Final

FARALLON DE MEDINILLA 2017 SPECIES LEVEL CORAL REEF SURVEY REPORT

Dr. Jessica Carilli, SSC Pacific
Mr. Stephen H. Smith, SSC Pacific
Mr. Donald E. Marx Jr., SSC Pacific
Dr. Leslie Bolick, SSC Pacific
Dr. Douglas Fenner, NOAA

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Commander Pacific Fleet
250 Makalapa Drive
Joint Base Pearl Harbor Hickam
Hawaii 96860-3134

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Jessica Carilli
Stephen H. Smith
Donald E. Marx Jr.
Leslie Bolick
Douglas Fenner

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14. ABSTRACT
Coral reef surveys were conducted at Farallon de Medinilla (FDM) September 27 – October 1, 2017 by Space and Naval Warfare Systems Center Pacific (SSC 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 2015 (NMFS 2015). Two reports have been produced, based upon the field data obtained. The first report, entitled "Farallon De Medinilla 2017 Coral Reef Survey Report," is dated May 2018 (Carilli et al. 2018). This document should be regarded as the second report of the 2017 survey results. The May 2018 report fulfilled all Terms and Conditions numbers 4 and 5 of the 2015 MITT BO (NMFS 2015). In order to provide an increased level of detail, the current document was commissioned to provide information on the specific species of scleractinian corals observed at FDM. The primary objectives of the field survey were to quantify the abundance and location around the island of Endangered Species Act (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. As noted above, the 2017 survey fully fulfilled Terms and Conditions 4 and 5, specifically to "provide reports of any observed in-water effects (e.g., crater size, observed mortality) to corals resulting from detonations of high-explosive bombs as they are 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" and "survey coral reef habitat around FDM within 20 meters of water depth to confirm presence or absence and abundance of ESA-listed corals and to assess general trends in coral reef species

composition, percent coral coverage, and condition (disease, predators, extent of breakage, etc.)."A publication by Smith and Marx (2016) also satisfied a portion of Terms and Conditions 5 of the 2015 MITT BO.
Surveys were conducted in all habitat types around the island, including collection of approximately 750 photoquadrats on 50 transects and 250 additional representative photos in the survey area. Corals from 26 genera were identified in photoquadrats and representative photographs for this reporting effort.
During the course of the survey and subsequent data analysis, it became apparent that FDM appears to support both new distribution records as well as possible new species of scleractinian corals. As a result of that finding, Commander Pacific Fleet (COMPACFLT) funded a more in-depth coral analysis to better characterize the scleractinian fauna at the species level. This report presents those findings, as well as the previously reported findings from the May 2018 report (Carilli et al. 2018).
A single confirmed specimen of the ESA-listed coral Acropora globiceps was observed; seven other colonies that could potentially be A. globiceps were also observed in the same area as the confirmed specimen. Six colonies of coral were also identified as probably the ESA-listed coral Pavona diffluens, here described as Pavona cf. diffluens. This coral species had not previously been confirmed in the Commonwealth of the Northern Mariana Islands (CNMI), although Randall (2003) lists it in Guam. This evidence shows that ESA listed corals are present, but rare, in waters of <20m depth around FDM. Three potentially new (undocumented in the scientific literature) species of Acropora corals were also recorded during this survey.
There was a severe coral bleaching event underway at FDM during the surveys, caused by regional anomalously warm sea surface temperatures. On average, 77.3% of corals analyzed exhibited some form of bleaching, and 47.8% were completely bleached. Observations of broken, diseased and dead corals were rare (comprising <1% of the corals analyzed). However only 22% of corals analyzed were considered "healthy" due to widespread bleaching.
There was little overall evidence of any adverse impacts to coral from training, including the use of high-explosive bombs. Only three 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 as well (e.g., Smith and Marx 2016), a substantial percentage of all ordnance items supported scleractinian coral growth on the actual ordnance items.

15. SUBJECT TERMS
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Table of Contents

Final

Figures

Tables

Final

Executive Summary

Coral reef surveys were conducted at Farallon de Medinilla (FDM) September 27 – October 1, 2017 by Space and Naval Warfare Systems Center Pacific (SSC 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 2015 (NMFS 2015). Two reports have been produced, based upon the field data obtained. The first report, entitled "Farallon De Medinilla 2017 Coral Reef Survey Report," is dated May 2018 (Carilli et al. 2018). This document should be regarded as the second report of the 2017 survey results. The May 2018 report fulfilled all Terms and Conditions numbers 4 and 5 of the 2015 MITT BO (NMFS 2015). In order to provide an increased level of detail, the current document was commissioned to provide information on the specific species of scleractinian corals observed at FDM. The primary objectives of the field survey were to quantify the abundance and location around the island of Endangered Species Act (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. As noted above, the 2017 survey fully fulfilled Terms and Conditions 4 and 5, specifically to "provide reports of any observed in-water effects (e.g., crater size, observed mortality) to corals resulting from detonations of high-explosive bombs as they are 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" and "survey coral reef habitat around FDM within 20 meters of water depth…to confirm presence or absence and abundance of ESA-listed corals and to assess general trends in coral reef species composition, percent coral coverage, and condition (disease, predators, extent of breakage, etc.)."A publication by Smith and Marx (2016) also satisfied a portion of Terms and Conditions 5 of the 2015 MITT BO.

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in waters of <20m depth around FDM. Three potentially new (undocumented in the scientific literature) species of *Acropora* corals were also recorded during this survey.

There was a severe coral bleaching event underway at FDM during the surveys, caused by regional anomalously warm sea surface temperatures. On average, 77.3% of corals analyzed exhibited some form of bleaching, and 47.8% were completely bleached. Observations of broken, diseased and dead corals were rare (comprising <1% of the corals analyzed). However only 22% of corals analyzed were considered "healthy" due to widespread bleaching.

There was little overall evidence of any adverse impacts to coral from training, including the use of high-explosive bombs. Only three 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 as well (e.g., Smith and Marx 2016), a substantial percentage of all ordnance items supported scleractinian coral growth on the actual ordnance items.

Introduction

Farallon de Medinilla (FDM) is an uninhabited island in the Mariana Archipelago. 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 performed in 2011) in support of environmental compliance for the Mariana Islands Training and Testing Range. The 2017 survey described in this report is the first survey since 2012 and the first survey since 20 species of coral were listed under the Endangered Species Act (ESA) in 2014 (NOAA 2014). The 1999-2004 surveys were completed by a Navy contractor and 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). All surveys since 2005, including this survey, have been performed by the same Navy scientific divers. Explosive Ordnance Disposal (EOD) Detachment Marianas provided dive support and explosive safety oversight for all surveys. The 2004 decision to employ an all Navy team was made due to safety and liability concerns due to the presence of unexploded ordnance around FDM.

The 2017 FDM survey was conducted to satisfy requirements of the Mariana Islands Testing and Training Biological Opinion (MITT BO; NMFS 2015)[1]. 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]

During the course of the survey, and subsequent data analysis, it became apparent that FDM appears to support both new distribution records as well as possible new, undescribed species of scleractinian corals. As a result of that finding, COMPACLFT funded a more in-depth coral analysis to better characterize the scleractinian fauna at the species level. This report presents those findings, as well as the previously reported findings from the May 2018 report focused on coral genera (Carilli et al. 2018). In this report, "specimen" is used to discuss individual examples (colonies or individuals) of a species that are notable or representative of a particular feature of interest.

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

[1] NMFS issued a revised Biological Opinion (BO) in 2017, however, the survey goals were developed prior to the revised BO being issued under the Terms and Conditions of the 2015 NMFS BO.

address the goals above and satisfy the MITT BO (NMFS 2015) requirements, as listed above in the preceding paragraph. The approved survey plan (SSC Pacific 2017a) focused on collecting scaled and geo-referenced photographs of coral-bearing substrates within each habitat around FDM that supports corals in order to assess species composition and coral condition, and conduct directed searches for ESA-listed corals, which were the regulatory driver for this survey. Regions dominated by unconsolidated sediment were not surveyed. This survey methodology was significantly different from past surveys at FDM in that the focus was on collecting quantitative and georeferenced data.

As noted, a key element of this survey was to assess scleractinian corals of all taxa. Particular emphasis was placed upon identifying and geo-locating any 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 have been 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). *A. globiceps* has also been recorded in Tinian and Pagan (Tetra Tech 2014) and Guam (Brainard et al. 2011). *A. retusa* has been tentatively identified at other islands within CNMI (Fenner and Burdick 2016), and has been 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) have been 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 searched in particular for any occurrence of these four species (Figure 1).

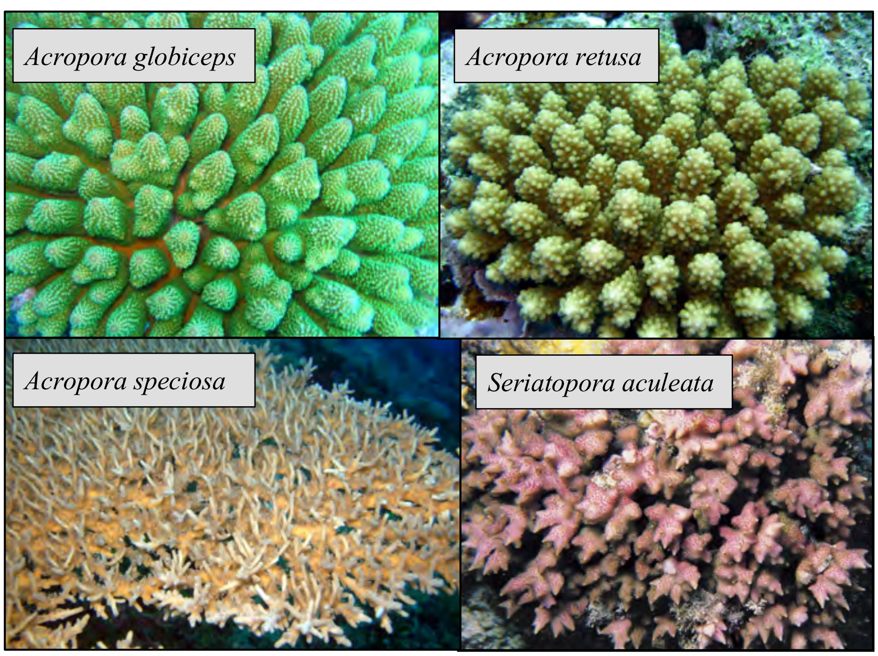

Figure 1: ESA-listed corals previously observed or thought to possibly occur at FDM. All *Acropora* images are by and copyright of Douglas Fenner. *Seriatopora* image credit: Australian Institute for Marine Science Coral Fact Sheets (http://coral.aims.gov.au/).

Final

Methods

Data collection
Two SDS marine ecologists completed different but complementary underwater tasks to address the survey goals, described in detail in the FDM survey plan (SSC-PAC 2017a) and field implementation plan (SSC-PAC 2017b). Dive locations were selected to provide comprehensive island coverage and target areas considered to be the most likely to support Threatened coral species. Dive surveys were conducted at a range of depths from 30-70 feet to capture diverse habitats, and were conducted in previously-defined Habitat types 2-5 (Figure 2; Appendix A). Because water clarity was excellent, with visibility in excess of 100 feet on most dives, meaningful qualitative observations could also be made of the sea floor at depths below 70 feet. All dives were completed with support from the Explosive Ordnance Disposal Detachment Marianas (EOD DETMAR) dive team, which provided safety oversight for all diving activities.

The in-water tasks completed by the SDS marine ecologist Navy divers are listed in Table 1.

Table 1: Tasks performed during 2017 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**
ESA-listed corals to be enumerated from georeferenced photoquadrats if encountered	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**
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 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**

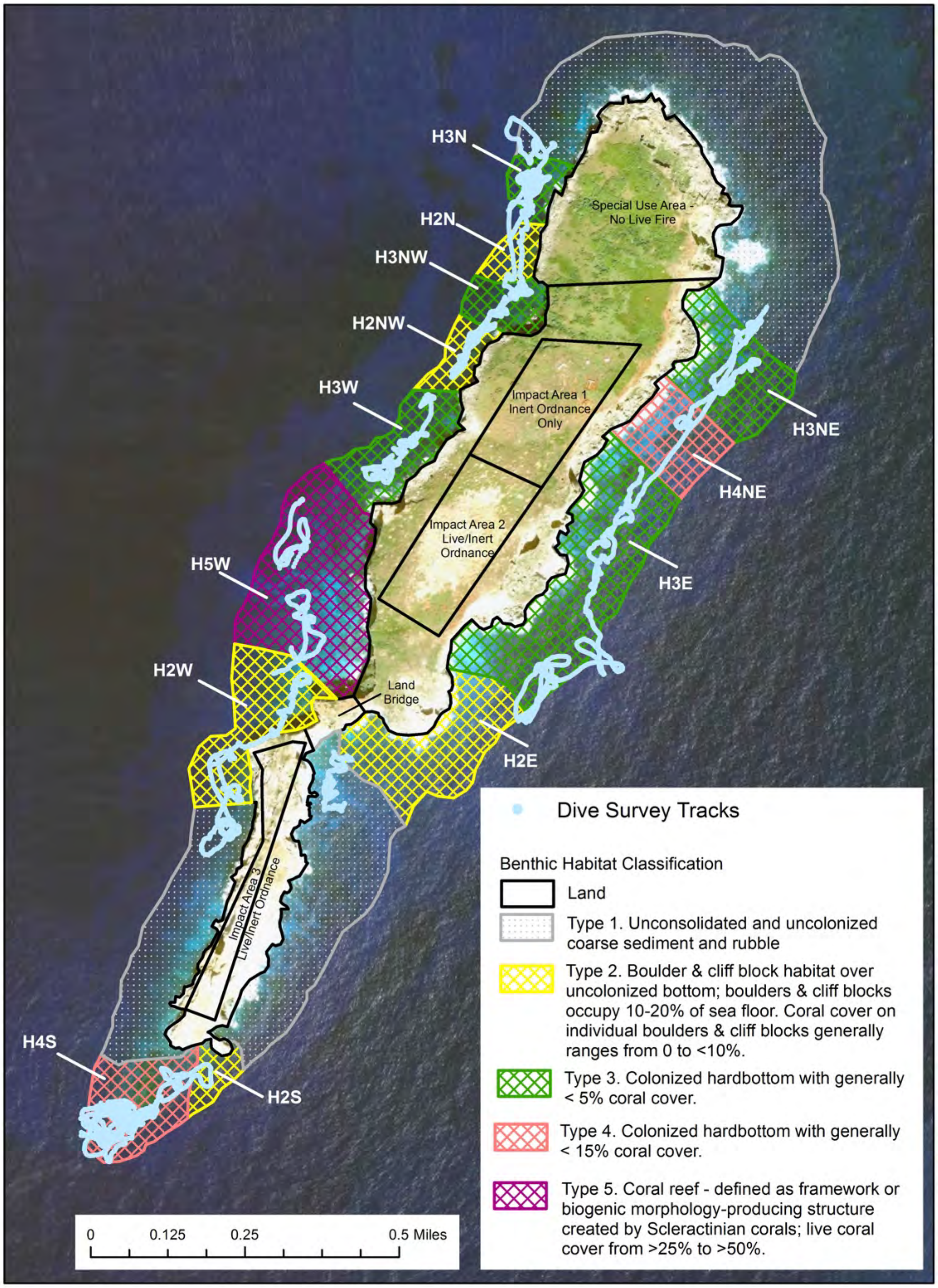

Figure 2: Map of FDM with approximate locations of different habitat types, defined based on historical coral cover (See Habitat Classification Key). Light blue lines were plotted from Latitude/Longitude positions of divers obtained by the SeaTrac underwater acoustic positioning system at two second intervals, showing total area surveyed in 2017.

Diver 1 was primarily tasked with collecting photoquadrat images [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 and so were not used. Instead, the underwater camera was fitted with a 37" metal monopod to set the perpendicular offset distance and thus acquire a standard set of scaled images. 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 would allow measurement of individual coral colonies within the image frame using software such as ImageJ at a later date with additional resources if so desired. Appendix B includes metadata related to photoquadrat imagery collection.

In addition to photoquadrat images, representative photographs of as many coral species as possible were taken by Diver 2, to allow for subsequent identification and assessment of coral diversity at FDM [G3]. Diver 2 also photographed possible Threatened corals encountered during his directed search efforts [G1]. These photographs were not collected for species abundance analysis; the photoquadrat images were collected for that purpose.

Site-level observations

The apparent health of all corals, as well as the percentages of coral-bearing substrate and coral occupying said coral-bearing substrate, were subjectively assessed and recorded during the dives [G2, G4]. Additional potential coral health indicators which divers looked for during the dives were: 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* sp.; d) predation from Crown-of-Thorns starfish (COTS), gastropod corallivores (e.g., *Drupella* sp.), and parrotfish; e) coral-killing sponge species; f) 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 et al. (2008) to be indicative of reduced water quality.

In addition, all divers were tasked to collect 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 was a key element of the 2017 survey, and has been a key element during each of the previous 14 surveys. Divers collected information on the following potential ordnance impact signs if they were encountered, 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

The most commonly encountered ordnance items, and their respective size classes used here are noted below:
1. Rifle shells [small]
2. MK 76 25lb (58 cm x 10 cm) [small]
3. MK 82 500 lb (168 cm x 27cm) [large]
4. M 117 750 lb (206 cm x 43 cm) [large]
5. MK 83 1000 lb (302 cm x 36 cm) [large]
6. MK 84 2000 lb (328 cm x 48 cm) [large]

Objects such as ordnance or rock introduced to the marine environment quickly (within months) become 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). Here, '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. Based on previous annual surveys at FDM, fresh items, as defined here, were likely introduced less than one year prior to the survey. Old objects, in contrast, 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 upon the degree of development and the species involved, it is possible to conclude subjectively that some ordnance items have been submerged for many years.

All divers were also tasked with making note of any other ESA-listed species observed from the surface or underwater, or heard underwater during dives, while completing the above tasks [G6]. At the time of this survey there was one ESA-listed fish species and five ESA-listed sea turtle species which had been recorded from the Mariana archipelago and may use the waters around FDM. These species are:
1. Scalloped hammerhead shark (*Sphyrna lewini*): NOAA has 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 have been classified as Threatened under ESA. This species has never been sighted or reported from FDM (Smith and Marx 2016).
2. Five species of sea turtles have been recorded within the Mariana Archipelago. However, only two species have ever been recorded from FDM (Smith and Marx 2016): the green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*). Both of these species have been 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).

To the extent possible, the following data were recorded for each turtle specimen observed:

1. Species
2. Sex (for Green sea turtles sex cannot be determined until the specimen is approximately 60 cm or greater in carapace length)
3. Carapace length group (< 50 cm; 50 cm < 100 cm; > 100 cm)
4. Activity when first sighted (swimming, resting, feeding)
5. Presence/absence of fibropapilloma tumors; number and size of tumors
6. Any apparent abnormalities, injuries, bite scars, etc.

Georeferencing
Each diver wore an acoustic transponder that allowed the diver's relative position (range and bearing) from the boat to be tracked. A topside computer and specialized software (NavPoint, by SeaTrac) was used to convert their relative position into real-world coordinates (latitude and longitude) during the dives. Diver tracks were recorded as real-world positions with timestamps every few seconds by another computer program (TerraTerm). Photographs taken by the divers were then georeferenced to real-world locations by matching the timestamp of the photographs to the timestamp of their dive tracks, using a third computer program (HoudahGeo).

Image analysis
All images were initially examined and then analyzed to different extents based on the types of photographs collected. As many coral species as possible that were captured in the diversity-focused photographs (Diver 1 photographs) were identified to species with the assistance of coral taxonomist and co-author Dr. Douglas Fenner. This analysis focused on identifying any of the four Threatened species listed above and identification to the lowest possible taxonomic level of as many as possible of the particularly challenging corals that were photographed.

In photoquadrat images, all scleractinian coral colonies that could theoretically be identified were annotated with a number. Subsequently, one SSC Pacific scientist 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 Randall (1995), Veron (2000), and Veron et al. (2018). Taxa names, health codes and any identification notes were then recorded in Excel workbooks with records organized by Dive and Transect numbers. These identifications were reported in Carilli et al. (2018). Many corals could not be identified to species, or even genus, during the first round of image analysis. The follow-on identification effort was focused on expanding the number of colonies identified and narrowing identifications to species level where possible. To facilitate the re-analysis of this large dataset (3766 individual annotation points), representative photographs of individual coral species observed were compiled. This image database was mainly comprised of photographs collected by divers during the survey. This compilation of photographs and related identifications is included as a separate submission together with this September 2018 survey report, titled "FDM coral species representative photos final".

In addition to taxonomic identifications, each colony was assigned a health code when possible to denote bleaching, disease and damage (Table 2). Note that photoquadrats were not randomly distributed within each surveyed habitat, but were collected in locations that included living corals and that the diver assessed as being representative of the habitat. This representative survey design prompted the more comprehensive identification of all corals on all photoquadrats (rather than e.g., selecting random points for identification on each image). This additional effort also produced a rich dataset for possible future analysis 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)

Excel workbooks were used to compile coral IDs by transect and photoquadrat. 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. For the subsequent analysis effort, further effort was taken to ensure that all entries were: (a) identified to species when possible, or (b) to genus when species identification was not possible, (c) if a specimen was determined not possible to identify, it was given the code "NP" in the workbook or (d) if an annotation point was mistakenly placed on an organism that was not a scleractinian coral, it was assigned the code "XX". This was accomplished first by both SDS divers assessing all problematic specimens and Dr. Fenner independently identifying and cross-checking a portion of the images for accuracy. Dr. Fenner also worked with the team to refine the representative photograph compilation such that all identifications of each type of coral represented in the survey imagery could be identified to the lowest taxonomic level possible. For those taxa that were not identifiable to species, names were assigned based on distinctive morphology or genus and differentiated if possible (e.g., "*Favia* unknown #2"). Finally, a fourth team member compiled the entire dataset into a master workbook and revised any identifications that were determined incorrect via either the cross-checking exercise or representative photograph compilation effort, in order to complete identification to species as closely as possible by comparing photoquadrat imagery to the photograph compilation.

Coral identification challenges

Coral identification presents many problems. 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* be split into three different genera: *Montastraea, Orbicella,* and *Phymastrea*.

As noted above, 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 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 that 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 secure coral identifications are based on skeleton examination under a dissecting microscope.

Underwater photographs have the distinct advantage of providing evidence that can be examined by many people and for long after dives have been completed, and provide an archive of information from a particular time point that can be re-examined at a later time. 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 closeup 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 much more difficult. When corals are bleached, as many of the corals during the survey reported here, saturation is hard to avoid and identification is much more difficult because small features of coral skeletons often cannot be seen 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. Morphologies of coral colonies within the same species can vary greatly due to genetic and environmental factors; however, differentiating features (for example the number of septa or shape of the axial corallite) generally remain similar within species. Energy levels (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.

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 secure identification. Furthermore, coral skeleton samples could not be collected, and in-water work 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, noting that identifications presented here vary in certitude. Some of the photographs are good enough 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.

The following describes further the identification structure used here. Any particular colony was not assumed to be a named species. Since it is possible a given colony is a new (undescribed) species, we confirmed to the best practice not to shoehorn colonies that do not display characteristic features into a named species. Here, when a colony clearly displayed the characteristic features of a single named species, it was assigned to that species – for example, *Astreopora cucullata* corallites are angled downwards on the colony sides. When a colony could be identified to genus but displayed characteristic features that are shared by several species in that genus, and therefore could not confidently be placed into a single species, it was termed "unknown". Within some genera, for example *Acropora*, there were multiple unknown species that were probably different from one another (for instance, the overall colony shapes differed significantly), and these were differentiated by numbers. For other genera, for example *Cyphastrea*, the differentiating characteristics between species are too small to be visible in these photographs, and thus all colonies of *Cyphastrea* were assigned to the same unknown species category.

Three of the ESA-listed species that could occur at FDM are *Acropora* corals, so particular attention was taken to photographing and identifying corals of this genus. Features that are usually the most helpful in *Acropora* sp. identification are colony shape, the 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 in photographs. Literature specifying and illustrating these features for named species is 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.

Species list compilation

After image analysis work was completed, a coral taxa list of all corals observed in the 2017 survey was compiled and refined. This list includes all genus and species names assigned to taxa in this analysis, representing a partial list of coral taxa in the study area (Appendix C). Names used for the 2017 survey are in general consistent with Veron et al. (2018), but in some cases uses spelling from the World Register of Marine Species (WORMS; www.marinespecies.org). A species list from surveys conducted between 2001-2004 was also compiled, and observations from all surveys noted (Appendix C; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). In cases where corals were observed during a prior survey but not the 2017 survey, the original spelling of names as used in those published reports was retained, although in some cases taxonomic changes have occurred since publication of those reports. For one coral observed in 2017, *Acropora surculosa*, neither Veron et al. (2018) nor WORMS recognize this as a distinct species, but rather a synonym of *Acropora hyacinthus*; however the coral taxonomist co-author of this report (D. Fenner) believes this is a distinct species, and it is recognized in the Marianas by Randall (1995) so this terminology is retained here.

Data analysis
Following final data compilation into a master dataset and review at the species level, pivot tables were used for summary analysis in Excel. Percent coverage of coral-bearing substrate and percent coverage of coral are summarized in Table 3 for comparison between habitat subareas, habitats and years (2017 survey vs. historic). For each habitat type, proportions (based on number of occurrences) of coral genera 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, S) 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:

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

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 takes into account the abundance and evenness of species present in the community and is calculated as:

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

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.

Note that the survey design located transects in shallow (maximum depth approximately 10m) vs. comparatively deep (approximately 10-20m depth) strata within each habitat type to ensure broad coverage of habitat characteristics. Stratified datasets were generally not sufficiently large to analyze separately, so shallow and deep strata were combined for data analysis, with the exception of habitat H3 condition analyses.

Results

Surveys were conducted in all habitat types around the island, including collection of approximately 750 photoquadrats on 50 transects and 250 representative photos in the survey area. Habitat descriptions and representative photographs are presented in Appendix A.

[G1] ESA-listed corals
Identification of corals to species in the Indo-Pacific is inherently challenging because of high diversity and variable within-species morphology that occurs between genetically different individuals (as it does in all species including humans and dogs, for instance) and under different

physical regimes (for example, see Fenner and Burdick 2016). The most secure identification of corals requires skeleton samples which were not available. The white of bleached corals during this survey made identification much more difficult and uncertain, but could not be avoided. Therefore, results presented here represent plausible identifications, but should be interpreted with a degree of caution.

Only one (1) colony of *A. globiceps* could be positively confirmed from photographs (Figure 3). Seven other colonies captured in photographs may possibly be *A. globiceps*, but probably not (Figure 4). No colonies of the *A. globiceps* look-alike *A. gemmifera,* or other very similar species (*A. monticulosa*, *A. digitifera, A. humilis*) were seen in any of the photos. All of the coral colonies that were confirmed to be, or could possibly be *A. globiceps* were identified in one area around the island (Figure 5).

Figure 3: (Left) Confirmed ESA-listed *Acropora globiceps* colony. This colony was captured in photoquadrat image IMG_3780 (image shown cropped here). (Right) A colony resembling the ESA-listed species *Pavona diffluens* (image IMG_1996 shown cropped here). *Pavona diffluens* was described from the Red Sea but colonies have not been reported between the Red Sea and the Mariana Islands; Randall (2003) reported *Pavona diffluens* from Guam. Microscopic examination of skeletons (preferably side by side) from the two locations may be needed to confirm this identification. This specimen has an unusual morphology that is very similar to *Pavona duerdeni* and *Favia stelligera*.

Figure 4: Two *Acropora* spp. colonies that may be *A. globiceps*, or possibly a new species, but for which identification was not confirmed. (Left) Image numbers IMG_1661 (representative photo, not photoquadrat). (Right) Image number IMG_3737 (photoquadrat).

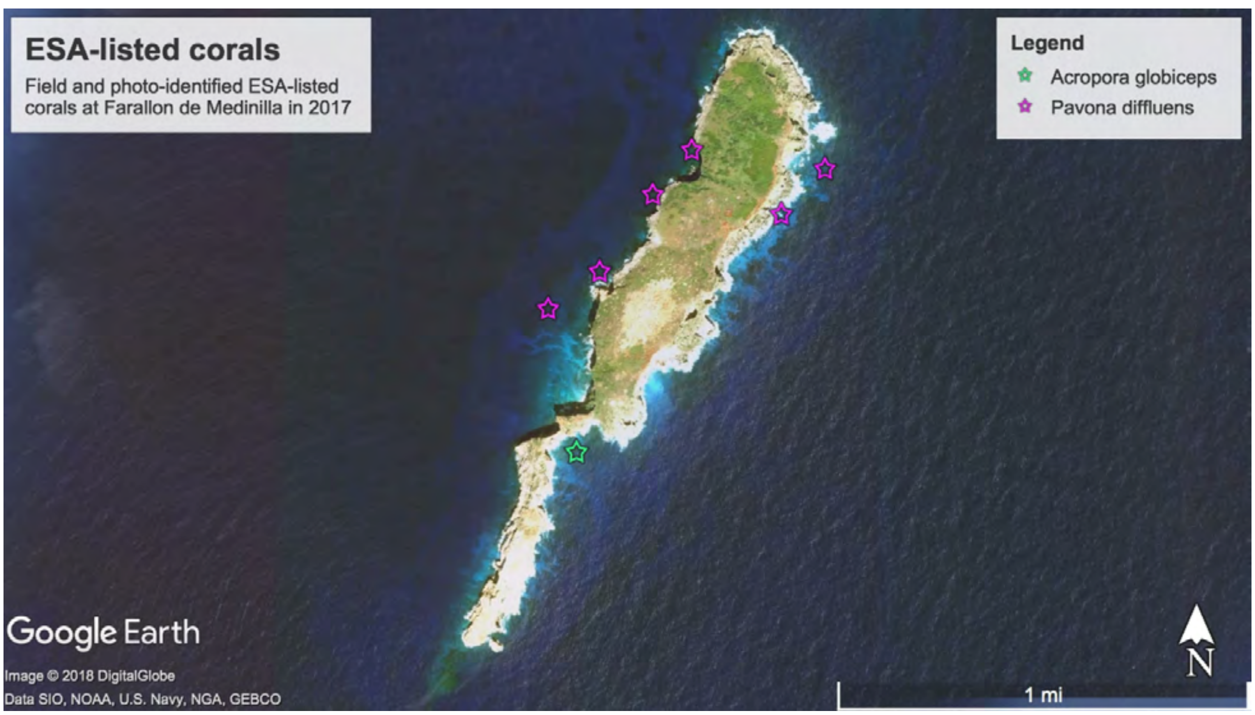

Figure 5: Map of FDM showing locations of corals identified in this study as ESA-listed species.

No *Acropora retusa, A. speciosa,* and no *Seriatopora aculeata* colonies were seen, and none have ever been reported during the previous 14 surveys. However, six colonies of the coral *Pavona* cf. *diffluens* were identified from the collected photographs, located around the island (Figures 3 and 5). *P. diffluens* is ESA-listed; however neither NOAA, nor J.E.N. Veron recognize its presence within the Mariana Archipelago (Veron 2000, Fenner and Burdick 2016). Contrary to that perspective, Randall (2003) reported *P. diffluens* from Guam.

In summary, one (1) colony of the ESA-listed coral species *Acropora globiceps* and six (6) colonies of the ESA-listed *Pavona* cf. *diffluens* were reasonably confidently identified based on morphological characteristics assessed in photographs collected during the 2017 survey. Seven (7) additional corals may have been *A. globiceps* (6 of which were captured in photoquadrat imager) and were counted as such in the data compilation (Appendix C).

[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 (Department of the Navy 2016). Habitats were divided into six primary types described in SSC Pacific 2017a and presented in Figure 2 and Appendix A. There was no apparent change, addition or deletion to these six types observed during the 2017 survey. That is, the basic habitat types remained largely unchanged in the opinion of the biologists who have conducted all surveys since 2005.

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 not targeted for survey in 2017.

Type 2 habitat (H2) was 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 previously field-identified on some of these blocks. The confirmed specimen of *A. globiceps* as well as the other possible *A. globiceps* colonies were also observed in this habitat type during the 2017 survey.

Type 3 and Type 4 habitats (H3 and H4) were defined as colonized hard bottoms with 0-5% and 5-15% coral cover, respectively. Type 5 habitat (H5) was defined as 100% hard bottom, and occurs in only one relatively small region on the southwest side of FDM. A small area that comprised H5 (approximately 500m x 250m, see red labeled H5 in Figure 2). was defined as being comprised of true coral reef, with live coral cover ranging from more than 25% to over 50%.

Percent coverage of coral-bearing substrate (i.e. rock) and percent coverage of coral observed in 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 2). Coral cover encountered in 2017 was highly variable between and within habitat types, so estimates of total coral cover in the different habitat types should be considered rough estimates. A habitat map such as that produced previously (Figure 2) based only on 2017 observations would have resulted in combining H3 and H4 into one habitat type, but the habitat map produced previously is still largely accurate.

During 2017, fewer dives were made than in previous years, and they generally covered less area owing to different requirements for this survey. However, sampling distribution was comprehensive around the island. Also, no dives were made below 20 meters, due to the 2015 BO requirement to survey to that depth (NMFS 2015); depths of up to 31 m were surveyed during the 2005-2012 events (Smith et al. 2013). Therefore, comparing the observations between time periods is somewhat problematic. Nevertheless, 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 and percent coverage of coral.

Habitat Type Subarea (Refer to Figure 2)	% rock 2017	% coral on rock 2017	% rock Prior years	% coral on rock Prior years	Notes
H2N	20-35%	<10-50%	10-20%	0-10%	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	10-20%	10-25%	10-20%	0-10%	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	10-20%	<5-20%	10-20%	0-10%	Highly variable sea floor cover; > 2/3 of colonies bleached; *Porites* massive corals were either not bleached, or only slightly pale.
H2S	10-20%	≤5%	10-20%	0-10%	
H2E	10-20%	0-10%	10-20%	0-10%	Area included many old (3-5 yrs) dead *P. meandrina* (complex) colonies; bleaching was severe for living *Pocillopora* colonies.
H2 (median ±range)	**22.5 ±12.5%**	**25±25%**	**15±5%**	**5±5%**	
H3N	85%	<5-25%	≥85%	<5%	Coral cover highly variable; similar stretches during dive ranged from <5% to >25%.
H3NW	80%	<5-10%	≥80%	<5%	Coral cover generally < 5%; some limited areas had 10-15% coral.
H3W	80%	<5%	≥80%	<5%	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	≥70%	5%	≥70%	<5%	With a few small exceptions, coral cover ~5% on suitable substrate. Appeared to be more *P.*

Habitat Type Subarea (Refer to Figure 2)	% rock 2017	% coral on rock 2017	% rock Prior years	% coral on rock Prior years	Notes
					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	50-70%	5-20%	≥50-70%	<5%	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 (median ±range)	**67.5 ±17.5%**	**15±10%**	**67.5 ±17.5%**	**<5%**	
H4S	80%	15%	≥80%	<15%	~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	100%	5-10%	100%	<15%	
H4 (median ±range)	**90±10%**	**10±5%**	**90±10%**	**<15%**	
H5W (H5)	100% classic coral reef	40-65%	100% classic coral reef	>25 to >50%	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.

[G3] Coral species composition

Corals from 26 genera were identified in the photoquadrat and representative photographs taken by both divers (Appendix C). A total of 11.2% of coral colonies annotated in the photoquadrat imagery were not identified to species or genus; these colonies were generally captured at the edges of photographs and were thus too blurry, or were severely bleached and were completely washed out in imagery; when they occurred, these issues made it impossible to identify colonies in these photographs even to genus with confidence. In total, at least 83 unique taxa of corals were either positively identified or recognized as individual species but not able to be identified below genus level (or, in one case, was recognized as a unique species but not able to be identified even to genus; Appendix C). This includes 21 species not previously recorded at FDM (green and blue in Appendix C).

Three likely new, undescribed species of *Acropora* and three potentially new, undescribed possible hybrids of *Pocillopora* were recorded in survey photos, as determined to the best of our ability. The taxonomy of many members of the genus *Pocillopora* is disputed, and many taxonomists believe hybrids are not uncommon (Pinzón and LaJeunesse 2011, Pinzón et al. 2013). The corals coded as hybrids do not fit into recognized species; they could be new variants of recognized species or new species altogether, but give the prevalence of hybridization in *Pocillopora* and the occurrence of shared features between the corals here called hybrids and recognized species, it is reasonable to assume they may be hybrids. *Pocillopora ankeli* was positively identified and relatively common in the survey photos; this coral has not been recorded from Guam or CNMI according to Veron et al. (2018).

Each habitat around FDM (Figure 2) was comprised of slightly different coral communities (Figure 6, Appendix D). For instance, Habitat H5 and H4 were dominated by massive *Porites* sp. colonies. Habitat H5 also had the highest abundances of a potentially undescribed or hybrid *Pocillopora* sp., *Astreopora cucullata,* and *Porites rus* compared to other habitats. Habitat H4 had the most juvenile *Pocillopora* coral colonies. Habitat H2 had relatively lower abundance of massive *Porites* colonies, and the most common corals in that habitat was *Pocillopora meandrina.* In all habitats, individual species of *Acropora* corals were comparably rare, and the genus *Acropora* comprised between ~5-8% of the community in all Habitats except H5, where they were less numerically abundant (~2%). These findings are consistent with earlier survey efforts (Smith et al. 2013). 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.

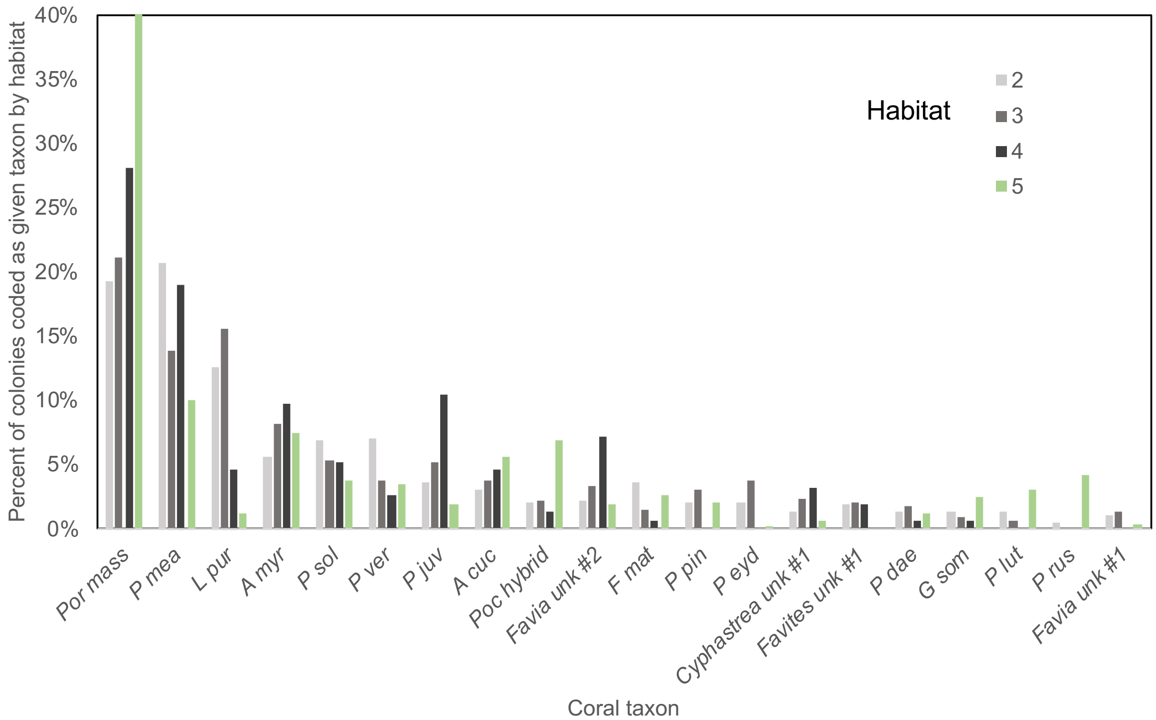

Figure 6: Coral community composition for each major habitat type assessed, based on coral colony counts for the 20 most common scleractinian coral taxa only (for visual clarity). The y-axis represents percent coral counts for all identified colonies within a habitat. The x-axis displays the coral taxon identified in this study for each habitat type, using shorthand codes. See Appendix C for coral codes.

Coral diversity is moderately high for all habitats, with Habitats 2 and 3 exhibiting slightly higher diversity compared to Habitats 4 and 5 based on the Shannon and Simpson indices (Table 4). Note that several coral IDs represent multiple species (e.g., groups such as *Porites* massive and *Pocillopora* juvenile, genera including *Astreopora*), thus species richness and subsequently-derived diversity indices calculated in this study likely underestimate the true coral species diversity at FDM. This is consistent with the comparatively larger numbers of coral species recorded during previous surveys at FDM.

Table 4: Coral community diversity indices by habitat

Habitat	2	3	4	5
Shannon Index (H)	3.11	3.01	2.63	2.63
Simpson Index (S)	0.92	0.92	0.89	0.84

[G4] Coral condition

Corals around FDM were undergoing a severe bleaching event during the 2017 survey, as predicted by Coral Reef Watch (Figure 7). The 2017 FDM survey was undertaken when corals were experiencing approximately 14 degree-heating-weeks (DHW) of heat stress, far beyond the 8 DHW threshold that defines coral bleaching "Alert Level 2", which typically results in significant coral mortality.

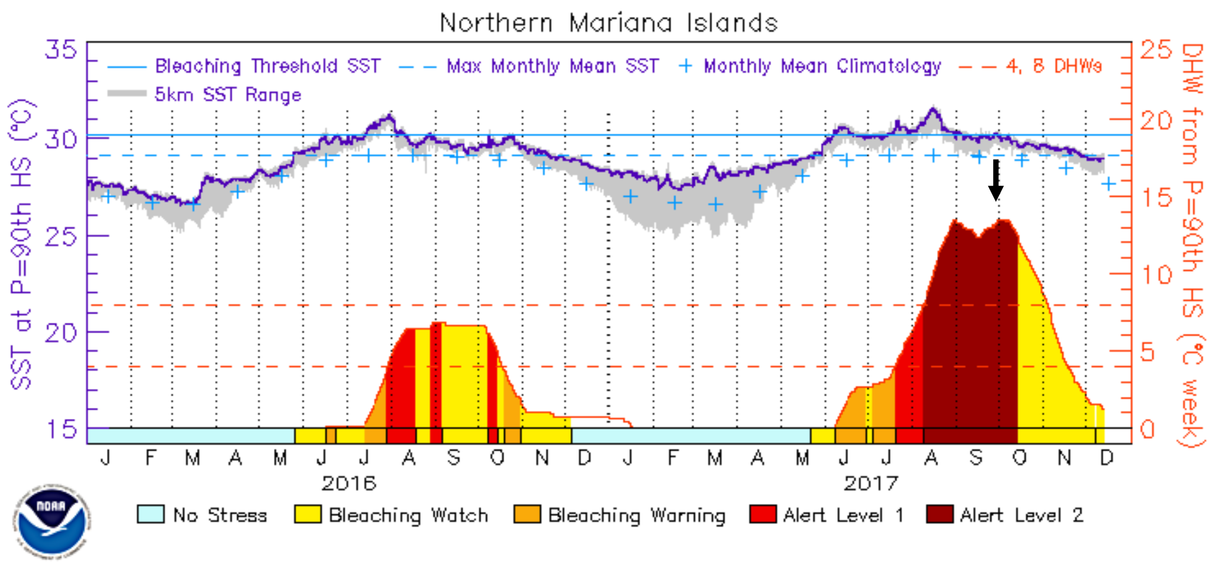

Figure 7: Sea surface temperature (SST, blue line) estimated from satellite data, as well as calculated heat stress expressed in degree-heating-weeks (DHW, red line and colored shading) at the Northern Mariana Islands "virtual station." The arrow denotes the approximate time of the 2017 FDM survey.

On average across the island, 47.8% of coral colonies analyzed in photoquadrats were completely bleached (Table 5, Figure 8, Figure 9). Many colonies that were not completely bleached were partially bleached (mottled) or pale. Overall, 77.3% of corals around the island for which a condition was determined clearly exhibited some form of bleaching (Table 5). Note that 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 8: Landscape image of H5W showing extensive coral bleaching.

Table 5: Results of coral condition analyses for each habitat.
Percentages in each column represent the percentage of corals that were observed under that condition category in the photoquadrats, averaged across all transects from each location. 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. Note that for H3, "Shallow" refers to approximately 0-10m water depth, and "Deep" refers to approximately 10-20m water depth.

Coral condition	**H2**	**H3 Shallow**	**H3 Deep**	**H4**	**H5**	***FDM***
Bleached	49.4%	46.1%	40.0%	46.7%	53.0%	*47.8%*
Mottled	8.6%	17.1%	13.2%	13.9%	2.8%	*10.1%*
Pale	18.3%	20.1%	16.4%	11.1%	25.9%	*19.4%*
Some Bleaching	*76.3%*	*83.3%*	*69.6%*	*71.7%*	*81.6%*	*77.3%*
Diseased	0.2%	0.2%	0%	0%	0.8%	*0.3%*
Broken	0.1%	0%	0.6%	0%	0%	*0.1%*
Healthy	22.7%	16.3%	29.9%	28.3%	17.6%	*22%*
Number of colonies keyed for condition	1213	596	532	180	642	*3163*

Corals that exhibited the lowest frequency of complete bleaching included *Acanthastrea brevis*, *Acropora globiceps* and two other *Acropora* sp*.*, *Cyphastrea* sp., most of the Favids, *Goniopora somaliensis, Leptastrea* spp*.,* and *Porites rus* and massive *Porites* spp. In contrast, *Astreopora* spp*.,* 6 of the 16 *Acropora* spp., and *Pocillopora meandrina, P. verrucosa, Pocillopora* hybrids*,* and *Pocillopora* juveniles all experienced the highest frequency of complete bleaching.

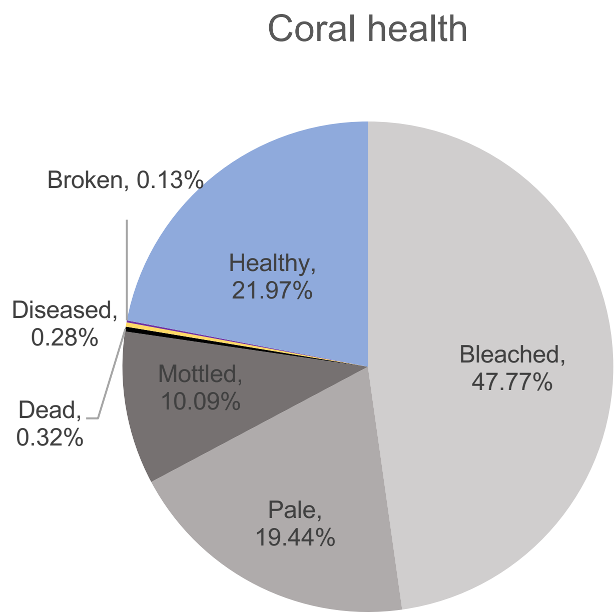

Figure 9: Summary of coral colony health status recorded.

Only a few coral fragments were observed (Figure 10). No ordnance, nor signature signs of ordnance impacts such as craters, were observed near these fragments. This suggests that the breakage may have been caused by the high wave energy environment around the island or other impacts, and not from training activities.

Figure 10: Representative observation of coral breakage (photoquadrat IMG_3639). 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 characterized by patches of dark discolored tissue. Little to no excess mucous production was observed in the remaining coral colonies that were not bleached.

There were a few small areas of about 2 to 3m^2 each, that contained 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 11.

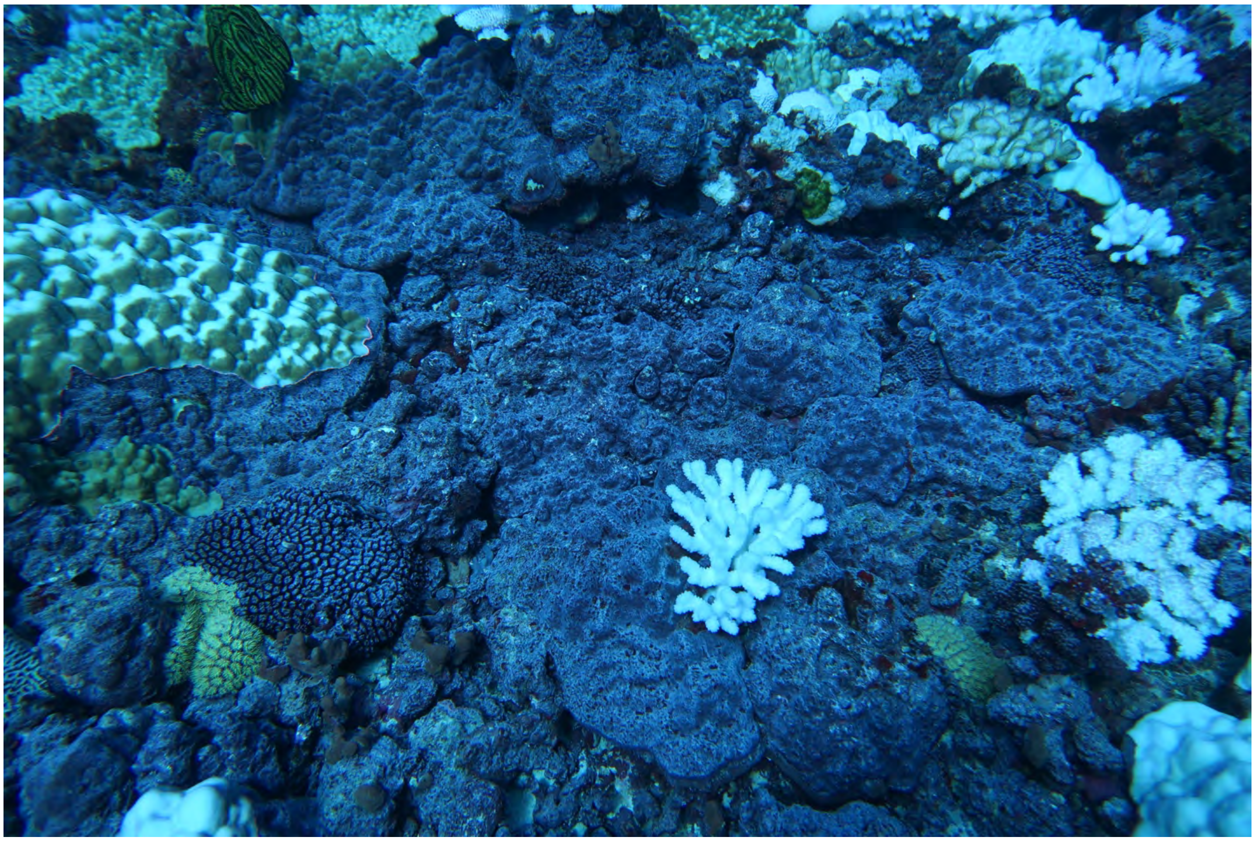

Figure 11: Photoquadrat showing likely coral overgrowth by the sponge *Terpios hoshinota* (gray surfaces). The massive Porites colony on the left edge of the photograph shows two flanks where the sponge has started to grow up over the living, but bleached coral.

Other observations

Turf algae and crustose coralline algae (CCA) appeared to be the dominant functional algal groups in the depth zones surveyed. The calcareous green algae *Halimeda sp.* was abundant and sometimes dominant.

Several areas around FDM showed accumulations of cyanobacteria (Blue-green algae; Figure 12). The ecological role of cyanobacteria on coral reefs is not well understood. Seafloor cover by cyanobacteria was also abundant in 2007, consistent with the conclusions of Pacific Islands Fisheries Science Center surveys at other islands in the Marianas Archipelago (Brainard et al. 2012).

Figure 12: Recently dead *Acropora* sp. coral with cyanobacteria on skeleton and surrounding reef

No fish, crab or lobster traps were sighted. No nets, net fragments, fishing line or spears were observed.

No Crown-of-Thorns (COTs) starfish were sighted on any of the dives. No evidence of COTs predation was observed. Parrotfish bite marks were observed, particularly on massive *Porites* colonies. Unusual macro-bioeroder activity was not noted, nor were high numbers of gastropod corallivores. No coral barnacle (*Cantellius* sp.) outbreaks were noted. These other observations were compiled opportunistically; a focused effort to quantify these factors was not conducted.

[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 (76.2% and 97%, respectively; Table 6, Appendix E). Only one small, fresh ordnance item was observed, a 50-caliber brass cartridge case. All other items were large ordnance - bombs or rockets, or fragments thereof. The most commonly sighted bombs were in the 250 to 500 lb. range, that is, MK 81 or MK 82 bombs, respectively. Two bombs were classified as "fresh" because they had little marine growth on them; all other items were classified as "old," suggesting they had been submerged for at least several months and in some cases probably many years. About half (49.5%) of the ordnance items appeared to be essentially intact; the rest were broken, seriously bent, or were 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 generally lying on the bottom and covered in algae, corals, and other organisms. The ordnance items would be generally indistinguishable from the surrounding benthic community were their shapes not distinctive. A number of large ordnance items (750 and 2,000 pound bombs) which had been repeatedly sighted during past surveys were no longer at the same locations where they had been observed in the past. The divers speculated that these items had moved downslope due to wave and/or earthquake events, but no evidence of their movement (for example, paths of disturbed benthos or debris) were discovered.

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

	Size of ordnance			Condition of ordnance			
	Large	Small	Fragment	Fresh	Old	Intact	Broken
Number of items	77	1	23	3	98	50	51
Percentage	76.2	1.0	22.8	3.0	97.0	49.5	50.5

The vast majority of ordnance items observed during the 2017 survey were old. While this was also the first survey during which the entire island was not circumnavigated, the perceived absence of many fresh items suggests high accuracy of recent training, with ordnance apparently hitting intended the land targets and thus avoiding detrimental impact to the marine ecosystem. Figure 13 illustrates typical old ordnance items observed during the 2017 FDM survey, and Figure 14 presents a map of all observed and photographed ordnance items.

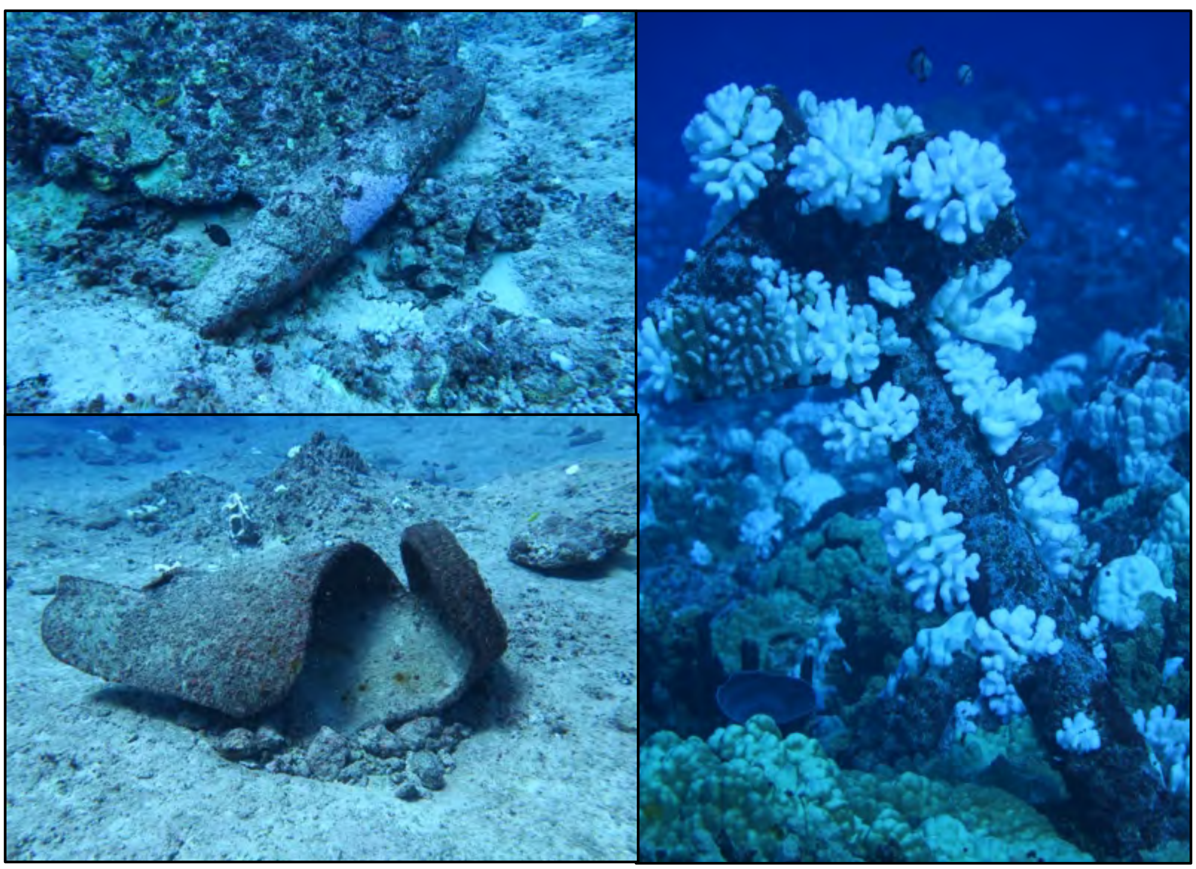

Figure 13: Representative examples of ordnance observed at FDM in 2017.

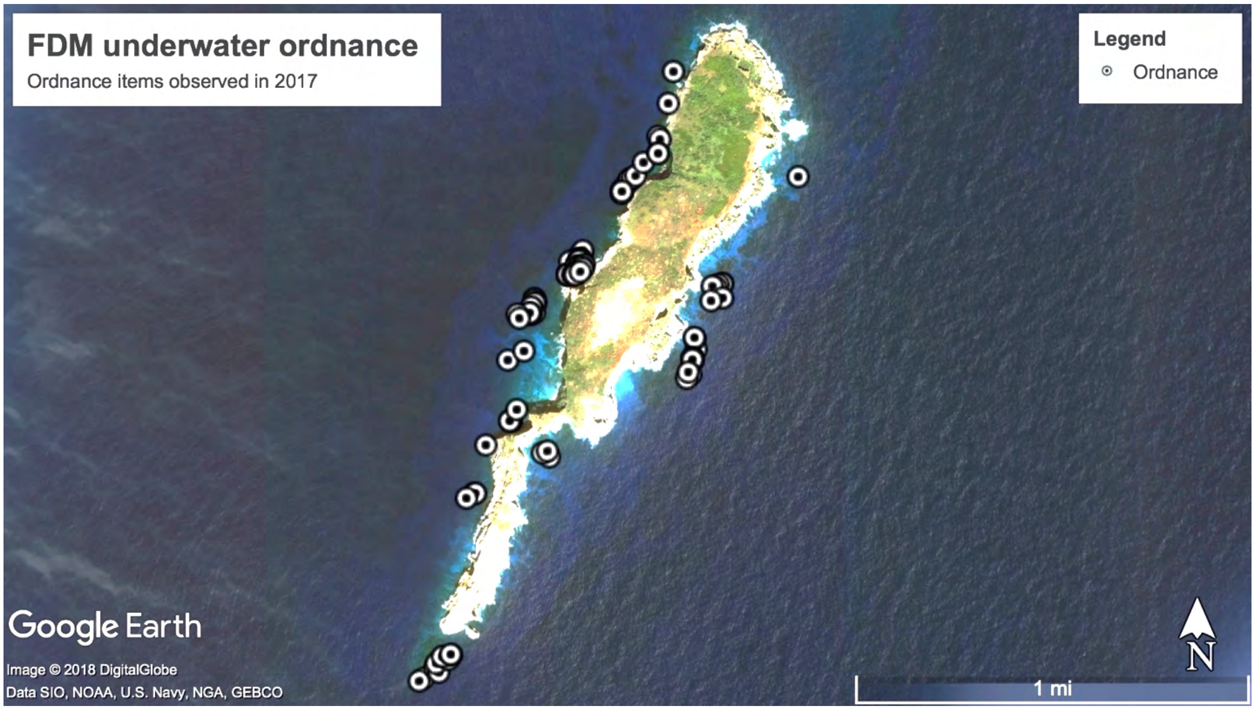

Figure 14: Map of locations of georeferenced photos of observed ordnance.

There was overall little evidence of any adverse impacts to 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), 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 surveys; it was based on the type of damage (bending, deep gouges in the bomb cases, etc.) that the ordnance displayed.

Many of the ordnance items supported coral growth, both new recruits as well as large mature colonies. 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.

[G6] Incidental observations of ESA-listed species

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

No marine mammals were sighted underwater or from the surface during the 2017 FDM survey.

Three small, healthy Green sea turtles (*Chelonia mydas*) were sighted (Table 7). No Hawksbill sea turtles (*Eretmochelys imbricata*) were sighted, although one unidentified sea turtle was seen at the limit of visibility (Table 7).

Table 7: Sea Turtle sightings during the 2017 FDM survey.

Sighting	Dive Date & No.	Location	Green Sea turtle	Unidentified Sea turtle	Size	Sex	Apparent Health	Activity
1	9/28 # 2	H2S/H4S	0	1	NA	NA	NA	NA
2	9/29 # 2	H3E	1	0	<50 cm	NA	No lesions, tumors, scars	Swimming
3	9/30 # 2	H3N	1	0	<50 cm	NA	No lesions, tumors, scars; four small carapace abnormalities	Swimming
4	9/30 # 2	H3N	1	0	<50 cm	NA	No lesions, tumors, scars	Swimming
TOTAL			3	1				

The same Green sea turtle was sighted several times during dive 2 on September 30, 2017 (sighting number 3, Table 7, Figure 15). It was identified by the presence of four small abnormalities along the posterior edge of the carapace. Those abnormalities did not look like typical fibropapilloma tumors or lesions associated with a compromised carapace. The carapace of that individual was exceptionally bright and clean. The other Green sea turtle sightings were definitely different individuals, based upon their size and/or carapace condition. All the Green sea turtles were estimated to have straight-line carapace lengths of less than 50 cm; therefore, they were judged to be sub-adults, and it was not possible to sex them. The single unidentified turtle was probably a Green sea turtle due to its estimated size (70 cm); but this could not be confirmed.

The giant manta ray (*Manta birostris*) and the oceanic whitetip shark (*Carcharhinus longimanus*), both of which were ESA-listed in 2018 (83 FR 2916 and 83 FR 4153) were not sighted during the 2017 survey and none were observed during any of the 14 previous marine surveys.

Two ESA-listing Candidate species of Giant clams (*Tridacna gigas* and *T. squamosa*) were observed incidentally during this survey, as was *T. maxima* (Figure 16). *T. gigas* 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). The largest specimen observed during the 2017 survey, presumably a *T. gigas*, was seen below the maximum depth of that dive, and was estimated to have a shell length of 75 cm.

Figure 15: Turtle observed during sighting number 3.

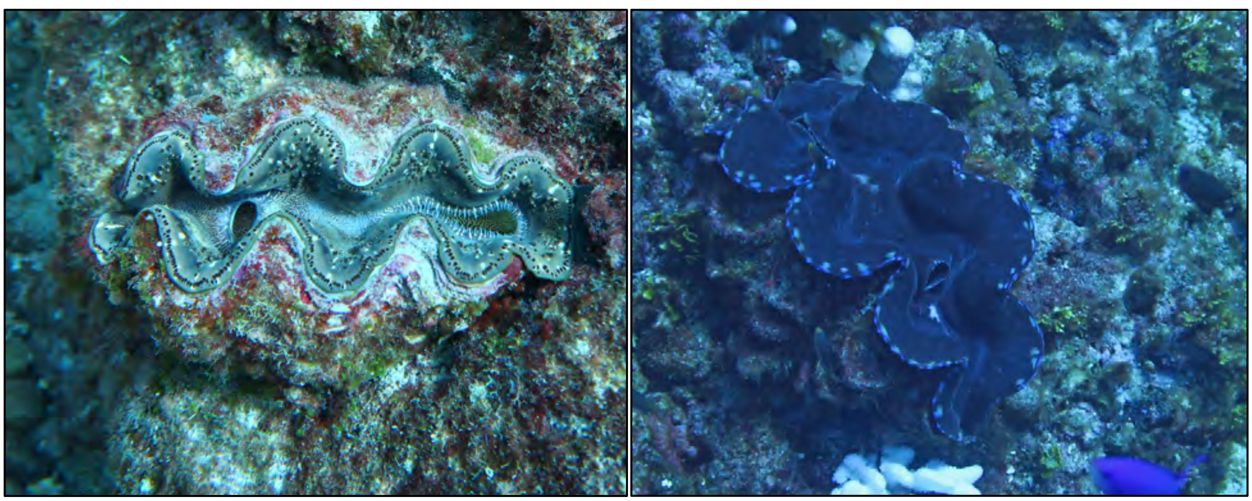

Figure 16: (Left) Example of *Tridacna maxima* observed during survey (cropped from non-photoquadrat number 1350). (Right) Example of *Tridacna squamosa* observed during survey (cropped from non-photoquadrat image 1686).

Other observations

Opportunistic observations of selected fishery target fishes (FTF) were recorded. The authors believe that several of these observations are potentially significant and should be noted. The behavior of FTF has been shown to be indicative of spearfishing pressure (Feary et al. 2011, Januchowski-Hartley et al. 2011, Goetze et al. 2017). As noted in Smith and Marx (2016), between 2005 and 2012, 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 divers 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 (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. Figure 17 and Figure 18 illustrate an FTF and Non-FTFs photographed during this survey, respectively.

Figure 17: Nearshore Fishery Target Species Yellowsaddle goatfish (*Parupeneus cyclostomus*).

Figure 18: Near shore Non-Fishery Target species: (left) Blackblotched stingray (*Taeniura meyeni*) and (right) Arc-Eyed Hawkfish (*Paracirrhites arcatus*).

Discussion

[G1] ESA-listed corals

The ESA-listed coral *Acropora globiceps* was not recorded in the 2001 or 2002 FDM surveys (Belt Collins 2001, 2003). In the 2003 and 2004 surveys, *A. globiceps* was recorded on two individual dives as being "rare" (<5 colonies). Similarly, in the 2017 survey, one confirmed *A. globiceps* was observed, and seven other colonies that might be *A globiceps* were recorded. This comparison suggests that *A. globiceps* has been consistently rare at FDM. During earlier surveys, corals that look very similar to *A. globiceps*: *A. gemmifera* and *A. humilis*, were recorded as being rare or occasional (<5 or 5-15 colonies on a dive, respectively; Belt Collins 2001, 2003; The Environmental Company 2004, 2005). In the 2017 survey, no *A. gemmifera* nor *A. humilis* were recorded, although one colony was originally suspected to be *A. humilis* (Figure 19). *Acropora* corals are the most biodiverse genera in the Pacific, and *Acropora* are also generally some of the most susceptible corals to impacts such as coral bleaching (e.g., Pratchett et al. 2013). Interestingly, the confirmed *A. globiceps* colony (image 3780) was not bleached, and only one of the other 7 colonies that may be *A. globiceps* was bleached (images 1661, 3723, 3730, 3737, 3757, 3773, 3774). The apparent decrease in frequency of *A. humilis* and *A. gemmifera* at FDM in 2017 compared to earlier surveys could reflect an actual decrease in the abundance of these species at FDM, possibly due to prior bleaching events or natural turnover, but it is more likely that this is an apparent result caused by differing survey methodologies or locations, or observer error in species identifications. Because earlier surveys (2001-2004) collected coral species data in the field instead of collecting photographs for later identification and archival purposes, it is not possible to assess the accuracy of those field identifications. In addition, 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.

Figure 19: *Acropora* new species #1, originally thought to be *A. humilis*, a species that often looks similar to the ESA-listed *A. globiceps*. This specimen does not have characteristics consistent with *A. globiceps*, either.

[G2] Percent coral coverage

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 2). At 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 H2 and H3, coral cover on hard substrates in these habitats appears to have increased in density between the prior surveys that concluded in 2012 and the 2017 survey (

Table 3). In habitat type H4 and H5, coral cover was the highest around the island (~50% in general), and remained steady since the last surveys. A coral coverage/habitat type map was created for consultation purposes (Department of the Navy 2016, Figure 2). That map was prepared by Smith, based upon his observations between 2005 and 2012, as reported in various documents, including Smith and Marx (2016), and is still considered accurate, although habitat boundaries grade into one another and should be considered approximate.

[G3] Coral species composition

Species lists of corals observed were prepared during the FDM surveys completed prior to 2005. Subsequent surveys, from 2005 – 2012, focused on collecting data on potential ordnance impacts, fin fish and on the health and general condition of corals at the level of order (Scleractinia, *Millepora*, etc.), as well as 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). Thus, these later surveys did not collect data on coral species composition per se, although they did include observations on the most abundant coral genera and species. However, it should be noted, that preparing species lists and quantifying coral species composition were also not key objectives during any of the previous surveys. The primary objective of these surveys was to look for and assess potential ordnance impacts.

Of the at least 83 scleractinian coral taxa identified during the 2017 survey, only 34 were clear matches with those taxa in the species list compiled from the species-level FDM earlier surveys conducted between 2001-2004 (Appendix C; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). The coral species list compiled here includes four species observed only by Diver 1 and not included in the quantitative assessment completed on photoquadrat images, as well as several higher-level taxonomic identifications such as juvenile *Pocillopora* sp. colony, *Porites* massive, and *Astreopora* sp. which themselves almost certainly include more than one species, possibly additional species than are listed here. Here, we assume that the category *Porites* massive includes at least 5 individual coral species (likely *P. lobata, P. lutea, P. evermanni, P. australiensis, P. solida*). Thus, the species list from the 2017 survey is comprised of a minimum of 83 total unique categories/species from 26 genera. In contrast, the compiled species list from surveys completed between 2001-2004 included at total of 106 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). Some of the species observed during the 2017 survey were not recorded during prior surveys; likewise, some of the species recorded previously were not recorded in 2017. This apparent discrepancy has many potential underlying causes, including, but not limited to, taxonomic errors in either or both surveys, changes in the coral community with time, or differences in survey locations/depths.

The assessment of coral species composition at FDM in 2017 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) many corals at

FDM did not appear to present in their typical morphology (possibly because of the high energy environment at the island), and 3) the methodology employed here cannot distinguish coral species with the highest level of confidence (as would be possible were sampling conducted, for example). The island hosts a large number and diversity of corals that can be challenging to differentiate in situ or from photographs.

Smith and Marx (2009) reported that *Pocillopora* was subjectively 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. These findings are somewhat consistent with those from 2017. *Porites* sp. 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* sp. colonies were dominant in 2017 as well, followed by *Pocillopora meandrina* (13.8% of all colonies island-wide were *P. meandrina*). *Pocillopora* sp. overall comprised 26.9% of all coral colonies around the island (Figure 20). This suggests that *Pocillopora* spp. corals have reduced in density, or *Porites* spp. corals could have increased in relative abundance between past surveys at FDM and the 2017 survey.

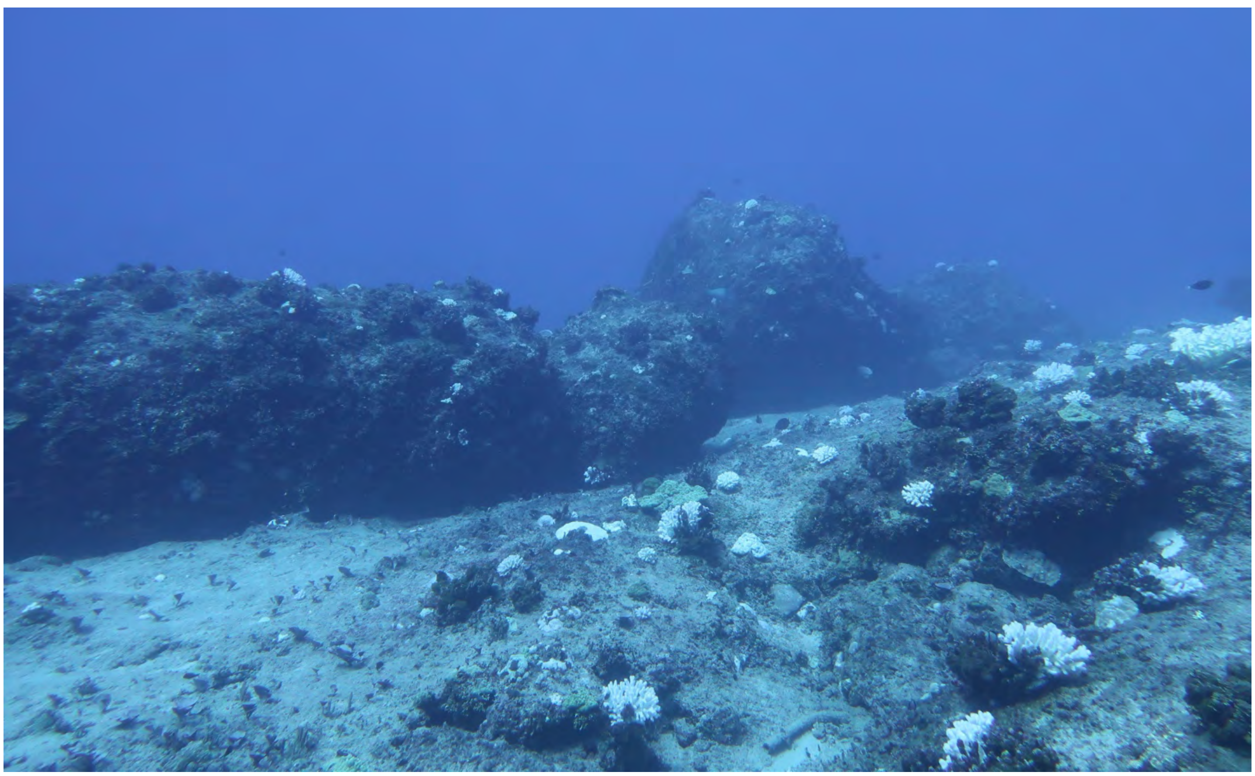

Figure 20: Example of cliff blocks eroded off of the island and now hosting corals, many of the genus *Pocillopora*.

The following contains some limited observations on the coral species observed during the 2017 survey. There are several massive *Porites* species present at FDM. Most cannot be identified to species reliably in the field or from photographs. *P. evermanni* can be identified by a more uniform rounded colony shape, usually a brown color, and tentacles that extend only halfway in the center of corallites. Neither Veron (2000) nor Randall (1995) report *P. evermanni* as present in the Mariana Archipelago, but D. Fenner has found it on Saipan, where it is a light tan. Some colonies in some of the photographs from FDM look similar to these Saipan colonies, and thus were identified as *P. evermanni*. It is not possible to say with high confidence which species of massive *Porites* are present on FDM other than *P. evermanni* from photographs, and even with skeleton identification, differentiation of massive *Porites* species can be quite difficult and unsure. However, based on published records and gross colony morphology, as well as comparison of corallite sizes in photographs, it is possible that *Porites lobata*, *P. lutea* and *P. solida* were present, and maybe *P. australiensis*.

It is possible that three entirely new species of *Acropora* were captured in the photos. Describing these new species to science would require skeleton samples and expert study.

Three *Acropora* sp. specimens were recorded only once (*Acropora* unknown species #3, #5, #11); that is, each were captured in a single photo for each (indicating that these species are relatively rare at FDM). Each specimen was clearly a separate species, were not any of the ESA-listed species that could occur at FDM, and furthermore, a different species than any of the other *Acropora* seen in any of the other photos. However, although these corals, plus eight other *Acropora* spp. corals, are unlikely to be new to science, they were not able to be identified to species for this report. Primarily, this is because photographs captured were not sufficiently detailed to unequivocally differentiate key features.

A potentially new distribution record for the Mariana Archipelago was confirmed for *Pocillopora ankeli*; Veron (2000) does not list this species as being present; however, Randall (1995) records it from Guam.

Pocillopora brevicornis may also be a new distribution record for the Mariana Archipelago. It is not listed as being present there by either Veron (2000) or Randall (1995).

Pocillopora meandrina and *P. verrucosa* were both confirmed to be present. It should be noted that this genus is undergoing revision and some taxonomists believe these two, along with *P. elegan*s are the same species and/or that they hybridize. During this survey, and previous ones, it was subjectively estimated that *P. meandrina*/*P. verrucosa* was the most widely distributed scleractinian at FDM, and the most abundant, based upon sea floor cover by this species. From the 2017 survey data, massive *Porites* spp. corals were the most numerically abundant group (730 or 23.5% of all colonies identified), followed by *P. meandrina*/*P. verrucosa* (560 colonies, or 18% of all identified colonies).

Five species from the Family Agariciidae were positively identified in photoquadrat imagery: *Pavona chiriquensis, P. dueredeni*, *P.* cf. *diffluens* (an ESA-listed species), *P. varians,* and *P. venosa*. Two additional species were field identified (*Pachyseris speciosa* and an unknown *Leptoseris* sp.), but no adequate photos of those species were obtained. Randall (1995) and Carpenter et al. (2008) as referenced in Brainard et al. (2011) have claimed *P. diffluens* as present within the archipelago, although Veron (2000) only lists it from the Red Sea, NE Africa, the Persian Gulf and Pakistan. Fenner and Burdick (2016) are equivocal about whether *P. diffluens* occurs in the Mariana archipelago, but at the very least a coral occurs in the archipelago that is very similar to it. The photographs taken at FDM in 2017 are the same species as that observed at other islands in the archipelago. Comparison of skeleton samples with those from the

Red Sea will be necessary to determine whether the corals in the Marianas are the same species as *P. diffluens* in the Red Sea, but they are very similar at the very least.

Three coral families, *Dendrophylliidae, Euphylliidae,* and *Fungiidae* each had only one representative species. The family *Acroporidae* had the highest number of taxa represented at FDM, with 26 individual species (although most, 18 of these, were unidentified).

[G4] Coral condition

A regional bleaching event occurred in 2007; this extended from southern Japan through the Mariana Archipelago and south at least as far as the Republic of Palau. At FDM, some scleractinian corals showed slight to severe bleaching during that event. Surveys completed the following year (2008) showed a subjectively very high degree of recovery from the 2007 event (Smith and Marx 2016). It is possible that other bleaching events have occurred at FDM since the last 2012 survey, but these were unrecorded.

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. The patches of *T. hoshinota* observed during the 2017 survey are the first known recording of this sponge at FDM. Future surveys should return to the locations of the georeferenced images of the sponge to assess whether it successfully overgrew additional corals, or was thwarted.

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 *Pocillopora* 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 *Pocillopora* spp.. The 2017 survey did not detect any of the coral barnacles (*Cantellius* sp.). However, in the area most heavily impacted by *Cantellius* sp. (southern tip of FDM) there were substantial numbers of *Pocillopora* spp. skeletons (mostly *P. meandrina* complex) that were estimated to have been dead for 3 to 6 years, suggesting that the *Cantellius* sp. barnacles, which mostly infested *Pocillopora* corals in 2012, killed many of those colonies. The age estimate of dead corals was based upon the condition of the corallites and degree of overgrowth by new corals and crustose calcareous algae.

In 2013, water temperatures were elevated in the Marianas archipelago, and the Coral Reef Watch virtual station at Saipan indicated several weeks of coral bleaching Alert Level 1 (bleaching likely) and one week of Alert Level 2 (mortality likely). Since then, several weeks of coral bleaching Warnings (possible bleaching) were issued for that site every year, and in 2017 excessive heat stress accumulated, resulting in approximately 2.5 months of Alert Level 2 conditions. The 2017 FDM survey was conducted approximately 2/3 of the way through this 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). It is likely that at least some corals are likely to survive this bleaching event, although significant mortality of *Acropora* and *Pocillopora* corals, which had the highest rates of bleaching, could be expected. It is currently not well established how long corals can survive in a bleached state without dying, largely because this depends strongly on the energy (fat) reserves of individual corals, the ability of corals to increase feeding on zooplankton while bleached, and other stressors. In contrast to the *Acropora* and *Pocillopora* corals, *Porites rus*, *Favia* spp. and *Favites* spp. corals were least bleached. A shift in community composition towards more of these stress-tolerant, "weedy" species is expected under a changing climate that causes more bleaching events (Darling et al. 2013), and this can be expected to occur at FDM.

Of the top 20 most abundant coral categories, *P. meandrina* (2nd most abundant) and juvenile *Pocillopora* sp. (7th most abundant) corals suffered the most severe bleaching, 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 (and thus quantified here) that were recently dead as evidenced by a light covering of cyanobacteria (e.g., *Acropora* coral recorded in a non-photoquadrat image and shown in Figure 12). Similarly, 84% and 91% of corals from the 4th and 8th most abundant coral taxa, *Astreopora myriophthalma* and *A. cucullata* exhibited complete bleaching.

In contrast, 93% of *Porites rus* corals (19th most abundant) and 82% and 81% of *Favites* unknown #2 and *Favia* unknown #2 (15th and 10th most abundant, respectively) were scored as healthy.

Pocillopora eydouxi colonies showed less bleaching than *P. meandrina/verrucosa/elegans* complex colonies. 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 (e.g., Sampayo et al. 2008), or differences in physiology between species that affect susceptibility to heat stress (e.g., Baird et al. 2009).

[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 9m^2 and one 1m^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 has affected coral communities at FDM. Only three relatively fresh ordnance items were observed, but no blast pits, craters, or significant areas of coral breakage were 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.

[G6] Other ESA-listed species

Aside from the single confirmed *Acropora globiceps* and six *Pavona* cf. *diffluens* coral colonies observed, the only other ESA-listed species observed were three green turtles and one unidentified turtle. Under the ESA, the Giant Manta ray (*Manta birostris*) and the oceanic whitetip shark (*Carcharhinus longimanus*) have recently been listed as threatened (February 21 and March 1, 2018, respectively). Neither species has ever been sighted at FDM.

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). Two ESA-listing Candidate species of Giant clams (*Tridacna gigas* and *T. squamosa*) were observed incidentally during this survey, as was *T. maxima* (Figure 16). 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). 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 benthic survey 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.

As noted in Smith and Marx (2016), 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. Over-exploitation appears to have taken place for many of the species of FTF since the last fish surveys in 2012. Crew members of the support ship used in 2017 revealed that FDM is routinely visited by commercial and subsistence spearfishermen who market their catches in Saipan and even Guam.

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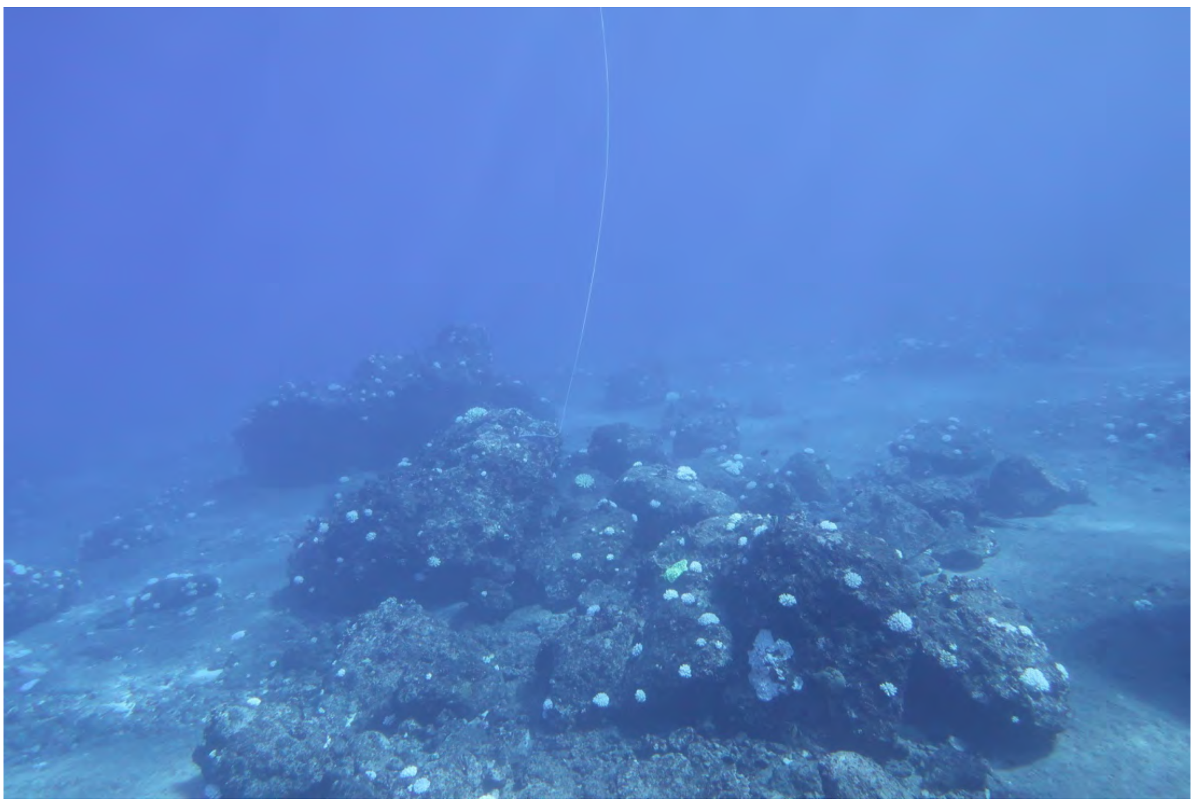
Appendix A.
Benthic Community Descriptions

The following descriptions and images are representative of benthic communities at sites surveyed within the four major habitat types surveyed for the 2017 FDM benthic survey effort (H2, H3, H4, H5). Hard substrate and coral cover metrics are taken from Table 4.

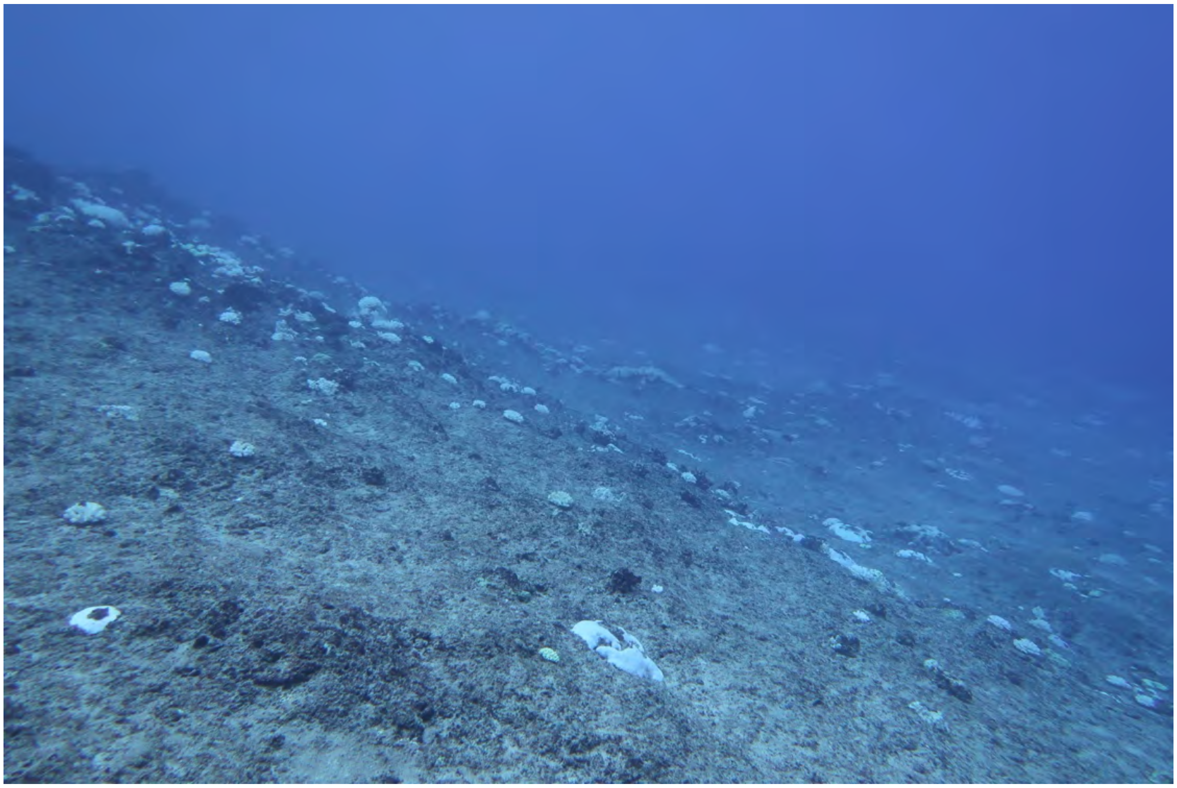
H2

Habitat Type H2 is comprised primarily of boulders and cliff blocks that have eroded off of FDM, and provide hard substrate for coral colonization amongst otherwise unconsolidated and uncolonized sediments. In this habitat, boulders and cliff blocks comprised approximately 10-20% of the seafloor (mean hard substrate capable of supporting corals was 22.5% in 2017), and mean coral cover on rock substrate was 25% in 2017, higher than earlier surveys when mean coral cover was typically ~5%.



H3

Habitat type H3 consists primarily of hardbottom (mean cover 67.5% in 2017), with generally low coral cover (mean 15% cover in 2017, up from <5% during earlier surveys).



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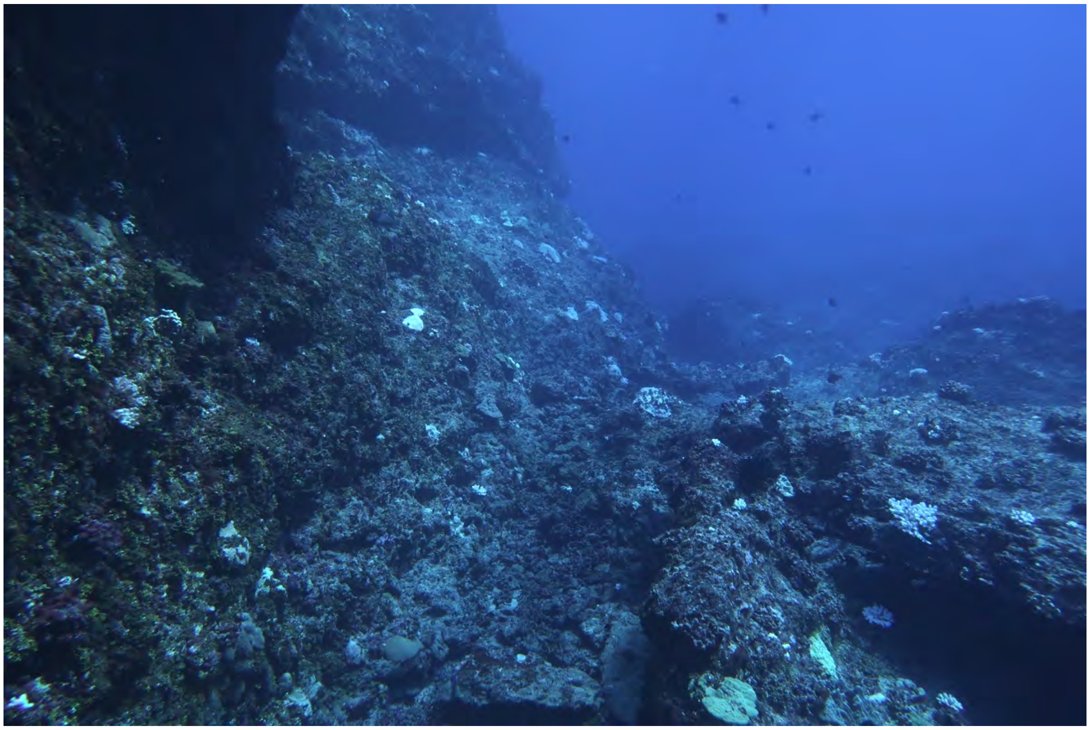
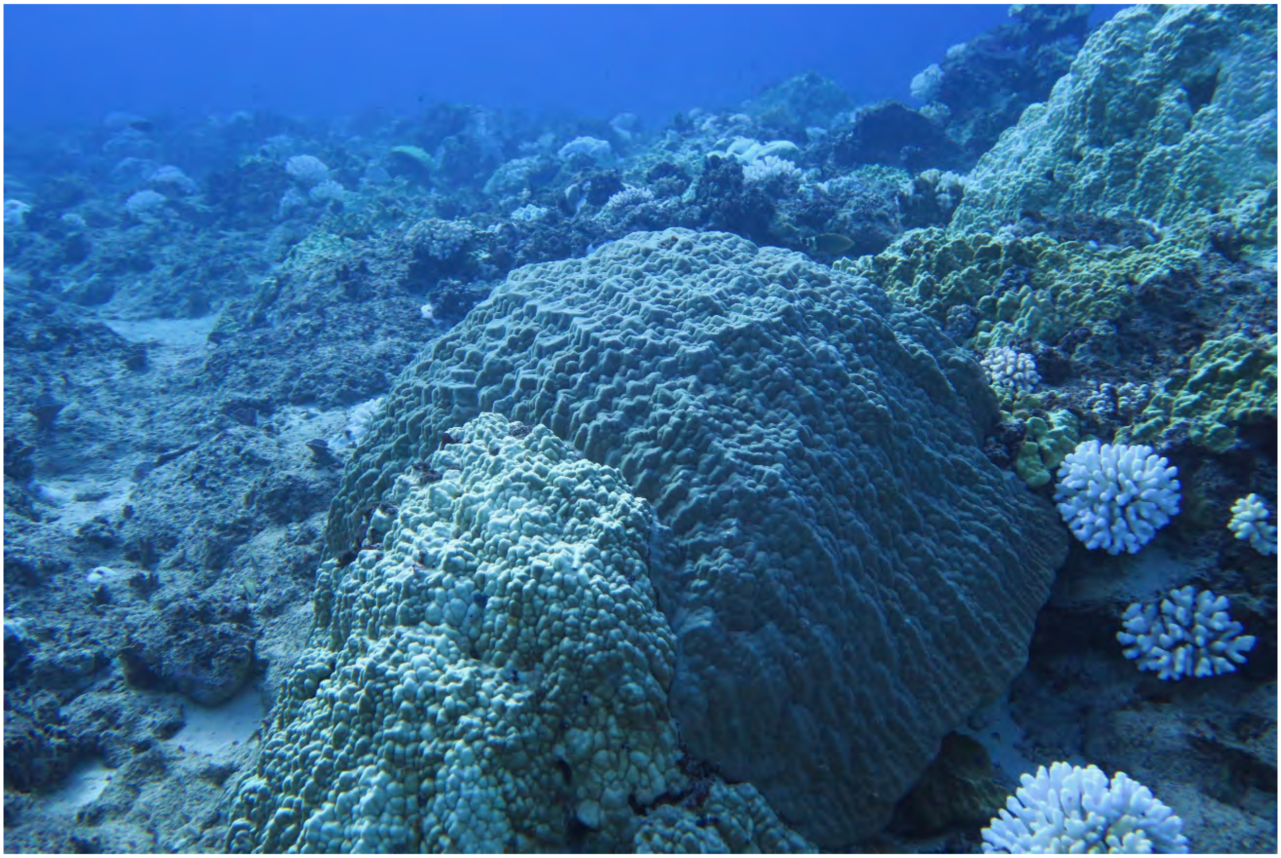
H4

Habitat type H4 is comprised mostly of hardbottom (mean 90% hard substrate in 2017) with generally <15% live coral cover (mean of 10% live coral on rock in 2017).



H5

Habitat type H5 represents the only classic framework-building coral reef at FDM, with 100% hardbottom. Live coral cover ranged between 40-65% in 2017.



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Appendix B
FDM Photoquadrat 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, etc. Photoquadrats were georeferenced and watermarked with latitude/longitude locations and archived with PACFLT. Times are in local time, ChST (UTC+10).

Date	Site	Dive	Maximum depth (ft)	Start Time	Transects	Photo Numbers
9/27	H2NW	1	70	9:39	3	3067 - 3133
9/27	H3NW	2	35	10:46	4	3134 - 3257
9/27	H2W	3	50	15:06	2	3259 - 3338
9/27	H2W	4	35	16:08	4	3339 - 3450
9/28	H3NE, H4NE	1	70	8:57	3	3451 - 3522
9/28	H2S, H4S	2	35	10:13	4	3523 - 3611
9/28	H3E	3	50	14:27	4	3612 - 3705
9/28	H2E	4	35	15:32	4	3706 - 3816
9/29	H4S	1	70	9:31	3	3817 - 3885
9/29	H3E	2	35	11:20	3	3886 - 3956
9/29	H5W	3	45	16:08	3	3957 - 4032
9/30	H3E	1	70	9:12	3	4034 - 4090
9/30	H3N	2	50	11:04	2	4091 - 4141
9/30	H3W	3	45	14:57	4	4142 - 4228
10/1	H5W	1	70	8:35	2	4229 - 4263
10/1	H2N	2	40	10:11	4	4264 - 4341

Appendix C.
Scleractinian coral species lists.

Individual coral taxa identified at FDM during prior species-level surveys in 2001-2004 (column 3), and in 2017 (column 4); in these columns, a "1" indicates presence of this taxon as recorded. Note that *Porites* massive probably includes at least 5 species, but these are also already listed in the species list, below. Column 5 lists the total number of coral colonies identified from a given taxon in the photoquadrat imagery; note that not all taxa recorded in 2017 were represented in the photoquadrats. Records highlighted in blue were identified in 2017 but not during 2001-2004 surveys. Records highlighted in green are potentially new (undescribed) species or hybrids. Records highlighted in yellow are categories unique to the 2017 survey, which were not used in earlier surveys. 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 that identifications primarily used spelling of genus and species names from Veron as of July 2018 (Veron et al. 2018), or the World Register of Marine Species (www.marinespecies.org) when not included in Veron. See methods section for further details.

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Acanthastrea brevis	A bre	0	1	9
Acanthastrea echinata	A ech	1	0	
Acropora aculeus	A acu	1	0	
Acropora austera	A aus	1	0	
Acropora bifurcata	A bif	1	0	
Acropora caroliniana	A car	1	0	
Acropora cerealis	A cer	1	1	2
Acropora digitifera	A dig	1	0	
Acropora gemmifera	A gem	1	0	
*Acropora globiceps** (note that total includes all corals in photoquadrats that might be *A. globiceps*)	A glo	1	1	7
Acropora granulosa	A gra	1	0	
Acropora humilis	A hum	1	0	
Acropora nasuta	A nas	1	1	5
Acropora new species #1	Ac new #1	0	1	6
Acropora new species #2	Ac new #2	0	1	3
Acropora new species #3	Ac new #3	0	1	2
Acropora palifera	A pal	1	0	

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Acropora robusta	A rob	1	0	
Acropora samoensis	A sam	1	0	
Acropora sarmentosa	A sar	1	0	
Acropora sp.	Ac sp	0	1	10
Acropora sp. unknown #1	Ac sp. unk #1	0	1	13
Acropora sp. unknown #2	Ac sp. unk #2	0	1	2
Acropora sp. unknown #3	Ac sp. unk #3	0	1	1
Acropora sp. unknown #4	Ac sp. unk #4	0	1	2
Acropora sp. unknown #5	Ac sp. unk #5	0	1	1
Acropora sp. unknown #6	Ac sp. unk #6	0	1	3
Acropora sp. unknown #7	Ac sp. unk #7	0	1	2
Acropora sp. unknown #8	Ac sp. unk #8	0	1	2
Acropora sp. unknown #9	Ac sp. unk #9	0	1	4
Acropora sp. unknown #10	Ac sp. unk #10	0	1	4
Acropora sp. unknown #11	Ac sp. unk #11	0	1	1
Acropora surculosa	A sur	0	1	6
Acropora tenuis	A ten	1	0	
Acropora valida	A val	1	0	
Alveopora fenestrata	A fen	1	0	
Astrea annuligera	A ann	0	1	16
Astrea curta (recorded as Montastrea curta in earlier reports)	A cur	1	1	6
Astreopora cucullata	A cuc	0	1	106
Astreopora eliptica	A eli	1	0	
Astreopora gracilis	A gra	1	0	
Astreopora myriophthalma	A myr	1	1	194
Astreopora ocellata	A oce	1	0	
Astreopora randalli	A ran	1	0	
Astreopora sp.	Astreopora	0	1	9
Coscinaraea columna	C col	1	0	
Cyphastrea chalcidicum	C cha	1	0	

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Cyphastrea microphthalma	C mic	1	0	
Cyphastrea serailia	C ser	1	0	
Cyphastrea sp. unknown #1	Cyphastrea unk #1	0	1	46
Diploastrea heliopera	D hel	1	0	
Echinopora lamellosa	E lam	1	0	
Euphyllia glabrescens	E gla	1	0	
Favia favus	F fav	1	0	
Favia maritima	F mari	1	1	3
Favia marshae	F mar	1	0	
Favia matthai	F mat	1	1	66
Favia pallida	F pal	1	1	13
Favia speciosa	F spe	1	0	
Favia stelligera	F ste	1	1	21
Favia unknown #1	Favia unk #1	0	1	26
Favia unknown #2	Favia unk #2	0	1	77
Favia unknown #3	Favia unk #3	0	1	1
Favia unknown #4	Favia unk #4	0	1	1
Favites abdita	F abd	1	0	
Favites flexuosa	F fle	1	1	1
Favites halicora	F hal	1	0	
Favites pentagona	F pen	1	0	
Favites russelli	F rus	1	0	
Favites unknown #1	Favites unk #1	0	1	42
Favites unknown #2	Favites unk #2	0	1	1
Favites unknown #3	Favites unk #3	0	1	8
Favites unknown #4	Favites unk #4	0	1	12
Fungia scutaria	F scu	1	0	
Galaxea fascicularis	G fas	1	1	12
Gardineroseris planulata	G pla	1	0	
Goniastrea minuta	G min	0	1	2
Goniastrea palauensis	G pal	1	0	

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Goniastrea pectinata	G pec	1	1	11
Goniastrea peresi	G per	0	1	1
Goniastrea retiformis	G ret	1	0	
Goniopora lobata	G lob	1	0	
Goniopora somaliensis	G som	0	1	38
Herpolitha limax	H lim	0	1	1
Hydnophora microconos	H mic	1	1	14
Leptastrea bottae	L bot	1	0	
Leptastrea inaequalis	L ina	1	0	
Leptastrea purpurea	L pur	1	1	291
Leptastrea transversa	L tra	1	1	10
Leptoria phrygia	L phr	1	0	
Leptoseris mycetoseroides	L myc	1	0	
Leptoseris sp.	---	0	1	
Lobophyllia corymbosa	---	0	1	
Lobophyllia hemprichii	L hem	1	1	
Merulina ampliata	M amp	1	1	1
Montastrea valenciennesi	M val	1	0	
Montipora aequituberculata	M aeq	1	0	
Montipora caliculata	M cal	1	0	
Montipora danae	M dan	1	0	
Montipora foveolata	M fov	1	0	
Montipora grisea	M gri	1	0	
Montipora hoffmeisteri	M hof	1	0	
Montipora monasteriata	M mon	1	0	
Montipora spumosa	M spu	1	0	
Montipora tuberculosa	M tub	1	1	3
Montipora unknown #1	M unk #1	0	1	9
Montipora unknown #2	M unk #2	0	1	5
Montipora unknown #3	M unk #3	0	1	1
Montipora venosa	M ven	1	0	

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Montipora verrilli	M veri	1	0	
Montipora verrucosa	M ver	1	0	
Oulophyllia bennettae	O ben	0	1	3
Oulophyllia crispa	O cri	1	1	3
Pachyseris speciosa	---	0	1	
Pavona chiriquiensis	P chi	0	1	23
Pavona cf. *diffluens**	P dif	0	1	6
Pavona duerdeni	P due	1	1	6
Pavona maldivensis	P mal	1	0	
Pavona minuta	P min	1	0	
Pavona varians	P var	1	1	21
Pavona venosa	P ven	1	1	9
Platygyra daedalea	P dae	1	1	40
Platygyra pini	P pin	1	1	63
Platygyra ryukyuensis	P ryu	1	0	
Platygyra sinensis	P sin	1	0	
Plesiastrea versipora	Pl ver	1	1	3
Plerogyra sinuosa	P sin	1	0	
Pocillopora ankeli	P ank	0	1	11
Pocillopora damicornis	P dam	1	0	
Pocillopora elegans	P ele	1	0	
Pocillopora eydouxi	P eyd	1	1	58
Pocillopora eydouxi hybrid	P eyd bybrid	0	1	3
Pocillopora hybrid #1	Poc hybrid #1	0	1	83
Pocillopora hybrid #2	Poc hybrid #2	0	1	6
Pocillopora juvenile	P juv	0	1	115
Pocillopora meandrina	P mea	1	1	428
Pocillopora verrucosa	P ver	1	1	132
Pocillopora woodjonesi	P woo	1	0	
Porites australiensis	P aus	1	1	8
Porites evermanni	P eve	0	1	18

Coral Taxon	Coral code	Taxon recorded in prior surveys (2001-2004)	Taxon recorded in 2017 survey	Number of colonies in photoquadrats, 2017
Porites lichen	P lic	1	0	
Porites lobata	P lob	1	1	15
Porites lutea	P lut	1	1	36
Porites massive	Por mass	0	1	671
Porites murrayensis	P mur	1	0	
Porites rus	P rus	1	1	29
Porites solida	P sol	1	1	150
Porites vaughani	P vau	1	0	
Psammocora haimeana	P hai	1	0	
Psammocora obtusangula	P obt	1	0	
Psammocora superficialis	P sup	1	0	
Scapophyllia cylindrica	S cyl	1	1	5
Siderastrea savignyana	S sav	1	0	
Stylophora pistillata	S pis	1	0	
Tubastrea faulkneri	T fau	1	0	
Turbinaria stellulata	T ste	0	1	20
Unknown	Unk	0	1	7
Total individual coral taxa recorded		106	83 (85 if *Porites massive* and *Pocillopora juvenile* are included)	
Shared taxa, both survey periods		34		
Total individual colonies identified				3105

Appendix D
Coral community composition charts

Figure 21 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.

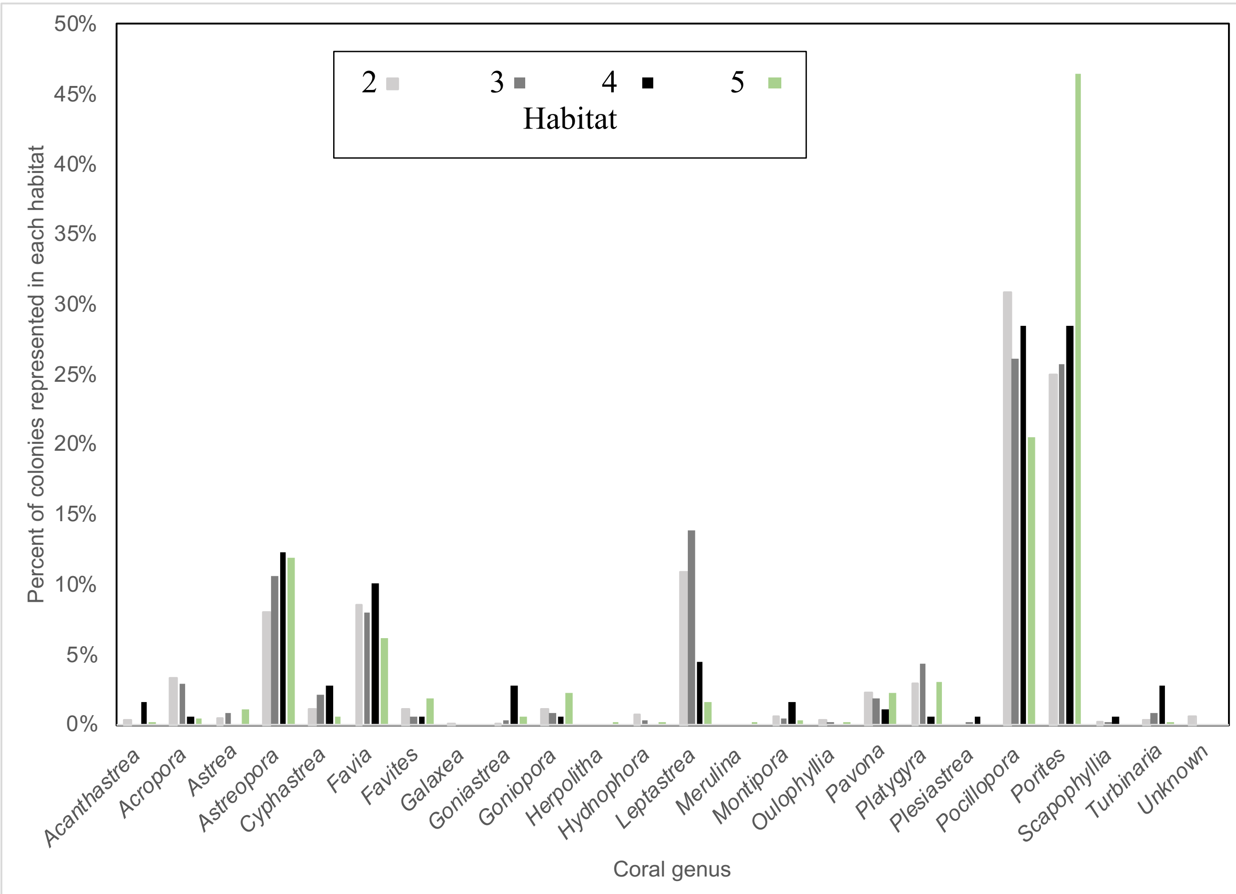

Figure 21: Coral community composition by habitat and genera based on coral counts from photoquadrats.

Appendix E
Ordnance observed

Details on ordnance items observed and photographed during the 2017 FDM benthic habitat survey.

	Size of ordnance			Condition of ordnance				
Item #	Large	Small	Fragment	Fresh	Old	Intact	Broken	Photo #
1		X		X		X		1310
2			X		X		X	1452
3	X				X	X		1640
4	X				X	X		1643
5			X		X		X	1650
6	X				X	X		1672
7	X				X	X		1694
8	X				X		X	1701
9			X		X		X	1702
10	X				X		X	1703
11	X				X	X		1734
12	X				X	X		1821
13	X				X		X	1845
14	X				X		X	1846
15	X				X		X	1847
16			X		X		X	1853
17	X				X		X	1860
18	X				X		X	1880
19	X				X	X		1896
20	X				X	X		1925
21	X				X	X		1928
22	X				X	X		1929
23	X				X	X		1931
24	X				X		X	1933
25	X				X	X		1934
26	X				X		X	1943
27	X				X	X		1944
28	X				X	X		1954
29	X				X	X		1955
30	X				X		X	1961
31	X				X	X		1962

Item #	Size of ordnance: Large	Small	Fragment	Condition of ordnance: Fresh	Old	Intact	Broken	Photo #
32			X		X		X	1964
33	X				X	X		1965
34	X				X	X		1965
35	X				X	X		1965
36	X				X	X		1966
37	X				X	X		1969
38			X		X		X	1970
39	X				X		X	1977
40	X				X		X	1978
41	X				X		X	1979
42	X				X	X		2013
43	X				X	X		2018
44	X				X	X		2038
45	X				X	X		2043
46	X				X	X		2044
47	X				X	X		2046
48	X				X	X		2051
49	X				X	X		2052
50			X		X		X	2053
51			X		X		X	2054
52	X				X	X		2137
53			X		X		X	3069
54	X				X	X		3070
55	X				X		X	3083
56			X		X		X	3108
57	X				X	X		3141
58	X				X	X		3170
59	X				X	X		3172
60	X				X		X	3197
61			X		X		X	3268
62			X		X		X	3271
63	X				X	X		3279
64	X				X		X	3279
65	X				X		X	3390
66	X				X		X	3413
67			X		X		X	3473
68	X				X	X		3521

Item #	Size of ordnance			Condition of ordnance				Photo #
	Large	Small	Fragment	Fresh	Old	Intact	Broken	
69	X				X		X	3643
70	X			X		X		3644
71			X		X		X	3657
72	X				X		X	3704
73	X				X	X		3706
74	X				X	X		3745
75	X				X	X		3816
76			X		X		X	3829
77			X		X		X	3842
78	X				X	X		3852
79			X		X		X	3863
80	X				X		X	3872
81	X				X	X		3891
82			X		X		X	4056
83			X		X		X	4088
84	X				X	X		4089
85			X		X		X	4151
86	X				X	X		4154
87			X		X		X	4161
88	X			X		X		4163
89	X				X		X	4171
90	X				X		X	4174
91			X		X		X	4176
92			X		X		X	4176
93	X				X	X		4176
94	X				X		X	4193
95	X				X		X	4194
96	X				X		X	4197
97	X				X	X		4254
98	X				X	X		4257
99	X				X		X	4320
100	X				X	X		4323
101	X				X		X	4340
Sum	77	1	23	3	98	50	51	
Percentage	76.2	1.0	22.8	3.0	97.0	49.5	50.5	