine and Freshwater Research* 59: 703–716.

Darling ES, McClanahan TR, Côté IM (2013) Life histories predict coral community disassembly under multiple stressors. *Global Change Biology*, *19*: 1930–1940.

Darling, E.S., McClanahan, T.R. and Côté, I.M., 2013. Life histories predict coral community disassembly under multiple stressors. *Global Change Biology*, 19(6), pp.1930-1940.

Department of the Navy. 2016. Memorandum from Navy to NMFS Protected Resources Division on revised coral coverage around FDM.

Donner, S.D. and Carilli, J., 2019. Resilience of Central Pacific reefs subject to frequent heat stress and human disturbance. Scientific Reports, 9(1), pp.1-13.

Dwita, N.P.M. and Widjoyo, N.S., 2022. Diversity of reef fish on Lembeh Island as an indicator of the coral reef health condition. In *IOP Conference Series*: *Earth and Environmental Science* 967(1), p.012006).

Endangered Species Act in 2014 (79 FR 53851).

Fenner, D., personal communication with the authors 2017 – 2018 on multiple occasions.

Fenner, D. and Burdick, D.R., 2016. Field identification guide to the threatened corals of the US Pacific Islands.

Frade, P.R., Bongaerts, P., Englebert, N., Rogers, A., Gonzalez-Rivero, M. and Hoegh-Guldberg, O., 2018. Deep reefs of the Great Barrier Reef offer limited thermal refuge during mass coral bleaching. *Nature Communications*, 9(1), p.3447.

Feary, D.A., Almany, G.R., Jones, G.P. and McCormick, M.I., 2007. Coral degradation and the structure of tropical reef fish communities. *Marine Ecology Progress Series*, 333, pp.243-248.

Feary, D.A., Cinner, J.E., Graham, N.A. and Januchowski-Hartley, F.A., 2011. Effects of customary marine closures on fish behavior, spear-fishing success, and underwater visual surveys. *Conservation Biology*, 25(2), pp.341-349.

Hackerott, S., Martell, H.A. and Eirin-Lopez, J.M., 2021. Coral environmental memory: causes, mechanisms, and consequences for future reefs. *Trends in Ecology & Evolution*, 36(11), pp.1011-1023.

HDR EOC and CSA International, Inc. 2011. Supplemental marine resource surveys to support the CVN transient pier, Apra Harbor, Guam. Task 2- Potential mitigation site reconnaissance surveys. Contract N62470-10-D-3011 CTO KB03. Prepared for Naval Facilities Engineering Command, Pacific (Pearl Harbor, HI). August. 115 pp.

Naval Information Warfare Center (NIWC) 2021 Farallon de Medinilla Marine Survey Plan. SOW Task 3; 21 June 2021.

Naval Information Warfare Center (NIWC) 2022 Farallon de Medinilla Field Implementation Plan. SOW Task 4; 24 May 2022

Neal, B.P., Condit, C., Liu, G., dos Santos, S., Kahru, M., Mitchell, B.G. and Kline, D.I., 2014. When depth is no refuge: cumulative thermal stress increases with depth in Bocas del Toro, Panama. *Coral Reefs*, 33, pp.193-205.

NMFS (National Marine Fisheries Service). 2020. Biological Opinion on (1) United States (U.S.) Navy Mariana Islands Training and Testing Activities; and (2) the National Marine Fisheries Service's promulgation of regulations and issuance of a letter of authorization pursuant to the Marine Mammal Protection Act for the U.S. Navy to "take" marine mammals incidental to Mariana Islands Training and Testing activities from August 2020 through August 2027. OPR-2019-00469. July 10, 2020. https://doi.org/10.25923/6r20-b791

Olinger, L.K., Chaves-Fonnegra, A., Enochs, I.C. and Brandt, M.E., 2021. Three competitors in three dimensions: photogrammetry reveals rapid overgrowth of coral during multispecies competition with sponges and algae. *Marine Ecology Progress Series*, 657, pp.109-121.

Pavlowich, T. and Kapuscinski, A.R., 2017. Understanding spearfishing in a coral reef fishery: Fishers' opportunities, constraints, and decision-making. *PLoS One*, 12(7), p.e0181617.

Pérez-Rosales, G., Rouzé, H., Torda, G., Bongaerts, P., Pichon, M., Under The Pole Consortium, Parravicini, V. and Hédouin, L., 2021. Mesophotic coral communities escape thermal coral bleaching in French Polynesia. *Royal Society Open Science*, 8(11), p.210139.

Randall, R. H. (2003) An annotated checklist of hydrozoan and scleractinian corals collected from Guam and other Mariana Islands. *Micronesica* 35-36:121-137.

Sampayo, E.M., Ridgway, T., Bongaerts, P. and Hoegh-Guldberg, O., 2008. Bleaching susceptibility and mortality of corals are determined by fine-scale differences in symbiont type. *Proceedings of the National Academy of Sciences*, *105*(30): 10444-10449.

Sandin, S.A. and McNamara, D.E., 2012. Spatial dynamics of benthic competition on coral reefs. *Oecologia*, 168, pp.1079-1090.

Smith, S.H. and Marx, D.E., 2009. Assessment of Near Shore Marine Resources at Farallon de Medinilla: 2006, 2007 And 2008, Commonwealth of the Northern Mariana Islands. Naval Facilities Engineering Command, February 2009.

Smith, S.H. Marx, D.E. and Shannon, L.H. 2013. Calendar Year 2012 Assessment of Near Shore Marine Resources at Farallon De Medinilla, Commonwealth Of The Northern Mariana Islands. Naval Facilities Engineering Command, April 2013. Report No. SSR-NAVFAC-EXWC-EV-1307.

Smith, S.H. and Marx, D.E., 2016. De-facto marine protection from a Navy bombing range: Farallon De Medinilla, Mariana Archipelago, 1997 to 2012. *Marine Pollution Bulletin*, *102*(1): 187-198.

Stafford-Smith, M.G. and Ormond, R.F.G., 1992. Sediment rejection mechanisms of 42 species of Australian scleractinian corals. *Australian Journal of Marine and Freshwater Research* 43: 683–705.

Teitelbaum, A. and Friedman, K., 2008. Successes and failures in reintroducing giant clams in the Indo-Pacific region. *SPC Trochus Information Bulletin*, *14*: 19-26.

Tetra Tech. 2014. Coral Marine Resources Survey Report in support of the Commonwealth of the Northern Mariana Islands Joint Military Training Environmental Impact Statement/Overseas Environmental Impact Statement. Prepared for Naval Facilities Engineering Command, Pacific. Contract: N62742-11-D-1801 Task Order: 0002.

The Environmental Company, 2004. Year 2003 Assessment of Marine and Fisheries Resources, Farallon de Medinilla, Commonwealth of the Northern Mariana Islands. Final Report prepared for Pacific Division, Naval Facilities Engineering Command, January 2004. Contract No. N62742-02-D-1802.

The Environmental Company, 2005. Year 2004 Assessment, Marine and Fisheries Resources, Farallon de Medinilla, Commonwealth of the Northern Mariana Islands. Final Report prepared for Pacific Division, Naval Facilities Engineering Command, May 2005. Contract No. N62742-02-D-1802.

Veron, J.E., 2000. *Corals of the World, vol. 1–3*. Australian Institute of Marine Science, Townsville, pp. 404-405.

Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M., 2016. Corals of the World. Accessed 17 Feb 2023, version 0.01. http://www.coralsoftheworld.org/page/home/?version=0.01

Wang, J.T., Chen, Y.Y., Meng, P.J., Sune, Y.H., Hsu, C.M., Wei, K.Y. and Chen, C.A., 2012. Diverse interactions between corals and the coral-killing sponge, *Terpios hoshinota* (Suberitidae: Hadromerida). *Zool Stud*, *51*: 150-159.

Wild, C., et al., 2005. Influence of coral mucus on nutrient fluxes in carbonate sands. *Marine Ecology Progress Series,* 287: 87–98.

Zamani, N.P. and Madduppa, H.H., 2011. A standard criteria for assesing the health of coral reefs: implication for management and conservation. *Journal of Indonesia Coral Reefs*, 1(2), pp.137-146.

APPENDIX A
BENTHIC COMMUNITY DESCRIPTIONS

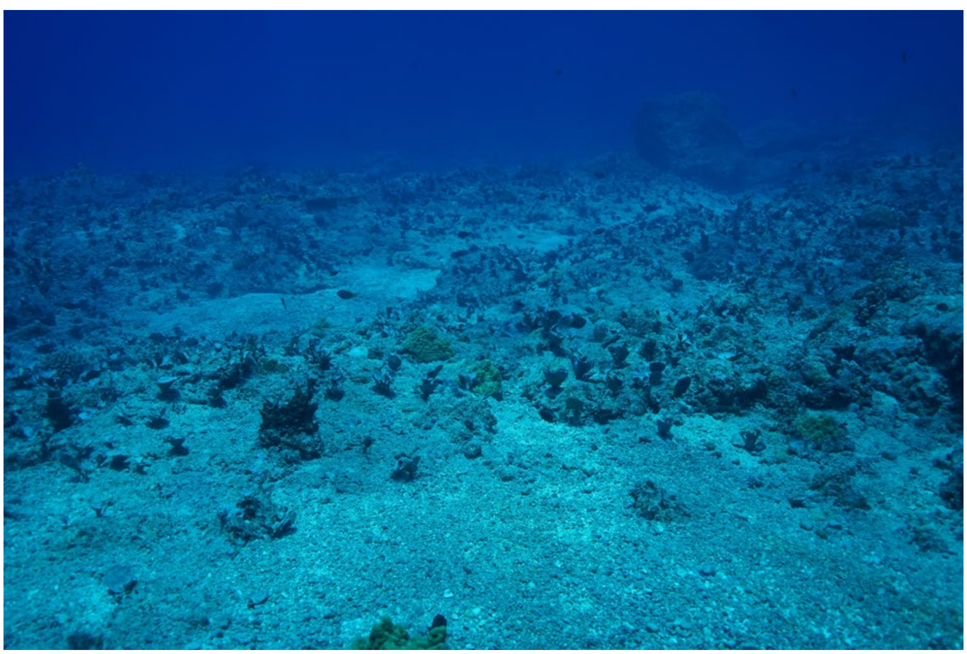
The following descriptions and images are representative of benthic communities at sites surveyed within the four major habitat types for the 2022 FDM benthic survey effort (H2, H3, H4, H5). Hard substrate and coral cover metrics are taken from Table 3.

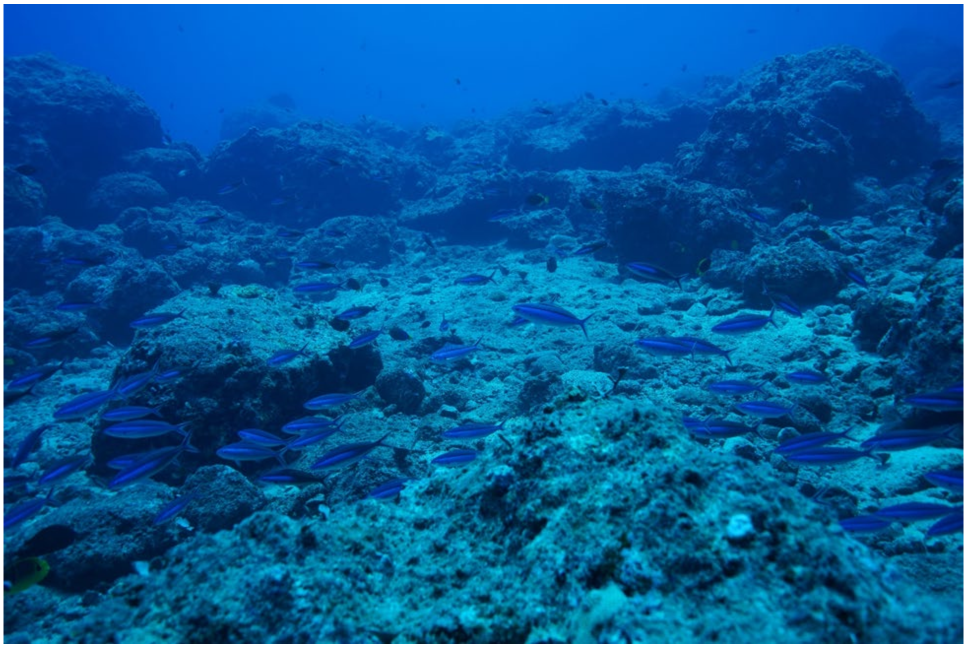
H2

Habitat Type H2 is a highly variable region containing many boulders and cliff blocks that have eroded from FDM, in addition to many wide sand valleys and areas of consolidated hard bottom that have been covered with sand and algae in some locations. The 2022 study found that the amount of hard substrate capable of supporting corals ranged from 75 to 100% in this habitat type, while the percent living coral cover ranged from 1-19%. In 2017, H2 habitats were found to be comprised primarily of boulders and cliff blocks (hard substrate 10-35%), and mean coral cover on rock substrate was reported as 0-50% in 2017. The team re-evaluated selected landscape images from 2017 to re-assess the amount of hard substrate and living coral. This was in part because of *in situ* observations from the 2022 survey. Some areas of hard substrate were covered in a thin layer of sand and algae (and thus may have been mistaken or interpreted as unconsolidated material), and because the amount of hardbottom appeared much higher in 2022 compared to the prior surveys. After analyzing landscape photographs from both 2017 and 2022, the "recalibrated" assessment for 2017 in H2W was 76-94% for hard substrate and 9-20% for coral coverage, which was generally more similar to the 2022 observations. Some representative images from H2 habitat areas taken during the 2022 survey are shown below.

H3

Habitat type H3 consists of a mix of predominately hardbottom, with some unconsolidated small rocks and sand (hard substrate 47-95%), with variable coral cover (1-24%). These results are similar to the 2017 findings of 50-85% hard bottom and 5-25% coral cover. Some representative landscape images from habitat H3 are shown below.



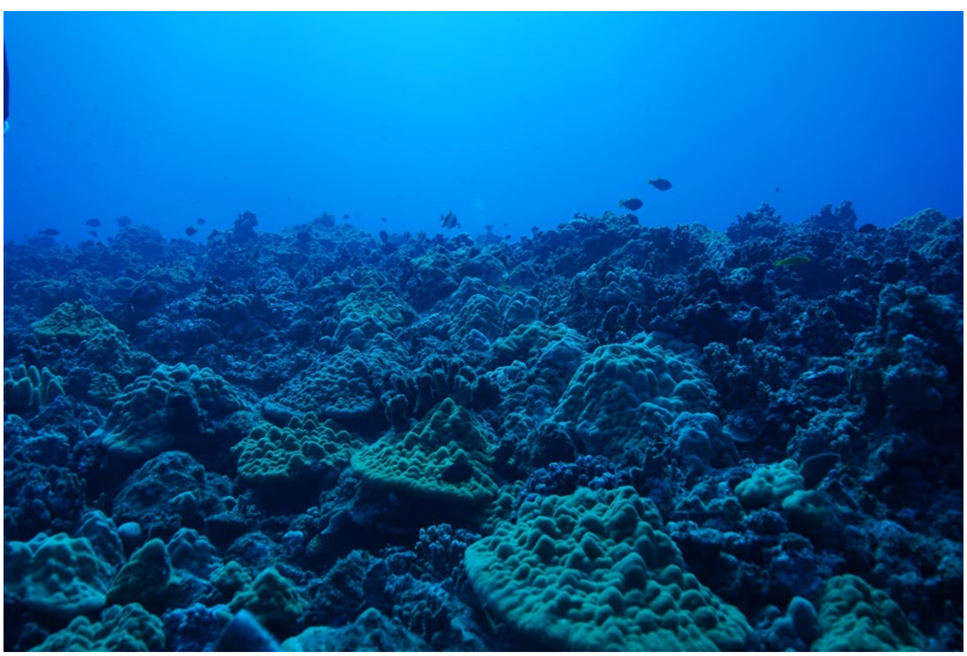


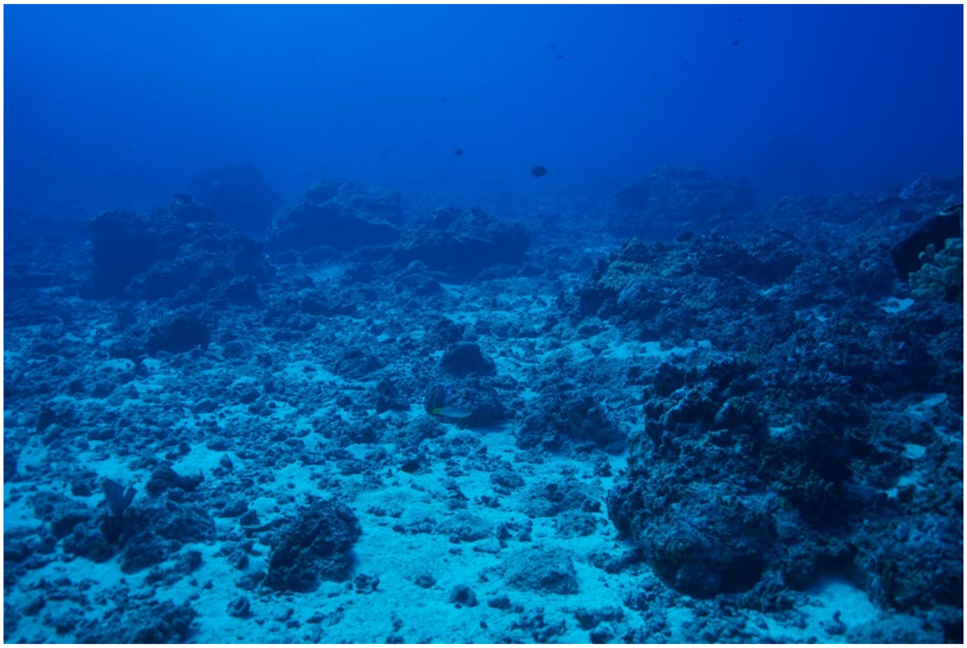
H4

Habitat type H4 is comprised of a combination of bare rock, hard substrate that is covered by sand and *Padina* algae, and some unconsolidated regions (small rocks and sand). For 2022, hard bottom coverage ranged between 51 and 81%, and live coral coverage ranged from 3-10%. In 2017, hard bottom ranged from 80-100% and live coral cover ranged from 5-15%. Some representative 2022 landscape images from habitat type H4 are shown below.

H5

Habitat type H5 contains both classic framework-building coral reefs and some areas of hard bottom that are covered by sand. In 2022, hardbottom was observed to range between 85-98%, with 12-32% live coral cover on a site-wide basis. Some small areas contained 100% live coral cover. In 2017, this habitat was recorded as 100% hardbottom, with live coral cover ranging between 40-65%. Some representative 2022 landscape photographs are included below.





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APPENDIX B
FDM PHOTOGRAPH METADATA

Photo numbers span range of photographs taken during a particular dive/transect. Not all photographs in this range were photoquadrats; some were landscape images or images of particular coral specimens, ordnance, etc. Photoquadrats, landscape images, ordnance images, and photographs of probable ESA-listed corals were georeferenced and watermarked with latitude/longitude locations and archived with PACFLT.

Date	Site	Dive	Max Depth (ft)	Start Time	Transects	Photo Numbers
8/14	H3W	1	70	11:18	2	P1040268-P1040287 DSC0028-DSC0013
8/14	H5W	2	47	14:13	4	P1040290-P1040350 DSC0042-DSC0061
8/14	H2W	3	37	15:48	4	P1040352-P1040400 DSC0069-DSC00118
8/15	H5, H3W, H2NW	1	101	08:47	1	P1040405-P1040413
8/15	H3N	2	51	12:36	5	P1040416-P1040488 DSC00124-DSC00174
8/15	H2N, H3NW	3	36	13:37	8	P1040490-P1040612 DSC00180-DSC00223
8/16	H5W, H3W	1	70	08:44	6	P1040623-P1040712 DSC00247-DSC00294
8/16	H3NW, H2N	2	50	13:04	4	P1040718-P1040777 DSC00003-DSC00036
8/16	H2W ext, H2W	3	34	14:26	5	P1040779-P1040856 DSC00038-DSC00070
8/17	H2NW, H3NW	1	50	09:22	6	P1040860-P1040954 DSC00080-DSC00134
8/17	H3W	2	51	10:44	5	P1040976-P1050074 DSC00142-DSC00155
8/17	H4S, H2W	3	36	14:23	1	P1050080-P1050096 DSC00215
8/18	North Tract Transect	1	98	08:30	1	P1050099-P1050100

Date	Site	Dive	Max Depth (ft)	Start Time	Transects	Photo Numbers
8/18	H2E, H2E Ext	2	42	09:48	5	P1050107-P1050192 DSC00250-DSC00283
8/18	H3NE	3	43	14:35	4	P1050209-P1050290 DSC00287-DSC00330
8/19	H3NE, H4NE	1	71	08:06	5	P1050324-P1050411 DSC00338-DSC00367
8/19	H2E	2	41	09:08	4	P1050421-P1050492 DSC00372-DSC00395
8/19	H3E	3	36	11:03	5	P1050509-P1050603

APPENDIX C
SCLERACTINIAN CORAL SPECIES LISTS

Individual coral taxa identified at FDM during prior species-level surveys from 2001–2004, 2017, and 2022; in these columns, a “1” indicates at least one coral colony of this taxon was recorded. Note that *Porites* massive probably includes at least 5 species; in 2017, some massive *Porites* colonies were differentiated as different species; this was generally not done in 2022 in the interest of analytical time. Also included is the total number of coral colonies identified from a given taxon in the photoquadrat imagery. Records highlighted in blue are corals identified in 2022, but not in 2017 or the 2001-2004 surveys. Records highlighted in yellow are categories unique to the 2017 and/or 2022 survey. ESA-listed species are identified with an asterisk. No corals were collected during any of the surveys; all identifications were made in the field and/or from photographs. Note: identifications primarily used spelling of genus and species names from Veron as of February 2023 (www.coralsoftheworld.org) and the World Register of Marine Species (www.marinespecies.org) when not included in Veron.

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Acanthastrea brevis	0	1	1	9	8	A bre	
Acanthastrea echinata	1	0	1	NA	1	A ech	
Acanthastrea regularis	0	0	1	NA	49	A reg	Some colonies may have been recorded as one of the Favia unknowns in 2017
Acropora aculeus	1	0	0	NA	NA	A acu	
Acropora austera	1	0	0	NA	NA	A aus	Possibly recorded as Acropora sp. unknown #11 in 2017
Acropora caroliniana	1	0	0	NA	0	A car	not recognized as occurring in Marianas by Corals of the World
Acropora cerealis	1	1	1	2	1	A cer	
Acropora digitifera	1	0	1	NA	1	A dig	
Acropora gemmifera	1	0	1	NA	4	A gem	Possibly recorded as possible Acropora new species #3 in 2017

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
*Acropora globiceps**	1	1	1	7	10	A glo	
Acropora granulosa	1	0	0	NA	NA	A gra	Possibly recorded as Acropora unidentified #5 in 2017
Acropora humilis	1	0	1	NA	2	A hum	Possibly recorded as Acropora new species #1 in 2017
Acropora hyacinthus (†Recorded as Acropora bifurcata for earlier surveys and Acropora surculosa in 2017)	1†	1†	1	6	6	A hya	*Acropora bifurcata* recognized as separate species to *A. hyacinthus* in Corals of the World, but not recognized as occuring in Marianas. Considered same species as *A hyacinthus* by WoRMS; *A surculosa* is now *A hyacinthus*
Acropora monticulosa	0	0	1	NA	1	A mon	
Acropora nasuta	1	1	1	5	39	A nas	
Acropora new species #1	0	1	1	6	1	Acropora new 1	
Acropora new species #2	0	1	0	3	NA	Acropora new 2	
Acropora new species #3	0	1	0	2	NA	Acropora new 3	
*Acropora retusa**	0	0	1	NA	10	A ret	Possibly recorded as Acropora new species #1/#2 in 2017
Acropora robusta	1	0	0	NA	NA	A rob	
Acropora samoensis	1	0	0	NA	NA	A sam	
Acropora sarmentosa	1	0	0	NA	NA	A sar	not recognized as occurring in Marianas by Corals of the World
Acropora sp.	0	1	1	10	20	Acropora sp	Photo not clear enough to ID to species
Acropora juvenile	0	0	1	NA	3	Acr juv	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Acropora sp. unknown #1	0	1	1	13	1	Acropora unknown 1	
Acropora sp. unknown #2	0	1	0	2	NA	Acropora unknown 2	
Acropora sp. unknown #3	0	1	0	1	NA	Acropora unknown 3	
Acropora sp. unknown #4	0	1	1	2	1	Acropora unknown 4	
Acropora sp. unknown #5	0	1	0	1	NA	Acropora unknown 5	
Acropora sp. unknown #6	0	1	0	3	NA	Acropora unknown 6	
Acropora sp. unknown #7	0	1	0	2	NA	Acropora unknown 7	
Acropora sp. unknown #8	0	1	0	2	NA	Acropora unknown 8	
Acropora sp. unknown #9	0	1	0	4	NA	Acropora unknown 9	
Acropora sp. unknown #10	0	1	0	4	NA	Acropora unknown 10	
Acropora sp. unknown #11	0	1	0	1	NA	Acropora unknown 11	
Acropora tenuis	1	0	1	NA	4	A ten	
Acropora valida	1	0	0	NA	NA	A val	
Alveopora fenestrata	1	0	0	NA	NA	A fen	
Alveopora minuta	0	0	1	NA	6	A min	
Alveopora sp.	0	0	1	NA	2	Alveopora sp	Photo not clear enough to ID to species
Astrea annuligera	0	1	1	16	99	A ann	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Astrea curta (†previously known/recorded as Montastrea curta)	1†	1	1	6	21	A cur	
Astreopora cucullata	0	1	1	106	181	A cuc	not recognized as occurring in Marianas by Corals of the World; identified in 2017 photos by Doug Fenner
Astreopora eliptica	1	0	0	NA	NA	A eli	not recognized as occurring in Marianas by Corals of the World
Astreopora gracilis	1	0	0	NA	NA	Ast gra	
Astreopora myriophthalama	1	1	1	194	583	A myr	
Astreopora ocellata	1	0	1	NA	6	A oce	
Astreopora randalli	1	0	0	NA	NA	A ran	
Astreopora sp.	0	1	1	9	10	Astreopora sp	Photo not clear enough to ID to species
Coscinaraea columna	1	0	0	NA	NA	C col	
Cycloseris costulata	0	0	1	NA	1	C cos	
Cyphastrea chalcidicum	1	0	0	NA	NA	C cha	
Cyphastrea microphthalma	1	0	0	NA	NA	C mic	
Cyphastrea ocellina (†previously recorded as Cyphastrea sp. unknown #1 in 2017; believe these are all or nearly all *C oce*)	0	1†	1	46	199	C oce	
Cyphastrea seriaila	1	0	0	NA	NA	C ser	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Diploastrea heliopera	1	0	1	NA	1	D hel	
Dipsastrea marshae (†previoulsy recorded as Favia marshae, name no longer accepted by WoRMS)	1†	0	0	NA	NA	D mar	not recognized as occurring in Marianas by Corals of the World
Echinopora lamellosa	1	0	0	NA	NA	E lam	
Echinophyllia tarae	0	0	1	NA	5	E tar	not recognized as occurring in Marianas by Corals of the World; newly described species; tentative ID
Euphyllia glabrescens	1	0	0	NA	NA	E gla	
Favia danae	0	0	1	NA	1	F dan	
Favia favus	1	0	1	NA	2	F fav	
Favia marítima	1	1	1	3	4	F mari	
Favia matthai	1	1	1	66	419	F mat	Some colonies may have been recorded as Favia unknown 2 in 2017; or some Favia unknown 2 colonies may have been recorded as *Favia matthai* in 2022
Favia pallida	1	1	0	13	NA	F pal	
Favia speciosa	1	0	1	NA	1	F spe	
Favia stelligera	1	1	1	22	75	F ste	
Favia unknown #1	0	1	1	26	14	Favia unknown 1	
Favia unknown #2	0	1	1	77	17	Favia unknown 2	
Favia unknown #3	0	1	1	1	17	Favia unknown 3	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Favites abdita	1	0	1	NA	60	F abd	Possibly recorded as Favites unknown #2 in 2017
Favites flexuosa	0	0	1	NA	18	F fle	Possibly recorded as Favites unknown #3 in 2017
Favites halicora	1	0	0	NA	NA	F hal	not recognized as occurring in Marianas by Corals of the World
Favia helianthoides	0	0	1	NA	2	F hel	
Favites pentagonia	1	0	0	NA	NA	F pen	not recognized as occurring in Marianas by Corals of the World
Favites russelli	1	0	1	NA	16	F rus	
Favites unknown #1	0	1	1	42	8	Favites unknown 1	
Favites unknown #2	0	1	1	1	1	Favites unknown 2	
Favites unknown #3	0	1	1	8	2	Favites unknown 3	
Favites unknown #4	0	1	1	12	1	Favites unknown 4	
Favites sp.	0	0	1	NA	1	Favites sp	Photo not clear enough to ID to species
Fungia scutaria	1	0	0	NA	NA	F scu	
Galaxea fascicularis	1	1	1	12	14	G fas	
Gardineroseris planulata	1	0	1	NA	107	G pla	
Goniastrea minuta	0	1	1	2	2	G min	
Goniastrea palauensis	1	0	0	NA	NA	G pal	
Goniastrea pectinata	1	1	1	11	50	G pec	One colony recorded as *G peresi* in 2017 (typo)
Goniastrea retiformis	1	0	1	NA	36	G ret	
Goniopora lobata	1	0	0	NA	NA	G lob	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Goniopora somaliensis	0	1	1	38	148	G som	
Goniopora sp.	0	0	1	NA	1	Goniopora sp	Photo not clear enough to ID to species
Herpolitha limax	0	1	1	1	1	H lim	
Hydnophora microconos	1	1	1	14	28	H mic	
Isopora palifera (†Recorded as Acropora palifera in earlier surveys; name no longer recognized)	1†	0	0	NA	NA	I pal	
Leptastrea bottae	1	0	0	NA	NA	L bot	
Leptastrea inaequalis	1	0	0	NA	NA	L ina	not recognized as occurring in Marianas by Corals of the World
Leptastrea purpurea	1	1	1	291	2076	L pur	
Leptastrea transversa	1	1	1	10	35	L tra	
Leptoria phrygia	1	0	0	NA	NA	L phr	
Leptoseris mycetoseroides	1	0	0	NA	NA	L myc	
Leptoseris sp.	0	1	0	NA	NA	Leptoseris sp	No photos taken; field ID to genus
Lobophyllia corymbosa	0	1	0	NA	NA	L cor	No photos taken; field ID
Lobophyllia hemprichii	1	1	1	NA	1	L hem	
Merulina ampliata	1	1	1	1	1	M amp	
Montipora aequituberculata	1	0	1	NA	2	M aeq	
Montipora caliculata	1	0	0	NA	NA	M cal	
Montipora danae	1	0	0	NA	NA	M dan	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Montipora foveolata	1	0	1	NA	12	M fov	
Montipora grisiea	1	0	0	NA	NA	M gri	
Montipora hoffmesiteri	1	0	0	NA	NA	M hof	
Montipora monasteriata	1	0	0	NA	NA	M mon	
Montipora spumosa	1	0	0	NA	NA	M spu	not recognized as occurring in Marianas by Corals of the World
Montipora tuberculosa	1	1	1	3	1	M tub	
Montipora unknown #1	0	1	0	9	NA	Montipora unknown 1	
Montipora unknown #2	0	1	0	5	NA	Montipora unknown 2	
Montipora unknown #3	0	1	0	1	NA	Montipora unknown 3	
Montipora venosa	1	0	1	NA	4	M ven	
Montipora verrilli	1	0	0	NA	NA	M veri	
Montipora verrucosa	1	0	0	NA	NA	M ver	
Oulophyllia bennettae	0	1	0	3	NA	O ben	not recognized as occurring in Marianas by Corals of the World
Oulophyllia crispa	1	1	1	3	4	O cri	
Pachyseris speciosa	0	1	0	NA	NA	Pac spe	No photos taken; field ID to genus
Parascolymia australis	0	0	1	NA	2	Par aus	
Pavona chiriquensis	0	1	1	23	195	P chi	
Pavona cf. diffluens	0	1	1	4	1	P dif	not recognized as occurring in Marianas by Corals of the World; "cf." indicates looks like this species
Pavona duerdeni	1	1	1	8	3	P due	
Pavona maldivensis	1	0	0	NA	NA	P mal	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Pavona minuta	1	0	0	NA	NA	P min	
Pavona varians	1	1	1	21	182	P var	
Pavona venosa	1	1	1	9	11	P ven	
Phymastrea colemani	0	0	1	NA	16	P col	Some colonies may have been recorded as Favia unknown 3 in 2017
Phymastrea valenciennesi (†previously known/recorded as Montastrea valenciennesi)	1†	0	0	NA	NA	P val	not recognized as occurring in Marianas by Corals of the World
Platygyra daedelea	1	1	1	40	23	P dae	
Platygyra pini	1	1	1	63	149	P pin	
Platygyra ryukuensis	1	0	0	NA	NA	P ryu	not recognized as occurring in Marianas by Corals of the World
Platygyra sinensis	1	0	0	NA	NA	P sin	not recognized as occurring in Marianas by Corals of the World
Pleisiastrea versipora	1	1	1	3	28	Ple ver	
Pleurogyra sinuosa	1	0	0	NA	NA	P sin	
Pocillopora ankeli	0	1	1	11	36	P ank	
Pocillopora damicornis	1	0	1	NA	1	P dam	
Pocillopora elegans	1	0	0	NA	NA	P ele	
Pocillopora eydouxi	1	1	1	58	108	P eyd	
Pocillopora eydouxi hybrid	0	1	0	3	NA	P eyd bybrid	
Pocillopora hybrid #1	0	1	1	83	3	Poc hybrid 1	
Pocillopora hybrid #2	0	1	1	6	2	Poc hybrid 2	
Pocillopora juvenile	0	1	1	115	103	P juv	can't ID to species because too small

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Pocillopora meandrina	1	1	1	428	145	P mea	
Pocillopora verrucosa	1	1	1	132	29	P ver	
Pocillopora woodjonesi	1	0	0	NA	NA	P woo	
Pocillopora sp.	0	0	1	NA	2	Pocillopora sp	Photo not clear enough to ID to species
Porites australiensis	1	1	1	8	30	P aus	
Porites deformis	0	0	1	NA	15	P def	
Porites evermanni	0	1	not specified	18	not specified	P eve	did not attempt to differentiate massive Porites in 2022
Porites lichen	1	0	0	NA	NA	P lic	
Porites lobata	1	1	not specified	15	not specified	P lob	did not attempt to differentiate massive Porites in 2022
Porites lutea	1	1	not specified	36	not specified	P lut	did not attempt to differentiate massive Porites in 2022
Porites massive	0	1	1	671	1735	Por mass	refers to P. evermanni, P. lobata, P. lutea etc.
Porites murrayensis	1	0	0	NA	NA	P mur	
Porites rus	1	1	1	29	46	P rus	
Porites solida	1	1	1	150	56	P sol	Some *Gardinoseris planulata* may have been ID'd as P sol in 2017
Porites vaughani	1	0	0	NA	NA	P vau	
Psammocora haimiana	1	0	0	NA	NA	P hai	not recognized as occurring in Marianas by Corals of the World
Psammocora nierstraszi	0	0	1	NA	2	P nie	
Psammocora obtusangula	1	0	0	NA	NA	P obt	

Coral Taxon	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Taxon recorded in 2022 survey	Number of colonies recorded in photoquadrats, 2017	Number of colonies recorded in photoquadrats, 2022	Coral shorthand code	Reference/ Note
Psammocora profundacella (†previously recorded as Psammocora superficialia)	1†	0	0	NA	NA	P pro	
Scapophyllia cylindrica	1	1	1	5	1	S cyl	
Siderastrea savignyana	1	0	0	NA	NA	S sav	not recognized as occurring in Marianas by Corals of the World
Stylophora pistillata	1	0	0	NA	NA	S pis	
Tubastraea faulkneri	1	0	0	NA	NA	T fau	
Turbinaria stellutata	0	1	1	20	185	T ste	
Unknown/NP	0	1	1	7	642	Unk/NP	No one can ID even to genus (i.e. photo too blurry)
Total individual coral taxa recorded	105	77	86				
Shared taxa, prior and 2022 survey periods	72						
New taxa, 2022	13						
Total individual scleractinian coral colonies marked in photos				3103	8209		
Total individual scleractinian coral colonies identified				3096	7567		

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APPENDIX D
CORAL COMMUNITY COMPOSITION CHARTS

Figure 31 presents genus-level scleractinian coral community composition for all identified colonies from photoquadrats, showing overall general similarity but some differences between habitat types around FDM.

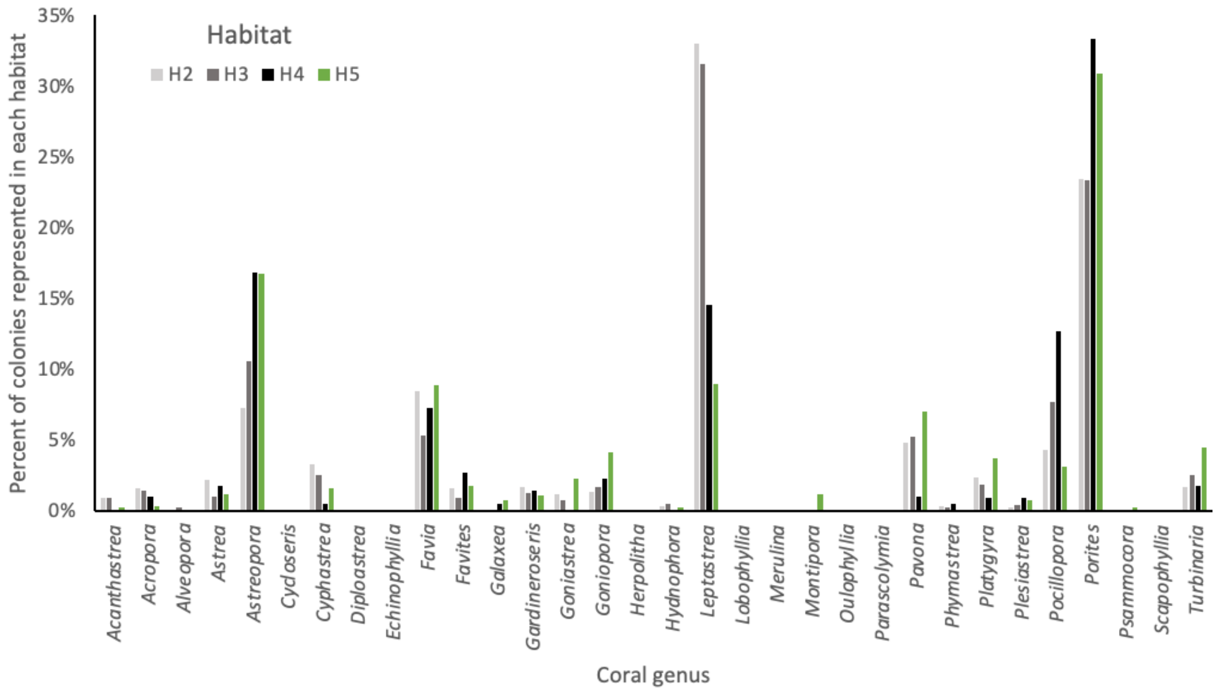

Figure 31: Coral community composition by habitat and genera based on coral counts from photoquadrats.

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APPENDIX E
ORDNANCE OBSERVED

Details on ordnance items observed and photographed during the 2022 FDM benthic habitat survey.

Item #	Size of ordnance				Condition of ordnance				Photo #
	Large	Medium	Small	Fragment	Fresh	Old	Intact	Broken	
1	X					X	X		DSC00059
2	X					X	X		DSC00137 & DSC00138
3	X					X	X		DSC00206 & DSC00207
4		X				X	X		DSC00225
5	X					X	X		DSC00227 & DSC00228
6	X					X	X		DSC00254
7		X				X	X		DSC00255 & DSC00259
8				X		X	X		DSC00257 & DSC00260
9	X					X	X		DSC00261
10	X					X	X		DSC00262
11	X					X	X		DSC00264
12	X					X	X		DSC00265
13	X					X	X		DSC00275
14	X					X	X		DSC00278 & DSC00279
15	X					X	X		DSC00288
16		X				X	X		DSC00293
17	X					X	X		DSC00297
18	X					X	X		DSC00298
19	X					X	X		DSC00299
20	X					X	X		DSC00302
21	X					X	X		DSC00005
22		X				X	X		DSC00011
23		X				X	X		DSC00015
24	X					X	X		DSC00025
25	X					X	X		DSC00033
26		X				X	X		DSC00034 & DSC00035
27	X					X		X	DSC00216
28	X					X	X		DSC00217
29		X				X	X		DSC00091

Item #	Size of ordnance				Condition of ordnance				Photo #
	Large	Medium	Small	Fragment	Fresh	Old	Intact	Broken	
30				X		X			DSC00096
31	X					X		X	DSC00098
32				X		X			DSC00102 & DSC00103
33	X					X	X		DSC00104
34				X		X			DSC00108
35		X				X		X	DSC00110
36	X					X	X		DSC00112
37		X				X		X	DSC00128
38		X				X	X		DSC00138 & DSC00139
39	X					X	X		DSC00146
40				X		X			DSC00147
41				X		X			DSC00149
42	X					X	X		DSC00160
43	X					X	X		DSC00165
44	X					X		X	DSC00166
45	X				X marked EMPTY		X		DSC00167 & DSC00168 & DSC 00169
46	X					X	X		DSC00170
47	X					X	X		DSC00171 & DSC00172
48	X					X	X		DSC00173 & DSC 00174
49	X					X	X		DSC00175
50				X		X			DSC00176
51	X					X	X		DSC00177
52	X					X	X		DSC00179
53	X					X	X		DSC00186 & DSC00187 & DSC00188
54	X					X	X		DSC00186 & DSC00187 & DSC00189
55				X		X			DSC00192
56	X					X	X		DSC00193
57	X					X		X	DSC00196
58				X		X	X		DSC00198
59	X					X	X		DSC00229
60	X					X	X		DSC00241

Item #	Size of ordnance				Condition of ordnance				Photo #
	Large	Medium	Small	Fragment	Fresh	Old	Intact	Broken	
61	X					X	X		DSC00242
62	X					X	X		DSC00243
63	X					X	X		DSC00248
64	X					X	X		DSC00249
65		X				X	X		DSC00258 & P1050490
66				X		X	X		DSC00276
67	X					X	X		DSC00279
68	X					X	X		DSC00282
69	X					X	X		DSC00345
70	X					X	X		DSC00347 & DSC00348
71	X					X	X		DSC00352
72		X				X	X		DSC00364, DSC00365, DSC00368 & DSC00370
73	X					X	X		DSC00376
74	X					X	X		DSC00382 & DSC00383
75	X					X	X		DSC00386
76	X					X		X	DSC00400
77	X					X	X		DSC00401 & DSC00402
78			X		X				P1050332
79	X					X			DSC00153
80	X					X			P1050352
81	X					X	X		P1050439
82	X					X	X		DSC00175
Sum	61	12	1	10	2	80	65	7	
Percentage	72.6%	14.3%	1.2%	11.9%	2.4%	97.6%	90.3%	9.7%	

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14. ABSTRACT

Coral reef surveys were conducted at Farallon de Medinilla (FDM) August 14–19, 2022 by Naval Information Warfare Center (NIWC) Pacific Scientific Diving Services (SDS). Surveys were conducted in all habitat types around the island, including collection of approximately 1,050 photoquadrats on 73 transects and 615 representative photos in the survey area. Corals in photoquadrat images were identified to the lowest taxonomic level with a reasonable degree of confidence. A total of 16 colonies identified as the ESA-listed coral Acropora globiceps were observed. In addition, a total of 27 colonies believed to be the ESA-listed coral Acropora retusa were observed during the 2022 survey: 10 colonies were captured in photoquadrat images (0.12% of all enumerated coral colonies), and an additional 17 colonies were captured in representative photographs. A. retusa has not previously been positively identified at FDM, although it is included in the range of this coral. This evidence indicates that ESA listed corals are present, but relatively rare, in waters <30 m depth around FDM. There was a mild coral bleaching event underway at FDM during the 2022 survey, which was caused by regional anomalously warm sea surface temperatures. There was insufficient evidence of any adverse impacts to the coral from training, including the use of high-explosive bombs. Only two relatively fresh ordnance items were observed. All other ordnance encountered was historical. No impacts attributable to ordnance (e.g., craters, fresh scars near ordnance) were observed anywhere around the island.

15. SUBJECT TERMS
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