Final

FARALLON DE MEDINILLA 2017 CORAL REEF SURVEY REPORT

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

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Prepared for U.S. Navy Pacific Fleet
Commander Pacific Fleet
250 Makalapa Drive
Joint Base Pearl Harbor Hickam
Hawaii 96860-3134

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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 (SPAWAR) Systems Center 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). The primary objectives of this 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. The 2017 survey fully fulfilled Terms and Conditions 4 and 5 from the 2015 MITT BO (NMFS 2015), 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 or ESA-listed corals and to assess general trends in coral reef species composition, percent coral coverage, and condition (disease, predators, extent of breakage, etc.)". Smith and Marx (2016) also satisfied a portion of Terms and Conditions 5 of the 2015 MITT BO (NMFS 2015).

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. Corals from 23 genera were identified in photoquadrat and representative photographs for this reporting effort (Appendix C).
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 the ESA-listed coral Pavona diffluens. This coral species has not been confirmed in the Commonwealth of the Northern Mariana Islands (CNMI), although Randall (2003) lists it in Guam. This evidence confirms that ESA listed corals are present, but rare, in waters of <20m depth around FDM.
This survey also satisfied the requirement to "assess general trends in coral reef species composition, percent coral coverage, and condition (disease, predators, extent of breakage, etc.)" at <20m depth around FDM (NMFS 2015).
There was a severe coral bleaching event underway at FDM during the surveys, caused by regional anomalously warm sea surface temperatures.
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. In summary, there were no observed effects of training, including the use of high-explosive bombs, on corals at FDM during this survey effort.

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Executive Summary

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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. The Navy's U.S. Pacific Fleet (PACFLT) funded an initial survey in 1997 and 13 annual marine ecological surveys of near shore marine resources at FDM between 1999 and 2012 (no survey was performed in 2011) in support of environmental compliance for the Mariana Islands. The 2017 survey presented 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 in 2014 (79 FR 53851). The 1999 – 2004 surveys were completed by a Navy contractor and a representative from the U.S. Fish and Wildlife Service, the National Marine Fisheries Service and the Commonwealth of the Northern Mariana Islands. All surveys since 2005, including this survey, have been performed by the same Navy scientists. 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]

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 PACFLT to design an appropriate survey protocol to gather quantitative data needed to address the goals above and satisfy the MITT BO requirements, as listed above in the preceding paragraph (NMFS 2015). The approved survey plan (SSC-PAC 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.

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

As noted, a key element of this survey was to assess corals of all taxa. Particular emphasis was placed upon identifying and geo-locating any specimens of the scleractinian corals listed as Threatened and 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 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) as well as 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).

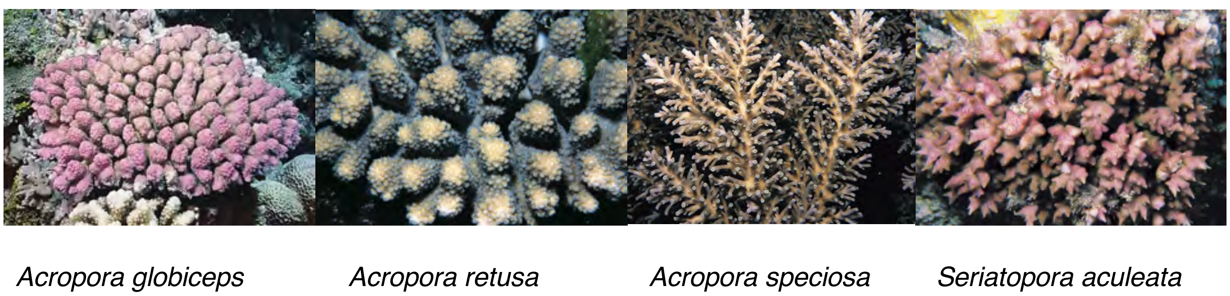

Figure 1: ESA-listed corals previously observed or thought to possibly occur at FDM. Image credits: Australian Institute for Marine Science Coral Fact Sheets (http://coral.aims.gov.au/).

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. Because water clarity was excellent, in excess of 100 feet on most dives, meaningful qualitative observations could also be made of the sea floor at depths below 70 feet.

The in-water tasks completed by the Navy marine ecologist divers are listed in Table 1. 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 for acquiring 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. The standard sizing of these photoquadrat images 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.

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.

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**

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) apparent damage from fish traps, nets, anchors, fishing line or spears; g) evidence of sediment accumulation; and h) evidence of high levels of macro-bioeroders, shown by Cooper (2008) to be indicative of reduced water quality.

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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 queried and saved by the SeaTrac acoustic system and associated software every two seconds, showing total area surveyed in 2017.

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 information 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. was it badly bent, gouged, etc.)
5. Fresh ordnance fragments
6. Old ordnance
7. Old ordnance fragments

Objects such as ordnance or rock introduced to the marine environment quickly 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. Old objects support an abundance of naturally occurring benthic flora or fauna such as algal turf, crustose calcareous algae, coral, tube worms, bryozoans, etc. indicative of having been submerged and/or exposed for several months to many years. Depending upon the degree of development and the species involved, it is possible to determine 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]. Within the Mariana Archipelago, at the time of this survey there was one fish species and five sea turtle species which had been recorded from the archipelago and may use the waters around FDM, and were currently listed under the ESA. 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. Their dive tracks were recorded as real-world positions 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 were identified to species with the assistance of coral taxonomist Dr. Douglas Fenner. Dr. Fenner's analysis focused on identifying any of the four Threatened species listed above and identification to the lowest possible taxonomic level of as many of the particularly challenging corals photographed as possible. Note that coral species identification, particularly in highly biodiverse locations like FDM, can be extremely challenging. In addition, Dr. Fenner suggested that because FDM is such an extreme energy environment, many coral taxa may not occur in their 'common morphology', which complicates visual identification.

In photoquadrat images, all coral colonies that could theoretically be identified were annotated with a number and then identified to species when possible and to genus when species-level identification could not be completed. In addition, 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 (> 5000 records) for possible future analysis of coral species diversity, within-taxa 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

Coral identification proceeded by the analyst comparing each numbered coral in the photoquadrat to coral references and guides including Randall (1995) and Veron (2000). Taxa names, health codes and any identification notes were then recorded in Excel workbooks with records organized by Dive and Transect numbers. Taxa names were keyed to photoquadrat number and coral ID number, which were used to share, compare and update identifications. All identifications were independently assessed by two analysts, and the final draft of all workbooks were reviewed for accuracy and consistency in naming and organization by all team members.

If a coral could not be identified to either species or genus, it was coded with one of several codes and annotated with the identification issues, e.g. photograph resolution or quality insufficient, or coral too similar to others to quickly differentiate. In the latter case, these records represent taxa that could potentially be identified given additional time spent consulting coral taxonomy experts and/or literature, although resources were not available to complete such work for this report. Likewise, some of the corals identified to genus may be identifiable to species at a later time and this effort is ongoing for a follow-on report. Note that there are discrepancies among taxonomists when classifying many coral groups, as well as significant challenges with field identification of morphologically similar species such as the massive *Porites* corals *P. australiensis*, *P. lichen*, *P. lobata*, and *P. lutea*. In these cases, it may not be possible to identify those photographed corals to species with high confidence, even with the addition of more effort and resources.

As image analysis work proceeded, a coral taxa list was compiled and refined based on coral identifications by the SDS team with assistance from Dr. Fenner. 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).

Data analysis

Following final data review, Excel spreadsheets of all coral records in all transects were compiled into a master dataset for summary analysis. This report is focused on assessment of coral genera; assessment of species-level data is ongoing and a subsequent report will summarize data at the species or lowest taxonomic identifications that can be confirmed. For this report, all taxonomic identifications were rolled up to the genus level for summary and quantitative comparison.

Unidentified corals were assigned to one of three classes based on their potential to be identified given further taxonomic work (Table 3). For two classes, Xa and Xc, image quality and resolution are acceptable and it is possible to carry out further identification work. Xc coral observations represent priority data points for further analysis; these corals may be identified with further effort (medium priority for further assessment). Xa coral observations represent more problematic species to identify; for these observations further analysis may or may not lead to improvements in identification (low priority for further assessment). Xb coral observations represent data points that occur in portions of images that are not of sufficient quality to warrant further assessment. Most corals coded as Xb occurred at the edges of photoquadrats (where image distortion is sometimes pronounced) and/or colonies were very small. Corals identified to genus only for this report were deemed a high priority for further species-level identification effort.

Table 3: Description of coral codes for three types of unidentified coral taxa

Coral Codes of Unidentified Taxa	Priority for further assessment	Description of Identification Issue
Xa	LOW	Image quality and resolution are acceptable but identification of these taxa or records is problematic. These corals *may or may not* be identified to genus or species with further effort.
Xb	N/A	Image quality and resolution are not sufficient for further taxonomic work. These corals cannot be identified to genus or species with further effort.
Xc	MEDIUM	Image quality and resolution are acceptable and these corals *are likely to be* identified to genus or species with further effort.

Percent coverage of coral-bearing substrate and percent coverage of coral are summarized in a table for comparison between habitat subareas, habitats and years (2017 survey vs. historic). Coral composition summaries are presented as bar charts by habitat. Note that the survey design located transects in shallow (maximum depth 10m) vs. comparatively deep (approximately 10-20m depth) strata within each habitat type to ensure broad coverage of habitat characteristics. Since stratified datasets were not sufficiently large to analyze separately, shallow and deep strata were combined for data analysis, with the exception of habitat H3. For each habitat type, proportions (based on number of occurrences) of coral genera in each transect were computed, then averaged to assess community composition. This same analysis was conducted for coral condition.

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. Photoquadrat metadata is presented in Appendix A. Habitat descriptions and representative photographs are presented in Appendix B.

[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 under different physical regimes (for example, see Fenner and Burdick 2016). Positive identification generally requires sampling corals for microscopic and/or genetic analysis. 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 two other very similar species (*A. monticulosa* and *A. digitifera*) were seen in any of the photos. A single specimen of *A. humilis* was positively identified; this species also closely resembles *A. globiceps* but is not ESA-listed. All of the specimens 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) Confirmed ESA-listed Pavona diffluens colony. This colony was captured in non-photoquadrat image IMG_1996 (image shown cropped here). 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).

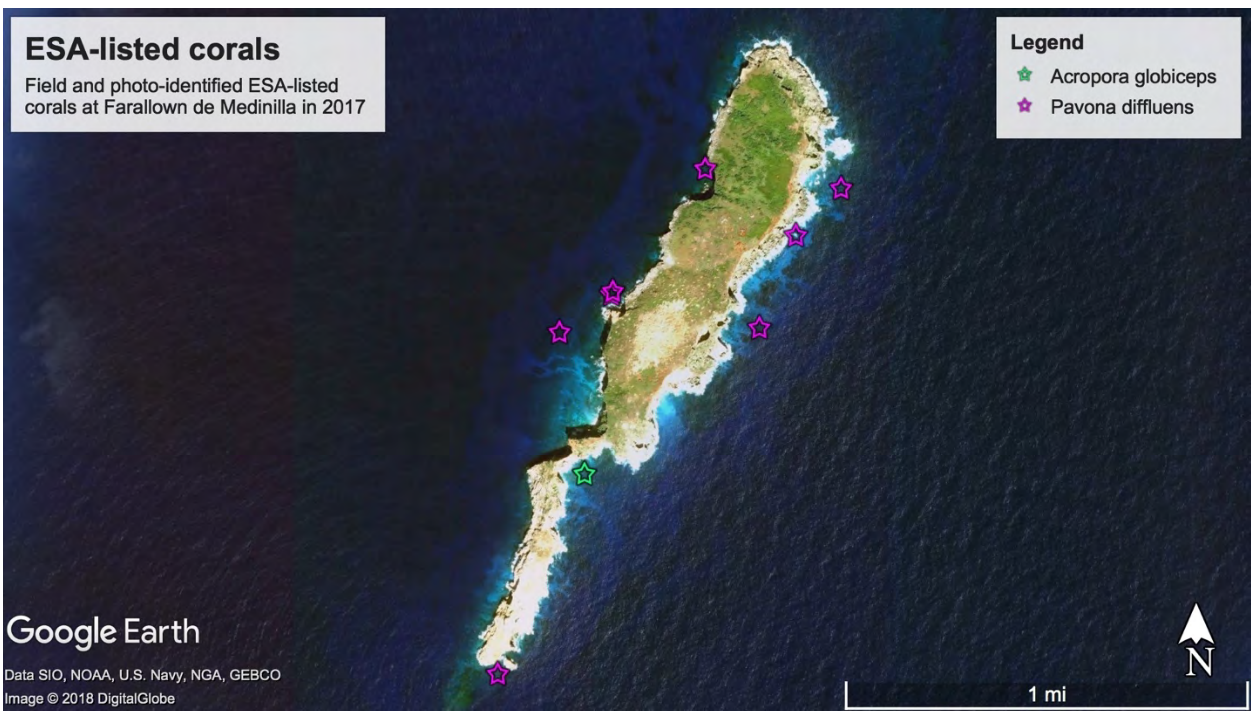


Figure 5: Map of FDM showing locations of corals identified in this study as ESA-listed species.

A number of specimens of an unidentified *Acropora sp.*, closely resembling *A. globiceps* were seen in both the photoquadrats and representative/general photos (Figure 4). A meticulous inspection of those photos and comparisons with specimens from Samoa, Tonga, Fiji and CNMI suggest this may be a new species, closely resembling *A. globiceps*, but differing in important distinguishing characteristics. Morphologies of specimens within the same species can vary greatly due to environmental factors. 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.

No *Acropora retusa, A. speciosa,* and no *Seriatopora aculeata* specimens were seen, and none have ever been reported during the previous 14 surveys. However, six colonies of the coral *Pavona 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 Marina 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 diffluens* were confidently identified based on morphological characteristics assessed in photographs collected during the 2017 survey.

[G2] Percent coral coverage

Habitat types around FDM were previously defined by compiling semi-quantitative data acquired from multiple previous surveys by SDS divers at FDM. Habitats were divided into six primary types described in SSCPAC 2017a and presented in Figure 2; Appendix B). 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 endangered 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 within H5 (approximately 500m x 250m, see red 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 4 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 with 2017 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 4: 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%**	

Final

Habitat Type Subarea (Refer to Figure 2)	% rock 2017	% coral on rock 2017	% rock Prior years	% coral on rock Prior years	Notes
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. 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,

Habitat Type Subarea (Refer to Figure 2)	% rock 2017	% coral on rock 2017	% rock Prior years	% coral on rock Prior years	Notes
					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.

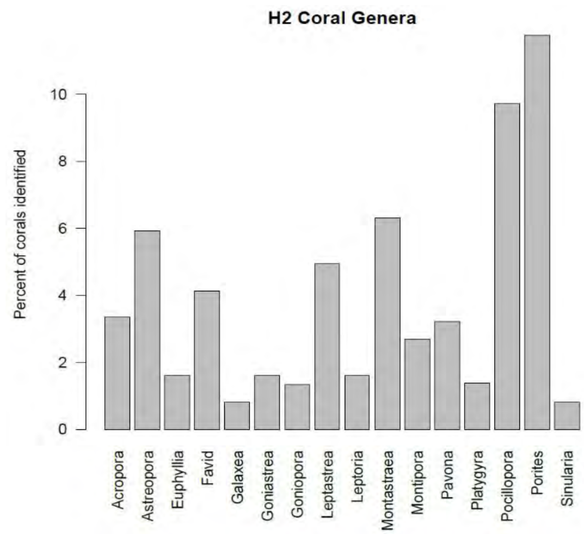
[G3] Coral species composition

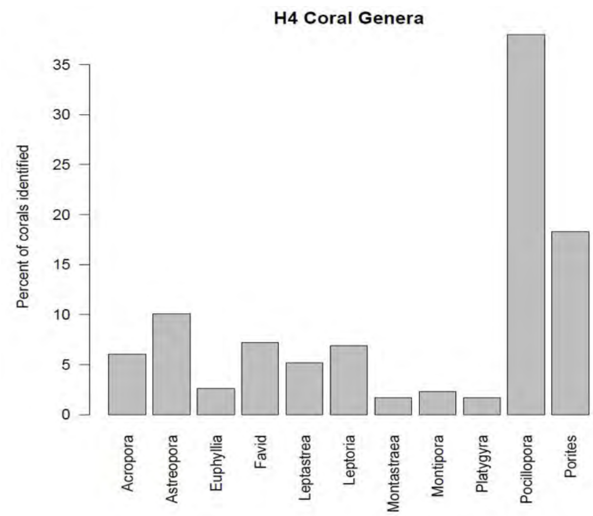
Corals from 23 genera were identified in the photoquadrat and representative photographs taken by both divers (Appendix C). Approximately 30% of coral colonies in the photoquadrat imagery were not identified to species or genus; these were generally small colonies, or rare morphologies that were not easily identified. It is estimated that 25% of these unidentified corals could possibly be identified with further effort; while approximately 5% cannot be further identified due to insufficient image quality. Approximately 71 species of corals were either positively identified or recognized as individual species but not yet identified below genus level (Appendix C).

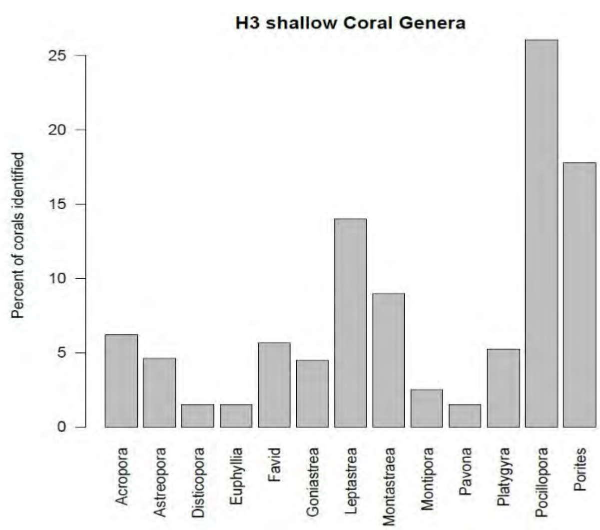
Two new, undescribed species of *Acropora* and two new, undescribed species of *Pocillopora* (based on tentative identificationss) were recorded in survey photos. In addition, corals representing potential hybrids between *Pocillopora* species were captured in survey photos. The taxonomy of many members of the genus *Pocillopora* is disputed, and many taxonomists believe hybrids are not uncommon (Pinzón and LaJeunesse 2011, Pinzón et al. 2013). *Pocillopora ankeli* was positively identified and was relatively common in the survey photos; this coral has not been recorded from Guam or CNMI according to the coral taxonomist J.E.N Veron (2000). Further assessment of imagery of these colonies is ongoing, and will be provided in a subsequent report.

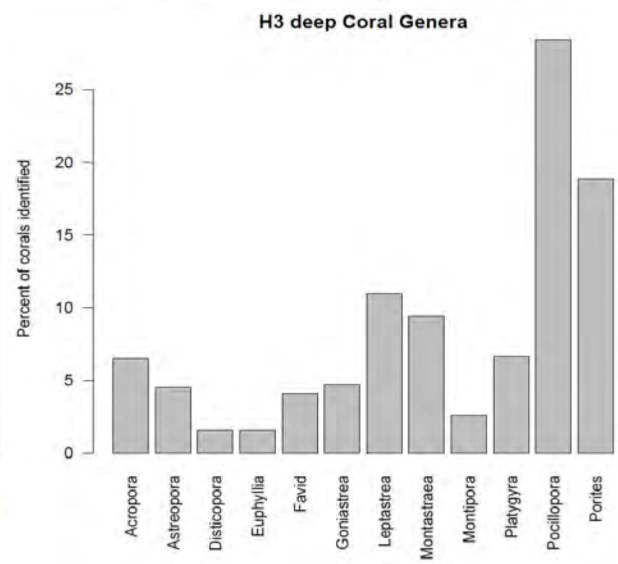
Each habitat around FDM (Figure 2) was comprised of slightly different coral communities (Figure 6, and see Appendix D for figures that include unidentified taxa). For instance, Habitat H2 is dominated approximately equally by *Pocillopora* and *Porites* colonies, while Habitat H4 is strongly dominated by *Pocillopora* and Habitat H5 by *Porites*. These findings are consistent with earlier survey efforts (Smith et al. 2013). *Acroporids* comprised between ~5-8% of the community in all Habitats except H5, where they were less numerically abundant (~2%). Note that these calculations are based on counts of coral colonies and do not take into account colony sizes; if sizes were included, benthic cover could be computed and the community composition may appear differently weighted compared to the numerical abundances presented here.

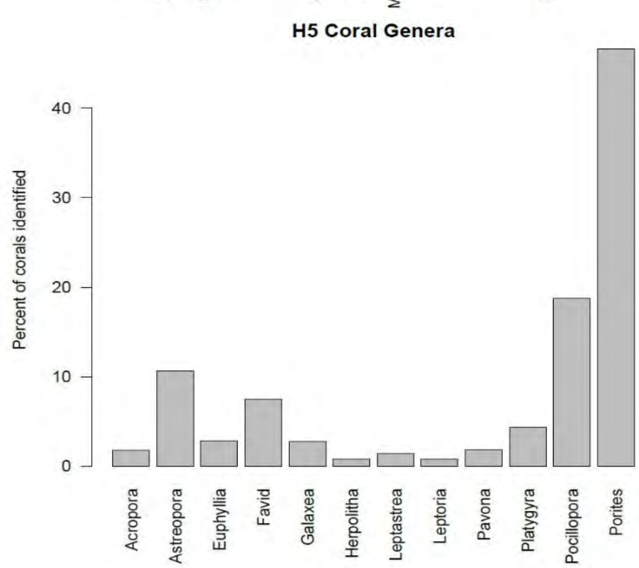
Figure 6: (following page) Coral community composition by genera for each habitat type, based on coral counts. The Y-axis represents percent coral counts for all colonies, not including unidentified corals. The X-axis displays the coral genera identified in this study for each habitat type. (Appendix D, Figures 21-25 displays the same including unidentified corals)


H2 Coral Genera
Percent of corals identified
0
2
4
6
8
10
Acropora
Astreopora
Euphyllia
Favid
Galaxea
Goniastrea
Goniopora
Leptastrea
Leptoria
Montastraea
Montipora
Pavona
Platygyra
Pocillopora
Porites
Sinularia


H4 Coral Genera
Percent of corals identified
0
5
10
15
20
25
30
35
Acropora
Astreopora
Euphyllia
Favid
Leptastrea
Leptoria
Montastraea
Montipora
Platygyra
Pocillopora
Porites


H3 shallow Coral Genera
Percent of corals identified
0
5
10
15
20
25
Acropora
Astreopora
Disticopora
Euphyllia
Favid
Goniastrea
Leptastrea
Montastraea
Montipora
Pavona
Platygyra
Pocillopora
Porites


H3 deep Coral Genera
Percent of corals identified
0
5
10
15
20
25
Acropora
Astreopora
Disticopora
Euphyllia
Favid
Goniastrea
Leptastrea
Montastraea
Montipora
Platygyra
Pocillopora
Porites


H5 Coral Genera
Percent of corals identified
0
10
20
30
40
Acropora
Astreopora
Euphyllia
Favid
Galaxea
Herpolitha
Leptastrea
Leptoria
Pavona
Platygyra
Pocillopora
Porites

[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.

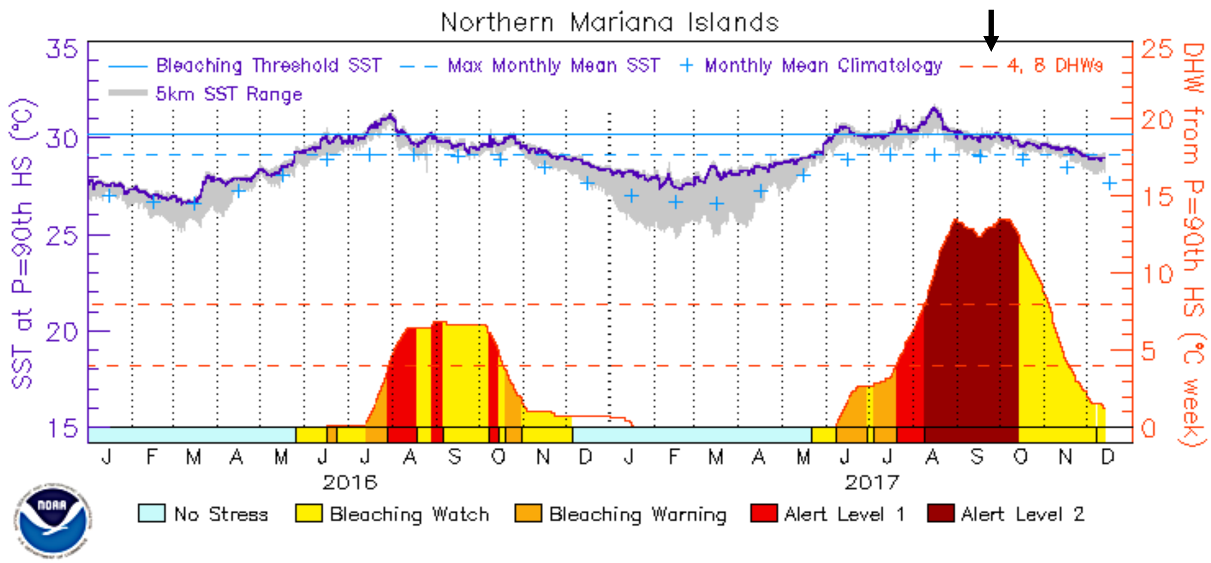


Figure 7: Sea surface temperature (SST, blue line) estimated from satellite data, as well as calculated heat stress expressed in degree-heating-weeks (DHW, red line and colored shading) at the Northern Mariana Islands "virtual station." The arrow denotes the approximate time of the 2017 FDM survey.

On average across the island, 49.9% of coral colonies analyzed in photoquadrats were completely bleached (Table 5, Figure 8). Many colonies that were not completely bleached were partially bleached (mottled) or paling. Overall, 80.1% of corals around the island exhibited some form of bleaching (Table 5).

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 habitats surveyed around the island. The "(Not ID'd)" row represents the overall percentage of coral colonies that were not identified to species or genus during our initial analysis, and therefore did not receive a condition score either. 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	*48.1%*	*47.1%*	*50.1%*	*55.3%*	*48.7%*	49.9%
Mottled	*12.1%*	*18.8%*	*16.6%*	*11.2%*	*3.0%*	12.3%
Pale	*15.9%*	*19.7%*	*17.6%*	*8.0%*	*29.7%*	18.2%
Some Bleaching	76.1%	85.6%	84.3%	74.5%	81.4%	80.1%
Diseased	*1.1%*	*0%*	*0%*	*0%*	*0.9%*	0.4%
Broken	*0%*	*0%*	*0%*	*2.3%*	*0%*	0.5%
Healthy	*28.6%*	*16.2%*	*17.7%*	*25.2%*	*18.2%*	21.2%
(Not Identified)	*(33%)*	*(21%)*	*(22%)*	*(18.6%)*	*(19.4%)*	

Euphllia spp., species from the Favid Family including *Favia spp*. and *Favites spp*., *Galaxea spp*., *Goniopora spp*., *Leptoria spp*., *Montastrea valenciennesi*, and *Platygyra spp.* appeared to be generally healthy and for the most part did not present with bleaching symptoms. Some *Acropora spp*. individuals and massive *Porites spp.* appeared to be somewhat resistant to bleaching as well, with some colonies appearing with normal coloration. The condition of individual coral genera or species could be explored quantitatively with additional resources; for instance, in Habitat 5, 98% of *Pocillopora spp.* corals were 100% bleached and 0% were healthy, but only 62% of *Porites* were 100% bleached, and 38% were recorded as healthy. Additional analysis along these lines is anticipated during a subsequent reporting effort.

Only a few coral fragments were observed (Figure 9). 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 natural impacts, and not from training activities.

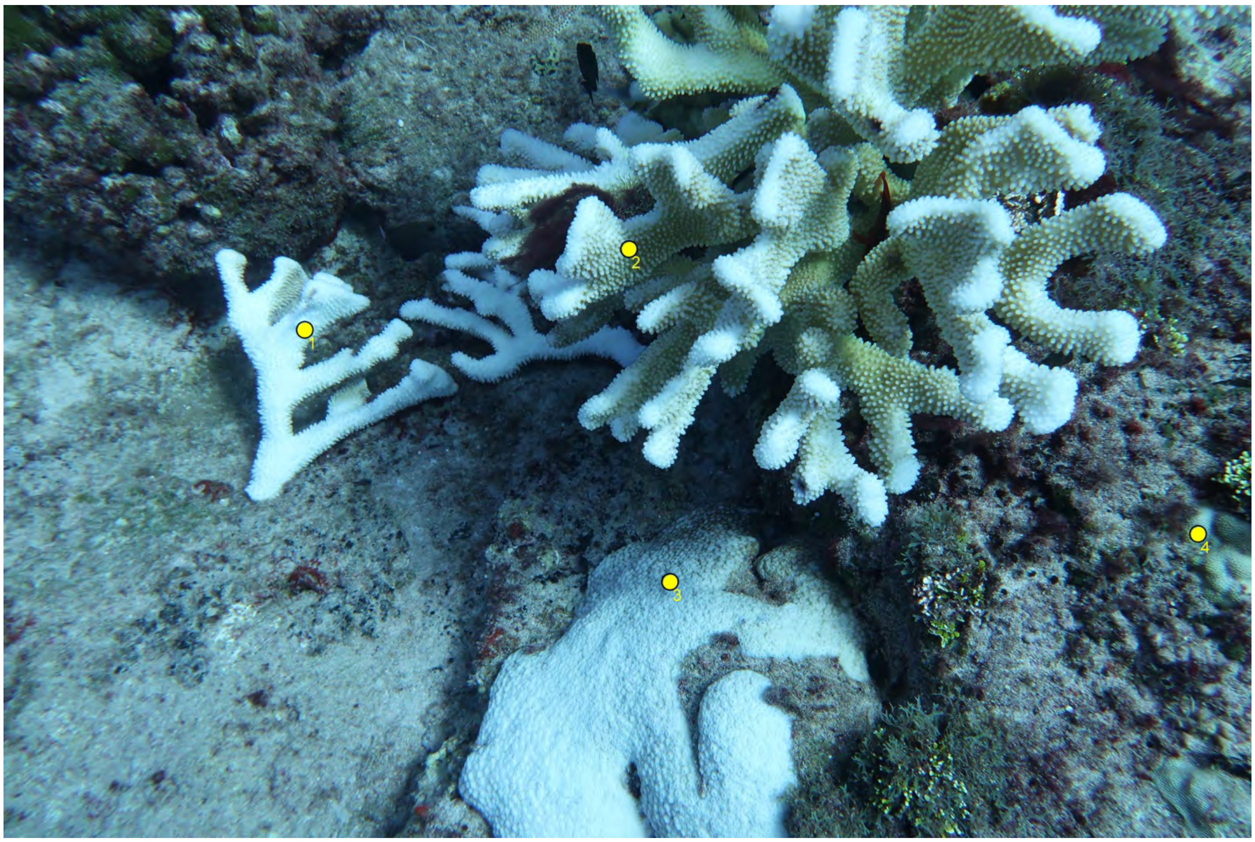


Figure 9: Representative observation of coral breakage (photoquadrat IMG_3639). The yellow dots were placed to number all coral colonies for identification. This allowed multiple scientists to refer directly to the same coral colony for identification confirmation.

Very little disease was observed, with only 0.4% of colonies in the photoquadrats exhibiting an unidentified disease. 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 remnants of what appeared to be fossilized gray coral colonies; the authors believe this was caused by overgrowth of the coral-killing sponge, *Terpios hoshinota*. An example patch is shown in Figure 10.

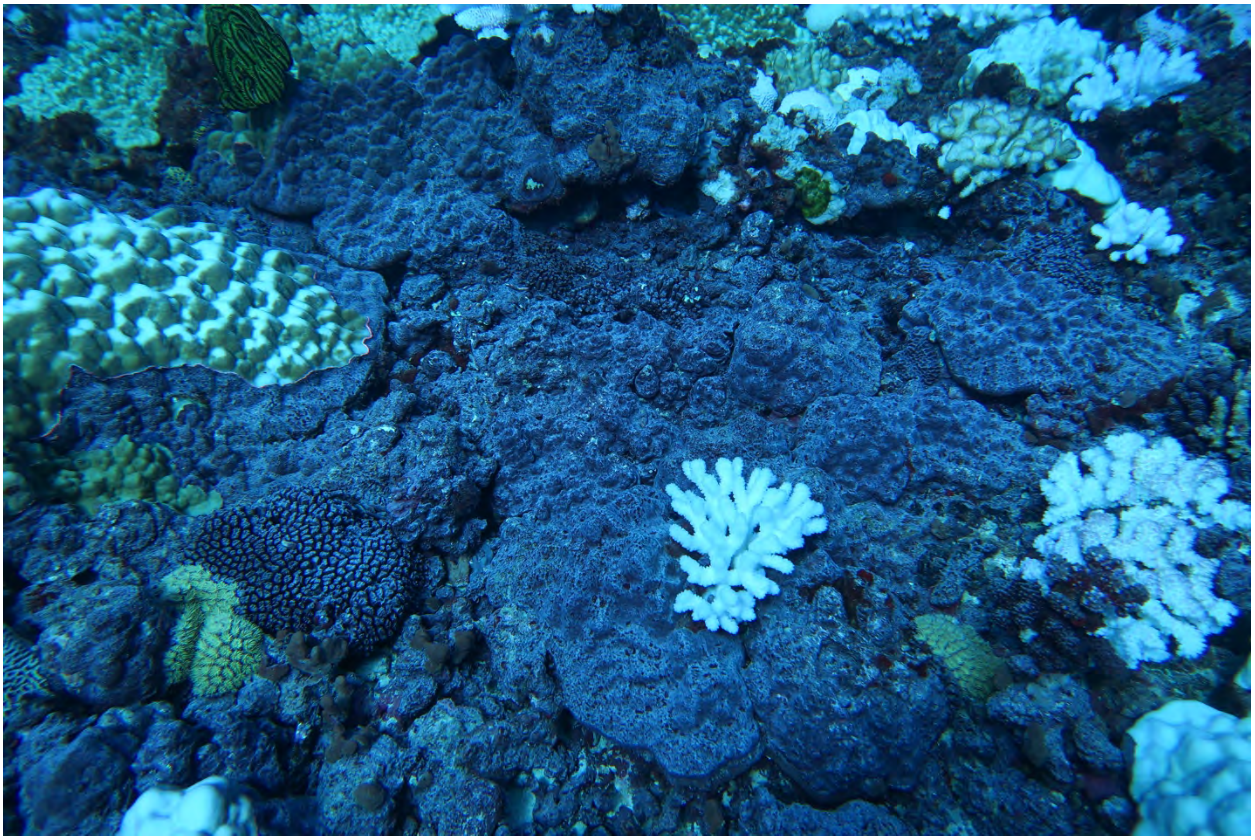


Figure 10: Photoquadrat showing likely coral overgrowth by the sponge Terpios hoshinota (gray surfaces). The massive Porites colony on the left edge of the photograph shows two flanks where the sponge has started to grow up over the living, but bleached coral.

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 11). 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 11: Recently dead Acropora sp. *coral with cyanobacteria on skeleton and surrounding reef*

No fish, crab or lobster traps were sighted. No nets, or 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 very fresh ordnance item was observed, a 50-caliber brass cartridge case; that case was also the only small item observed. All other items were 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 other bombs were classified as "fresh" because they had little marine growth on them. 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 may be significant. Figure 12 illustrates typical old ordnance items observed during the 2017 FDM survey, and Figure 13 presents a map of all observed and photographed ordnance items.

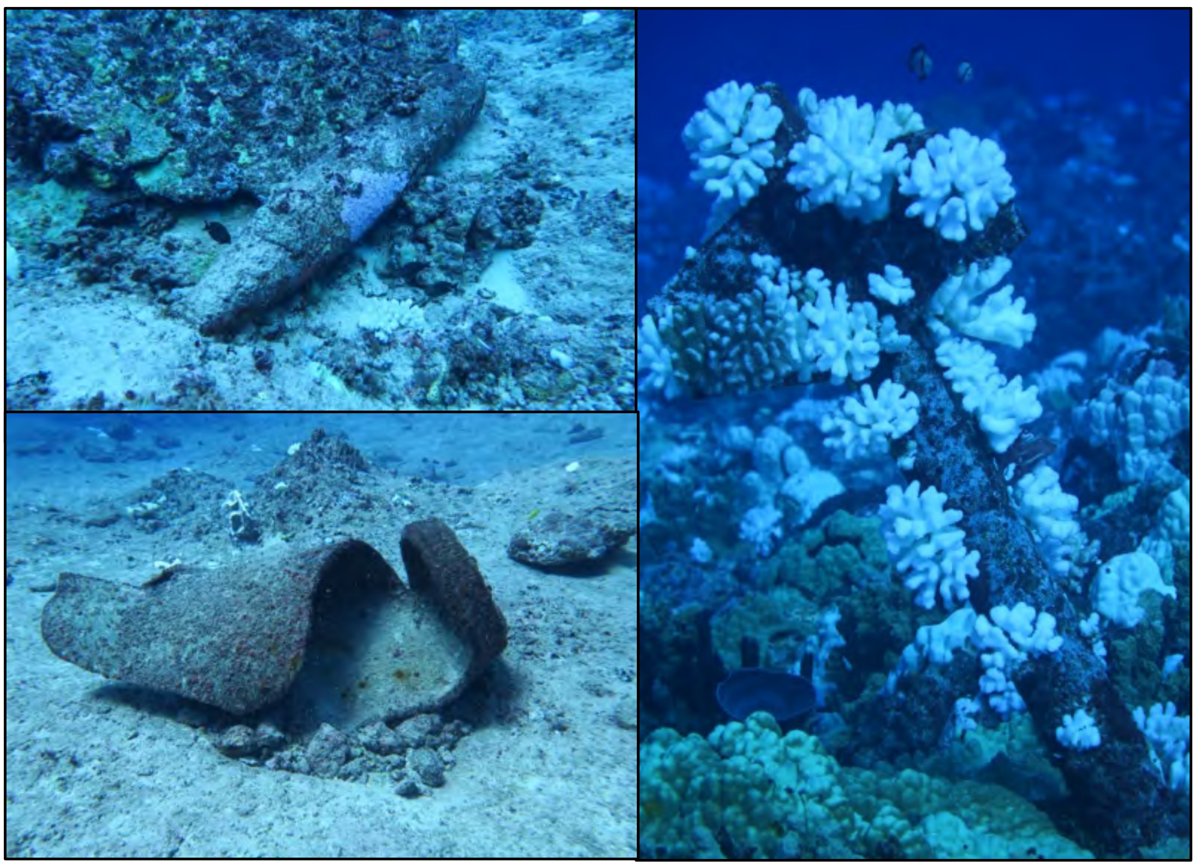


Figure 12: Representative examples of ordnance observed at FDM in 2017.

Final

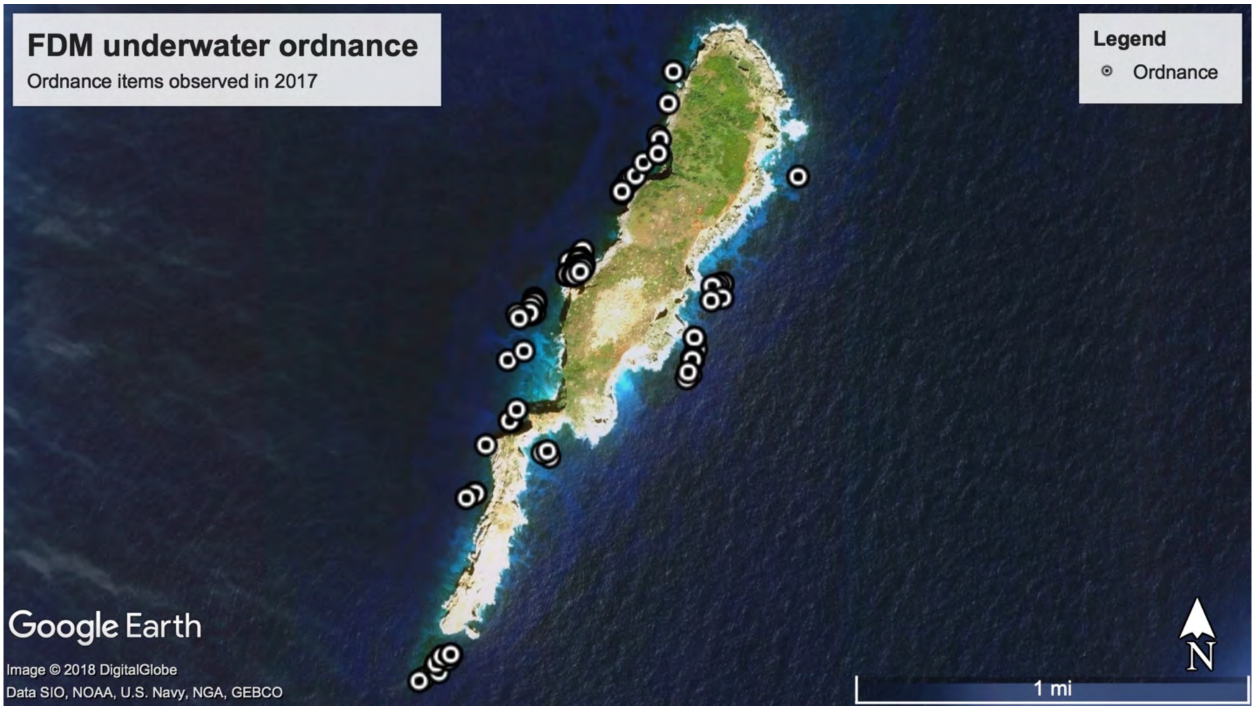


Figure 13: Map of locations of georeferenced photos of observed ordnance.

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 14). 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 proposed for ESA listing at the time of the survey, 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 *Tridacna squamosa*) were observed incidentally during this survey (Figure 15). Those two species have been observed during previous surveys conducted by SDS scientists. The 2001-2004 surveys conducted by other scientists list observations of *Tridacna maxima* and *T. squamosa*, but not *T. gigas* (Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). Counts of giant clams were not included in the scope of work for this project. The largest specimen was seen below the maximum depth of that dive, and was estimated to have a shell length of 75 cm.

Final

Figure 14: Turtle observed during sighting number 3.

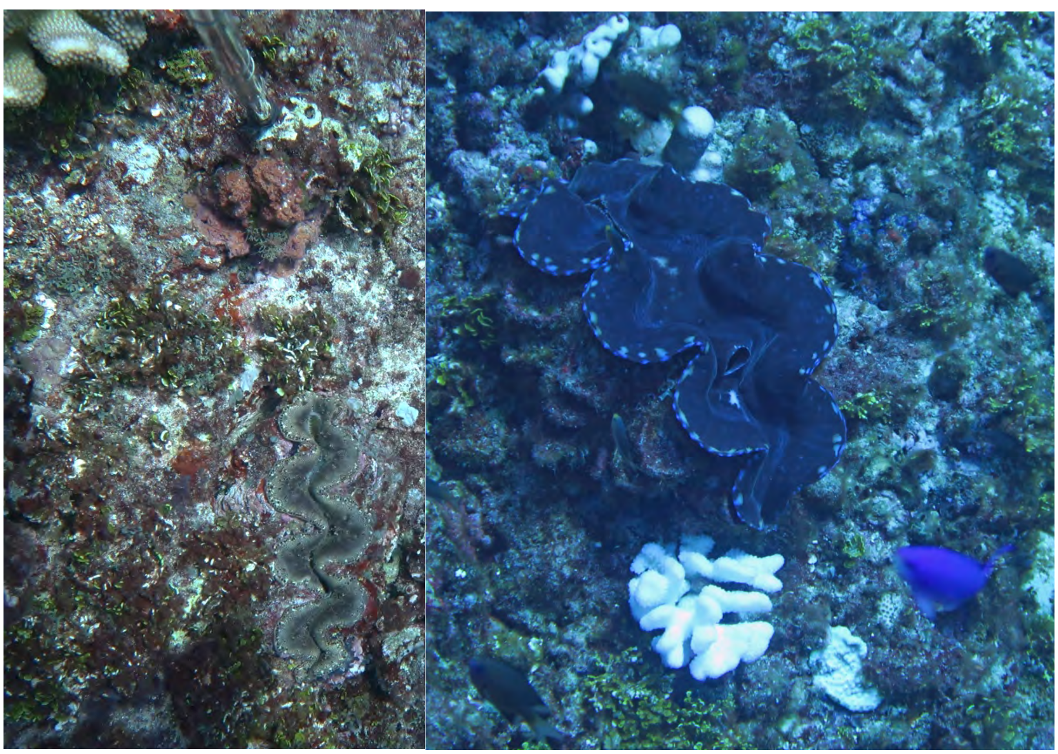


Figure 15: (Left) Example of Tridacna squamosa observed during survey (cropped from photoquadrat number 3560). (Right)Example of Tridacna gigas observed during survey (cropped from non-photoquadrat image 1686).

Other observations

Opportunistic observations of selected fishery target fishes (FTF) were recorded, although this task was not in the scope of work. 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. 2010, Pavlowich 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. Figures 16 & 17 illustrate an FTF and Non-FTFs photographed during this survey.

Figure 16: Nearshore Fishery Target Species Yellowsaddle goatfish (Parupeneus cyclostomus).

Figure 17: Near shore Non-Fishery Target species: (left) Blackblotched stingray (Taeniura meyeni) and (right) Arc-Eyed Hawkfish (Paracirrhites arcatus).

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Discussion

[G1] ESA-listed corals

In the 2003 and 2004 surveys, the ESA-listed coral *Acropora globiceps* was recorded on two individual dives as being "rare" (<5 colonies). In addition, corals that look very similar to *A. globiceps*, *A. gemmifera* and *A. humilis*, were recorded as being rare or occasional (5-15 colonies on a dive; Belt Collins 2001, 2003; The Environmental Company 2004, 2005). However, in the 2017 survey, while one confirmed *A. globiceps* was observed, no *A. gemmifera* were recorded, and *A. humilis* was only recorded in one photograph (Figure 18). *Acropora* corals are the most biodiverse genera in the Pacific, and *Acroporids* 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* and 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, or could be the result of differing survey methodologies or locations, or even observer error in species identifications during earlier surveys. 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 these field identifications.

Figure 18: A. humilis*, a species that often looks similar to the ESA-listed* A. globiceps

[G2] Percent coral coverage

There is only one area around FDM, habitat area 5W, 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 densely covered areas, are too sparse to be considered true coral reefs. 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 4). 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 (DoN 2016). That map was prepared 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 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 not key objectives during any of the previous surveys. The primary objective of these surveys was to look for and assess potential ordnance impacts.

A number of corals identified so far in the images collected during the 2017 survey were not included in the species list compiled from these earlier surveys (Appendix C; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005). The coral species list prepared for this report should be considered tentative, because further analysis is ongoing for a subsequent report; however this effort identified 71 species from 23 genera, while the compiled species list from surveys completed between 2001-2004 included 109 species from 36 genera (Appendix C). Some of the species observed during the 2017 survey were not identified during prior surveys; likewise, some of the species observed previously were not observed in 2017. This could be because the earlier surveys did not completely assess the coral diversity at FDM (each subsequent survey found an additional ~5-7 species not seen previously; Belt Collins Hawaii 2001, 2003; The Environmental Company 2004, 2005), because the coral community has changed with time, or because each survey assessed slightly different portions of the island. However, as stated above, identification of corals to species in the Indo-Pacific is particularly challenging, and it is possible that species identifications completed in the field during prior surveys were not accurate, and/or that the authors of this report have made some errors in identification from photographs collected in 2017. Further efforts to refine species identifications in the 2017 photographs is ongoing at this time.

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). The island hosts a large number and diversity of corals that can be challenging to differentiate from photographs. Assessment of species from the collected imagery is ongoing and will be detailed in a subsequent report.

Smith and Marx (2009) reported that *Pocillopora* was the dominant scleractinian coral genus at FDM in general, while *Porites* genera corals were particularly abundant in the area of the island containing habitat H5, which is consistent with the findings in 2017 as well (46.6% of all colonies in photoquadrats; Figure 6).

The following contains some limited observations on the coral species observed during the 2017 survey. Further coral species observations will be provided in a subsequent report. Of the massive *Porites spp.* observed, *Porites lobata*, *P. lutea* and *P. solida* were present, as well as *P. evermanni,* which neither Veron (2000) nor Randall (1995) show as present in the Mariana Archipelago. However, there is a move in the coral taxonomic field to replace *P. lutea* with *P. evermanni*, at least in many locations (D. Fenner, personal communication). *P. australiensis* is also likely present, based on tentative identifications.

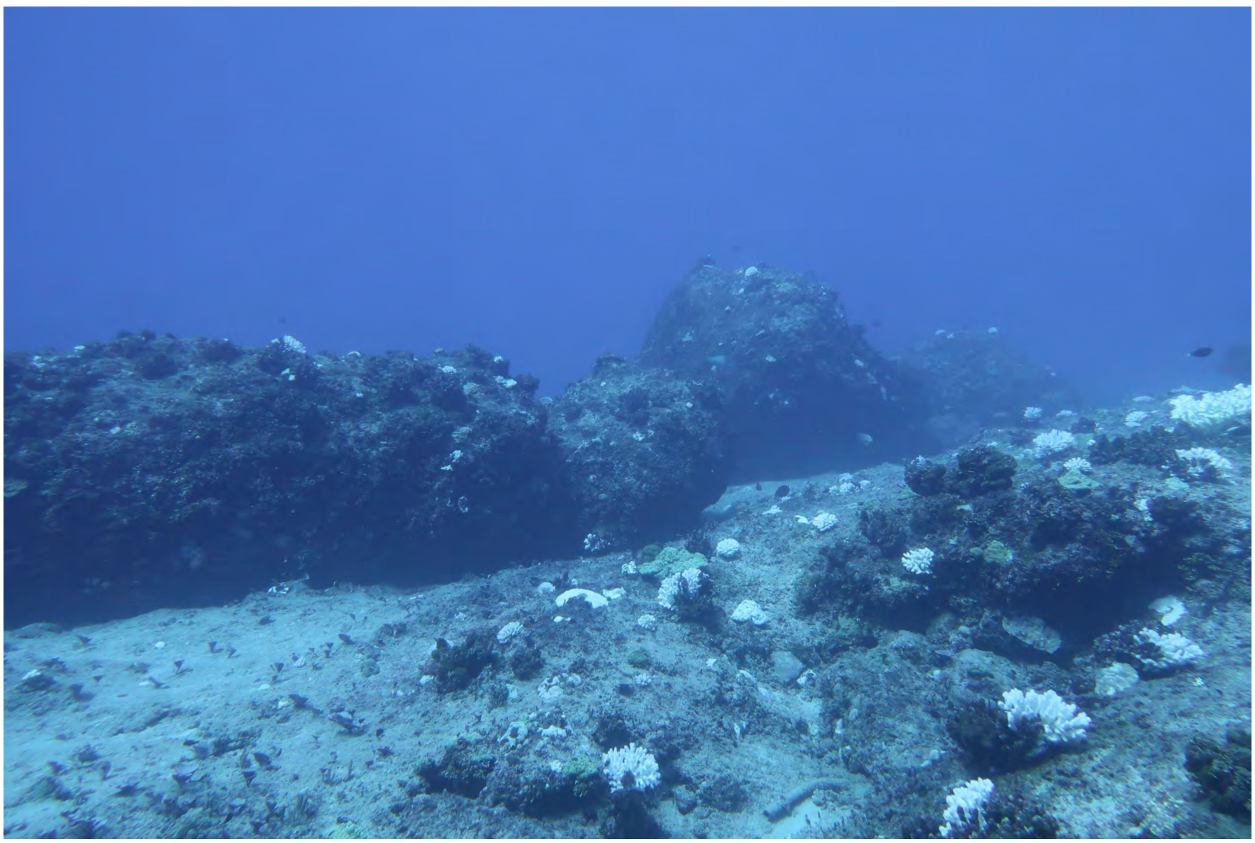

Figure 19: Example of cliff blocks eroded off of the island and now hosting corals.

It is possible that two entirely new species of *Acropora* were captured in the photos. Describing these new species to science would require a significant amount of future work.
Three *Acropora* sp. specimens were recorded only once; that is, 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 are unlikely to be new to science, they were not able to be identified to species for this report.

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. With further time devoted to species-level data analysis for this project, this could be quantified.

Subjectively, the *P. meandrina/verrucosa/elegans* complex suffered the most severe bleaching of any of the corals observed, with an estimated >90% moderately to severely bleached. Species-level data analysis will allow quantification and comparison of bleaching comparison by species and provide insight into expected changes in coral community composition given expected increasing bleaching events with time.

Only two species from the Family Agariciidae were positively identified: *Pavona dueredeni* and *P. diffluens* (an ESA-listed species). 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 Fenner believes the photographs taken at FDM in 2017 are very likely *P. diffluens* (personal communication).

The family Faviidae had the largest number of genera (8) and the largest number of species confirmed (12), with several unidentified species (at least 3). Given additional time, it is expected that these challenging species will be positively identified.

[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.

In prior survey years, coral condition was assessed as generally good-excellent. The exceptions to this were significant breakage after typhoon TingTing passed over FDM in 2004, a bleaching event in 2007 that killed approximately 15% of the *Pocilloporid* corals, and an infestation of the coral barnacle *Cantellius sp.* in 2012. Subsequent surveys showed that coral recovered from Typhoon TingTing in 2004 and the bleaching event in 2007. This was evident from the survey observations after those occurrences that showed nearly all corals observed as healthy, including *Pocilloporids*. The 2017 survey did not detect any of the coral barnacles (*Cantellius sp*.). However, in the area most heavily impacted by *Cantellius sp*. (southern tip of FDM) there were substantial numbers of *Pocilloporid* skeletons (*P. meandrina* complex) that were estimated to have been dead for 3 to 6 years, suggesting that the *Cantellius sp.* snails, 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 significant 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 heartening 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, just over 80% of corals exhibited some level of bleaching or paling). This suggests that at least some corals are likely to survive this bleaching event, although significant mortality of *Pocilloporid* corals, which were subjectively the most strongly affected genera, may occur and may result in species-composition changes with time. 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.

Pocillopora eydouxi specimens showed subjectively less bleaching than the *P. meandrina/verrucosa/elegans* complex. Many colonies of *P. eydouxi* showed little or no signs of bleaching, even those located next to severely bleached members of the *P. meandrina/verrucosa/elegans* complex. This same pattern was observed during the 2007 bleaching event (Smith and Marx 2009), and could be related to different symbiodinium clades hosted by each species (eg. Sampayo et al. 2008), or differences in physiology between species that affect susceptibility to heat stress (eg. Baird et al. 2009).

[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 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 diffluens* coral colonies observed, the only other ESA-listed species observed were three green and one unidentified swimming turtles. 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 of those species have been observed at FDM: *Tridacna gigas (*observations by authors and personal communication with Balazs 2016) and *Tridacna squamos* (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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Final

Appendix A. 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.

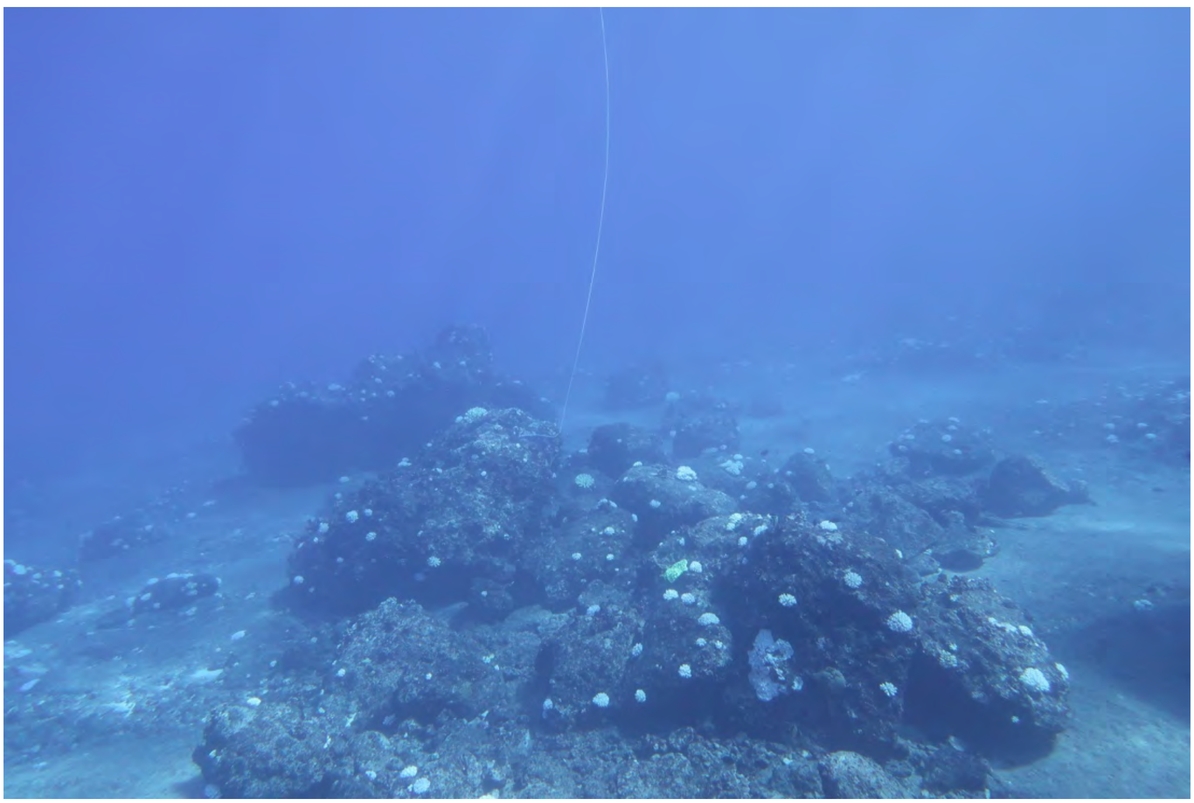
Date	Site	Dive	Maximum depth (ft)	Start Time	Transects	Photo Numbers
9/27	H2NW	1	70	9:39	3	3067 - 3133
9/27	H3NW	2	35	10:46	4	3134 - 3257
9/27	H2W	3	50	3:06	2	3259 - 3338
9/27	H2W	4	35	4:08	4	3339 - 3450
9/28	H3NE, H4NE	1	70	8:57	3	3451 - 3522
9/28	H2S, H4S	2	35	10:13	4	3523 - 3611
9/28	H3E	3	50	2:27	4	3612 - 3705
9/28	H2E	4	35	3:32	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	4:08	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	2:57	4	4142 - 4228
10/1	H5W	1	70	8:35	2	4229 - 4263
10/1	H2N	2	40	10:11	4	4264 - 4341

Appendix B. 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.

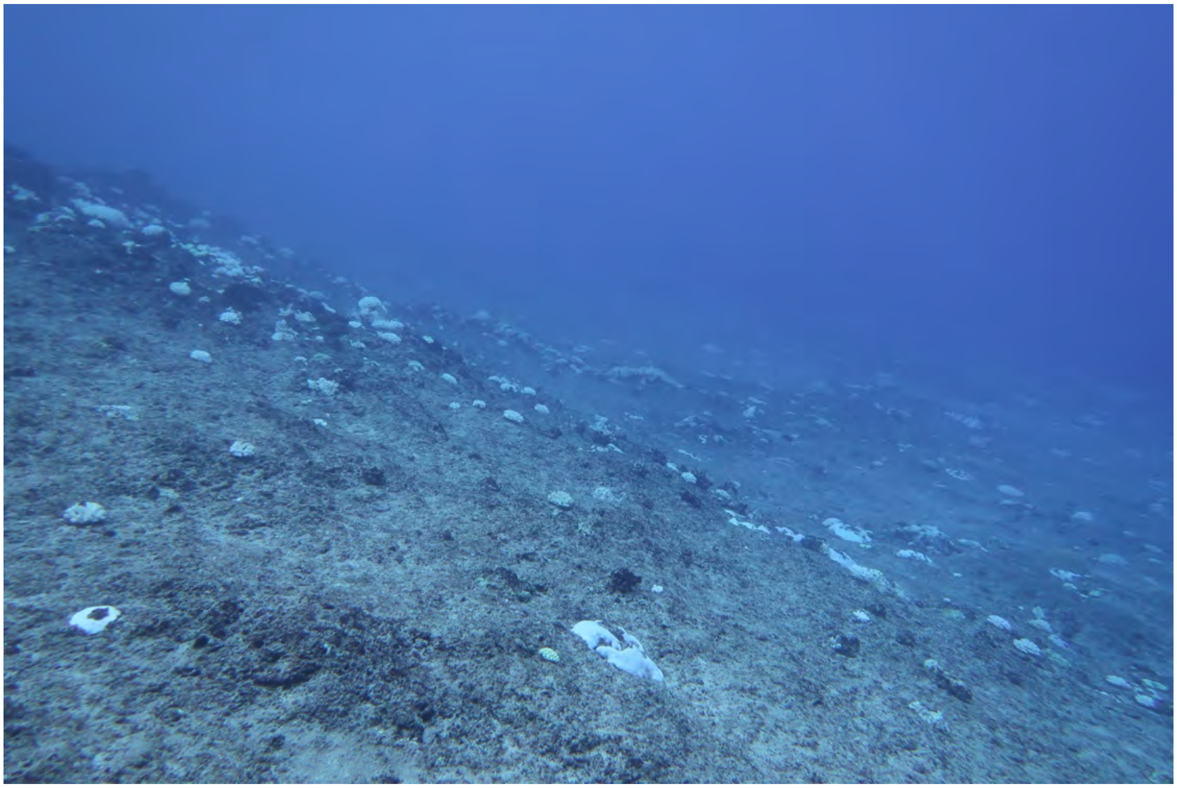
H2

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 is comprised of mostly hardbottom (mean cover 67.5% in 2017) with generally low live coral cover (mean 15% cover in 2017, up from <5% during earlier surveys).



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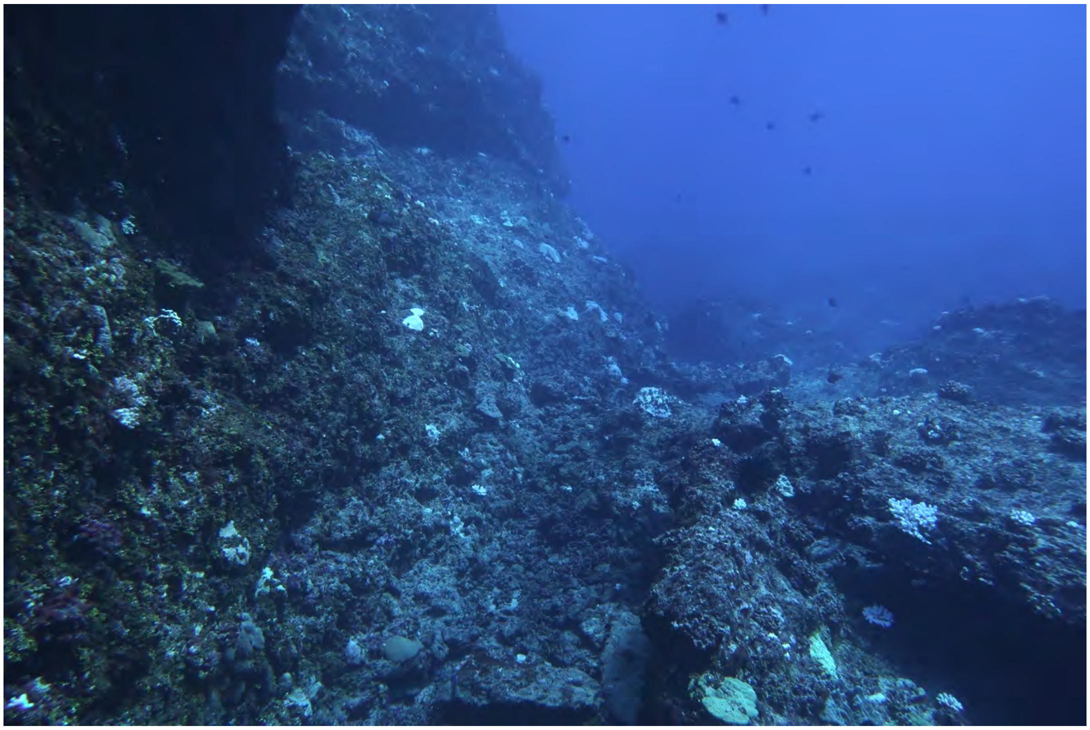
H4

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).



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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 C. Scleractinian coral species lists.

Numbers in the table below indicate number of individual species (not colonies/individuals) observed. Species records highlighted in gray were identified in 2017 but not during previous surveys. Species records highlighted in blue were identified in prior surveys, and may be identified from the 2017 dataset, but some specimens from that genus were not yet identified to species for this report. 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.

Coral species	Positively identified 2017	Field identified prior surveys
Acanthastrea echinata	0	1
Acanthastrea brevis	1	0
Acropora austera	0	1
Acropora aculeus	0	1
Acropora bifurcata	0	1
Acropora caroliniana	0	1
Acropora cerealis	1	1
Acropora circulosa	1	0
Acropora digitifera	0	1
Acropora gemmifera	0	1
*Acropora globiceps**	1	1
Acropora granulosa	0	1
Acropora humilis	1	1
Acropora hyacinthus	0	1
Acropora nasuta	1	1
Acropora palifera	0	1
Acropora robusta	0	1
Acropora samoensis	0	1
Acropora sarmentosa	0	1
Acropora tenuis	1	1
Acropora valida	0	1
Acropora likely new species 1	1	0
Acropora likely new species 2	1	0
Acropora sp. (eight different species not yet identified; possibly in list above)	8	0

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Coral species	**Positively identified 2017**	**Field identified prior surveys**
Alveopora fenestrata	0	1
Astreopora eliptica	0	1
Astreopora gracilis	0	1
Astreopora cucullata	1	0
Astreopora myriophthalma	1	1
Astreopora ocellata	1	1
Astreopora randalli	1	1
Astreopora sp. Additional	1	0
Coscinaraea columna	0	1
Cyphastrea chalcidicum	0	1
Cyphastrea serailia	0	1
Cyphastrea microphthalma	0	1
Cyphastrea sp.	1	0
Diploastrea heliopera	0	1
Echinopora lamellosa	0	1
Euphyllia glabrescens	0	1
Euphyllia cristata	1	0
Euphyllia sp.	1	0
Favia favus	0	1
Favia marshae	0	1
Favia maritima	1	1
Favia matthaii	1	1
Favia palida	1	1
Favia speciosa	0	1
Favia stelligera	1	1
Favia sp.	1	1
Favites abdita	0	1
Favites flexuosa	1	1
Favites halicora	0	1
Favites pentagonia	0	1
Favites russelli	0	1
Fungia scutaria	0	1
Galaxea fascicularis	1	1

Final

Coral species	**Positively identified 2017**	**Field identified prior surveys**
Galaxea sp.	1	0
Gardineroseris planulata	0	1
Goniastrea palauensis	0	1
Goniastrea pectinata	1	1
Goniastrea retiformis	1	1
Goniopora lobata	0	1
Goniopora minor	1	0
Goniopora sp.	1	0
Herpolitha limax	1	1
Hydnophora microconos	0	1
Leptastrea bottae	0	1
Leptastrea inaequalis	0	1
Leptastrea purpurea	1	1
Leptastrea transversa	1	1
Leptoseris mycetoseroides	0	1
Leptoria phrygia	0	1
Leptoria sp.	1	0
Lobophyllia hemprichii	1	1
Lobophyllia corymbosa	1	0
Merulina ampliata	0	1
Montastrea curta	0	1
Montastrea valenciennesi	1	1
Montipora aequituberculata	0	1
Montipora caliculata	0	1
Montipora danae	0	1
Montipora foveolata	0	1
Montipora grisiea	0	1
Montipora hoffmesiteri	0	1
Montipora monasteriata	0	1
Montipora spumosa	0	1
Montipora tuberculosa	1	1
Montipora undata	1	0
Montipora venosa	0	1

Final

Coral species	Positively identified 2017	Field identified prior surveys
Montipora verrilli	0	1
Montipora verrucosa	0	1
Montipora sp. Unidentified	1	1
Oulophyllia crispa	0	1
Pachyseris speciosa	1	0
*Pavona diffluens**	1	0
Pavona duerdeni	1	1
Pavona minuta	0	1
Pavona maldivensis	0	1
Pavona varians	0	1
Pavona venosa	1	1
Platygyra daedelea	1	1
Platygyra pini	1	1
Platygyra ryukyuensis	0	1
Platygyra sinensis	0	1
Platygyra sp.	1	0
Plesiastrea versipora	0	1
Pleurogyra sinuosa	0	1
Pocillopora ankeli	1	0
Pocillopora brevicornis	1	0
Pocillopora capitata	1	0
Pocillopora damicornis	1	1
Pocillopora elegans	1	1
Pocillopora eydouxi	1	1
Pocillopora verrucosa	1	1
Pocillopora meandrina	1	1
Pocillopora woodjonesi	0	1
Pocillopora sp.	1	0
Porites australiensis	1	1
Porites evermanni	1	0
Porites lichen	0	1
Porites lobata	1	0
Porites lutea	1	1

Coral species	Positively identified 2017	Field identified prior surveys
Porites murrayensis	0	1
Porites rus	1	1
Porites solida	1	1
Porites vaughani	0	1
Psammocora haimeana	1	1
Psammocora obtusangula	0	1
Psammocora superficialis	0	1
Scaphophyllia cylindrica	0	1
Siderastrea savignyana	0	1
Stylophora pistillata	0	1
Tubastrea faulkneri	0	1
Turbinaria stellulata	1	0
Total	*71*	*109*

Final

Appendix D. Coral community composition charts including unidentified species classes
The Y-axis of each chart represents percent coral counts for all data from that habitat area. The X-axis displays the coral genera identified in this study plus the three classes of unidentified corals: Xa, may be able to identify with further effort; Xb, not possible to identify due to poor image quality; Xc likely able to be identified with further effort.

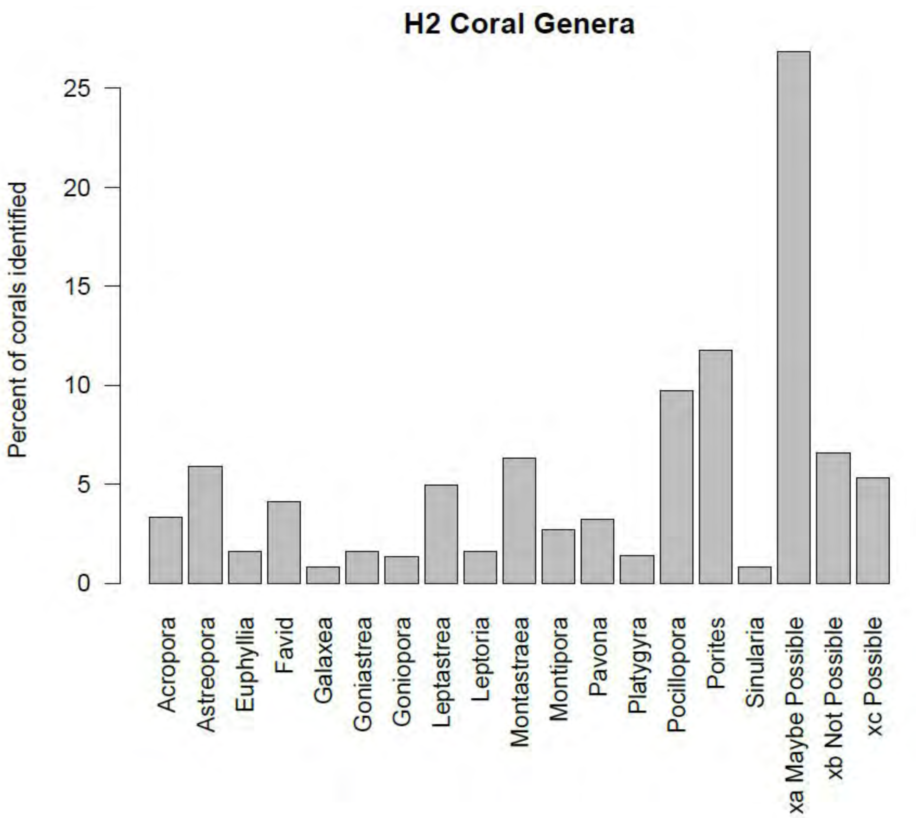

Figure 20: H2 coral community composition by genera based on coral counts.

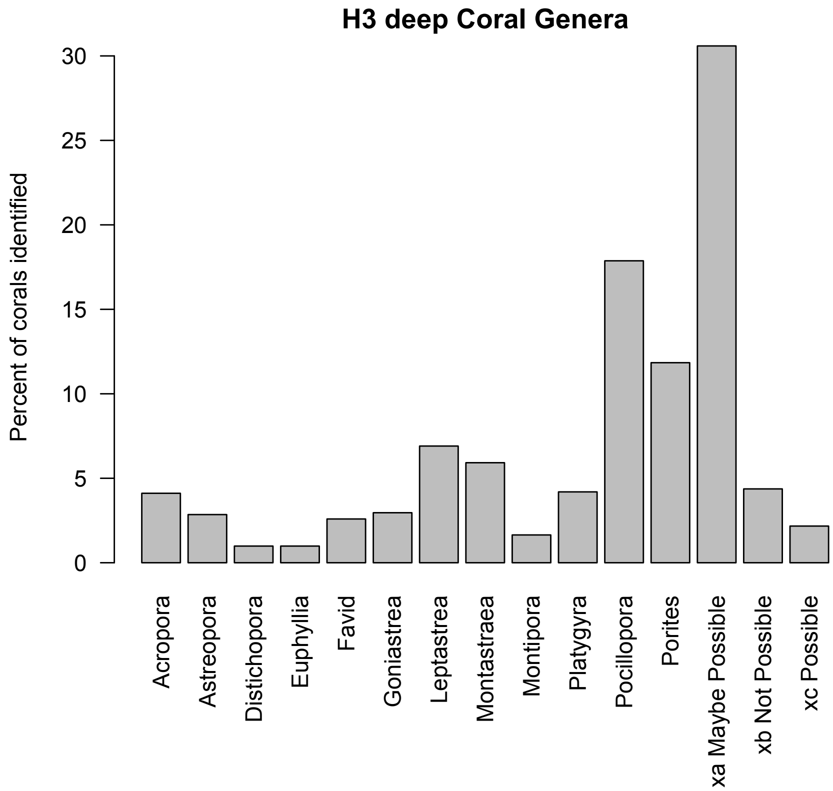

Figure 21: H3D coral community composition by genera based on coral counts.

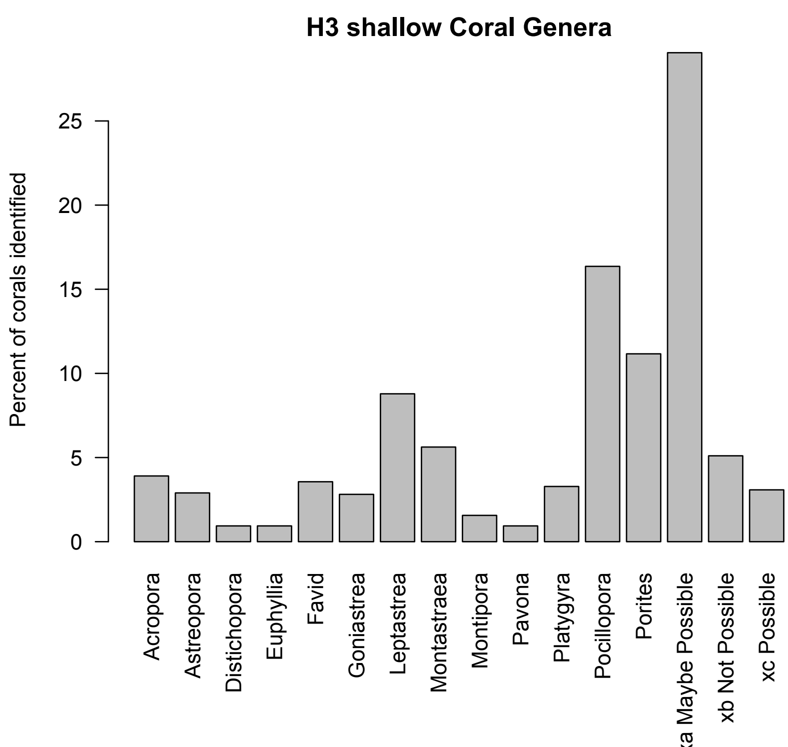

Figure 22: H3S coral community composition by genera based on coral counts.

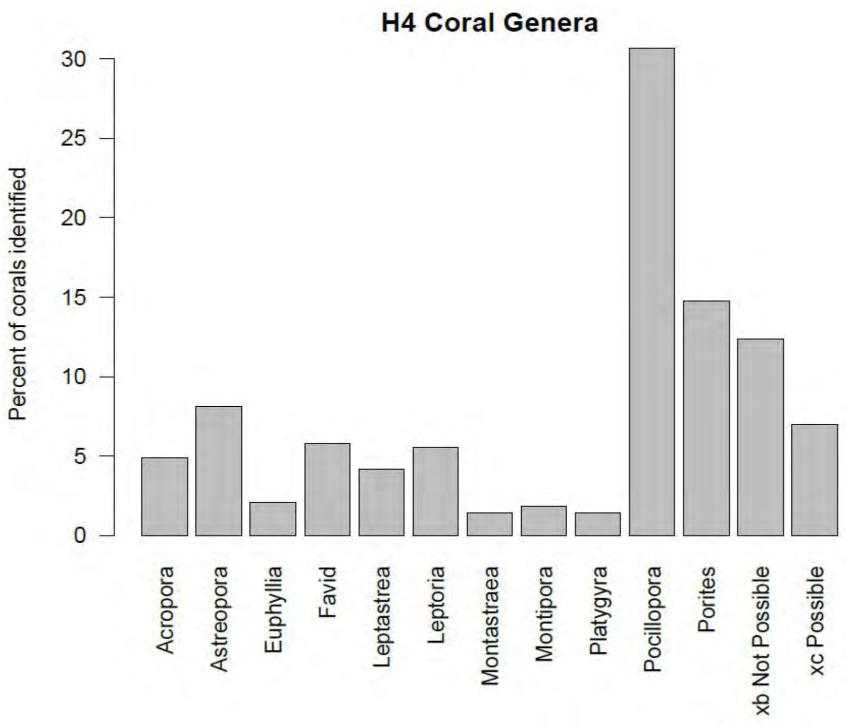

Figure 23: H4 coral community composition by genera based on coral counts.

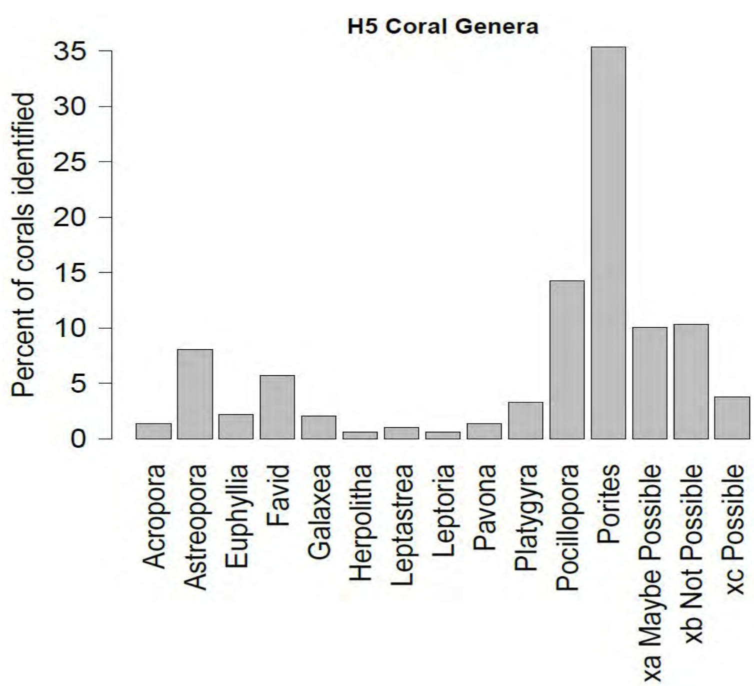

Figure 24: H5 coral community composition by genera based on coral counts.

Final

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

	Size of ordnance			Condition of ordnance				
Item #	Large	Small	Fragment	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	