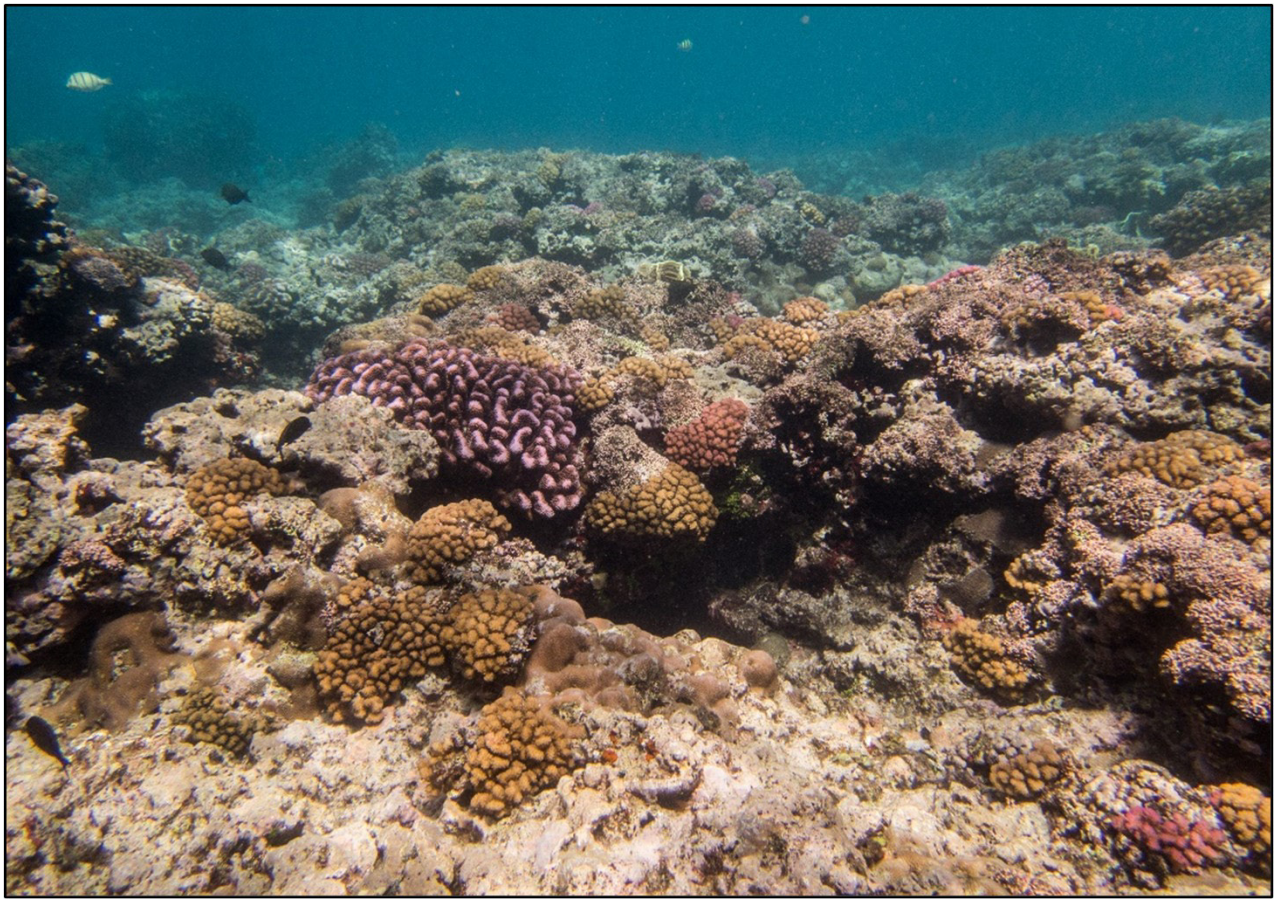
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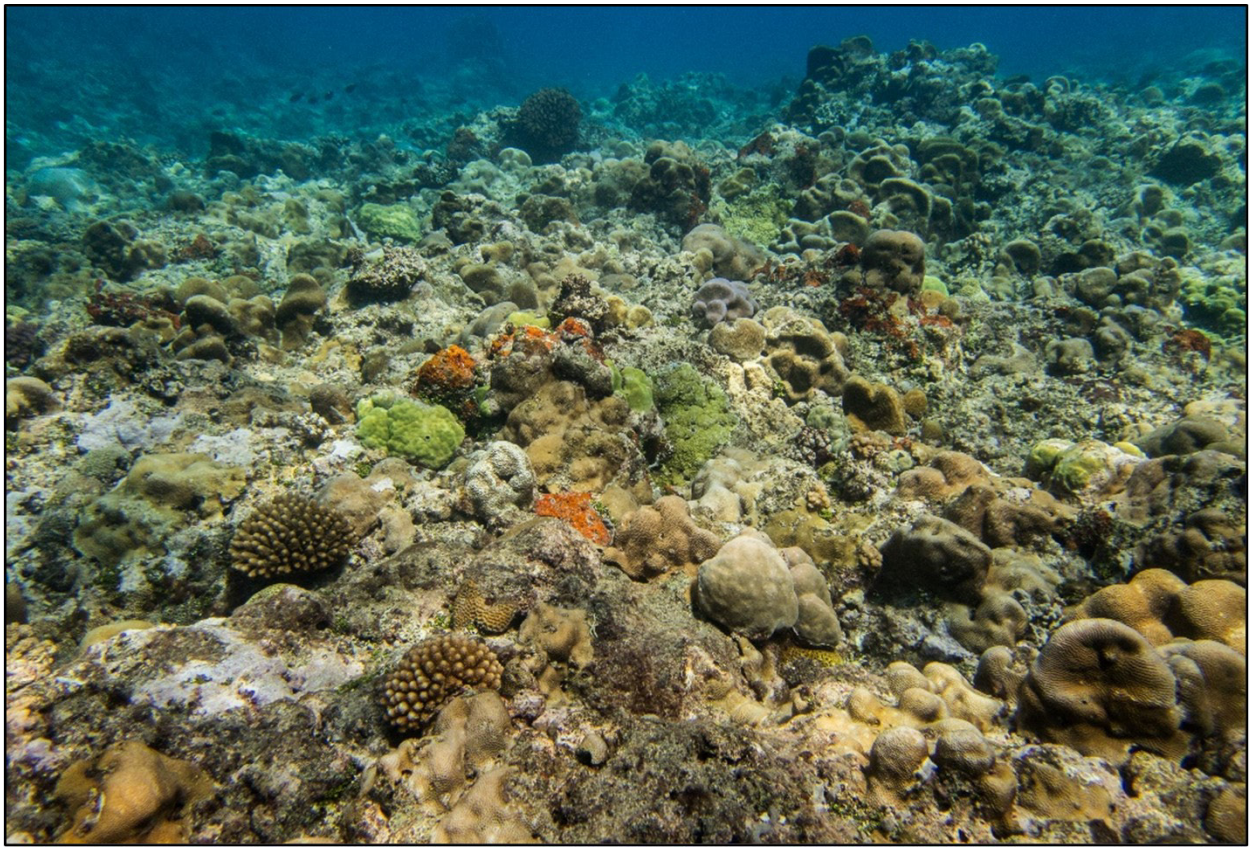
Natural Resource Stewardship and Science

Coral Species Inventory at War in the Pacific National Historical Park

Final Report

Natural Resource Report NPS/WAPA/NRR—2024/2619





ON THIS PAGE
A large number of coral species were observed at diversity survey site Asan-CS-4, a site also notable for hosting the largest number of *Acropora globiceps* colonies, two of which are visible at the lower left.
Photo: David Burdick

ON THE COVER
Relatively high cover of several *Pocillopora* species along the upper reef front at site Agat-CS-2.
Photo: David Burdick

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Final Report

Natural Resource Report NPS/WAPA/NRR—2024/2619

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January 2024

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National Park Service
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Fort Collins, Colorado

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Executive Summary

The War in the Pacific National Historical Park (WAPA), a protected area managed by the National Park Service (NPS), was established "to commemorate the bravery and sacrifice of those participating in the campaigns of the Pacific Theater of World War II and to conserve and interpret outstanding natural, scenic, and historic values on the island of Guam." Coral reef systems present in the park represent a vital element of Guam's cultural, traditional, and economical heritage, and as such, are precious and in need of conservation. To facilitate the management of these resources, NPS determined that a scleractinian (stony coral) species survey was necessary to establish a baseline for existing coral communities and other important factors for conservation. EnviroScience, Inc. performed a survey of stony coral species, coral habitat, and current evidence of stressors at WAPA's Hågat and Asan Units in 2022. This report summarizes these findings from a management perspective and compares its findings to previous survey data from 1977 and 1999 (Eldridge et al. 1977; Amesbury et al. 1999).

WAPA is located on the tropical island of Guam, located on the west-central coast of the island, and encompasses 2,037 acres. Underwater resources are a significant component of the park, as 1,002 acres consists of water acres. The park is comprised of seven units, of which two of these, the Hågat and Asan Beach Units, include all the oceanic water acres for the park. The Hågat Beach Unit (local spelling, formerly known as "Agat") is located at the south-west portion of the park and consists of 38 land acres and 557 water acres (NPS 2003). The Asan Beach Unit consists of 109 acres of land and 445 water acres (NPS 2003).

A current baseline for existing coral communities and other important factors for conservation necessitates the need for up-to-date data on the location, presence, relative abundance, and present health of corals. Park managers need this updated data to determine where and how to best focus conservation priorities and identify restoration opportunities. Management actions in park reef areas informed by this inventory included identifying locations where there were: high rates of sedimentation; high coral biomass; rare or threatened species, with a priority given to species endemic to Guam and listed as "threatened" under the U.S. Endangered Species Act (ESA; *Acropora globiceps*, *A. retusa*, *A. speciosa*, and *Seriatopora aculeata*); coral persistence and decline, disease and/or nuisance species, including the crown-of-thorns starfish (*Acanthaster cf. solaris,* "COTS") and the sponge *Terpios hoshinota*; and bleached areas.

All work carried out was in accordance with the NPS statement of work (SOW) requirements, which involved a quantitative inventory using both new and pre-existing transects. The resulting transects totaled 61 (including the four from the 1999 study), each measuring 50 meters in length and distributed across depths of up to 50 feet. Divers took photo-quadrat samples covering an area of approximately 9 m^2, encompassing 50 photo-quadrats of dimensions 0.50 m x 0.36 m (n=50). The collective area surveyed across all 61 transects amounted to ~549 m^2. Additionally, a qualitative search was conducted to enhance documentation of coral species that have limited distribution and might not be captured by transects, along with identifying harmful species and stressors. Timed

roving diver coral diversity surveys were carried out at a total of 20 sites occurring within the waters of WAPA, including eight sites at the Hågat unit and 12 sites at the Asan unit.

The findings from this report reveal significant disparities in benthic cover compositions between Hågat and Asan units. The Hågat unit exhibits high abundances of turf algae and unconsolidated sediment while the Asan beach unit presents a different scenario, with hard coral as the dominant benthic cover, followed closely by crustose coralline algae (CCA). The Asan unit is also more difficult to access from shore or boat relative to Hågat which provides that unit some protection from human influences. The Asan beach unit's prevalence of hard coral, CCA, and colonizable substrate suggests a more favorable environment for reef growth and the potential benefits of maintaining robust coral cover in the area. These distinct differences in benthic communities highlight the contrasting ecological dynamics and habitats of the two study areas.

Across both Hågat and Asan beach unit transects, a total of 56 hard coral species were recorded from 27 genera, with 44 species recorded from the Hågat unit and 48 species recorded from the Asan unit. Of the four historical transects surveyed in the Asan unit from 1999, three experienced declines in percent coral cover (17.38-78.72%), while the fourth had an increase (10.98%). During the timed roving diver coral diversity surveys, a total of 245 hard coral species, including 241 scleractinian coral species representing 49 genera and 4 non-scleractinian coral species representing 4 genera were recorded. Uncertainties related to coral identification, unresolved boundaries between morphospecies, differences in taxonomists' perspectives, and the rapidly evolving state of coral taxonomy have significant implications for species determinations during coral diversity surveys. While the recent surveys have provided valuable insights into coral diversity in WAPA waters, ongoing taxonomic research and collaboration among experts will be essential to obtain a more comprehensive and accurate understanding of coral biodiversity in the region.

Of the several ESA coral species that were searched for among the Hågat and Asan beach units, *Acropora retusa* was the only coral species found among quantitative transects (n=2) and *A. globiceps* was observed during coral diversity surveys. *Acropora speciosa*, which was dominant in the upper seaward slopes in 1977, is now conspicuously absent from all the surveys conducted in 2022 (Eldredge et al., 1977). The disappearance and reduction of these once-dominant species underscores the urgency of implementing conservation measures to safeguard the delicate balance of Guam's coral reefs and preserve the diversity and ecological integrity of these invaluable marine ecosystems.

Other formerly common or locally abundant species were infrequently encountered during the diversity surveys, including *Acropora monticulosa*, *A.* sp. “obtusicaulis”, *A. palmerae*, *Stylophora* sp. “mordax”, *Montipora* sp. “pagoensis”, and *Millepora dichotoma*. Significant bleaching-associated mortality was recorded for these species, most of which are restricted to reef front/margin zones exposed to moderate-to-high levels of wave energy.

Sedimentation was present in both Hågat and the Asan units, though it was more commonly encountered in Hågat transects. While significant portions of the reef area within the WAPA Hågat unit are in poor condition due to a variety of stressors, some areas still hosted notable coral

communities, which should be a potential focus for park management to prevent further degradation. There is a need for more effective management of point source pollution concerns, particularly when subpar wastewater treatment or runoff from areas with potential pollution or sediment-laden water is flowing from nearby terrestrial environments. Future monitoring efforts should aim to establish a framework that facilitates a deeper understanding of potential point source pollution incidents. This would empower park managers to collaborate with adjacent communities, both within and outside of park boundaries, to mitigate the localized impacts of pollution (McCutcheon and McKenna, 2021).

COTS were encountered during transect surveys as well as in coral diversity surveys. including along the upper reef front/reef margin at site Agat-CS-2. The frequency of these observations, particularly in the WAPA Hågat unit and where stress-susceptible corals are already uncommonly encountered, raise concern about the ability of the populations of these coral species to recover following acute disturbance events, and calls in to question the ability of some of these species to persist in WAPA waters, and in Guam's waters more broadly. More frequent crown-of-thorns control efforts, even if only a handful of sea stars are removed during a single effort, may be required to prevent further loss to vulnerable species.

There were several documented incidents of *Terpios hoshinota* covering large sections of branching coral in the reef flat along transects, but it is still unclear how detrimental this sponge is to the overall reef system. There is a concern that elevated levels of organic matter and nutrients in the water, such as those resulting from sewage discharge or stormwater runoff, could lead to increased *Terpios* populations (De Voogd et al. 2013). Consequently, it is important to track populations in known areas of sedimentation and poor water quality.

The presence of unique species at single survey sites within the study areas underscores the ecological importance of certain locations. Some species are known to occur in other locations in Guam, while a few may be limited to specific sites within WAPA waters. These differences are likely influenced by environmental and biological factors such as poor water quality, severe heat stress events, chronic predation by crown-of-thorns sea stars, disease, and reduced herbivore populations. These factors collectively shape the condition of the benthic community, leading to variations in species distribution and abundance across the study sites. Documenting coral stress and identifying potentially harmful species allows for proactive management strategies to prevent the establishment of nuisance or detrimental species while populations are still manageable. Updated data on the location, presence, relative abundance, and health of corals is essential for park managers to prioritize conservation efforts and identify restoration opportunities effectively.

Observations from this report raise concerns about the health and resilience of coral ecosystems in the Hågat unit and emphasize the need for knowledge of local factors that shape benthic community structure. Understanding the drivers responsible for these variations is crucial for effective conservation and management strategies to preserve the ecological balance and overall health of coral reefs in both units. Continued monitoring efforts will be critical in assessing long-term trends and changes in benthic cover and enabling adaptive management approaches to safeguard these valuable marine ecosystems in the face of ongoing environmental challenges.

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List of Acronyms

AIC	Akaike Information Criterion
ANOSIM	Analysis of similarity
CCA	Crustose Coralline Algae
CL	Colin Lock
COTS	Crown-of-Thorns Starfish
DB	David Burdick
df	Degrees of freedom
DNRGPS	Department of Natural Resources Global Positioning System
ESA	Endangered Species Act
GPS	Global Positioning System
GLTMP	Guam Long-term Coral Reef Monitoring Program
IUCN Red List	International Union for Conservation of Nature Red List of Threatened Species
km^2	Square kilometers
KMZ	Keyhole Markup Zipped
m	Meters
NCRMP	National Coral Reef Monitoring Program
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
PERMANOVA	Permutational multivariate analysis of variance
SE	Standard Error
SIMPER	Similarity percentages
WWII	World War II
WAPA	War in the Pacific National Historical Park
WoRMS	World Register of Marine Species

Introduction

The War in the Pacific National Historical Park (WAPA), a protected area managed by the National Park Service (NPS), was established "to commemorate the bravery and sacrifice of those participating in the campaigns of the Pacific Theater of World War II and to conserve and interpret outstanding natural, scenic, and historic values on the island of Guam." Coral reef systems present in the park represent a vital element of Guam's cultural, traditional, and economical heritage, and as such, are precious and in need of conservation. To facilitate the management of these resources, NPS determined that a scleractinian (stony coral) species survey was necessary to establish a baseline for existing coral communities and other important factors for conservation. EnviroScience, Inc. performed a survey of stony coral species, coral habitat, and current evidence of stressors at WAPA's Hågat and Asan Units in 2022. This report summarizes these findings from a management perspective and compares its findings to previous survey data from 1977 and 1999 (Eldridge et al. 1977; Amesbury et al. 1999).

Study Area

WAPA is located on the tropical island of Guam, approximately 13 degrees north of the equator and about 3,300 miles southwest of Hawaii. The park, established in 1978, is located on the west-central coast of the island and encompasses 2,037 acres. Underwater resources are a significant component of the park, as 1,002 acres consists of water acres.

Guam boasts a diverse range of reef types, encompassing fringing reefs, patch reefs, submerged reefs, offshore banks, and barrier reefs. Among these, fringing reefs dominate, encircling a substantial portion of the island (Randall and Eldredge, 1976). The park is comprised of seven units, each location containing historical features associated with World War II (WWII). Two of these, the Hågat and Asan Beach Units, include all the oceanic water acres for the park. These beaches were strategically important during WWII as docking points for the US Navy and as battlefields between American and Japanese troops. After preservation of these units in 1978, both beaches suffered additional damage from Typhoon Paka in 1997 and Super-Typhoon Pongsona in 2002. Since Typhoon Mawar occurred in 2023, coral assemblages in the park waters have likely undergone changes, although a formal assessment of the damage has not been conducted yet.

Hågat Beach Unit

The Hågat Beach Unit (local spelling, formerly known as "Agat" [old spelling retained in site data]) is located at the south-west portion of the park, west of the Village of Hågat, and consists of 38 land acres and 557 water acres (Figure A-1 of Appendix A) (NPS 2003). The unit is bordered by Apaca point to the north (including the delta of the Namo River and two large coral outcroppings), Highway 2 on the east, and Bangi Point and Alutom Island to the south. The western boundary in Hågat Bay is drawn along the coral reef system from Bangi Point and north to Apaca Point.

Asan Beach Unit

The Asan Beach Unit is located in the northern portion of the park, three miles west of Hagåtña, the capitol of Guam, and consists of 109 acres of land and 445 water acres (Figure A-1 of Appendix A) (NPS 2003). The unit is bordered by the western edge of Adelup Point on the east, Marine Drive to

the south, and extends to western edge of Asan Point along the Matgue River. The northern boundary is drawn across Agana Bay extending west from Adelup Point to Asan Point.

Previous Research

Previous coral inventories were conducted at Hågat Bay in 1977 (Eldridge et al. 1977) and both Hågat and Asan Bays in 1999 (Amesbury et al. 1999). In 1977, a total of 164 species from 46 genera were recorded from Hågat Bay (Eldridge et al. 1977). After updating to currently utilized names via Dave Burdick's expertise, the species total was adjusted to 153 species in 49 genera. The species list included those found in qualitative 20-minute searches along each 100-meter transect in addition to quantitative analysis using a modified point-centered quarter technique. Percent coral cover from 12 transects ranged from 1% to 59.8%, with a mean of 25% coral cover overall. The study differentiated between four biotopes: Biotope I (Fringing Reef-flat Platform and Associated Facies, no transects due to low coral); Biotope II (Reef Margin and Associated Facies, mean coral cover of 51.7%); Biotope III (Reef Front and Associated Facies, mean coral cover of 35.18%); and Biotope IV (Upper Seaward Slopes, Shallow Submarine Terraces, and Associated Facies, mean coral cover of 26.8%). ESA species *Acropora speciosa* (recorded as *Acropora rambleri* and *A. rayneri*) was found to be a dominant species found in the upper seaward slopes. Other dominant species included *Porites lutea* in reef flats and reef fronts and *Goniastrea retiformis* in the reef margin. *Acropora humilis* is listed as 'Near Threatened' in the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List). This species, originally identified as *Acropora ocellata,* was also observed occasionally in the reef margin.

The 1999 study, which examined both Hågat and Asan Bays, reported a total of 57 species observed from 22 genera (Amesbury et al. 1999). After updating to currently utilized names via Dave Burdick's expertise, the species total was adjusted to 42 species in 21 genera. The authors attributed the lower diversity of coral species encountered compared to the 1977 study to the point quarter method, which involved more intensive observations within a relatively small area in the transect. From 24 transects in Hågat Bay, coral cover ranged from <0.01% to 19.05%, with an overall mean of 5.81%. Transects located in the fore reef had a mean coral cover of 10.13%, and those in the reef flat yielded a mean coral cover of 1.49%. Asan Bay coral cover (n=16) ranged from <0.01 to 84.33%, with an overall mean of 22.27%. Transects located in the fore reef had a mean coral cover of 30.88%, and those in the reef flat yielded a mean coral cover of 13.66%. *Leptastrea purpurea* was found to be the most abundant coral species, occurring at most sites. Large colonies of *Porites rus* and *Porites cylindrica* contributed to low coral diversity in areas where these species occurred.

Coral Stressors

In recent decades, Guam has witnessed a gradual decline in health, diversity, and productivity of coral, primarily attributed to local anthropogenic stressors such as recurring crown-of-thorn starfish (COTS) outbreaks, deteriorating water quality, and increased fishing pressure due to population growth (Burdick et al. 2008). Additionally, the effects of climate change, particularly the shifts in sea temperatures, have become an additional global stressor on Guam's coral reefs, resulting in abrupt and devastating consequences in some areas (Raymundo et al. 2019). In the last decade, severe coral bleaching events occurred in 2013, followed by subsequent events in 2014, 2016, and 2017. The

frequency of such events raises significant alarm among natural resource managers regarding the likelihood of rapid and substantial coral cover loss, shifts in species composition, and overall decline in reef health (Raymundo et al. 2019).

Approximately 1.8 square kilometers (km^2) of Asan Bay falls within the boundaries of the WAPA Asan Unit and serves as a sink for material from the Asan watershed (Minton 2005). Over the past 25 years, anthropogenic activities in the adjacent watersheds, such as intentionally set wildfires, construction, and agriculture, have increased (National Resource Conservation Service 1996). These practices lead to accelerated erosion by removing vegetation that stabilizes the soil. While rainfall on Guam typically results in sediment discharge from rivers to coastal waters, the island is also susceptible to typhoons every 2-3 years, causing heavy precipitation that rapidly transports unstabilized soil to the coast and impacts WAPA's nearshore reefs (Minton et al. 2007, Porter et al. 2005).

The indigenous crown-of-thorns starfish (*Acanthaster* cf. *solaris*) are vital for maintaining coral diversity on reefs due to their preference for consuming fast-growing coral species (Birkeland and Lucas 1990). Under certain conditions, COTS populations can rapidly expand to unsustainable densities, defined as exceeding 30 individuals per hectare (0.3 individuals/$100m^2$), leading to devastating outbreaks that can decimate reefs (Birkeland 1982, De'ath et al. 2012). In some instances, these outbreaks may lead to the extinction of local coral species, and under severe conditions, they can lead to the complete eradication of living coral populations on a reef (Moran 1986). Since at least 2003, chronic widespread outbreaks of COTS have been observed on the coral reef areas of Guam, primarily affecting the east and northwest coasts (Burdick et al. 2008).

The encrusting cyanobacteriosponge *Terpios hoshinota* also poses a threat to Guam's coral reefs. It was first identified in Guam in the 1970s (Rützler and Muzik 1993) and is now spreading in coral reefs across the northwestern Pacific (Liao et al. 2007). The sponge encrusts a range of hard substrates, including live coral, and under certain conditions, it can undergo significant outbreaks leading to the mass mortality of corals and other organisms residing in the affected areas (Bryan 1973; Rützler and Muzik 1993).

Project Objectives

A current baseline for existing coral communities and other important factors for conservation necessitates the need for up-to-date data on the location, presence, relative abundance, and present health of corals. Park managers need this updated data to determine where and how to best focus conservation priorities and identify restoration opportunities. Management actions in park reef areas informed by this inventory included:

- Identification of locations where high rates of sedimentation and nutrient run-off may affect coral reproduction and growth. This data will be used to identify and curtail terrestrial and aquatic activities contributing to such increased inputs.
- Delineation of zones with high coral biomass that may be sensitive to diving, snorkeling, or fishing, which may warrant new visitor management techniques.

- Identification of the occurrence of rare and threatened coral species and actions to prevent negative impacts. Several coral species endemic to Guam (*Acropora globiceps*, *A. retusa*, *A. speciosa*, and *Seriatopora aculeata*) listed as "threatened" under the U.S. Endangered Species Act (ESA) were prioritized during the survey.
- Identifications of locations where coral has persisted and declined significantly over the last two decades. This included analysis of historical and observational data to determine the former and current occupancy of coral species in the park.
- Identifications of presence and relative abundance of any emerging diseases or species that could negatively impact coral health and warrant active management. This information was used to determine coral disease intervention strategies and prevent the establishment of harmful species invasion while populations are still relatively small and easy to manage. These included nuisance r range expanding species that may be detrimental to coral survival such as the crown-of-thorns starfish (*Acanthaster cf. solaris*) and the sponge *Terpios hoshinota*.
- Determination of the full impacts of bleaching in a variety of coral habitats at different depth contours, which will allow the evaluation of the need to protect rare corals, develop, and plan for a coral nursery and outplanting program, and help with visitor use management.

Methods

All the work carried out was in accordance with the NPS statement of work (SOW) requirements, which involved a quantitative inventory using both new and pre-existing transects. Additionally, a qualitative search was conducted to enhance documentation of coral species that have limited distribution and might not be captured by transects, along with identifying harmful species and stressors.

Quantitative Surveys

Sampling Design

The original project goal was to re-survey 40 transects from the 1999 Amesbury et al. survey and add 21 additional transects in coral habitat mapped by NOAA, for a total sample effort of 61 transects. In drawing those additional transects, it became apparent that only 4 of those transects had 20% coral cover (Asan 1, 2, 7, and 9; Figures A-2a and A-2b of Appendix A). Because the goal of this project was to obtain information on rare or sensitive corals and their stressors, it was decided to only resurvey the four 1999 transects with at least 20% coral cover in 1999. Fifty-seven new transects would be drawn to retain the same total effort.

The sample draw was performed by the NPS Inventory Team, with feedback from both park and contractor staff. The sample frame for these new transects was the intersection of polygons labeled 10-50% or 50-90% coral in the NOAA habitat map, and the boundaries of the Asan and Hågat marine areas extended further offshore, except left or right along the shoreline. Transects were allocated proportionally to the target area in Asan and Hågat; the Asan sample frame area was 46.33 ha and the Hågat area was 72.54 ha, resulting in 22 new transects in Asan and 35 in Hågat.

Within these Hågat and Asan sample frames, an equal probability spatially balanced sample (Stevens and Olsen 2004) was generated via the spsurvey R package version 5.3 (Dumelle et al. 2022) and R version 4.1.3 (R Core Team 2022). Both sample and oversample sites were drawn with a minimum 50m separation so the resulting transects could not overlap. The results of the sample draw were centers for samples; the geometry of each sample was a 1m wide by 50m long transect. Because the target area had a strong depth gradient, random orientation of transects anchored at those points would generate data that was difficult to summarize or interpret, as some transects would have substantial variation in depth while others would not. To account for this, transects were oriented along the depth contours, minimizing within-transect depth variation and acquiring larger sample sizes for a specific depth in a specific area. Transects centered on each sample point were generated by using a 5x5 pixel (25m x 25m) neighborhood on the bathymetry raster to calculate aspect, then orienting the transect perpendicular to the direction of greatest slope.

The resulting transects totaled 61 (including the four from the 1999 study), each measuring 50 meters in length and distributed across depths of up to 50 feet (15.2 m; Table 1).

Table 1. WAPA quantitative site locations in the Hågat and Asan beach units. Coordinates reflect the start point of the transect.

Site	Reef Zone	Latitude	Longitude	Date Surveyed
Agat-001	Fore Reef	13.386812	144.653572	24-Apr-22
Agat-002	Bank/Shelf	13.401818	144.658970	24-Apr-22
Agat-003	Reef Flat	13.382787	144.652022	25-Apr-22
Agat-004	Bank/Shelf	13.381438	144.645463	22-Apr-22
Agat-005	Reef Flat	13.391037	144.659189	26-Apr-22
Agat-006	Bank/Shelf	13.403344	144.658466	21-Apr-22
Agat-007	Bank/Shelf	13.385031	144.647796	22-Apr-22
Agat-008	Bank/Shelf	13.378851	144.645028	22-Apr-22
Agat-009	Bank/Shelf	13.401257	144.656392	21-Apr-22
Agat-010	Bank/Shelf	13.402924	144.656946	21-Apr-22
Agat-011	Fore Reef	13.380185	144.645897	22-Apr-22
Agat-012	Fore Reef	13.385747	144.652113	25-Apr-22
Agat-013	Bank/Shelf	13.400762	144.659531	21-Apr-22
Agat-014	Bank/Shelf	13.398570	144.658032	24-Apr-22
Agat-015	Bank/Shelf	13.383755	144.647180	22-Apr-22
Agat-016	Bank/Shelf	13.386773	144.648482	24-Apr-22
Agat-017	Fore Reef	13.386805	144.652495	24-Apr-22
Agat-018	Fore Reef	13.401538	144.659173	24-Apr-22
Agat-019	Reef Flat	13.381431	144.650620	25-Apr-22
Agat-020	Bank/Shelf	13.380691	144.645259	22-Apr-22
Agat-021	Bank/Shelf	13.399932	144.656596	21-Apr-22
Agat-022	Bank/Shelf	13.404078	144.658203	21-Apr-22
Agat-023	Bank/Shelf	13.385154	144.647586	22-Apr-22
Agat-024	Bank/Shelf	13.376950	144.643973	22-Apr-22
Agat-025	Fore Reef	13.400766	144.660543	26-Apr-22
Agat-026	Bank/Shelf	13.402883	144.657880	21-Apr-22
Agat-027	Bank/Shelf	13.380112	144.645583	22-Apr-22
Agat-028	Fore Reef	13.385466	144.650024	24-Apr-22
Agat-029	Fore Reef	13.398850	144.660402	26-Apr-22
Agat-030	Bank/Shelf	13.400666	144.657175	21-Apr-22
Agat-031	Bank/Shelf	13.381650	144.645962	22-Apr-22
Agat-032	Bank/Shelf	13.386204	144.648621	24-Apr-22
Agat-033	Reef Flat	13.383652	144.652771	25-Apr-22
Agat-034	Fore Reef	13.403343	144.659580	24-Apr-22
Agat-035	Reef Flat	13.381537	144.649891	25-Apr-22

Table 1 (continued). WAPA quantitative site locations in the Hågat and Asan beach units. Coordinates reflect the start point of the transect.

Site	Reef Zone	Latitude	Longitude	Date Surveyed
Asan-001	Fore Reef	13.480589	144.705600	25-Jun-22
Asan-002	Reef Flat	13.477578	144.705539	27-Apr-22
Asan-003	Reef Flat	13.478045	144.721149	28-Apr-22
Asan-004	Reef Flat	13.476807	144.704562	27-Apr-22
Asan-005	Fore Reef	13.477205	144.717096	23-Apr-22
Asan-006	Reef Flat	13.478785	144.704073	27-Apr-22
Asan-007	Fore Reef	13.479652	144.719036	25-Jun-22
Asan-008	Reef Flat	13.476862	144.706019	25-Apr-22
Asan-009	Bank/Shelf	13.478881	144.709370	23-Apr-22
Asan-011	Fore Reef	13.480822	144.725528	25-Jun-22
Asan-012	Fore Reef	13.476463	144.716400	23-Apr-22
Asan-013	Reef Flat	13.477730	144.704515	27-Apr-22
Asan-014	Reef Flat	13.478422	144.723308	14-Aug-22
Asan-016	Reef Flat	13.474713	144.715254	14-Aug-22
Asan-017	Bank/Shelf	13.479748	144.708768	23-Apr-22
Asan-018	Fore Reef	13.477654	144.709716	25-Jun-22
Asan-020	Reef Flat	13.476555	144.704689	27-Apr-22
Asan-021	Fore Reef	13.479056	144.707214	23-Apr-22
Asan-022	Fore Reef	13.480434	144.720474	23-Apr-22
Asan-026	Bank/Shelf	13.478994	144.727207	28-Apr-22
Asan-037	Bank/Shelf	13.479509	144.708315	23-Apr-22
Asan-084	Bank/Shelf	13.479316	144.728233	28-Apr-22
Asan-H01	Bank/Shelf	13.482670	144.727166	23-Apr-22
Asan-H02	Bank/Shelf	13.482292	144.727833	23-Apr-22
Asan-H07	Reef Flat	13.476167	144.705500	25-Apr-22
Asan-H09	Bank/Shelf	13.482511	144.726667	23-Apr-22

Survey Protocol

The quantitative sampling took place between April 24 and August 14, 2022. The sites located seaward of the reef margin were surveyed using scuba equipment and accessed by a vessel, while the shallow reef flat sites were accessed from shore. Transect start points were identified and located using GPS coordinates, and each point was marked with a surface float.

Before submerging, the EnviroScience team ensured that the camera was correctly set and ready for underwater use. A photograph of the dive slate was captured before each dive, clearly labeled with the date/time, habitat type, and transect number (WAPA-001 through WAPA-061). One end of the

transect line was firmly fastened to a 5-pound dive weight to ensure stability. Following secure attachment, the diver proceeded along either a known depth contour or a known compass bearing, accurately unspooling 51 meters (m) of transect line. Subsequently, the line was pulled tight and securely tied off to another 5-pound dive weight. Divers dragged a reel with a surface float and Garmin eTrex 10 handheld GPS along the 50-m transect to record its exact location. Due to the drag acting on the line, the buoy with the GPS receiver was usually between ~2–8 m behind the divers, depending on depth. The offset position of the buoy in relation to the diver, and the ~5–10 m accuracy of the recreational grade GPS receiver is expected to result in an error radius around a photographed coral colony of between 5 and 12 m.

Photographs were captured using an Olympus Tough TG-6 waterproof camera housed in a Backscatter waterproof housing, paired with a Backscatter M52 wide-angle lens and two Backscatter Mini Flash 1 Underwater Strobe MF-1. Prior to initiating the photo-quadrat sampling on each transect, the diver ensured proper camera settings for the underwater conditions and took four landscape-oriented photographs at the zero-meter mark. The initial photo faced magnetic north (0°), followed by three consecutive photos at 90-degree intervals in a clockwise direction. These initial photographs offered a general overview of the habitat and relief at each location.

Along the transect, at 1-meter intervals, starting from the zero-meter mark and concluding at the 49-meter mark, 50 photo-quadrats were photographed from a perpendicular angle, positioned at a height of 0.5 meters above the substrate, in accordance with the method outlined by Brown et al. (2011). To maintain uniformity in photographing, a monopod was utilized to maintain distance from the reef.

Each transect covered a total sampled area of approximately 9 m^2, encompassing 50 photo-quadrats of dimensions 0.50 m x 0.36 m (n=50). The collective area surveyed across all 61 transects amounted to ~549 m^2.

Furthermore, additional data were collected alongside the transect, including: 1) documentation of coral species and health, including any signs of disease, bleaching, or "recent coral mortality"; 2) identification of invasive or nuisance species, such as harmful algal blooms, invasive algae, sponges, and corallivores like crown-of-thorns; and 3) recording and mapping of other potential stressors, such as sedimentation (observed as a thin layer of sediment and substantial turf), or indicators of stress impacting coral assemblages, such as pigmentation response (observed as red spots on corals). Divers also took supplementary (non-quantitative) photographs of notable coral species from the transect area that occurred outside of the photo-quadrats. These corals were noted as present and described as part of the qualitative results, but were not included in the point count data.

Data Analysis

After data collection in the field, all datasheets were digitized by scanning. The collected data were consolidated and transcribed into digital databases to facilitate analysis and statistical evaluations. In addition to the newly acquired data, information from previous studies (Eldridge et al. 1977; Amesbury et al. 1999) was similarly transcribed from the original publications into databases for comparative purposes. To ensure consistency, coral names were standardized according to Dave Burdick’s expertise.

Image Analysis

In this study, transect images were analyzed using CoralNet, an online platform that employs artificial intelligence and machine learning techniques. Specifically, each image was subjected to analysis using 51 randomly generated points. Initially, the analysis involved human examination of all 51 points, but subsequently, a hybrid human observer-CoralNet robot approach was adopted, incorporating a 95% accuracy threshold. To mitigate inter-observer bias, a coral ID expert collaborated with a coral ID specialist, who underwent training to ensure consistent assessments. The coral ID expert meticulously reviewed all data generated by the coral ID specialist as well as evaluated the accuracy of all robot-generated identifications until independently verifying the target 95% accuracy rate. This comprehensive methodology was implemented to elevate the reliability and precision of the coral identification process, capitalizing on the advantages offered by the CoralNet platform.

Benthic Classification

The benthic classification scheme employed in this analysis closely resembled the one used by the NPS Inventory and Monitoring Division (https://irma.nps.gov/DataStore/DownloadFile/427176), which itself was adapted from the scheme utilized by the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center. All hard corals, including scleractinians, hydrozoans (e.g., *Millepora* and stylasterids), and octocorals (e.g., *Heliopora*) were identified to species when possible, and to genus when specific species identification was not possible. Common, conspicuous macrophytes (e.g., *Halimeda*, *Asparagopsis*, *Padina*, etc.) were identified to genus, while algae that could not be identified to genus were categorized as crustose coralline algae (primarily Order Corallinales), crustose coralline red algae (primarily Order Peyssonneliales), adherent fleshy macroalgae (e.g., *Lobophora*), non-geniculate branching coralline algae, geniculate branching corallite algae (e.g., *Jania*), fleshy macroalgae, turf algae, biofilm (what is sometimes called “bare rock”), cyanobacteria, or chrystophytes.

Soft corals were identified to genus when possible, while those without a genus level ID were categorized as “soft coral.” Points falling on macroinvertebrates were grouped into broader categories (e.g., sea stars, urchins, sea cucumbers, corallimorphs, zoanthids, encrusting sponges, erect sponges). Certain ecologically significant taxa including *Acanthaster*, *Terpios*, *Coralliophila*, *Drupella*, and *Tridacna,* were given their own individual classification. Due to current limitations in CoralNet, where only one label can be associated with a given point, all points identified using a biological cover class were assumed to be on a hardbottom substrate type.

To assess the biological cover occurring on unconsolidated substrate types, EnviroScience introduced new classes that combined the unconsolidated substrate type with the biological cover class (e.g., rubble-CCA, sand-cyanobacteria, sand-Padina, or sand-Caulerpa). Furthermore, new classes were created combining the coral taxon with a health condition (e.g., *Acropora abrotanoides*-bleached), specifically for those points directly situated on affected portions of the coral colonies. These comprehensive adaptations were made to ensure the accurate assessment of biological cover and substrate types in the analyzed coral reef images.

Identifications resulting from the point count analysis were subsequently categorized into functional groups for the final analysis. A complete listing of the label set utilized can be found in Appendix B. These functional groups were defined as follows:

- **Crustose Coralline Algae (CCA):** Comprising any of the hard calcareous algae.
- **Colonizable Substrate:** Characterized as thin turf/biofilm on rock.
- **Hard Coral:** Encompassing scleractinians, the hydrozoans *Millepora* and *Distichopora*, and the octocoral *Heliopora*
- **Macro Algae:** Encompassing fleshy red, green and/or brown algae
- **Other Invertebrates:** Incorporating soft corals, sponges, echinoderms, mollusks, and other cnidarians such as zoanthids and Corallimorpharia
- **Other Algae:** Incorporating cyanobacteria, chrysophyta
- **Turf algae:** Representing thick algal mats growing on hard substrate
- **Tape-Wand-Shadow (TWS**): Referring to points that coincided with obstructions in the photograph, such as the measuring tape, framer, or shadow (excluded from the final analysis)
- **Unconsolidated Sediment:** Including sand, thin sediment over rock, rubble, and *Halimeda* disc sediments (eroded to the point of being sand)
- **Seagrass**: *Enhalus acoroides*

Statistics

Permanova Analysis

Benthic community interactions in Hågat and Asan transects were evaluated with distance-based analyses using Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). Euclidean distance resemblance matrices were calculated using untransformed percent cover data from transect benthic groups. Data were left untransformed so that the significance of non-dominant groups was not overinflated. Permutational multivariate analysis of variance (PERMANOVA) was based on Euclidean distance resemblance matrices and used to test for benthic community differences and estimate components of variation between the different areas of WAPA and the different habitat types (Anderson et al. 2008). If significant differences were found, groups or species contributing to observed differences were examined using similarity percentages (SIMPER) to assess the percent contribution of each variable to dissimilarity between groups (Clarke et al. 2014).

Coral species composition was compared between study sites using PERMANOVA on square-root transformed coral species percent cover data with Euclidean distance similarity matrices. Diversity indices for coral species, including Margalef's species richness (d), Pielou's evenness (J'), and Shannon diversity (H'), were calculated to make comparisons between Hågat and Asan and between habitat types. Similarity matrices from diversity indices, based on square-root transformed data and Euclidean distance, were tested for significant dissimilarities using analysis of similarity (ANOSIM) (Clarke et al. 2014).

Logistic Regression Modelling

One of the main objectives of this study was to predict the probability of presence/absence for coral species protected under the ESA within the Asan and Hågat beach units. Specific species of interest included *Acropora globiceps, Acropora retusa, Acropora speciosa,* and *Seriatopora aculeata*. *Acropora humilis*, listed as 'Near Threatened' in the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List), was also included in this list. The occurrence of these species was hypothesized to be predictable based on a suite of available and measurable environmental variables that included depth, seafloor roughness (rugosity), area of colonizable substrate and area of unconsolidated sediment. Predictability was also hypothesized to be related to the abundance of various functional groups including hard corals, CCA, turf algae, macroalgae, COTS, other invertebrates, and other organisms.

Transect surveys conducted in both beach units therefore included abundance measurements of each of the ESA species as well as measurements of the aforementioned environmental variables along the surveyed transect. Additionally, the presence of ESA species in the vicinity of the transect (i.e., within 1 m on either side) was noted for each independent transect observation and recorded as a separate categorical variable.

Prior to the development of the regression models, a test of multicollinearity, using a Spearman Rank correlation matrix, was conducted on the environmental variables to identify and exclude those variables that were highly redundant to improve overall model fit. The reduced set of variables were subsequently used in both rounds of model development.

Logistic regression modelling was used to develop predictable relationships between the presence/absence of ESA species and candidate explanatory variables. The 50 m transect surveys conducted in the Asan and Hågat units yielded only two independent observations of one ESA species, *Acropora humilis*. As such, a predictive model could only be developed for the presence/absence of *Acropora humilis,* which served as the response variable in the first round of model development. The first round therefore included models to predict the presence/absence of *A. humilis* as a function of different combinations of the explanatory variables. Additionally, the categorical variable, presence of ESA species, was converted to a dummy variable to use as a candidate explanatory variable for the first round of model development.

A second round of logistic regression modelling was conducted to predict the overall presence/absence of any ESA species as a function of the same suite of explanatory variables. The vicinity surveys that were conducted alongside the transect surveys yielded independent observations of a second ESA species, *A. globiceps* at eight sites. In addition to encountering *A. globiceps*, A. humilis was also observed in the vicinity surveys at four other sites. Therefore, the categorical variable, presence of ESA species (i.e., presence of either *A. humilis* or *A. globiceps*), was selected to serve as the main response variable for the second round of model development.

Spearman rank correlation analysis was conducted using JMP statistical software (version 16.2.0; SAS Institute Inc., Cary, NC). Logistic regression modelling was performed using R statistical software (version 4.2.1; R Foundation for Statistical Computing, Vienna, Austria).

Qualitative Surveys

Timed roving diver coral diversity surveys were carried out at a total of 20 sites occurring within the waters of WAPA, including eight sites offshore the village of Hågat ("Hågat unit"), in southwestern Guam, and 12 sites offshore the village of Asan-Maina ("Asan unit"), in central-western Guam (Table 2, Figure 1). The sites were selected in a non-random manner using satellite imagery, LiDAR bathymetry data, and firsthand knowledge of the study areas, with the aim of maximizing the diversity of reef habitats covered by the surveys. Surveys were carried out between January 22 and March 12, 2023, by David Burdick (DB), an independent consultant and researcher at the University of Guam Marine Laboratory, with technical assistance provided by Colin Lock (CL), an independent consultant and recent graduate of the University of Guam's Marine Biology graduate program. The 17 sites located seaward of the reef margin were surveyed using scuba equipment and accessed by a vessel chartered with GenX Sports, while the three shallow reef flat sites were accessed from shore and were surveyed while snorkeling. The surveys at sites along the seaward slope generally ranged from depths of 10 to 25 m, reef front/reef margin surveys from 0.5 to 10 m depth, and reef flat surveys from 0.5 to 1.7 m. A maximum survey depth of 33 m was reached at site ASAN-CS-6, near Adelup Pt.

Table 1. WAPA coral diversity site locations. Coordinates utilize the WGS 1984 Geographic Coordinate System.

Site	Reef Zone	Latitude	Longitude	Date Surveyed
Agat-CS-1	Seaward slope	13.378698	144.643781	19-Feb-23
Agat-CS-2	Reef front	13.383643	144.647615	19-Feb-23
Agat-CS-3	Reef flat	13.383574	144.651707	5-Mar-23
Agat-CS-4	Reef front	13.386084	144.651019	19-Feb-23
Agat-CS-5	Reef front	13.391208	144.65518	19-Feb-23
Agat-CS-6	Seaward slope	13.394715	144.653908	5-Mar-23
Agat-CS-7	Reef front	13.395746	144.658997	5-Mar-23
Agat-CS-8	Seaward slope	13.401661	144.657587	5-Mar-23
Asan-CS-1	Reef flat	13.477184	144.705241	22-Jan-23
Asan-CS-2	Seaward slope	13.480589	144.7056	5-Feb-23
Asan-CS-3	Seaward slope	13.480502	144.707648	5-Feb-23
Asan-CS-4	Reef front	13.478319	144.708714	5-Feb-23
Asan-CS-5	Seaward slope	13.478353	144.712049	12-Mar-23
Asan-CS-6	Reef front	13.476771	144.713167	12-Mar-23
Asan-CS-7	Seaward slope	13.475671	144.715385	26-Feb-23
Asan-CS-8	Reef front	13.478615	144.717589	5-Feb-23
Asan-CS-9	Seaward slope	13.481749	144.71961	26-Feb-23
Asan-CS-10	Reef flat	13.478405	144.722451	29-Jan-23
Asan-CS-11	Reef front	13.480829	144.722571	12-Mar-23
Asan-CS-12	Seaward slope	13.482342	144.72625	26-Feb-23

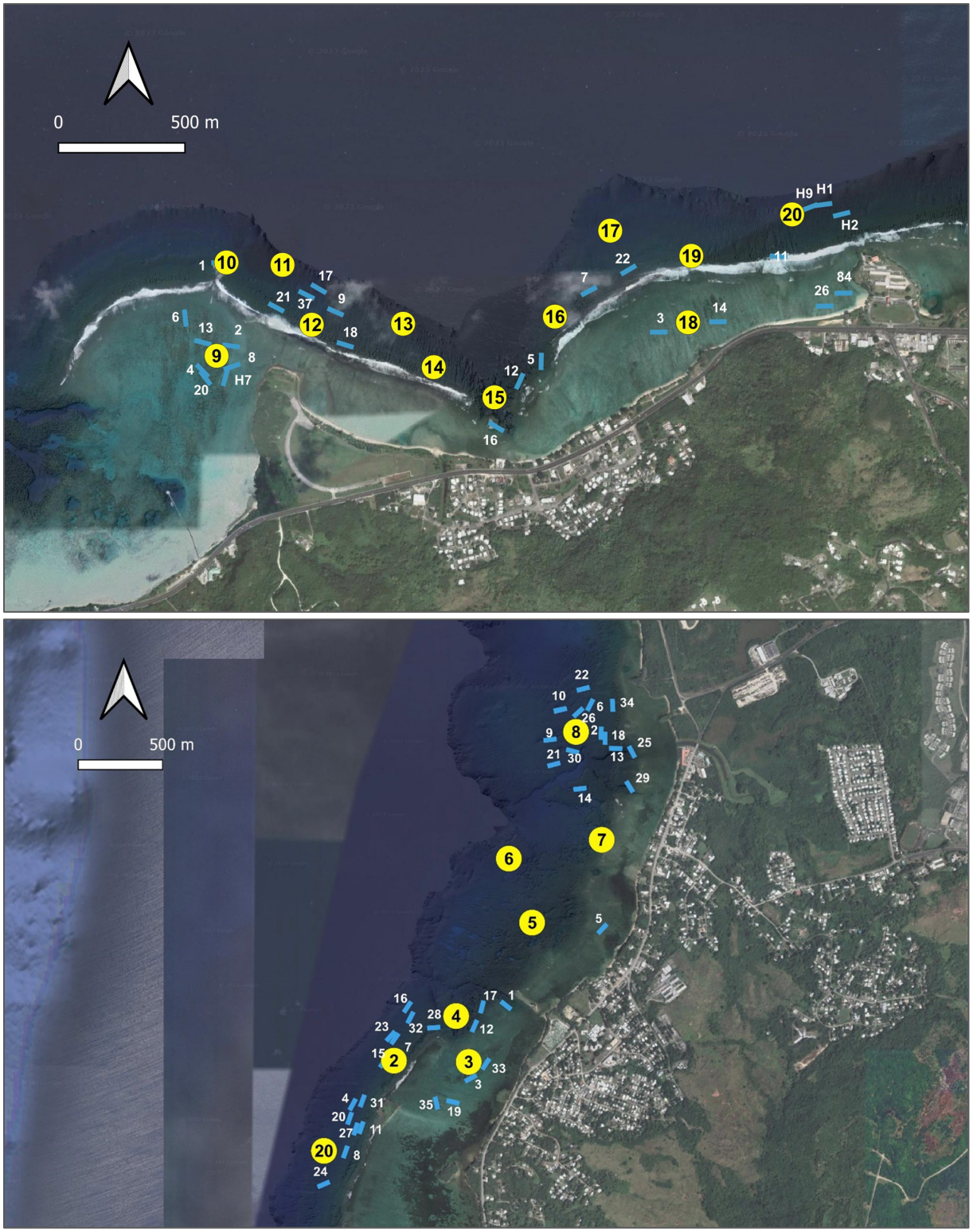


Figure 1. Location of coral diversity survey sites (yellow dots) and photo transect survey sites (blue lines) occurring on WAPA submerged lands offshore of the village of Asan (top), in central-western Guam, and the village of Hågat, in southwestern Guam (bottom).

Survey Protocol

Sites were located in the field using a handheld Garmin GPS 78S receiver. Upon reaching the seafloor, the divers began the 45-minute-long survey simultaneously, and Mr. Burdick obtained an image of his watch to capture the survey start time. During the survey DB and CL individually obtained whole colony digital images of each colony suspected of representing a species that had not previously been encountered during that survey; close-up images were obtained of colonies when needed. Images obtained by CL were examined by DB and any additional species encountered by CL were recorded. All colonies of ESA-listed coral species encountered during the surveys were photo-documented. DB used an Olympus TG-5 compact digital point-and-shoot camera in an Olympus PT-058 housing, with a Canon Powershot ELPH 300 HS in a Canon WP-DC41 housing used as a backup camera, while CL used a Sony A6400 mirrorless digital camera in a Seafrogs housing. The survey track was generally haphazard, and the divers aimed to cover a moderate depth range, usually venturing deeper initially and moving back upslope in a loose zigzag pattern, deviating to investigate habitats of interest. A Garmin GPSmap 78s GPS receiver in a waterproof pack attached to a surface float was towed by DB throughout the duration of each survey.

Image Management

Images were imported into Adobe Lightroom Classic 6.14 for management and post-processing. All photographed colonies were identified to species using various references described below, with family, genus, and species keywords applied to each image within Lightroom. All colony images were exported as jpegs and renamed using the "SITE-CS-#, Genus species 1, Genus species 2 YYYYMMDD original filename" format, while reefscape and other images were renamed using the "SITE-CS-#, YYYYMMDD original filename" format.

Georeferencing of Survey Images

GPS tracks were downloaded from the receiver using the DNRGPS (Department of Natural Resources Global Positioning System) application. Geographic coordinates for the approximate location at which each image was obtained were generated with the software application Robogeo, which interpolates the estimated position of the GPS receiver using the image timestamp and the locations of the two GPS track points recorded by the receiver immediately before and after the image was taken. As mentioned previously, accuracy of the GPS due to drag was approximately 5-10 m. Particular care was taken to bring the buoy directly above the diver when photographing colonies of ESA-listed species; as such, the error radius around those colonies is likely to be lower, estimated at ~5 m.

Reduced resolution versions of the georeferenced images were exported as Google KMZ (Keyhole Markup Zipped) files using Robogeo. Google KMZ file format is a portable image mapping that allows users to overlay the estimated locations of all images on satellite imagery and view each image interactively by clicking the image location point feature within Google Earth. A separate Google KMZ file containing only the georeferenced *Acropora globiceps* images was also generated. The approximate depth at which each image was obtained was generated with QGIS 3.24.3 by extracting depth values from the 2020 National Geodetic Survey (NGS) lidar bathymetry data (National Geodetic Survey 2020) for each image point feature.

Once species determinations were made for all imaged colonies a simple database was created in Excel with records generated for the time of the first appearance of each unique species for each site. Species accumulation curves were generated for each site by plotting the elapsed time at which each new unique species was recorded. Species presence/absence data for each site were used to generate species incidence frequency data, which were in turn uploaded to iNext Online (Chao et al. 2014, Chao et al. 2016) to generate sampling size-based rarefaction/extrapolation and sample completeness curves for all sites combined, as well as separate curves for the Hågat and Asan units.

Coral colonies were identified using a combination of several references, including Randall and Burdick (in prep); Randall and Myers (1983); Rowlett (2020); Veron et al.'s (2016) Corals of the World website (coralsoftheworld.org); Veron (2000); Wallace (1999); and Wallace, Done and Muir (2012). These main references were also supplemented by recently published studies, as well as an unpublished preliminary phylogenetic tree generated by Dr. Peter Cowman of James Cook University using >1000 *Acropora* specimens obtained by various researchers from across the Indo-Pacific, including 48 samples representing ~34 Guam *Acropora* morphospecies (Cowman et al., unpubl. data). In some instances, original descriptions and images of the types were also examined. The perspective of Dr. Doug Fenner, an experienced coral taxonomist and diversity survey specialist, was also sought for the identification of several colonies. Families and genera considered valid on the World Register of Marine Species (WoRMS) website (WoRMS Editorial Board 2023) were used, although the genera *Stylocoeniella* and *Madracis* were placed in the Family Pocilloporidae for this study based on the results Fukami et al. (2008). A few species names considered invalid on the site, such as *Acropora surculosa*, were used in the present study to maintain consistency with the perspective of the late Richard Randall, a geologist and coral taxonomist who studied the corals of the Mariana Islands for decades. Tentative names assigned by Randall and Burdick (in prep) were used for several corals believed to represent undescribed species (e.g., *Acropora* sp. "obtusicaulis"). The open nomenclature qualifier "cf." (abbreviation for the Latin *conferre* = "to bring together") was used when the application of a described species' name to a Guam morphospecies was uncertain. However, given the uncertain status of numerous Indo-Pacific coral species, genera, and even families, all species determinations, including those without the "cf." qualifier, should be considered hypotheses, subject to revision as genetic, morphological, and other evidence becomes available. The qualifier *sensu* (="in the sense used by") was used when a Guam morphospecies compared favorably to a particular author's perspective of a named coral species, which may differ from that of another taxonomist. When possible *sensu* was used in reference to a specific reference by an author or group of authors (e.g., Veron et al. 2016), but several Guam morphospecies use the qualifier "*sensu* Randall" and are based on unpublished information and personal communications provided to DB by Richard Randall since 2007.

Results

Quantitative Results

Benthic Cover

The percent benthic cover at each of the transects at the Hågat and Asan beach units is illustrated in Figures A-3a and A-3b of Appendix A. At the Hågat unit, turf algae had the highest mean benthic cover (28.33% ± 2.25%), followed by unconsolidated sediment (24.79% ± 3.36%, Figure 2). Hard coral cover was the third lowest benthic cover group at 4.97% ± 0.54%. In contrast, at the Asan unit, hard coral had the highest mean benthic cover (21.89% ± 3.92%), followed by CCA (20.30% ± 3.00%) and unconsolidated sediment (17.47% ± 3.21%). The range of mean benthic cover in transects varied greatly for CCA, hard coral, turf algae, and unconsolidated sediments, with ranges across both study sites from <3.00% to greater than 50.00% (Table 3). Maximum benthic cover between beach units differed greatly for hard coral and unconsolidated sediment types. The maximum hard coral cover in the Asan unit (64.51%) was 53.37% higher than that of the Hågat unit (11.14%), while the maximum cover of unconsolidated sediment in the Hågat unit (73.99%) was 23.00% higher than that of the Asan unit (50.99%).

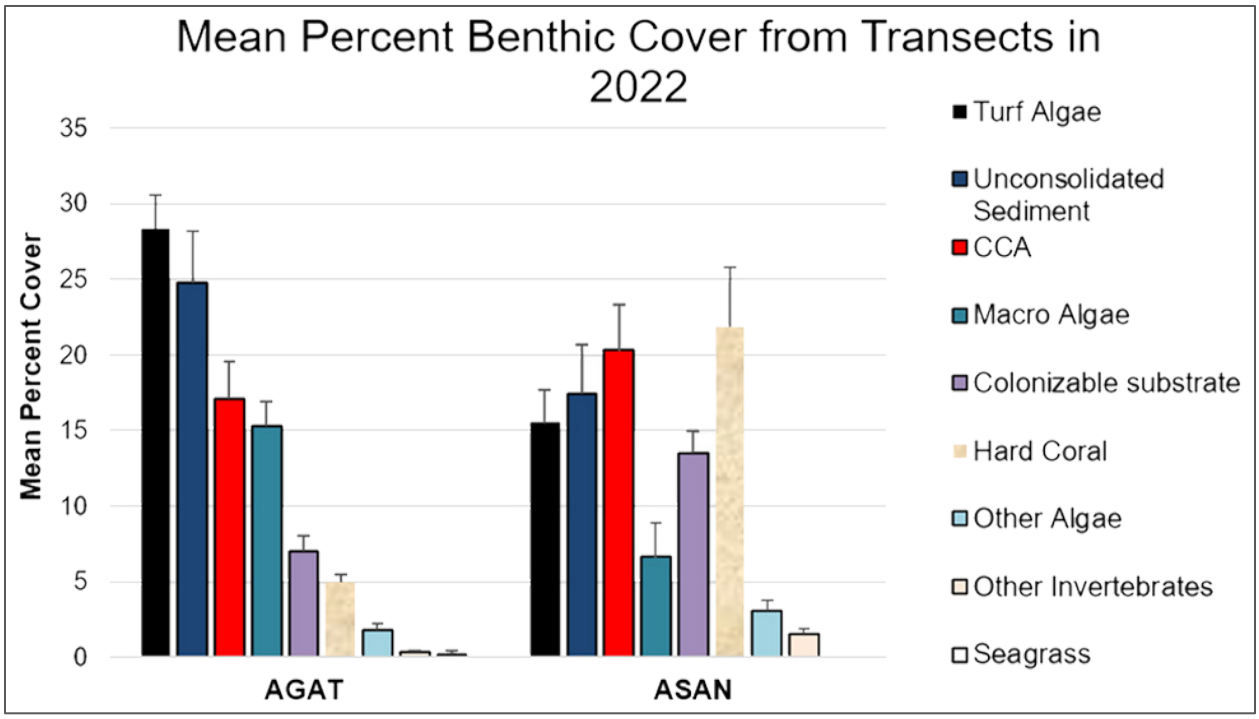


Figure 2. Mean percent benthic cover + standard error (SE) from transect surveys within Hågat and Asan beach units in 2022.

Table 3. Range of Mean Percent Cover Categories from Transect Surveys at Hågat (AGAT), Asan, and both Study Sites Combined, in 2022.

Benthic Cover Type	AGAT	ASAN	Combined
CCA	1.03-55.70%	0.87-61.10%	0.87-61.10%
Colonizable substrate	0.21-22.45%	5.05-34.33%	0.21-34.33%
Hard coral	0.00-11.14%	0.63-64.51%	0.00-64.51%
Macro Algae	1.54-39.31%	0.08-40.26%	0.08-40.26%
Other Algae	0.00-13.04%	0.08-12.21%	0.00-12.21%
Other Invertebrates	0.00-1.57%	0.21-7.74%	0.00-7.74%
Seagrass	0.00-8.00%	0.00-0.00%	0.00-8.00%
Turf algae	5.16-55.32%	2.28-42.24%	2.28-55.32%
Unconsolidated sediment	2.22-73.99%	0.13-50.99%	0.13-73.99%

Benthic cover differed by zone (Figure 3 and Figure 4). For both Hågat and Asan beach units, CCA had the largest cover in forereefs (33.43% ± 4.68% and 38.35% ± 4.51% respectively), followed by turf algae (27.42% ± 3.10% and 19.62% ± 4.85%). Unconsolidated sediment had the largest cover in reef flats (59.58% ± 3.83% and 29.95% ± 4.71% respectively). In contrast, the bank/shelves of the Hågat unit had larger benthic cover of turf algae (33.37 ± 2.62%) and unconsolidated sediment (23.40% ± 3.04%), while those of the Asan unit had more coral cover (29.01% ± 9.30%), followed by turf algae (18.06% ± 3.36%) and unconsolidated sediment (17.52% ± 4.53%). In general, the Asan unit had more hard coral cover (15.98% ± 4.88% – 29.01% ± 9.30%) and colonizable substrate (6.84 ± 0.43% – 17.08% ±2.13%) across all three zones compared to the Hågat unit, with hard coral cover ranging from 3.85% ± 2.04% – 6.32% ± 0.97%, and colonizable substrates ranging from 2.57% ± 0.75% – 15.41% ± 1.62%.

PERMANOVA analysis revealed significant differences in benthic community composition between AGAT and ASAN sites in 2022 (Table 4). SIMPER analysis identified the observed dissimilarity between study sites was due to significantly higher unconsolidated sediment cover at AGAT and significantly higher coral cover at ASAN (contributing 27% and 26%, respectively). SIMPER analysis also identified the observed dissimilarity between habitat types was due to significantly higher CCA cover in the fore reef habitat than the bank/shelf or reef flat (contributing 26% and 16%, respectively) and significantly higher unconsolidated sediment in the reef flat than the bank/shelf or fore reef habitats (contributing 34% and 50%, respectively; Table 5 and Table 6).

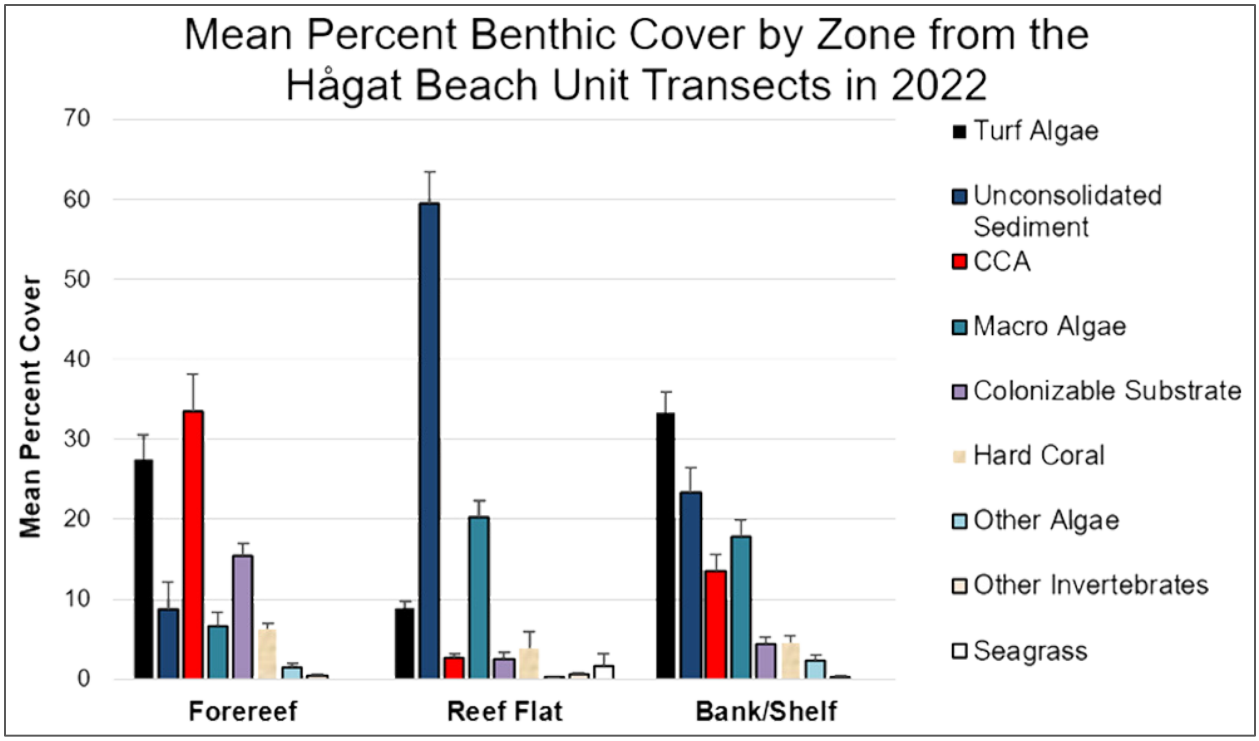


Figure 3. Mean percent benthic cover + SE by zone from transect surveys within the Hågat beach unit in 2022.

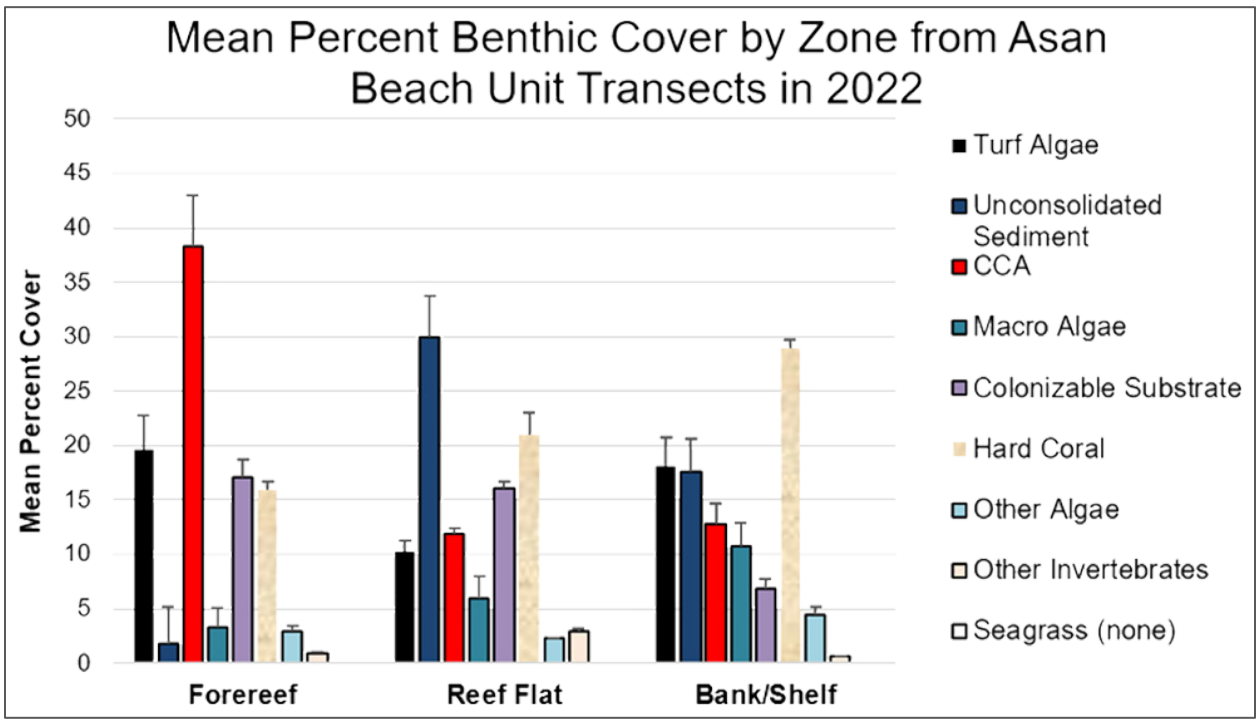


Figure 4. Mean percent benthic cover + SE by zone from transect surveys within the Asan beach unit in 2022.

Table 4. PERMANOVA results comparing 2022 mean percent benthic cover in AGAT and ASAN transect surveys.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Benthic cover site	9580.1	1	9.8709	**0.001***
Residual	57261	59	–	–
Total	66842	60	–	–

* Denotes significant value (also in bold text).

Table 5. PERMANOVA results comparing 2022 mean percent benthic cover between habitat types.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Benthic cover habitat	20519	2	12.845	**0.001***
Residual	46323	58	–	–
Total	66842	60	–	–

* Denotes significant value (also in bold text).

Table 6. PERMANOVA results comparing 2022 mean percent benthic cover between ASAN and AGAT and habitat types.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Site	8381.6	1	13.322	**0.001***
Habitat	20948	2	16.648	**0.001***
Site*Habitat	3194.1	2	2.5385	**0.022***
Residual	34603	55	–	–
Total	78614	60	–	–

* Denotes significant value (also in bold text).

Coral Genera Cover

Figure 5 displays the observed genera having greater than 0.05% mean between both beach units (the complete list of species is provided in Appendix C). Hard coral cover was predominantly comprised of the genus *Porites*, with 3.10% ± 0.50% mean cover at the Hågat unit and 15.11% ± 3.79% cover at the Asan unit (Figure 6 and Figure 7). At the Hågat unit, other dominant genera included *Acropora* (0.25% ± 0.17%), *Pocillopora* (0.24% ± 0.14%), and *Goniastrea* (0.24% ± 0.11%). At the Asan unit, dominant genera included *Leptoria* (1.4% ± 1.29%), *Pocillopora* (0.48% ± 1.55%), and *Goniastrea* (0.24% ± .90%).

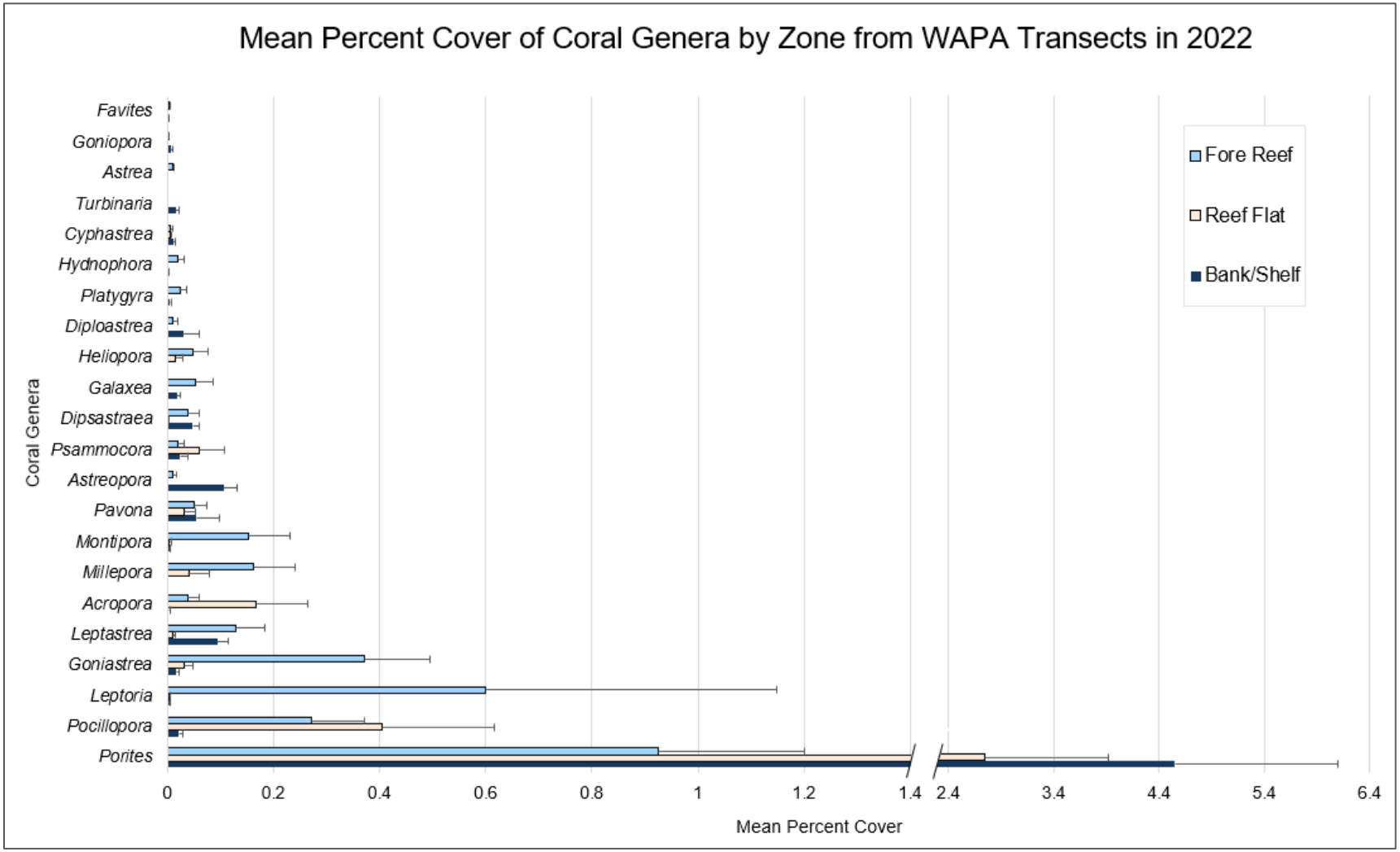


Figure 5. The observed genera having greater than 0.05% mean between habitat types. Porites was the predominant genus at the fore reef (0.92% ± 0.28%), reef flat (2.74% ± 1.17%), and bank/shelf (4.55% ± 1.55%) zones. Other dominant coral genera included *Pocillopora* in the fore reef (0.92% ± 0.28%) and reef flat (0.40% ± 0.21%, and *Leptoria* (0.60% ± 0.55%) and *Goniastrea* (0.37% ± 0.12%) in the fore reef.

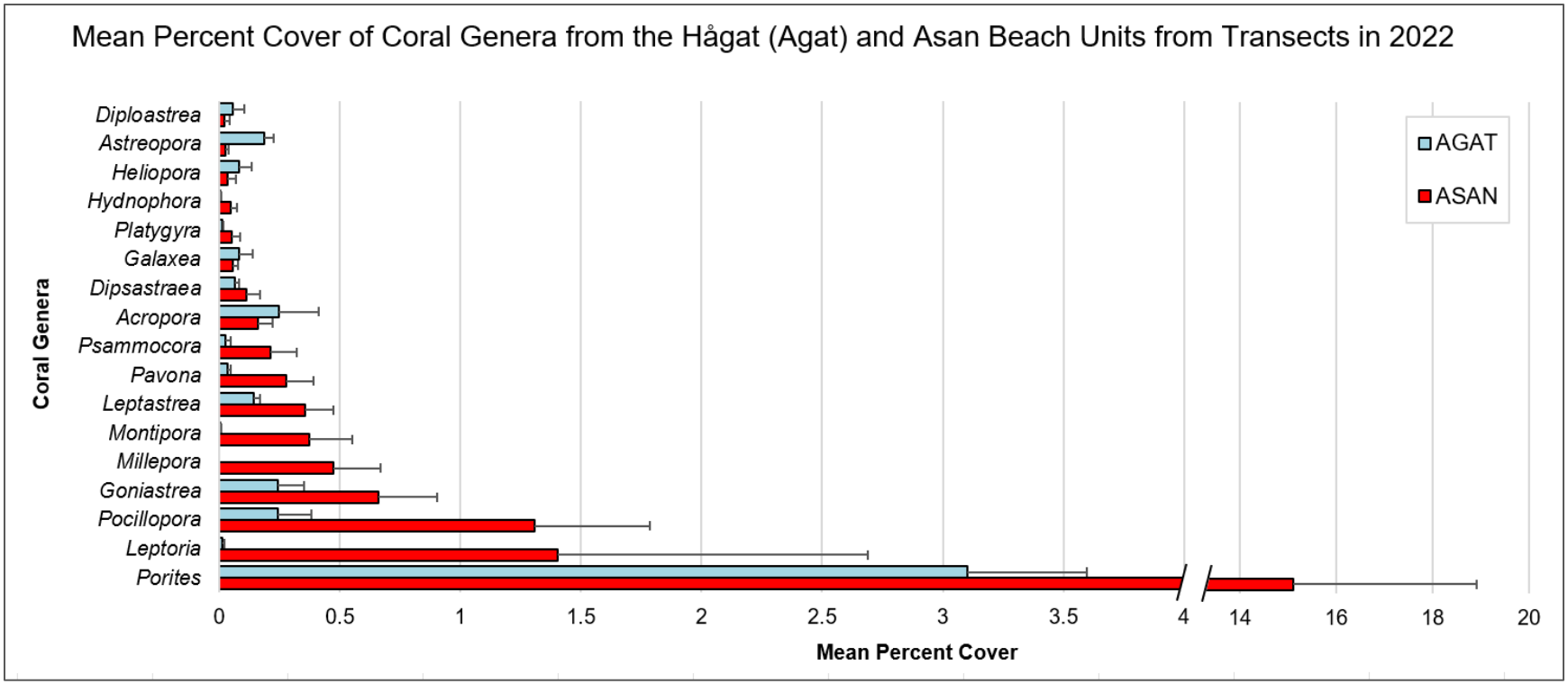


Figure 6 Mean Percent Cover + SE of coral genera from transect surveys within the Hågat and Asan beach units in 2022. Includes genera with a total cover of >0.05%.

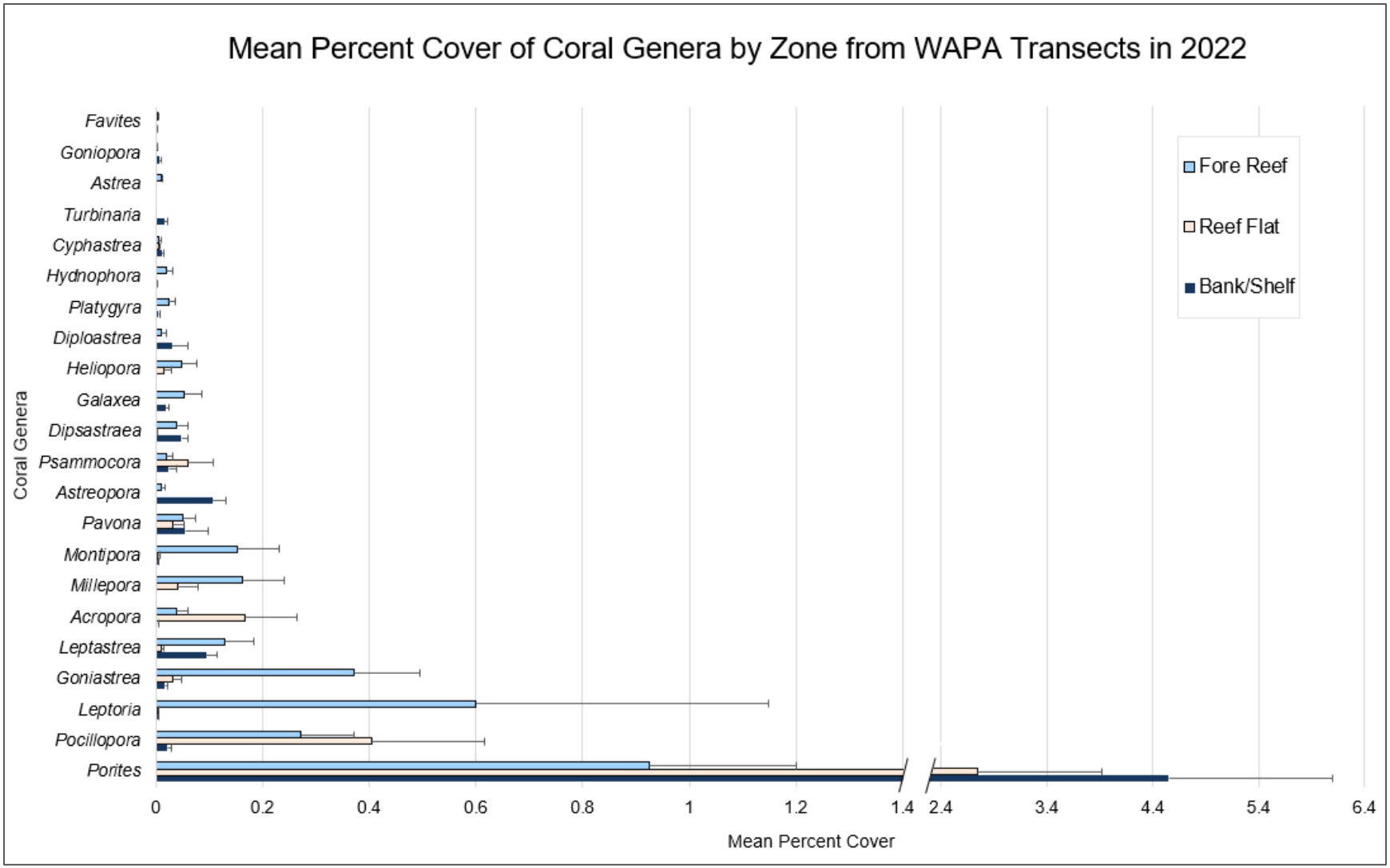


Figure 7. Mean Percent Cover + SE of coral genera from transect surveys within WAPA transects by zone in 2022. Includes genera with a total cover of >0.05%.

PERMANOVA analysis revealed significant differences in coral genera composition between Hågat and Asan beach units (Table 7). SIMPER analysis indicated that this difference was due to significantly higher *Porites* cover in the Asan unit contributing 44% to of differences. PERMANOVA analysis also revealed that *Porites* cover was the driving difference between habitat types with average *Porites* abundances higher in the bank shelf and reef flat habitat than the fore reef habitat contributing 30% and 29% of differences, respectively.

Table 7. PERMANOVA results comparing coral genera mean percent cover between Asan and Hågat beach units and across habitat types.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Site	9845.7	1	4.9245	**0.001**
Habitat	24912.0	2	6.23	**0.001**
Site*Habitat	9298.8	2	4.651	**0.001**
Total	167120.0	60	–	–

* Denotes significant value (also in bold text).

Coral genera diversity measures were averaged for Asan and Hågat beach units and between habitat types for transects. ANOSIM analysis revealed no significant differences in diversity between coral communities (Table 8 and Table 9).

Table 8. Coral Genera Diversity Comparison between Hågat and Asan beach units.

Random Transect Coral Diversity Measures	Hågat	Asan
Margalef's species richness (d)	3.87 ± 0.36	3.69 ± 0.45
Pielou's evenness (J')	0.78 ± 0.04	0.76 ± 0.05
Shannon diversity (H'(loge))	1.32 ± 0.09	1.48 ± 0.14

Table 9. Coral Genera Diversity Comparison between Fore Reef, Reef Flat, and Bank/Shelf Zones.

Random Transect Coral Diversity Measures	Fore Reef	Reef Flat	Bank Shelf
Margalef's species richness (d)	3.96 ± 0.53	3.80 ± 0.57	3.78 ± 0.41
Pielou's evenness (J')	0.79 ± 0.05	0.78 ± 0.20	0.77 ± 0.05
Shannon diversity (H'(loge))	1.44 ± 0.35	1.40 ± 0.16	1.39 ± 0.12

Coral Species Cover

Across both Hågat and Asan beach unit transects, a total of 56 hard coral species were recorded from 27 genera, with 44 species recorded from the Hågat unit and 48 species recorded from the Asan unit. However, more coral species were identified in roving diver qualitative surveys as described below.

Maps illustrating coral species diversity from transects are provided in Figures A-4a and A-4b of Appendix A, and the complete list of species recorded is provided in Appendix C.

Figure 8 displays the observed genera or species having greater than 0.05% mean cover between both beach units. Hard coral cover at the Hågat and Asan beach units was predominantly comprised of the species belonging to *Porites*, including *Porites rus* (1.01% ± 0.34% and 9.08% ± 3.39% respectively) and *Porites* spp. (1.98% ± 0.29% and 3.96% ± 0.79%). *Porites cylindrica* was only found in the Asan beach unit (1.73% ± 1.00%). Other dominant species at the Hågat and Asan units included *Leptoria* spp. (0.01% ± 0.01% and 1.40% ± 1.29% respectively), *Pocillopora* spp. (0.23% ± 0.14% and 0.68% ± 0.19%), and *Goniastrea retiformis* (0.22% ± 0.11% and 0.59% ±0.23%). All other species had a total mean percent cover less than 0.50%.

Species presence was compared for each beach unit by zone (Figure 9 and Figure 10). In general, *Porites rus* and *Porites* spp. were found mostly in bank/shelves at both beach units, as well as the Hågat unit forereef and Asan unit reef flats (including *Porites cylindrica*). *Pocillopora* spp. and *Goniastrea retiformis* were found mostly in the forereef at both units, and *Pocillopora* spp. also appeared in reef flats in the Asan unit. *Leptoria* spp. were largely found in forereefs at the Asan unit.

Hard coral species were grouped by depth for both Hågat and Asan beach units. At Hågat (Figure 11) average transect depths ranged from 0.13 m to 12.81 m. No coral was found at Hågat 005 (0.13 m), the shallowest depth sampled. Porites spp. were generally found throughout the range of depths and was the dominant coral genus at most depths, with the highest percent cover of 8.66% occurring at Hågat 025 (1.38 m). *Porites rus* was more heavily represented at depths between 7.16 m and 10.30 m, with the highest percent cover of 7.70% occurring at Hågat 010 (9.74 m). From depths of 0.56 m - 0.73 m (Hågat 003 and 033) the dominant genus was *Acropora* (4.19 % and 2.38% coral cover respectively) including *Acropora muricata* at Hågat 033 (1.89%). Hågat 012 (1.07 m) also had a unique coral community composition by comparison, with dominant species including *Pocillopora* spp. (4.63%) *Goniastrea retiformis* (2.23%), and *Heliopora coerulea* (1.34%). *Goniatrea retiformis* (2.30%) was the dominant coral species at Hågat 028 (2.69 m). *Galaxea fascicularis* (1.97%) was notably present at Hågat 017 (3.83 m).

At the Asan beach unit (Figure 12), average transect depths ranged from 0.68 m - 16.93 m. *Porites* spp. were generally found throughout the range of depths. *Porites rus* (33.58%) was the dominant coral species at Asan 020 (1.40 m), while *Porites cylindrica* (23.75%) was the dominant coral species at Asan 004 (1.16 m). *Leptoria* spp. (33.51%) was the dominant coral genus at Asan 012 (2.51 m), and *Psammocora* spp. (2.82%) at Asan 008 (1.01 m). Other notable species included *Pocillopora grandis* (07.87%) at Asan 006 (0.99 m), and the presence of *Montipora* spp. (1.36%-3.81%) and *Millepora platyphylla* (0.38% - 3.75%) from a depth range of 2.86 m - 5.01 m (Asan 021, 022, 007, and 005)

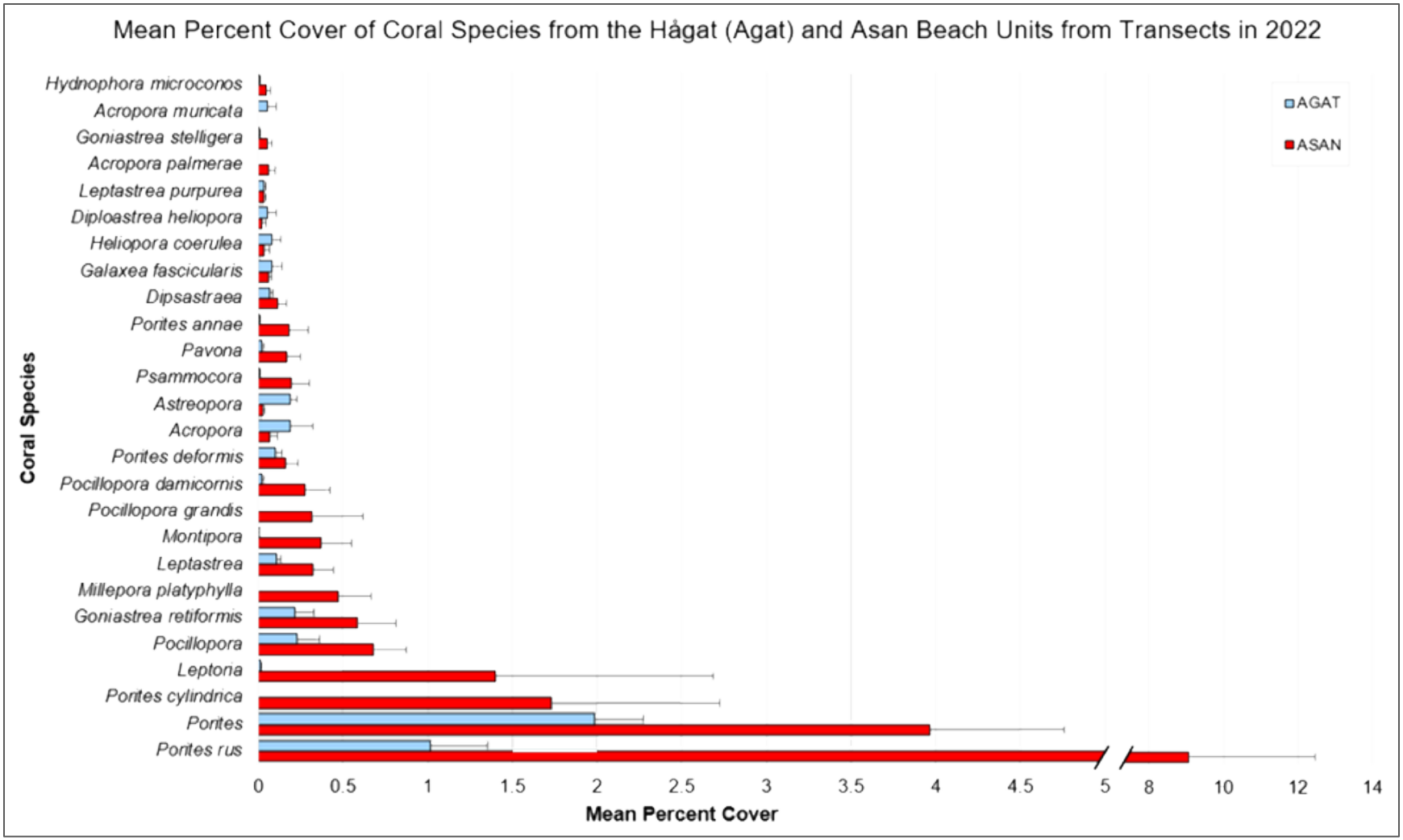


Figure 8. Mean Percent Cover + SE of coral species from transect surveys within the Hågat (Agat) and Asan beach units in 2022. Includes species with a total cover of >0.05%.

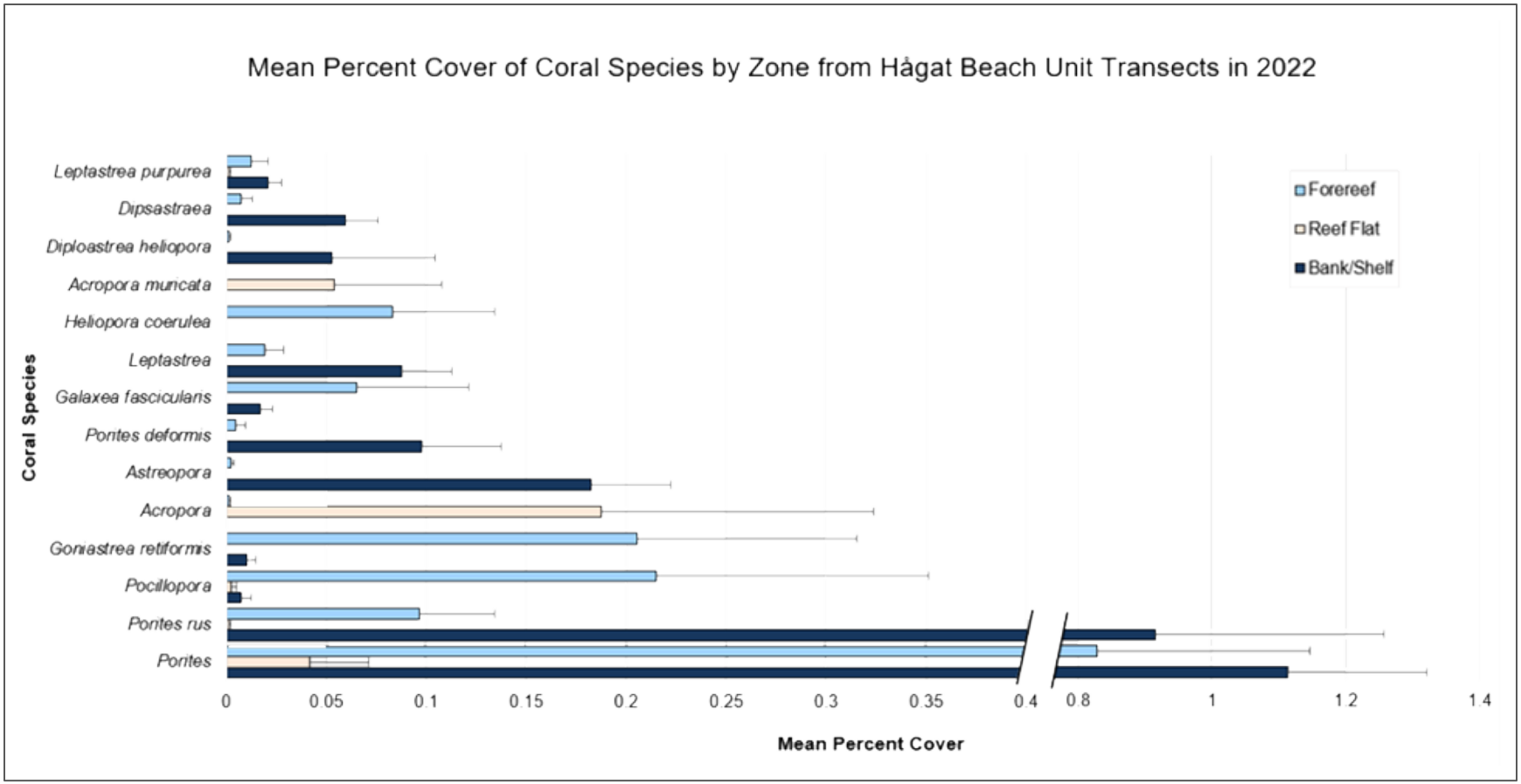


Figure 9. Mean Percent Cover + SE of coral species from transect surveys by zone within the Hågat beach unit in 2022. Includes species with a total cover of >0.05%.

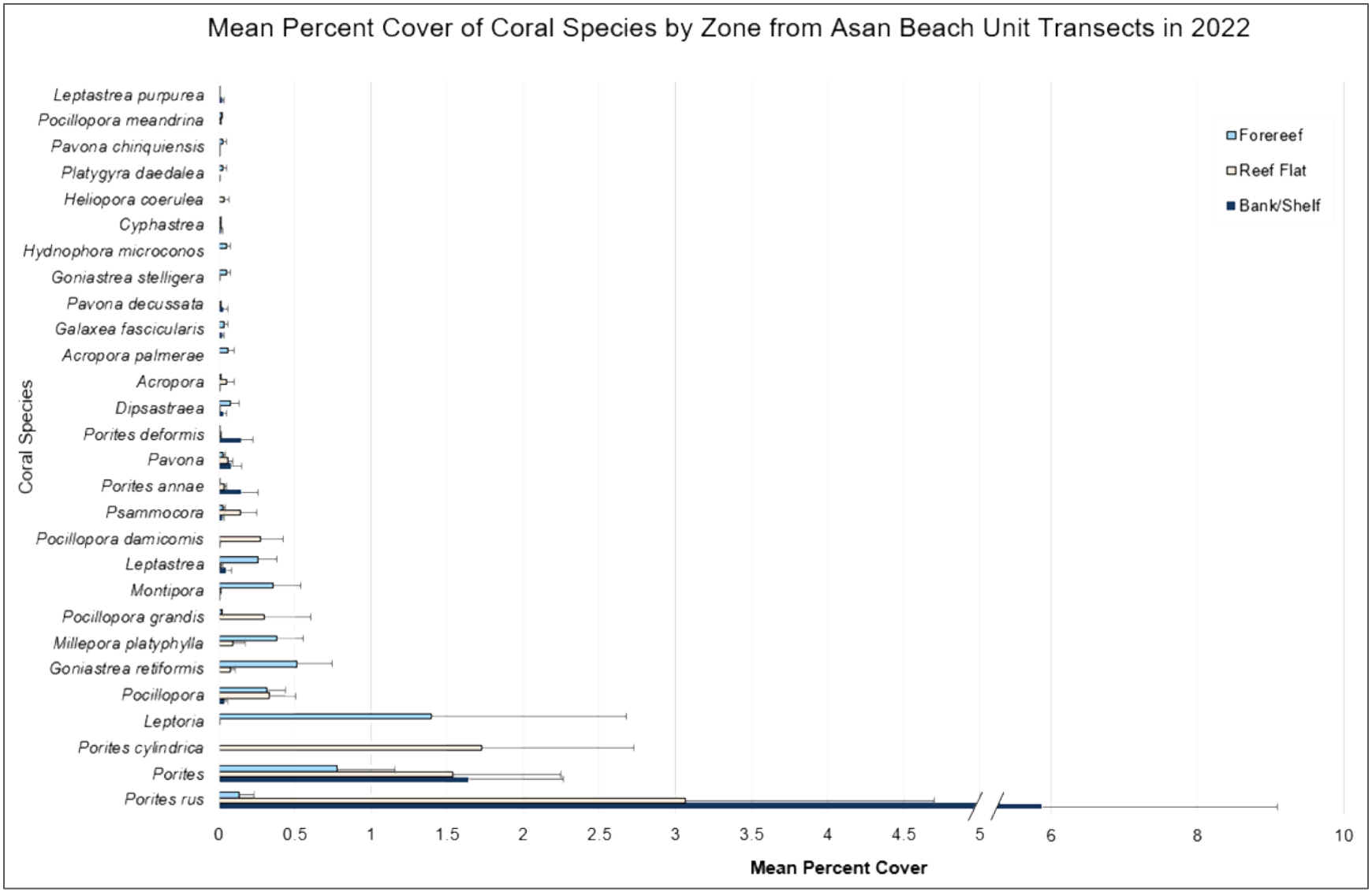


Figure 10. Mean Percent Cover + SE of coral species from transect surveys by zone within the Asan beach unit in 2022. Includes species with a total cover of >0.05%.

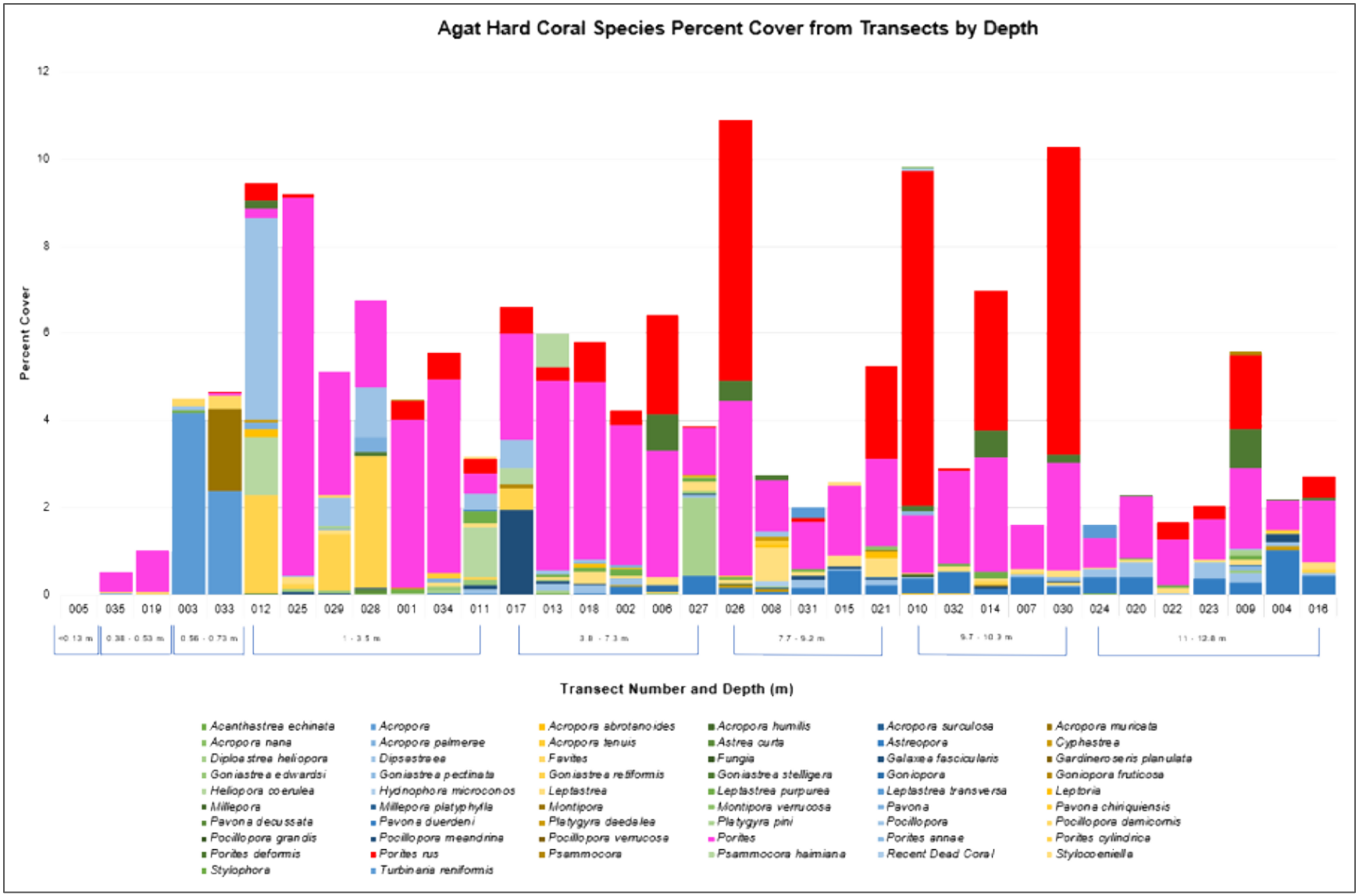


Figure 11. Mean percent cover of coral species from transects by depth within the Hågat (Agat) beach unit in 2022. Transects are grouped in depth bins (m) from shallowest to deepest.

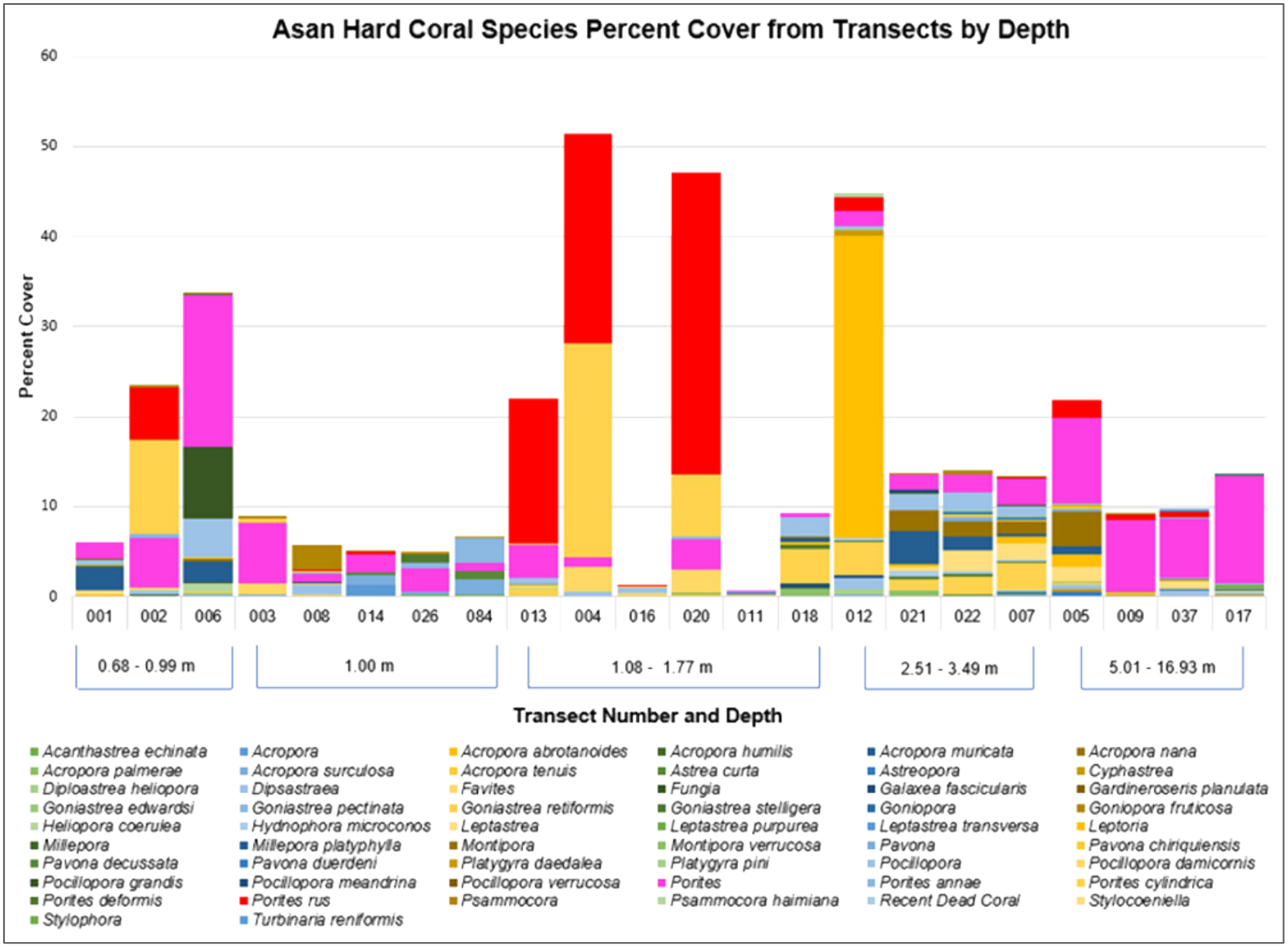


Figure 12. Mean percent cover of coral species from transects by depth within the Asan beach unit in 2022. Transects are grouped in depth bins (m) from shallowest to deepest.

Protected Species – Quantitative Image Analysis

No coral species listed by the ESA (notably *Acropora globiceps, A. retusa, A. speciosa, and Seriatopora aculeata*) were found in the 2022 species inventory quantitative image analysis. *Acropora humilis* is listed as 'Near Threatened' in IUCN Red List. This species was found at the Asan beach unit in transects 2 (reef flat; 4 points; 0.17% cover) and H09 (bank/shelf; 1 point; 0.04% cover), yielding an average estimated cover for the Asan beach unit of 0.008% (Figures A-5a and A-5b of Appendix A).

Coral Stressors

Diver observations of stressors from field data sheets were summarized into several groups. Table 10 includes observed sedimentation, general stress (pigmentation response), and any recent coral mortality. Sedimentation was observed as a thin layer of sediment with substantial turf cover (Figure 13). Pigmentation response due to stress was typically observed as pink or red spots on corals, and recent mortality was defined as any tissue loss that showed underlying coralline skeleton identifiable to species that appeared white or had a very thin layer of algae suggesting the tissue has died in days-weeks (both observed in Figure 14). Overall, nearly half of transects sampled were observed to have significant sedimentation (49%) and recent mortality (46%). A greater incidence of sedimentation was observed at the Hågat beach unit (60%) compared to Asan (35%), along with higher incidence of recent mortality (51% compared to 38%). By contrast, a larger percentage of transects at Asan had observed coral stress (46%) compared to Hågat, likely due to higher coral cover.

Table 10. Diver-noted Stressors observed along transects in Hågat and Asan beach units in 2022.

Beach Unit	Total Transects	Stressor	No. Transects Observed In	% Observed In
Hågat	35	Sedimentation	21	60%
	35	General Stress (Pigmentation Response)	10	29%
	35	Recent mortality	18	51%
Asan	26	Sedimentation	9	35%
	26	General Stress (Pigmentation Response)	12	46%
	26	Recent mortality	10	38%
All	61	Sedimentation	30	49%
	61	General Stress (Pigmentation Response)	22	36%
	61	Recent mortality	28	46%

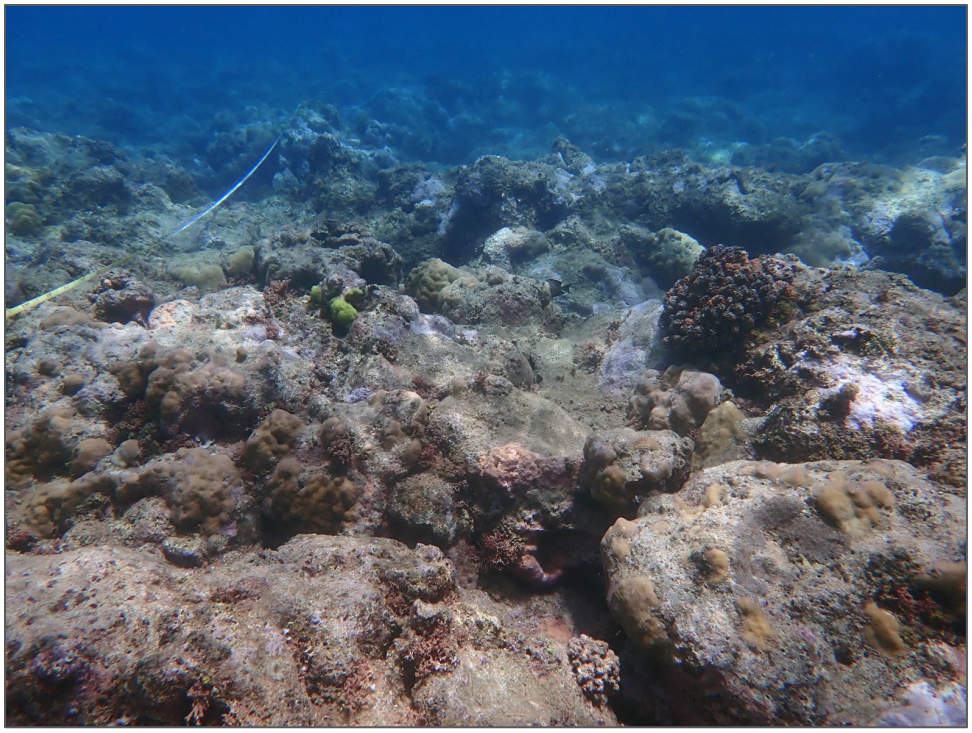


Figure 13. Sediment-laden turf algae and macroalgae at transect site 25 within the Hågat unit. Image: Kelly O'Connell

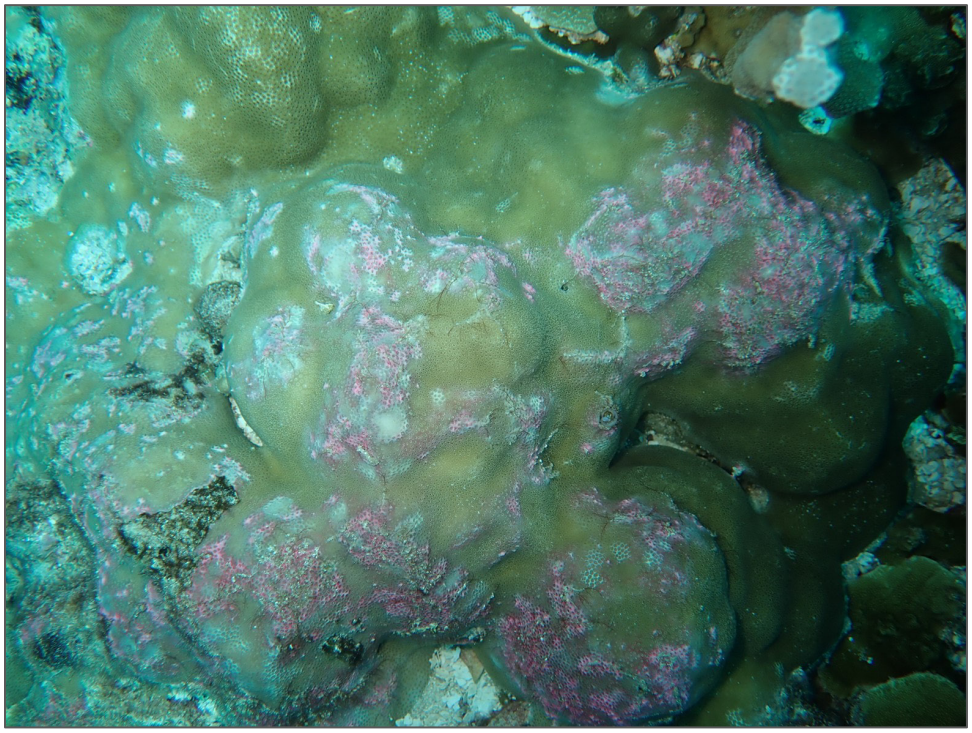


Figure 14. Pigmentation response with recent mortality on a coral at historical transect site Asan-H2. Image: Caitlin Langwiser.

From the point count data, turf algae growing on hard substrate (TURS) was another variable that was indicative of coral reef stress (Figure A-6a and A-6b of Appendix A). Since hard substrates are colonizable by corals and CCA, observations of turf algae on hard substrate (including live and dead coral formations) in relatively high percentages of bottom cover (>20%) represented areas of the reef where corals, reef building algae, and their habitats were being outcompeted by turf algae. Problematic TURS observations were noted throughout the Hågat sites (Figure A-6a of Appendix A), with the exception of the sites between Alutom Island and Hågat Invasion Beach (Agat sites 035, 019, 003, and 033) where those sites also were observed to be poor for coral colonization as they were dominated by unconsolidated sediment (Figure A-3b of Appendix A) with very little colonizable substrate.

Observations of cyanobacteria in the quantitative transect percent cover observations were common throughout the study area except for near-shore areas (Figure A-7a and Figure A-7b of Appendix A). The highest observations of cyanobacteria were observed in Hågat unit off Apaca Point in the fore reef, bank / shelf areas and in similar habitats in the Asan unit, with relatively lower observations in both units within the areas of reef flat. The observed lower percent cover of cyanobacteria in the reef flat relative to areas farther offshore was most likely due to a lack of hard substrates that cyanobacteria could colonize without disruption from wave action, rather than improved water quality. The presence of the Namo River confluence and its associated water quality inputs near Apaca Point could also influence the percent cover of cyanobacteria and turf algae observed nearby (Figures A-7a and Figure A-3a of Appendix A).

Table 11 includes nuisance species observed from transects, including the number of COTS (Figure 15, Figure A-5a and A-Figure 5b of Appendix A) observed and the presence of *Terpios hoshinata* (Figure 16). The greatest number of COTS were observed from the Hågat beach unit at a density of 0.37 COTS/100m^2, which was above the unsustainable density threshold as previously reported (Birkeland 1982, De'ath et al. 2012). By contrast, COTS density at Asan was 0.08 COTS/100m^2, giving a total density for both sites of 0.25 COTS/100m^2. Transects containing COTS are illustrated in Figures A-5a and A-5b of Appendix A. *Terpios hoshinota* was encountered less frequently, where the sponge was observed in 3% of Hågat transects and 12% of Asan transects, yielding a 7% observation rate for both sites combined.

Table 11. Nuisance species observed from transects in Hågat and Asan beach units in 2022.

Beach Unit	Total Transects	Nuisance species	No. Transects Observed In	% Observed In	No. COTS Observed	No./100m^2
Hågat	35	*Acanthaster* cf. *solaris* (Crown-of-Thorns)	9	26%	13	0.37
	35	*Terpios hoshinota*	1	3%	–	–
Asan	26	*Acanthaster* cf. *solaris* (Crown-of-Thorns)	2	8%	2	0.08
	26	*Terpios hoshinota*	3	12%	–	–
All	61	*Acanthaster* cf. *solaris* (Crown-of-Thorns)	11	18%	15	0.25
	61	*Terpios hoshinota*	4	7%	–	–

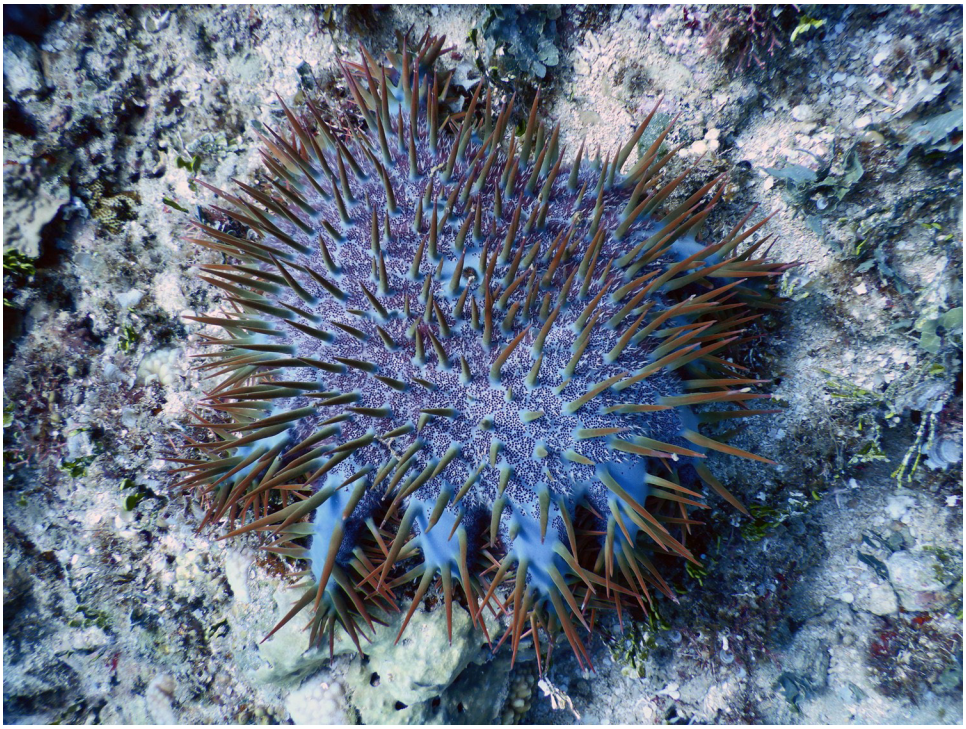


Figure 15. Crown-of-thorns starfish located along transect 10 within the Hågat unit. Image: Kelly O'Connell.



Figure 16. Encrusting sponge *Terpios hoshinota* forming a "blackish sheet" over coral along transect 3 within the Hågat unit. Image: Kelly O'Connell.

Logistic Regression Modelling

Of the ten explanatory variables evaluated for multicollinearity, a significant positive correlation was observed between CCA and colonizable substrate ($r(59) = 0.60$; $p < 0.0001$), and unconsolidated sediment and macroalgae ($r(59) = 0.51$; $p < 0.0001$) (Appendix D). CCA and unconsolidated sediment were subsequently excluded from the logistic models. Although there were pairs of parameters that were significantly negatively correlated to each other (e.g., hard coral and macroalgae) these variables were retained to develop predictability based on variables that may be easily measured via direct observations in future surveys.

Round 1 Logistic Modelling Results

For the first round of logistic modelling, a total of 14 models were developed that incorporated each explanatory variable separately and in combination with other variables to further evaluate significance of interaction effects (Appendix E). Hard coral abundance, recorded as percent benthic cover, and the presence of *A. globiceps/A. humilis* entered significantly and independently in two of the 14 models (Table 12; Appendix F). Additionally, the interactive factor between hard coral and presence of *A. globiceps/A. humilis* also entered significantly in a separate model; however, when this interactive factor was included in another model with hard coral and presence of *A. globiceps/A. humilis* additively, the associated coefficients for the individual variables and the interactive factor between them did not show a significant association (Table 12). The associated AIC value for this model was, however, the lowest among the values for all other models ($AIC_{14} = 12.349$) suggesting that this model represented the best fit and was therefore subsequently selected as the final model for predicting the presence of *A. humilis*.

Table 12. Model statistics for 14 logistic models evaluated for determining the probability of encountering the ESA species, *A. humilis*.

Model	Estimated Coefficient	Standard Error	P-value	AIC
1. Colonizable Substrate	0.0201	0.092	0.827	21.558
2. Depth	0.0001	0.164	0.999	21.605
3. Hard Coral	0.0759	0.036	0.035	16.297
4. Macroalgae	-1.9263	1.831	0.293	15.612
5. Maximum Rugosity	-0.0012	0.006	0.833	21.558
6. Other Invertebrates	-0.5466	1.413	0.699	21.289
7. Other Organisms	0.0691	0.195	0.724	21.491
8. Turf Algae	-0.1613	0.133	0.225	18.311
9. COTS	-16.4384	4168.426	0.997	20.794
10. Presence of AGLO	-16.2889	4390.308	0.997	21.183
11. Presence of AHUM	-14.2162	2797.442	0.996	21.469
12. Presence of AGLO/AHUM	4.0600	1.737	0.019	16.911
13. Presence of AGLO/AHUM x Hard Coral	0.2189	0.107	0.041	14.878

Table 12 (continued). Model statistics for 14 logistic models evaluated for determining the probability of encountering the ESA species, *A. humilis*.

Model	Estimated Coefficient	Standard Error	P-value	AIC
14. Hard Coral +	0.1992	0.211	0.346	12.349
Presence of AGLO/AHUM +	-40.4211	22106.01	0.999	12.349
Hard Coral x Presence of AGLO/AHUM	2.3175	978.129	0.998	12.349

The equation for the selected logistic regression model for predicting the presence of *A. humilis* is as follows:

$$\text{logit}(P) = \beta0 + \beta1*X1 + \beta2*X2 + \beta3*(X1*X2) \quad \text{Eq. 1}$$

Where:

- logit (P) represents the log odds of encountering *A. humilis*.
- P represents the probability of encountering *A. humilis*.
- β0, β1, β2, and β3 are the estimated coefficients from the logistic regression model.
- X1 and X2 are the values of the two independent variables, hard coral abundance and presence of *A. humilis*, respectively.
- X1*X2 represents the interaction term between X1 and X2.

Substituting the model estimates in Equation 1, yields:

$$\text{logit}(P) = -12.9875 + 0.1992*X1 + (-40.4211*X2) + 2.3175*(X1*X2)$$

To obtain the predicted probability (P) for specific values of X1 and X2, the logistic function is applied to convert the logit back to the predicted probability, using the following equation:

$$P = 1/(1 + \exp(-(\beta0 + \beta1 * X1 + \beta2 * X2 + \beta3 * X1*X2))) \quad \text{Eq. 2}$$

or,

$$P = 1/(1 + \exp(-(-12.9875 + 0.1992*X1 + (-40.4211*X2) + 2.3175*(X1*X2))))$$

Example for Calculating the Predicted Probability for Encountering A. humilis

To further illustrate the use of Eq. 2 in future calculations of predicted outcomes using the selected logistic model, the following two examples are provided:

1) If X1 = 45%, and X2 = 1 (indicating presence of either *A. globiceps* or *A. humilis* in the vicinity of the surveyed transect), then the predicted probability of encountering *A. humilis* at the surveyed transect is:

$$P = 1/(1 + \exp(-(-12.9875 + 0.1992*45 + (-40.4211*1) + 2.3175*(45*1))))$$

P = 1 or 100%

In the above example, Eg.1, the probability of encountering *A. humilis* when the abundance of hard coral is 45% and a protected species (i.e., *A. humilis* or *A. globiceps*) is present in the vicinity of a transect, is 100%.

2) If X1 = 20%, and X2 = 0 (indicating absence of either *A. globiceps* or *A. humilis* in the vicinity of the surveyed transect), then the predicted probability of encountering A. humilis at the surveyed transect is:

P = 1/(1 + exp(-(-12.9875 + 0.1992*20 + (-40.4211*0) + 2.3175*(45*0))))

P = 0.000122964 or 0.012%

In the above example, Eg.2, the probability of encountering *A. humilis* when the abundance of hard coral is 20% and a protected species (i.e., *A. humilis* or *A. globiceps*) is absent in the vicinity of a transect, is 0.01%.

Round 2 Logistic Modelling Results

For the second round of logistic modelling, similar to round 1, a total of 14 models were developed that incorporated each explanatory variable separately and in combination with other variables to further evaluate significance of interaction effects (Appendix E). Colonizable substrate, depth and abundance of macroalgae entered significantly and independently in three of the 14 models (Table 13; Appendix F). The interactive factors between macroalgae and depth, and between colonizable substrate, depth, and macroalgae also entered significantly in two other models. The model that included the interaction between macroalgae and depth had the lowest AIC value making it the best fit model. Therefore, to further test the main effects of the interactive variables independently along with the interaction factor, a separate model was evaluated with all three parameters (Table 13). Although a significant association was not observed between the coefficients of the three parameters, the AIC yielded the second lowest value among all other candidate models. Given that the interactive factor between macroalgae and depth entered significantly in the best fit model (AIC = 37.383), the main effects also were included in the model that was subsequently selected as the final model for predicting the occurrence of either protected species, *A. humilis* or *A. globiceps,* in the vicinity of a surveyed transect.

Table 13. Model statistics for 14 logistic models evaluated for determining the probability of encountering either protected species, *A. humilis* or *A. globiceps* in the vicinity of a surveyed transect.

Model	Estimated Coefficient	Standard Error	P-value	AIC
1. Colonizable Substrate	0.1603	0.056	0.004	47.461
2. Depth	-0.2324	0.116	0.044	52.747
3. Hard Coral	0.0069	0.021	0.74	58.323
4. Macroalgae	-0.2195	0.099	0.026	45.521

Table 13 (continued). Model statistics for 14 logistic models evaluated for determining the probability of encountering either protected species, *A. humilis* or *A. globiceps* in the vicinity of a surveyed transect.

Model	Estimated Coefficient	Standard Error	P-value	AIC
5. Maximum Rugosity	0.0023	0.002	0.33	57.506
6. Other Invertebrates	0.2551	0.187	0.173	56.717
7. Other Organisms	0.1342	0.095	0.159	56.561
8. Turf Algae	-0.0324	0.028	0.247	56.971
9. COT	-0.7916	0.929	0.394	57.431
10. Colonizable Substrate * Macroalgae	-0.0091	0.007	0.216	56.203
11. Colonizable Substrate * Depth	0.0023	0.011	0.835	58.386
12. Macroalgae * Depth	-0.2303	0.108	0.033	37.383
13. Colonizable Substrate*Depth*Macroalgae	-0.013	0.006	0.036	46.337
14. Macroalgae +	-0.0395	0.093	0.67	41.041
Depth +	0.0153	0.167	0.927	41.041
Macroalgae*Depth	-0.2083	0.137	0.129	41.041

The equation for the selected logistic regression model for predicting the occurrence of either *A. humilis* or *A. globiceps* is as follows:

$$\text{logit}(P) = \beta0 + \beta1*Z1 + \beta2*Z2 + \beta3*(Z1*Z2) \quad \text{Eq. 3}$$

Where:

- logit (P) represents the log odds of encountering either *A. humilis* or *A. globiceps*
- P represents the probability of encountering *A. humilis* or *A. globiceps*.
- β0, β1, β2, and β3 are the estimated coefficients from the logistic regression model.
- Z1 and Z2 are the values for macroalgae abundance and depth (m), respectively.
- Z1*Z2 represents the interaction term between Z1 and Z2.

Substituting the model estimates in Eq. 3, yields:

$$\text{logit}(P) = 0.37375 + (-0.03955*Z1) + (0.01528*Z2) + (-0.20827*(Z1*Z2)))$$

To obtain the predicted probability (P) for specific values of Z1 and Z2, the logistic function is applied to convert the logit back to the predicted probability, using the following equation:

$$P = 1/(1 + \exp(-(\beta0 + \beta1 * Z1 + \beta2 * Z2 + \beta3 * Z1*Z2))) \quad \text{Eq. 4}$$

or,

$$P = 1/(1 + \exp(-(0.37375 + (-0.03955*Z1) + (0.01528*Z2) + (-0.20827*(Z1*Z2)))))$$

Example for Calculating the Predicted Probability for Encountering the ESA species, A. humilis or A. globiceps

To further illustrate the use of Eq. 4 in future calculations of predicted outcomes using the selected logistic model, the following examples are provided:

3) If Z1 = 15%, and Z2 = 5m, then the predicted probability of encountering the ESA species, *A. humilis* or *A. globiceps* in the vicinity of a surveyed transect is:

$$P = 1/(1 + \exp(-(0.37375 + (-0.03955*15) + (0.01528*5) + (-0.20827*(15*5)))))$$

$$P = 0.000000142 \text{ or } 0.0000142\%$$

In the above example, Eg.3, the probability of encountering either ESA species in the vicinity of a surveyed transect where the macroalgae abundance is 15% and the depth is 5m is 0.00001%.

4) If Z1 = 1.5%, and Z2 = 10m, then the predicted probability of encountering *A. humilis* at the surveyed transect is:

$$P = 1/(1 + \exp(-(0.37375 + (-0.03955*1.5) + (0.01528*10) + (-0.20827*(1.5*10)))))$$

$$P = 0.06557 \text{ or } 6.56\%$$

In the above example, Eg.4, the probability of encountering either ESA species in the vicinity of a surveyed transect where the macroalgae abundance is 1.5% and the depth is 10m is 6.6%.

Model Application: Uses and Limitations

Two models were successfully developed for predicting the presence of ESA species using relatively few factors that can be readily measured and recorded in the field. The model developed in Round 1 demonstrated that the abundance of hard coral and the presence of an ESA species in the vicinity were important factors in predicting the presence, specifically, of *A. humilis* along transects. Other physical factors such as rugosity and colonizable substrate did not appear to have a significant influence on the presence of *A. humilis*. Other functional groups such as turf algae, COTS, and other invertebrates and organisms also did not show a significant effect on predicting the presence of *A. humilis*. It is possible that these factors may be important in predicting the presence of other ESA species that were not encountered in the current study's transect or vicinity surveys. Future surveys conducted in other areas of the Hågat and Asan units may yield observations of the other ESA species of interest that could subsequently be used in developing new models to evaluate the factors that may influence and help predict their presence or absence.

The model developed in Round 2 was based on input data that included one other species, *A. globiceps*, thereby broadening the applicability of the model and helping to further elucidate the role of the dependent variables in predicting the occurrence of either of the two ESA species. Although the final selected model included abundance of macroalgae and depth as important predictors for the presence of *A. humilis* or *A. globiceps*, it is relevant to note that the variable, colonizable substrate

also showed a significant effect on predictability of ESA species and may serve as a potential surrogate variable in future analyses undertaken for model refinement.

It is important to note that predictive models such as those developed in this study require validation using an independent data set in order to ensure that the model generalizes well to new data and is not subject to overfitting (i.e., conforming to specific patterns and noise present only in the training data thereby losing its ability to make accurate predictions with new data). The dataset used to develop the predictive models was limited to 61 sites across both beach units with ESA species recorded at only two of the 61 sites. Therefore, it was not possible to reserve a separate set of sites for model validation and refinement. Of the five ESA species of interest, only one species was observed at the surveyed transects. A logistic model could therefore only be developed for predicting the occurrence of this species. While the second model provided an algorithm for predicting the occurrence of any ESA species, the lack of variability in the data set (i.e., only two out of 61 observations included an ESA species), further contributes to the uncertainty of the model's predictive ability for other ESA species of interest.

Despite the limitations discussed, the derived models are an important first step towards developing essential tools to predict hard coral distribution in highly heterogeneous areas of WAPA. These models serve as baseline algorithms that can be immediately used to identify potential areas for targeted surveys and can also be further refined with the collection of additional data on future surveys.

Qualitative Results for Coral Diversity Surveys

Species Totals: WAPA Waters and Individual Units

A total of 245 hard coral species, including 241 scleractinian coral species representing 49 genera and 4 non-scleractinian coral species representing 4 genera were recorded during the timed roving diver coral diversity surveys conducted within reef areas occurring on WAPA submerged lands. An additional 3 scleractinian coral species from 3 genera and one non-scleractinian coral species were observed at the diversity survey sites after the 45-minute survey period; one scleractinian genus (*Euphyllia*) had not been recorded during the survey period. Four additional species representing 4 genera were identified from the quantitative transect point counts and from the supplementary images obtained at the transect sites surveyed by the EnviroScience team in April 2022. A review of images of corals obtained by DB while diving or snorkeling in WAPA waters between October 2007 and May 2022 yielded 21 additional species not detected at the diversity or photo transect survey sites. In total, 274 hard coral species were recorded from WAPA submerged lands prior to and during the coral diversity surveys. A comprehensive list of all hard corals observed at the diversity survey sites is provided in Appendix G, and a list of additional species, including those identified in images obtained by EnviroScience staff at the transect survey sites and those photographed on WAPA submerged lands prior to the diversity surveys, is provided in Appendix H. The approximate locations of all colonies photographed at the diversity survey sites within the Asan and Hågat units are provided in Figure 17 and Figure 18.

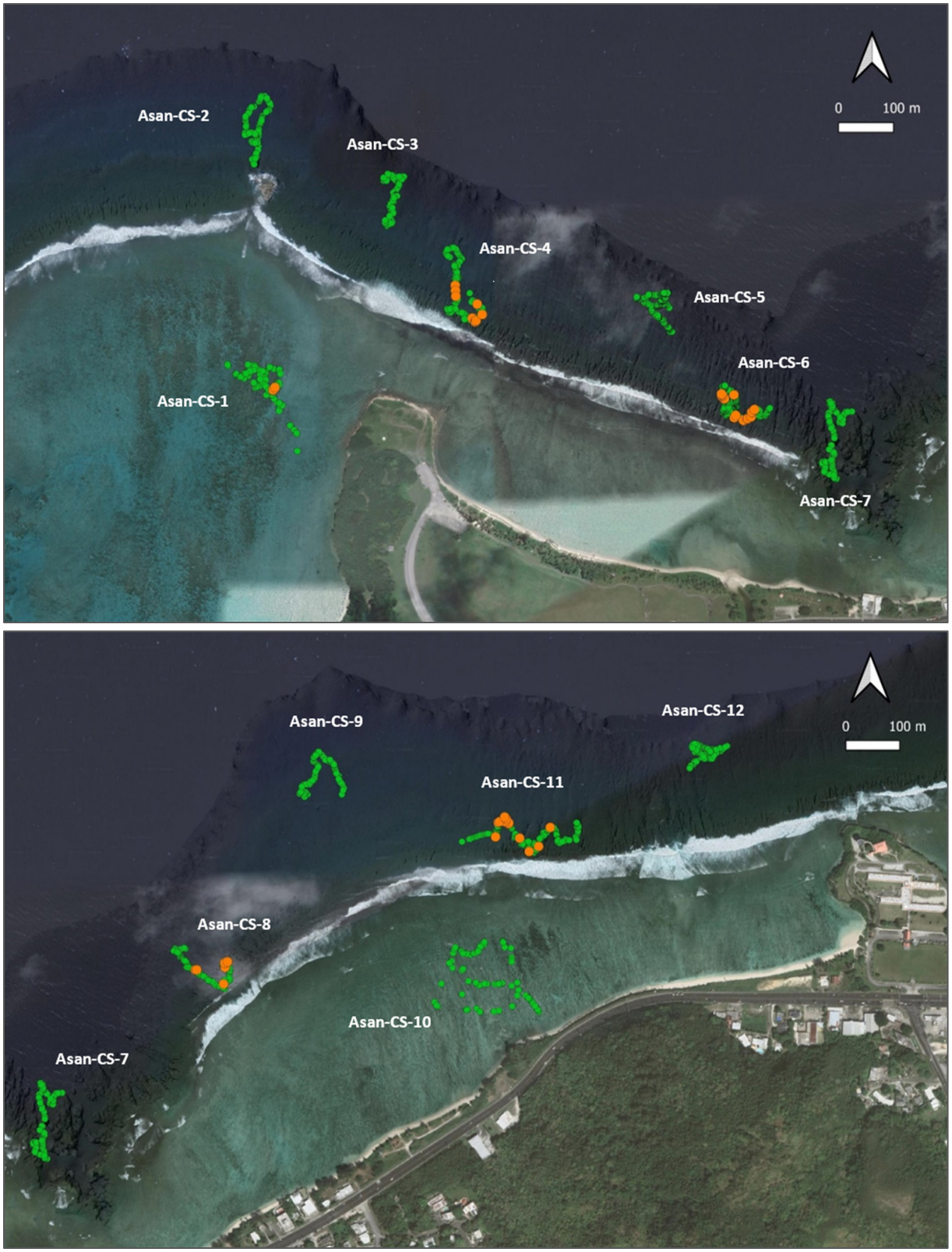


Figure 17. Location of all coral colonies (green dots) photographed at the coral diversity survey sites in the western (top) and eastern (bottom) portions of the WAPA Asan unit. The larger orange dots represent the locations of *Acropora globiceps* colonies.



Figure 18. Location of all coral colonies (green dots) photographed at the coral diversity sites occurring in the WAPA Hågat unit. The larger orange dot represents the location of the single *Acropora globiceps* colony observed in the Hågat unit.

Species Richness and Unique Species Within WAPA Waters, Beach Units, and Reef Zones

Asan vs Hågat Beach Units

A total of 215 scleractinian species representing 42 genera were observed within the Asan unit during the coral diversity surveys, while 169 scleractinian coral species representing 41 genera were observed within the Hågat unit. Three non-scleractinian coral species representing 3 genera were observed within the Asan unit and 4 non-scleractinian species representing 4 genera were observed within the Hågat unit during the surveys. Of the additional 29 total species observed outside of the 45-minute survey period at the diversity survey sites, those detected at the photo transect sites, and those observed between 2007 and 2022, 18 were observed in the Asan unit and 11 were observed in the Hågat unit. In total, 236 species were detected within the Asan unit prior to and during the diversity surveys, while a total of 184 species were detected within the Hågat unit.

The number of hard coral (scleractinian and non-scleractinian) species at diversity survey sites within the Asan unit ranged from 23 to 98, with a mean of 73 ± 21, while the number of species at sites within the Hågat unit ranged from 40 to 84, with a mean of 66 ± 14 (Figure 19). The mean number of species in the Asan unit was negatively skewed by the exceptionally low number of species (23) observed at the shallow reef flat site Asan-CS-10. Excluding all reef flat survey sites, a mean of 81 ± 10 species was observed within the Asan unit and a mean of 70 ± 10 species was observed within the Hågat unit.

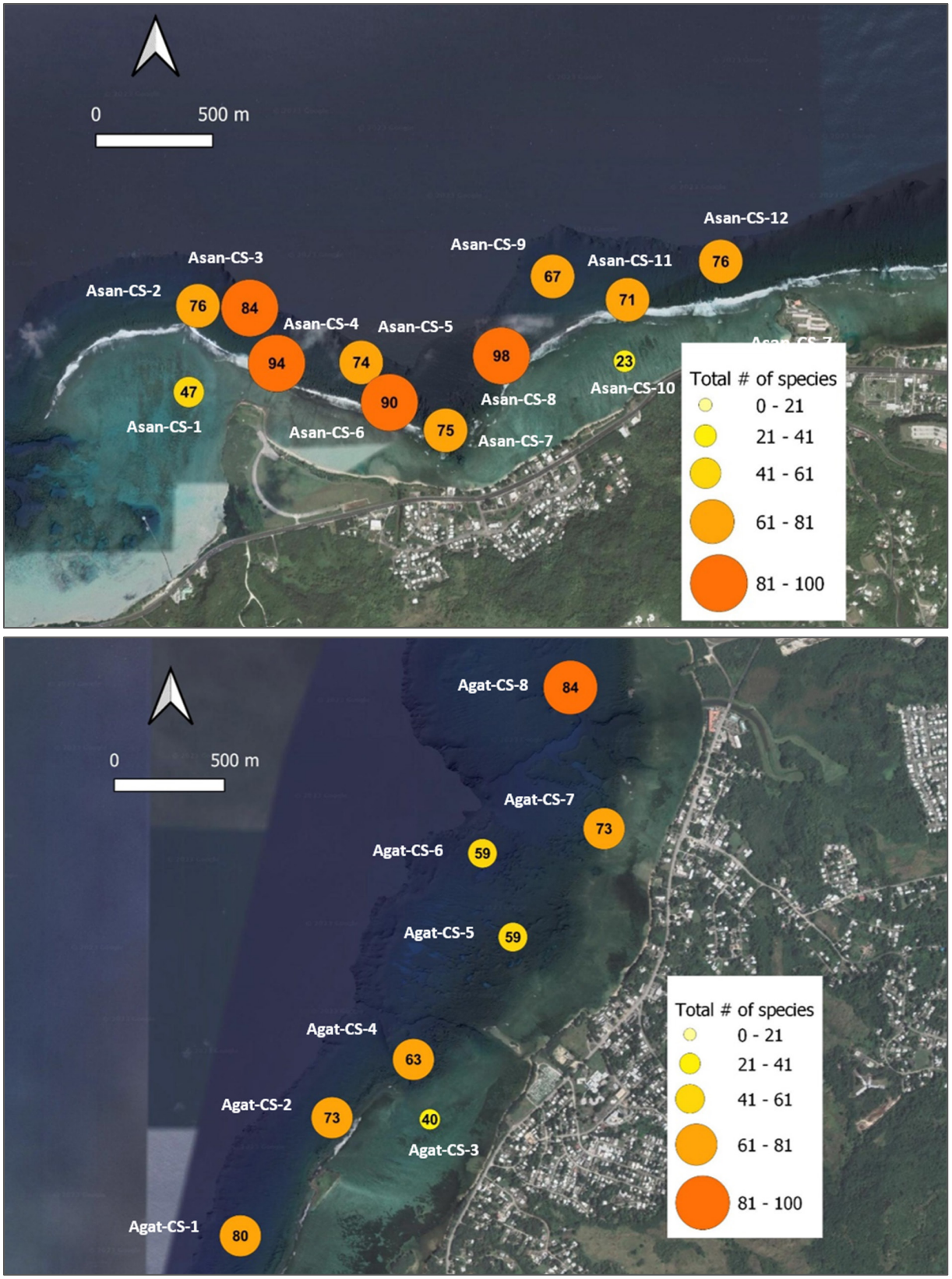


Figure 19. Total number of hard coral species recorded during diversity surveys at sites within the WAPA Asan (top) and Hågat (bottom) units.

Differences by Habitat Type

A similar number of species was detected at sites within the reef front and seaward slope zones during the diversity surveys within WAPA waters, while the reef flat sites generally hosted lower numbers of species. A total of 167 species and a mean of 78 ± 15 species (range of 59 to 98 species) were observed at reef front sites, a total of 184 species and a mean of 75 ± 8 species (range of 59 to 84 species) were observed at the seaward slope sites, and a total of 67 species and a mean of 37 ± 12 (range of 23 to 47) species were observed at the reef flat sites.

The waters of the Asan unit hosted 67 hard coral species that were not observed in the Hågat unit, including the now uncommon, and likely undescribed, *Acropora* sp. "obtusicaulis," which is restricted to the upper reef front and reef margin zones, and *Acropora monticulosa*, another species restricted to shallow, wave exposed reef areas (Table 14). A thicket formed by a species that closely resembles the staghorn coral, *Acropora aspera*, was also observed on a reef flat within the Asan unit. While fewer coral species were observed in park waters offshore of the village of Hågat, the area still hosted 22 species not observed in the Asan unit (Table 14), including *Acropora muricata*, a staghorn species now rare in Guam's waters, and *Pavona clavus*, a rare species in Guam's waters that formed a large portion of Hap's reef and which is now only found in small patches on the reef (Figure I-17 of Appendix I).

Table 14. List of unique hard coral species only observed within the WAPA Asan unit and only within the Hågat unit during the coral diversity surveys and supplemental data reviews.

Family	Species	Asan [4]	Hågat [4]
Acroporidae	*Acropora* cf. *aspera* [3]	X	–
Acroporidae	*Acropora* cf. *cerealis sensu* Randall	X	–
Acroporidae	*Acropora* cf. *latistella*	X	–
Acroporidae	*Acropora* cf. *cophodactyla sensu Veron* 2000 [3]	–	X
Acroporidae	*Acropora* cf. *minuta*	X	–
Acroporidae	*Acropora* cf. *multiacuta-loripes*	X	–
Acroporidae	*Acropora* cf. *valida sensu* Veron	X	–
Acroporidae	*Acropora gemmifera sensu* Randall [3]	X	–
Acroporidae	*Acropora monticulosa*	X	–
Acroporidae	*Acropora muricata*	–	X
Acroporidae	*Acropora paniculate*	X	–
Acroporidae	*Acropora selago sensu* Randall	X	–
Acroporidae	*Acropora* sp. "obtusicaulis"	X	–
Acroporidae	*Acropora* sp. A	X	–

[1] Species representing genera observed only within the corresponding unit during the diversity surveys.

[2] Species detected in the corresponding unit from supplemental photographs at transect sites.

[3] Burdick between Oct. 2007 and May 2022.

[4] An "X" denotes that a species was detected and an endash (–) denotes that a species was not detected.

Table 14 (continued). List of unique hard coral species only observed within the WAPA Asan unit and only within the Hågat unit during the coral diversity surveys and supplemental data reviews.

Family	Species	Asan [4]	Hågat [4]
Acroporidae	*Acropora* sp. B	X	–
Acroporidae	*Alveopora tizardi* [1]	X	–
Acroporidae	*Astreopora* cf. *elliptica*	X	–
Acroporidae	*Montipora berryi*	–	X
Acroporidae	*Montipora* cf. *colei sensu* Randall	X	–
Acroporidae	*Montipora danae*	X	–
Acroporidae	*Montipora efflorescens sensu* Randall	X	–
Acroporidae	*Montipora grisea-informis*	X	–
Acroporidae	*Montipora socialis sensu* Randall	X	–
Acroporidae	*Montipora studeri* [3]	X	–
Acroporidae	*Montipora tuberculosa*	X	–
Acroporidae	*Montipora venosa*	X	–
Acroporidae	*Montipora* sp. -foveolate A	X	–
Acroporidae	*Montipora* sp. -glabrous A	X	–
Acroporidae	*Montipora* sp. -glabrous B	X	–
Acroporidae	*Montipora* sp. -papillate C	X	–
Acroporidae	*Montipora* sp. -papillate [2]	X	–
Acroporidae	*Montipora* sp. -papillate F	X	–
Acroporidae	*Montipora* sp. -tuberculate A	X	–
Acroporidae	*Montipora* sp. -tuberculate B	X	–
Acroporidae	*Montipora* sp. -tuberculate [2]	–	X
Acroporidae	*Montipora* sp. -tuberculate E	X	–
Agariciidae	*Leptoseris explanata*	X	–
Agariciidae	*Leptoseris* cf. *hawaiiensis*	–	X
Agariciidae	*Leptoseris* sp. "rubra"	X	–
Agariciidae	*Pavona bipartite*	–	X
Agariciidae	*Pavona cactus*	–	X
Agariciidae	*Pavona clavus*	–	X
Agariciidae	*Pavona* sp. "encrustans"	X	–
Coscinaraeidae	*Coscinaraea columna* [1 3]	–	X
Dendrophylliidae	*Turbinaria* cf. *irregularis*	X	–
Euphylliidae	*Galaxea astreata*	–	X

[1] Species representing genera observed only within the corresponding unit during the diversity surveys.

[2] Species detected in the corresponding unit from supplemental photographs at transect sites.

[3] Burdick between Oct. 2007 and May 2022.

[4] An “X” denotes that a species was detected and an endash (–) denotes that a species was not detected.

Table 14 (continued). List of unique hard coral species only observed within the WAPA Asan unit and only within the Hågat unit during the coral diversity surveys and supplemental data reviews.

Family	Species	Asan [4]	Hågat [4]
Fungiidae	*Cycloseris* cf. *erosa*	X	–
Fungiidae	*Cycloseris cf. tenuis*	X	–
Fungiidae	*Cycloseris explanulata*	X	–
Fungiidae	*Cycloseris vaughani*	X	–
Fungiidae	*Danafungia scruposa sensu Veron*	–	X
Fungiidae	*Herpolitha limax*	X	–
Fungiidae	*Pleuractis paumotensis*	X	–
Fungiidae	*Polyphyllia talpina* [1]	X	–
Fungiidae	*Sandalolitha dentata* [1]	X	–
Fungiidae	*fungiid sp. A*	X	–
Leptastraeidae	*Leptastrea pruinosa*	X	–
Lobophylliidae	*Acanthastrea cf. hemprichii*	X	–
Lobophylliidae	*Acanthastrea cf. regularis*	X	–
Lobophylliidae	*Lobophyllia robusta*	X	–
Lobophylliidae	*Lobophyllia* sp. A	–	X
Merulinidae	*Cyphastrea ocellina sensu Randall*	X	–
Merulinidae	*Dipsastrea cf. lizardensis*	X	–
Merulinidae	*Favites abdita*	X	–
Merulinidae	*Favites cf. sp. "crassisepta"*	X	–
Merulinidae	*Favites rotundata*	X	–
Merulinidae	*Goniastrea cf. favulus*	X	–
Merulinidae	*Platygyra sp. A*	X	–
Merulinidae	*Scapophyllia cylindrica* [1]	X	–
Plerogyridae	*Plerogyra simplex* [1]	–	X
Pocilloporidae	*Pocillopora* cf. *bairdi*	–	X
Pocilloporidae	*Pocillopora* cf. *brevicornis*	–	X
Pocilloporidae	*Pocillopora cf. kelleheri*	X	–
Pocilloporidae	*Pocillopora sp. 2*	X	–
Pocilloporidae	*Stylophora* sp. *"mordax"* [1]	–	X
Poritidae	*Goniopora* cf. *palmensis*	–	X
Poritidae	*Goniopora cf. tenella sensu Veron 2000*	X	–
Poritidae	*Goniopora sp. -encrusting B*	X	–

[1] Species representing genera observed only within the corresponding unit during the diversity surveys.

[2] Species detected in the corresponding unit from supplemental photographs at transect sites.

[3] Burdick between Oct. 2007 and May 2022.

[4] An “X” denotes that a species was detected and an endash (–) denotes that a species was not detected.

Table 14 (continued). List of unique hard coral species only observed within the WAPA Asan unit and only within the Hågat unit during the coral diversity surveys and supplemental data reviews.

Family	Species	Asan [4]	Hågat [4]
Poritidae	*Goniopora* sp. -encrusting C	–	X
Poritidae	*Goniopora sp. -massive A*	X	–
Poritidae	*Goniopora* sp. -massive C	–	X
Poritidae	*Goniopora sp. -massive* [2]	X	–
Poritidae	*Goniopora sp. -submassive A (short brown polyps)*	X	–
Poritidae	*Porites cf. densa*	X	–
Psammocoridae	*Psammocora obtusangula sensu* Randall	–	X
Psammocoridae	*Psammocora sp. "loculata"*	X	–
Psammocoridae	*Psammocora* sp. "rosacea"	–	X
Psammocoridae	*Psammocora stellata*	X	–
Tubiporidae	*Tubipora musica* [1]	–	X

[1] Species representing genera observed only within the corresponding unit during the diversity surveys.

[2] Species detected in the corresponding unit from supplemental photographs at transect sites.

[3] Burdick between Oct. 2007 and May 2022.

[4] An "X" denotes that a species was detected and an endash (–) denotes that a species was not detected.

Unique Species

All diversity survey sites except a single site in the Hågat unit (Agat-CS-2) hosted at least one hard coral species not found at any other site (Figure 20). Most survey sites within the Hågat unit hosted one or two unique species, with the exception of site Agat-CS-8, at which 3 species unique to that site were observed. Survey sites within the Asan unit generally hosted a larger number of unique species, with 4 sites hosting 5 or 6 unique species and 2 sites with 3 unique species. Site Asan-CS-5 and Asan-CS-6 hosted the greatest number of unique species (6).

A total of 43 hard coral species occurred in all three major reef zones (reef flat, reef front/margin, and seaward slope zones) covered by the diversity survey. A total of 105 species were only found within a single reef zone, including 6 only found within the reef flat zone, 34 within the reef front/margin zone, and 65 within the seaward slope zone. A total of 93 species were found within two zones. It is important to note, however, that while a species may have been recorded within two or three reef zones, without relative abundance data the contribution of a given species to the coral community within a reef zone, and the likelihood of encountering the species within the zone, can only be roughly approximated based on qualitative observations made during the diversity surveys. It should also be noted that the surveys at some of the sites included a short period of time on a part of the reef that could be considered a different reef zone than where the majority of the survey was conducted—especially when the boundary between two zones was even less distinct than usual.

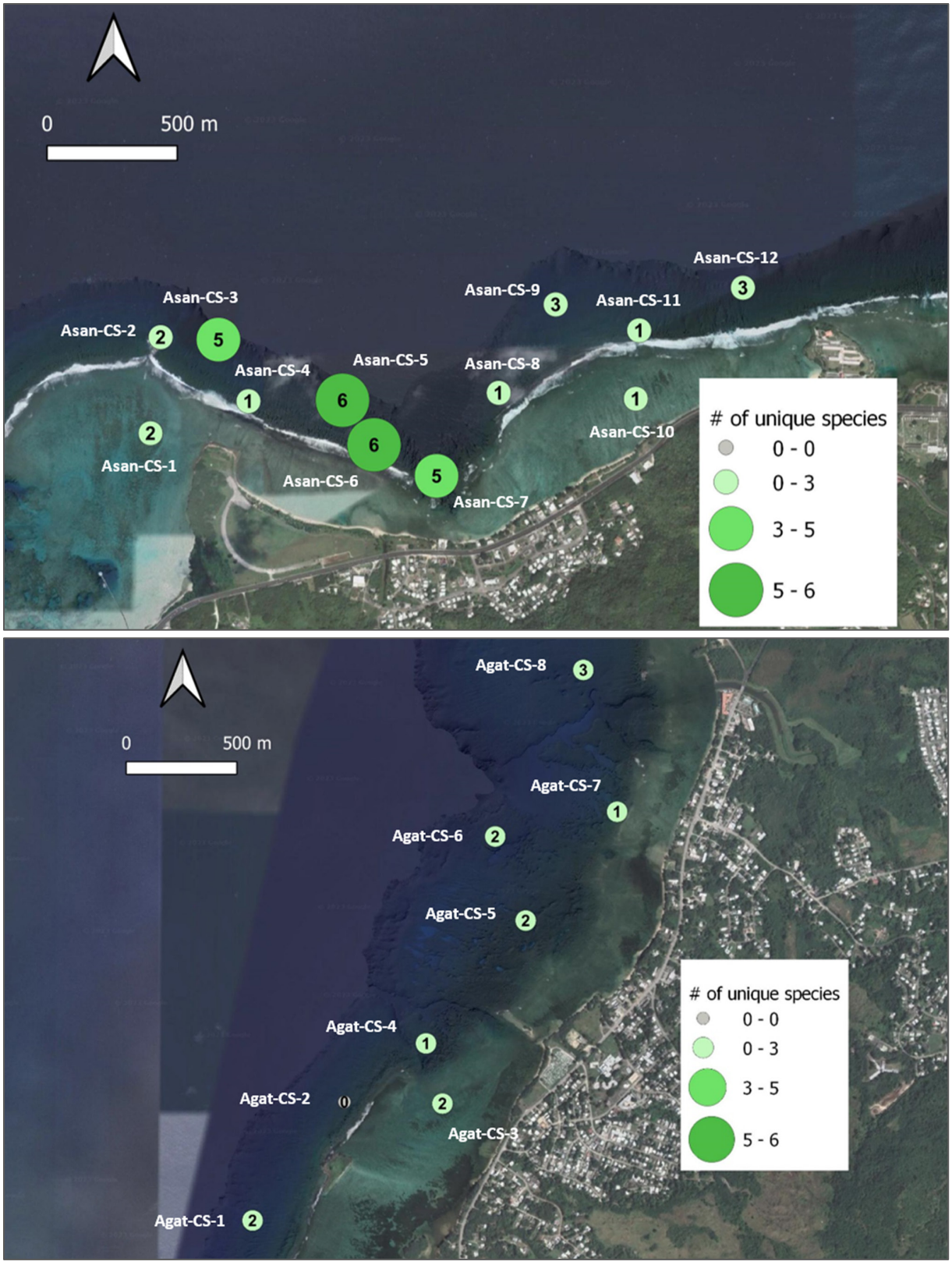


Figure 20. Total number of hard coral species unique to each diversity survey site within the WAPA Asan (top) and Hågat (bottom) units.

Rarefaction/Extrapolation Curves: Estimated Species Richness with Additional Effort/Sample Coverage

Based on a rarefaction/extrapolation curve generated using species incidence frequencies (for only species occurring within the 45-min survey period) an estimated total of 267 species are expected to occur within WAPA waters; bootstrap lower and upper limits (95% confidence) were 246 and 288 species, respectively (Figure 21a). An estimated 255 species (range of 224 to 286 species) are expected to occur within the Asan unit, and an estimated 198 species (range of 178 to 217 species) are expected to occur in the Hågat unit (Figure 21b). A sample completeness curve generated using the species frequency data indicated that the number of species detected at the diversity survey sites represented 97% of the estimated total number of species for WAPA waters, suggesting the sample size of 20 sites was sufficient for detecting nearly all of the species within WAPA waters (Figure 22a). However, the sample coverage for the number of sites surveyed within each unit was lower, at 94% for Asan and 92% for Hågat, suggesting that several additional sites would need to be surveyed to attain a similar sample coverage rate for each beach unit (Figure 22b).

The additional 4 species observed at the diversity survey sites outside the survey period, the 4 species observed at the transect survey sites, and the 21 species observed in park waters between 2007 and 2022 place the 274 total species observed in park waters above the 267 total estimated with the rarefaction/extrapolation curve, and towards the bootstrap upper limit (288 species). However, the additional ~65 species considered likely to occur within WAPA waters (Appendix J) would put the total at around 340 species, far higher than even the bootstrap upper limit estimated from the rarefaction/extrapolation curve.

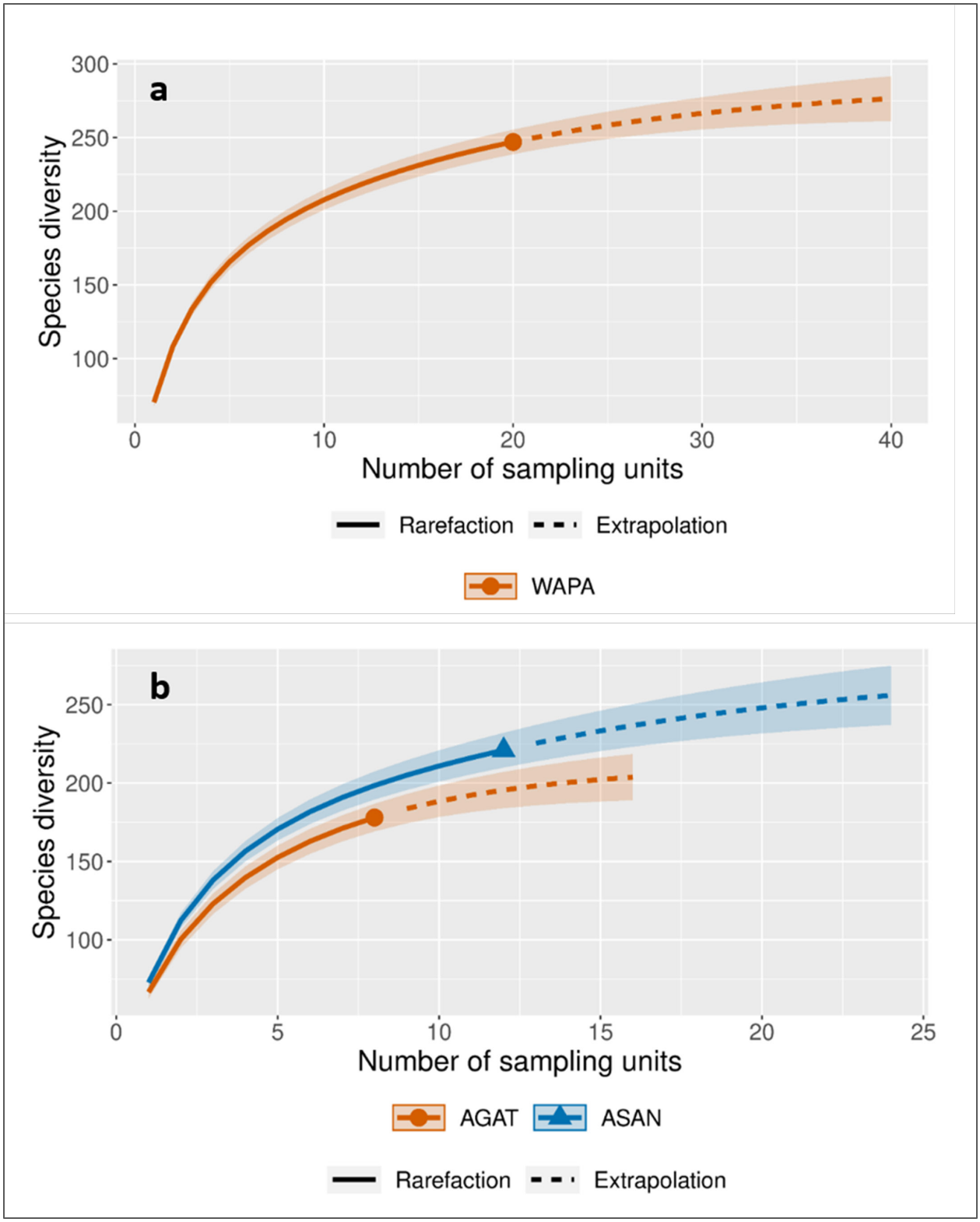


Figure 21. Sample size-based rarefaction and extrapolation curves generated using species incidence frequency data for all coral diversity sites occurring on WAPA submerged lands (top) and for the Asan and Hågat units separately (bottom).

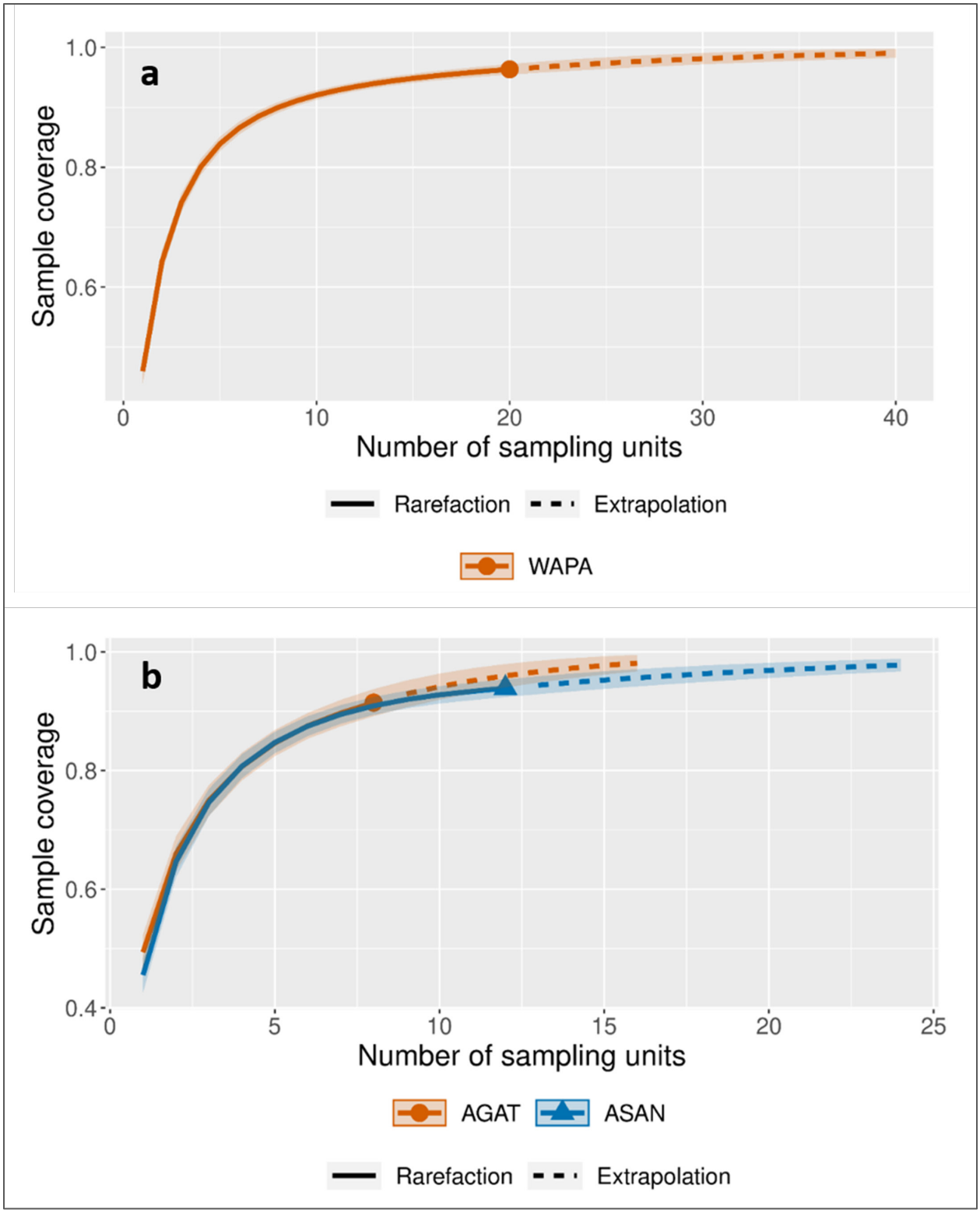


Figure 22. Sample completeness curves generated using species incidence frequency data for all coral diversity sites occurring on WAPA submerged lands (top) and for the Asan and Hågat units separately (bottom).

Protected Species – Qualitative Diversity Survey Sites

A total of 46 colonies of the ESA-listed coral species*, Acropora globiceps*, were observed at the coral diversity survey sites. No other ESA-listed coral species were observed at the diversity survey sites, at the transect survey sites, or in WAPA waters by DB prior to the surveys. Including the 18 colonies observed at the transect survey sites, 64 *A. globiceps* colonies were observed during this study. All but one of the *A. globiceps* colonies observed during the diversity surveys occurred within the Asan unit, and all but two were observed within the reef front zone. Two colonies were observed on the reef flat ~225 m to the west of Asan Pt. and ~200 m landward of the reef margin (site Asan-CS-1), an area with vigorous water movement. *Acropora globiceps* was observed at all 4 of the survey sites occurring within the reef front zone in the Asan unit, but at only one of the 4 reef front sites in the Hågat unit. The largest number (16) of *A. globiceps* colonies was observed at site Asan-CS-6, located ~200 m northwest of Asan Cut, while 11 and 9 colonies were observed at sites Asan-CS-11 and Asan-CS-4, respectively. *Acropora globiceps* was observed at three other diversity survey sites, including Asan-CS-8 (7 colonies), Asan-CS-1 (2 colonies), and Agat-CS-7 (1 colony).

Inventory Year Comparison

In order to compare hard coral species across study years, names were standardized according to Dave Burdick's expertise. The adjusted number of species observed is displayed in Table 15, and a complete list of species for each study is presented in Appendix C. It is difficult to compare results from 1977 due to the way the report combined qualitative and quantitative results. By comparison, the 1999 and 2022 methods were similar, and quantitative mean results are similar for Agat and Asan beach units.

Table 15. Comparison of WAPA coral inventories conducted in 1977, 1999, and 2022, including number of sites, percent coral cover, and taxa observed.

Beach Unit	Year	No. Sites1	Min %	Max %	Mean %	No. Species	No. Genera
Hågat	1977	12	1	59.80	24.97	153[2]	49
	1999	24	<0.01	19.05	5.81	34	17
	2022[3]	35	0	11.14	4.97	44	25
	2022[4]	8	NA	NA	NA	173	45
Asan	1977	NA	NA	NA	NA	NA	NA
	1999	16	<0.01	84.33	22.27	32	19
	2022[3]	26	0.63	64.51	21.89	52	24
	2022[4]	12	NA	NA	NA	218	45

[1] 1977 transects = 100 m long plus 20-minute search along the transect; 1999 and 2022 transects = 50 m long; 2022 roving diver survey = 45 minutes

[2] Additionally includes all species found from 20-minute qualitative analysis

[3] Quantitative portion of 2022

[4] Qualitative portion of 2022

Table 15 (continued). Comparison of WAPA coral inventories conducted in 1977, 1999, and 2022, including number of sites, percent coral cover, and taxa observed.

Beach Unit	Year	No. Sites1	Min %	Max %	Mean %	No. Species	No. Genera
All	1977	12	1	59.80	24.97	153[2]	49
	1999	40	<0.01	84.33	12.39	42	21
	2022[3]	61	0	64.51	12.18	60	27
	2022[4]	20	NA	NA	NA	245	53

[1] 1977 transects = 100 m long plus 20-minute search along the transect; 1999 and 2022 transects = 50 m long; 2022 roving diver survey = 45 minutes

[2] Additionally includes all species found from 20-minute qualitative analysis

[3] Quantitative portion of 2022

[4] Qualitative portion of 2022

Table 16 compares the coral cover and diversity between the historical transects in Asan. Asan-H07 had the largest loss in coral cover (-78.72%), but the greatest gain in diversity (+5). Asan-H02 and -H09 also had decreases in coral cover (-17.38% and 23.92% respectively) and diversity (-2 for both). By comparison, Asan-H01 had an increase in coral cover (10.98%) and decrease in diversity (-3).

Table 16. Coral cover and diversity comparison between 1999 and 2022 repeated transects in Asan.

	1999		2022			
Transect No.	Diversity	% Coral Cover	Diversity	% Coral Cover	%Change in Diversity	% Change in Cover
Asan-H01	11	53.53	8	64.51	-3	10.98
Asan-H02	11	73.57	9	56.19	-2	-17.38
Asan-H07	3	83.62	8	4.90	+5	-78.72
Asan-H09	10	84.33	8	60.41	-2	-23.92

Discussion

Benthic Cover in Hågat Unit vs Asan Beach Unit

The data gathered in 1977, 1999, and 2022 indicate a notable decline in coral cover in the Hågat unit over time (Table 16). Coral cover was substantially higher in 1977, followed by a decrease in 1999 and a further reduction in 2022 (Eldridge et al. 1977, Amesbury et al. 1999). Since park annual surveys suggests coral cover in the Hågat unit has remained stable from 2008–2019 at 3% (2008 – 3.0%, 95% CI = 2.4–3.7%; 2019 – 3.4%, 95% CI = 2.4–4.0%; McCutcheon and McKenna, 2021), the significant loss of coral cover occurred primarily between 1977 and 1998 (Table 16). Transect coral cover at the Hågat unit was slightly higher during this study at 4.97% ± 0.54% compared to cover at fixed transect sites surveyed by WAPA park staff suggesting the permanent transect sites may not be fully representative of the entire Hågat unit. Although there is value in conducted fixed permanent surveys, it may be worthwhile for NPS to conduct stratified random surveys across beach units every few years to track coral cover across the greater area. Additionally, it would be beneficial to implement regular manta tow surveys to detect and document large-scale disturbances around the park (McCutcheon and KcKenna 2021).

Coral cover at the Asan beach unit during this study was about 22% (21.89% ± 3.92%) which reflects the stable coral cover reflected in NPS WAPA annual surveys spanning from 2008–2019 (2008 – 21.8%, 95% CI = 10.7–32.8%; 2019 –22.3%, 95% CI = 15.6–29.0%; McCutcheon and McKenna, 2021). This number is also congruous with the coral cover reported by Amesbury et al. in 1999.

The deeper (> 15 m) seaward slope areas in the Asan beach unit observed during the diversity surveys, such as coral diversity sites Asan-CS-3 and Asan-CS-12, hosted significantly greater coral cover, fewer instances of compromised coral colony health, and overall better substrate condition in comparison to the seaward slope in the Hågat unit (Figure I-19 of Appendix I) However, the coral communities at these mid-depth and deeper sites in the Asan beach unit were primarily dominated by mounding *Porites* spp. and *P. rus*, with few *Acropora*, *Montipora*, and other more stress-susceptible species, suggesting that the decades of documented predation by crown-of-thorns sea stars, impacted water quality, depauperate herbivorous fish populations, and, more recently, severe heat stress have likely shifted these communities towards a fewer number of dominant, generally stress-tolerant coral taxa.

Stressors and their Implications

Guam's coral reefs face a myriad of daunting threats that jeopardize their health and long-term survival. These vital underwater ecosystems have been severely impacted by a combination of natural and anthropogenic factors. Rising sea temperatures due to climate change have induced coral bleaching events, causing the corals to expel their symbiotic algae and makes them more susceptible to diseases and mortality (McCutcheon and McKenna 2021; Burdick et al. 2019). Ocean acidification, resulting from the absorption of excess carbon dioxide, also poses a grave concern, as it hampers the ability of corals to build their calcium carbonate skeletons, essential for reef formation.

Moreover, land-based pollution, driven by urban development and agriculture, introduces sediment, nutrients, and contaminants into Guam's coastal waters. These pollutants can smother coral reefs, fuel

harmful algal blooms, and exacerbate the degradation of water quality (Burdick et al. 2019). Overfishing and destructive fishing practices further strain the resilience of these reefs by depleting key herbivorous fish species that play a crucial role in controlling algae and promoting coral growth (Burdick et al., 2019). The ongoing expansion of coastal infrastructure and tourism activities can lead to physical damage to coral reefs through activities like anchor drops and trampling, disrupting the fragile balance of these ecosystems.

Sedimentation

One of Guam's most pressing threats is sedimentation. Environmental conditions commonly influenced by sedimentation have the potential to impact the physiology of marine organisms, with significant implications for their reproductive performance and their ability to provide new recruits. Under stressful conditions, energy originally intended for reproduction may be redirected towards somatic growth and maintenance, ultimately diminishing reproductive fitness (Minton et al 2007).

Sedimentation was present in both Hågat and the Asan units, though it was more commonly encountered in Hågat transects. While significant portions of the reef area within the WAPA Hågat unit are in poor condition due to a variety of stressors, some areas still hosted notable coral communities, such as the relatively high cover of several *Pocillopora* species along the reef margin and upper reef front at coral diversity site Agat-CS-2 and the mixed *Acropora* cf. *pulchra-A. muricata* thickets on the reef flat at coral diversity site Agat-CS-3, offshore of the Agat Cemetery (Figure I-14 of Appendix I). These areas should be a potential focus for park management to prevent further degradation.

Deeper (> approx. 8–10 m) reef areas within the WAPA Hågat unit, such as the reef areas surveyed at coral diversity survey sites Agat-CS-1 and Agat-CS-8, hosted especially low (<10%) coral cover primarily comprised of a small number of generally stress-tolerant taxa such as mounding *Porites* spp. (Figure I-13 of Appendix I). Most of the benthic cover in these areas was comprised of sediment-laden turf algae and macroalgae, indications that water quality is a likely contributor to the poor condition of the benthic community in this area, along with chronic predation by the crown-of-thorns sea stars, disease, depauperate herbivore populations, and severe heat stress events. The quantitative benthic cover results (Figures 2-4) support these observations with clear disparities in benthic cover compositions between Hågat unit and Asan beach unit. The Hågat unit exhibits high abundances of turf algae (Figure A-6a of Appendix A). and unconsolidated sediment while the Asan beach unit presents a different scenario, with hard coral as the dominant benthic cover, followed closely by crustose coralline algae (CCA). These distinct differences in benthic communities underscore the contrasting ecological dynamics and habitats of the two study areas. The Asan beach unit's prevalence of hard coral, CCA, and colonizable substrate suggests a more favorable environment for reef growth and the potential benefits of maintaining robust coral cover in the area.

There is a need for more effective management of point source pollution concerns, particularly when subpar wastewater treatment or runoff from areas with potential pollution or sediment-laden water is flowing from nearby terrestrial environments. An existing challenge lies in the marine water quality monitoring protocol's incapability to detect or pinpoint such occurrences. Future monitoring efforts should aim to establish a framework that facilitates a deeper understanding of potential point source

pollution incidents. This would empower park managers to collaborate with adjacent communities, both within and outside of park boundaries, to mitigate the localized impacts of pollution (McCutcheon and McKenna, 2021).

Crown-of-thorns starfish and Terpios hoshinota

For the past few decades, coral reefs have been increasingly plagued by various pests and other destructive agents. COTS have been recognized for their capacity to initiate outbreaks in Guam, resulting in substantial harm to coral reefs (Hoot 2017) through declines in coral cover, loss of rugosity, and decreased fish and benthic diversity (Kayal et al. 2012). The factors instigating these population surges of COTS are subject to ongoing debate, and the outbreaks typically manifest at a local scale (Timmers et al. 2011, Timmers et al. 2012). Notably, COTS exhibit selective feeding habits, displaying a preference for rapidly growing, branching corals like *Acropora* spp. over slower-growing corals such as *Porites* spp. (De'ath and Moran 1998; Pratchett 2001; McCutcheon and McKenna 2021). This predilection is particularly concerning as the corals most susceptible to bleaching align with those favored by COTS, which can have repercussions on reef diversity. In instances like the Hågat and Asan units, where *Porites* spp. dominate the reefs (potentially due to historical COTS outbreaks, Burdick et al. 2019), the risk of substantial coral cover loss to COTS outbreaks may be lower. Nevertheless, COTS could further diminish the already limited diversity by eradicating preferred coral species in the area. Additionally, COTS have been observed feeding on less preferred corals like *Porites* spp. when their preferred options are scarce (Burdick et al. 2008, McCutcheon and McKenna 2021).

COTS were encountered during transect surveys (Table 10) as well as in coral diversity surveys. including along the upper reef front/reef margin at site Agat-CS-2 (Figure I-16 of Appendix I). The calm waters prevalent in the WAPA Hågat unit allow these coral predators to regularly feed within the shallow depths of the reef front and reef margin, reef zones they typically can't access in other parts of the island due to exposure to a higher amount wave energy. Recently eaten colonies of preferred prey species were regularly encountered at seaward slope sites in both the Hågat and Asan units. Moran and De'ath (1992) characterized a COT outbreak as occurring when there were more than 15 COTS per hectare (or 0.15 per 100m^2), based on their findings that substantial COTS-related coral mortality was evident only on reefs where *Acanthaster* starfish reached or exceeded this density. However, scientists estimate that a healthy coral reef with about 40-50% coral cover can support about 20-30 crown-of-thorns starfish per hectare and according to the definition used for surveys on the Great Barrier Reef, a local crown of thorns population is considered in 'active outbreak status' when densities reach or exceed 30 individuals per hectare. The frequency of these observations (Table 10), particularly in the WAPA Hågat unit and where stress-susceptible corals are already uncommonly encountered, raise concern about the ability of the populations of these coral species to recover following acute disturbance events, and calls in to question the ability of some of these species to persist in WAPA waters, and in Guam's waters more broadly. More frequent crown-of-thorns control efforts, even if only a handful of sea stars are removed during a single effort, may be required to prevent further loss to vulnerable species.

There were several documented incidents of *Terpios hoshinota* covering large sections of branching coral in the reef flat along transects, but it is still unclear how detrimental this sponge is to the overall reef system (Table 11). The black-colored sponge grows symbiotically with several cyanobacteria and is known for occasional massive outbreaks where it smothers and kills corals and other sessile organisms (De Voogd et al. 2013). *Terpios* is native to Guam's coral reef ecosystem and is not categorized as an invasive species. However, it could be characterized as a "nuisance" species, capable of causing harm to the reef ecosystem, especially when impacted by human activities. Similar to many other sponges, *Terpios* relies on nutrients and organic substances in the water. Therefore, there is a concern that elevated levels of organic matter and nutrients in the water, such as those resulting from sewage discharge or stormwater runoff, could lead to increased *Terpios* populations (De Voogd et al. 2013). Consequently, it is important to track populations in known areas of sedimentation and poor water quality.

Coral Bleaching and its implications on Guam's reefs

Coral bleaching events are one of the greatest threats to the world's coral reefs. Coral bleaching events have escalated, with a prevailing scientific consensus indicating an anticipated rise in both their frequency and severity due to heightened thermal stress associated with climate and environmental change (Heron et al. 2016a, van Hooidonk et al. 2016). The vulnerability of corals to thermal stress can differ among genera, species, and even within colonies of the same species. The park waters of Guam have faced recurrent instances of extensive bleaching on shallow reefs spanning the years 2013-2017 (Heron et al. 2016b, Eakin et al. 2017, Burdick and Raymundo 2018, Raymundo et al. 2019; McCutcheon and McKenna 2021). The reefs faced a substantial challenge in 2013 when they experienced record-breaking heat stress, resulting in significant coral bleaching and coral mortality along the shallow seaward slopes (Burdick and Raymundo 2018, Raymundo et al. 2019). Furthermore, in the years 2014 through 2015, the reefs were subjected to a combination of heat stress and extreme low tides attributed to a powerful El Niño event, which inflicted extensive damage to branching *Acropora* stands on the shallow reef flats of Guam, including a site within WAPA's Asan unit (Raymundo et al. 2017, Raymundo et al. 2019). Although 2016 witnessed a relatively milder bleaching event, this respite was short-lived as 2017 marked the most severe year on record in terms of heat stress and coral bleaching (Burdick and Raymundo 2018, Raymundo et al. 2019; McCutcheon and McKenna 2021). Although these bleaching events were detrimental to some of these areas of Guam, there was no significant difference detected between live coral cover before (2010) and after (2018) the period of severe bleaching on the seaward slope sites on the west/leeward coast where Asan and Hågat are located (Raymundo et al. 2017, Burdick and Raymundo 2018, Burdick et al. 2019, Raymundo et al. 2019, McCutcheon and McKenna 2021).

However, several formerly common or locally abundant species were infrequently encountered during the diversity surveys, including *Acropora monticulosa*, *A*. sp. "obtusicaulis", *A. palmerae*, *Stylophora* sp. "mordax", *Montipora* sp. "pagoensis", and *Millepora dichotoma*. Significant bleaching-associated mortality was recorded for these species, most of which are restricted to reef front/margin zones exposed to moderate-to-high levels of wave energy, between 2013 and 2017. These severe coral bleaching events resulted in significant losses of *A. muricata* on Guam's reefs, pushing the species close to extirpation. The *A. muricata* population at Hågat Cemetery is one of

only two known remaining thickets of any significant size in Guam's waters. Several *Acropora* species are found only within a relatively narrow depth range along the reef front and reef margin zones, likely due to these species' preference for higher wave energy environments, tolerance for intermittent exposure to intense light (e.g., between wave breaks or during calm conditions), the avoidance of crown-of-thorns sea stars of moderate-to-high amounts of wave energy, and possibly other factors. A particularly distinct species found in this part of the reef in areas with moderate-to-high wave exposure is a species currently called *A. monticulosa* (but which may represent an undescribed or erroneously synonymized species).

Six relatively small *A. monticulosa* colonies were observed at the diversity survey sites, all within the Asan unit, but no large colonies once common in this reef zone were observed (Figure I-9 of Appendix I). The near complete absence of large *A. monticulosa* colonies, and the significantly fewer number of colonies of all sizes, is not limited to park waters, and is a result of very high mortality rates associated with the 2013–2017 bleaching events.

Like *Acropora monticulosa*, a species Randall formerly called *Acropora ocellata* and which he most recently considered a new species, *Acropora* sp. "obtusicaulis," suffered catastrophic decline, estimated at >90% by DB, as a result of the 2013 and 2017. This species is also restricted to just a few meter-wide depth range within the reef front and reef margin zones, in areas with exposure to moderate-to-high amounts of wave energy. Only three colonies of these once locally-common species were observed during the diversity survey, including two at Asan-CS-4 and one at Asan-CS-8 (Figure I-10 of Appendix I). Colonies highly similar to the Guam *Acropora* sp. "obtusicaulis" were observed by DB in Wallis in 2018, and by Victor Bonito in Fiji, but it's not yet clear if these are the same species or if they represent morphologically similar, but genetically distinct, species within a complex.

Like *A. monticulosa* and *Acropora* sp. "obtusicaulis," the encrusting/digitate *A. palmerae* in the Marianas is limited to shallow reef fronts and reef margins exposed to relatively high degree of wave energy. But also like these species, *A. palmerae* suffered devastating declines as a result of the 2013–2017 bleaching events. This species was once common in its preferred environment but is now infrequently encountered. A total of seven *A. palmerae* colonies were observed during the diversity surveys, including a relatively large (~1.25 m) colony found at site Asan-CS-4 (Figure I-11 of Appendix I). An encrusting *Acropora* that can form large colonies with no tendency to form branches is considered by Randall and Burdick (in prep) to be distinct from *A. palmerae*, and is potentially the same as Veron's *A. minuta*.

While DB expected to encounter far fewer colonies of these species than had been observed in WAPA waters prior to the 2013–2017 bleaching events, the observation of only two colonies of the once-common species, *Stylophora* sp. "mordax," was unexpected and was cause for concern (Figure I-8 of Appendix I). Significant bleaching-associated mortality of this species was observed between 2013 and 2017, and predation by crown-of-thorns sea stars may have contributed to the mortality of colonies that survived the bleaching events, or colonies that recruited after the events.

It's not yet clear what the genetic relationship is between the Guam *Stylophora* sp. "mordax" and Flot et al.'s (2011) Clade C, which included both stoutly- and thinly-branched forms sampled from Western Pacific locales (but not from the Mariana Islands). Randall maintained that the Guam *Stylophora* sp. "mordax" was distinct from *S. pistillata*, even after the publication of the Flot et al. (2011) study. Although the Guam *Stylophora* sp. "mordax" does appear to show some variation in branch shape and thickness, the thin-branched form commonly referred as *S. pistillata* in the Western Pacific has not been observed in Guam's waters. The generally isolated occurrence of *Stylophora* sp. "mordax" in Guam's waters is also in contrast to sometimes dense, extensive cover sometimes observed with *S. pistillata*. The results of a larval transport modeling study that predicted a high degree of reproductive isolation for Mariana Islands marine taxa with pelagic larval durations less than ~50 days (Kendall and Poti 2015), and the results of several studies that provide evidence that other nominal coral species are species complexes comprised of multiple genetically distinct lineages (see Warner et al. 2015, Cowman et al. 2020, Wepfer et al. 2020, Bongaerts et al. 2021, and Juszkiewicz et al. 2022 for examples) has caused DB to reconsider the application of currently accepted names for species to many Marianas corals. For the time-being, DB is maintaining that Randall's *Stylophora* sp. "mordax" is separate from the *Stylophora* species found elsewhere in the Western Pacific until further study is conducted.

Anecdotal observations made by DB at sites around the island since 2004, and a preliminary analysis of coral genus-level data derived by DB from a subset of available towed-diver benthic photo images obtained during NOAA National Coral Reef Monitoring Program (NCRMP) research cruises around Guam between 2003 and 2011 (NOAA NCRMP and Guam Long-term Coral Reef Monitoring Program [GLTMP], 2023) indicate that the cover of numerous Montipora species has declined significantly in the last two decades as a result of predation by the crown-of-thorns sea star and, more recently, by heat stress events. Many species in this genus appear to be highly susceptible to both pervasive stressors and are now much less common than 10 years ago. This genus is nearly as speciose in Guam's waters as *Acropora*, with 31 species reported in Randall (2003) and an estimated 15–20 species not reported by Randall (2003). Several *Montipora* species in Guam's waters appear to be undescribed, such as a species Randall is calling *Montipora* sp. "pagoensis"; this species was observed at several diversity survey sites with both the Asan and Hågat units (Figure I-11 of Appendix I), but the large number of nominal species, the sometimes subtle morphological differences between nominal species, and the lack of any recent integrative studies of this group that would identify morphological characters that align with the genetic data, currently makes any assessment of Guam's *Montipora* necessarily limited and subject to substantial revision. The high degree of susceptibility of many *Montipora* species to heat stress and crown-of-thorns sea stars, and the documented decline in the cover of *Montipora* on Guam's seaward slopes, makes it imperative to conduct such an assessment of Guam's *Montipora* before some species are lost, or before they become so rare they cannot be found without significant effort. An assessment of Guam's *Montipora* could identify genetically distinct species, but without integrating samples of Guam *Montipora* species into an Indo-Pacific-wide phylogeny that includes samples of putative topotype specimens, the application of names of described species and the identification of undescribed species could not be made with confidence, and accurate assessments of the distribution, population size, and conservation status of these species could not be achieved.

Species of the hydrozoan hard coral genus *Millepora* also experienced catastrophic declines in Guam's waters associated with the 2013–2017 coral bleaching events. While several *M. platyphyllya* colonies were encountered during the diversity surveys, only a single colony of a branching *Millepora* species that appears to be *M. dichotoma* (but which is also similar to *M. latifolia*) was observed (Figure I-12 of Appendix I). *Millepora dichotoma* is now uncommonly encountered in Guam's waters, and the detection of just a single, rather pale and unhealthy-looking colony during the diversity surveys raises serious concerns about the persistence of this species within WAPA waters, and on Guam's reefs more broadly.

Stress-susceptible coral taxa, such as *Acropora* and *Montipora*, were uncommonly encountered during the surveys within the Hågat unit, generally limited to small areas, such as the reef margin at coral diversity site Agat-CS-7 where numerous *A. tenuis* colonies were observed (Figure I-15 of Appendix I). Coral diversity site Agat-CS-7 was the site within the Hågat unit at which an *A. globiceps* colony was observed.

Other Mortality and Disease

As human populations continue to grow, nutrients, terrigenous silt, pollutants, and pathogens can find their way into nearshore benthic communities (Raymundo et al. 2008). Although the connection between human-induced stressors and the susceptibility of these communities to diseases remains unclear, deteriorating water quality, notably caused by eutrophication and sedimentation, is a contributing factor to the onset of coral diseases. Although specific coral diseases were not identified during this study, instances of recent mortality were documented alongside transects. The percentage of transects that contained corals with recent mortality/stress was indicative that coral disease, bleaching, predation, and other stressors are present and widespread throughout the park (Table 10) and further investigation is warranted.

Pigmentation response was common and occurred among stony corals in transects (Table 10). This response, typically observed as bright pink material along a lesion border, is commonly regarded as a generalized stress reaction of the host coral, triggered by various factors, and is consequently classified as an instance of an abiotic disease (Raymundo et al. 2005). The response was accompanied by increased skeletalization of affected corallites, which caused a visible thickening of corallite walls (Figure 14). This response could be indicative of a variety of environmental stressors resulting from unidentified chemical and/or microbial agents (Raymundo et al. 2005).

Coral disease is not captured effectively in the processing of benthic images and although noted while conducting transect surveys, this is not a preferred method for quantitative study of coral disease. Additional in situ surveys specific to coral disease within the park are recommended, especially in areas of particular interest.

Coral Species Richness and Unique Species Within WAPA Waters, Beach Units, and Reef Zones

Asan vs Hågat Beach Units

The difference in the number of species detected within the Asan and Hågat units during the diversity surveys (Figure 19) would likely be less if the number of sites surveyed was equal, and the number of

species detected prior to the surveys may have been influenced by differences in effort. However, these differences cannot be fully explained by effort alone. Some of the differences may be due to geophysical factors, such as wave exposure, reef structure, and habitat diversity, but the poor substrate quality, low coral cover, and depauperate reef fish communities in much of the Hågat unit and across most of the southwest coast of Guam, are indications that impaired water quality, chronic predation by crown-of-thorns sea stars, heavy fishing pressure, and other stressors have resulted in conditions that no longer support as diverse a reef community or as robust reef growth as in the past. Unlike the results from the coral diversity surveys, the quantitative transect results (Table 8) do not suggest coral diversity is different among the beach units. However, it is unlikely the methods for the benthic cover analysis are as effective at determining coral diversity as the concerted coral diversity surveys, especially for rare or cryptic species. A comprehensive analysis of available historical data is required to determine if the current level of diversity in the Hågat unit and the southwest coast more broadly has indeed declined in recent decades.

Differences by Habitat Type

The similar number of species found within the reef front and seaward slope zones is notable, given the significantly larger depth range covered at the seaward slope sites (mean of 15 m) during the diversity surveys, in comparison to depth range covered at reef front sites (mean of 8.5 m). The relatively high number of species within the narrow reef front zone is likely influenced in part by the range of microhabitats typical of the often highly rugose reef structure within this zone, the number of coral species that prefer the higher wave energy environment, and the effects of wave energy on biological processes, such as the limited amount of predation by crown-of-the-thorns sea star due to avoidance of wave energy and the potentially mitigative effect of wave energy on the deposition of sediment and other particulates. Interestingly, the mean number of hard coral species detected within the reef front zone in the Asan beach unit was higher than in the Hågat unit (88 ± 12 vs. 67 ± 7 species), while the mean number of species detected within the seaward slope zone was very similar between the units (75 ± 5 vs. 74 ± 13 species). This discrepancy may be related to the significantly lower degree of wave energy that reaches the reef front within the Hågat unit, and thus the lesser effect of wave energy in mitigating the impacts of poor water quality, which is chronic and severe across large portions of the Hågat unit, and crown-of-thorns sea stars, which are regularly observed feeding within the reef front and reef margin zones in the Hågat unit.

The quantitative transect findings suggest that habitat type also plays a crucial role in shaping the benthic community composition, with distinct variations in cover for CCA and unconsolidated sediment across fore reef, bank/shelf, and reef flat habitats (Figure 4). The higher CCA cover in the fore reef habitat highlights the importance of this habitat for crustose coralline algae and its potential role in supporting coral reef formation and stabilization. Meanwhile, the significant difference in unconsolidated sediment cover between reef flat and the fore reef and bank/shelf habitats may be indicative of varied environmental conditions and sedimentation rates in these areas and warrant regular monitoring of these habitats.

Protected Species

Several coral species *(Acropora globiceps, A. retusa, A. speciosa*, and *Seriatopora aculeata*) that are listed as "endangered" or "threatened" under the U.S. Endangered Species Act (ESA) were searched for among the Hågat and Asan beach units. *A. retusa* was the only coral species found among quantitative transects (n=2) and *A. globiceps* was observed during coral diversity surveys.

The depth of the observed *A. globiceps* colonies ranged from 0.7 to 6.4 m, with a mean of 4.1 m. This species is known to occur at greater depths, but colonies are rarely observed below 10 m, due to its apparent preference for a moderate-to-high degree of wave exposure. The chronically elevated densities of *Acanthaster* on Guam's reefs may also contribute to the rarity of *A. globiceps* at depths greater than 6 m on the leeward coast, as the sea stars tend to avoid areas of moderate wave energy. The low density of *A. globiceps* in the Hågat unit may be a result of the considerably lower degree of wave exposure, as well as the generally impaired water quality in this area, both of which contribute to suboptimal environmental conditions for *A. globiceps*. The low degree of wave exposure in the Hågat area would also allow *Acanthaster* to access the reef front and reef margin zones on a frequent basis, thus the risk of predation of preferred prey such as *Acropora* and *Montipora*, as well as other taxa, is greater along the southwest coast of Guam than at reef front and reef margin zones north of Orote Pt. and along the windward coast.

Acropora globiceps is not an especially rare species on Guam's reefs, and in upper seaward reef slopes with relatively clear water and exposure to a moderate degree of wave energy several colonies can be encountered during the course of a typical dive or snorkel. Several other Guam *Acropora* species are much rarer than *A. globiceps*, including some that were once common along the reef margin and upper reef front zones prior to the multiple bleaching events between 2013 and 2017. However, data obtained by the Guam Long-term Coral Reef Monitoring Program at shallow (5 m) reef front sites along the west and north coasts between 2013 and 2017 indicate that the density of *A. globiceps* colonies declined by approximately 50% during this period (NOAA NCRMP and GLTMP, 2023). In situ observations and colony bleaching status data extracted from photo transect images strongly support the assertion that the decline was primarily the result of coral bleaching-related mortality associated with extended periods of unusually high sea surface temperatures.

Acropora speciosa, which was dominant in the upper seaward slopes in 1977, is now conspicuously absent from all the surveys conducted in 2022 (Eldredge et al., 1977). The disappearance and reduction of these once-dominant species underscores the urgency of implementing conservation measures to safeguard the delicate balance of Guam's coral reefs and preserve the diversity and ecological integrity of these invaluable marine ecosystems.

Other Notable Species

Several notable hard coral species were observed during the diversity surveys, including some rarely encountered species, a few that may represent new records for Guam, several that are undescribed species currently planned for inclusion in Randall and Burdick (in prep), and some that DB has not yet observed in Guam's waters.

One of the most important finds made during the diversity surveys was the discovery of a staghorn thicket at site Asan-CS-10, on the shallow reef flat platform between Asan Cut to the west and Adelup Pt. to the east, referred to *Acropora* cf. *aspera* in this study (Figure I-1 of Appendix I). Colonies within the thicket exhibited curved branches; retracted tentacles; thicker radial corallites; and slightly wider, shorter, and more darkly pigmented axial corallites than the nearby *A*. cf. *pulchra* colonies. These characters are shared with a staghorn species currently called *A. aspera* in Guam's waters; the axial corallites in other *A. aspera* colonies at a similar depth are typically slightly larger, but *A. aspera* fragments from the same source population placed in a nursery exhibited remarkable phenotypic plasticity, including in axial corallite diameter (R. Cristostomo, unpubl. data). If the thicket at the Asan reef flat is indeed the Guam *A. aspera*, this small reef area represents the only other location on Guam currently known to host this now-rare species, which was believed to be limited to a supra-thicket and surrounding small thickets and isolated colonies on the reef flat in eastern Cocos Lagoon. A small number of *A. aspera* colonies were observed near Alutom Island, within the boundaries of the Hågat unit, prior to the first severe bleaching event in 2013, but no living colonies were found in this area during a staghorn coral mortality assessment conducted by Dr. Laurie Raymundo and DB in 2015.

A single colony of a distinctive species tentatively called *Acropora* cf. *loripes sensu* (Veron et al. 2016) was observed at diversity survey site Asan-CS-6, within the reef front zone at a depth of between 5 and 6 m (Figure I-2 of Appendix I). The partially "naked" upper branch surfaces of this species, which is rarely encountered in Guam's waters, bears some resemblance to a colony depicted as *A. loripes* on Veron et al.'s (2016) coralsoftheworld.org website. The Guam species is unlikely to be Brook's *A. loripes*, or the species on coralsoftheworld.org, so this name is only being used as a placeholder until further study can be conducted.

Eleven colonies of an infrequently encountered, and likely undescribed, *Acropora* species tentatively called *A*. cf. *kimbeensis* were observed at depths between 18 and 33 m at three sites within the Asan unit and one site within the Hågat unit (Figure I-3 of Appendix I). The caespito-corymbose colony form and the long tubular radial corallites with nariform openings are similar to those described by Wallace (1999) for *A. kimbeensis* from Kimbe Bay in Papua New Guinea. The Guam species is unlikely to be *A. kimbeensis*, but is currently being referred to as *A*. cf. *kimbeensis* as a placeholder until further study can be conducted.

A colony of a species consistent with *Alveopora tizardi* was observed at site Asan-CS-7 at a depth of ~12 m (Figure I-4 of Appendix I). Within the Mariana Islands, DB has only seen a single *Alveopora tizardi* colony at Tinian until this colony was observed during the diversity survey conducted for this study.

A colony that appears to be an *Acanthastrea* species was observed at a depth of 10 m at site Asan-CS-2 (Figure I-4 of Appendix I). The species shares some morphological features with the genus *Dipsastraea*/*Favia*, similar to some of the colonies depicted as *A. regularis* on Veron et al.'s (2016) coralsoftheworld.org website. Examination of a collected specimen would be required to determine to which genus it belongs, and additional study would be required to determine its specific identity. Randall had not reported a *Dispastraea/Favia*-like *Acanthastrea* species from Guam, but DB has

seen a handful of colonies in Guam's waters, usually in shaded habitats, such as on channel walls, or the sides of reef fissures, where the above colony was observed.

Several colonies representing undescribed encrusting *Pavona* species were observed during the diversity surveys (Figure I-5 of Appendix I). After an assessment of a considerable number of collected specimens and years of detailed in situ observations, Richard Randall recognized at least three, possibly four, species of encrusting *Pavona* species from the Mariana Islands, in addition to the previously described *P. varians* and *P. chiriquiensis*. Randall and Burdick (in prep) have tentatively called these species *Pavona* sp. "contorta," *Pavona* sp. "meandrina," *Pavona* sp. "albamarginata," and *Pavona* sp. "encrustans." While the morphological differences that led Mr. Randall to consider these species separate from *P. varians* and *P. chiriquiensis* are sometimes subtle, especially in younger colonies, these differences are distinct and consistent.

Additional notable species encountered at the diversity survey sites include *Turbinaria* cf. *irregularis*, *Favites* sp. "crassisepta," an unidentified fungiid sp., and *Astreopora* sp. B (Figure I-6 of Appendix I). The single observed *Turbinaria* cf. *irregularis* colony may be an aberrant form of the commonly encountered *T. stellulata*, but the unusually exsert corallites, with some pointing in different directions, bears some resemblance to a few of the colonies depicted as *T. irregularis* on Veron et al.'s (2016) coralsoftheworld.org website. *Favites* sp. "crassisepta," which is being described as a new species in Randall and Burdick (in prep), has exceptionally large and exsert septa distinct from any other known *Favites* (or *Dipsastraea*/*Favia*) species. The single observed unidentified fungiid had two mouths; was folded over on itself; and had exceptionally thick, rough septa. The several *Astreopora* sp. B colonies observed during the surveys were closest to *A. randalli*, but had exceptionally small calices and had their tentacles partially expanded during the day; the colonies were also usually larger, and with different color forms than typically observed in *A. randalli* in Guam's waters. Another notable species encountered during the diversity surveys was an undescribed *Leptoseris* species tentatively called *Leptoseris* sp. "rubra." A single *Leptoseris* sp. "rubra" colony was observed at diversity survey site ASAN-CS-5 (Figure I-7 of Appendix I). This species is typically observed below 20 m on Guam's reefs and is most commonly seen in Apra Harbor.

While most species were observed at more than one diversity survey site, a significant number (49, or 20% of the total number of species detected during the survey period) were found at only a single site. Many of these 49 species are known to occur at other locations in Guam and are likely to be found at other locations within WAPA waters with additional effort, but a few, such as the *Acropora* cf. *aspera* noted above and *Pavona clavus* at Hap's Reef, may be limited to these single locations within park waters. As discussed in more detail below, the reef flat area where the *A*. cf. *aspera* was found may be the only location other than Cocos Lagoon where this species is found in all of Guam's waters, while *Pavona clavus* has not yet been observed by DB at any other site on Guam except for Hap's Reef. Importantly, it's not clear what the relationship is between *Pavona clavus* and a highly morphologically similar species typically found in the reef front zone currently referred to as *P. bipartita*.

Further study may determine that these forms are genetically indistinguishable, but if their distinctiveness is confirmed the importance of the little remaining *P. clavus* at Hap's Reef should be even further elevated. The unusual morphology of the *Acropora muricata* colonies observed at diversity survey site Agat-CS-3, which had been tracked by Dr. Laurie Raymundo and DB for many years, has not been seen by DB at any other site in the Marianas [although DB has only observed this *A. muricata* morphology at a single site in Wallis, in the South Pacific]. Preliminary results of a genetic analysis of several of Guam's staghorn species by a graduate student of Dr. David Combosch at the University of Guam Marine Laboratory suggests that these colonies are genetically indistinguishable from typical Guam *A. muricata* (Combosch et al., unpubl. data). The unusually thick branches and the numerous short, irregular branchlets along the primary stems may be the result of one or more genetic mutations perpetuated in the relatively limited area through asexual reproduction.

Additional Observations at Coral Diversity Sites

Staghorn coral rubble covering ~150–200 m^2 was observed at a reef area along the reef margin just north of Ga'an Pt., at coral diversity survey site Agat-CS-5 (Figure I-15 of Appendix I). An image of living *Acropora acuminata* from Ga'an Pt. in the Randall and Myers (1983) coral field guide, and the current absence of this species in the area, suggests the rubble was likely formed by this now-rare species. Note that there is confusion over the identity of Verrill's *A. acuminata*. The morphospecies in the Marianas that Randall called *A. acuminata* is clearly distinct from the arborescent table-forming species to which this name is applied by Veron et al. (2017); Wallace (1999); and Wallace, Done, and Muir (2012). While Verrill's description does not address the colony form, the *A. acuminata* holotype exhibits radial corallites more similar to the Guam *A*. "acuminata," and quite distinct from the larger, tubular radial corallites of the arborescent table form. The arborescent table-forming species, which has not been observed in Guam's waters, may be the same as, or closely allied with, Brook's *Madrepora nigra*.

Only a few small patches of living *Pavona clavus* tissue were observed near the base of Hap's Reef, a popular dive site, during the coral diversity survey conducted at the site (Agat-CS-6). A substantial portion of the Hap's reef structure was formed by a supracolony of this species, and when DB first observed the reef in 2005 large areas of the reef were still comprised of living *P. clavus* (Figure I-17 of Appendix I). The striking loss in the cover of this now-rare coral species is likely primarily due to predation by the crown-of-thorns sea star (*Acanthaster* cf. *solaris*), the densities of which reached a peak around Guam in the mid-2000s and continue to remain at elevated levels that threaten the persistence of preferred prey species on Guam's reefs. Mortality associated with the 2013–2017 bleaching events, as well as disease, may have also played a role in the decline of *P. clavus* and other corals at Hap's Reef.

The slightly greater depth across some areas of the reef flat in the vicinity of diversity survey site Asan-CS-1, just to the west of Asan Pt. in Tepungan Bay, generally supported more structural complexity, larger colonies, and considerably more reef fish (including a large blacktip reef shark observed during the survey) in comparison to the shallower, more truncated coral formations at site Asan-CS-10 (Figure I-18 of Appendix I). However, several thickets of the staghorn species,

Acropora cf. *pulchra*, and a thicket that appears to be the much rarer *A. aspera*, were found at Asan-CS-10, while no staghorn was observed at site Asan-CS-1.

The reef at Asan Cut, which is a popular diving and fishing site, hosts among the most dramatic topographic relief and overall structural complexity of any of Guam's reefs (Figure I-20 of Appendix I). The diversity survey site within the cut (Asan-CS-7) did not yield as many coral species as expected, given the diversity of microhabitats in the area, but this is likely related to the relatively limited exploration of the large site allowed during the 45-minute survey, with much of the survey conducted at deeper portions of the site. A significant number of additional coral species would likely be detected with additional survey effort in the vicinity of Asan Cut, which DB's qualitative observations also suggest host a large number of species restricted to depths shallower than at which most of the survey was conducted.

A fissure in the reef at diversity survey site Asan-CS-2, on the north side of Camel Rock, hosted some uncommon coral species, such as *Cyphastrea ocellina sensu* Randall and *Acanthastrea* cf. *regularis* (Figure I-21 of Appendix I). The fissure was adjacent to a small, shallow cavern at the base of Camel Rock that hosted shade-tolerant corals, such as the hydrozoan coral, *Distichopora* sp. Additional survey effort in this area, particularly when calm water conditions allow safe exploration of the cavern, may yield additional species, possibly including small azooxanthellate scleractinian corals that prefer shaded, cryptic habitats in shallow waters.

The greatest depth reached during the WAPA coral diversity surveys (33 m) was at site Asan-CS-5, approximately 300 m to the northwest of Asan Cut. An area with high cover of plating *Porites rus*, and scattered colonies of uncommonly encountered caespito-corymbose *Acropora* species, an undescribed species of *Leptoseris*, and other notable coral species, were observed in this area (Figure I-22 of Appendix I).

The greatest number of coral species was detected at the shallow reef front site Asan-CS-8; this site was also notable for an area with several hundred healthy colonies of the highly bleaching-susceptible species, *Acropora verweyi* (Figure I-23 of Appendix I). DB has not observed this high a density of *A. verweyi* colonies in Guam's waters since before the first severe bleaching event in 2013. It's not clear why this species was still found in such high numbers in this area, but the potential cooling influence of freshwater submarine discharge or regular exposure to super-heated reef flat water (which could potentially have selected for more heat-tolerant genotypes), should be investigated. Diversity site Asan-CS-4, which also occurred within the reef front zone in the Asan unit, also hosted a large number of coral species (90) and was notable for hosting the largest number (16) of the ESA-listed coral species, *Acropora globiceps* (Figure I-23 of Appendix I).

Rarefaction/Extrapolation Curves: Estimated Species Richness with Additional Effort/Sample Coverage

The rarefaction/extrapolation curve estimated a total of 267 species occurring within WAPA waters. When including the additional ~65 species likely to occur within WAPA waters that were observed outside of the survey period, the total jumps to around 340 species, which is higher than the bootstrap upper limit estimated from the rarefaction/extrapolation curve. It is not clear why the discrepancy in

these values is so large, but it may be related to the much longer time period and total dive time over which the additional species recorded prior to the diversity surveys were accumulated, in comparison to the relatively limited total dive time for the diversity surveys. The impacts of continued predation by crown-of-thorns sea stars and the significant bleaching-associated mortality of numerous coral species in the years leading up to the diversity survey may have made some species much less common than they were when Randall (2003) made most of the observations on which he based his abundance and distribution information for those species, and even in comparison to the first decade DB spent on Guam's reefs.

Implications of applying different taxonomies and approaches to species determinations and their limitations

The observed increase in species richness in WAPA waters, compared to historical reports, is likely a result of greater effort and specialized coral diversity searches conducted during the surveys (Table 16; Eldridge et al., 1977, Amesbury et al. 1999). This suggests that the earlier reports from 1977 and 1999 might have underestimated the true diversity due to limited sampling efforts, focusing on specific locations or easily accessible areas. In contrast, this study employed more extensive and comprehensive sampling strategies, covering a wider range of habitats and depths. The integration of remote sensing technology and high-resolution mapping tools has also enhanced the efficiency of coral directed surveys since the development of these reports. Aerial and satellite imagery can provide valuable information about the distribution of coral habitats, enabling researchers to target specific areas with high potential for diverse coral communities.

However, the uncertainty associated with the identification of some corals based solely on field characters, the unresolved or unconfirmed boundaries between many morphospecies, the differing perspectives of leading coral taxonomist on the validity of various species, and the rapidly evolving state of coral taxonomy have significant implications for arriving at image- and in situ-based species determinations during coral diversity surveys. As such, the actual number of species encountered during the surveys may be significantly higher or lower than the species counts reported above, and different observers will undoubtedly produce different numbers depending on their experience level, the references they rely upon, the state of coral taxonomy at the time of the surveys, and their general approach to assigning species determinations. While it is not possible in this study to account for all of these factors, a more conservative approach to species determination (for those species recorded only during the 45-min survey period) roughly simulated by combining morphologically similar forms yielded a count of 224 species, compared to the 245 total reported above, while a more liberal approach roughly simulated by splitting some morphologically similar forms into separate species yielded a count of 255 species.

The uncertainty associated with the factors above led DB to rely wholly upon image-based species determinations for this assessment in order to facilitate the comparison of the results of this assessment to those of future assessments. The image library of all colonies suspected of representing separate species at each survey site will be a valuable resource that can be evaluated by other coral field identification specialists (or by DB) after further systematics/taxonomic work has been conducted on various coral groups.

The number of families and genera recorded during the survey should generally be less sensitive to some of the above-mentioned factors than the number of species, but disagreements among leading taxonomists regarding the validity of several coral genera means that the perspective of a given specialist on the status of those genera could significantly change the number of genera reported during diversity surveys. For example, the World Register of Marine Species lists 16 valid genera within the Family Fungiidae, with several former *Fungia* subgenera elevated to the genus level based on the work of Gittenberger et al. (2011). However, Veron et al. (2016) state that they believe further evidence is required to validate the elevation of the subgenera to genera, so the number of coral genera reported for a given diversity assessment such as this one could vary by several genera based simply on the perspective of the author on the validity of these fungiid genera.

Comparison of WAPA species totals to totals reported for Guam

The most recently published comprehensive list of hard coral species reported from the Mariana Islands was Randall's 2003 article in the journal Micronesica. The Randall (2003) list included 377 scleractinian and 26 hydrozoan coral species, but a significant number of species were azooxanthellate (and some zooxanthellate) corals obtained through dredge sampling at depths well below recreational dive limits (40 m). While a thorough review of Randall's field notes and collected specimens would be necessary to provide an accurate value for the number of shallow (< 40 m) hard coral species in the Randall (2003) list, a preliminary assessment indicates 245 of the species are shallow zooxanthellate scleractinian corals. The number of shallow azooxanthellate scleractinian species represented in the list cannot be determined without further study. Of the 26 hydrozoan species listed In Randall (2003), only 8 appear to be shallow water species. In the period when Mr. Randall and DB were developing the Randall and Burdick (in prep) publication, a multi-volume *Reef-building Corals of the Mariana Islands* book series (that is still in development by DB), Mr. Randall did not provide DB information for 9 species included in the Randall (2003) list. These species are likely to be shallow zooxanthellate species, but some may be occur only below 40 m. It's also possible that he did not provide information about these species because he had changed his mind about their validity.

In the 20 years since the publication of the Randall (2003) list, and after Mr. Randall's further study of the literature and his immense specimen collection, he recognized numerous additional described and undescribed hard coral species from the Mariana archipelago. Descriptions for most of these species, which include an additional 53 described and 28 previously undescribed shallow zooxanthellate species, were provided to DB by Mr. Randall for inclusion in Randall and Burdick (in prep). DB has also documented 31 additional species morphologically similar to described shallow zooxanthellate species, as well as 29 shallow zooxanthellate species that appear to be undescribed species. Additionally, Dr. Doug Fenner, in an informally published field guide to the corals of the Mariana Islands, reported three (3) species from the CNMI that neither Mr. Randall nor DB have observed in Guam or elsewhere in the Mariana Islands (Fenner, 2021). Dr. Victor Bonito, a former UOGML graduate student and Director of Reef Explorer Fiji, reported at least two (2) species of *Acropora* from Apra Harbor that neither Randall nor DB have observed in Guam's waters, and Dr. Laurie Raymundo with the UOG Marine Laboratory photographed the first reported *Oulastrea crispata* colony in the Mariana Islands. Wallace (2009) also reports *Acropora valenciennessi* from

Guam, but neither Mr. Randall nor DB have ever observed this species in the Marianas and consider the record doubtful, or perhaps the species is very rare or has since been extirpated from Guam's waters. Including the additional species mentioned above, and accounting for decisions by Randall and DB to synonymize or split some of the species in Randall (2003), DB currently has documentation for 392 shallow zooxanthellate scleractinian morphospecies from the Mariana Islands. Due to the continued challenges in the delineation of coral species boundaries and the proper application of taxonomic nomenclature it is possible, likely even, that this number could change significantly as scleractinian coral systematics and taxonomy evolves. This number may also change as additional species are encountered or are lost from Guam's waters due local and regional stressors. Still, it appears highly likely that the number of distinct hard coral species known from Guam's waters is considerably (~60%) higher than was reported in Randall (2003).

Approximately 160 shallow zooxanthellate scleractinian species in the Randall (2003) list were observed within WAPA waters prior to or during this study, representing about 65% of the total number of species in the Randall (2003) list. Some of the other 81 zooxanthellate scleractinian species (e.g., several *Goniopora* and *Montipora* species) observed in this study may have been reported by Randall (2003), but their identities could not be confirmed. The total of 241 shallow zooxanthellate scleractinian coral species reported from WAPA waters prior to and during the present study represents ~40% of the 392 species documented from the Mariana Islands to-date. Several of the shallow zooxanthellate species reported from the Marianas that were not detected in this study are known only from a small number of colonies, while others appear to be restricted to Apra Harbor or have only been reported other islands in the archipelago. The likelihood of occurring within WAPA waters was assessed for each of the 144 shallow zooxanthellate scleractinian coral species reported from the Marianas that have not yet been observed in WAPA waters; the results of the assessment suggest that an estimated 65 additional species are likely to occur within WAPA waters, 61 are unlikely to occur in WAPA waters, 13 are highly unlikely to occur in WAPA waters, and 5 that have likely been extirpated from the Mariana Archipelago (Appendix J). Several species assessed as likely to occur in WAPA waters may be encountered with relatively minimal effort, but others may be rare and observed only after a significant amount of effort.

As mentioned above, it's not clear how many of the hydrozoan and azooxanthellate scleractinian coral species in the Randall (2003) list were shallow-water species, nor is it clear if there are additional species represented in Randall's large coral collection or if there are additional species Randall had not observed. Two hydrozoan corals, *Millepora latifolia* and an undescribed *Stylaster* sp., are known from shallow waters in the Mariana Islands but were not observed in WAPA waters prior to or during the present study. *Millepora latifolia* appears to be rare, as colonies that could be confidently identified as this species have not been observed (Dave Burdick, personal communication), but at least one *Stylaster* sp. is common and is very likely to be found within WAPA waters with additional effort. Both of the known reef-building octocoral species reported from the Mariana Islands, *Heliopora coerulea* and *Tubipora musica*, were observed during the present study.

Of the estimated 2400 nominal extant zooxanthellate scleractinian corals, Veron et al. (2017) currently considers 831 of these species valid. This number is likely to be much higher, especially in light of Cowman et al.'s (2020) finding that more than 50% of the *Acropora* specimens in their study could not be readily assigned to any of the 414 nominal *Acropora* species, and their suggestion that recent revisions (e.g., Wallace et al. 2012) significantly underestimated the true diversity of this particularly speciose coral genus.

Management Actions

Restoring lost corals and establishing more heat-resistant and resilient reefs have garnered significant attention among scientists and natural resource managers worldwide. There are currently ongoing initiatives in Guam to actively rehabilitate staghorn *Acropora* communities. Over the past decade, two coral nurseries have been established, serving as sources of coral fragments for potential outplanting onto the neighboring reefs (McCutcheon and McKenna 2021). Although initial small-scale pilot projects have yielded positive results, addressing the increasingly severe threats to coral reefs demands the implementation of large-scale and inventive restoration endeavors (Dobson et al. 2021). Researchers are currently exploring the viability of cultivating heat-tolerant coral species in nurseries and then transplanting them to bolster the resilience of reefs. Resource managers should continue to collaborate with other scientists to assess the effectiveness and long-term outcomes of these methods. Coral survival hinges on ideal conditions such as optimal water quality. Sedimentation, predation, and other stressors should be largely considered when selecting future locations for sites for these nurseries and out-planting sites (Dobson et al. 2021, McCutcheon and McKenna 2021).

Specific coral diversity sites in which ESA or target species are thriving (Table 15) may be a good indicator of the required conditions for successful outplanting in the future and should be further monitored. Additionally, logistic models can be used as potential predictors for the occurrence of an ESA species at specific locations based on benthic composition. These models detailed in the logistic modeling results section provide park management with the necessary tools in the form of simplistic algorithms to help identify areas that may be vulnerable to coral degradation. This can subsequently help in conservation efforts by identifying the suitability of different habitats for endangered and protected species of hard coral thereby prioritizing areas for restoration and protection as well as ensuring that resources are efficiently allocated to maximize the chances of species survival and reproduction. Future surveys that include repeat measurements of a subset of the surveyed transects as well as new transect areas that can provide an independent data set will help in refining the derived models and allow for a robust assessment of their predictive power for future use.

It is evident that the ongoing efforts to determine the most threatened coral taxa are crucial. Several researchers at University of Guam Marine Laboratory have been intermittently involved in this endeavor. However, a comprehensive resolution of these matters requires international collaboration, a process that is currently underway but expected to span several years. There is a need for formal taxonomic work including the improvement of phylogenetic systematics among a particular genus or species group. This work is crucial for the revision of a group's taxonomy and to fine tune species distributions. Distinguishing whether species are unique to the Marianas or part of the broader

Micronesian region, as opposed to having a wide Indo-Pacific distribution, could be highly informative for natural resource managers and academic partners.

In the case of COTS, a strong recommendation is to implement active control efforts, discarding the notion that control becomes necessary only when densities exceed 30 individuals per hectare. Guam, and especially the Hågat unit, is well beyond the point where even relatively low densities are sustainable. The risk of over-removing COTS is virtually non-existent, but even extracting a few during a single dive would, at the very least, slow down the decline of stress-sensitive coral genera like *Acropora* and *Montipora*. These corals are relatively rare along the seaward slope in both units, with a particular scarcity observed in the Hågat unit. A nuisance species monitoring program should be implemented throughout park waters to track the spread of both COTS and *Terpios hoshinota*. It's justifiable to consider a proactive approach of culling COTS whenever they are present, effectively integrating monitoring with control efforts. Priority can be given to biodiversity hotspots across all reef zones in the Hågat unit and the seaward slope deeper than approximately 7 meters in the Asan beach unit as COTS seldom venture above this depth due to the consistent wave exposure in that unit.

In the evaluation of whether water closures or restrictive access to visitors within the park is warranted, it does not appear that places within park waters that people use the most are particularly susceptible to impacts from visitors. *Acropora globiceps* is the only ESA-listed species expected to show up in any survey in Guam's waters, and it lives in a rather limited depth range and wave exposure preference, and that zone is rarely visited by divers, never visited by reef gleaners, and isn't threatened by free dive spearfishermen that may fish there. The problems plaguing the reefs in the park, the island, and across much of the world are much larger and much more intractable than visitor impacts. The park faces more pressing challenging like the loss of corals due to coral bleaching and COTS, limited coral recovery due to reproductive isolation and chronic water quality issues, depauperate herbivore populations from overharvesting and habitat impacts, chronically elevated COTS densities, and coral disease prevalence. Anchoring can cause physical harm to corals by breaking or dislodging them, as well as smothering them with sediments, ultimately leading to coral stress and decline. The park may benefit from the installation of mooring buoys in less sensitive areas. By providing a designated and secure anchoring point for boats and vessels, buoys can help reduce the destructive impact of anchor damage on coral reefs and direct recreation away from reefs suitable for rare or protected species. The park's awareness of the remaining rare coral stands of species like *Pavona clavus*, *Acropora aspera*, and *Acropora muricata* have practical implications for management and funding justification to improve water quality in these areas, expand nurseries, or create a mooring buoy program.

Unfortunately, drawing attention to the location of these rare species often increases the risk of damage to it. The park has a responsibility to educate the public in proper reef etiquette throughout the park and beyond. Educating visitors on how to interact with coral is of paramount importance for the conservation and preservation of park marine ecosystems. Visitors, whether snorkeling, diving, or simply wading in shallow waters, can unintentionally cause harm to corals through physical contact or by using sunscreen products that contain harmful chemicals. Proper education empowers visitors

to make informed choices, such as maintaining a respectful distance from corals and choosing reef-safe sunscreen options. By fostering an understanding of the ecological significance of coral reefs and the potential consequences of reckless behavior, education plays a pivotal role in ensuring that visitors become responsible stewards of these invaluable underwater ecosystems, contributing to their long-term health and resilience.

Conclusions

This comprehensive inventory report provides essential insights into the benthic cover, coral genera composition, and unique species within WAPA and offers a crucial baseline for effective coral reef conservation and park management decisions. The findings from this report reveal significant disparities in benthic cover compositions between Hågat and Asan units, as well as between different habitat types. These distinct differences in benthic communities highlight the contrasting ecological dynamics and habitats of the two study areas.

The presence of unique species at single survey sites within the study areas underscores the ecological importance of certain locations. Some species are known to occur in other locations in Guam, while a few may be limited to specific sites within WAPA waters. These differences are likely influenced by environmental and biological factors such as poor water quality, severe heat stress events, chronic predation by crown-of-thorns sea stars, disease, and reduced herbivore populations. These factors collectively shape the condition of the benthic community, leading to variations in species distribution and abundance across the study sites.

Documenting coral stress and identifying potentially harmful species allows for proactive management strategies to prevent the establishment of nuisance or detrimental species, such as the crown-of-thorns starfish and the sponge *Terpios hoshinota*, while populations are still manageable. Updated data on the location, presence, relative abundance, and health of corals is essential for park managers to prioritize conservation efforts and identify restoration opportunities effectively.

However, uncertainties related to coral identification, unresolved boundaries between morphospecies, differences in taxonomists' perspectives, and the rapidly evolving state of coral taxonomy have significant implications for species determinations during coral diversity surveys. While the recent surveys have provided valuable insights into coral diversity in WAPA waters, ongoing taxonomic research and collaboration among experts will be essential to obtain a more comprehensive and accurate understanding of coral biodiversity in the region.

Observations from this report raise concerns about the health and resilience of coral ecosystems in the Hågat unit and emphasize the need for knowledge of local factors that shape benthic community structure. Understanding the drivers responsible for these variations is crucial for effective conservation and management strategies to preserve the ecological balance and overall health of coral reefs in both units. Continued monitoring efforts will be critical in assessing long-term trends and changes in benthic cover and enabling adaptive management approaches to safeguard these valuable marine ecosystems in the face of ongoing environmental challenges.

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Appendix A. Maps

Figures 1-7b show maps depicting transect locations and survey results.

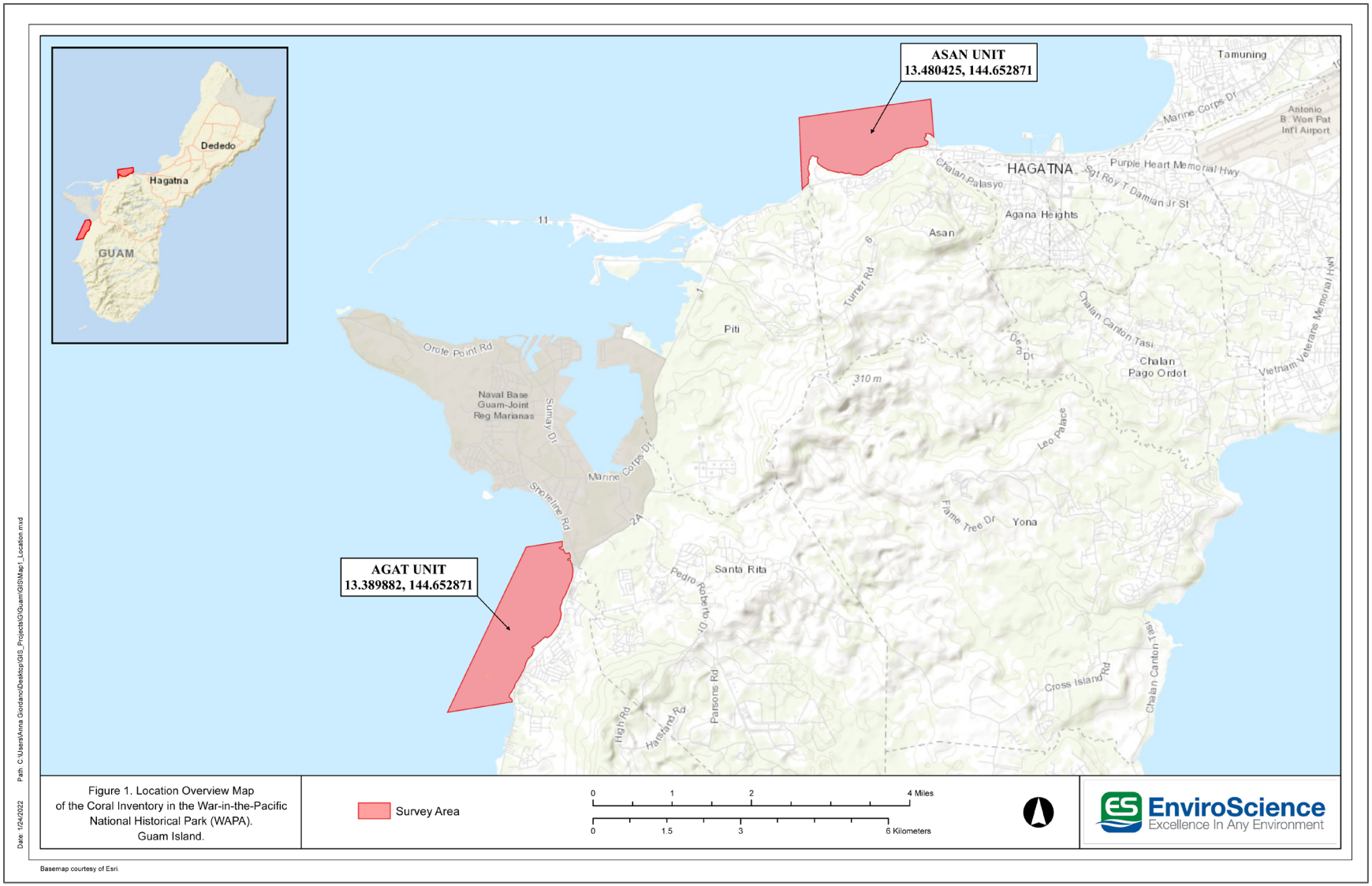


Figure A-1. Location overview map of the coral inventory in the War-in-the-Pacific National Historical Park (WAPA), Guam Island.

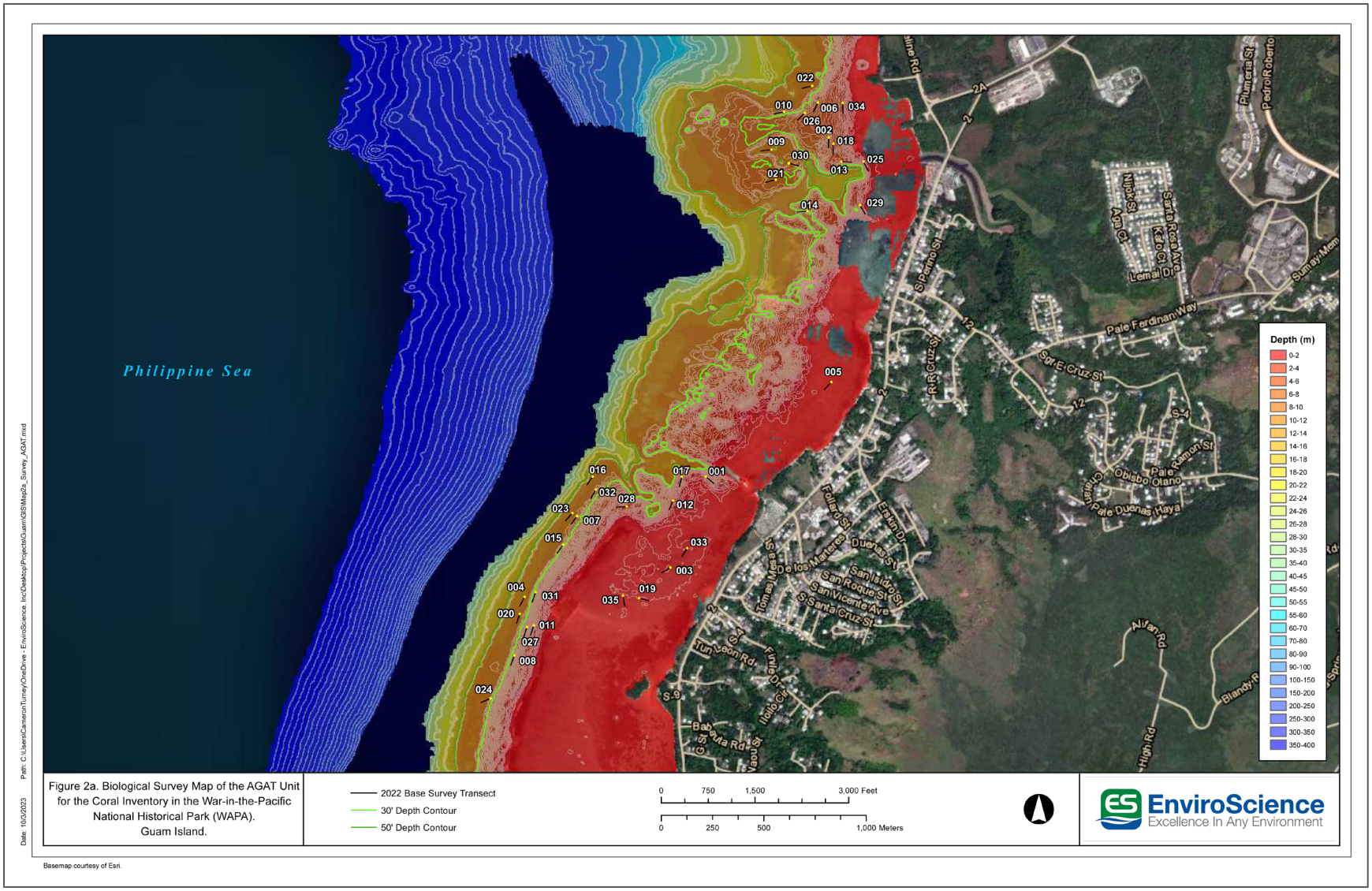


Figure A-2a. Biological survey map of the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

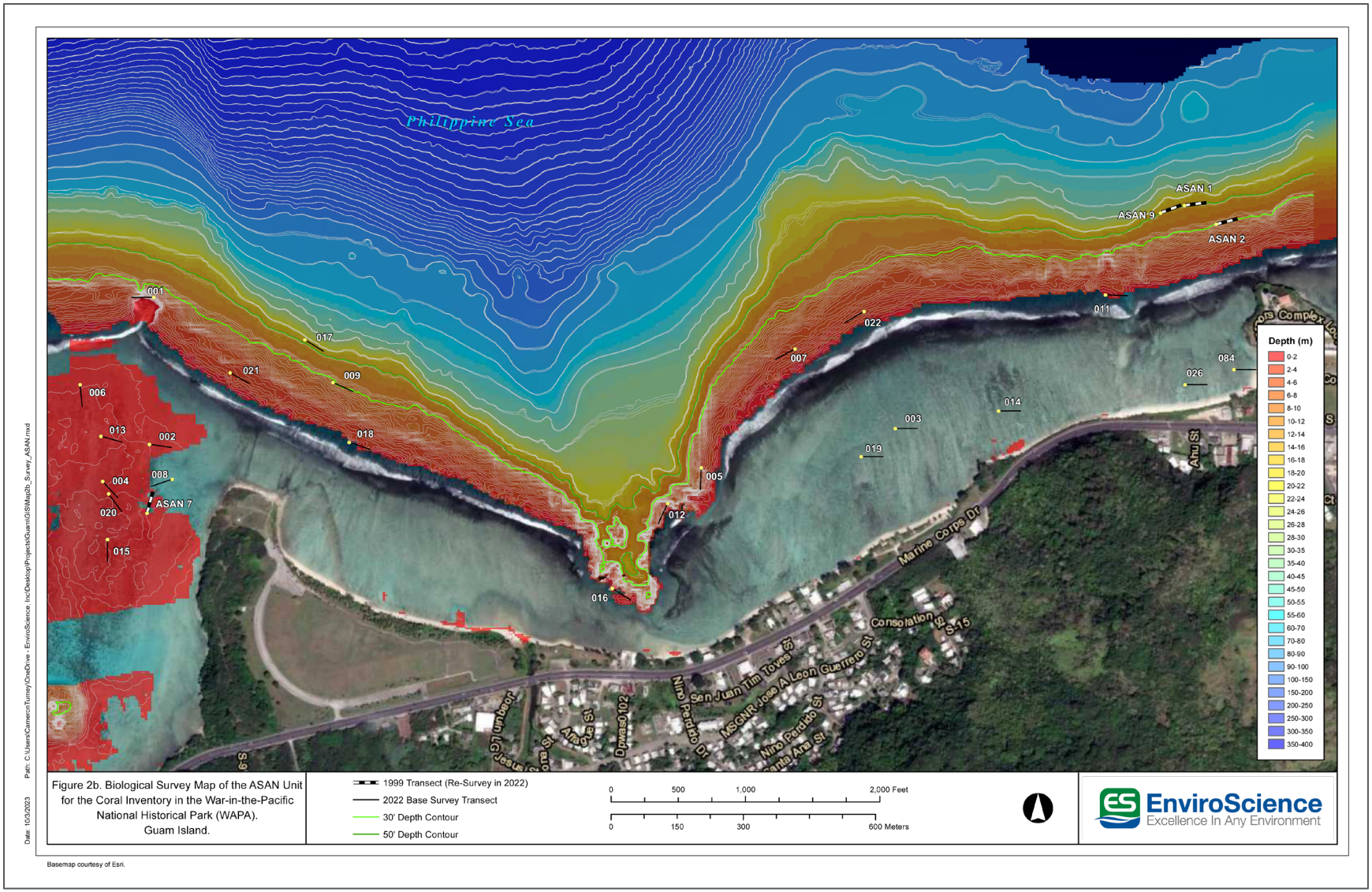


Figure A-2b. Biological survey map of the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

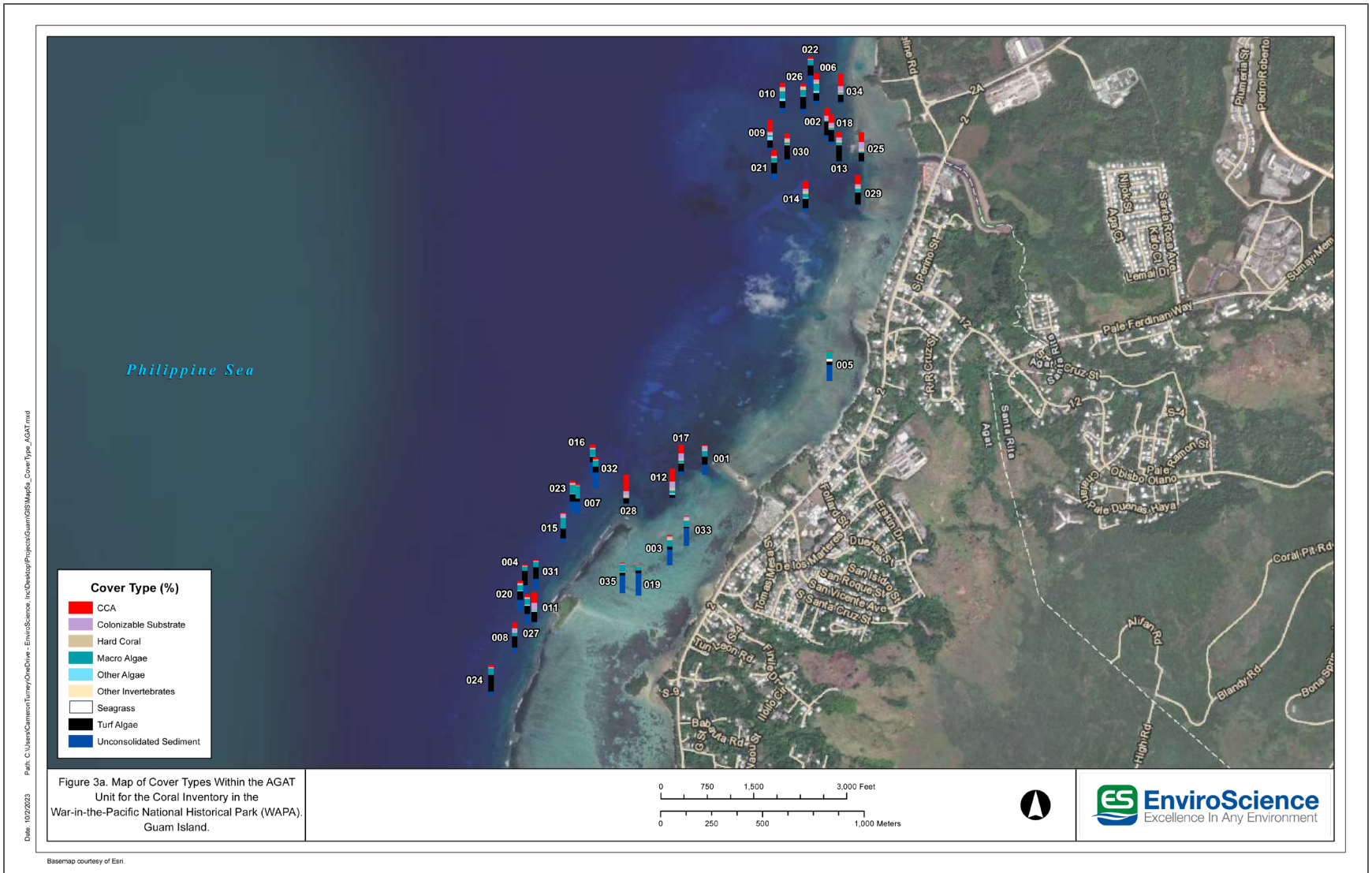


Figure A-3a. Map of cover types within the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

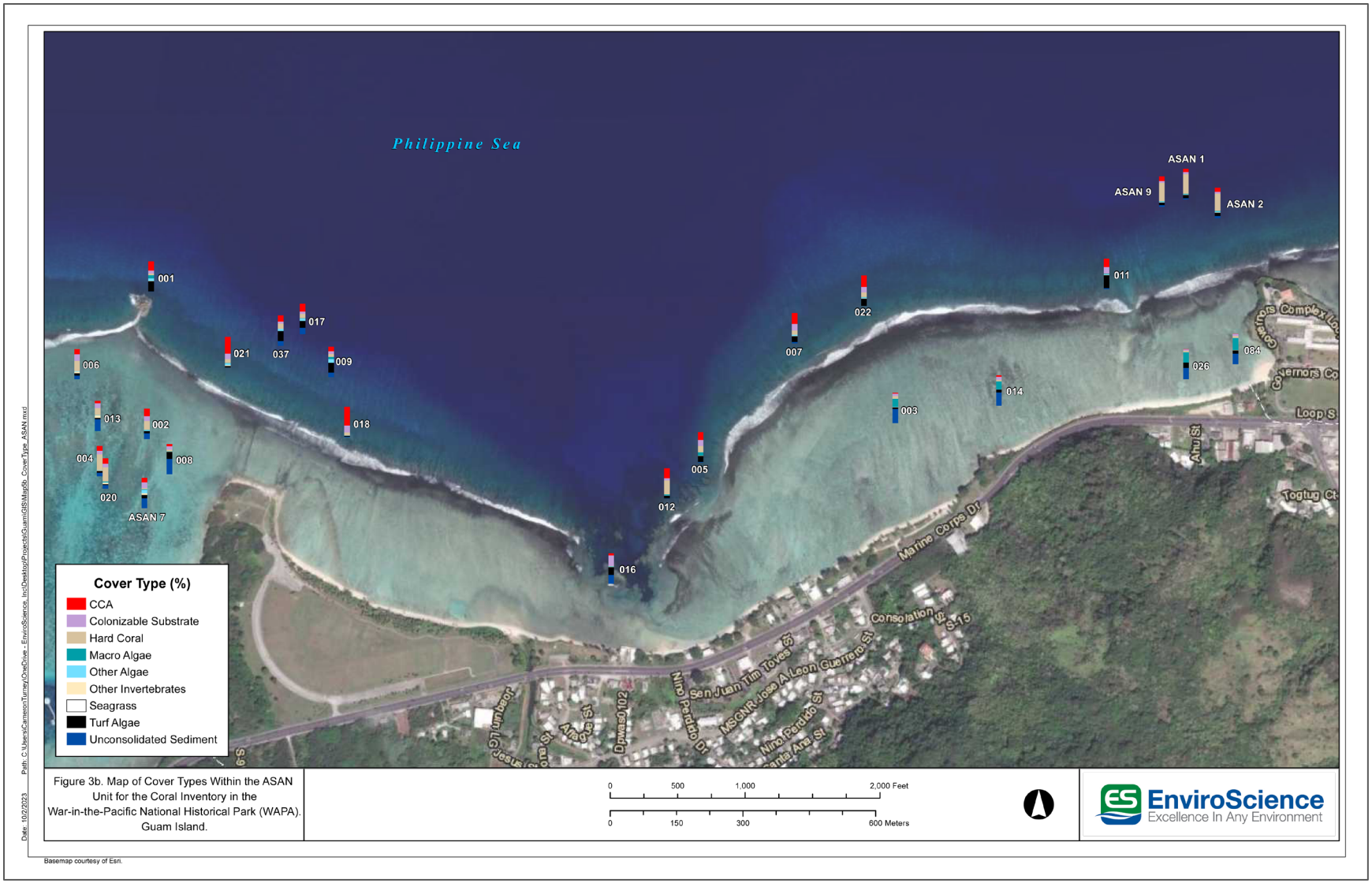


Figure 3b. Map of Cover Types Within the ASAN Unit for the Coral Inventory in the War-in-the-Pacific National Historical Park (WAPA). Guam Island.

Date: 10/2/2023 Path: C:\Users\CameronTurney\OneDrive - EnviroScience Inc\Desktop\Projects\Guam\GIS\Map5b_CoverType_ASAN.mxd

Figure A-3b. Map of cover types within the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

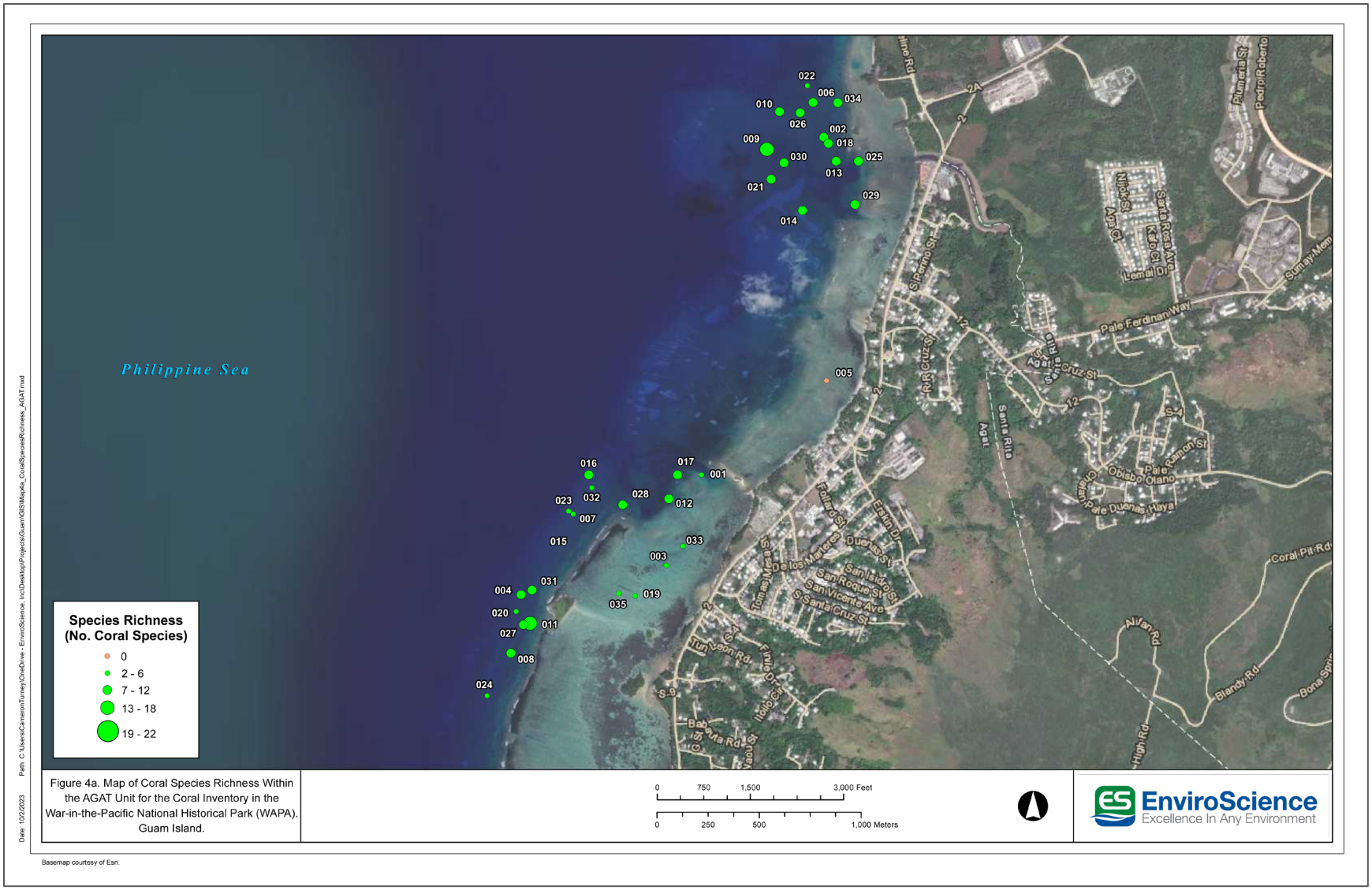


Figure A-4a. Map of coral species richness within the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

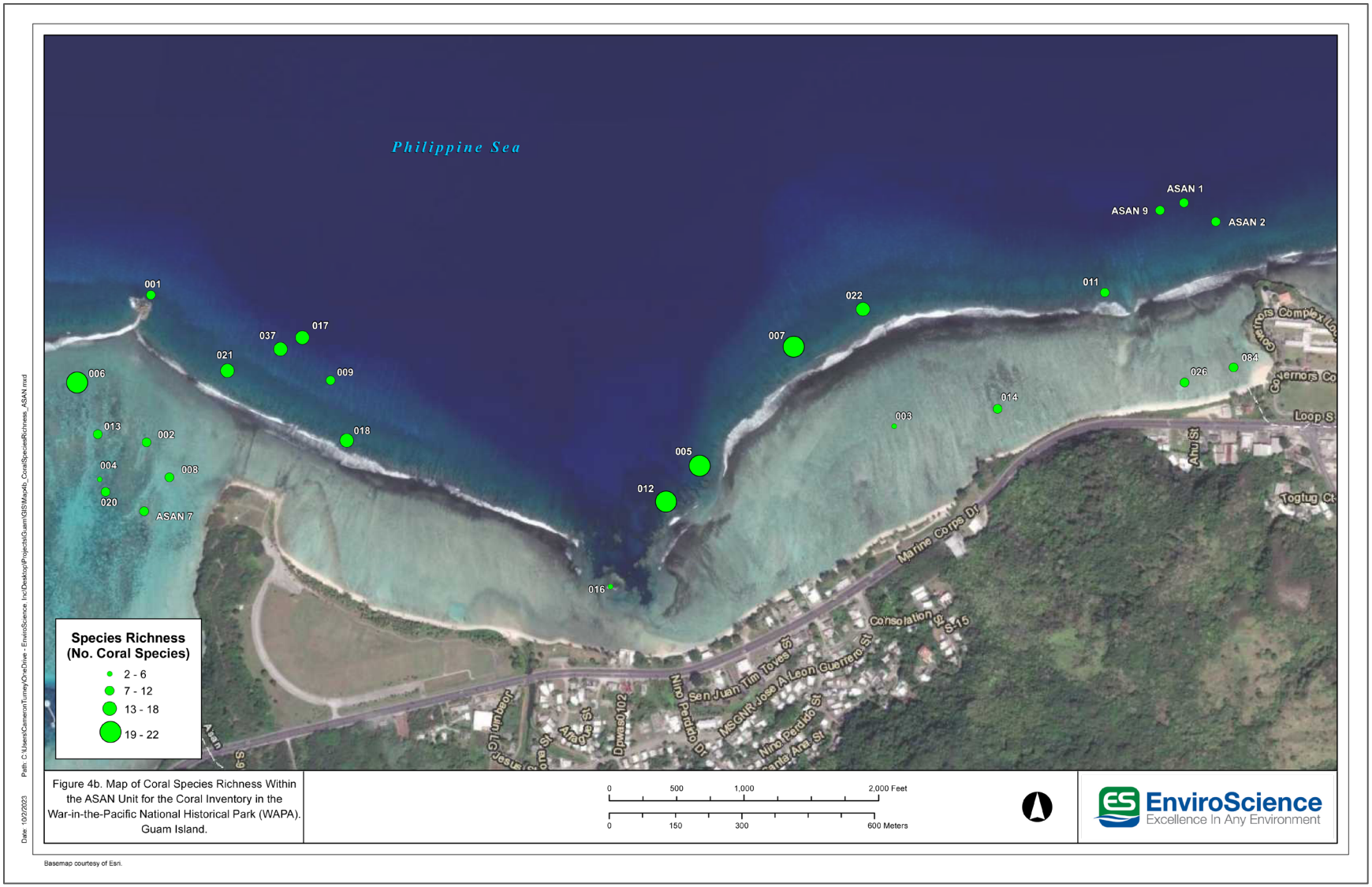


Figure A-4b. Map of coral species richness within the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

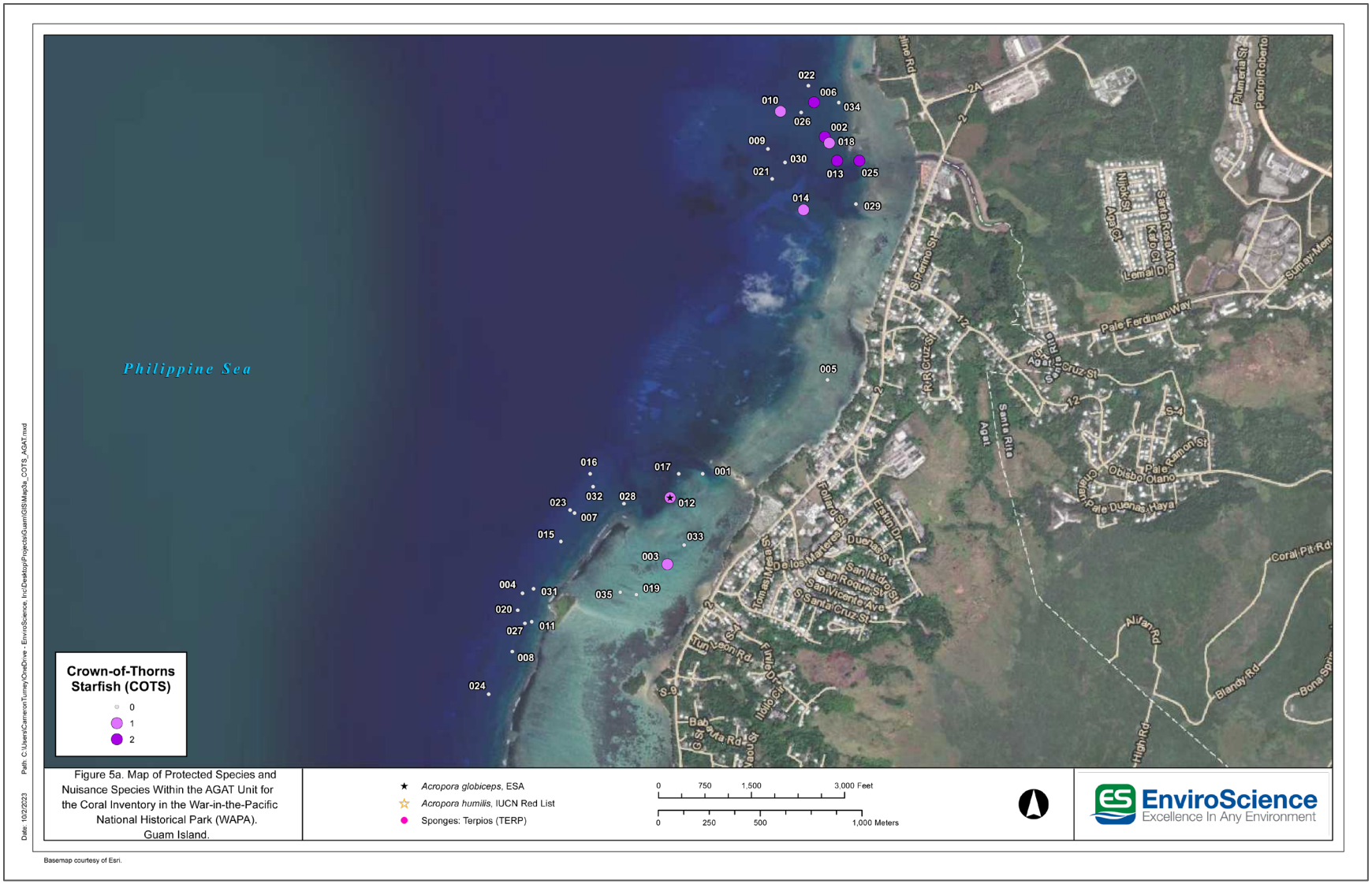


Figure A-5a. Map of protected species and nuisance species within the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

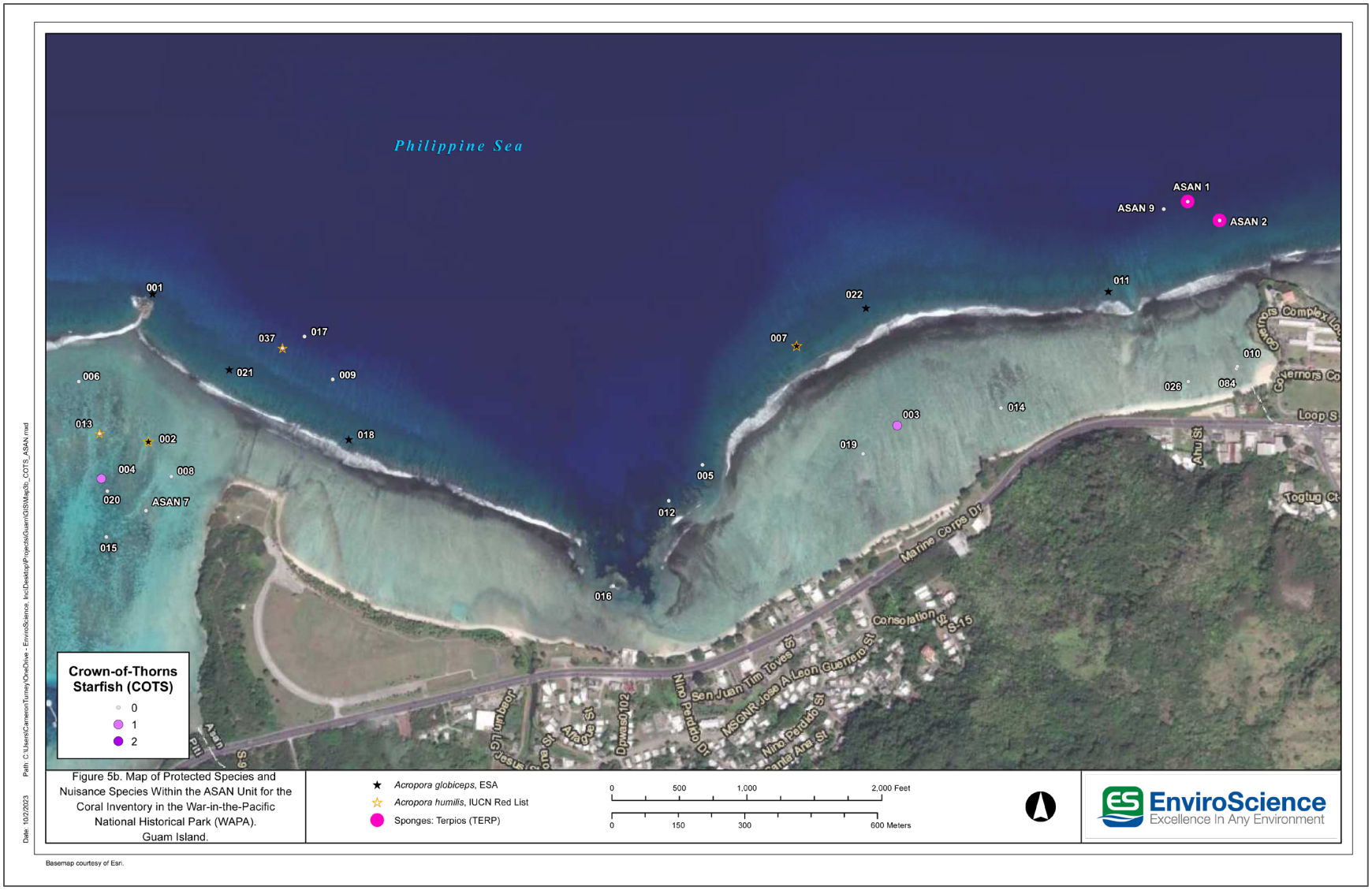


Figure 5b. Map of Protected Species and Nuisance Species Within the ASAN Unit for the Coral Inventory in the War-in-the-Pacific National Historical Park (WAPA). Guam Island.

Figure A-5b. Map of protected species and nuisance species within the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

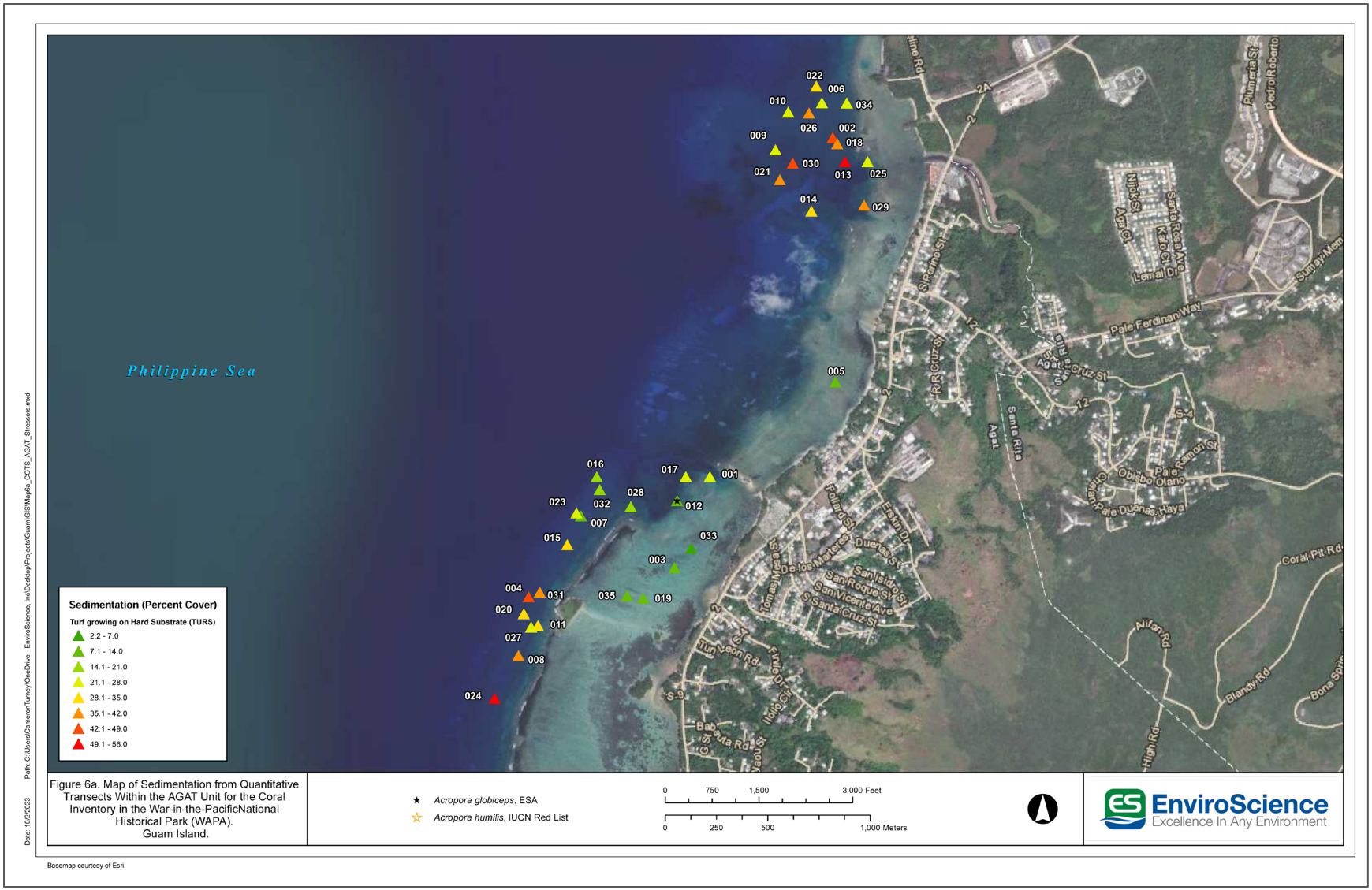


Figure A-6a. Map of sedimentation from quantitative transects within the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

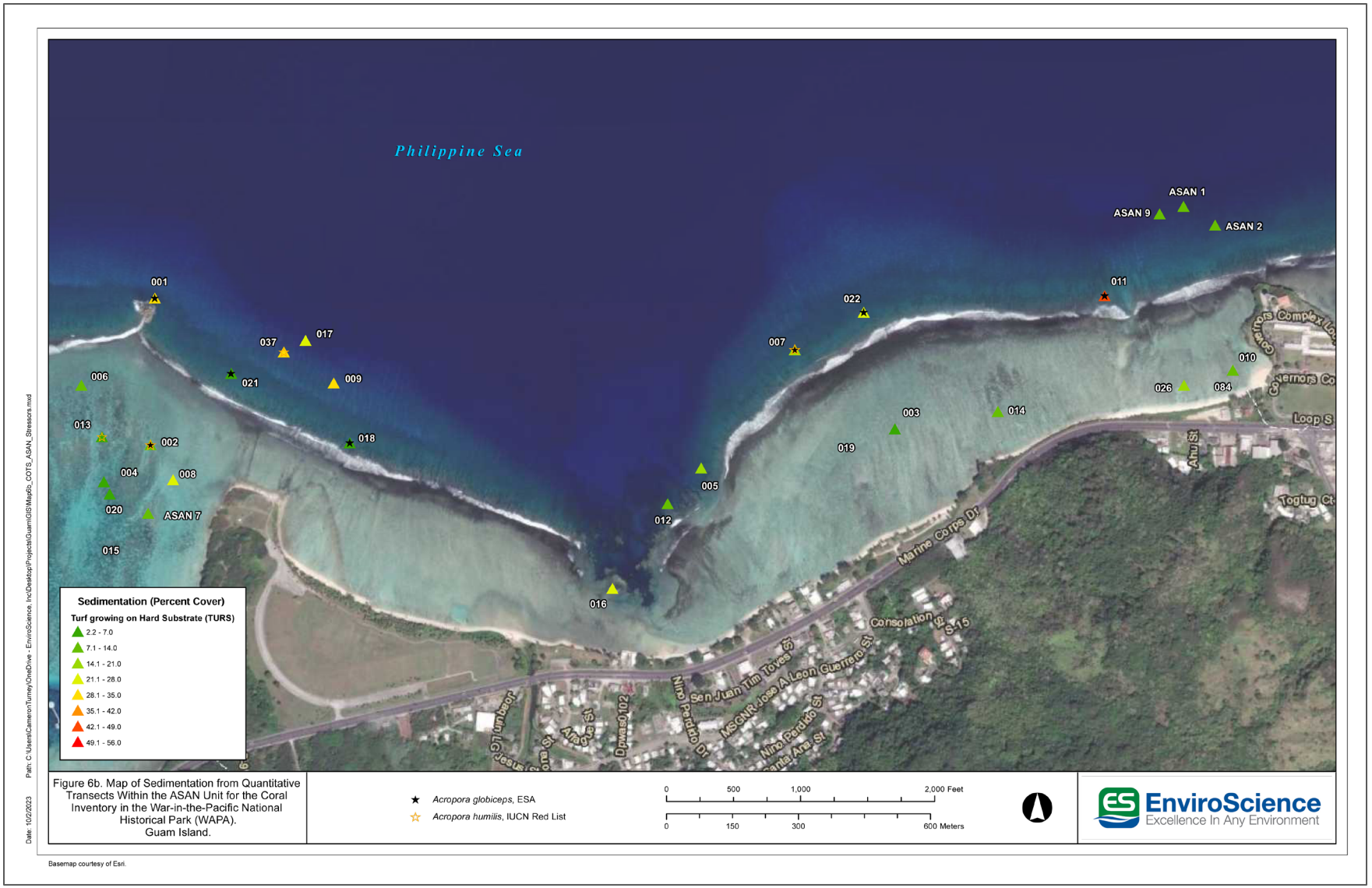


Figure A-6b. Map of sedimentation from quantitative transects within the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

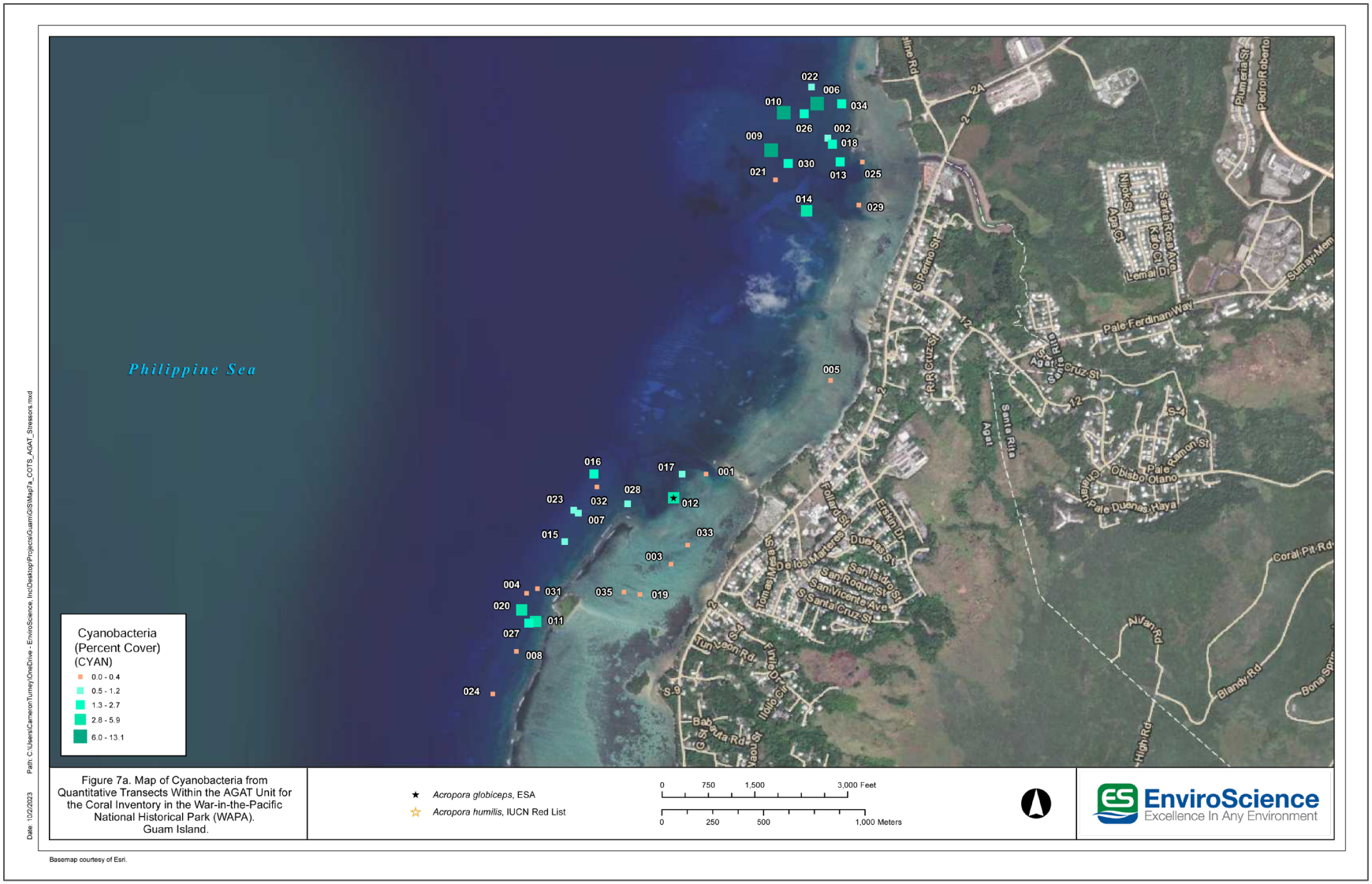


Figure A-7a. Map of cyanobacteria from quantitative transects within the Agat unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

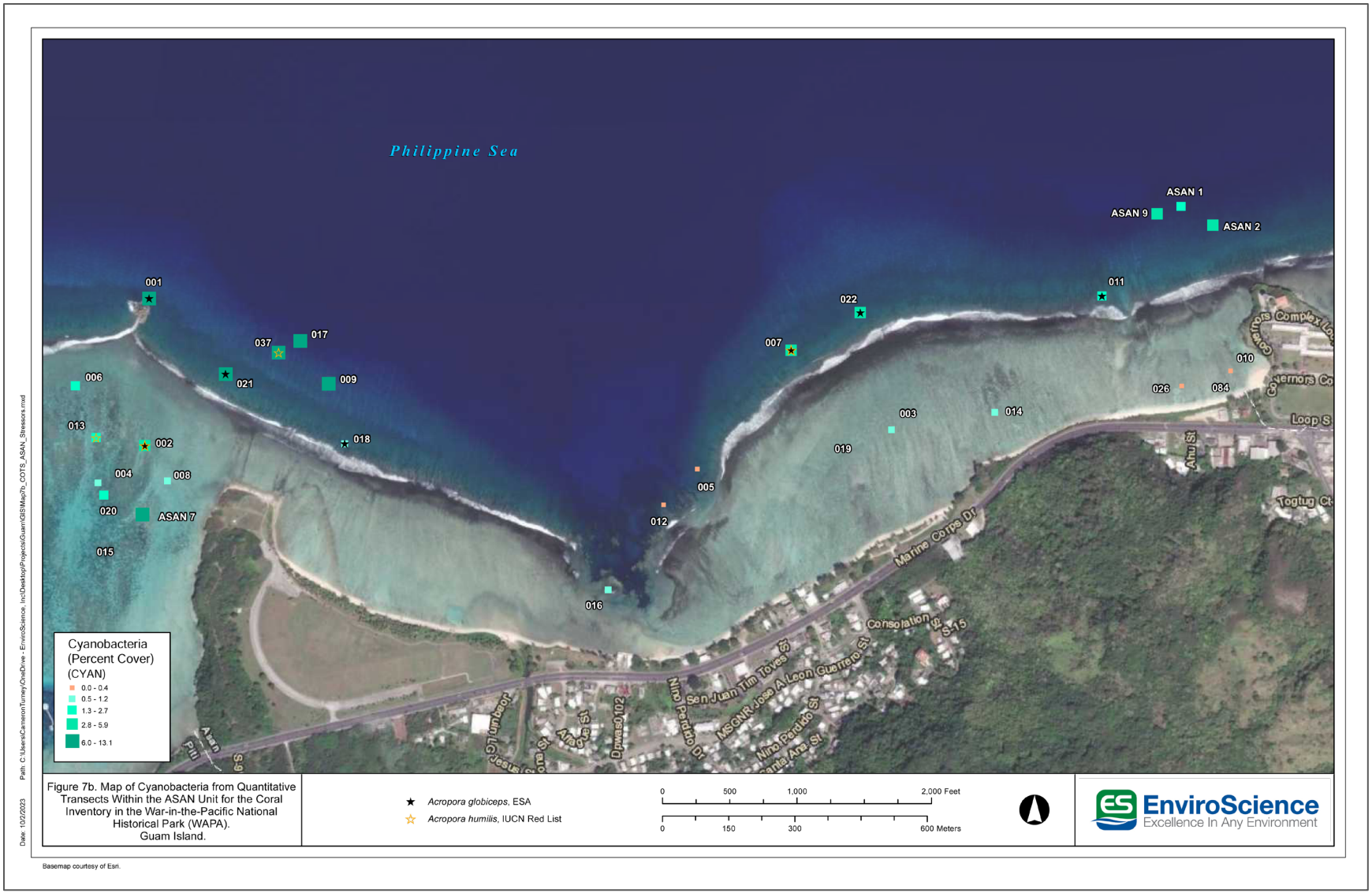


Figure A-7b. Map of cyanobacteria from quantitative transects within the Asan unit for the coral inventory in the War-in-the-Pacific National Historical Park on Guam Island.

Appendix B. Label Set

Table B-1. Label set.

Functional Group	Name	Short Code
CCA	Actinotrichia sp.	ACTO
	Amphiroa sp.	AMP
	Macroalgae: Articulated calcareous	BCAA
	Branching coralline algae -non-articulated	BCAN
	Crustose coralline algae	CCA
	Non CCA Crustose Algae	CCRA
	Dead Halimeda	DHAL
	Halimeda	HALI
	Mastophora_articulated_calcareous	MAST
	Neomeris	NEOM
Colonizable substrate	Thin Turf/Biofilm on Rock	TURF
Hard coral	Acropora abrotanoides	AABR
	Acropora azurea	AAZU
	Acropora (caespitose)	ACCE
	Acropora (corymbose)	ACCO
	Acropora (digitate)	ACDI
	Acropora cophodactyla	ACOP
	Astrea curta	ACUR
	Acropora digitifera	ADIG
	Acanthastrea echinata	AECH
	Acropora globiceps	AGLO
	Acropora humilis	AHUM
	Acropora latistella	ALAT
	Acropora monticulosa	AMON
	Acropora muricata	AMUR
	Acropora muricata bleached	AMUR-BL
	Astreopora myriophthalma	AMYR
	Acropora palmerae	APAL
	Acropora cf. pulchra	APUL
	Acropora cf. pulchra (bleached)	APUL-BL
	Astreopora	ASSP
	Acropora surculosa	ASUR
	Acropora tenuis	ATEN
	Acropora verweyi	AVER

Table B-1 (continued). Label set.

Functional Group	Name	Short Code
Hard coral (continued)	Coscinaraea columna	CCOL
	Cyphastrea	CYSP
	Diploastrea heliopora	DHEL
	Echinophyllia	ECHS
	Echinopora	ECSP
	Favites abdita	FABD
	Dipsastraea	FASP
	Favites	FAVS
	Favites flexuosa	FFLE
	Dipsastraea pallida	FPAL
	Goniastrea stelligera	FSTE
	Fungia	FUSP
	Goniastrea edwardsi	GEDW
	Galaxea fascicularis	GFAS
	Goniopora fruticosa	GFRU
	Goniastrea	GON
	Goniopora	GOSP
	Goniastrea pectinata	GPEC
	Gardineroseris planulata	GPLA
	Goniastrea retiformis	GRET
	Herpolitha	HLIM
	Hydnophora microconos	HMIC
	Isopora	IPAL
	Leptastrea	LESP
	Lobophyllia	LOBO
	Leptoria	LPHR
	Leptastrea purpurea	LPUR
	Leptastrea transversa	LTRA
	Merulina	MAMP
	Millepora platyphylla	MIPL
	Montastraea	MONT
	Montipora	MOSP
	Montipora verrucosa	MVER
	Oulophyllia	OCRI
	Porites annae	PANN
	Pavona	PAVS

Table B-1 (continued). Label set.

Functional Group	Name	Short Code
Hard coral (continued)	Pavona chiriquiensis	PCHI
	Porites cylindrica	PCYL
	Platygyra daedalea	PDAE
	Pocillopora damicornis	PDAM
	Pavona decussata	PDEC
	Porites deformis	PDEF
	Psammocora haimiana	PDIG
	Pavona duerdeni	PDUE
	Pocillopora elegans	PELE
	Pocillopora grandis (eydouxi)	PEYD
	Platygyra	PLAT
	Pocillopora ligulata	PLIG
	Plesiastrea versipora	PLVE
	Pocillopora meandrina	PMEA
	Pocillopora	POCS
	Porites Sub-Massive	POSB
	Porites (massive)	POSM
	Porites	POSP
	Platygyra pini	PPIN
	Porites rus	PRUS
	Porites rus - White Syndrome	PRWS
	Pocillopora setchelli	PSET
	Pachyseris	PSPE
	Psammocora	PSSP
	POLYPHYLLIA	PTAL
	Pavona varians	PVAR
	Pocillopora verrucosa	PVER
	Recent Dead Coral	REDC
	Stylocoeniella	SARM
	Scapophyllia	SCYL
	Stylophora	SMOR
	Turbinaria reniformis	TREN
	Turbinaria stellulata	TSTE
	Heliopora coerulea	HCOE
	Millepora_arborescent	MISP
Macro Algae	Asparagopsis	ASP

Table B-1 (continued). Label set.

Functional Group	Name	Short Code
Macro Algae (continued)	Brown fleshy algae	BFA
	Bryopsis spp.	BRYP
	Caulerpa	CLP
	Dictyota	DICT
	Macroalgae	FMA
	Macroalgae: Erect coarse branching	FMAC
	Macroalgae: Encrusting: brown	FMAD
	Green fleshy algae	GFA
	Galaxaura	GLXU
	Padina	PAD
	Red fleshy algae	RFA
	Turbinaria (algae)	TURB
	Tydemania spp.	TYDM
Other Invertebrates	Crown of Thorns Sea Star	APLA
	Echinoderms: Sea stars	ASTE
	Corallimorpharia	CORM
	Coralliophila violacea	CVI
	Dysidea sp	DYS
	Echinoderms: sea urchin	ECH
	Sea cucumber	HOLO
	Molluscs	MOLL
	Sarcophyton	SARC
	Soft Coral	SC
	Encrusting sponge	SEN
	Sponges: Erect forms	SER
	Sinularia	SINU
	Sponges: Terpios	TERP
	Tridacna: Giant clam	TRID
	Zoanthid	Z
Other Algae	Cyanobacteria	CYAN
	Chrysophyta	CHRY
Seagrass	Seagrass (Enhalus acoroides)	ENHA
Turf algae	Turf growing on hard substrate	TURS
TWS	Framer	FRA
	Shadow	SHAD
	TAPE	TAPE

Table B-1 (continued). Label set.

Functional Group	Name	Short Code
Unconsolidated sediment	Sand	SAND
	Thin Sediment over Rock	SHB
	Rubble	RB
	Halimeda (disc sediments)	HS

Appendix C. Listing of Coral Species Found in Hågat and Asan Bays from Historical 1977 and 1999 Surveys and the 2022 Quantitative Survey

Tables C-1 and C-2 list the coral species found in Agat and Asan Bays during studies from 1977 (Agat only, qualitative), 1999 (qualitative), and 2022 (quantitative). Names from previous studies have been aligned with current nomenclature using the World Register of Marine Species (WoRMS), as well as published and unpublished material produced by Richard Randall; Mr. Randlal conducted the 1977 survey and provided determinations for corals collected as part of the 1999 survey. Note that each of these survey efforts employed a different survey methodology and differing levels of sampling effort; any explicit comparisons between the lists of species obtained from these efforts should consider these differences. Species observed during the 1977 or 1999 surveys that were not detected during the 2022 coral diversity survey are denoted with an asterisk.

Table C-1. List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
Acanthastrea echinata	X	X	X	–
Acanthastrea sp. 1*	X	–	–	Current name could not be determined
Acropora abrotanoides	X	–	X	–
*Acropora austera**	X	–	–	1977: as *A. brueggemani*
*Acropora cerealis**	X	–	–	1977: as *A. hystrix* (?); also possible is *A*. cf. *secale*
Acropora digitifera	X	–	–	1977: as *A. convexa*
Acropora cf. *dissimilis*	X	–	–	1977: as *A. nana*
Acropora granulosa sensu Randall*	X	–	–	1977: as *A. rayneri*
Acropora cf. *humilis*	X	–	–	Near Threatened (IUCN Red List)
Acropora cf. *latistella* sensu Veron*	X	–	–	1977: as *A. delicatula*
*Acropora longicyathus**	X	–	–	1977: as *A. echinata*; may also include *A. syringodes*
*Acropora monticulosa**	X	–	–	1977: as *A. smithi*
Acropora muricata	X	–	X	1977: as *A. formosa*
Acropora cf. *nasuta*	X	–	–	1977: as *A. nasuta*
Acropora palmerae	X	–	–	1977: includes *A. monticulosa* (?); may refer to an undescribed digitate species
*Acropora paniculata**	X	–	–	1977: as *A. rambleri*
Acropora cf. *polystoma**	X	–	–	1977: as *Acropora* sp. 1
Acropora cf. *pulchra*		X	X	1999: as *A. aspera*
*Acropora studeri**	X	–	–	–
Acropora cf. *surculosa*	X	–	–	1977: as *A. surculosa*
Acropora tenuis	X	–	X	1977: as *A. kenti*
*Acropora tubicinaria**	X	–	–	Current name could not be determined
*Acropora valida**	X	X	–	–

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
Acropora verweyi	X	–	–	1977: as *A. murrayensis*; may also include *A. squarrosa*
Acropora wardii sensu Randall*	X	–	–	1977: as *Acropora wardii*
Acropora sp. “obtusicaulis”*	X	–	–	1977: as *A. ocellata*
Acropora spp. (corymbose)	–	–	X	2022: possibly *A.* cf. *humilis*
*Alveopora verrilliana**	X	–	–	–
Alveopora sp. 1*	X	–	–	Current name could not be determined
Anomastraea sp. 1*	X	–	–	Current name could not be determined; very likely not an *Anomastraea* species
Astrea curta	–	–	X	–
Astreopora gracilis	X	X	–	–
Astreopora listeri	X	–	–	–
Astreopora myriophthalma	X	X	–	1977: includes *A. profunda* (?)
Astreopora randalli	–	X	–	–
Astreopora spp.	–	–	X	–
Cycloseris sp. 1*	X	–	–	Current name could not be determined
Cyphastrea agassizi	X	–	–	1977: as *Leptastrea bottae*
Cyphastrea chalcidicum	X	X	–	–
Cyphastrea serailia	X	X	–	–
Cyphastrea sp. A	X	–	–	1977: as *Cyphastrea* sp. 1 (?)
Cyphastrea spp.	–	–	X	2022: likely *C. chalcidicum* or *C. serailia*
Desmophyllum sp. 1*	X	–	–	–
Diploastrea heliopora	X	–	X	–
Dipsastraea favus	X	X	–	1977, 1999: as *Favia favus*
Dipsastraea matthai	X	–	–	1977: as *Favia matthaii*
Dipsastraea pallida	X	X	–	1977, 1999: as *Favia pallida*

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
Dipsastraea speciosa	X	–	–	1977: as *Favia speciosa*
Dipsastraea spp.	–	–	X	–
Distichopora sp. A	X	–	–	1977: as *Distichopora* sp. 1
*Echinophyllia aspera**	X	–	–	–
*Echinopora lamellosa**	X	X	–	1977, 1999: likely *E.* cf. *pacifica*
*Euphyllia glabrescens**	X	–	–	–
*Favites abdita**	X	–	–	–
*Favites complanata**	X	–	–	Current name could not be determined; very likely not *F. complanata*
*Favites favosa**	X	–	–	Current name could not be determined; very likely not *F. favosa*
Favites flexuosa	X	–	–	1977: includes *F. virens* (?)
Favites cf. *valenciennesi sensu* Veron	X	X	X	1977: as *Plesiastrea* sp. 1 (?); 1999: as *Favites russelli; 2022:* as *Favites* sp.
Favites sp. “crassisepta”	X	–	–	1977: as *Favia rotumana*
Fungia fungites	X	–	–	–
Fungia spp.	–	–	X	–
Galaxea fascicularis	X	–	X	–
*Galaxea horrescens**	X	–	–	1977: as *Acrhelia horrescens*
Galaxea sp. 1*	X	–	–	Current name could not be determined
Gardineroseris planulata	X	–	X	1977: as *Pavona planulata*
Goniastrea edwardsi	X	X	X	1977: as *G. parvistella*
Goniastrea pectinata	X	X	X	–
Goniastrea retiformis	X	–	X	–
Goniastrea stelligera	X	–	X	1977: as *Favia stelligera*

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
*Goniopora arbuscula**	X	–	–	Current name could not be determined; likely not *G. arbuscula*
*Goniopora columna**	X	–	–	–
Goniopora sp. 1*	X	–	–	Current name could not be determined
Goniopora sp. 2*	X	–	–	Current name could not be determined
Goniopora fruticosa	–	–	X	–
Goniopora spp.	–	X	X	–
Heliopora coerulea	X	–	–	–
Herpolitha limax	X	–	–	–
Hydnophora microconos	X	–	X	–
*Isopora palifera**	X	–	–	1977: as *Acropora palifera*
Leptastrea purpurea	X	X	X	–
Leptastrea transversa	X	–	–	–
Leptastrea spp.	–	–	X	2022: likely *L. purpurea* and *L.* cf. *immersa*
Leptoria phrygia	X	–	X	2022: as *Leptoria*
*Leptoseris gardineri**	X	–	–	1977: as *Pavona gardineri*
*Leptoseris hawaiiensis**	X	–	–	–
Leptoseris incrustans	X	–	–	–
Leptoseris mycetoseroides	X	–	–	–
*Lithophyllon concinna**	X	–	–	1977: as *Fungia concinna*
Lobactis scutaria	X	–	–	1977: as *Fungia scutaria*
*Lobophyllia corymbosa**	X	–	–	–
*Lobophyllia flabelliformis**	X	–	–	1977: as *L. costata*
Lobophyllia hemprichii	X	–	–	–
Merulina ampliata	X	–	–	–

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
*Millepora dichotoma**	X	–	–	–
Millepora platyphylla	X	–	–	1977: includes *M. exaesa* (?)
*Montipora aequituberculata**	X	–	–	1977: as *M. composita*
Montipora conicula	X	–	–	–
*Montipora danae**	X	–	–	–
*Montipora ehrenbergii**	X	–	–	–
*Montipora elschneri**	X	–	–	–
Montipora floweri sensu Randall*	X	–	–	1977: as *M. floweri*
*Montipora foliosa**	X	–	–	–
Montipora foveolata	X	X	–	–
*Montipora granulosa**	X	–	–	–
*Montipora grisea**	X	–	–	1977: as *M. patula* (?)
Montipora floweri sensu Veron	X	–	–	1977: as *M. hoffmeisteri*
Montipora lobulata	X	–	–	–
Montipora monasteriata	X	–	–	–
*Montipora socialis**	X	–	–	–
*Montipora subtilis**	X	–	–	Current name could not be determined
*Montipora tuberculosa**	X	–	–	–
Montipora verrilli	X	–	–	–
Montipora verrucosa	X	X	X	–
Montipora spp.	–	X	X	–
*Mycedium elephantotus**	X	–	–	1977: as *Mycedium* sp. 1
Oulophyllia crispa	X	–	–	–
Pachyseris speciosa	X	–	–	–
Paracyathus sp. 1*	X	–	–	Current name could not be determined

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
Pavona chiriquiensis	–	–	X	–
Pavona clavus	X	–	–	–
*Pavona decussata**	–	X	–	–
Pavona duerdeni	X	–	X	1977: as *P. maldivensis*
Pavona maldivensis	X	–	–	1977: as *P. pollicata*
Pavona minuta	X	–	–	–
Pavona varians	X	X	–	–
Pavona venosa	X	X	–	1977: as *P. obtusata*
Pavona sp. “meandrina”	X	–	–	1977: as *Pavona* sp. 1
Pavona spp.	–	–	X	–
Platygyra daedalea	X	–	X	1977: as *P. rustica* and *P. lamellina* (?)
Platygyra pini	X	X	X	1977: as *P. sinensis* (?)
*Plerogyra sinuosa**	X	–	–	–
Plesiastrea peroni	X	–	–	1977: as *P. versipora*
*Pleuractis paumotensis**	X	–	–	1977: as *Fungia paumotensis*
Pocillopora damicornis	X	X	X	–
Pocillopora elegans	X	–	–	–
Pocillopora grandis	X	–	–	1977: as *P. eydouxi*
Pocillopora ligulata sensu Randall	X	–	–	1977: as *P. ligulata*
Pocillopora meandrina	X	–	–	–
Pocillopora setchelli	X	–	–	–
Pocillopora verrucosa	X	X	–	1977: includes *P. danae* (?)
Pocillopora woodjonesi	X	–	–	–
Pocillopora sp. “conicula”	X	–	–	1977: as *P. brevicornis*
Pocillopora spp.		–	X	–

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
*Polycyathus verrilli**	X	–	–	–
Porites annae	X	–	X	1977: as P. compressa (?) and P. duerdeni (?)
Porites australiensis	X	–	–	–
Porites cylindrica	X	–	–	1977: as *P. cocosensis* and *P. andrewsi* (?)
Porites deformis	X	–	X	1977: as *P. matthaii* (?)
*Porites horizontalata**	X	–	–	–
Porites lichen	X	X	–	–
Porites lobata	X	X	–	–
Porites lutea	X	X	–	–
*Porites monticulosa**	X	–	–	1977: as *Porites* (*S.*) *convexa*
Porites murrayensis	X	–	–	–
Porites rus	X	X	X	1977: as *Porites* (*S.*) *iwayamaensis*; 1999: includes *P. danae* (?)
*Porites superfusa**	X	X	–	1977: as *Porites* sp. 1
Porites sp. “mammalata”	X	–	–	1977: as *Porites* (*S.*) *hawaiiensis* and *Porites* (*S.*) sp. 1 (?)
Porites sp. 2*	X	–	–	Current name could not be determined
Porites spp. -massive	–	–	X	–
Porites spp. -submassive	–	–	X	–
Psammocora columna	X	X	–	1977, 1999: as *Coscinaraea columna*
Psammocora contigua	X	X	–	–
Psammocora haimiana	X	–	X	1977: as *P. togianensis*
Psammocora nierstraszi	X	–	–	–
Psammocora profundacella	X	X	–	–
Psammocora superficiales sensu Randall	X	–	–	1977: *P. verrilli* (?)
Psammocora sp. “nodulosa”	X	–	–	1977: as *P. haimeana*

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-1 (continued). List of coral species found in Hågat Bay during the study years of 1977, 1999, and 2022.

Species Name	1977*	1999*	2022*	Comments
Psammocora spp.	–	–	X	–
*Seriatopora hystrix**	X	–	–	–
Stylocoeniella armata	X	X	X	2022: as *Stylocoeniella*
Stylocoeniella guentheri	X	–	–	–
Stylophora sp. "mordax"	X	–	X	1977: as *S. pistillata; 2022:* as *Sylophora*
Turbinaria stellulata	–	–	X	2022: originally identified as *T. reniformis*

* An "X" indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-2. List of coral species found in Asan Bay during the study years of 1999 and 2022

Species Name	1999*	2022*	Comments
Acanthastrea echinata	X	X	–
Acropora abrotanoides	–	X	–
Acropora cf. *dissimilis*	–	X	2022: as *A. azurea*
Acropora cf. *humilis*	–	X	Near Threatened (IUCN Red List)
Acropora palmerae	–	X	2022: may include *A. minuta*
Acropora cf. *pulchra*	–	X	–
Acropora cf. *surculosa*	–	X	–
Acropora sp. "obtusicaulis"	–	X	2022: as Acropora (digitate)
Acropora spp. -caespitose	–	X	2022: likely *A*. cf. *secale*, *A. cerealis sensu* Randall, and/or *A*. cf. *dissimilis*
Acropora spp. -corymbose	–	X	2022: likely *A*. cf. *nasuta* and/or *A. surculosa*
Astrea curta	–	X	–
Astreopora myriophthalma	X	–	–
Astreopora randalli	X	–	–

* An "X" indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-2 (continued). List of coral species found in Asan Bay during the study years of 1999 and 2022

Species Name	1999*	2022*	Comments
Astreopora spp.	–	X	–
Cyphastrea chalcidicum	X	–	–
Cyphastrea serailia	X	–	–
Cyphastrea spp.	–	X	2022: likely *C. chalcidicum* or *C. serailia*
Diploastrea heliopora	–	X	–
Dipsastraea favus	X	–	1999: as *Favia favus*
Dipsastraea pallida	X	–	1999: as *Favia pallida*
Dipsastraea spp.	–	X	–
*Echinopora lamellosa**	X	–	1999: likely *E.* cf. *pacifica*
*Euphyllia cristata**	X	–	–
Favites cf. valenciennesi sensu Veron	X	X	2022: as *Favites* sp.
Fungia spp.	–	X	–
Galaxea fascicularis	X	X	–
Goniastrea edwardsi	X	X	–
Goniastrea retiformis	X	X	–
Goniastrea stelligera	–	X	–
Goniopora spp.	–	X	–
Heliopora coerulea	X	X	–
Hydnophora microconos	–	X	–
Leptastrea purpurea	X	X	–
Leptastrea transversa	X	X	–
Leptastrea spp.	–	X	2022: likely *L. purpurea* and *L.* cf. *immersa*
Leptoria phrygia	X	X	2022: as *Leptoria*

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-2 (continued). List of coral species found in Asan Bay during the study years of 1999 and 2022

Species Name	1999*	2022*	Comments
Millepora platyphylla	–	X	–
Montipora foveolata	X	–	–
Montipora verrucosa	X	X	–
Montipora spp.	X	X	–
Pavona chiriquiensis	–	X	–
Pavona decussata	–	X	–
Pavona divaricata	X	–	–
Pavona duerdeni	–	X	–
Pavona varians	X	–	–
Pavona venosa	X	–	–
Pavona spp.	–	X	–
Platygyra daedalea	–	X	–
Platygyra pini	X	X	–
Pocillopora damicornis	X	X	–
Pocillopora grandis	–	X	–
Pocillopora meandrina	–	X	–
Pocillopora verrucosa	–	X	–
Pocillopora spp.	–	X	–
Porites annae	–	X	–
Porites cylindrica	X	X	–
Porites deformis	–	X	–
Porites lichen	X	–	–
Porites lobata	X	–	–

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Table C-2 (continued). List of coral species found in Asan Bay during the study years of 1999 and 2022

Species Name	1999*	2022*	Comments
Porites lutea	X	–	–
Porites rus	X	X	1999: includes *P. danae* (?)
Porites spp. -massive	–	X	–
Porites spp. -submassive	–	X	–
Porites spp. -other	–	X	–
Psammocora haimiana	–	X	–
Psammocora profundacella	X	–	–
Psammocora spp.	–	X	–
Stylocoeniella armata	X	–	–
Turbinaria stellulata	–	X	2022: originally identified as *T. reniformis*

* An “X” indicates that species was observed during that year and an endash (–) indicates that it was not.

Appendix D. Spearman Rank Correlation Analysis

Table D-1 and Figure D-1 show spearman rank correlation results.

Table D-1. JMP® Output of Spearman Rank Correlation Analysis.

Variable	by Variable	Spearman ρ	Prob>|ρ
Depth (m)	Max Rugosity	0.4408	0.0004*
Hard coral	Max Rugosity	0.2153	0.09506
	Depth (m)	-0.0353	0.78704
Turf algae	Max Rugosity	0.1621	0.21109
	Depth (m)	0.4680	0.0001*
	Hard coral	-0.4306	0.0005*
Unconsolidated sediment	Max Rugosity	-0.3813	0.0024*
	Depth (m)	-0.1357	0.29609
	Hard coral	-0.4469	0.0003*
	Turf algae	-0.1726	0.18306
CCA	Max Rugosity	0.3923	0.0018*
	Depth (m)	0.1044	0.42303
	Hard coral	0.4103	0.0010*
	Turf algae	0.1142	0.38100
	Unconsolidated sediment	-0.8446	<0.0001*
Macro Algae	Max Rugosity	-0.1493	0.25009
	Depth (m)	0.0706	0.58806
	Hard coral	-0.5408	<0.0001*
	Turf algae	0.1621	0.21109
	Unconsolidated sediment	0.5132	<0.0001*
	CCA	-0.6239	<0.0001*
Colonizable substrate	Max Rugosity	0.0437	0.73802
	Depth (m)	-0.3767	0.0028*
	Hard coral	0.3503	0.0056*
	Turf algae	-0.1502	0.24708
	Unconsolidated sediment	-0.5680	<0.0001*
	CCA	0.5963	<0.0001*
	Macro Algae	-0.6450	<0.0001*
Other Organisms	Max Rugosity	0.0236	0.8570
	Depth (m)	0.1859	0.1514
	Hard coral	0.2920	0.0224*
	Turf algae	0.0029	0.9826

* Variable was found to be significant (also shown in orange and red font).

Table D-1 (continued). JMP® Output of Spearman Rank Correlation Analysis.

Variable	by Variable	Spearman ρ	Prob>|ρ
Other Organisms (continued)	Unconsolidated sediment	-0.2813	0.0281*
	CCA	0.3984	0.0015*
	Macro Algae	-0.3572	0.0047*
	Colonizable substrate	0.1640	0.2067
Other Invertebrates	Max Rugosity	-0.1456	0.2629
	Depth (m)	-0.2546	0.0477*
	Hard coral	0.3682	0.0035*
	Turf algae	-0.3184	0.0124*
	Unconsolidated sediment	-0.1415	0.2768
	CCA	0.2007	0.1209
	Macro Algae	-0.4243	0.0007*
	Colonizable substrate	0.3691	0.0034*
	Other Organisms	0.3142	0.0137*

* Variable was found to be significant (also shown in orange and red font).

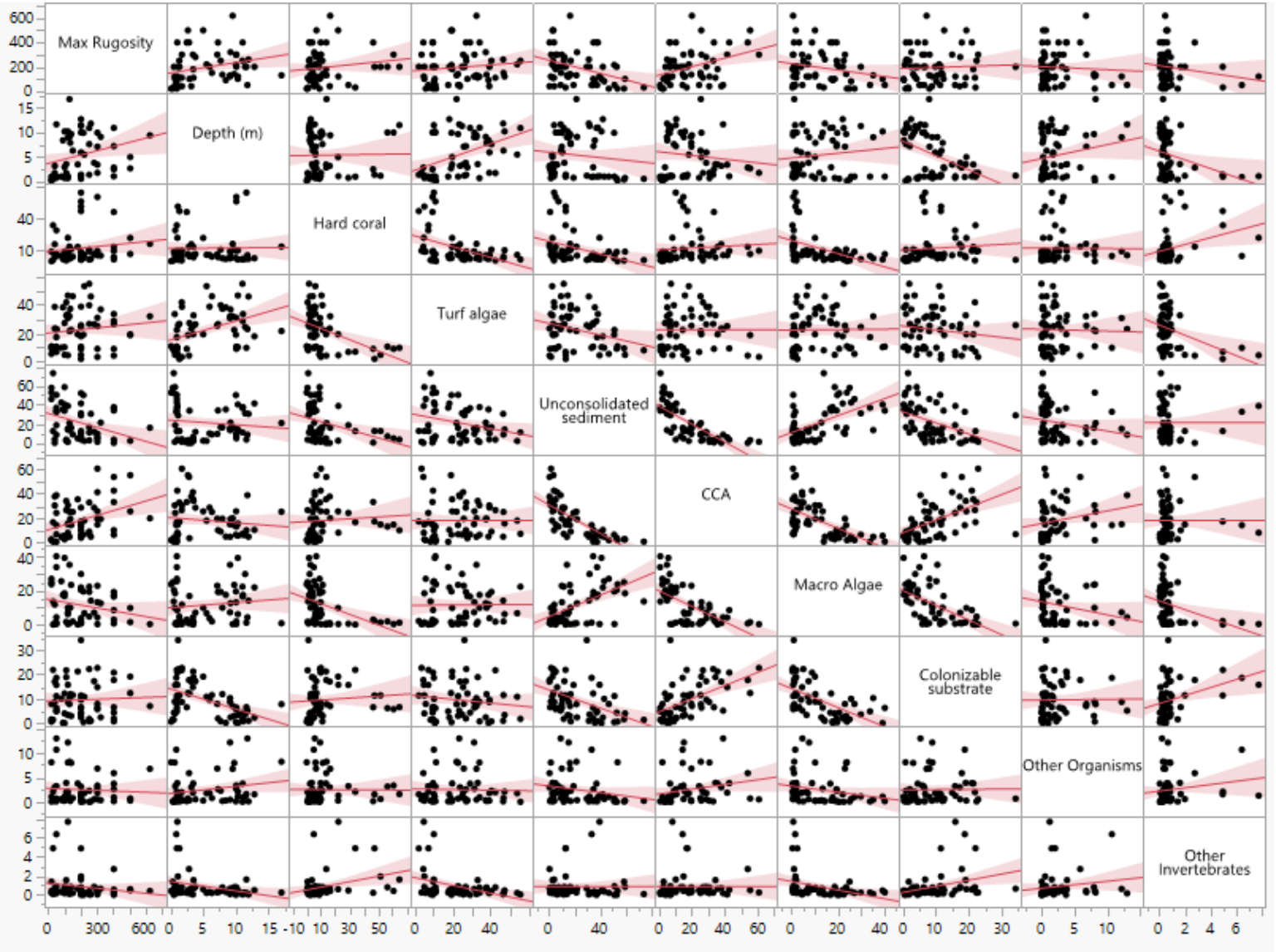


Figure D-1. Spearman Rank Correlation Scatterplot Matrix

Appendix E. R Script

Round 1 Model Development

```
Agat.Asan <-


readXL("P:/10_Projects/N/National_Park_Service/480M/15310_WAPA_Coral_Inven
tory/Data/Data Analyses_YB/Dataset for R.xlsx",

   rownames=FALSE, header=TRUE, na="", sheet="Data for Round 1",
stringsAsFactors=TRUE)

GLM.1 <- glm(A.humilis.Outcome ~ Colonizable.substrate,
family=binomial(logit), data=Agat.Asan)

summary(GLM.1)

exp(coef(GLM.1))  # Exponentiated coefficients ("odds ratios")

GLM.2 <- glm(A.humilis.Outcome ~ Depth..m., family=binomial(logit),
data=Agat.Asan)

summary(GLM.2)

exp(coef(GLM.2))  # Exponentiated coefficients ("odds ratios")

GLM.3 <- glm(A.humilis.Outcome ~ Hard.coral, family=binomial(logit),
data=Agat.Asan)

summary(GLM.3)

exp(coef(GLM.3))  # Exponentiated coefficients ("odds ratios")

GLM.4 <- glm(A.humilis.Outcome ~ Macro.Algae, family=binomial(logit),
data=Agat.Asan)

summary(GLM.4)

exp(coef(GLM.4))  # Exponentiated coefficients ("odds ratios")

GLM.5 <- glm(A.humilis.Outcome ~ Max.Rugosity, family=binomial(logit),
data=Agat.Asan)

summary(GLM.5)

exp(coef(GLM.5))  # Exponentiated coefficients ("odds ratios")

GLM.6 <- glm(A.humilis.Outcome ~ Other.Invertebrates,
family=binomial(logit), data=Agat.Asan)

summary(GLM.6)

exp(coef(GLM.6))  # Exponentiated coefficients ("odds ratios")
```

```
GLM.7 <- glm(A.humilis.Outcome ~ Other.Organisms, family=binomial(logit),
data=Agat.Asan)

summary(GLM.7)

exp(coef(GLM.7))  # Exponentiated coefficients ("odds ratios")

GLM.8 <- glm(A.humilis.Outcome ~ Turf.algae, family=binomial(logit),
data=Agat.Asan)

summary(GLM.8)

exp(coef(GLM.8))  # Exponentiated coefficients ("odds ratios")

GLM.9 <- glm(A.humilis.Outcome ~ X..COT, family=binomial(logit),
data=Agat.Asan)

summary(GLM.9)

exp(coef(GLM.9))  # Exponentiated coefficients ("odds ratios")

GLM.10 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO,
family=binomial(logit), data=Agat.Asan)

summary(GLM.10)

exp(coef(GLM.10))  # Exponentiated coefficients ("odds ratios")

GLM.11 <- glm(A.humilis.Outcome ~ ESA.Species_AHUM,
family=binomial(logit), data=Agat.Asan)

summary(GLM.11)

exp(coef(GLM.11))  # Exponentiated coefficients ("odds ratios")

GLM.12 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO.AHUM,
family=binomial(logit), data=Agat.Asan)

summary(GLM.12)

exp(coef(GLM.12))  # Exponentiated coefficients ("odds ratios")

GLM.13 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO.AHUM:Hard.coral,
family=binomial(logit), data=Agat.Asan)

summary(GLM.13)

exp(coef(GLM.13))  # Exponentiated coefficients ("odds ratios")

GLM.14 <- glm(A.humilis.Outcome ~ Hard.coral + ESA.Species_AGLO.AHUM +
Hard.coral:ESA.Species_AGLO.AHUM,

  family=binomial(logit), data=Agat.Asan)

summary(GLM.14)
```

```
exp(coef(GLM.14))  # Exponentiated coefficients ("odds ratios")
```

Round 2 Model Development

```
Agat.Asan2 <-


readXL("P:/10_Projects/N/National_Park_Service/480M/15310_WAPA_Coral_Inven
tory/Data/Data Analyses_YB/Dataset for R.xlsx",

   rownames=FALSE, header=TRUE, na="", sheet="Data for Round 2",
stringsAsFactors=TRUE)

GLM.1 <- glm(ESA.Outcome ~ Colonizable.substrate, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.1)

exp(coef(GLM.1))  # Exponentiated coefficients ("odds ratios")

GLM.2 <- glm(ESA.Outcome ~ Depth..m., family=binomial(logit),
data=Agat.Asan2)

summary(GLM.2)

exp(coef(GLM.2))  # Exponentiated coefficients ("odds ratios")

GLM.3 <- glm(ESA.Outcome ~ Hard.coral, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.3)

exp(coef(GLM.3))  # Exponentiated coefficients ("odds ratios")

GLM.4 <- glm(ESA.Outcome ~ Macro.Algae, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.4)

exp(coef(GLM.4))  # Exponentiated coefficients ("odds ratios")

GLM.5 <- glm(ESA.Outcome ~ Max.Rugosity, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.5)

exp(coef(GLM.5))  # Exponentiated coefficients ("odds ratios")

GLM.6 <- glm(ESA.Outcome ~ Other.Invertebrates, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.6)

exp(coef(GLM.6))  # Exponentiated coefficients ("odds ratios")
```

```
GLM.7 <- glm(ESA.Outcome ~ Other.Organisms, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.7)

exp(coef(GLM.7))  # Exponentiated coefficients ("odds ratios")

GLM.8 <- glm(ESA.Outcome ~ Turf.algae, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.8)

exp(coef(GLM.8))  # Exponentiated coefficients ("odds ratios")

GLM.9 <- glm(ESA.Outcome ~ X..COT, family=binomial(logit),
data=Agat.Asan2)

summary(GLM.9)

exp(coef(GLM.9))  # Exponentiated coefficients ("odds ratios")

GLM.10 <- glm(ESA.Outcome ~ Colonizable.substrate:Macro.Algae,
family=binomial(logit), data=Agat.Asan2)

summary(GLM.10)

exp(coef(GLM.10))  # Exponentiated coefficients ("odds ratios")

GLM.11 <- glm(ESA.Outcome ~ Colonizable.substrate:Depth..m.,
family=binomial(logit), data=Agat.Asan2)

summary(GLM.11)

exp(coef(GLM.11))  # Exponentiated coefficients ("odds ratios")

GLM.12 <- glm(ESA.Outcome ~ Macro.Algae:Depth..m., family=binomial(logit),
data=Agat.Asan2)

summary(GLM.12)

exp(coef(GLM.12))  # Exponentiated coefficients ("odds ratios")

GLM.13 <- glm(ESA.Outcome ~ Colonizable.substrate:Depth..m.:Macro.Algae,
family=binomial(logit), data=Agat.Asan2)

summary(GLM.13)

exp(coef(GLM.13))  # Exponentiated coefficients ("odds ratios")

GLM.14 <- glm(ESA.Outcome ~ Macro.Algae + Depth..m. +
Macro.Algae:Depth..m., family=binomial(logit), data=Agat.Asan2)

summary(GLM.14)

exp(coef(GLM.14))  # Exponentiated coefficients ("odds ratios")
```

Appendix F. R Output

Round 1 Model Results

Model 1

```
> GLM.1 <- glm(A.humilis.Outcome ~ Colonizable.substrate,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.1)

Call:

glm(formula = A.humilis.Outcome ~ Colonizable.substrate, family =
binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.3271  -0.2641  -0.2526  -0.2405   2.6470

Coefficients:

                     Estimate Std. Error z value Pr(>|z|)

(Intercept)           -3.59186    1.23068  -2.919  0.00352 **

Colonizable.substrate  0.02012    0.09192   0.219  0.82675

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.558  on 59  degrees of freedom

AIC: 21.558

Number of Fisher Scoring iterations: 6

> exp(coef(GLM.1))  # Exponentiated coefficients ("odds ratios")

          (Intercept) Colonizable.substrate

           0.02754709            1.02032153
```

Model 2

```
> GLM.2 <- glm(A.humilis.Outcome ~ Depth..m., family=binomial(logit),
data=Agat.Asan)
```

```
> summary(GLM.2)

Call:

glm(formula = A.humilis.Outcome ~ Depth..m., family = binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.2584  -0.2583  -0.2582  -0.2581   2.6147

Coefficients:

              Estimate Std. Error z value Pr(>|z|)

(Intercept) -3.3851135  1.1415971  -2.965  0.00302 **

Depth..m.    0.0001337  0.1638716   0.001  0.99935

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.605  on 59  degrees of freedom

AIC: 21.605

Number of Fisher Scoring iterations: 6

> exp(coef(GLM.2))  # Exponentiated coefficients ("odds ratios")

(Intercept)   Depth..m.

  0.0338738   1.0001337
```

Model 3

```
> GLM.3 <- glm(A.humilis.Outcome ~ Hard.coral, family=binomial(logit),
data=Agat.Asan)

> summary(GLM.3)

Call:

glm(formula = A.humilis.Outcome ~ Hard.coral, family = binomial(logit),

    data = Agat.Asan)

Deviance Residuals:
```

```
    Min       1Q   Median       3Q      Max
-0.9964  -0.1446  -0.1220  -0.1087   2.5216
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -5.33677    1.68523  -3.167  0.00154 **
Hard.coral   0.07588    0.03605   2.105  0.03532 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 17.605  on 60  degrees of freedom
Residual deviance: 12.297  on 59  degrees of freedom
AIC: 16.297
Number of Fisher Scoring iterations: 7
> exp(coef(GLM.3))  # Exponentiated coefficients ("odds ratios")
(Intercept)  Hard.coral
0.004811376 1.078831395
```

Model 4

```
> GLM.4 <- glm(A.humilis.Outcome ~ Macro.Algae, family=binomial(logit),
data=Agat.Asan)
> summary(GLM.4)
Call:
glm(formula = A.humilis.Outcome ~ Macro.Algae, family = binomial(logit),
    data = Agat.Asan)
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.79463  -0.16185  -0.00006   0.00000   2.05265
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.8338     1.2526  -0.666    0.506
```

```
Macro.Algae  -1.9263     1.8312  -1.052    0.293

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 11.612  on 59  degrees of freedom

AIC: 15.612

Number of Fisher Scoring iterations: 12

> exp(coef(GLM.4))  # Exponentiated coefficients ("odds ratios")

(Intercept) Macro.Algae

  0.4344117   0.1456824
```

Model 5

```
> GLM.5 <- glm(A.humilis.Outcome ~ Max.Rugosity, family=binomial(logit),
data=Agat.Asan)

> summary(GLM.5)

Call:

glm(formula = A.humilis.Outcome ~ Max.Rugosity, family = binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.2844  -0.2714  -0.2560  -0.2414   2.6647

Coefficients:

              Estimate Std. Error z value Pr(>|z|)

(Intercept)  -3.163955   1.224107  -2.585  0.00975 **

Max.Rugosity -0.001191   0.005641  -0.211  0.83281

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.558  on 59  degrees of freedom

AIC: 21.558
```

```
Number of Fisher Scoring iterations: 6

> exp(coef(GLM.5))  # Exponentiated coefficients ("odds ratios")

 (Intercept) Max.Rugosity

  0.04225826   0.99881001
```

Model 6

```
> GLM.6 <- glm(A.humilis.Outcome ~ Other.Invertebrates,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.6)

Call:

glm(formula = A.humilis.Outcome ~ Other.Invertebrates, family =
binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.3025  -0.2851  -0.2670  -0.2438   2.5892

Coefficients:

                    Estimate Std. Error z value Pr(>|z|)

(Intercept)          -3.0613     0.9573  -3.198  0.00138 **

Other.Invertebrates  -0.5466     1.4131  -0.387  0.69889

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.289  on 59  degrees of freedom

AIC: 21.289

Number of Fisher Scoring iterations: 8

> exp(coef(GLM.6))  # Exponentiated coefficients ("odds ratios")

        (Intercept) Other.Invertebrates

         0.04682621          0.57889568
```

Model 7

```
> GLM.7 <- glm(A.humilis.Outcome ~ Other.Organisms,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.7)

Call:

glm(formula = A.humilis.Outcome ~ Other.Organisms, family =
binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.3641  -0.2593  -0.2428  -0.2363   2.6053

Coefficients:

                Estimate Std. Error z value Pr(>|z|)

(Intercept)     -3.58243    0.96029  -3.731 0.000191 ***

Other.Organisms  0.06914    0.19548   0.354 0.723548

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.491  on 59  degrees of freedom

AIC: 21.491

Number of Fisher Scoring iterations: 6

> exp(coef(GLM.7))  # Exponentiated coefficients ("odds ratios")

    (Intercept) Other.Organisms

     0.02780791      1.07159059
```

Model 8

```
> GLM.8 <- glm(A.humilis.Outcome ~ Turf.algae, family=binomial(logit),
data=Agat.Asan)

> summary(GLM.8)

Call:
```

```
glm(formula = A.humilis.Outcome ~ Turf.algae, family = binomial(logit),
    data = Agat.Asan)
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.61859  -0.33783  -0.11453  -0.05057   2.35410
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -1.1891     1.3568  -0.876    0.381
Turf.algae   -0.1613     0.1331  -1.213    0.225
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 17.605  on 60  degrees of freedom
Residual deviance: 14.311  on 59  degrees of freedom
AIC: 18.311
Number of Fisher Scoring iterations: 8
> exp(coef(GLM.8))  # Exponentiated coefficients ("odds ratios")
(Intercept)  Turf.algae
  0.3045029   0.8510067
```

Model 9

```
> GLM.9 <- glm(A.humilis.Outcome ~ X..COT, family=binomial(logit),
data=Agat.Asan)
> summary(GLM.9)
Call:
glm(formula = A.humilis.Outcome ~ X..COT, family = binomial(logit),
    data = Agat.Asan)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.2857  -0.2857  -0.2857  -0.2857   2.5373
Coefficients:
             Estimate Std. Error z value  Pr(>|z|)
```

```
(Intercept)   -3.1781     0.7217  -4.404 0.0000106 ***
X..COT       -16.4384  4168.4260  -0.004     0.997
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 17.605  on 60  degrees of freedom
Residual deviance: 16.794  on 59  degrees of freedom
AIC: 20.794
Number of Fisher Scoring iterations: 19
> exp(coef(GLM.9))  # Exponentiated coefficients ("odds ratios")
     (Intercept)           X..COT
0.04166666666667 0.00000007258962
```

Model 10

```
> GLM.10 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO,
family=binomial(logit), data=Agat.Asan)
> summary(GLM.10)
Call:
glm(formula = A.humilis.Outcome ~ ESA.Species_AGLO, family =
binomial(logit),
    data = Agat.Asan)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.2722  -0.2722  -0.2722  -0.2722   2.5746
Coefficients:
                  Estimate Std. Error z value   Pr(>|z|)
(Intercept)        -3.2771     0.7203  -4.550 0.00000538 ***
ESA.Species_AGLO  -16.2889  4390.3075  -0.004      0.997
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.183  on 59  degrees of freedom

AIC: 21.183

Number of Fisher Scoring iterations: 18

> exp(coef(GLM.10))  # Exponentiated coefficients ("odds ratios")

     (Intercept) ESA.Species_AGLO

0.03773584905660 0.00000008429664
```

Model 11

```
> GLM.11 <- glm(A.humilis.Outcome ~ ESA.Species_AHUM,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.11)

Call:

glm(formula = A.humilis.Outcome ~ ESA.Species_AHUM, family =
binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.2626  -0.2626  -0.2626  -0.2626   2.6017

Coefficients:

                  Estimate Std. Error z value   Pr(>|z|)

(Intercept)        -3.3499     0.7194  -4.656 0.00000322 ***

ESA.Species_AHUM  -14.2162  2797.4420  -0.005      0.996

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605  on 60  degrees of freedom

Residual deviance: 17.469  on 59  degrees of freedom

AIC: 21.469
```

```
Number of Fisher Scoring iterations: 16

> exp(coef(GLM.11))  # Exponentiated coefficients ("odds ratios")

     (Intercept) ESA.Species_AHUM

 0.0350877192982  0.0000006698819
```

Model 12

```
> GLM.12 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO.AHUM,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.12)

Call:

glm(formula = A.humilis.Outcome ~ ESA.Species_AGLO.AHUM, family =
binomial(logit),

    data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-1.1774 -0.1849 -0.1849  -0.1849   2.8557

Coefficients:

                     Estimate Std. Error z value Pr(>|z|)

(Intercept)            -4.060      1.009  -4.026 0.0000568 ***

ESA.Species_AGLO.AHUM    4.060      1.737   2.338    0.0194 *

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605 on 60  degrees of freedom

Residual deviance: 12.911 on 59  degrees of freedom

AIC: 16.911

Number of Fisher Scoring iterations: 7

> exp(coef(GLM.12))  # Exponentiated coefficients ("odds ratios")

           (Intercept) ESA.Species_AGLO.AHUM

            0.01724138           58.00000000
```

Model 13

```
> GLM.13 <- glm(A.humilis.Outcome ~ ESA.Species_AGLO.AHUM:Hard.coral,
family=binomial(logit), data=Agat.Asan)

> summary(GLM.13)

Call:

glm(formula = A.humilis.Outcome ~ ESA.Species_AGLO.AHUM:Hard.coral,

    family = binomial(logit), data = Agat.Asan)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.7110 -0.1734  -0.1734  -0.1734   2.9000

Coefficients:

                                 Estimate Std. Error z value Pr(>|z|)

(Intercept)                     -4.1901     1.0525  -3.981 0.0000686 ***

ESA.Species_AGLO.AHUM:Hard.coral   0.2189     0.1071   2.044     0.041 *

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 17.605 on 60 degrees of freedom

Residual deviance: 10.878 on 59 degrees of freedom

AIC: 14.878

Number of Fisher Scoring iterations: 7

> exp(coef(GLM.13))  # Exponentiated coefficients ("odds ratios")

                     (Intercept) ESA.Species_AGLO.AHUM:Hard.coral

                      0.01514492                       1.24474852
```

Model 14

```
> GLM.14 <- glm(A.humilis.Outcome ~ Hard.coral + ESA.Species_AGLO.AHUM +
Hard.coral:ESA.Species_AGLO.AHUM,

+   family=binomial(logit), data=Agat.Asan)

> summary(GLM.14)
```

```
Call:
glm(formula = A.humilis.Outcome ~ Hard.coral + ESA.Species_AGLO.AHUM +
    Hard.coral:ESA.Species_AGLO.AHUM, family = binomial(logit),
    data = Agat.Asan)
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.12091  -0.00571  -0.00381  -0.00277   1.59846
Coefficients:
                                  Estimate Std. Error z value Pr(>|z|)
(Intercept)                       -12.9875    12.5850  -1.032    0.302
Hard.coral                          0.1992     0.2112   0.943    0.346
ESA.Species_AGLO.AHUM             -40.4211 22106.0091  -0.002    0.999
Hard.coral:ESA.Species_AGLO.AHUM    2.3175   978.1293   0.002    0.998
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 17.6046  on 60  degrees of freedom
Residual deviance:  4.3487  on 57  degrees of freedom
AIC: 12.349
Number of Fisher Scoring iterations: 18
> exp(coef(GLM.5))  # Exponentiated coefficients ("odds ratios")
                      (Intercept)                       Hard.coral
ESA.Species_AGLO.AHUM
                     2.288705e-06                     1.220482e+00
2.788225e-18
Hard.coral:ESA.Species_AGLO.AHUM
                     1.015056e+01
```

Round 2 Model Results

Model 1

```
> GLM.1 <- glm(ESA.Outcome ~ Colonizable.substrate,
family=binomial(logit), data=Agat.Asan2)
> summary(GLM.1)
```

```
Call:

glm(formula = ESA.Outcome ~ Colonizable.substrate, family =
binomial(logit),

    data = Agat.Asan2)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-2.0161  -0.5428  -0.3509  -0.2485   2.2536

Coefficients:

                     Estimate Std. Error z value  Pr(>|z|)

(Intercept)           -3.61284    0.88885  -4.065 0.0000481 ***

Colonizable.substrate  0.16033    0.05571   2.878     0.004 **

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 43.461  on 59  degrees of freedom

AIC: 47.461

Number of Fisher Scoring iterations: 5

> exp(coef(GLM.1))  # Exponentiated coefficients ("odds ratios")

          (Intercept) Colonizable.substrate

           0.02697512            1.17390169
```

Model 2

```
> GLM.2 <- glm(ESA.Outcome ~ Depth..m., family=binomial(logit),
data=Agat.Asan2)

> summary(GLM.2)

Call:

glm(formula = ESA.Outcome ~ Depth..m., family = binomial(logit),

    data = Agat.Asan2)

Deviance Residuals:
```

```
    Min       1Q   Median       3Q      Max
-0.8922  -0.7882  -0.3917  -0.2645   2.4279
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.6861     0.4946  -1.387   0.1654
Depth..m.    -0.2324     0.1155  -2.012   0.0442 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 48.747  on 59  degrees of freedom
AIC: 52.747
Number of Fisher Scoring iterations: 5
> exp(coef(GLM.2))  # Exponentiated coefficients ("odds ratios")
(Intercept)   Depth..m.
  0.5035391   0.7926497
```

Model 3

```
> GLM.3 <- glm(ESA.Outcome ~ Hard.coral, family=binomial(logit),
data=Agat.Asan2)
> summary(GLM.3)
Call:
glm(formula = ESA.Outcome ~ Hard.coral, family = binomial(logit),
    data = Agat.Asan2)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7033  -0.5913  -0.5837  -0.5776   1.9385
Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.717471   0.443869  -3.869 0.000109 ***
```

```
Hard.coral   0.006921   0.020858   0.332 0.740023
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 54.323  on 59  degrees of freedom
AIC: 58.323
Number of Fisher Scoring iterations: 4
> exp(coef(GLM.3))  # Exponentiated coefficients ("odds ratios")
(Intercept)  Hard.coral
  0.1795196   1.0069450
```

Model 4

```
> GLM.4 <- glm(ESA.Outcome ~ Macro.Algae, family=binomial(logit),
data=Agat.Asan2)
> summary(GLM.4)
Call:
glm(formula = ESA.Outcome ~ Macro.Algae, family = binomial(logit),
    data = Agat.Asan2)
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.03017  -0.70095  -0.18630  -0.06134   2.28128
Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.33879    0.47669  -0.711   0.4773
Macro.Algae -0.21953    0.09891  -2.219   0.0265 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
```

```
Residual deviance: 41.521  on 59  degrees of freedom

AIC: 45.521

Number of Fisher Scoring iterations: 7

> exp(coef(GLM.4))  # Exponentiated coefficients ("odds ratios")

(Intercept) Macro.Algae

  0.7126347   0.8028963
```

Model 5

```
> GLM.5 <- glm(ESA.Outcome ~ Max.Rugosity, family=binomial(logit),
data=Agat.Asan2)

> summary(GLM.5)

Call:

glm(formula = ESA.Outcome ~ Max.Rugosity, family = binomial(logit),

    data = Agat.Asan2)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.8071  -0.6245  -0.5494  -0.4982   2.0726

Coefficients:

              Estimate Std. Error z value Pr(>|z|)

(Intercept)  -2.116803   0.639030  -3.313 0.000925 ***

Max.Rugosity  0.002325   0.002388   0.973 0.330375

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 53.506  on 59  degrees of freedom

AIC: 57.506

Number of Fisher Scoring iterations: 4

> exp(coef(GLM.5))  # Exponentiated coefficients ("odds ratios")

 (Intercept) Max.Rugosity
```

```
    0.120416     1.002327
```

Model 6

```
> GLM.6 <- glm(ESA.Outcome ~ Other.Invertebrates, family=binomial(logit),
data=Agat.Asan2)

> summary(GLM.6)

Call:

glm(formula = ESA.Outcome ~ Other.Invertebrates, family = binomial(logit),

    data = Agat.Asan2)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-1.0680  -0.5686  -0.5446  -0.5307   1.9921

Coefficients:

                    Estimate Std. Error z value   Pr(>|z|)

(Intercept)          -1.9010     0.4192  -4.535 0.00000577 ***

Other.Invertebrates   0.2551     0.1870   1.364      0.173

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 52.717  on 59  degrees of freedom

AIC: 56.717

Number of Fisher Scoring iterations: 4

> exp(coef(GLM.6))  # Exponentiated coefficients ("odds ratios")

        (Intercept) Other.Invertebrates

           0.149414            1.290573
```

Model 7

```
> GLM.7 <- glm(ESA.Outcome ~ Other.Organisms, family=binomial(logit),
data=Agat.Asan2)

> summary(GLM.7)

Call:
```

```
glm(formula = ESA.Outcome ~ Other.Organisms, family = binomial(logit),
    data = Agat.Asan2)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.0629  -0.5668  -0.5156  -0.5005   2.0447
Coefficients:
                Estimate Std. Error z value  Pr(>|z|)
(Intercept)     -2.02645    0.47744  -4.244 0.0000219 ***
Other.Organisms  0.13425    0.09527   1.409     0.159
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 52.561  on 59  degrees of freedom
AIC: 56.561
Number of Fisher Scoring iterations: 4
> exp(coef(GLM.7))  # Exponentiated coefficients ("odds ratios")
    (Intercept) Other.Organisms
      0.1318032       1.1436760
```

Model 8

```
> GLM.8 <- glm(ESA.Outcome ~ Turf.algae, family=binomial(logit),
data=Agat.Asan2)
> summary(GLM.8)
Call:
glm(formula = ESA.Outcome ~ Turf.algae, family = binomial(logit),
    data = Agat.Asan2)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7825  -0.6919  -0.5483  -0.4470   2.1973
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.95285    0.63616  -1.498    0.134
Turf.algae  -0.03238    0.02796  -1.158    0.247
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 52.971  on 59  degrees of freedom
AIC: 56.971
Number of Fisher Scoring iterations: 4
> exp(coef(GLM.8))  # Exponentiated coefficients ("odds ratios")
(Intercept)  Turf.algae
  0.3856402   0.9681388
```

Model 9

```
> GLM.9 <- glm(ESA.Outcome ~ X..COT, family=binomial(logit),
data=Agat.Asan2)
> summary(GLM.9)
Call:
glm(formula = ESA.Outcome ~ X..COT, family = binomial(logit),
    data = Agat.Asan2)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.6368  -0.6368  -0.6368  -0.4404   2.1823
Coefficients:
            Estimate Std. Error z value  Pr(>|z|)
(Intercept)  -1.4926     0.3634  -4.107 0.0000401 ***
X..COT       -0.7916     0.9291  -0.852     0.394
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
```

```
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 53.431  on 59  degrees of freedom
AIC: 57.431
Number of Fisher Scoring iterations: 5
> exp(coef(GLM.9))  # Exponentiated coefficients ("odds ratios")
(Intercept)      X..COT
  0.2247837   0.4531202
```

Model 10

```
> GLM.10 <- glm(ESA.Outcome ~ Colonizable.substrate:Macro.Algae,
family=binomial(logit), data=Agat.Asan2)
> summary(GLM.10)
Call:
glm(formula = ESA.Outcome ~ Colonizable.substrate:Macro.Algae,
    family = binomial(logit), data = Agat.Asan2)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7323  -0.6802  -0.5666  -0.3270   2.3943
Coefficients:
                                    Estimate Std. Error z value Pr(>|z|)
(Intercept)                        -1.162653   0.456268  -2.548   0.0108 *
Colonizable.substrate:Macro.Algae -0.009113   0.007359  -1.238   0.2156
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 52.203  on 59  degrees of freedom
AIC: 56.203
Number of Fisher Scoring iterations: 5
> exp(coef(GLM.10))  # Exponentiated coefficients ("odds ratios")
```

```
                    (Intercept) Colonizable.substrate:Macro.Algae
                      0.3126555                          0.9909285
```

Model 11

```
> GLM.11 <- glm(ESA.Outcome ~ Colonizable.substrate:Depth..m.,
family=binomial(logit), data=Agat.Asan2)

> summary(GLM.11)

Call:

glm(formula = ESA.Outcome ~ Colonizable.substrate:Depth..m.,

    family = binomial(logit), data = Agat.Asan2)

Deviance Residuals:

    Min       1Q   Median       3Q      Max

-0.6634  -0.6116  -0.5854  -0.5766   1.9337

Coefficients:

                                 Estimate Std. Error z value Pr(>|z|)

(Intercept)                     -1.716369   0.549741  -3.122   0.0018 **

Colonizable.substrate:Depth..m.  0.002319   0.011157   0.208   0.8353

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 54.386  on 59  degrees of freedom

AIC: 58.386

Number of Fisher Scoring iterations: 4

> exp(coef(GLM.11))  # Exponentiated coefficients ("odds ratios")

                    (Intercept) Colonizable.substrate:Depth..m.

                      0.1797176                        1.0023221
```

Model 12

```
> GLM.12 <- glm(ESA.Outcome ~ Macro.Algae:Depth..m.,
family=binomial(logit), data=Agat.Asan2)
```

```
> summary(GLM.12)

Call:

glm(formula = ESA.Outcome ~ Macro.Algae:Depth..m., family =
binomial(logit),

    data = Agat.Asan2)

Deviance Residuals:

     Min        1Q    Median        3Q       Max

-1.32389  -0.39834  -0.00565   0.00000   1.95945

Coefficients:

                     Estimate Std. Error z value Pr(>|z|)

(Intercept)             0.3566     0.5899   0.604    0.546

Macro.Algae:Depth..m.  -0.2303     0.1080  -2.132    0.033 *

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 33.383  on 59  degrees of freedom

AIC: 37.383

Number of Fisher Scoring iterations: 10

> exp(coef(GLM.12))  # Exponentiated coefficients ("odds ratios")

          (Intercept) Macro.Algae:Depth..m.

            1.4284172             0.7943342
```

Model 13

```
> GLM.13 <- glm(ESA.Outcome ~ Colonizable.substrate:Depth..m.:Macro.Algae,
family=binomial(logit), data=Agat.Asan2)

> summary(GLM.13)

Call:

glm(formula = ESA.Outcome ~ Colonizable.substrate:Depth..m.:Macro.Algae,

    family = binomial(logit), data = Agat.Asan2)
```

```
Deviance Residuals:

     Min        1Q    Median        3Q       Max

-1.04964  -0.66280  -0.28014  -0.00417   2.39274

Coefficients:

                                                Estimate Std. Error z value
Pr(>|z|)

(Intercept)                                    -0.284916   0.517676  -0.550
0.5821

Colonizable.substrate:Depth..m.:Macro.Algae -0.013045   0.006231  -2.093
0.0363 *

---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 54.429  on 60  degrees of freedom

Residual deviance: 42.337  on 59  degrees of freedom

AIC: 46.337

Number of Fisher Scoring iterations: 8

> exp(coef(GLM.13))  # Exponentiated coefficients ("odds ratios")

                                  (Intercept)
Colonizable.substrate:Depth..m.:Macro.Algae

                                    0.7520776
0.9870395
```

Model 14

```
> GLM.14 <- glm(ESA.Outcome ~ Macro.Algae + Depth..m. +
Macro.Algae:Depth..m., family=binomial(logit),

+   data=Agat.Asan2)

> summary(GLM.14)

Call:

glm(formula = ESA.Outcome ~ Macro.Algae + Depth..m. +
Macro.Algae:Depth..m.,

    family = binomial(logit), data = Agat.Asan2)
```

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.33751  -0.40218  -0.00796   0.00000   2.00472
Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)           0.37375    0.67474   0.554    0.580
Macro.Algae          -0.03955    0.09267  -0.427    0.670
Depth..m.             0.01528    0.16726   0.091    0.927
Macro.Algae:Depth..m. -0.20827    0.13721  -1.518    0.129
(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 54.429  on 60  degrees of freedom
Residual deviance: 33.041  on 57  degrees of freedom
AIC: 41.041
Number of Fisher Scoring iterations: 10
> exp(coef(GLM.2))  # Exponentiated coefficients ("odds ratios")
          (Intercept)           Macro.Algae             Depth..m.
   Macro.Algae:Depth..m.
            1.4531694             0.9612248             1.0153923
0.8119862
```

Appendix G. Hard coral species encountered during roving coral diversity surveys at sites located within WAPA submerged lands boundaries offshore of the villages of Asan and Hågat, Guam.

Tables G-1 and G-2 show hard coral species encountered during roving coral diversity surveys.

Table G-1. Scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Acroporidae	*Acropora abrotanoides* (Lamarck, 1816)	–	x	–	–	o	–	x	–	x	–	–	x	–	x	x	x	–	–	x	x	1	R	–0.7	–16.5	20
	Acropora aculeus sensu Veron	x	–	–	–	–	–	–	x	x	–	x	–	x	–	–	x	–	–	–	–	6	C	–0.6	–32.3	9
	Acropora cf. *aspera* (Dana, 1846)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	1	R	–0.2	–0.5	1
	Acropora cf. *cerealis sensu* Randall	–	–	–	–	–	–	–	–	–	–	–	x	–	x	x	–	–	–	–	–	3	U	–3.2	–7.0	6
	Acropora cf. *cophodactyla sensu* Veron 2000	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–1.0	–1.0	1
	Acropora digitifera (Dana, 1846)	–	x	–	–	–	–	x	–	–	–	–	x	–	x	–	x	–	x	x	–	7	C	–0.6	–5.9	8
	Acropora cf. *dissimilis* Verrill, 1902	–	–	–	x	–	–	x	–	–	–	–	x	–	x	–	–	–	–	x	–	5	U	–2.2	–4.1	7
	Acropora gemmifera sensu Randall	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	1	R	–5.5	–5.7	1
	Acropora globiceps (Dana, 1846)	–	x	–	–	–	–	x	–	x	–	–	x	x	x	–	x	x	–	x	–	9	C	–0.7	–6.4	47
	Acropora cf. *humilis* (Dana, 1846)	x	x	x	–	–	x	x	x	x	x	x	x	–	x	o	x	x	–	x	x	16	A	–0.6	–25.6	47
	Acropora cf. *kimbeensis* (Ehrenberg, 1834)	–	–	–	–	–	x	–	–	–	x	–	–	x	–	–	–	–	–	–	x	4	U	–18.0	–32.5	10
	Acropora cf. *latistella* (Brook, 1892)	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	–	–	–	x	3	U	–5.3	–16.7	4
	Acropora cf. *loripes sensu* Veron et al. 2016	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	1	U	–5.6	–6.0	1
	Acropora cf. *microclados* (Ehrenberg, 1834)	–	–	–	–	–	x	–	x	–	x	x	–	–	x	–	–	x	–	–	x	7	C	–5.5	–21.9	9
	Acropora cf. *minuta* Veron, 2000	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	x	–	–	–	–	3	U	–1.8	–4.6	5
	Acropora monticulosa (Bruggemann, 1879)	–	–	–	–	–	–	–	–	x	–	–	x	–	x	–	x	–	–	–	–	4	U	–1.0	–4.5	6
	Acropora muricata (Linnaeus, 1758)	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–0.5	–1.0	5
	Acropora cf. *nasuta* (Dana, 1846)	–	x	–	x	x	–	x	–	x	–	–	x	–	x	x	x	–	–	–	–	9	C	–0.6	–9.6	26
	Acropora palmerae Wells, 1954	–	–	–	–	–	–	x	–	–	–	–	x	–	–	–	x	–	–	x	–	4	U	–1.4	–5.2	8
	Acropora paniculata Verrill, 1902	–	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	–	–	–	2	U	–16.4	–29.7	2
	Acropora cf. *pulchra* (Brook, 1891)	–	–	x	–	–	–	–	–	x	–	–	x	–	–	–	x	–	x	–	–	5	U	–0.6	–6.0	13
	Acropora quelchi (Brook, 1893)	x	x	–	–	–	x	x	x	–	–	x	x	–	–	x	–	–	–	o	x	1	R	–3.5	–23.3	18
	Acropora cf. *secale* (Studer, 1878)	–	–	–	–	–	–	x	–	–	–	–	x	–	x	–	x	–	–	x	x	6	C	–0.7	–14.9	25
	Acropora selago sensu Randall	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	1	R	–6.4	–6.5	1
	Acropora cf. *surculosa* (Dana, 1846)	–	x	x	x	x	–	x	–	x	–	–	x	–	x	x	x	–	–	x	–	11	C	–0.7	–13.9	24
	Acropora tenuis (Dana, 1846)	x	–	–	–	–	x	x	x	x	x	x	x	–	x	–	x	x	–	–	x	12	C	–1.4	–28.5	18
	Acropora cf. *valida sensu Veron*	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	1	R	–3.9	–3.9	1
	Acropora verweyi Veron & Wallace, 1984	–	–	–	–	–	–	–	x	–	–	–	x	–	x	–	x	–	–	–	–	4	U	–2.0	–12.1	20
	Acropora sp. "obtusicaulis"	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	x	–	–	–	–	2	U	–2.4	–3.0	3
	Acropora sp. A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	1	R	–28.5	–28.5	1
	Montipora sp. "pagoensis"	–	x	x	–	–	–	x	–	–	x	–	x	–	x	–	–	–	–	x	–	7	C	–0.7	–12	21
	Montipora sp. –foveolate A	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	1	R	–4.2	–4.3	1
	Montipora sp. –glabrous A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	1	R	–21.5	–21.5	1

[1] An “x” denotes that the species was recorded during the survey period, an ‘o” denotes species observed outside the survey period, and an endash (“–”) denotes that the species was not observed.

[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Table G-1 (continued). Scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Acroporidae (continued)	*Montipora* sp. –glabrous B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	1	R	–14.0	–14.0	1
	Acroporidae *Montipora* sp. –papillate A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	o	–	1	R	–4.2	–4.4	1
	Montipora sp. –papillate C	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	x	–	2	U	–4.3	–7.8	7
	Montipora sp. –papillate D	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	x	–	–	x	–	3	U	–1.9	–9.2	11
	Montipora sp. –papillate E	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	2	U	–6.1	–7.7	2
	Montipora sp. –papillate F	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	–	–	x	–	3	U	–3.5	–7.2	3
	Montipora sp. –tuberculate A	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	1	R	–12.2	–12.2	1
	Montipora sp. –tuberculate B	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	x	–	3	U	–1.7	–6.7	4
	Montipora sp. –tuberculate C	–	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	2	U	–1.5	–4.9	2
	Montipora sp. –tuberculate D	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–9.5	–10.1	2
	Montipora sp. –tuberculate E	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	2	U	–7.3	–9.5	2
Agariciidae	*Gardineroseris planulata* (Dana, 1846)	x	x	–	x	x	x	x	x	–	–	x	–	–	–	x	–	–	–	x	x	11	C	–2.4	–23.5	13
	Leptoseris explanata Yabe & Sugiyama, 1941	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	1	R	–22.2	–22.2	1
	Leptoseris cf. *hawaiiensis* Vaughan, 1907	–	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–11.1	–16.0	2
	Leptoseris incrustans (Quelch, 1886)	–	–	–	–	x	x	x	x	–	–	–	–	x	–	x	–	x	–	–	x	8	C	–5.5	–23.6	13
	Leptoseris mycetoseroides Wells, 1954	–	–	–	–	–	x	–	x	–	–	–	–	–	–	x	–	–	–	–	–	3	U	–9.4	–21.9	4
	Leptoseris sp. "rubra"	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	1	R	–25	–25.1	1
	Pavona bipartita Nemenzo, 1980	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–3.7	–6.4	5
	Pavona cactus (Forskal, 1775)	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–5.7	–6.1	1
	Pavona chiriquiensis Glynn, Mate & Stemann, 2001	x	x	–	x	o	x	x	x	x	x	x	x	x	x	x	x	x	–	x	–	17	A	–1.3	–21.2	44
	Pavona clavus (Dana, 1846)	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–14	–14.9	3
	Pavona danai sensu Randall	–	x	x	–	–	–	–	–	x	–	–	–	–	–	–	–	–	x	–	–	4	U	–0.2	–1.9	9
	Pavona divaricata sensu Randall	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	2	U	–0.3	–0.6	3
	Pavona duerdeni Vaughan, 1907	–	x	–	–	x	–	–	–	–	x	x	x	–	x	–	x	x	–	x	x	1	R	–2.1	–15.7	24
	Pavona explanulata (Lamarck, 1816)	–	–	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	2	U	–6.5	–20.1	2
	Pavona maldivensis (Gardiner, 1905)	–	–	–	x	o	x	–	x	–	–	–	x	–	–	–	x	–	–	x	–	7	C	–2.1	–16.0	9
	Pavona minuta Wells, 1954	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	x	–	–	–	–	2	U	–2.0	–16.1	4
	Pavona varians Verrill, 1864	x	x	–	x	x	x	x	x	–	–	x	x	x	x	–	x	–	–	o	x	14	C	–3.6	–28.5	45
	Pavona venosa (Ehrenberg, 1834)	–	–	x	x	x	–	x	–	x	–	–	–	–	–	–	x	–	x	x	–	8	C	–0.3	–8.6	19
	Pavona cf. *venosa* (Ehrenberg, 1834)	–	–	–	x	x	–	x	–	x	–	–	–	–	x	–	–	–	–	–	–	5	U	–0.4	–7.6	10
	Pavona sp. "albamarginata"	–	–	–	–	x	–	x	–	–	–	–	x	–	x	–	–	–	–	x	–	5	U	–0.7	–4.7	5
	Pavona sp. "contorta"	x	x	–	x	x	–	x	x	x	–	–	–	–	–	–	x	–	x	–	–	9	C	–0.3	–17.9	20
	Pavona sp. "encrustans"	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	1	R	–1.2	–1.6	1
	Pavona sp. "meandrina"	–	–	x	x	–	–	x	–	–	–	–	–	–	–	–	x	–	x	o	–	6	C	–0.3	–7.2	7
Dendrophylliidae	*Turbinaria* cf. *irregularis* Bernard, 1896	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	1	R	–13.1	–13.1	1

[1] An “x” denotes that the species was recorded during the survey period, an ‘o” denotes species observed outside the survey period, and an endash (“–”) denotes that the species was not observed.

[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Table G-1 (continued). Scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Dendrophylliidae (continued)	*Turbinaria stellulata* (Lamarck, 1816)	x	–	–	–	–	–	–	–	–	x	x	x	x	–	x	–	x	–	–	x	8	C	–7.8	–25.5	14
	Diploastrea heliopora (Lamarck, 1816)	x	x	–	x	–	x	x	x	–	–	–	–	–	o	x	x	–	–	–	x	1	R	–4.2	–32.6	12
Euphylliidae	*Euphyllia glabrescens* (Chamisso & Eysenhardt, 1821)	–	–	–	–	–	–	–	–	–	–	–	o	–	–	–	–	–	–	–	–	1	R	–5.4	–5.4	1
	Galaxea astreata (Lamarck, 1816)	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–21.7	–25.0	3
	Galaxea fascicularis (Linnaeus, 1767)	x	x	–	x	x	x	x	x	–	x	x	x	x	x	x	x	x	–	x	x	17	A	–2.9	–27.7	32
Fungiidae	*Cantherellus*? sp. A	x	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	2	U	–21.4	–30.5	2
	Cycloseris costulata (Ortmann, 1889)	x	–	–	–	–	x	–	x	–	x	x	–	x	–	x	–	x	–	–	x	9	C	–11.5	–23.6	18
	Cycloseris cf. *erosa* (Doderlein, 1901)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	1	R	–18.0	–18.0	1
	Cycloseris explanulata van der Horst, 1921	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	1	R	–26.7	–26.7	1
	Cycloseris cf. *tenuis* (Dana, 1846)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	x	2	U	–21.5	–22.1	2
	Cycloseris vaughani (Boschma, 1923)	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	x	–	–	–	3	U	–11.4	–17.2	8
	Cycloseris sp. 1 (septal lobes)	x	–	–	–	–	–	–	x	–	x	x	–	x	–	–	–	–	–	–	–	5	U	–12.8	–27.7	11
	Danafungia scruposa sensu Randall	–	–	–	–	x	–	–	–	–	–	–	–	x	–	–	–	–	–	–	x	3	U	–5.9	–20.2	7
	Danafungia scruposa sensu Veron	x	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–25.4	–25.4	1
	Fungia fungites Linnaeus, 1758	–	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	2	U	–0.7	–4.0	4
	Herpolitha limax Esper, 1797	–	–	–	–	–	–	–	–	–	x	x	–	x	–	–	–	x	–	–	x	5	U	–11.9	–28.5	12
	Herpolitha weberi (van der Horst, 1921)	x	–	–	–	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	–	3	U	–15.9	–25	5
	Lobactis scutaria Lamarck, 1801	x	–	–	x	–	–	x	x	x	x	–	x	x	o	x	x	–	–	–	–	11	C	–0.7	–24.7	19
	Pleuractis granulosa Klunzinger, 1879	x	–	–	–	–	–	–	–	–	x	x	–	x	–	–	–	x	–	–	x	6	C	–11.7	–28.6	12
	Pleuractis paumotensis Stutchbury, 1833	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	1	R	–20.0	–20.2	1
	Polyphyllia talpina (Lamarck, 1801)	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	x	–	–	–	3	U	–15.9	–16.4	3
	Sandolitha dentata Quelch, 1884	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	1	R	–20.1	–32.8	2
	fungiid sp. A (thick, rough septa; two mouths)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	1	R	–17.8	–18.2	1
Incertae sedis	*Pachyseris speciosa* (Dana, 1846)	x	–	–	–	–	–	–	x	–	–	–	–	x	–	x	–	–	–	–	x	5	U	–11.6	–22.6	15
Leptastraeidae	*Leptastrea* cf. *immersa sensu Randall*	x	x	–	x	–	x	–	x	–	–	–	–	x	x	x	x	x	–	x	x	12	C	–3.7	–22.1	27
	Leptastrea pruinosa Crossland, 1952	–	–	–	–	–	–	–	–	–	–	x	x	x	x	–	x	–	–	–	x	6	C	–3.9	–28.7	5
	Leptastrea purpurea (Dana, 1846)	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	x	x	x	–	x	18	A	–0.4	–28.7	50
	Leptastrea transvera Klunzinger, 1879	–	x	–	–	x	–	–	–	–	–	–	x	–	x	x	x	–	–	x	x	8	C	–4.3	–21.9	13
Lobophylliidae	*Acanthastrea* cf. *brevis* Milne Edwards & Haime, 1849	x	–	–	–	–	x	–	x	–	–	x	x	x	x	–	x	–	–	–	x	9	C	–5.4	–28.0	9
	Acanthastrea echinata (Dana, 1846)	–	–	–	–	x	–	–	–	–	x	–	x	x	x	x	x	–	–	x	x	9	C	–1.9	–26.6	20
	Acanthastrea cf. *hemprichii* (Ehrenberg, 1834)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	1	R	–21.0	–21.7	2
	Acanthastrea cf. *regularis* Veron, 2000	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	x	–	–	–	–	2	U	–1.8	–10.4	2

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[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Table G-1 (continued). Scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Lobophylliidae (continued)	*Echinophyllia echinata* (Saville Kent, 1871)	x	–	–	x	–	x	x	x	–	x	x	–	–	–	x	–	–	–	–	x	9	C	–2.1	–26.6	15
	Lobophyllia hemprichii (Ehrenberg, 1834)	–	x	–	x	o	–	x	–	–	–	–	x	–	x	–	x	x	–	x	–	9	C	–1.4	–18.5	13
	Lobophyllia robusta Yabe & Sugiyama, 1936	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	x	2	U	–7.0	–28.6	5
	Lobophyllia? sp. A	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–18.3	–18.3	1
Merulinidae	*Astrea* cf. *annuligera sensu* Veron	x	–	–	–	–	–	–	–	–	x	x	–	x	–	–	x	x	–	–	–	6	C	–10.9	–14.6	8
	Astrea curta (Dana, 1846)	–	x	–	x	x	–	x	–	–	–	–	x	–	x	–	x	x	–	x	–	9	C	–1.1	–18.7	12
	Cyphastrea agassizi (Vaughan, 1907)	–	x	–	–	x	–	–	–	–	–	–	x	–	–	x	–	–	–	–	–	4	U	–2.4	–21.9	6
	Cyphastrea chaldicum (Forskal, 1775)	x	x	x	x	x	x	x	x	–	–	x	x	x	x	x	x	–	–	x	–	15	C	–0.6	–32.3	56
	Cyphastrea microphthalma (Lamarck, 1816)	x	x	–	–	–	–	–	x	–	–	x	–	–	–	–	x	–	–	–	–	5	U	–5.3	–18.7	10
	Cyphastrea ocellina sensu Randall	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	2	U	–8.8	–17.6	2
	Cyphastrea serailia (Forskal, 1775)	x	–	–	–	–	–	–	x	–	x	x	x	x	–	x	x	x	–	–	x	1	R	–7.7	–25.5	20
	Cyphastrea sp. A	x	–	–	–	–	x	–	x	o	x	x	x	x	–	x	–	x	x	–	x	12	C	–0.4	–33	31
	Dipsastraea danae Verrill, 1872	x	x	–	x	–	x	–	x	–	x	x	–	x	x	x	x	x	–	x	x	14	C	–1.3	–32.7	57
	Dipsastraea favus (Forskal, 1775)	x	x	–	x	x	x	–	–	–	x	x	–	x	x	x	x	x	–	x	x	14	C	–1.3	–24.9	52
	Dipsastraea helianthoides Wells, 1954	x	–	–	–	–	–	–	–	x	–	x	x	–	–	–	–	–	–	–	x	5	U	–1.5	–22	4
	Dipsastraea cf. *lizardensis Veron and Pichon, 1977*	–	–	–	–	–	–	–	–	–	–	–	–	–	x	o	–	–	–	–	–	2	U	–3.3	–5.4	4
	Dipsastraea maritima Nemenzo, 1971	–	–	–	–	–	x	–	–	–	x	x	x	–	–	x	–	–	–	–	–	5	U	–7.4	–21.7	6
	Dipsastraea mathaii Vaughan, 1918	–	x	–	x	–	o	x	–	x	x	–	x	–	x	x	x	–	x	x	–	12	C	–0.3	–14.8	33
	Dipsastraea pallida (Dana, 1846)	–	x	x	x	–	x	x	x	x	x	x	x	–	x	o	x	x	–	x	x	16	A	–0.7	–20.9	66
	Dipsastraea rotumana (Gardiner, 1899)	x	–	–	–	–	x	–	x	–	x	x	–	x	x	x	x	–	–	–	x	1	R	–4.5	–27.7	24
	Dipsastraea sp. "granulosa"	x	–	–	x	–	x	–	–	–	–	–	–	x	–	–	x	–	–	–	–	5	U	–1.8	–16.0	10
	Echinopora cf. *pacificus* Veron, 1990	–	–	–	–	x	–	–	x	–	–	–	–	x	x	–	–	–	–	–	x	5	U	–3.3	–29.2	6
	Favites abdita (Ellis & Solander, 1786)	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	x	–	–	–	–	3	U	–2.6	–4.0	5
	Favites flexuosa (Dana, 1846)	–	x	–	–	–	–	–	–	–	x	–	–	–	x	–	x	o	–	–	–	5	U	–3.0	–12.1	6
	Favites rotundata (Veron and Pichon, 1977)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	o	–	2	U	–3.9	–15.3	2
	Favites cf. *valenciennesi sensu* Veron	x	x	–	x	x	x	x	x	–	x	x	x	x	x	x	x	x	–	x	x	17	A	–1.8	–25.5	57
	Favites sp. "crassisepta"	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	2	U	–18.7	–23.3	5
	Favites cf. sp. "crassisepta"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	1	R	–2.2	–2.2	1
	Goniastrea edwardsi Chevalier, 1971	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	–	o	x	19	A	–1.1	–23.9	34
	Goniastrea cf. *favulus* (Dana, 1846)	–	–	–	–	o	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	2	U	–4.7	–6.8	2
	Goniastrea pectinata (Ehrenberg, 1834)	x	x	–	–	–	x	x	x	–	–	x	x	x	–	–	x	x	–	–	x	11	C	–6.1	–28.8	17
	Goniastrea retiformis (Lamarck, 1816)	–	x	x	x	x	–	x	x	x	–	–	x	–	x	x	x	–	x	x	–	13	C	–0.3	–10.1	36

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		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Merulinidae (continued)	*Goniastrea stelligera* (Dana, 1846)	–	x	–	x	x	–	x	x	–	x	x	x	x	x	–	x	–	–	x	x	13	C	–1.5	–17.5	33
	Hydnophora microconos (Lamarck, 1816)	–	x	–	x	–	–	x	–	–	x	x	x	o	x	–	x	x	–	x	–	11	C	–2.3	–12.6	18
	Leptoria phrygia (Ellis & Solander, 1786)	x	x	–	x	x	–	x	–	x	x	x	x	–	x	x	x	–	x	x	x	15	C	–0.3	–23.1	30
	Merulina ampliata (Ellis & Solander, 1786)	–	–	–	–	–	x	–	x	–	–	x	–	–	–	–	–	x	–	–	–	4	U	–12.0	–24.8	7
	Oulophyllia crispa (Lamarck, 1816)	x	–	–	–	–	–	–	o	–	x	x	x	x	–	x	–	–	–	o	x	9	C	–4.3	–22.2	9
	Platygyra daedalea (Ellis & Solander, 1786)	x	x	–	x	x	–	x	x	–	x	x	x	x	x	x	x	x	–	x	x	16	A	–0.5	–24.2	44
	Platygyra pini sensu Randall	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	19	A	–0.3	–26.6	48
	Platygyra cf. *verweyi sensu* Veron	–	–	–	–	–	–	–	x	–	–	–	–	x	x	x	–	–	–	–	–	4	U	–5.4	–24.0	6
	Platygyra sp. A (very rough septa)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	1	R	–19.7	–20.2	1
	Scapophyllia cylindrica Edwards & Haime, 1848	–	–	–	–	–	–	–	–	–	–	–	x	x	x	–	–	x	–	–	–	4	U	–4.7	–21.7	9
Plerogyridae	*Plerogyra simplex* Rehberg, 1892	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–5.9	–5.9	1
Plesiastreidae	*Plesiastrea peroni* Milne Edwards & Haime, 1857	x	–	–	–	–	–	–	x	–	x	x	–	x	–	x	–	x	–	–	–	7	C	–8.1	–29.8	9
Pocilloporidae	*Pocillopora acuta* Lamarck, 1816	–	–	x	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	4	U	–0.2	–8.5	14
	Pocillopora ankeli Sheer & Pillai, 1974	–	x	x	–	x	–	x	–	–	x	–	x	–	–	–	x	–	–	–	x	8	C	–0.9	–14.3	15
	Pocillopora cf. *bairdi* Schmidt–Roach, 2014	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–3.0	–3.0	1
	Pocillopora cf. *brevicornis* Lamarck, 1816	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–0.8	–3.2	4
	Pocillopora damicornis Linnaeus, 1758	x	x	x	x	x	–	x	–	x	–	–	–	–	o	x	x	–	x	x	–	12	C	–0.2	–21.0	49
	Pocillopora elegans Dana, 1846	–	x	x	x	–	–	x	–	–	x	–	x	x	x	–	x	–	–	x	x	11	C	–0.7	–29.6	27
	Pocillopora grandis Edwards & Haime, 1860	–	x	–	–	–	–	x	–	x	x	x	x	–	x	x	x	–	–	x	x	11	C	–0.7	–17.1	31
	Pocillopora cf. *kelleheri Veron, 2000*	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	x	–	3	U	–4.3	–21.3	4
	Pocillopora ligulata sensu Randall	–	x	–	–	–	–	x	–	x	–	–	x	–	x	–	x	–	–	x	–	7	C	–0.6	–6.5	11
	Pocillopora meandrina Dana, 1846	x	x	–	x	–	–	x	–	x	x	x	x	–	x	o	x	x	–	x	x	14	C	–0.8	–20.7	49
	Pocillopora setchelli Hoffmeister, 1929	–	x	–	x	–	–	x	–	–	–	–	x	–	x	o	x	–	–	x	–	8	C	–0.7	–6.6	92
	Pocillopora verrucosa (Ellis & Solander, 1786)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x	19	A	–0.6	–23.1	131
	Pocillopora woodjonesi Vaughan, 1918	–	x	–	–	–	–	x	–	–	–	–	–	–	x	–	x	–	–	x	–	5	U	–0.8	–6.6	8
	Pocillopora cf. sp. "conicula"	–	–	x	x	x	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–	5	U	–0.6	–8.4	9
	Pocillopora sp. "lobata"	–	x	–	x	–	–	–	–	x	–	–	x	–	–	–	–	–	–	–	–	4	U	–0.8	–4.4	13
	Pocillopora sp. 2	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	1	R	–1.4	–1.4	1
	Pocillopora sp. A	–	–	–	x	–	–	x	–	–	–	–	x	–	x	–	–	–	–	–	–	4	U	–3.4	–8.5	4

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Pocilloporidae (continued)	*Pocillopora* sp. B (molokensis–like)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	o	–	–	–	–	–	1	R	–4.6	–4.6	1
	Stylocoeniella armata (Ehrenberg, 1834)	x	x	x	x	x	x	x	x	x	–	–	–	x	x	x	x	–	–	–	x	14	C	–0.7	–28.6	21
	Stylocoeniella guentheri (Bassett Smith, 1890)	x	–	–	–	–	–	–	x	–	x	x	–	x	–	–	–	x	–	–	–	6	C	–13.2	–26.7	9
	Stylophora cf. *mordax* (Dana, 1846)	–	x	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–2.3	–4.3	3
Poritidae	*Goniopora fruticosa* Saville Kent, 1893	x	x	x	x	x	x	x	x	–	–	–	–	x	x	–	x	–	–	–	–	11	C	–0.8	–23.6	19
	Goniopora cf. *lobata–djiboutiensis*	–	–	–	–	o	–	–	x	–	–	–	–	–	–	–	–	x	–	–	–	3	U	–2.7	–12.8	4
	Goniopora cf. *minor–pendulus*	x	–	–	x	x	–	–	x	–	x	–	–	x	–	x	–	x	–	–	x	9	C	–2.2	–32.1	16
	Goniopora cf. *palmensis* Veron & Pichon, 1982	o	–	–	–	–	–	–	x	–	–	–	–	–	–	o	–	–	–	–	–	3	U	–6.7	–14.0	3
	Goniopora cf. *tenella sensu* Veron 2000	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	1	R	–8.3	–16.2	2
	Goniopora cf. *tenuidens* Quelch, 1886	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	2	U	–14.9	–24.1	3
	Goniopora cf. sp. "platylobus"	x	–	–	–	–	x	–	–	–	–	x	–	–	–	–	–	x	–	–	–	4	U	–8.7	–25.0	6
	Goniopora sp. –encrusting A	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	2	U	–17.9	–23.6	2
	Goniopora sp. –encrusting B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	1	R	–15.2	–15.3	1
	Goniopora sp. –encrusting C	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–20.3	–20.3	1
	Goniopora sp. –massive A	–	–	–	–	–	–	–	–	–	–	–	x	–	–	x	–	x	–	–	–	3	U	–7.9	–15.3	4
	Goniopora sp. –massive B	–	–	–	–	–	–	–	x	–	x	x	–	–	–	–	–	x	–	–	–	4	U	–11.5	–15.5	6
	Goniopora sp. –massive C	x	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–	3	U	–10.8	–23.6	6
	Goniopora sp. –massive D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	1	R	–15.7	–16.4	1
	Goniopora sp. –submassive A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	1	R	–20.9	–21.1	1
	Porites annae complex	x	x	x	x	x	–	x	x	x	x	x	x	x	x	–	x	x	x	x	x	18	A	–0.2	–25.1	86
	Porites cf. *australiensis* Vaughan, 1918	x	x	x	x	–	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	19	A	–0.2	–23.7	57
	Porites cylindrica Dana, 1846	–	–	x	–	x	–	–	x	x	–	–	–	–	–	–	–	–	x	–	–	5	U	–0.3	–13.2	17
	Porites cf. *densa* Vaughan, 1918	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	1	R	–15.5	–21.8	2
	Porites cf. *evermanni* Vaughan, 1907	x	–	–	–	–	x	–	x	–	x	x	x	x	–	x	–	x	x	o	x	12	C	–0.3	–22.5	22
	Porites cf. *heronensis* Veron, 1985	–	x	x	–	o	–	x	–	–	–	x	o	x	x	–	x	–	–	–	x	1	R	–0.5	–31.4	23
	Porites cf. *lichen sensu* Randall	x	x	–	x	–	x	–	x	–	–	–	–	–	x	–	x	x	–	o	x	1	R	–2.0	–29.8	23
	Porites cf. *lobata* Dana, 1846	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x	x	x	–	x	x	19	A	–0.7	–32.5	100
	Porites cf. *lutea* Edwards & Haime, 1860	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	U	–0.2	–32.5	138
	Porites cf. *murrayensis* Vaughan, 1918	x	–	–	x	x	x	x	x	–	x	x	–	x	x	–	–	x	–	–	–	11	C	–2.5	–32.4	25
	Porites cf. *myrmidonensis* Veron, 1985	x	–	–	–	–	–	–	x	–	–	x	–	x	–	–	x	–	–	x	x	7	C	–6.0	–32.4	16
	Porites cf. *solida–densa*	x	x	–	–	o	x	–	x	–	x	x	–	x	x	x	x	x	–	x	x	14	C	–5.2	–32.5	51
	Porites rus (Forskal, 1775)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	U	–0.2	–26.8	47
	Porites vaughani Crossland, 1952	–	x	–	–	–	–	–	–	–	x	–	x	–	x	o	x	–	–	x	–	7	C	–1.9	–13.2	13
	Porites sp. "mammalata"	x	x	–	x	x	x	x	x	–	–	–	–	–	–	–	–	x	–	–	–	8	C	–2.7	–24.1	21
Psammocoridae	*Psammocora columna* (Dana, 1846)	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–10.6	–10.6	1

[1] An “x” denotes that the species was recorded during the survey period, an ‘o” denotes species observed outside the survey period, and an endash (“–”) denotes that the species was not observed.

[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Table G-1 (continued). Scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Psammocoridae (continued)	*Psammocora contigua* (Esper, 1797)	–	x	–	x	x	–	x	–	x	–	–	–	–	–	x	–	–	x	–	–	7	C	–0.2	–8.0	17
	Psammocora haimiana Edwards & Haime, 1851	–	x	–	–	–	–	x	–	–	–	–	x	–	–	o	–	–	–	–	–	4	U	–0.9	–5.7	4
	*Psammocora nierstrasz*i van der Horst, 1921	x	–	–	x	x	x	x	x	–	x	x	x	x	x	x	x	x	–	o	x	16	A	–2.0	–25.1	34
	Psammocora obtusangula sensu Randall	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	R	–1.1	–7.9	4
	Psammocora profundacella Gardiner, 1898	x	x	–	–	–	x	x	x	–	x	x	x	x	–	x	x	x	–	–	x	13	C	–0.5	–24.1	22
	Psammocora stellata (Verrill, 1866)	–	–	–	–	–	–	–	–	x	x	x	–	–	–	–	–	x	x	–	–	5	U	–0.5	–18.7	17
	Psammocora superficiales sensu Randall	–	–	–	x	x	–	–	x	–	x	–	–	x	–	x	–	–	–	x	x	8	C	–2.8	–32.7	18
	Psammocora sp. "loculata"	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	–	–	x	–	3	U	–2.3	–6.8	10
	Psammocora sp. "nodulosa"	–	–	–	–	x	–	–	–	–	–	–	x	–	–	–	x	–	–	–	x	4	U	–2.3	–14.4	7
	Psammocora sp. "rosacea"	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–3.6	–5.8	3

[1] An “x” denotes that the species was recorded during the survey period, an ‘o” denotes species observed outside the survey period, and an endash (“–”) denotes that the species was not observed.

[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Table G-2. Non-scleractinian hard coral species recorded during the 45-minute survey period. Species totals for survey sites are provided at the bottom of the table. Additional species observed during qualitative surveys at photo transect survey sites and those observed by D. Burdick within WAPA submerged lands between October 2007 and May 2022 are provided in Appendix H.

Family	Scleractinian Hard Coral Species	Agat Diversity Survey Sites[1]								Asan Diversity Survey Sites[1]												Site Freq.[2]	Abund.[3]	Min Depth	Max Depth	# Colonies
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12					
Helioporidae	*Heliopora coerulea (Pallas, 1766)*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	–	–	x	18	A	–0.7	–18.3	24
Milleporidae	*Millepora dichotoma*	–	–	–	–	–	–	–	–	–	–	–	–	–	o	–	–	–	–	–	–	1	R	–4.7	–5.0	1
	Millepora platyphylla	–	x	x	x	–	–	x	x	–	–	–	x	–	x	–	x	x	–	x	–	1	R	–0.8	–14.3	>20
Stylasteridae	*Distichopora sp. A*	–	x	–	–	–	–	–	–	–	x	–	x	x	x	–	–	–	–	x	–	6	C	–1.9	–14.0	13
Tubiporidae	*Tubipora musica Linnaeus, 1758*	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	U	–3.9	–14.7	2
All Families	**Total species**	80	73	40	63	59	59	73	84	47	76	84	94	74	90	75	98	67	23	71	76	–	–	–	–	–

[1] An “x” denotes that the species was recorded during the survey period, an ‘o” denotes species observed outside the survey period, and an endash (“–”) denotes that the species was not observed.

[2] Site frequency values include species observed outside the survey period.

[3] Abundance values: R = rare (1 site), U = uncommon (2–5 sites), C = common (6–15 sites), A = abundant (16–20 sites).

Appendix H. Additional hard coral species observed within WAPA waters.

Table H-1 shows additional hard coral species observed within WAPA waters, including species observed in photo transect images and qualitative survey images obtained at the transect survey sites for this study (Location: UNIT ##), species photographed by Colin Lock during the 2023 diversity survey (Location: UNIT CS ##), species photographed by Dave Burdick between October 2007 and May 2022, and species reported in Eldredge et al. (1977) and Amesbury et al. (1999).

Table H-1. Additional hard coral species observed within WAPA waters.

Family	Scleractinian coral species	WAPA unit	Location	Reef zone	Date	Comments
Acroporidae	*Acropora acuminata*	Hågat	Agat Cemetery	flat	7/21/2013	–
	Acropora granulosa sensu Randall	Hågat	Agat Bay	front, slope	1977	as *A. rayneri*
	Acropora longicyathus	Hågat	Agat Bay	margin, front, slope	1977	as *A. echinata* and *A. syringodes*
	Acropora lutkeni	Asan	Camel Rock	front	7/24/2010	–
	Acropora cf. *polystoma*	Asan	Adelup Pt.	front	10/20/2007	–
	Acropora studeri	Hågat	Agat Bay	margin, front	1977	–
	Acropora tubicinaria	Hågat	Agat Bay	slope	1977	Current name unknown
	Acropora valida	Asan	ASAN 18	front	6/25/2022	–
	Acropora wardii	Hågat	Agat Bay	margin, front	1977	–
	Acropora arborescent sp. A	Hågat	Agat Cemetery	slope	2/14/2009	–
	Alveopora spongiosa	Asan	Asan Cut	slope	9/5/2011	–
	Alveopora verrilliana	Hågat	Agat Bay	front	1977	–
	Alveopora sp. 1	Hågat	Agat Bay	front, slope	1977	–
	Isopora palifera	Hågat	Agat Bay	front, slope	1977	as *Acropora palifera*
	Montipora aequituberculata	Hågat	Agat Bay	front, slope	1977	1977: as *M. composita*
	Montipora ehrenbergii	Hågat	Agat Bay	front, slope	1977	–

Table H-1 (continued). Additional hard coral species observed within WAPA waters.

Family	Scleractinian coral species	WAPA unit	Location	Reef zone	Date	Comments
Acroporidae (continued)	*Montipora elschneri*	Hågat	Agat Bay	margin, front, slope	1977	–
	Montipora foliosa	Hågat	Agat Bay	slope	1977	–
	Montipora granulosa	Hågat	Agat Bay	front, slope	1977	–
	Montipora subtilis	Hågat	Agat Bay	front, slope	1977	Current name unknown
	Montipora sp. –tuberculate F	Asan	ASAN 18	Front	6/25/2022	–
Agariciidae	*Leptoseris gardineri*	Hågat	Agat Bay	front, slope	1977	as *Pavona gardineri*
	Leptoseris hawaiiensis	Hågat	Agat Bay	margin, front, slope	1977	–
	Leptoseris scabra	Asan	Asan Cut	Slope	9/5/2011	–
	Leptoseris solida	Hågat	Hap's Reef	Slope	12/16/2007	–
	Leptoseris tubulifera	Asan	Camel Rock	slope	8/1/2010	–
	Pavona decussata	Asan	ASAN 84	flat	4/28/2022	–
	Pavona cf. *frondifera*	Agat	AGAT CS 5	front	2/19/2023	Photographed by CL
Caryophylliidae	*Desmophyllum* sp. 1	Hågat	Agat Bay	front, slope	1977	Curent name unknown
	Paracyathus sp.	Asan	Asan Cut	Slope	8/19/2012	–
	Paracyathus sp. 1	Hågat	Agat Bay	margin, front	1977	Curent name unknown
	Polycyathus verrilli	Hågat	Agat Bay	margin, front	1977	
Coscinaraeidae	*Anomastraea* sp. 1	Hågat	Agat Bay	margin, front, slope	1977	Current name unknown, likely not *Anomastraea*
Euphylliidae	*Euphyllia cristata*	Hågat	Agat Bay	slope	1999	–
	Galaxea horrescens	Hågat	Ga'an Pt.	slope	2/14/2009	–

Table H-1 (continued). Additional hard coral species observed within WAPA waters.

Family	Scleractinian coral species	WAPA unit	Location	Reef zone	Date	Comments
Euphylliidae (continued)	*Galaxea paucisepta*	Hågat	AGAT CS 6	slope	3/5/2023	Photographed by CL
	Galaxea sp. 1	Hågat	Agat Bay	front, slope	1977	Current name unknown
Fungiidae	*Cycloseris* sp. 1	Hågat	Agat Bay	slope	1977	Current name unknown
	Lithophyllon concinna	Hågat	Agat Bay	front, slope	1977	as *Fungia concinna*
	Pleuractis cf. *taiwanensis*	Hågat	Agat Cemetery	slope	2/14/2009	–
	Sandalolitha robusta	Asan	ASAN CS 5	Slope	3/12/2023	Photographed by CL
Leptastraeidae	*Leptastrea* cf. *bewickensis*	Asan	ASAN CS 11	Front	3/12/2023	Photographed by CL
Lobophylliidae	*Acanthastrea* sp. A	Asan	Asan Cut	slope	12/19/2009	–
	Acanthastrea sp. 1	Hågat	Agat Bay	front	1977	–
	Cynarina lacrymalis	Hågat	Agat Bay	slope	3/1/2009	–
	Echinophyllia aspera	Asan	Adelup Pt.	slope	6/14/2008	–
	Echinopora lamellosa	Hågat	Agat Bay	front, slope	1977	May be *E*. cf. pacificus
	Homophyllia cf. *australis*	Hågat	Agat Cemetery	slope	12/25/2007	–
	Lobophyllia corymbosa	Asan	ASAN 12	slope	4/23/2022	–
	Lobophyllia cf. *flabelliformis*	Hågat	Hap's Reef	slope	12/16/2007	–
Merulinidae	*Favites complanata*	Hågat	Agat Bay	margin, front, slope	1977	Current name unknown
	Favites favosa	Hågat	Agat Bay	front	1977	Current name unknown
	Mycedium elephantotus	Hågat	Agat Bay	front, slope	1977	as *Mycedium* sp. 1
Plerogyridae	*Plerogyra sinuosa*	Hågat	Agat Bay	front, slope	1977	–
Pocilloporidae	*Seriatopora hystrix*	Hågat	Agat Bay	margin, front, slope	1977	–

Table H-1 (continued). Additional hard coral species observed within WAPA waters.

Family	Scleractinian coral species	WAPA unit	Location	Reef zone	Date	Comments
Pocilloporidae (continued)	*Seriatopora stellata*	Asan	Asan Cut	slope	9/5/2011	–
Poritidae	*Goniopora arbuscula*	Hågat	Agat Bay	–	1977	Current name unknown
	Goniopora columna	Hågat	Agat Bay	–	1977	–
	Goniopora planulata sensu Randall	Asan	Camel Rock	slope	8/1/2010	–
	Goniopora sp. 1	Hågat	Agat Bay	–	1977	Current name unknown
	Goniopora sp. 2	Hågat	Agat Bay	–	1977	Current name unknown
	Porites horizontalata	Hågat	Agat Cemetery	slope	1/26/2008	–
	Porites monticulosa	Hågat	Agat Bay	margin, front, slope	1977	as *P. convexa*
	Porites cf. *stephensoni*	Asan	Adelup Pt.	slope	5/30/2022	–
	Porites superfusa	Hågat	Agat Bay	–	1977	as *Porites* sp. 1
	Porites sp. 2	Hågat	Agat Bay	–	1977	Current name unknown
Stylasteridae	*Stylaster* sp. A*	Asan	Asan Cut	slope	7/11/2020	–

Appendix I. Qualitative Photograph Log

Figures I-1 to I-23 show photos taken during qualitative surveys.

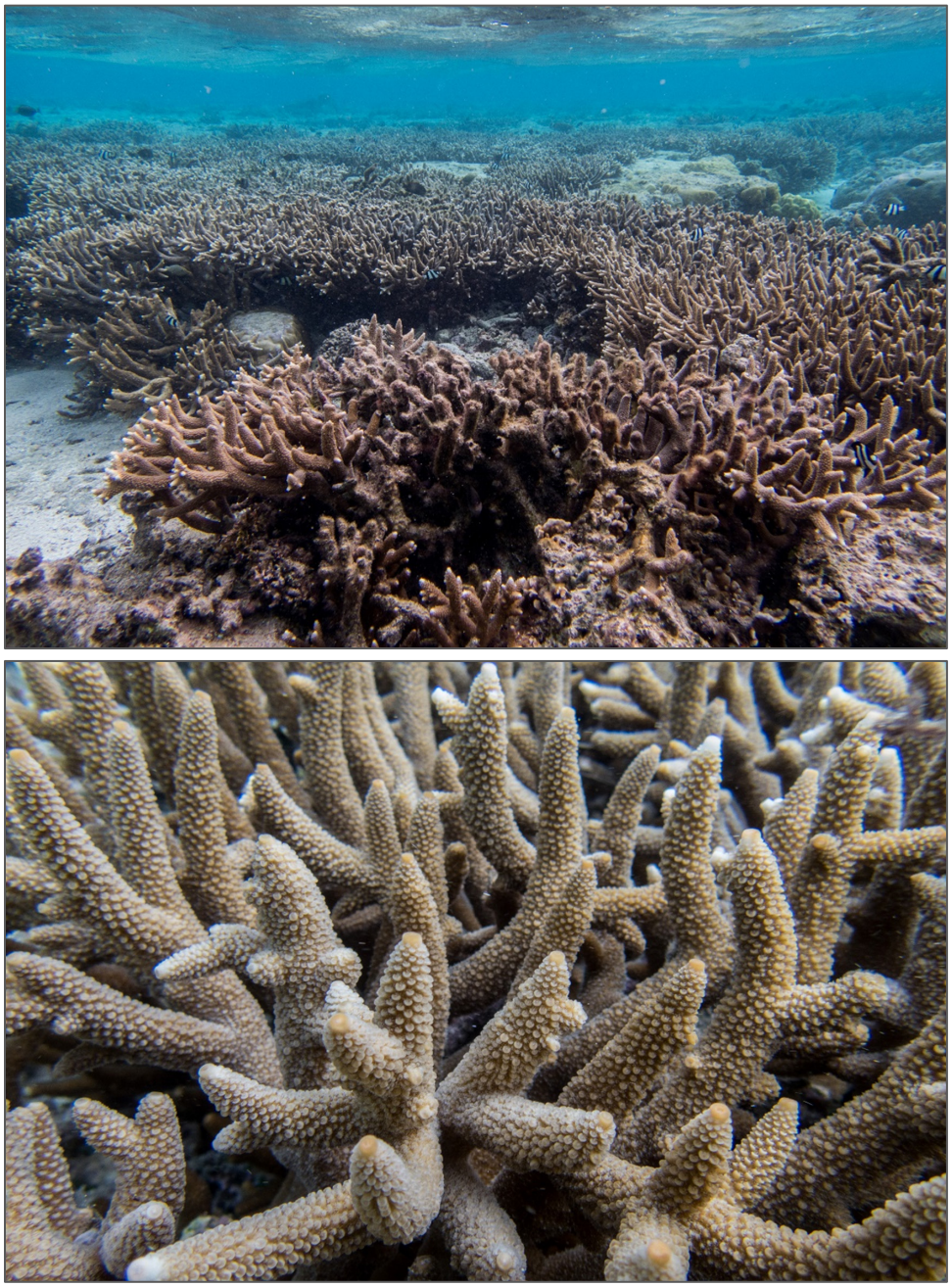


Figure I-1. Colonies within a staghorn thicket encountered at diversity survey site Asan–CS–10 appear to be the species currently called *A. aspera* in Guam's waters. This reef flat area represents the only other location on Guam currently known to host this now–rare species, which was believed to be limited to eastern Cocos Lagoon prior to this assessment.

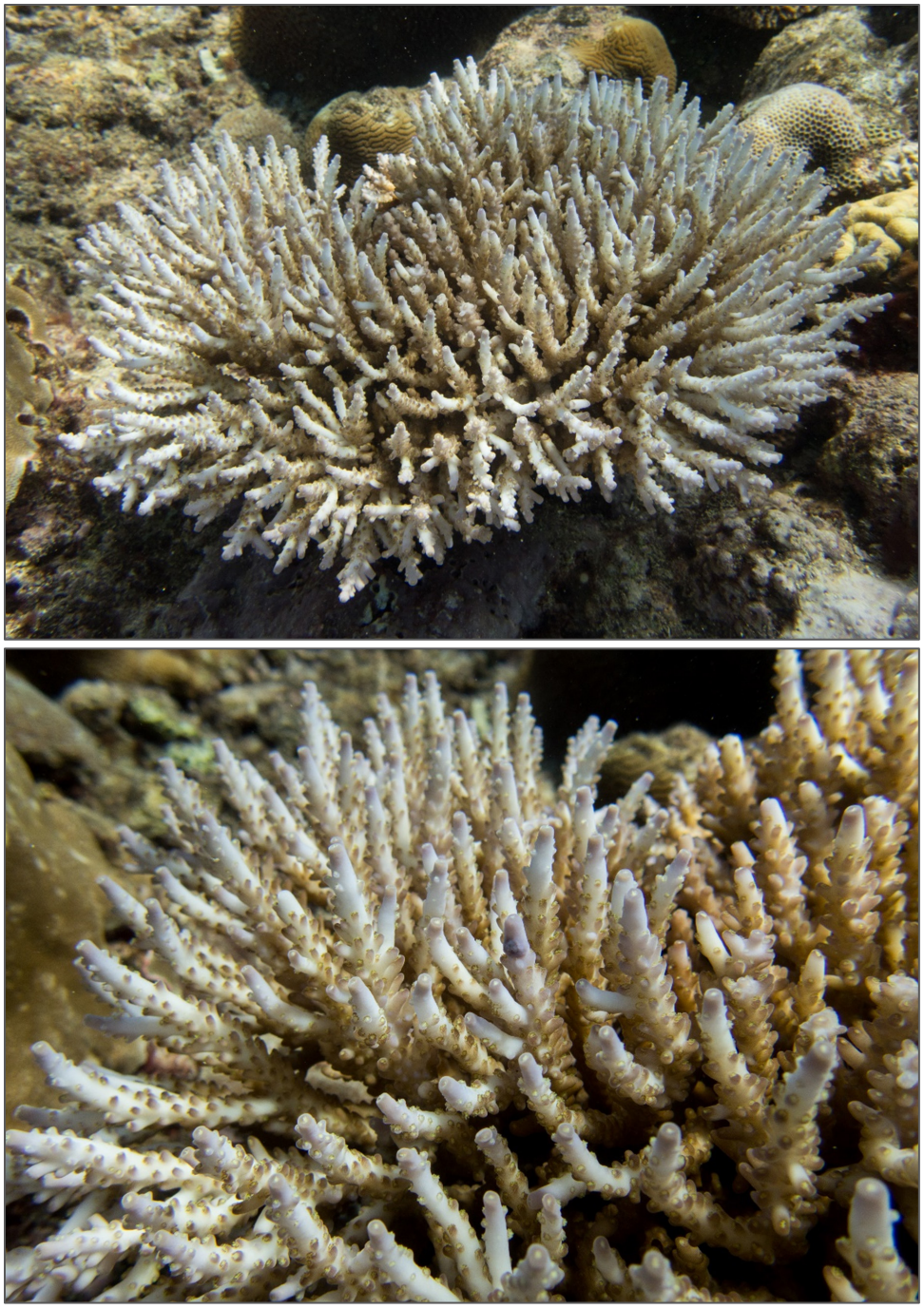


Figure I-2. A single colony of this distinctive *Acropora* species, called *A*. cf. *loripes* sensu Veron et al. (2016) as a placeholder, was observed at diversity survey site Asan–CS–6, within the reef front zone at a depth of between 5 and 6 m.

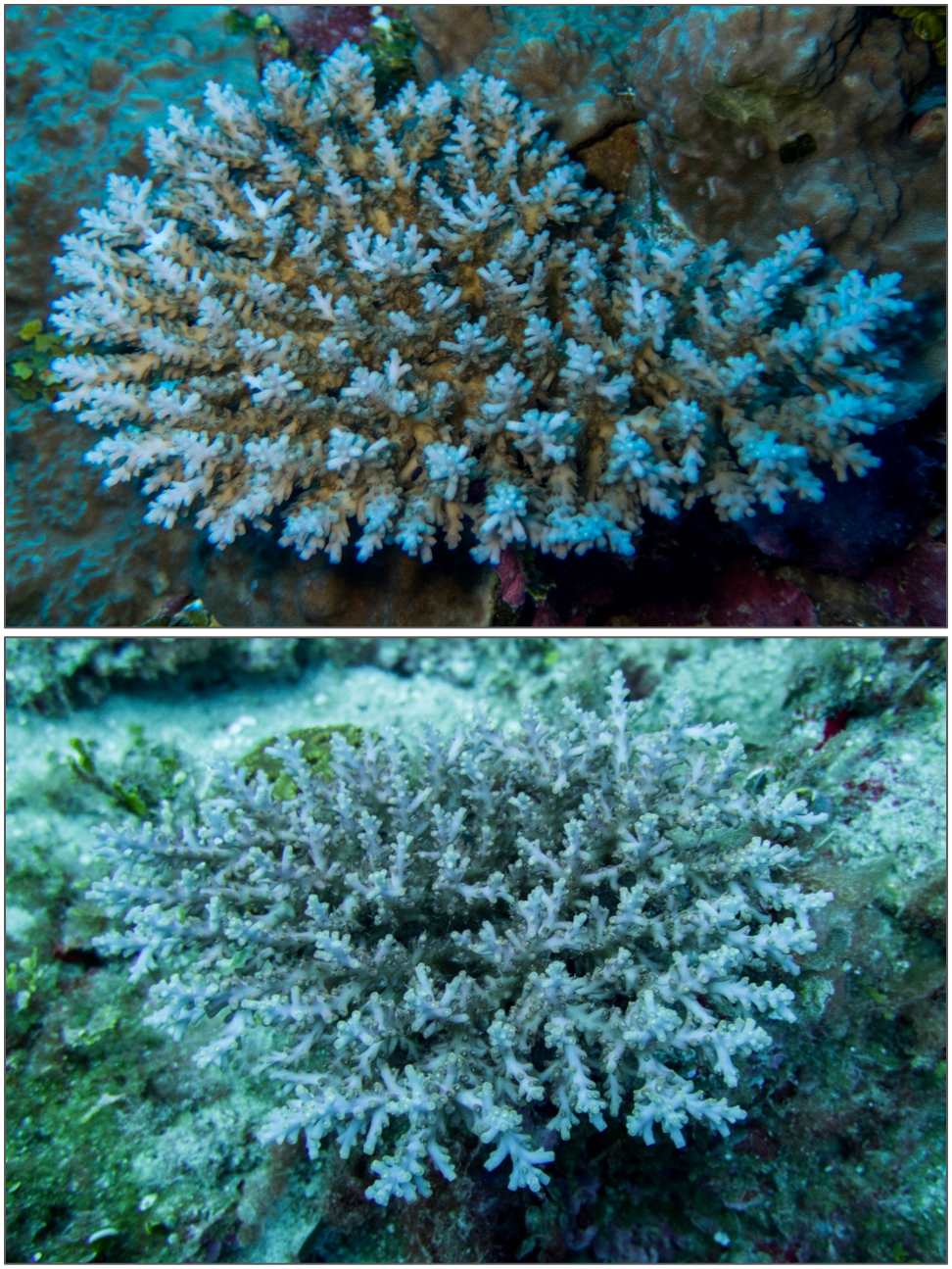


Figure I-3. Eleven colonies of this infrequently encountered, and likely undescribed species, tentatively called *Acropora* cf. *kimbeensis*, were observed at depths between 18 and 33 m at three sites within the Asan unit and one site within the Hågat unit. The colony in the top image, observed at a depth of 32 m, exhibited a more regular colony outline and branch arrangement than the colony in the bottom image, which was observed at a depth of 30 m, but they are believed to represent the same morphospecies.



Figure I-4. A colony of a species consistent with *Alveopora tizardi* at site Asan–CS–7 at a depth of ~12 m (top), and a colony of a species that appears to be an *Acanthastrea* species at a depth of 10 m at site Asan–CS–2.

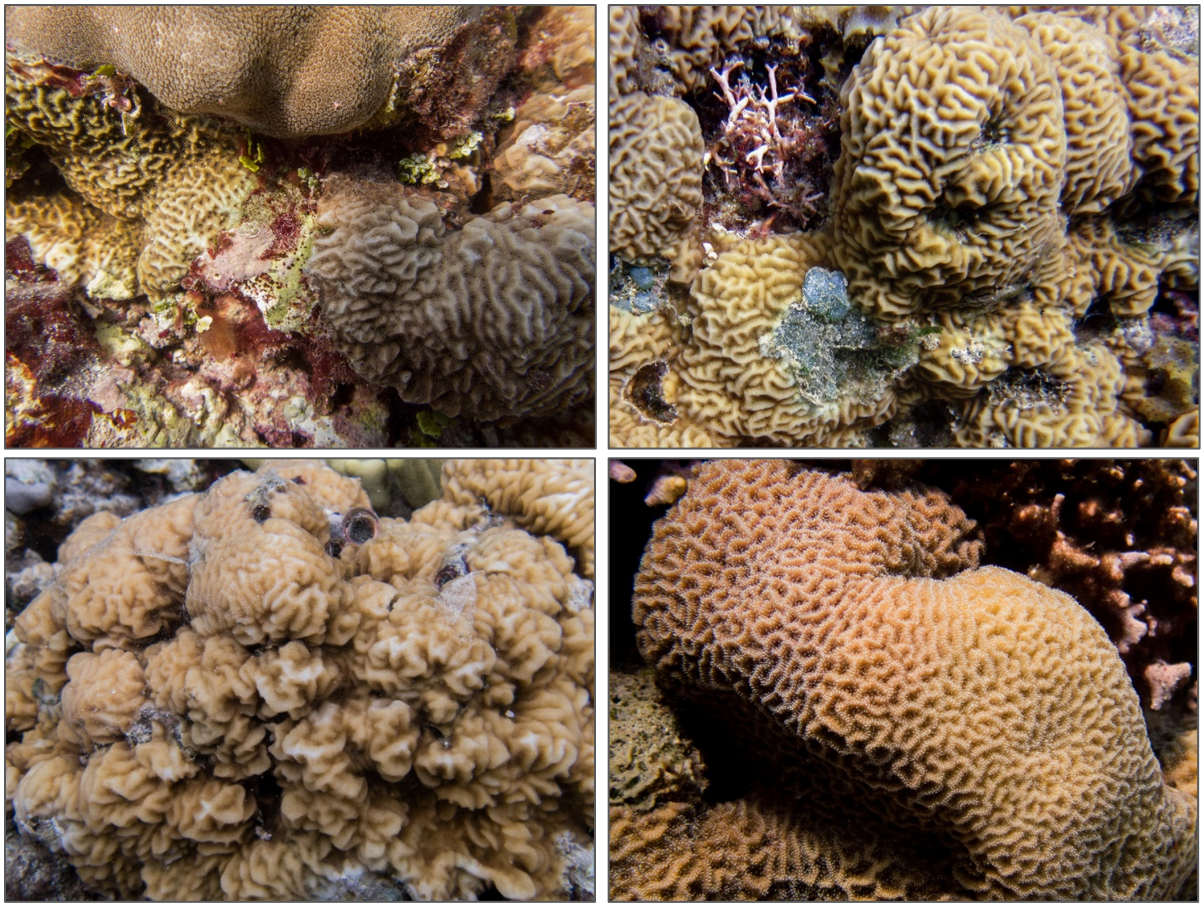


Figure I-5. *Pavona chiriquiensis* and *P. varians* (top left) and colonies consistent with species considered by Randall to be new, including *Pavona* sp. “meandrina” (upper right), *Pavona* sp. “contorta” (bottom left), and *Pavona* sp. “albamarginata” (bottom right).

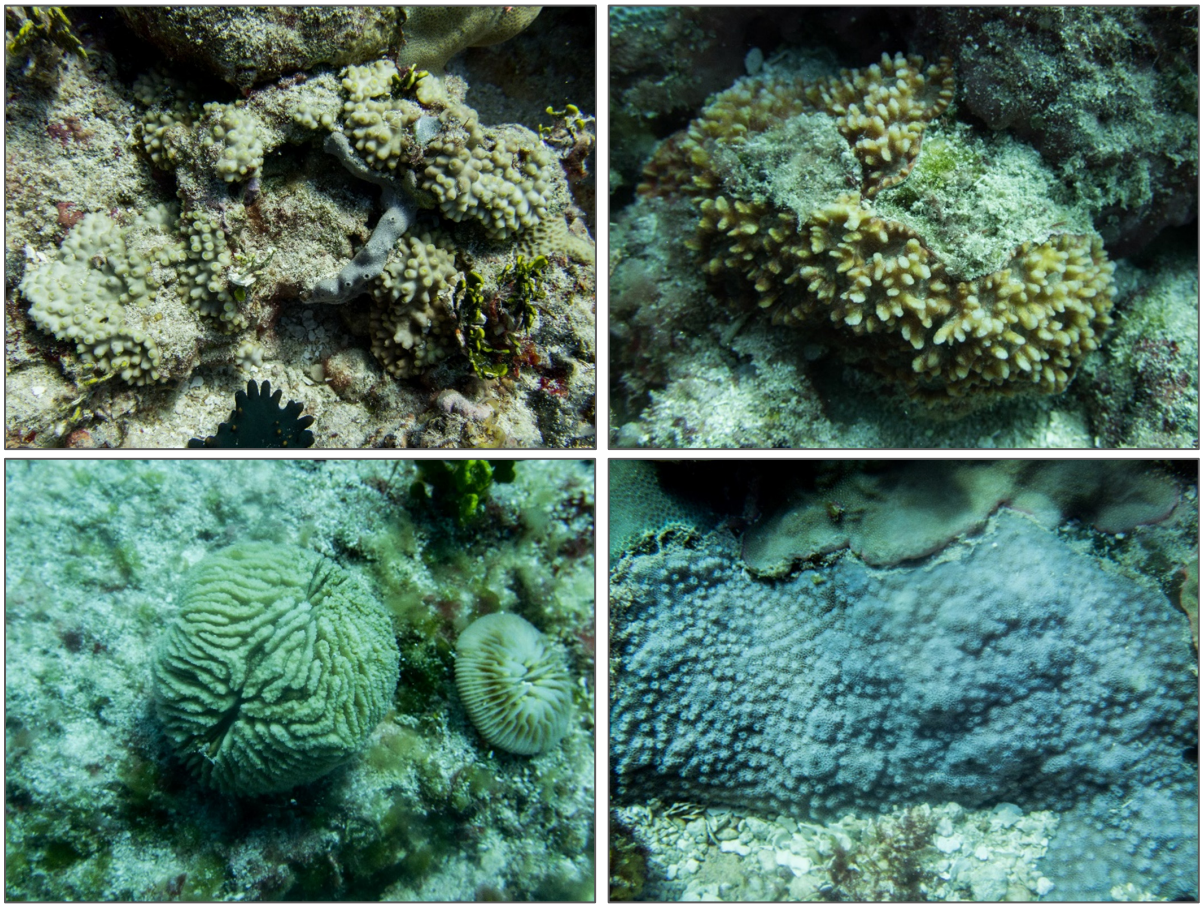


Figure I-6. Additional notable species encountered at the diversity survey sites, including a *Turbinaria* cf. *irregularis* (top left), *Favites* sp. “crassisepta” (top right), an unidentified fungiid sp. (bottom left), and *Astreopora* sp. B (bottom right).

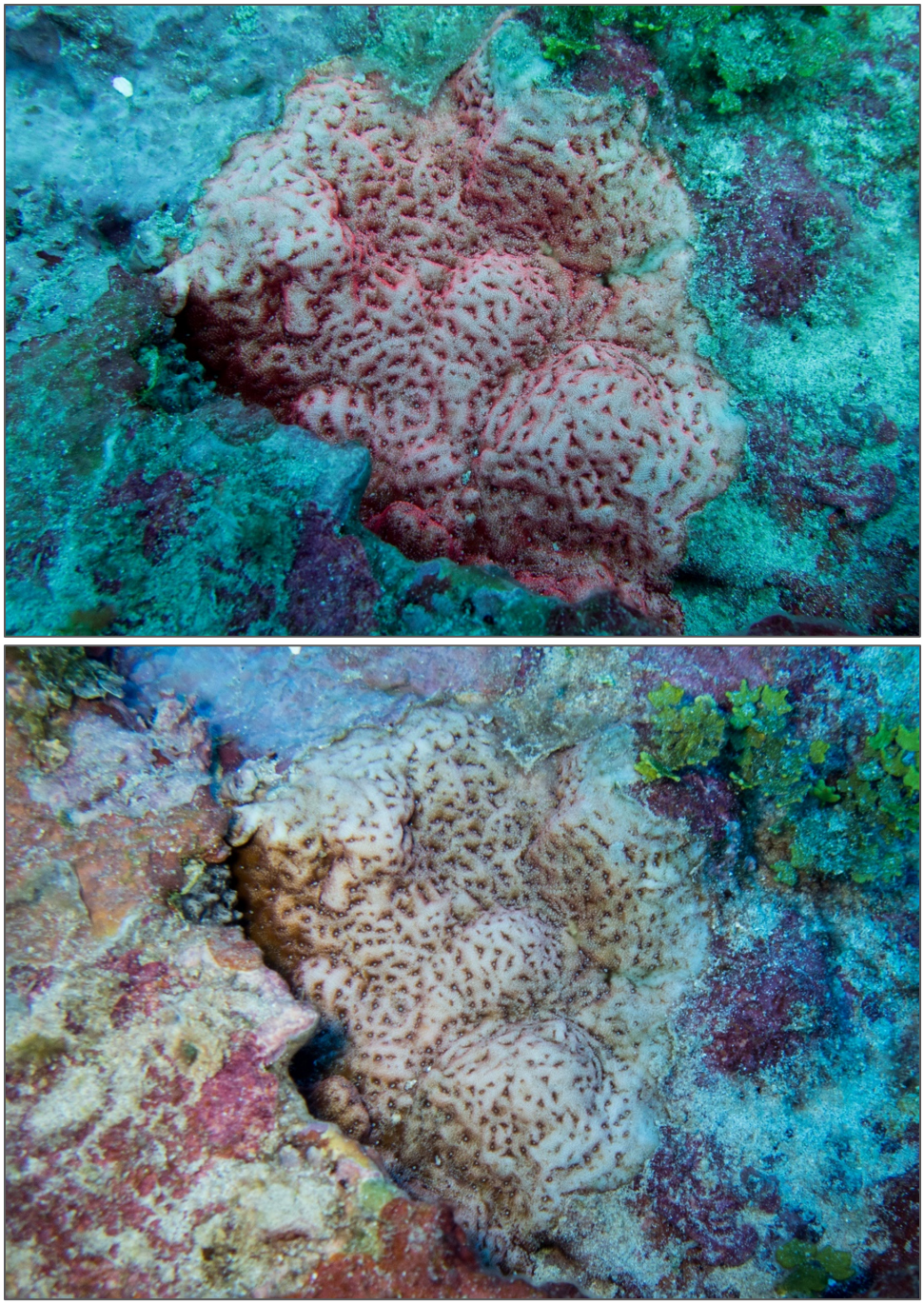


Figure I-7. A colony of a *Leptoseris* sp. “rubra” at diversity survey site ASAN–CS–5 in ambient light (top) and illuminated by the camera’s flash (bottom).

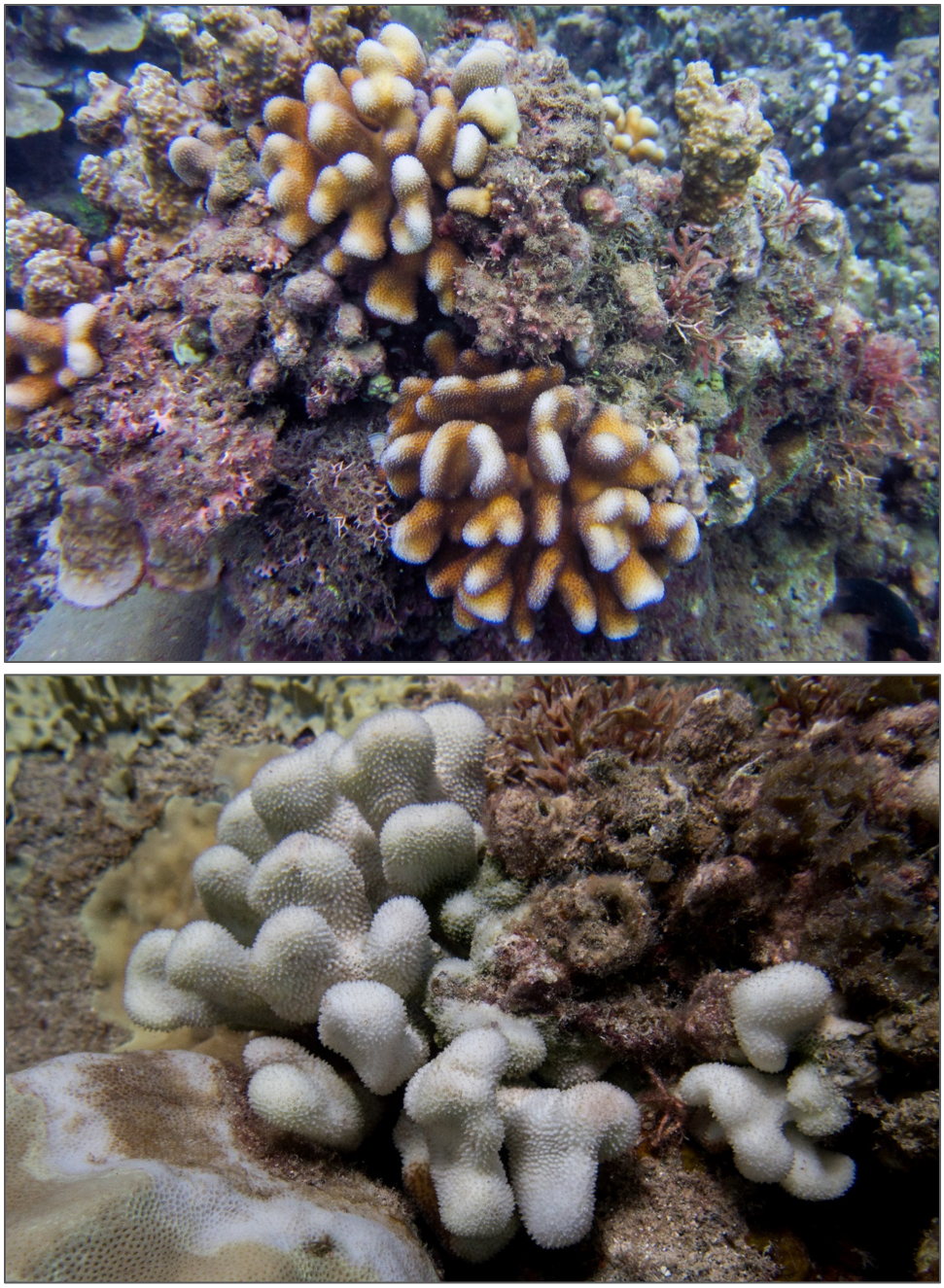


Figure I-8. Only two colonies of the once–common species, *Stylophora* sp. “mordax,” were observed during the diversity surveys, including what appears to be a single colony that had suffered partially mortality in the past and regrew (Asan–CS–5, top) and a mostly dead colony that likely was recently preyed upon by a crown–of–thorns sea star (Asan–CS–2, bottom).

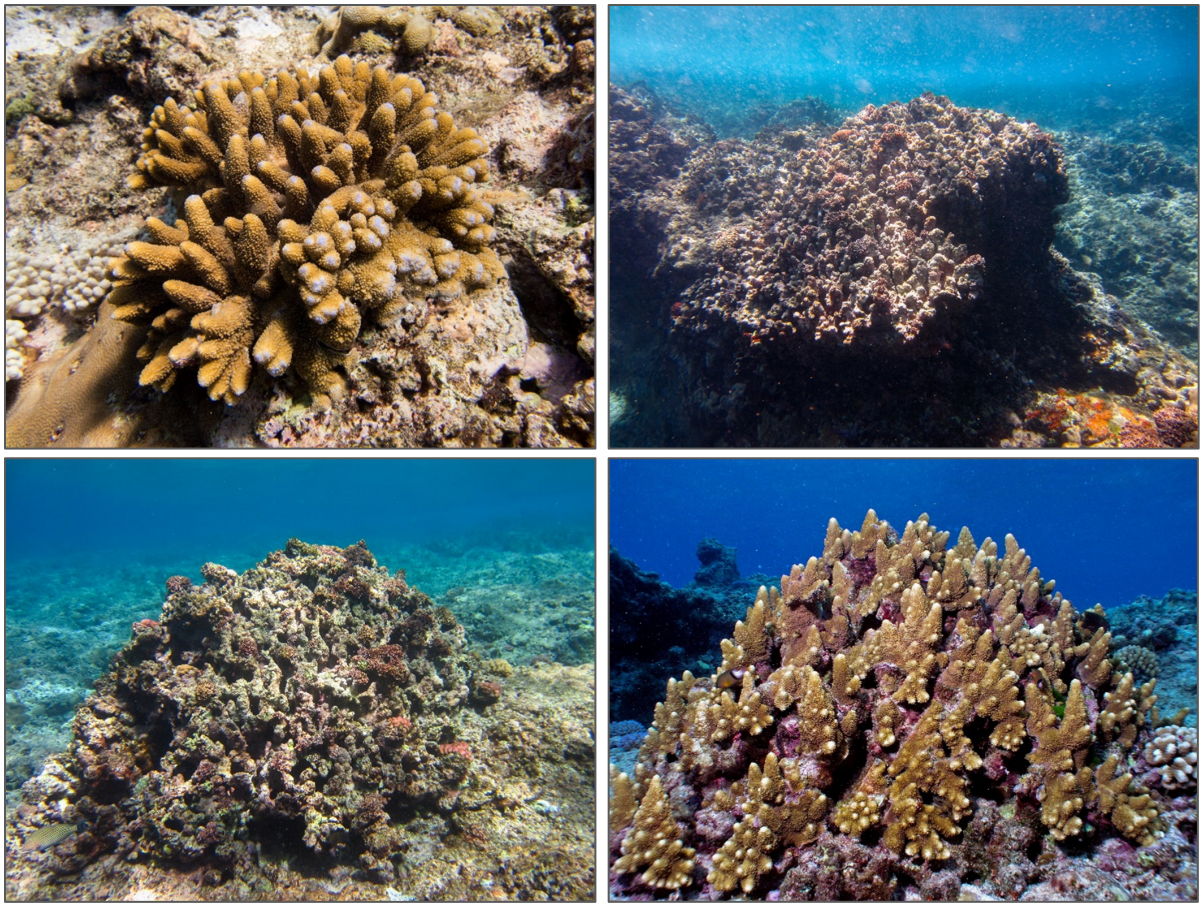


Figure I-9. One of the larger colonies of the now–uncommon species currently called *A. monticulosa* in Guam's waters that was observed during the diversity surveys was an approximately 40 cm diameter colony at site Asan–CS–6 (top left). The skeletons of several larger (> 1 m diameter) dead colonies were observed, including at site Asan–CS–11 (top right) and Asan–CS–8 (bottom left). The large living colony in the bottom right image was observed by DB along the reef front to the east of Camel Rock in 2010.

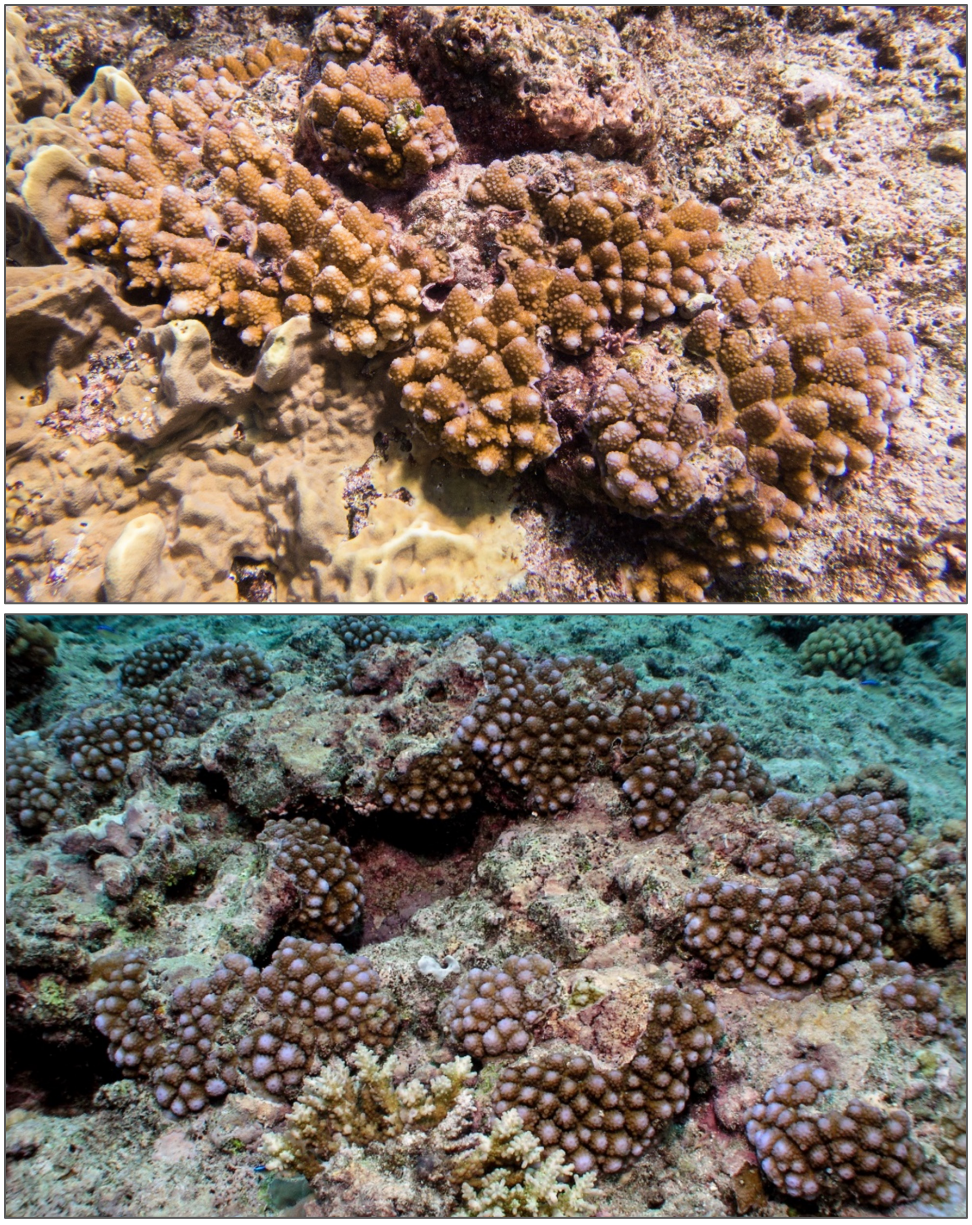


Figure I-10. The Acropora sp. “obtusicaulis” colony in the top image was one of only three living colonies observed during the diversity survey sites, this one encountered at site Asan–CS–4. The larger colony/colony aggregation in the bottom image, which was observed by DB at a reef front area between Asan Cut and Adelup Pt. in 2010, more clearly displays the cluster of separate colonies, possibly genets or ramets, typical of this species.

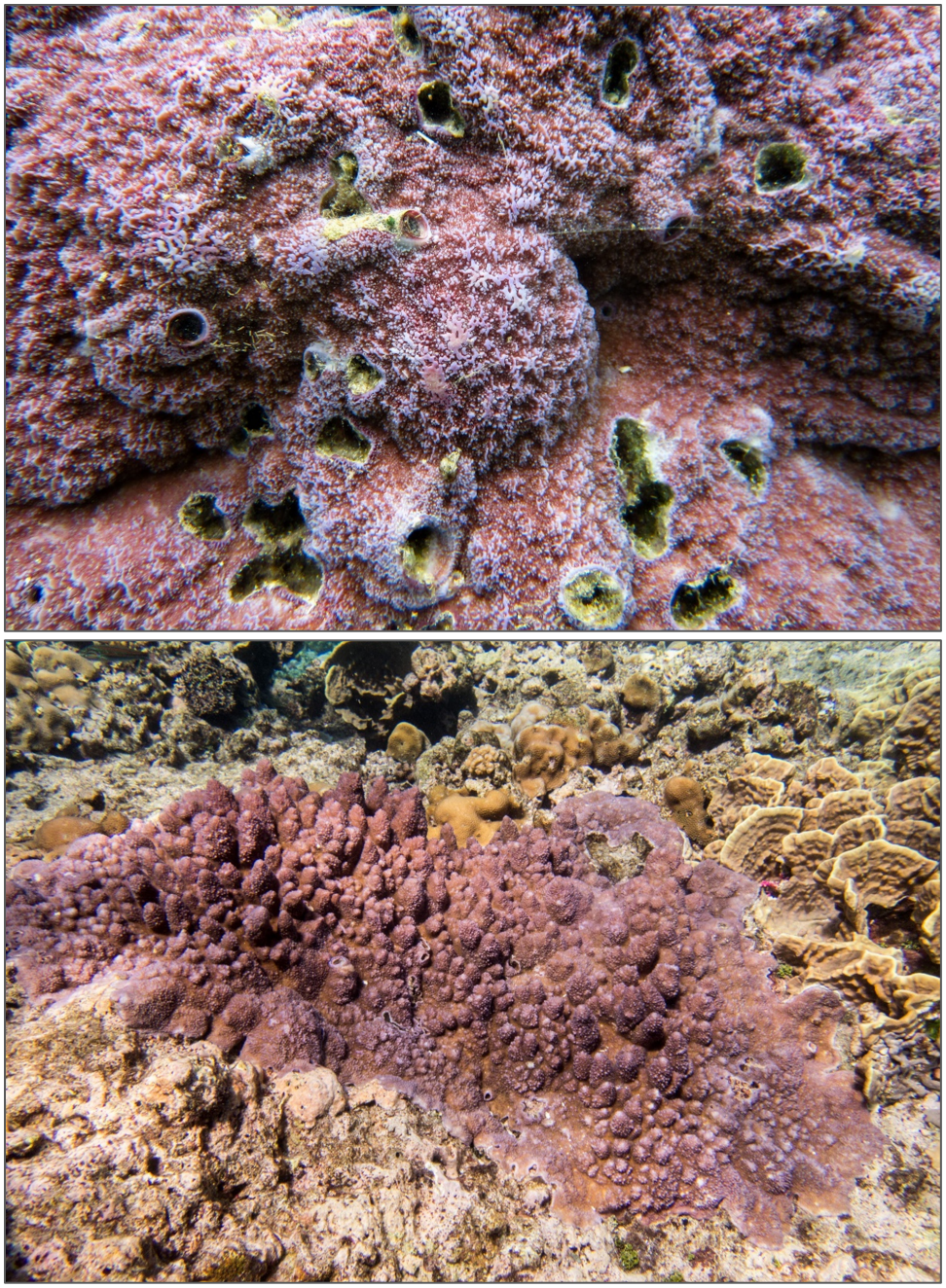


Figure I-11. A colony that appears to be a species, *Montipora* sp. “pagoensis, that Randall believed to be undescribed (top) and a relatively large colony of the encrusting–digitate species, *Acropora palmerae* (bottom).



Figure I-12. A single, rather pale and unhealthy–looking colony of a branching *Millepora* species that appears to be *M. dichotoma* (but which is also similar to *M. latifolia*) was observed during the coral diversity surveys (site Asan–CS–6).



Figure I-13. Deeper (> approx. 8–10 m) reef areas within the WAPA Hågat unit, such as the reef areas surveyed at coral diversity survey sites Agat–CS–1 (top) and Agat–CS–8 (bottom), host low (<10%) coral cover primarily comprised of a small number of generally stress–tolerant taxa such as mounding *Porites* spp.



Figure I-14. Relatively high cover of several *Pocillopora* species along the upper reef front at site Agat–CS–2 (top) and the mixed *Acropora* cf. *pulchra–A. muricata* thickets on the reef flat at site Agat–CS–3 (bottom), offshore of the Agat Cemetery.



Figure I-15. Staghorn coral rubble along the reef margin just north of Ga'an Pt., at coral diversity survey site Agat–CS–5 (top) and numerous *Acropora tenuis* colonies within a relatively narrow portion of the reef margin at site Agat–CS–7 (bottom).

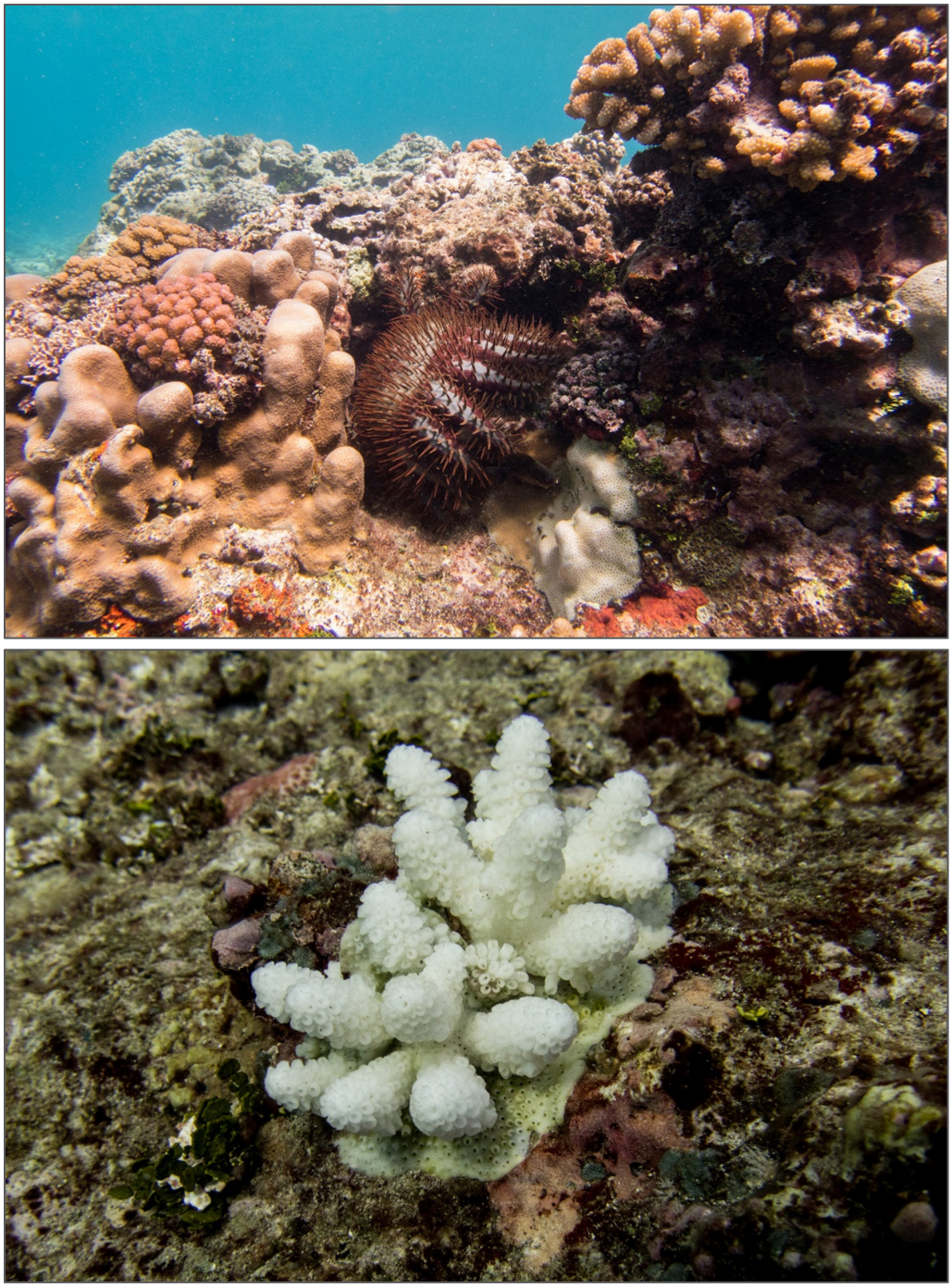


Figure I-16. Several crown–of–thorns sea stars (*Acanthaster* cf. *solaris*) were observed during the coral diversity surveys, including the individual in the top image, which was observed actively feeding in shallow water at site Agat–CS–2. Recently eaten colonies of preferred prey species, such as the *Acropora* cf. *humilis* colony in the bottom image (site Asan–CS–5), were regularly encountered at seaward slope sites in both the Hågat and Asan units.

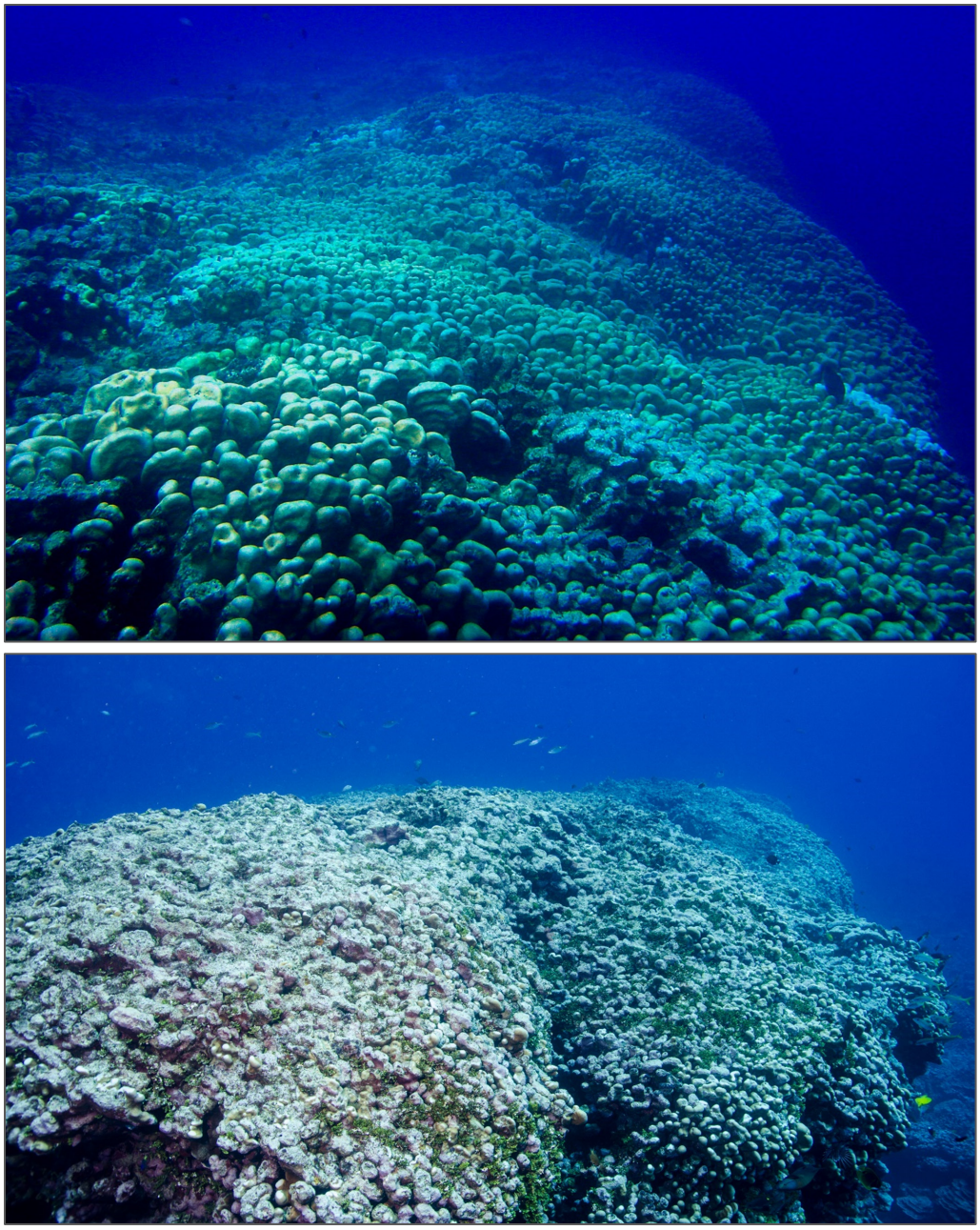


Figure I-17. A view of the mostly living *Pavona clavus* supra–colony on the west side of Hap's Reef, within the WAPA Hågat unit in May 2005 (top) and a similar perspective of the same, mostly dead supra–colony in Dec. 2016 [some living *P. clavus* can be seen in the lower right of the bottom image].

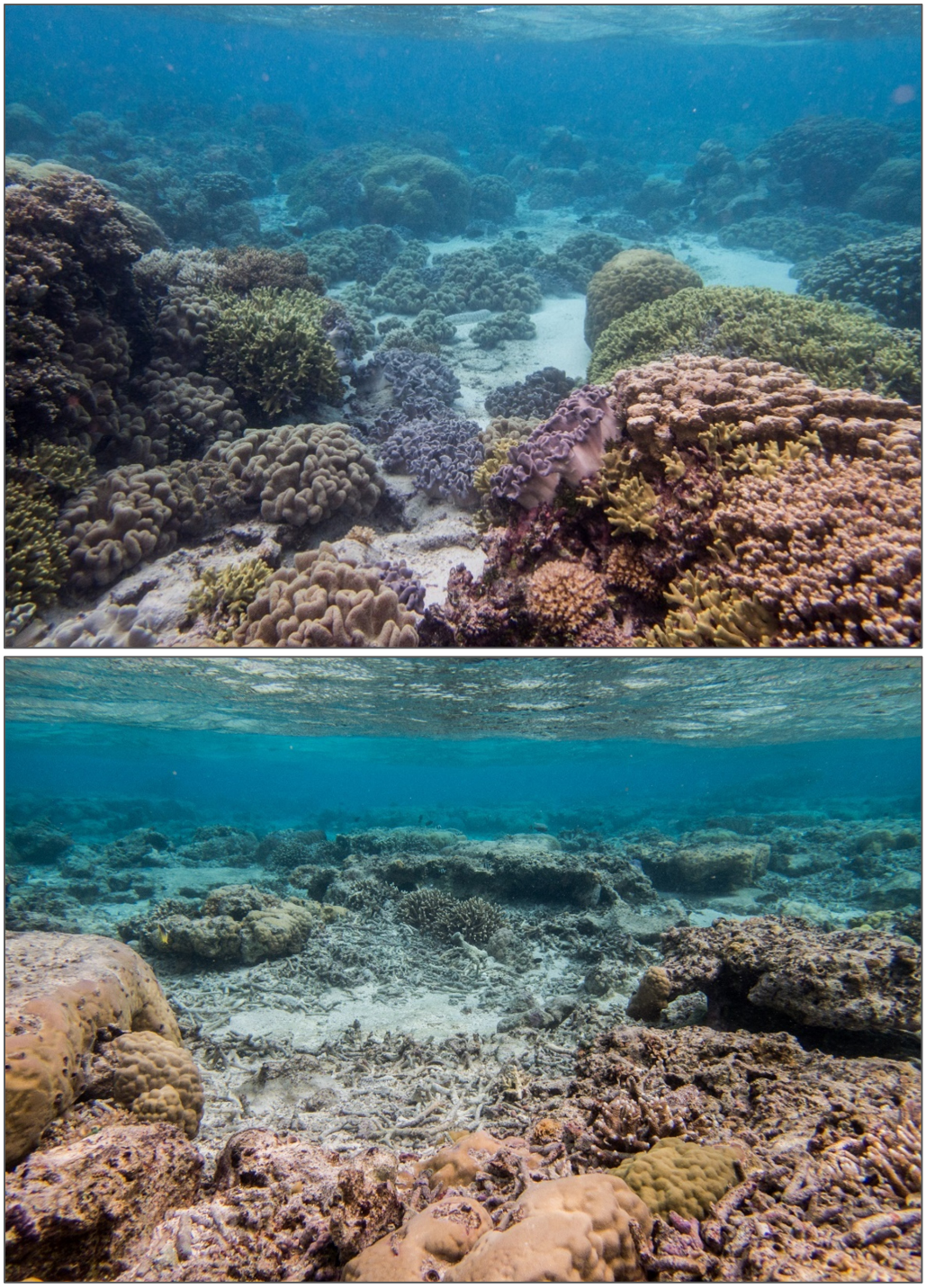


Figure I-18. The slightly deeper reef flat in the vicinity of diversity survey site Asan–CS–1, just to the west of Asan Pt. in Tepungan Bay (top), generally supported more structural complexity in comparison to the shallower, more truncated coral formations at site Asan–CS–10 (bottom).

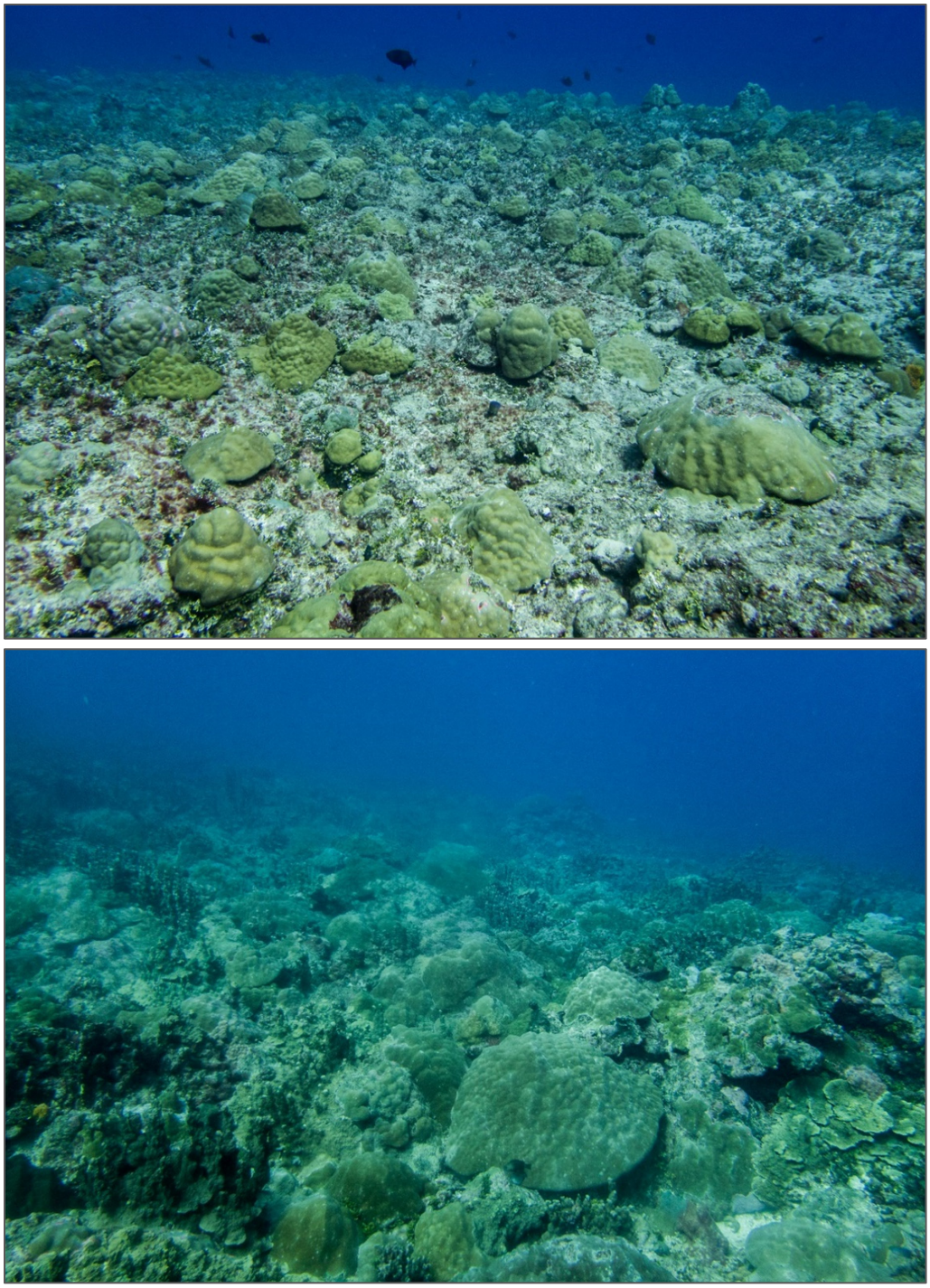


Figure I-19. The deeper (> 15 m) seaward slope areas in Asan observed during the diversity survey, such as sites Asan–CS–3 (top) and Asan–CS–12 (bottom), hosted significantly greater coral cover, fewer instances of compromised coral colony health, and overall better substrate condition in comparison to the seaward slope in the Hågat unit.

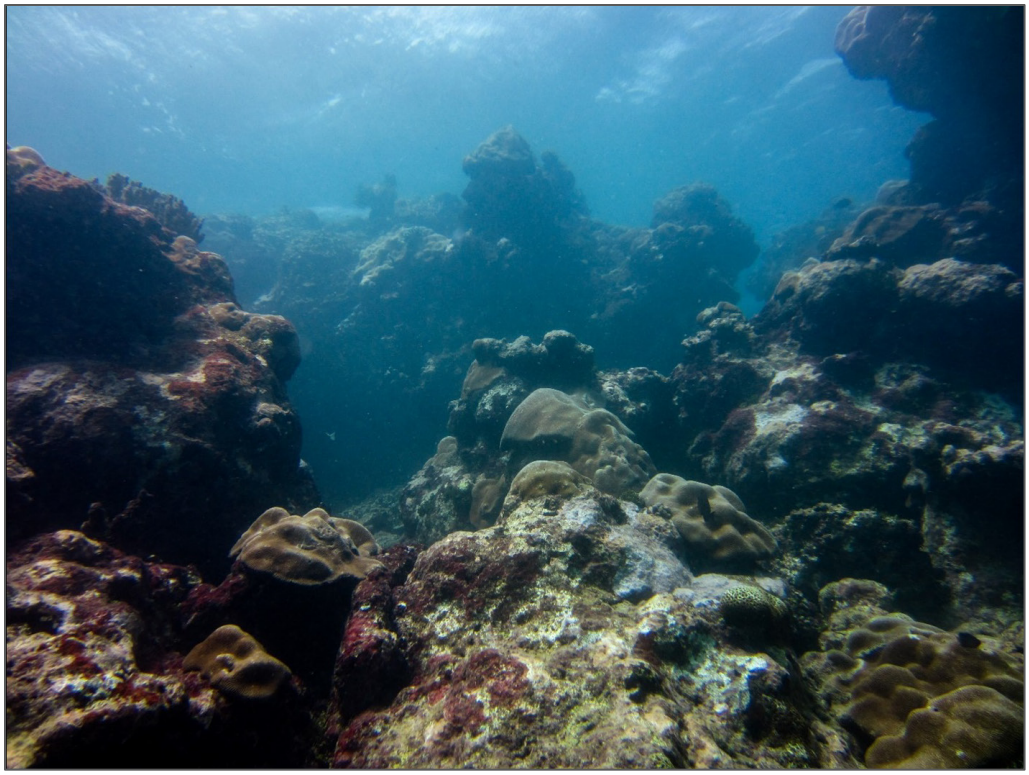


Figure I-20. The reef at Asan Cut, a popular diving and fishing site, hosts among the most dramatic topographic relief and overall structural complexity of any of Guam's reefs. Diversity survey site Asan–CS–7 occurred within cut, but was generally restricted to depths greater than 10 m along the north side of the cut.

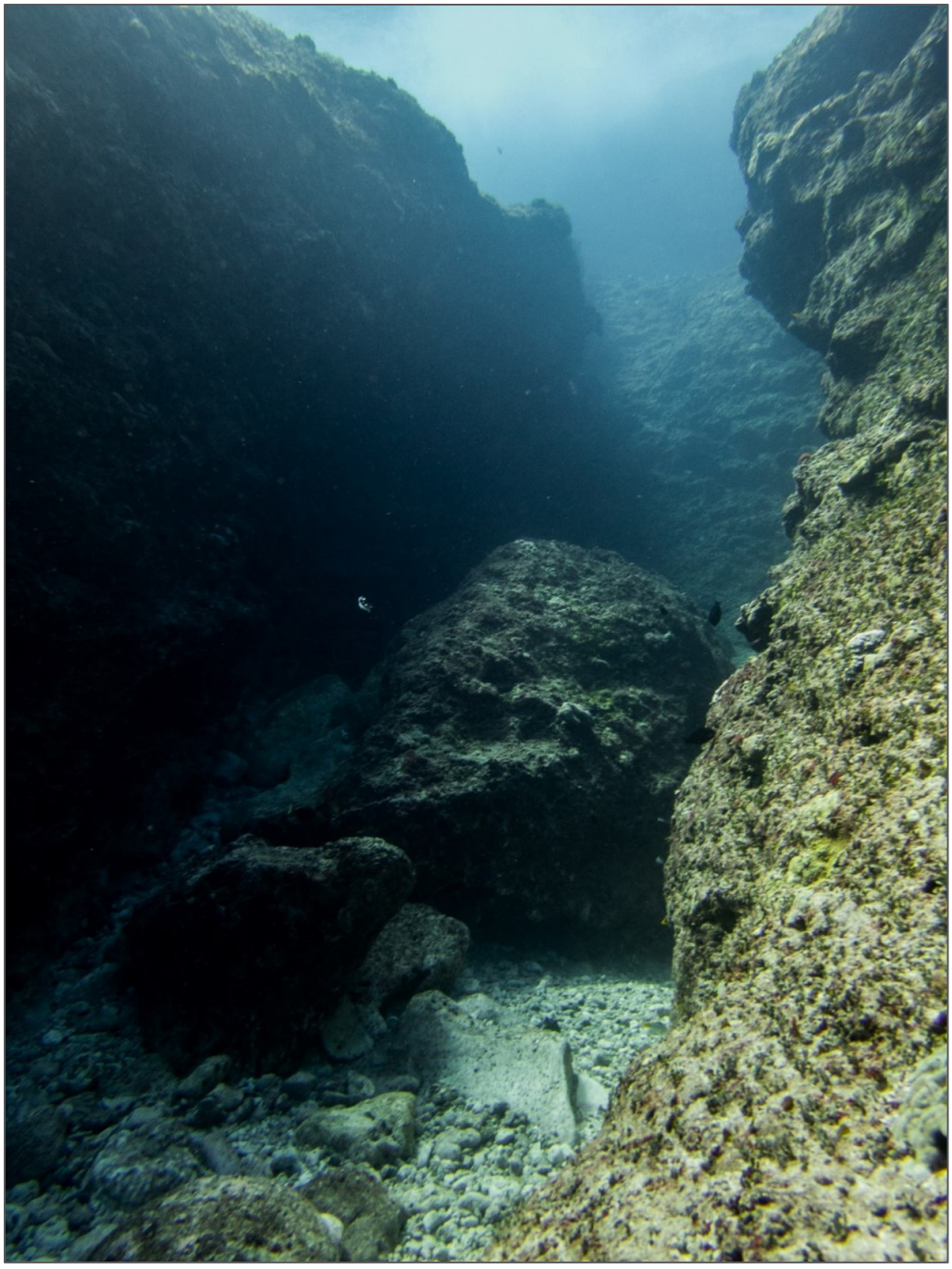


Figure I-21. A fissure in the reef at diversity survey site Asan–CS–2, to the north of Camel Rock, hosted some uncommon coral species, and was adjacent to a small, shallow cavern at the base of Camel Rock that hosted shade–tolerant corals.

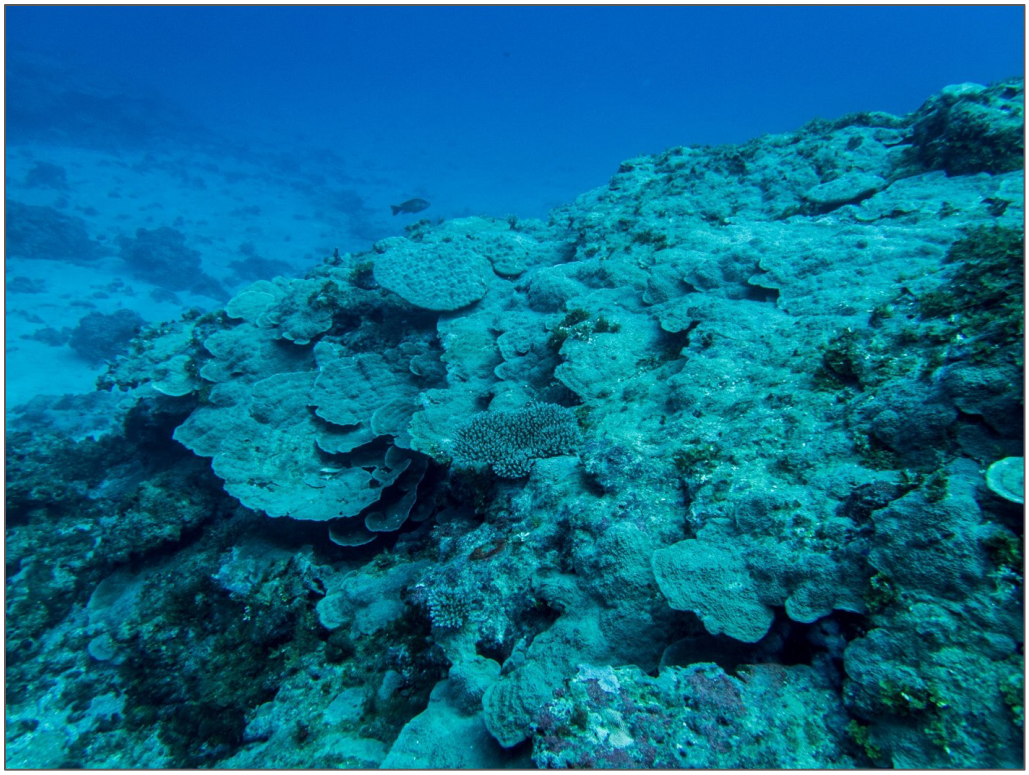


Figure I-22. The greatest depth reached during the WAPA coral diversity surveys (33 m) was at site Asan–CS–5, approximately 400 m to the northwest of Asan Cut. An area with high cover of plating *Porites rus*, and scattered colonies of uncommonly encountered *Acropora* species, an undescribed species of *Leptoseris*, and other notable coral species, were observed in this area.

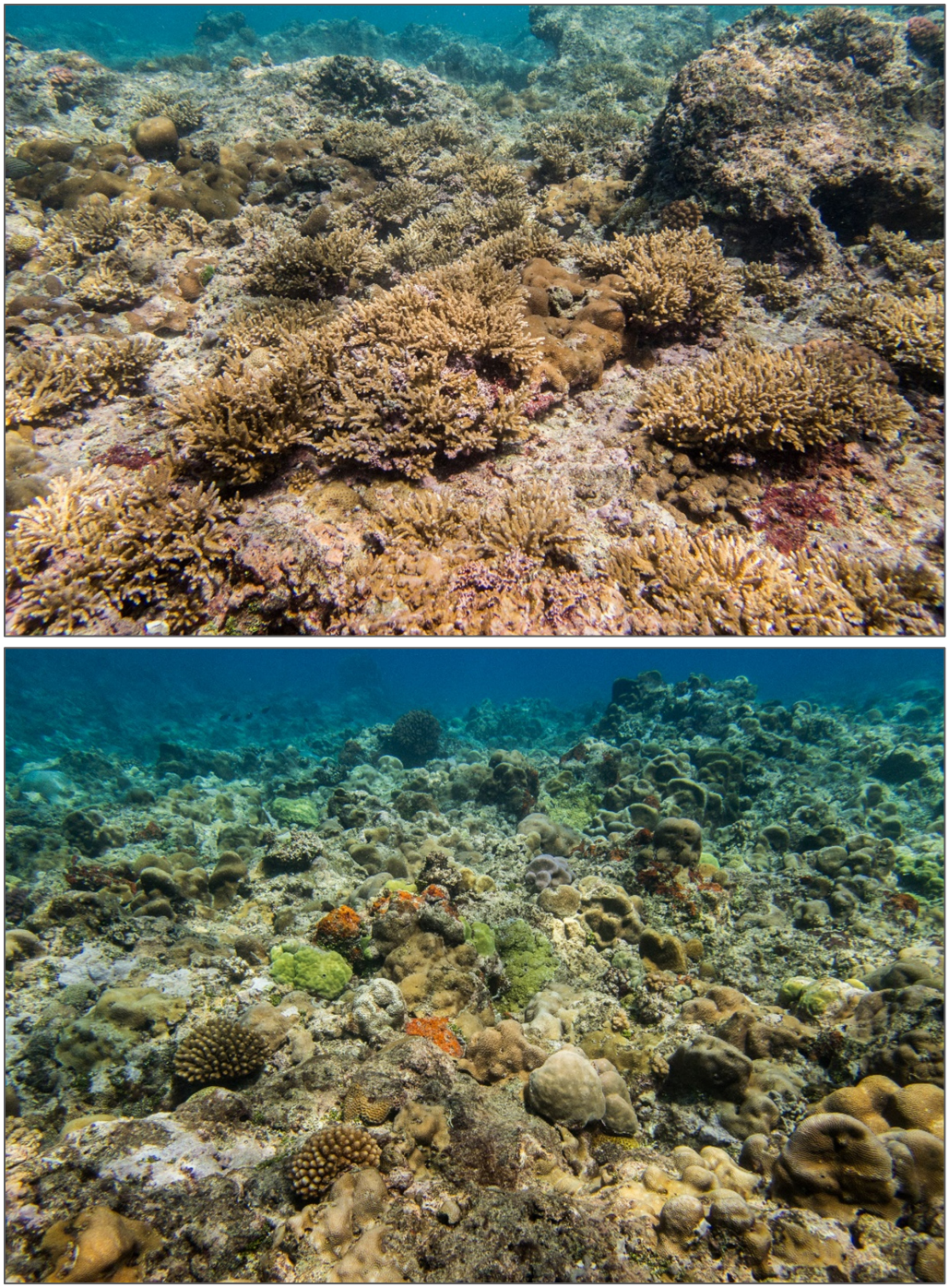


Figure I-23. The greatest number of coral species was detected at the shallow reef front site Asan–CS–8; this site was also notable for hosting an area with several hundred healthy colonies of the highly bleaching–susceptible species, *Acropora verweyi* (top). A large number of coral species was also observed at diversity survey site Asan–CS–4, a site also notable for hosting the largest number of *Acropora globiceps* colonies, two of which are visible in the lower left of the bottom image.

Appendix J. Additional shallow (< 40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Table J-1. Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Acroporidae	*Acropora* cf. *dendrum*	highly unlikely	Known from a single colony photographed by VB in Apra Harbor
	Acropora cf. *florida* (Dana, 1846)	highly unlikely	possibly extirpated; only reported from Cocos Lagoon by RR; DB has not observed this species in Guam's waters
	Acropora cf. *listeri* (Brook, 1893)	unlikely	known from single colony photographed by DB near Umatac Bay
	Acropora pinguis Wells, 1950	likely	rare; four colonies photographed by DB at appear to be this species; one was photographed near Anae Island, in SW Guam
	Acropora cf. *retusa* (Dana, 1846)	unlikely	rare, known from two colonies photographed by DB (West Hagåtña Bay and Asgadao Bay)
	Acropora cf. *retusa sensu* Wallace, 1999	unlikely	rare, known from two colonies photographed by DB in Apra Harbor
	Acropora cf. *robusta* (Dana, 1846)	likely	rare, could be form of *A. abrotanoides*
	Acropora cf. *rosaria sensu* Veron	likely	rare, but small *Acropora* sp. A colony observed in this study may be this species
	Acropora cf. *schmitti* Wells, 1950	unlikely	rare; may be stout form of *A. tenuis*; DB has only observed north of Tanguisson Pt.
	Acropora cf. *speciosa* (Quelch, 1886)	highly unlikely	known from a single specimen collected by DB and images of a colony obtained by VB, both in Apra Harbor
	Acropora striata (Verrill, 1864)	unlikely	rare, known only from Luminao Reef; DB has not observed living colony in Guam's waters

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Acroporidae (continued)	*Acropora teres* (Verrill, 1866)	likely	rare, but generally shares same habitat as *A*. cf. *pulchra* (and may actually be a form of *A*. cf. *pulchra*)
	Acropora vaughani sensu Randall Wells, 1954	unlikely	rare, appears to be restricted to Apra Harbor
	Acropora virgata (Dana, 1846)	unlikely	rare, currently known only from Apra Harbor, but once occurred in Cocos Lagoon and other locations
	Acropora sp. "compressa"	highly unlikely	possibly extirpated, last known living colony observed by DB in Tepungan Bay, has not revisited since 2012
	Acropora sp. "guamensis"	highly unlikely	possibly extirpated; DB has never observed in Guam's waters; may be an unusual form of *A. verweyi*
	Acropora sp. "tumonensis"	highly unlikely	possibly extirpated; last seen by DB in 2011 at Sharks Hole, colony later confirmed dead
	Acropora sp. A encrusting digitate	likely	close to *A. palmerae*, but with dense arrangement of digitate branches of similar heights
	Acropora corymbose sp. B (upturned radials)	unlikely	known from a single colony photographed by DB in southeastern Guam
	Acropora sp. Bonito's sp. 1	highly unlikely	Known from two colonies photographed by VB in Apra Harbor; DB and RR have not observed in Guam's waters
	Alveopora cf. *excelsa* Verrill, 1863	highly unlikely	DB has never seen this species in Guam's waters; known only from one specimen collected by RR from Bile Bay
	Alveopora fenestrata Lamarck, 1816)	unlikely	rare, DB has never seen this species in Guam's waters
	Alveopora minuta Veron, 2000	unlikely	rare, DB has never seen this species in Guam's waters
	Alveopora spongiosa Dana, 1846	likely	–
	Alveopora sp. "undulata"	unlikely	usually > 30 m, but one specimen collected from 12 m depth; DB has not observed this species in Guam's waters
	Astreopora expansa Bruggemann, 1877	unlikely	RR has some specimens in collection; known by DB from only 1 colony photographed in Apra Harbor
	Astreopora ocellata Bernard, 1896	likely	–

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Acroporidae (continued)	*Montipora caliculata* (Dana, 1846)	likely	–
	Montipora cf. *crassituberculata* Bernard, 1897	unlikely	uncommon, appears to be restricted to Apra Harbor; may be RR's Montipora (papillate sp. 1)
	Montipora orientalis Nemenzo, 1967	likely	*Montipora berryi* in this study is similar to this species, could be the same
	Montipora planiusculla (Dana, 1846)	likely	–
	Montipora turgescens	highly unlikely	reported from CNMI by D. Fenner; neither DB nor RR have ever observed in Guam or CNMI
	Montipora sp. "biprominens"	unlikely	rare, known only from Pago Bay, on east coast
	Montipora sp. "crassiformis"	likely	rare, but known from southwest coast
	Montipora sp. "distans"	likely	rare, but known from southwest coast
	Montipora sp. "micropora"	likely	rare to uncommon
	Montipora sp. "guamensis"	unlikely	RR only observed this species in Cocos Lagoon; DB has not observed this species in Guam's waters
	Montipora (papillate sp. 1)	likely	mostly restricted to Apra Harbor, but RR also observed along southwest coast
	Montipora sp. 3	likely	–
	Montipora tuberculate (with corallites) sp. A	unlikely	known from a single colony photographed by DB in Apra Harbor
	Montipora tuberculate (with corallites) sp. D	unlikely	known from a single colony photographed by DB in Apra Harbor
	Montipora tuberculate (with corallites) sp. E	unlikely	appears to be restricted to Apra Harbor
	Montipora tuberculate sp. "rectangles"	unlikely	appears to be restricted to Apra Harbor
	Montipora foveolate sp. 1	unlikely	known from a single colony photographed by DB in Tepungan Bay
	Leptoseris foliosa Dineson, 1980	likely	usually below 30 m, but DB found shallower in Toguon Bay, in southwestern Guam

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Agariciidae (continued)	*Leptoseris papyracea* (Dana, 1846)	likely	usually below 30 m, except in Apra Harbor; DB observed numerous colonies at ~25 m near Anae Island, in SW Guam
	Leptoseris troglodyta Hoeksema, 2012	unlikely	usually below 30 m on cavern ceilings
	Leptoseris sp. "septolobata"	likely	–
	Pavona cf. *diffluens* (Lamarck, 1816)	likely	may be form of *P. duerdeni*, but DB, RR, and DF think it is distinct; could represent undescribed species
	Pavona sp. "compactus"	highly unlikely	possibly extirpated; on Guam only reported from Pago Bay, all colonies killed by extreme low tide event
	Pavona sp. "nodulosa"	likely	a colony observed in this study thought to be a form *of Pavona danai* sensu RR may be this species; Db has not observed
Dendrophylliidae	*Turbinaria reniformis* Bernard, 1896	likely	–
Euphylliidae	*Euphyllia ancora* Veron and Pichon, 1980	unlikely	on Guam known only from Pago Bay
	Euphyllia paraancora Veron, 1990	likely	–
	Galaxea longisepta Fenner and Veron, 2000	likely	–
Fungiidae	*Ctenactis albitentaculata* Hoeksema, 1989	unlikely	appears to be restricted to Apra Harbor
	Ctenactis echinata (Pallas, 1766)	likely	–
	Cycloseris hexagonalis Edwards & Haime, 1848	unlikely	usually found below 35 m
	Cycloseris mokai Hoeksema, 1989	unlikely	known only from a single colony photographed by DB in Apra Harbor
	Cycloseris sp. 1 (high convex) Randall 2003	unlikely	known from specimen dredged from >100 m, and shallower specimen photographed by DB in Apra Harbor
	Danafungia horrida Dana, 1846	unlikely	rare, only reported from Apra Harbor
	Halomitra clavator Hoeksema, 1989	unlikely	rare, below 20 m

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Fungiidae (continued)	*Halomitra pileus* (Linnaeus, 1758)	unlikely	rare, usually below 20 m; DB has only observed single corallum in Pago Bay
	Lithophyllon repanda Dana, 1846	likely	–
	Lithophyllon spinifer Claereboudt & Hoeksema, 1987	unlikely	rare outside of Apra Harbor
	Pleuractis moluccensis van der Horst, 1919	likely	–
	Podabacia crustacea (Pallas, 1766)	unlikely	rare, usually below 30 m; DB has never seen on Guam
Leptastraeidae	*Leptastrea* cf. *inequalis* Klunzinger, 1879	unlikely	known from single colony photographed by DB in East Agana Bay
Lobophylliidae	*Acanthastrea ishigakiensis* Veron, 1990	likely	–
	Acanthastrea sp. "gigas"	likely	–
	Acanthastrea sp. B	likely	–
	Acanthastrea sp. C	unlikely	known from single colony photographed at Blue Hole
	Echinophyllia orpheensis Veron & Pichon, 1980	highly unlikely	reported from Saipan by DF; neither DB nor RR have observed seen this species in Guam's waters
	Lobophyllia cf. *agaricia* Milne Edwards & Haime, 1849	likely	rare, known from colony photographed by DB near Agfayan Bay, in SE Guam, but Lobophyllia sp. A may be this species
	Lobophyllia hatai Yabe, Sugiyama, and Eguchi, 1936	unlikely	uncommon in Apra Harbor, known only from Tepungan Bay outside of harbor
	Lobophyllia valenciennesii Edwards & Haime, 1849	unlikely	known from four colonies photographed by DB at Toguon Bay, Facpi Pt., and Santa Rosa Reef
	Lobophyllia cf. *vitensis* Bruggemann, 1877	likely	similar to two individuals in images DB obtained near Cabras Is. and in Pago Bay identified as *Micromussa pacifica* by JR
	"Paraacanthastrea" sp. "coniculata"	likely	–

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Merulinidae	*Astrea annuligera sensu* Randall	likely	individuals identified by RR in images obtained by DB appear highly similar *to P. versipora*; clearly different from *A. annuligera* sensu Veron et al. 2016; DB is unsure if he has observed this species in Guam's waters
	Cyphastrea sp. "incrustans"	unlikely	rare in Marianas
	Dipsastraea amicorum (Milne Edwards & Haime, 1850)	unlikely	known only from a single colony photographed by DB in Apra Harbor
	Dipsastraea speciosa (Dana, 1846)	likely	–
	Favites magnistellata Chevalier, 1971	unlikely	known from single colony collected by RR at Tanguisson Pt.; DB has not observed this species in Guam's waters
	Goniastrea palauensis (Yabe, Sugiyama, and Eguchi, 1936)	unlikely	known from single specimen collected by G. Paulay; neither RR nor DB have observed this species in Guam's waters
	Hydnophora exesa (Pallas, 1766)	likely	rare, but found along southwest coast
	Hydnophora sp. "expansa"	likely	rare, but known from southwest coast
	Hydnophora sp. "proliferata"	likely	rare, but known from southwest coast, also Galvez Bank
	Merulina scabricula Dana, 1846	unlikely	DB has not observed this species in Guam's waters
	Oulophyllia bennettae (Veron, Pichon & Best, 1977)	unlikely	known from Guam only from a single colony photographed by DB in Inarajan Bay; Fenner observed in Saipan and Tinian
	Pectinia paeonia (Dana, 1846)	unlikely	rare outside Apra Harbor
Pocilloporidae	"Astylocoeniella" sp. "paliformis"	highly unlikely	rare, in Marianas known only from Saipan and Tinian
	"Astylocoeniella" sp. "taiwanensis"	highly unlikely	in Marianas known only from one colony collected by RR in Tinian
	Pocillopora fungiformis Veron, 2000	highly unlikely	DB has never seen this species on Guam; reported from Tinian and Pagan by DF
	Pocillopora sp. "neudeckeri"	likely	uncommon outside Apra Harbor
	Pocillopora sp. "nodulosa"	unlikely	known only from three locations along northwest and central east coast

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Pocilloporidae (continued)	*Pocillopora* sp. 3	unlikely	3 colonies photographed by DB at Double Reef; RR has a few specimens in his collections, exact number unknown
	Seriatopora aculeata Quelch, 1886	unlikely	DB has seen only 2 colonies, both from near Facpi Pt., both could not be relocated, assumed dead
	Seriatopora caliendrum Ehrenberg, 1834	highly unlikely	in Marianas only reported from Saipan
	Seriatopora dendritica Veron, 2000	unlikely	DB has not observed this species in Guam's waters
	Seriatopora guttatus Veron, 2000	unlikely	DB has not observed this species in Guam's waters
Poritidae	*Goniopora* cf. *albiconis* Veron, 2000	unlikely	known from two colonies photographed by DB (Tumon Bay and Toguon Bay)
	Goniopora djiboutiensis Vaughan, 1907	likely	could be *G. djiboutiensis–lobata* in this study
	Goniopora cf. *eclipsensis* Veron & Pichon, 1982	likely	uncommon to locally common
	Goniopora norfolkensis Veron & Pichon, 1982	likely	uncommon to locally common
	Goniopora pandoraensis Veron & Pichon, 1982	likely	uncommon to locally common
	Goniopora pendulus Veron, 1985	likely	uncommon to rare
	Goniopora somaliensis Vaughan, 1907	likely	uncommon to rare
	Goniopora sp. "anastomosa"	likely	rare, but collected from Agat Bay (and Tumon Bay)
	Goniopora sp. "angulata"	unlikely	rare, known only from colony collected by RR from Tumon Bay and another from Sella Bay
	Goniopora sp. "crassiseptata"	likely	–
	Goniopora sp. "minuta"	likely	–
	Goniopora sp. "veroni"	likely	–
	Porites mayeri Vaughan, 1918	likely	rare to uncommon

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Table J-1 (continued). Additional shallow (<40 m) zooxanthellate scleractinian coral species reported from Guam by various authors and their estimated likelihood of occurring on WAPA submerged lands.

Family	Species	Likelihood	Comments*
Poritidae (continued)	*Porites* cf. *okinawensis* Veron, 1990	unlikely	rare, known only from two colonies photographed by DB in Bile Bay, in southwestern Guam
	Porites sp. "glabra"	likely	rare to uncommon
	Porites sp. "gongyloides"	likely	rare
	Porites sp. B	unlikely	known from single colony photographed by DB at Bile Bay
	"Poritipora" sp. A	unlikely	DB photographed two colonies in Apra Harbor, unsure how many specimens from Guam in RR's collection
	Stylaraea punctata (Linnaeus, 1758)	likely	–
Psammocoridae	*Psammocora exesa* (Dana, 1846)	highly unlikely	in Marianas known only from individual colonies observed at Maug (RR), Agrihan (Burdick), and Tinian (Fenner)
Incertae sedis	*Oulastrea crispata* (Lamarck, 1816)	highly unlikely	Known from a single colony observed by LR in the CNMI

* DB = David Burdick, DF = Doug Fenner, JR = Joe Rowlett, LR = Laurie Raymundo, RR = Richard Randall, VB = Victor Bonito.

Appendix K. Species accumulation curves for individual coral diversity survey sites.

Figures K-1 to K-3 show species accumulation curves for individual coral diversity survey sites.

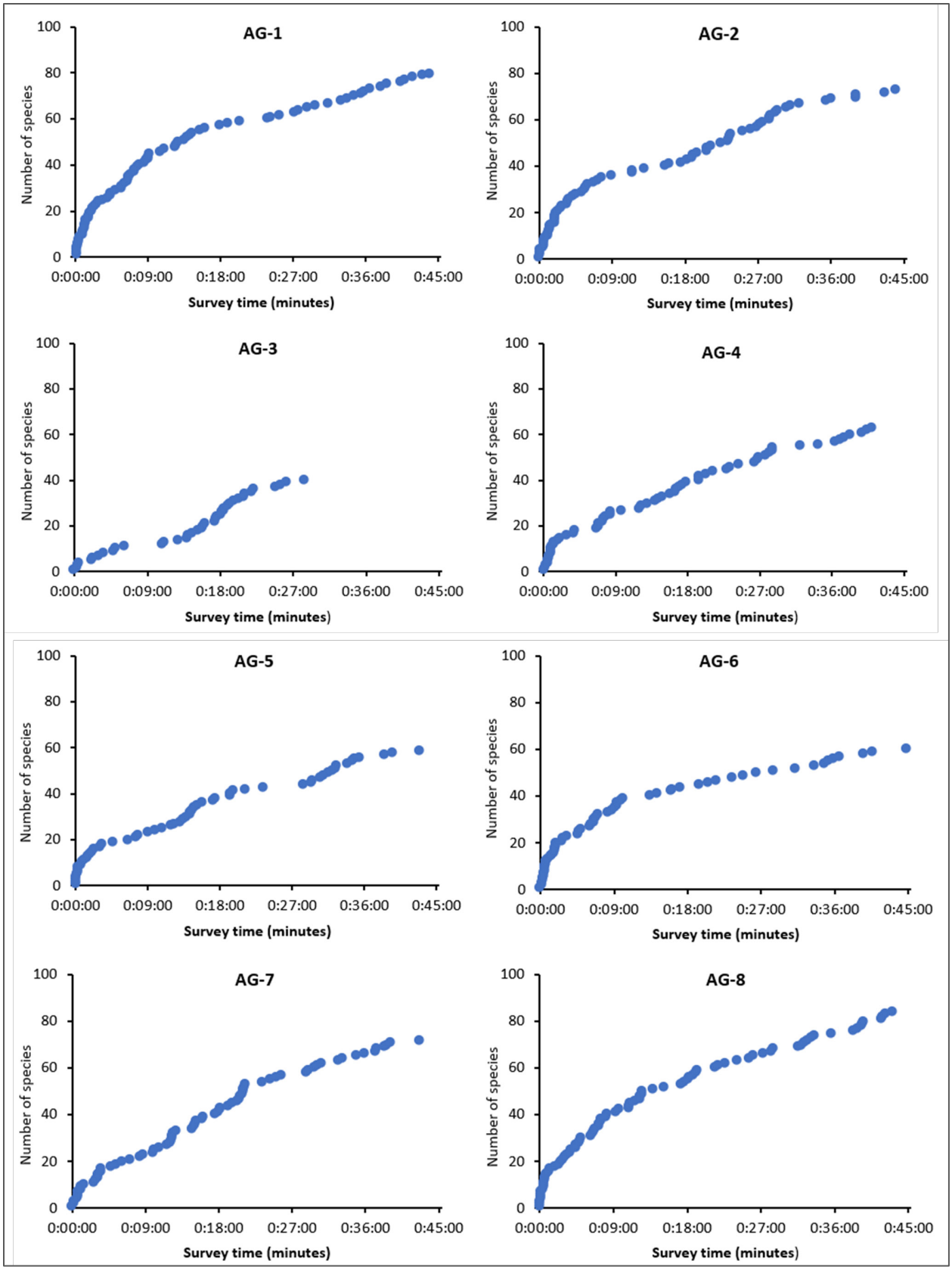


Figure K-1. Species accumulation curves at sites AG-1, AG-2, AG-3, AG-4, AG-5, AG-6, AG-7, and AG-8.

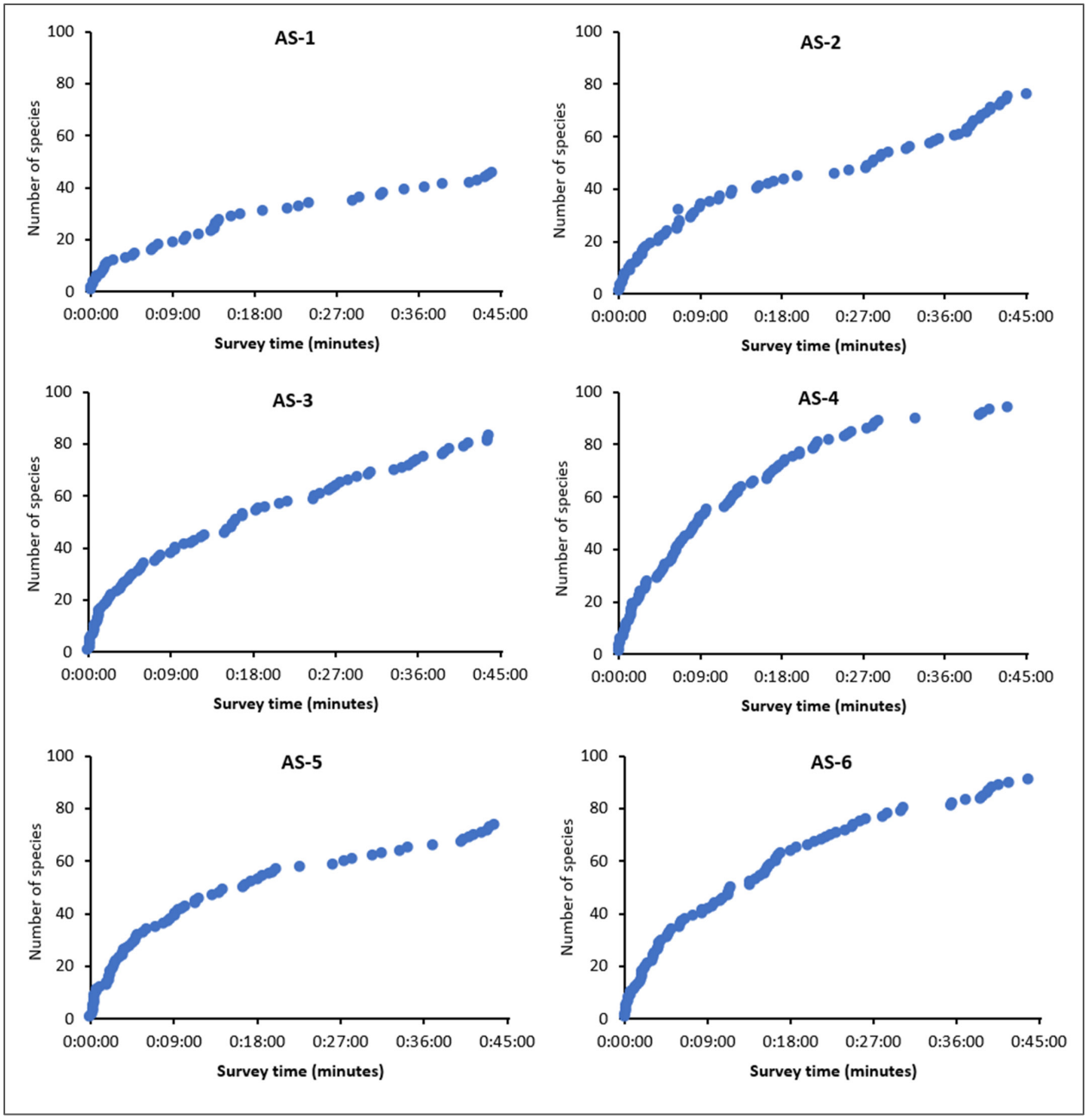


Figure K-2. Species accumulation curves for sites AS-1, AS-2, AS-3, AS-4, AS-5, and AS-6.

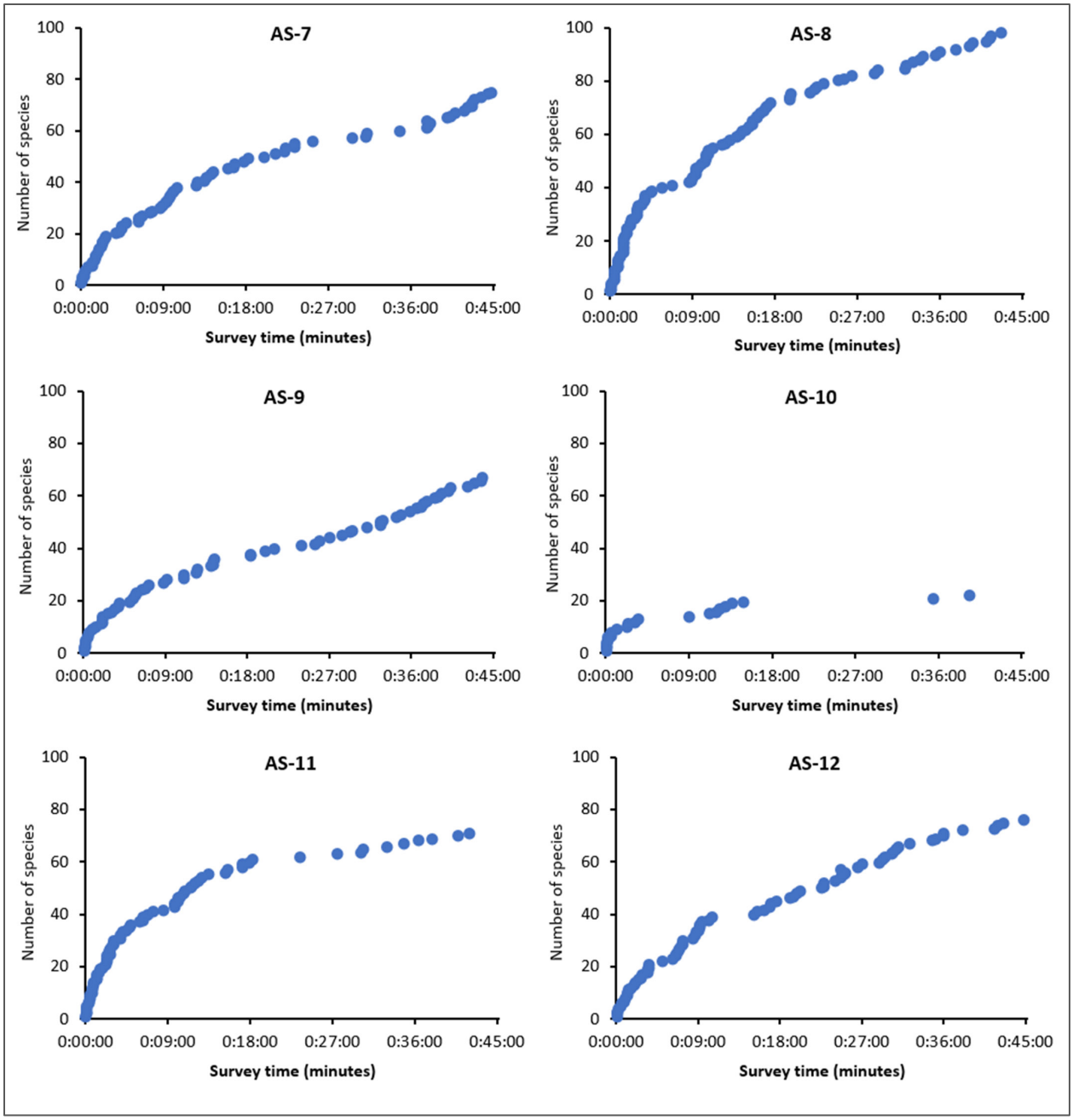


Figure K-3. Species accumulation curves for sites AS-7, AS-8, AS-9, AS-10, AS-11, and AS-12.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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