



# NOAA FISHERIES

## **Ecosystem Sciences Division Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Benthic Surveys, 2019 Update**

Morgan Winston, Courtney Couch, Brittany Huntington, and  
Bernardo Vargas-Ángel



**U.S. DEPARTMENT OF COMMERCE**  
**National Oceanic and Atmospheric Administration**  
National Marine Fisheries Service  
Pacific Islands Fisheries Science Center

NOAA Technical Memorandum NMFS-PIFSC-96  
<https://doi.org/10.25923/ws5s-km69>

February 2020

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NOAA Technical Memorandum NMFS-PIFSC-96

February 2020



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National Marine Fisheries Service  
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**Recommended citation**

Winston W, Couch C, Huntingon B, Vargas-Ángel B. 2020. Ecosystem Sciences Division standard operating procedures: data collection for rapid ecological assessment benthic surveys, 2019 update. NOAA Tech. Memo. NMFS-PIFSC-96, 56 p.

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## **Introduction**

This 2019 document update is intended as a reference and provides guidelines for training, sampling, and data entry for the monitoring of coral populations and benthic communities as part of the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) led by the Ecosystem Sciences Division (ESD) of the NOAA Pacific Islands Fisheries Science Center (PIFSC). The standard operating procedures (SOP) outlined in this document apply to the Pacific RAMP surveys that ESD and its partners conducted in 2019 on the coral reef ecosystems of the main Hawaiian Islands (vessel limitations prevented REA surveys in the Northwestern Hawaiian Islands in 2019). As part of ESD's ecosystem assessment and long term monitoring efforts, coral colonies and the benthic community functional groups are surveyed at Rapid Ecological Assessment (REA) sites selected using a stratified random sampling design. The details of the methods employed are outlined here.

## **Objectives**

The objective of this document is to provide updates incorporated in 2019 to the guidelines and procedures for implementation of sampling design, survey methodology, and data entry for the monitoring of reef coral populations and benthic communities as part of the Pacific RAMP led by ESD (Swanson et al. 2018).

The two primary objectives of the monitoring effort are: (1) to determine the status, trends, and variability of coral populations and (2) to determine the status, trends, and variability in benthic reef coral communities. Measured and generated coral population metrics include density, proportion occurrence, total abundance, size structure, partial mortality, prevalence of coral conditions such as disease and bleaching, and generic and species richness. Coral community metrics include relative abundance (percent cover), frequency of occurrence, and taxonomic composition.



# Methodology

## Description

### *Sampling Design*

Coral abundance metrics are typically heterogeneous and vary in space according to environmental covariates, such as depth, topographic complexity, and patchiness of reef habitats (Smith et al. 2011; Swanson 2011). To account for such variation, a stratified random sampling design (StRS) was applied to more effectively and efficiently sample coral populations across defined strata (Cochran 1977; Swanson et al. 2018).

The stratification scheme for these surveys incorporates (1) three depth categories (shallow: 0–6 m; mid-depth: >6–18 m; and deep: >18–30 m); (2) regional sub-island sectors; (3) reef zone components, including back reef, lagoon, and fore reef. This scheme creates a survey domain that encompasses the majority of the mapped area of reef and hard bottom habitats from 0 to 30 m and provides a mechanism in which to allocate random samples across strata based on the stratum's proportional area and the variance structure of the population within the stratum.

Digital spatial databases of benthic habitats, reef zones, bathymetry, and marine reserve boundaries are integrated within a geographical information system (GIS) framework to facilitate the spatial delineation of the sampling survey domain and strata. A shapefile containing individual grid cells of size 50 m × 50 m containing more than 10% hard-bottom reef habitats is overlaid onto the survey domain. Grid cells are randomly selected as survey sites. In 2018, a single stage sampling scheme was implemented and continued in 2019, such that within each selected grid cell, a fixed area of 10 m<sup>2</sup> is surveyed along a single belt transect.

Since 2013, annual survey effort is determined based on the number of days spent at each island and the number of sites allocated mainly by strata area and variance of target species. Targeted coral species for main Hawaiian Islands included *Porites lobata*, *Porites compressa*, *Pocillopora meandrina*, *Montipora capitata*, and *Montipora patula*.

### *Benthic survey components*

Surveys at each site are conducted within replicate segments (1 m × 2.5 m) spaced along one 30 m belt transect and include the following suite of observations:

- Adult coral colony ( $\geq 5$  cm) abundance, size, partial mortality, and disease/condition
- Juvenile coral colony ( $< 5$  cm) abundance and size
- Benthic cover

### *Adult coral colonies*

Adult coral colonies ( $\geq 5$  cm) are surveyed within four (1.0 m × 2.5 m) segments at 5 m increments along a single 30 m transect in the following manner: 0–2.5 m (segment 0); 5.0–7.5 m (segment 5); 10–12.5 m (segment 10); and 15–17.5 m (segment 15). The combined survey area of the segments is 10 m<sup>2</sup> per site. All colonies whose center falls within 0.5 m on either side of each transect line within each segment, are identified to lowest taxonomic level possible (genus or species), measured for size (maximum diameter to nearest cm), morphology

noted, and assessed for partial mortality and condition. Note that bottom time and/or air limitations on SCUBA may reduce the number of completed segments from four to three, particularly at deep sites where corals are abundant. A minimum of three completed segments is the target.

Partial mortality is estimated as percent of the colony in terms of old dead and recent dead, and the cause of recent mortality (or recent tissue loss) is identified when evident. Colony condition, including disease (i.e., all lesions other than recent tissue loss) and bleaching, is also noted along with the extent (percent of colony affected) and level of severity (on a scale from mild to acute for bleaching). The lowest taxonomic level for coral taxa is genus, except for a select number of species that can be consistently identified to species by all divers conducting the surveys. The species list may change for each survey year depending on the experience and training of the benthic divers conducting the surveys.

### *Juvenile coral colonies*

Juvenile coral colonies (<5 cm) are surveyed within three (1.0 m × 1.0 m) segments along the same transect: 0–1.0 m (segment 0); 5.0–6.0 m (segment 5); and 10.0–11.0 m (segment 10). The combined survey area of the segments is 3 m<sup>2</sup> per site. Juvenile colonies are distinguished in the field by a distinct tissue and skeletal boundary (not a fragment or remnant of larger colony). The size of each juvenile colony larger than 0.5 cm is measured by recording the maximum diameter to the nearest 0.5 cm. Similar to adult corals, juvenile corals are identified to genus given that in most cases, juvenile corals will likely be too small to be positively identified to the species level.

### *Benthic cover*

Estimates of benthic cover are generated from benthic substrate photographs (hereafter referred to as photoquadrats), which are taken along the 30 m transect at each site. Photoquadrats are collected at 1 m intervals along one side of the transect line, starting at the 1 m mark, for a total of 30 photoquadrats per site. The benthic photoquadrat imagery is analyzed using the web-based annotation tool CoralNet (Beijbom et al. 2015), which places 10 random points per photo. The benthic elements falling directly underneath each point are identified to three functional group levels: Tier 1 (e.g., hard coral, soft coral, macroalgae, turf algae), Tier 2 (hard coral by morphology: massive, branching, foliose, encrusting, etc.), and Tier 3 (e.g., hard coral by genus and morphology; macroalgae by genus and grouped genera). The standard operating procedures for the analysis of benthic substrate imagery can be accessed at Lozada-Misa et al. (2017), which includes the codes for Tiers 1, 2, and 3.

## **Field Implementation**

### *Equipment*

Survey dives are conducted from small (6–9 m) boats to the pre-selected, random stratified dive sites. Each small boat is equipped with standardized survey gear.

## *Gear required for benthic survey operations*

### Topside

- GPS unit loaded with pre-selected, random stratified sites
- REA site list
- REA site map
- Dive and Navigation Information datasheet
- Randomized list of depths per depth strata

### Per Buddy Pair

- One 30 m transect tape
- Surface marker buoy with 50 m dive reel

### Per Individual Diver

- Benthic survey data sheet on underwater slate
- Region specific field “cheat sheet” for coral taxonomic identification
- Pencils
- Rulers for adult and juvenile coral colony size measurements
- 0.5 m stick (PVC stick marked at 5 cm intervals)
- 1 m monopod (PVC collapsible stick for photoquadrats)
- Underwater digital camera
- Gray card for white balancing the camera

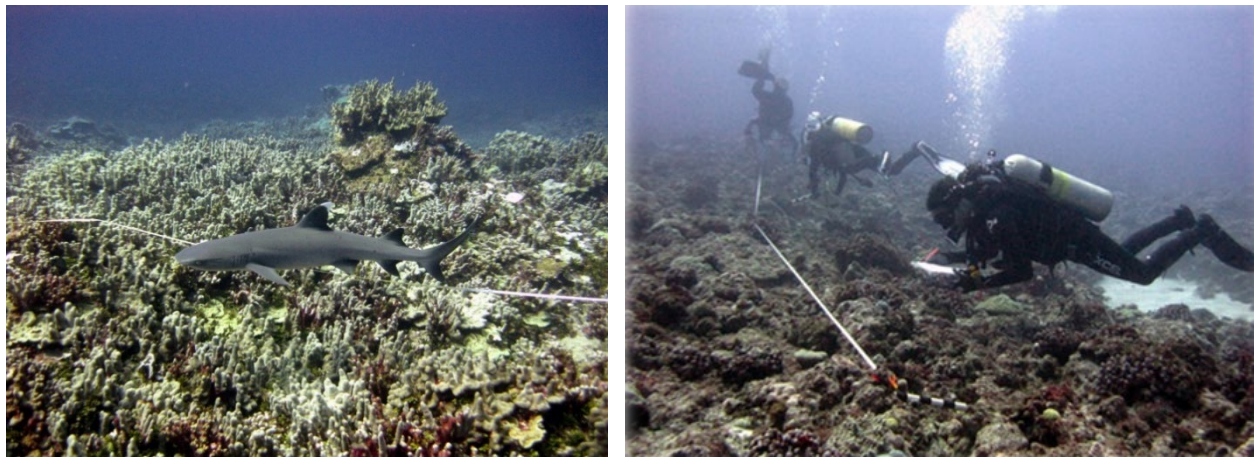
## *Site Selection and Assessment*

Prior to the start of each mission, random survey locations (REA sites) are generated in GIS and field survey maps are created. Waypoints are randomly placed within each REA site (50 m × 50 m grid cells), named with a site ID (a standard 3-letter island code and a 3 or 4 number site code), and uploaded into the benthic team GPS instruments.

Upon arrival at the REA site, a small boat depth sounder is used to identify the depth of the random point within the site. To avoid biasing the placement of the transect tape within the site should a depth contour exist, divers must place the transect tape at the depth from the depth sounder reading. If possible, divers should inspect the site from the surface by snorkeling to determine whether the substrate at the survey location is reef habitat. If it is not possible to inspect the site with these methods, divers should attempt to drop directly from the waypoint and descend to the predetermined depth. **The area to be surveyed must contain a minimum of 25% hard bottom habitat** (Figure 1). Do not conduct surveys in sand habitats unless the hard bottom substrate has just a light dusting cover of sand. If the benthic habitat is sand, sediment, or does not contain a minimum of 25% hard bottom habitat, the divers should swim in one direction for one minute to try to find suitable habitat within the depth range of target stratum. If no suitable hard bottom is found (Figure 1), the site must be aborted, and the team relocate to the next site. Divers should not swim toward a site that “looks” good (i.e., more coral). Record the GPS coordinate for the unsuitable site on the Dive and Navigation Information Sheet (Figure 3) and list as unsurveyable, either as sand, *Halimeda* flat, too deep, or other.

If the site depth needs to be adjusted (for example: the actual depth at the target waypoint is in the wrong depth stratum), divers should refer to the list of random depths for each depth strata rather than choosing their own depth.

Although the divers drop on the random waypoints for each site, the location of the actual survey may shift due to incorrect depth (as aforementioned) or sea conditions. Therefore, it is critical to record the latitude and longitude of the actual location from which surveys were executed with the handheld GPS unit. The small boat coxswain records the site waypoints while the divers are conducting the survey. Record the GPS coordinates for site locations on the Dive and Navigation Information Sheet (Figure 3).



**Figure 1. Examples of suitable habitat.**



**Figure 2. Examples of unsuitable habitat: (a) Halimeda flat, (b) sand.**

## Dive and Navigation Information

The Dive and Navigation Information form (Figure 3) is used to record descriptions of benthic REA sites surveyed during each diving operation day. A new sheet must be filled out each day as dives are completed. The sheet is turned in to the data manager at the end of each dive day. These sheets serve as permanent records. The following information is recorded:

- **Island:** Island or atoll being surveyed (e.g., French Frigate Shoals or Tutuila Island)
- **Local Time Zone (example):** PST (Pacific Standard Time)
- **Local Time = UTC  $\pm$  x** (e.g., x equals +10 hours in the MHI/NWHI; check with the data manager to obtain appropriate value of x per island/jurisdiction)
- **Vessel:** Name of the dive boat (e.g., HI-2, HI-3)
- **Survey Team:** Initials of divers conducting surveys
- **Cruise ID:** The 6-character code for the current cruise (e.g., HA-11-02)
- **Survey Year:** The current year (e.g., 2011)
- **Local Date:** The date at current location
- **Local Time:** The time at current location
- **Site ID:** The code for current site (e.g., TUT-001)
- **GPS Unit #:** Each dive team has a GPS with an assigned number (e.g., Benthic A).
- **Waypoint #:** The name of the waypoint programmed in the GPS corresponding to the dive site. Once the site is initially marked in the GPS, the name should be changed from the number automatically generated by the GPS unit (e.g., 014) to the Site ID name (e.g., TUT-001).
- **Dive #:** Cumulative site number of the day (e.g., 1, 2, 3)
- **Habitat Type:** Either taken from the Benthic Data Sheet (Figure 4), or, if the site is determined to be unsurveyable because of unsuitable habitat or depth, the designations Sand, *Halimeda*, too deep, or Other will be used. The habitat codes are listed at the bottom of this form.
- **Minimum and Maximum Depth:** These are minimum and maximum depth of the transect, in feet.
- **Latitude and Longitude:** Geographic coordinates for the position taken by the coxswain with the GPS located directly over the dive site once the divers have descended and set the surface buoy. This position should be taken directly from the GPS.
- **Zone Type:** Forereef (FRF), backreef (BRF), or lagoon (LAG)
- **Depth Category:** Recorded as shallow (S), mid-depth (M) or deep (D).
- **Diver Initials:** Initials of who dove at the survey site
- **# Adult Seg:** The number of adult segments surveyed along the transect
- **# Juv Seg:** The number of juvenile segments surveyed along the transect
- **Repeat Seg #:** (*optional*) Segment number if a segment was surveyed twice (to compare variability among divers).
- **SfM Camera #:** (*optional*) If a Structure from Motion (SfM) photomosaic survey was conducted, which camera was used.
- **SfM Photographer:** (*optional*) If SfM survey was conducted, note the initials of the diver.
- **Reef Complexity:** (*optional*) If SfM survey was conducted, visual estimate of structural complexity of the reef, either low (L), medium (M), or high (H).



### *List of tasks*

At each site, the following tasks should be completed by each dive team:

- Deploy transects
- Identify habitat type
- Record minimum and maximum depths in feet for each transect area
- Take site photographs
- Conduct ecological surveys: Adult corals and juvenile corals
- Take photoquadrats for benthic cover estimates

The separation of tasks among the dive team may vary, but all members should work cooperatively to survey each site as efficiently and safely as possible.

The 30 m transect line should be deployed along the depth contour targeting the waypoint depth as read from the boat's depth sounder.

### *Recording site and survey data*

Benthic survey and site characterization data are recorded underwater on the benthic survey data sheet (Figure 4). At the top of the data sheet, there are specific sections to record the diver names or initials, the date, the island and habitat types, site notes, site name, the minimum and maximum depth (ft) of the transect. There is additional space for comments at the bottom of the data sheet.

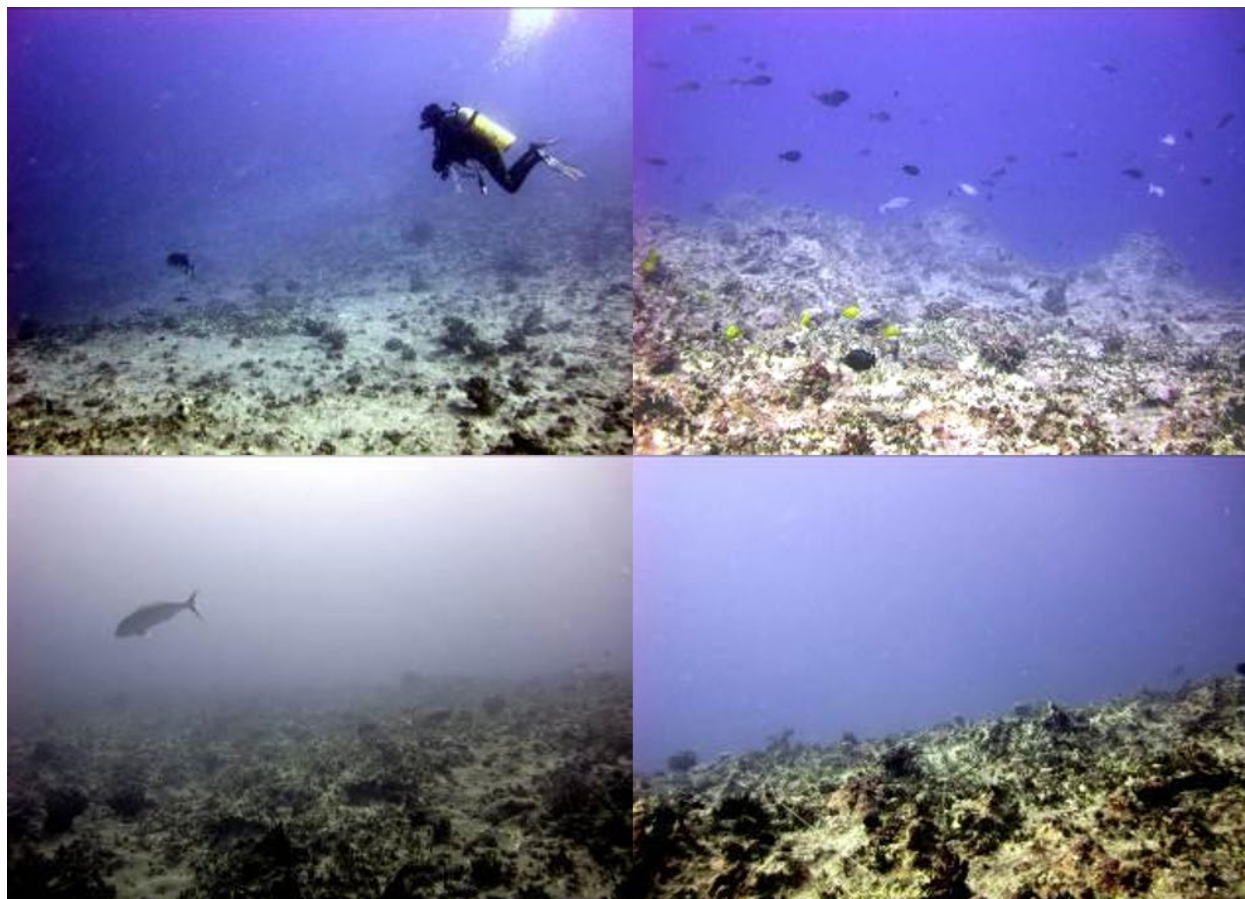
BENTHIC CORAL DATA SHEET						Observer:				Date:			
Location/Habitat:						Site Notes:							
Site:						Min Depth (ft):				Max Depth (ft):			
Col	T	Seg	Taxon	Morph	L (cm)	W (cm)	%Dead	%Recent	RD cause	Condition	Ex	Sv	Comment
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3													
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**Figure 4. Sample benthic survey data sheet used underwater to record coral colony survey and site characterization data.**



### ***Site photos***

The primary photographer should take a minimum of four landscape-oriented photos of the site (Figure 5). These photos are taken from within the general transect area, typically at evenly spaced intervals as the diver rotates 360°. More photos or video may be taken as needed to provide a permanent record of the overall characteristics or unique features of the site.



**Figure 5. Examples of site photos taken within a transect area.**

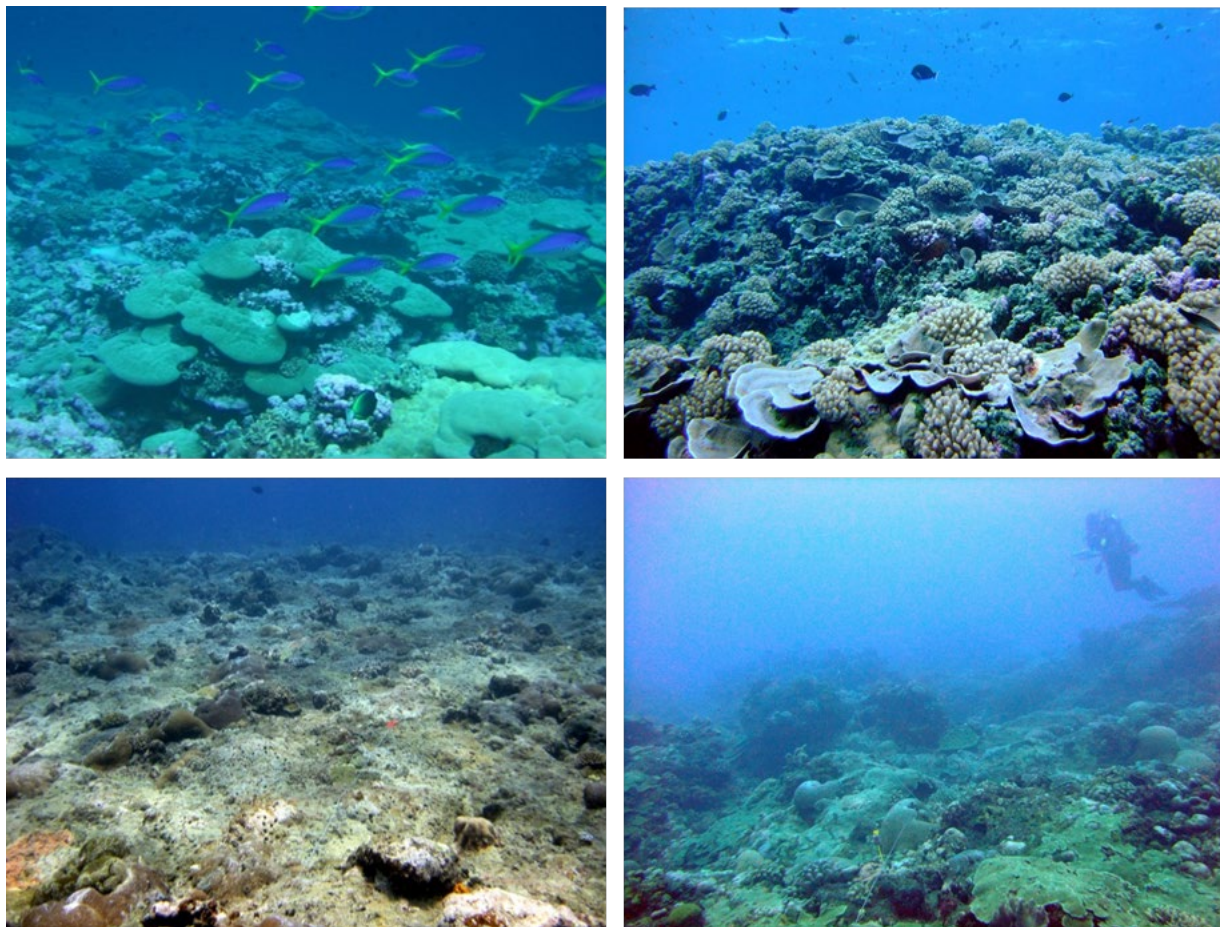
### ***Habitat types***

Reef habitat type describes the general survey area (50 m × 50 m grid cell, 2500 m<sup>2</sup>). This is characterized by selecting the most appropriate choice that describes the habitat encompassed by the general survey area from the following ten categories (Table 1) that have been modified from Kendall and Poti (2011). Because of the great variety of reef habitats comprising ecosystems around the many Pacific islands surveyed by the ESD, a survey area may not fall neatly into one of these categories. Select the category with a definition that fits the majority of the habitat.

**Table 1. Reef habitat types and codes.**

<b>Habitat Type</b>	<b>Code</b>
Aggregate reef	AGR
Aggregate patch reef	APR
Aggregate patch reefs	APS
Pavement	PAV
Pavement with patch reefs	PPR
Pavement with sand channels	PSC
Boulder/rock	ROB
Reef rubble	RRB
Spur and groove	SAG

1. Aggregate reef (AGR): Hard-bottom substrate with corals; also referred to as continuous or consolidated reef (Figure 6). This habitat type may have high relief but lacks the sand or pavement channels of spur and groove habitat. Most reefs that do not obviously fall in other types may be recorded as aggregate reef.



**Figure 6. Examples of aggregate reef.**



2. Aggregate patch reef (APR): Coral formations that are isolated from other coral reef formations by sand or other habitats and have no organized structural axis relative to the shore or shelf edge (Figure 7). They are often characterized by a circular or oblong shape with vertical relief of one meter or more in relation to the surrounding seafloor. This category of reef is larger or equal in size to the general survey area of  $50\text{ m} \times 50\text{ m}$ . This habitat type is most commonly noted in lagoon (e.g., Rose Atoll) or back reef areas (e.g., in northern Pearl and Hermes Atoll and Midway Atoll).



**Figure 7. Aerial imagery of an aggregate patch reef in Kaneohe Bay, Oahu, Hawaii. Photo by J. Levy, University of Hawai'i Applied Research Laboratory.**

3. Aggregate patch reefs (APS): This category is for patch reefs that have the same defining characteristics of an Aggregate (individual) Patch Reef, but are smaller in size. Therefore, multiple patch reefs are found within the 50 m  $\times$  50 m survey area (Figure 8).



**Figure 8. Examples of aggregate patch reefs habitat.**

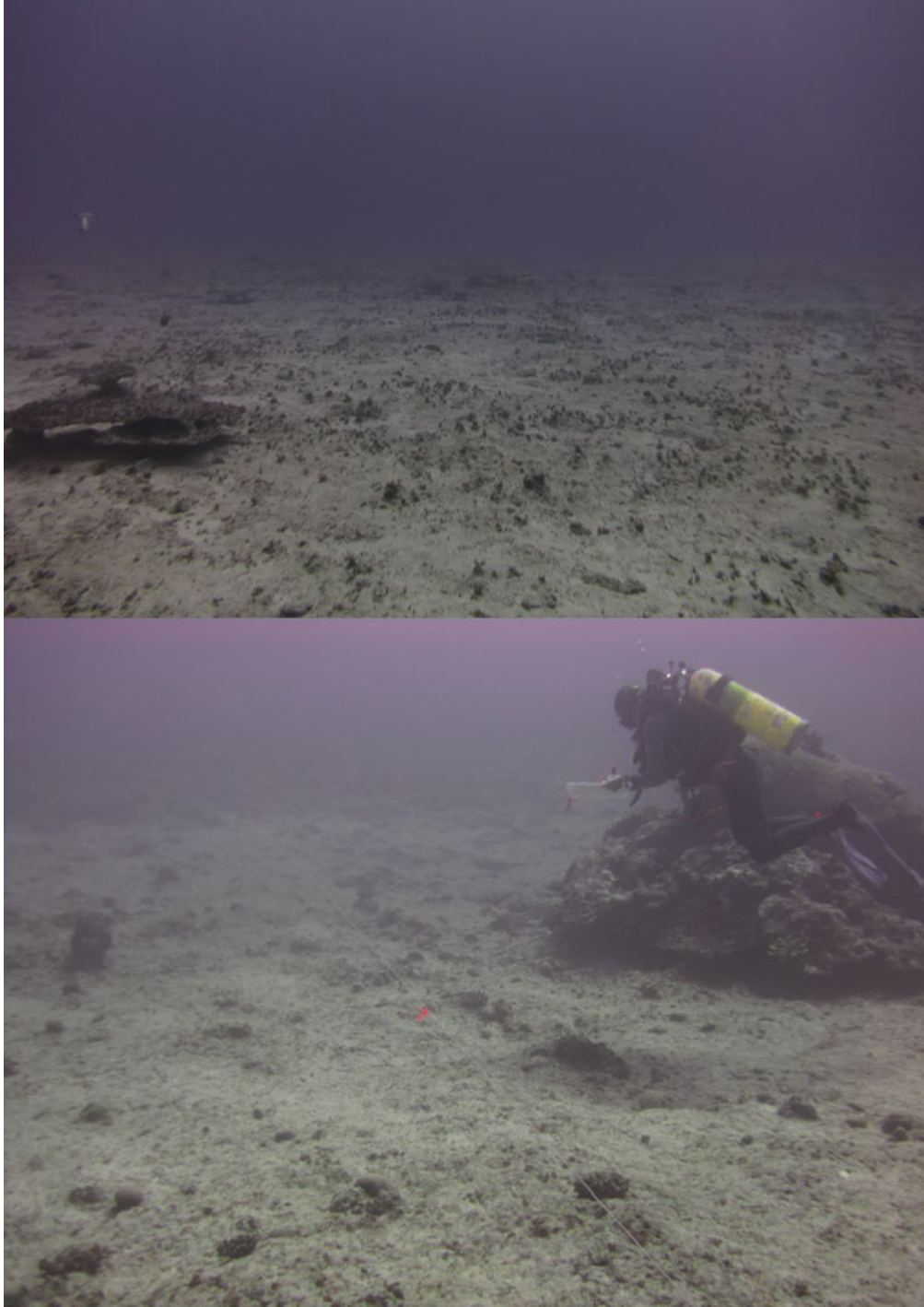
4. Pavement (PAV): Flat, low-relief, solid rock in broad areas often with partial coverage of sand, algae, hard coral, gorgonians, zoanthids, or other sessile invertebrates that are dense enough to begin to obscure the underlying surface (Figure 9).



**Figure 9. Example of pavement habitat. Photo by D. White, Hawai'i Department of Land and Natural Resources.**



5. Pavement with patch reefs (PPR): Areas of pavement with occasional patch reef formations that make up less than 10% of the general area (Figure 10).



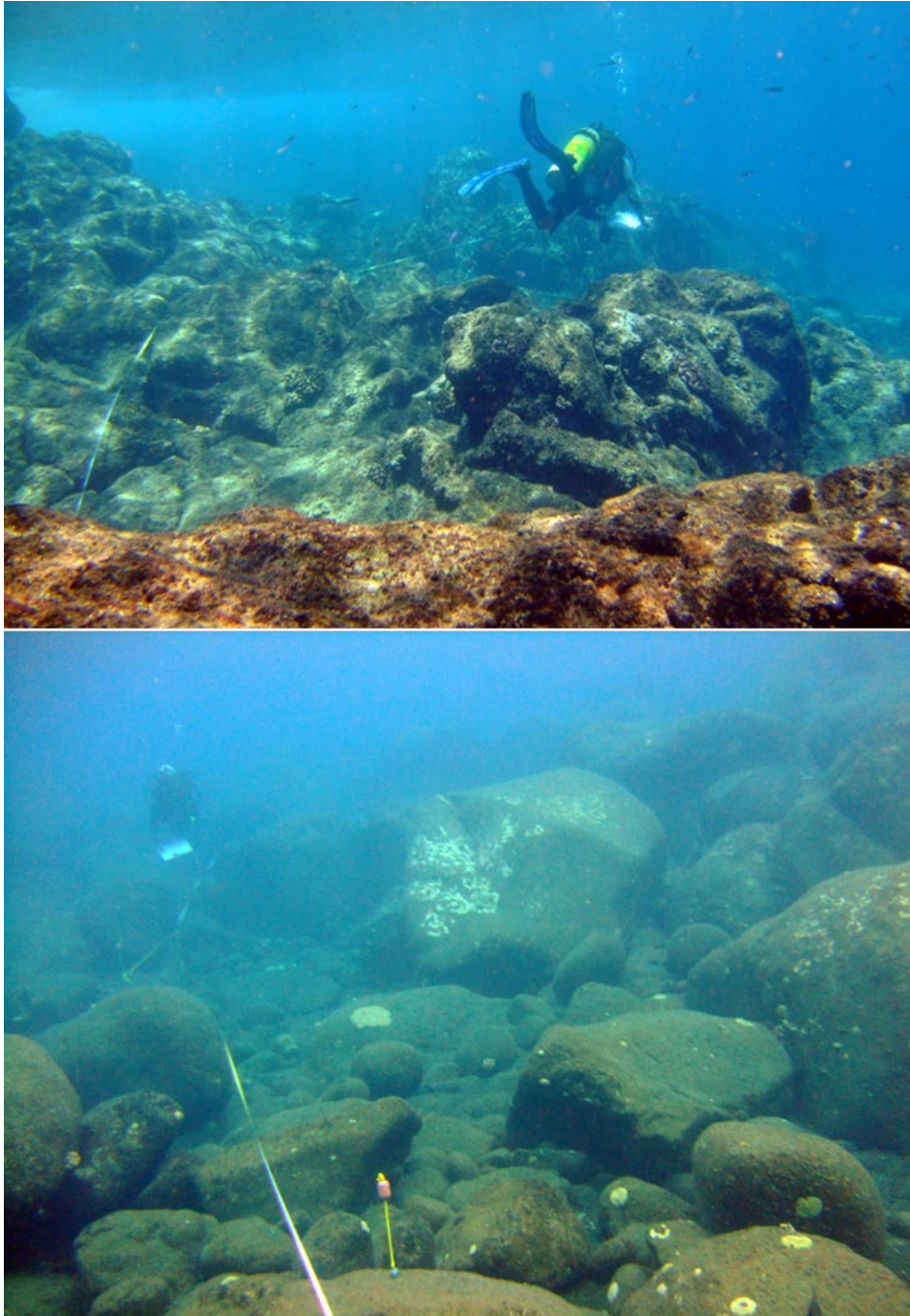
**Figure 10. Examples of pavement with patch reefs habitat.**

6. Pavement with sand channels (PSC): Habitats of pavement with alternating sand/surge channel formations that are perpendicular to the shore, bank, or shelf (Figure 11). The channels of this feature have low vertical relief relative to spur and groove formations and are typically erosional in origin. This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.



**Figure 11. Examples of pavement with sand channels habitat.**

7. Rock/Boulder (ROB): Large, irregularly shaped carbonate blocks or boulders or volcanic rock often extending offshore from the island bedrock or headlands. This habitat type can also occur as aggregations of loose rock fragments that have been detached and transported from their native beds. Individual boulders often range in diameter from 0.25 to 3 m, with very little benthic coral cover present (Figure 12).



**Figure 12. Examples of rock/boulder habitat.**

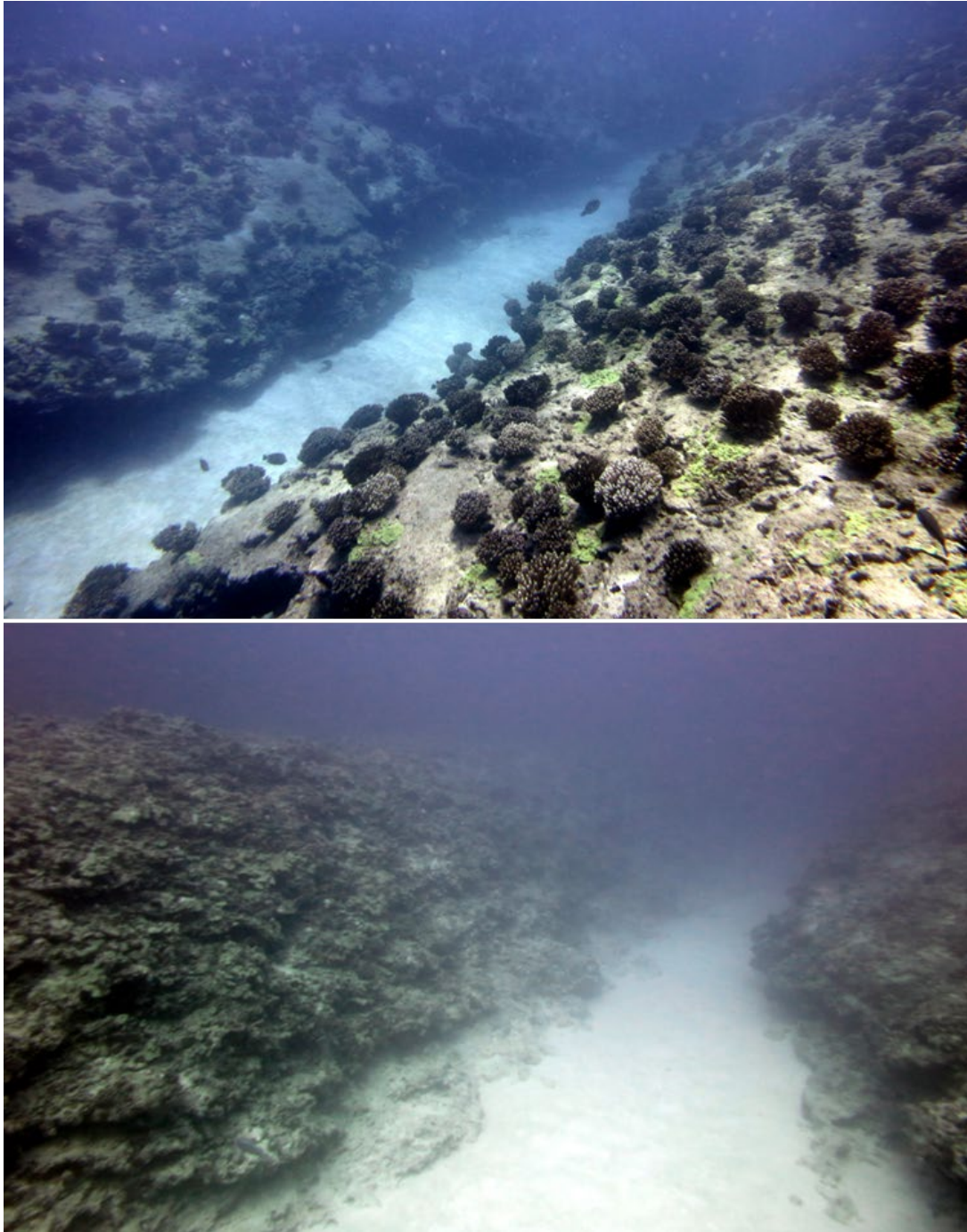


8. Reef rubble (RRB): Unconsolidated small (<10 cm) fragments of coral skeletons or reef rock often colonized with filamentous or other macroalgae (Figure 13). This habitat often occurs landward of well-developed reef formations in reef crest or back reef zones.



**Figure 13. Examples of rubble habitat.**

9. Spur and groove (SAG): Habitat with alternating sand and coral formations that are oriented roughly perpendicular to the shore, bank, or shelf (Figure 14). The coral formations (spurs) of this habitat type typically have a high, vertical relief relative to pavement with sand channels and are separated from each other by 1–5 m of sand or hard-bottom (grooves) substrate, although the height and width of these elements may vary considerably.

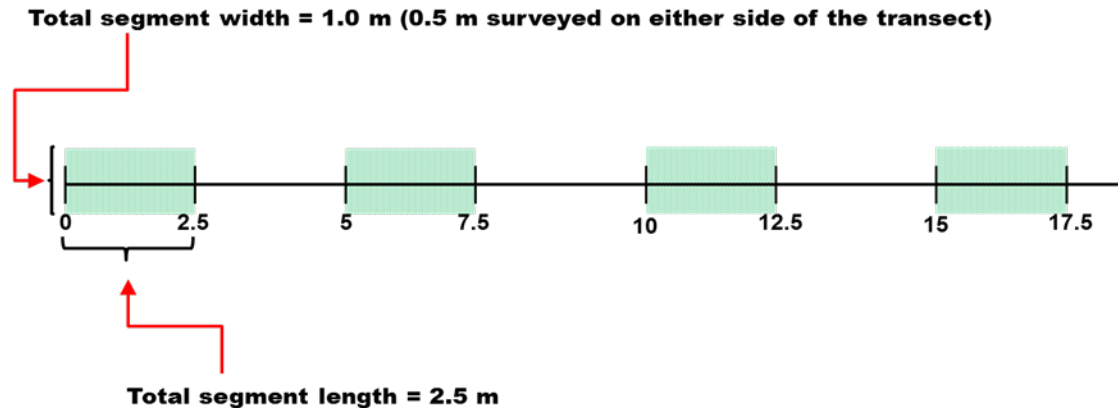


**Figure 14. Examples of spur-and-groove habitat.**

### Adult coral surveys

Surveys of adult coral colonies are conducted within four, 1.0 m wide  $\times$  2.5 m long segments centered along the 30-m transect (Figure 15), where each segment is numbered as follows:

**Segment 0** = 0–2.5 m; **Segment 5** = 5.0–7.5 m; **Segment 10** = 10–12.5 m; **Segment 15** = 15–17.5 m.

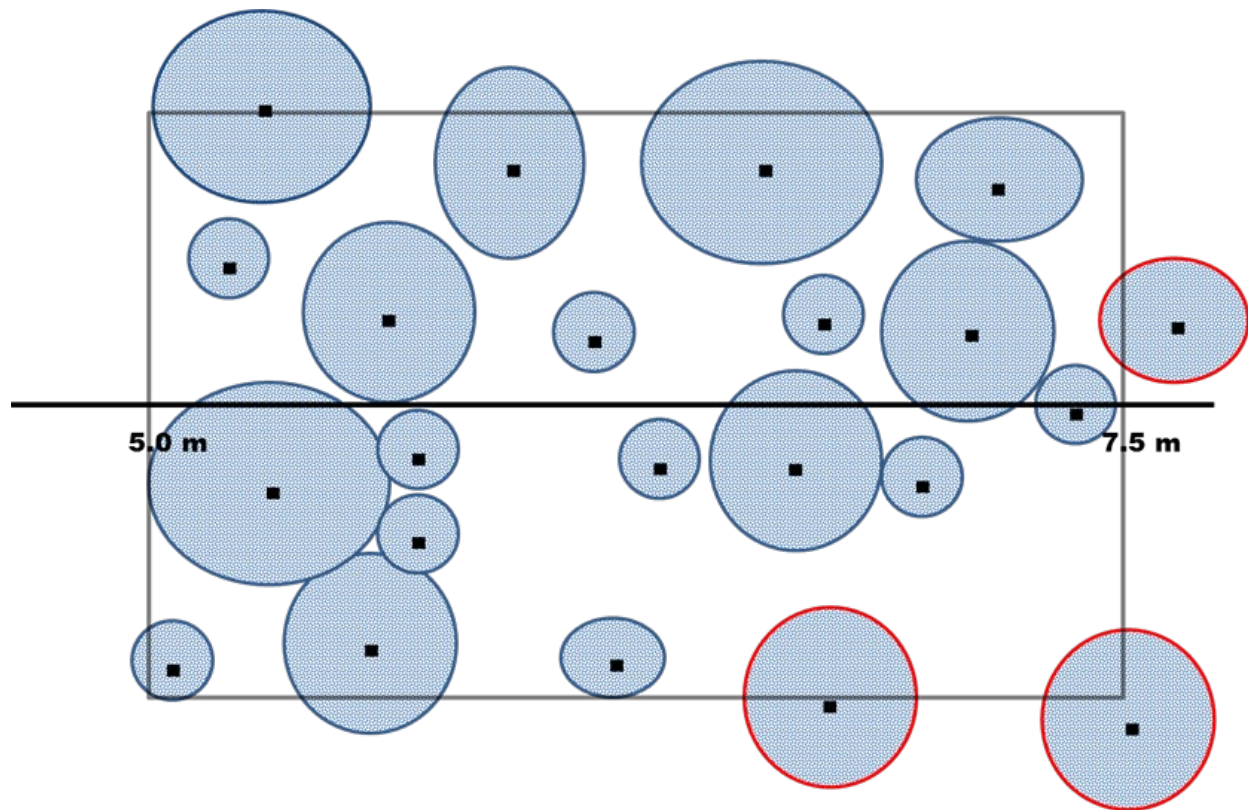


**Figure 15. Example of the four survey segments on a 30 m transect.**

Divers should survey adjacent segments to maintain a safe distance from their dive buddy. If a diver cannot completely survey the entire segment area in the time allotted (e.g., due to limited bottom time), the dimensions of the partial segment area survey will need to be recorded along with the coral colonies present.

Only adult coral colonies ( $\geq 5$  cm) whose center is found within the boundaries of the segment are included in the survey (Figure 16). However, large colonies whose center falls outside the segment but occupy more than 75% of the total segment are also counted. All Scleractinian coral species are included in these surveys, as well as the hydrozoan “fire corals” (*Millepora* spp.) and the octocoral “blue coral” (*Heliopora coerulea*).





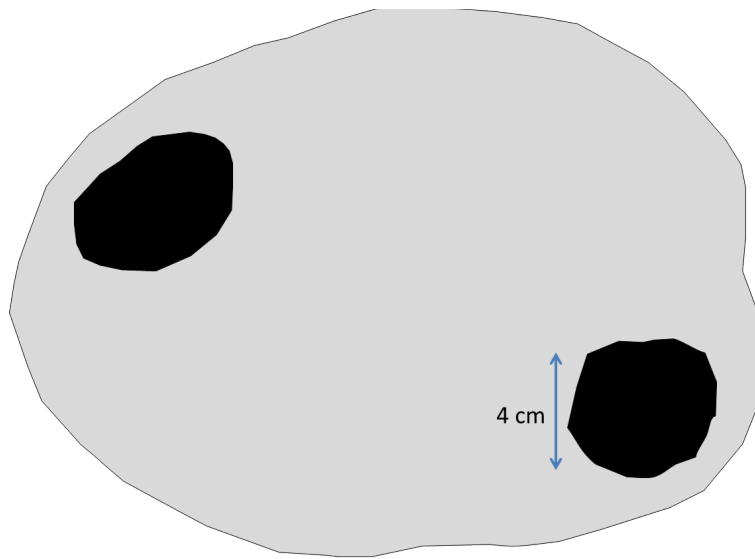
**Figure 16. Diagram to show an example of the center rule used to survey coral colonies. Modified from Zvuloni et al. (2008).**

#### ***Individual colony determination***

Due to partial mortality, identification of an individual colony can be difficult. The following considerations are used to determine an individual colony:

- 1) Are there pieces of live tissue on a common skeletal structure?
- 2) Are the pieces of tissue similar in color and polyp form?
- 3) Are the pieces of live tissue more than 10 cm apart?

If live tissue pieces are on a common skeletal structure, similar in color and polyp form, yet more than 10 cm apart, they are still considered as the same colony (Figure 17). If the live tissue pieces are not on a common skeletal structure and more than 10 cm apart, but similar in color and polyp form, they are considered different colonies. If the pieces of tissue are not similar in color and polyp form, they are considered different colonies, regardless of skeletal structure and the distance between pieces.



**Figure 17. Schematic diagram of a coral colony with live tissue pieces represented by black areas and the previous colony margin represented by the grey area.**

*Notes on remnant and fragment colonies:* Coral fragments that are broken and dislodged from the substrate should be recorded as such (note “fragment” on the datasheet under the “Comment” column). Coral tissue remnants that are attached, but clearly were part of a larger colony for which the original colony borders cannot be identified should be recorded as a remnants (note “remnant” on the datasheet). These colonies are likely non-reproductive but have been shown to have similar growth rates as the intact adult tissue. Both fragments and remnants can be smaller than 5 cm, yet must be included in the adult survey data since they cannot be defined as juveniles. By distinguishing juveniles from small colonies resulting from fission, estimates of juvenile abundance are improved.

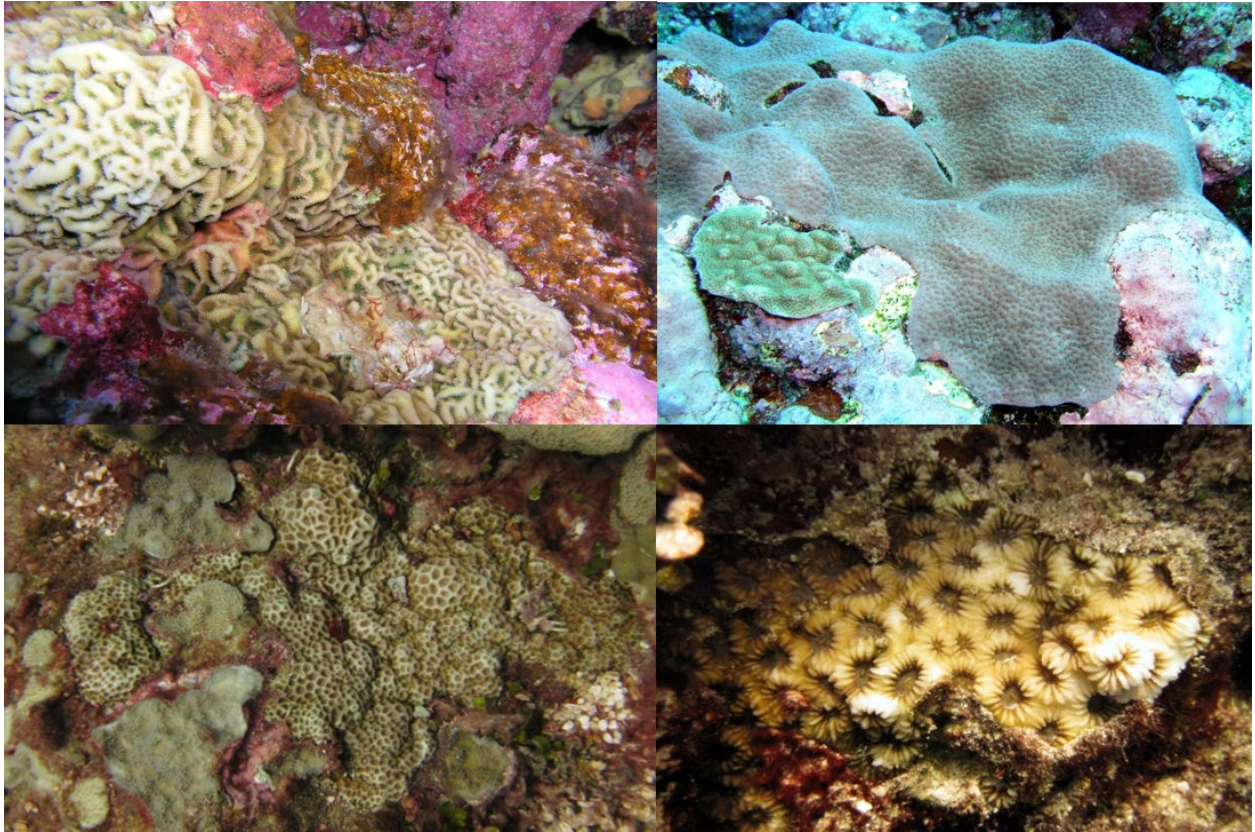
### ***Morphology***

To model the reproductive potential of coral populations, morphological (MORPH on datasheet) identification is critical in converting empirical length measurements from the field surveys to colony surface area. This category includes 11 simplified versions of colony growth morphologies and geometric shapes (Table 2). Morphologies may not always fit neatly into one of these 11 categories; however, the one which best describes the general shape of the colony should be recorded.

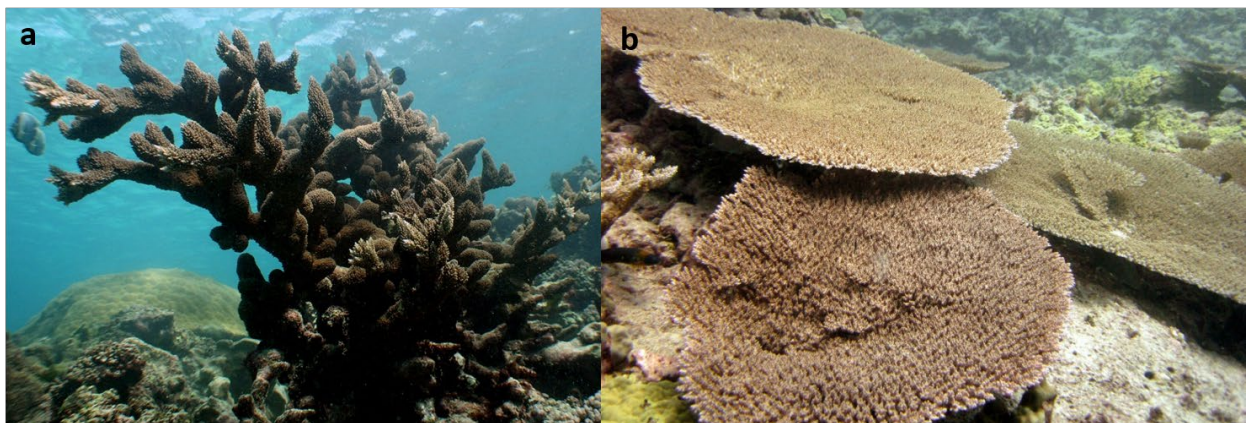
**Table 2. Morphology categories identified during field surveys of adult coral colonies.**

<b>Morphology</b>	<b>Code</b>	<b>Description</b>
Encrusting (mounding)	EM	Adheres to a benthic substrate (e.g., ledge); “frosting on a cake”; this category also includes colonies that are encrusting inverted. <i>Note: “encrusting flat” was merged into this category for 2019.</i>
Mounding	MD	Solid and similar in shape in all dimensions; ellipsoid—small or large, sometimes spherical
Plating	PL	Forms simple plate extending outwards from the benthic substrate, akin to the shingles on a roof, multiple plates on a larger structure (“shingles on a mound”), or vertically oriented bifacial plates. <i>Note: “bifacial plates” was merged into this category for 2019.</i>
Laminar Columnar	LC	Combination of laminar (tiers of flat, encrusting plates) and columnar morphologies; multiple plates on a larger structure with columns protruding from the top; “candles on a tiered birthday cake”; common for <i>Porites rus</i> and <i>Montipora capitata</i> .
Foliose	FO	Plates that form whorls—usually multiple plates, “a head of lettuce.”
Branching	BR	Branches present; “fingers.”
Knobby	KN	Stubby branches; “knuckles.”
Columnar	CO	Forms columns of stumps that may or may not share an encrusting common base like branching corals generally do; columns are considered to be structurally larger in length than width. <i>Note: “encrusting columnar” was merged into this category for 2019.</i>
Table	TB	Forms a table with one central leg attached to the substratum, common for <i>Acropora</i> spp. such as <i>A. cytherea</i> .
Mounding lobate	ML	Mounding, vertically oriented lobes or “pork chops”; common for <i>Pavona duerdeni</i> .
Disc (free living)	FR	Not attached to any substrate (except in the juvenile stage; e.g., <i>Lobactis</i> sp.) including species with forked axial furrows becoming Y, T, or X shaped.





**Figure 18. Example of encrusting mounding (EM) coral morphology.**



**Figure 19. Example of (a) branching and (b) table coral morphologies.**



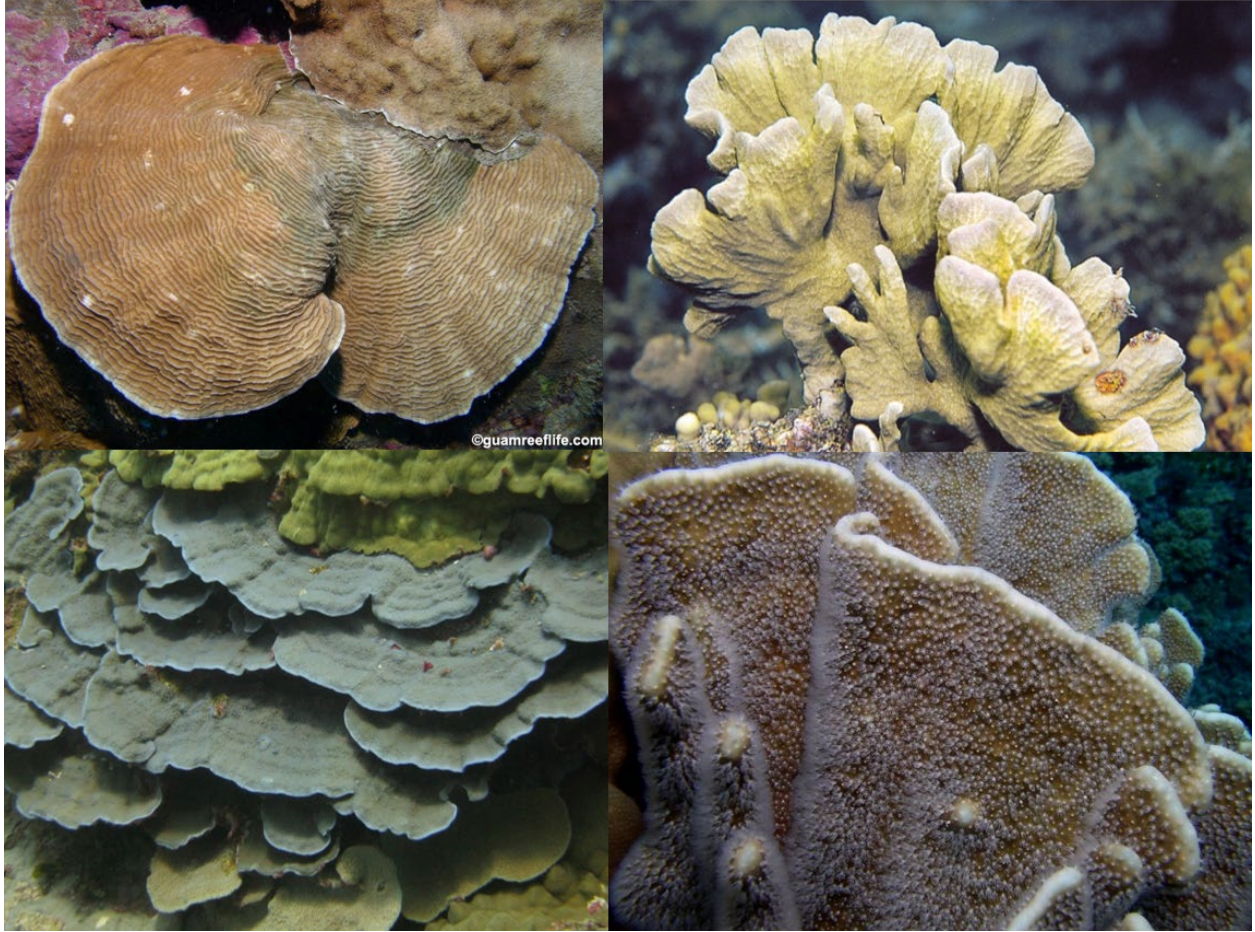
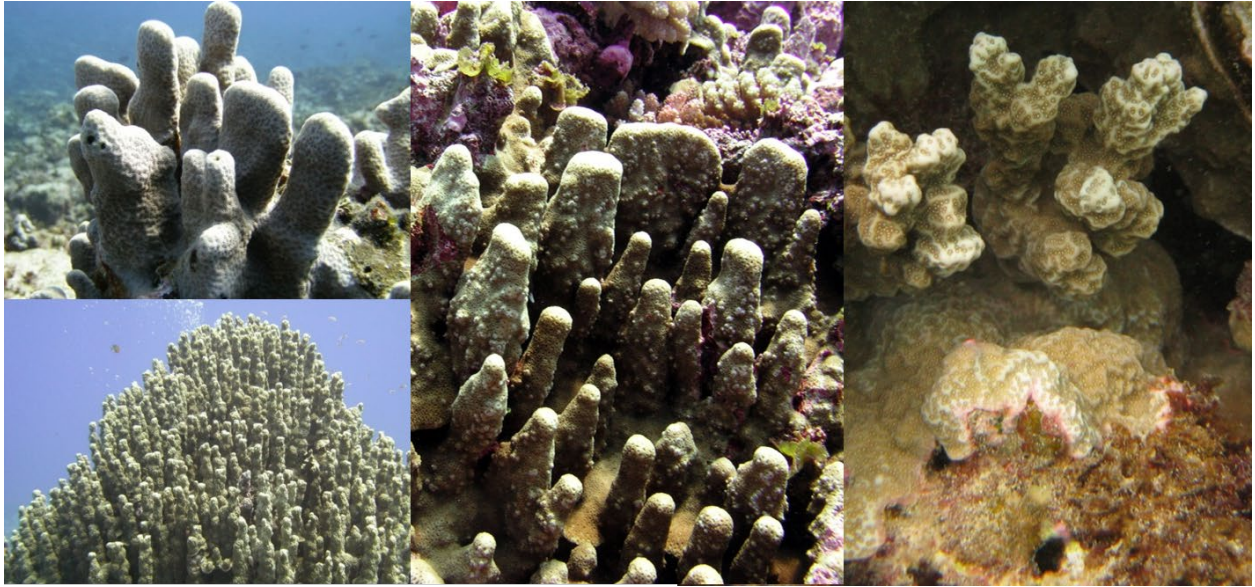


Figure 20. Example of plating coral morphology. *Guamreeflife.com* and *NOAA* photos.

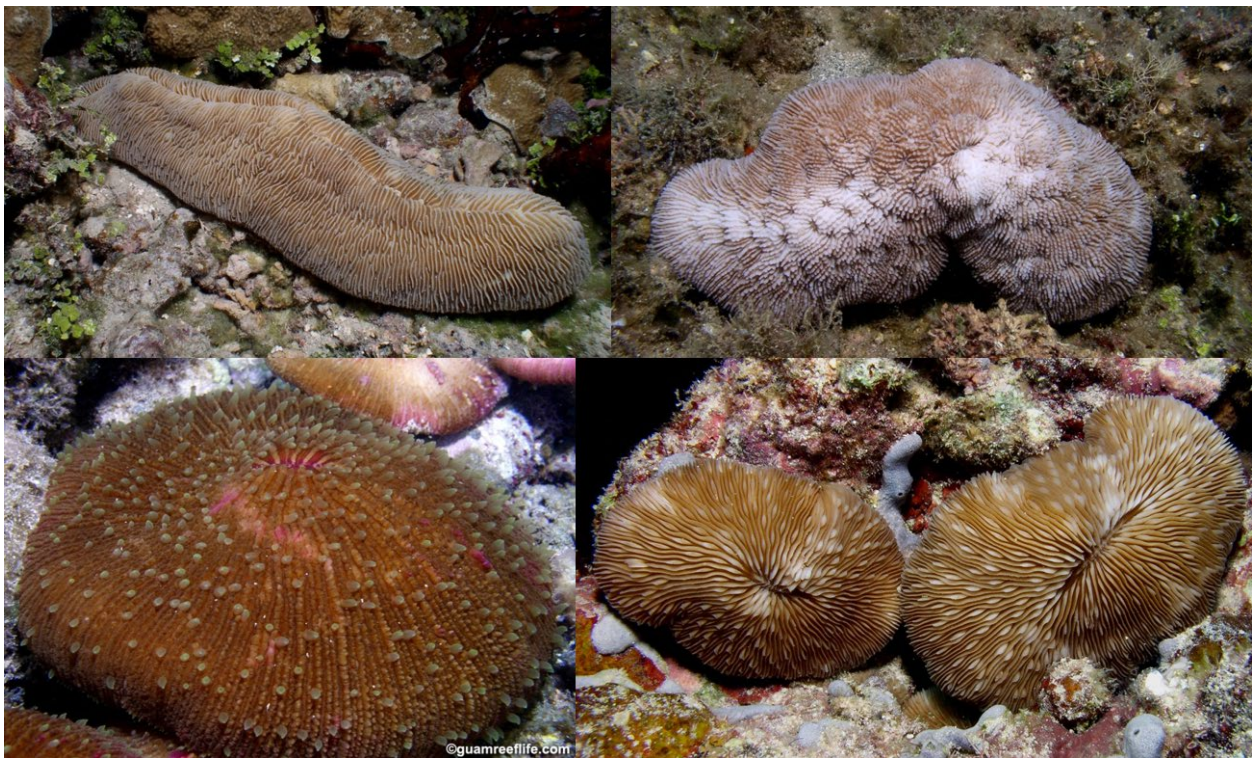


Figure 21. Example of mounding coral morphology.





**Figure 22. Example of columnar coral morphology.**

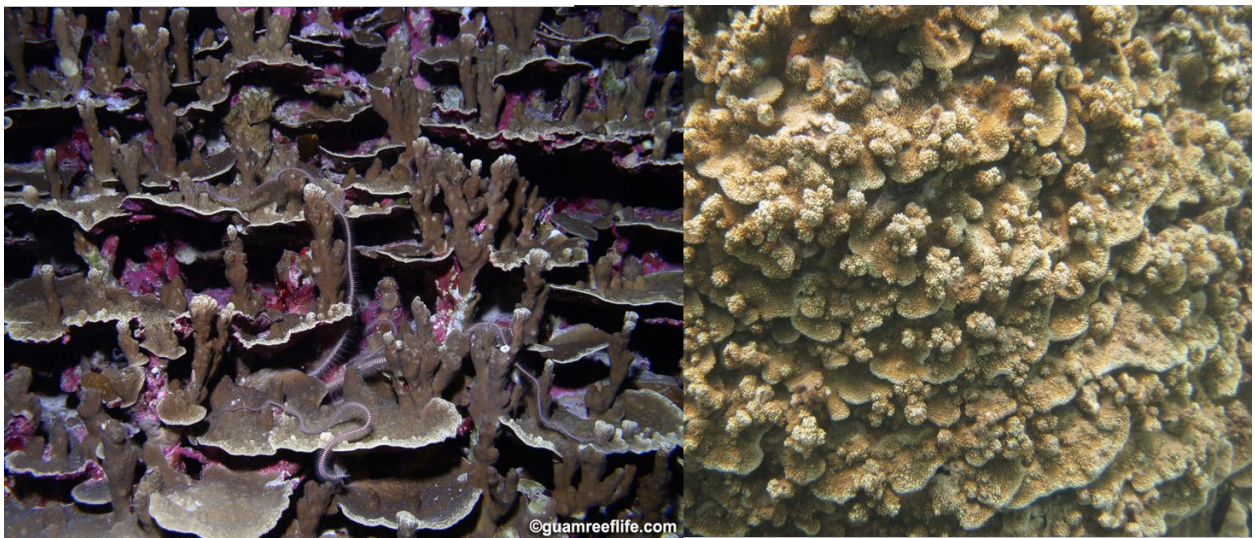


**Figure 23. Example of free living coral morphology.**



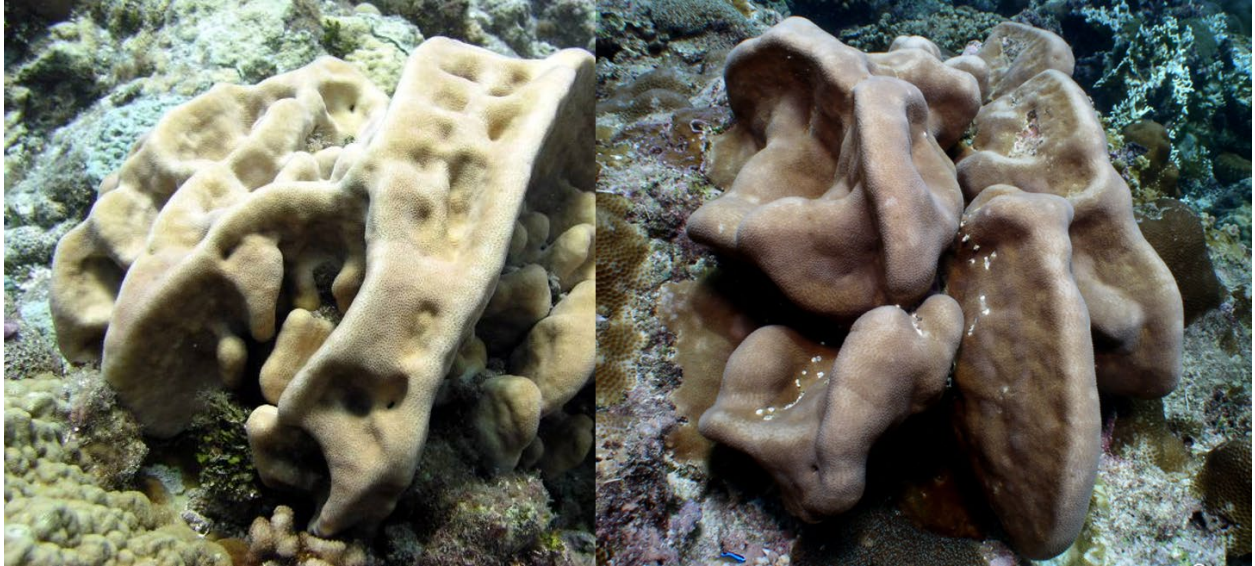


**Figure 24. Example of knobby coral morphology.**



**Figure 25. Example of laminar columnar coral morphology.**





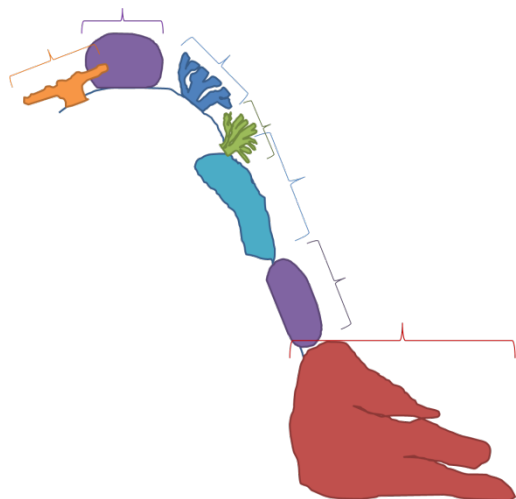
**Figure 26. Example of mounding lobate coral morphology.**



**Figure 27. Example of foliose coral morphology.**

### **Measurement of colony size**

The length of an entire adult colony (including partial mortality) is measured across the maximum diameter to the nearest centimeter (1 cm) (Figure 28). The diameter must be measured with respect to colony growth orientation rather than from a planar perspective. For juveniles only, the width of the colony is taken as the maximum distance perpendicular to the length of the colony.



**Figure 28. Schematic of maximum coral diameter measured depending on the orientation of various coral morphologies.**

### **Partial mortality**

Partial mortality is classified as either ‘old dead’ or ‘recent dead’ and estimated on each colony as a percent of colony surface area using the following criteria: to the nearest 1% for mortality ranging >0–10% and >90–100%; and to the nearest 5% for mortality ranging >10–90%. If a colony is entirely dead (in any combination of old dead and recent dead), **do not measure the colony**.

Old partial mortality (“% Dead” on datasheet; Figure 4) is defined as the non-living portion of a colony where the corallite structures are either gone or covered over by fouling organisms that are not easily removed. This portion of the colony is where the live tissue is presumed to have died within the last few months to years or longer. The cause of old dead mortality is rarely known and therefore not recorded.

Recent dead (“% Recent” on datasheet; Figure 4) is defined as the non-living portion of a colony in which the corallite structures are still intact (unless freshly bitten by a fish or abraded), and the exposed skeleton is either stark white or has only a very thin layer of sediment, biofilm (i.e., bacteria), diatoms, or tiny turf algae.

The cause of recent dead (“RD Cause” on datasheet; Figure 4) is recorded, even if it must be recorded as unknown. There are six general causes of recent mortality: disease, predation, overgrowth, sediment, physical damage, and unknown (Table 3). Within the categories disease, predation, and overgrowth, there are a few specific causes of recent dead that should be

identified if they can be scored with confidence (if not, simply denote one of the five general categories).

When there are multiple causes of recent dead, be sure to attribute a percent of recent mortality to *each* cause.

**Table 3. General (bold) and specific categories of recent dead partial mortality.**

<b>Recent Dead Cause</b>	<b>Code</b>
<b>Disease-general</b>	<b>DZGN</b>
Acute tissue loss - White syndrome	WSY
Sub-acute tissue loss	TLS
<i>Porites</i> ulcerative white spot	PUS
Banded Fungal Infection	BFI
Brown band disease	BRD
Black band disease	BBD
Ciliate infection	CIL
<b>Predation-general</b>	<b>PRED</b>
Crown of thorns predation	COTS
Fish predation	FISH
Gastropod predation	GAST
<b>Physical damage-general</b>	<b>DAMG</b>
<b>Unknown</b>	<b>UNKN</b>

***Recent mortality causes: Disease (DZGN)***

These are diseases that cause tissue loss lesions, leaving behind a recently dead area (small or large) of exposed coral skeleton. Six specific diseases should be recorded if observed including: acute tissue loss or White syndrome (WSY), sub-acute tissue loss (TLS), *Porites* ulcerative white spot (PUS), banded fungal infection (BFI), brown band disease (BRD), and black band disease (BBD). If recent dead percent is recorded and disease is noted, but the diver cannot define the disease type as one of these specific six diseases of interest, then the disease general code (DZGN) should be recorded.

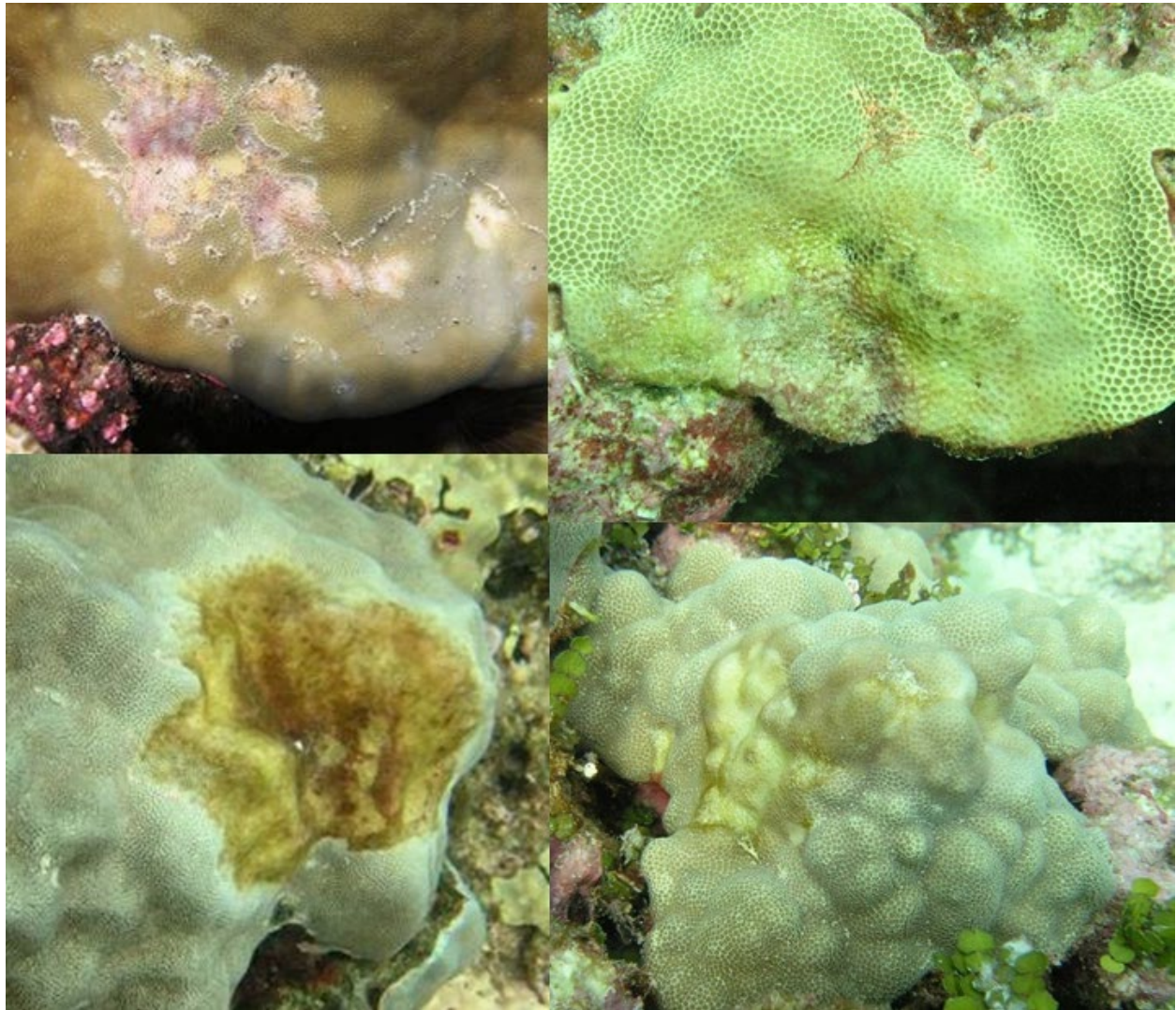
Acute tissue loss or White syndrome (WSY): Acute tissue loss or White syndrome is a collective term to describe lesions characterized by the rapid loss of tissue, leaving behind a sharp, clean band, where tissue is completely removed from the skeleton (Figure 29). A progression of filamentous and turf algae often covers the exposed skeleton, illustrated by a color gradient from bare skeleton to brown as the fouling community develops. The disease generally progresses rapidly, leaving behind a narrow to wide band of recently denuded coral skeleton (the entire colony may be almost completely stark white with only a little tissue remaining). Our assessments have recorded white syndrome on at least six Pacific genera representing four scleractinian families, with species of *Acropora* and *Montipora* being the most common hosts. In the Northwestern Hawaiian Islands this disease is lethal to table acroporids.





**Figure 29. Example of acute tissue loss or White syndrome.**

Sub-acute tissue loss (TLS): Sub-acute tissue loss is a collective term to describe lesions resulting in slow but progressive loss of tissue (Figure 30). It is distinguished from white syndrome by the narrow width of the zone of recently exposed skeleton. Bare white skeleton is often not present, but instead has only a very thin layer of sediment, biofilm (i.e., bacteria), diatoms, microalgae, or tiny turf algae. Look for progression in age of filamentous turf algae that has settled on dead areas of colony. The lesion margin is often mucousy or has sloughing tissue. This is easily confused with gastropod predation so take photos liberally.



**Figure 30. Examples of subacute tissue loss (TLS).**

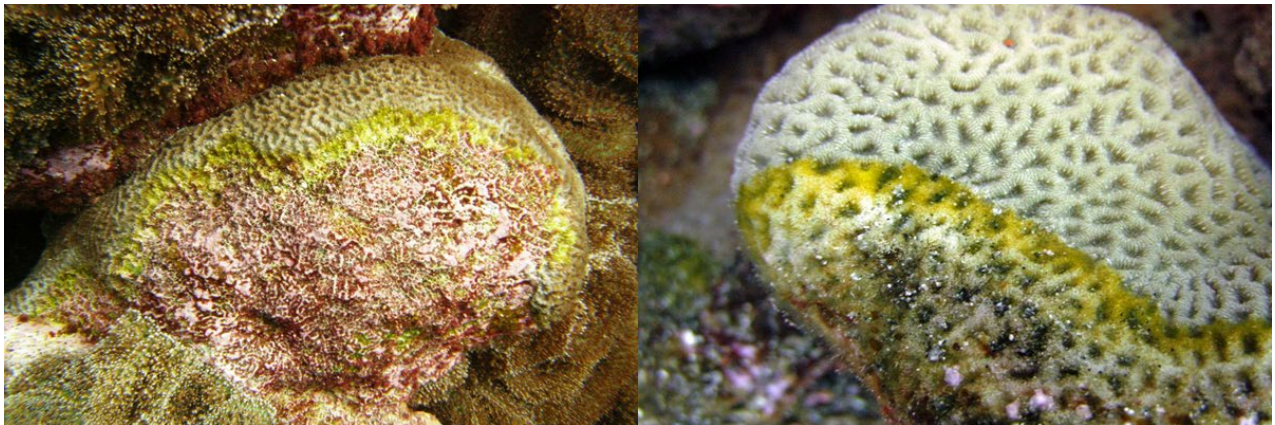


Porites ulcerative white spot (PUS): These multifocal patterns of tissue loss expose spots of bare white skeleton (Figure 31). Lesions are typically small (< 1 cm diameter) and regularly ovoid. These lesions may start as bleached spots. A colony may contain both bleached lesions and lesions devoid of tissue. Abundance: rare.



**Figure 31. Examples of *Porites* ulcerative white spot (PUS).**

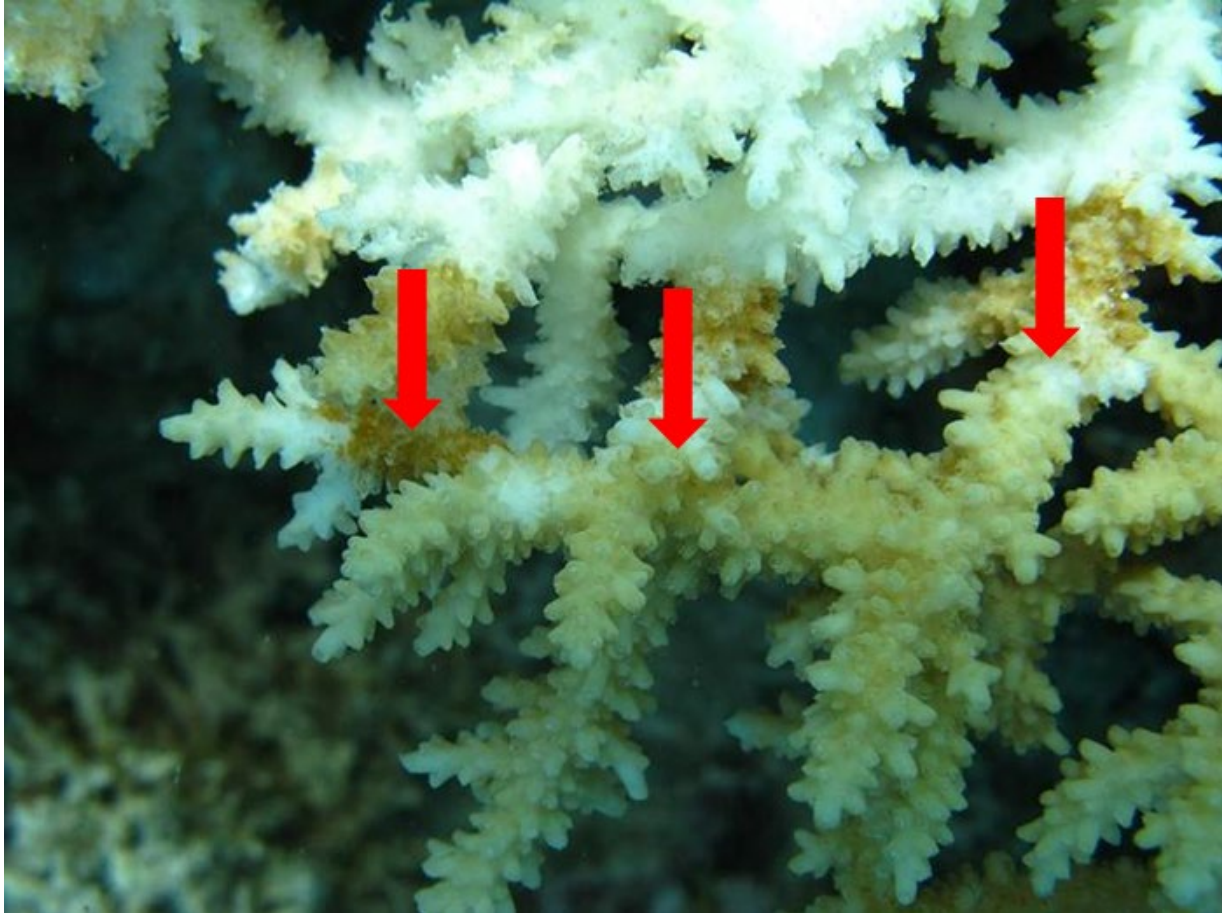
Banded fungal infection (BFI): Diseased colonies exhibit a distinct yellow to bright green mat about 1–3 cm wide on the coral tissue (Figure 32). A progression of filamentous and turf algae generally appears on the exposed skeleton as the tissue is lost. The unaffected coral tissue appears normal in color and morphology.



**Figure 32. Examples of banded fungal infection (BFI).**



Brown band disease (BRD): Brown band disease is characterized by bands composed of ciliates, varying from light to dark brown with ciliate density (Figure 33). A narrow white band may be present between live coral tissue and brown band. The rate of progression is rapid (20–100 mm/day).



**Figure 33. Example of brown band disease (BRD).**

Black band disease (BBD): This condition is characterized by a distinct black to grey mat, approximately 0.5–4 cm wide, on the living coral tissue that leaves behind the bare white skeleton (Figure 34). The band color can vary from black to gray or reddish-brown. The unaffected coral tissue appears normal in color and morphology. The skeleton distant from the tissue front often becomes progressively brown as it becomes colonized by a fouling community. Lesions are variable in size and shape. Distribution and abundance: rare across ESD's study region, although a major outbreak was reported in Kauai (main Hawaiian Islands) in 2013. Can be found across the globe and has been sighted in American Samoa and other areas in the main Hawaiian Islands.



**Figure 34. Examples of black band disease (BBD).**

Ciliate Infection (CIL): Lesions are variable in shape and size and are characterized by a diffuse gray to black band or patch about 0.5 to 3 cm wide, separating the healthy tissue from the exposed coral skeleton (Figure 35). The unaffected coral tissue appears normal in color and morphology; lesions have a speckled appearance caused by the presence of ciliates lodged in the coral skeleton. Generally, filamentous and turf algae appear on the exposed skeleton as the tissue is lost. Distribution and abundance: Rare, with sightings registered around the main Hawaiian Islands (Maui and Hawaii), affecting preferentially *Montipora capitata* and *Pocillopora meandrina*.



**Figure 35. Examples of ciliate infection (CIL).**



***Recent mortality causes: Predation (PRED)***

Crown of thorns sea star (COTS): The lesions caused by crown of thorn sea star predation are evident by the conspicuously shaped scars, forming focal-to-diffuse tissue loss lesions that expose the bare coral skeleton (Figure 36). Recent lesions are white and generally exhibit a discrete and scalloped border. The border may show visible strings of tissue and mucus when the scar is fresh. Usually crown of thorn sea stars can be seen in the survey area.



**Figure 36. Examples of crown of thorns sea star (COTS) predation.**

Fish (FISH): Recent lesions caused by fish predation are predominantly inflicted by corallivorous fishes (parrotfish, pufferfish, and butterfly fish families) (Figure 37). Fish bites are very distinctive gouges or scrapes. These bite marks may also involve damage of coral skeleton. Do not record damselfish bites/chimney or “blenny kisses.”



**Figure 37. Examples of fish (FISH) predation.**

Gastropod (GAST): Recent lesions caused by gastropod predation are focal, multifocal, or diffuse scars that expose the bare coral skeleton (Figure 38). Feeding scars have an irregular border. Shredded strings of tissue may be visible. Snails are often found on neighboring colonies if not immediately visible beside the feeding scars.



**Figure 38. Examples of gastropod predation (GAST).**

***Recent mortality causes: Physical Damage (general; DAMG)***

Any recent dead caused by physical damage to the colony including abrasion, breakage, dislodgement, or toppling of the colony. Damage caused by boating and fishing gear (such as nets, chain, line, anchors, etc.) are also included here. Often observed in coral fragments that have fallen and become partially buried in a sandy bottom habitat.

***Recent mortality causes: Unknown (UNKN)***

Recent dead lesions caused by unknown causes or by a cause not listed in Table 3 are recorded as unknown.

***Condition***

Colony condition (“Condition” on data sheet; Figure 4), includes instances of disease, bleaching, and sedimentation (Table 4). Unlike recent dead, the coral tissue is still alive and the polyps are visible. All condition codes require an assessment of extent (‘Ex’ on the datasheet) as percent of colony affected; estimated to the nearest 1% for extent ranging >0–10% and >90–100%; and to the nearest 5% for extent ranging >10–90%. Two conditions, bleaching (BLE) and patchy bleaching (BLP), also require assessment of severity. Severity values (Sv on data sheet) range from 1 to 3 (1 = slight paling, 2 = noticeable loss of pigmentation, 3 = almost or completely stark white). Given some corals naturally appear slightly pale (equivalent of severity 1), bleaching should only be recorded when the severity is 2 or 3. The default code in the data entry program is NDZ, which is defined as no condition recorded.

**Table 4. List of conditions that may be found on coral colonies.**

<b>CONDITION</b>	<b>Code</b>
Algal infection	ALG
Endolithic Fungal Infection	FUG
Skeletal growth anomalies	SGA
Porites trematodiasis	PTR
Barnacle or tube worm infestation (only record if extent >10%)	IIN
Pigmentation response (only record if extent >10%)	PRS
Discoloration (other than bleaching)	DIS
Bleaching (record severity as 2 or 3)	BLE
Patchy bleaching (record severity as 2 or 3)	BLP
Sedimentation (only record if extent >10%)	SEDI

***Algal infection (ALG)***

An algal infection is the colonization and overgrowth of living coral tissue by various species of algae. Look for visible signs of tissue damage, pigmentation, or discoloration around overgrowth. With heavy overgrowth, underlying coral tissue usually dies, leaving bare skeleton (Figure 39). This condition is most often associated with an infiltration of filamentous red turf algae and may cause a pigmentation response.

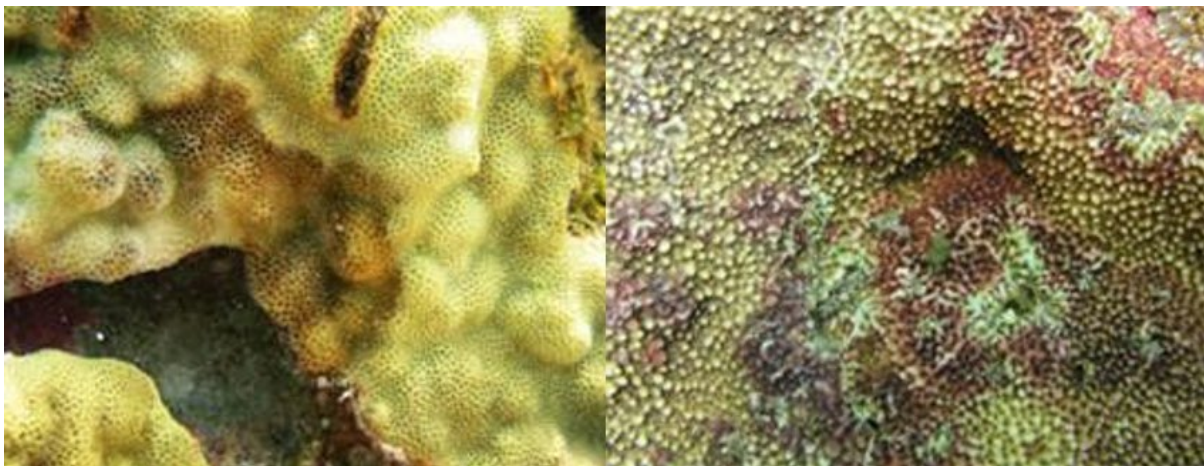




**Figure 39. Example of algal infection (ALG).**

**Endolithic fungal infection (FUG)**

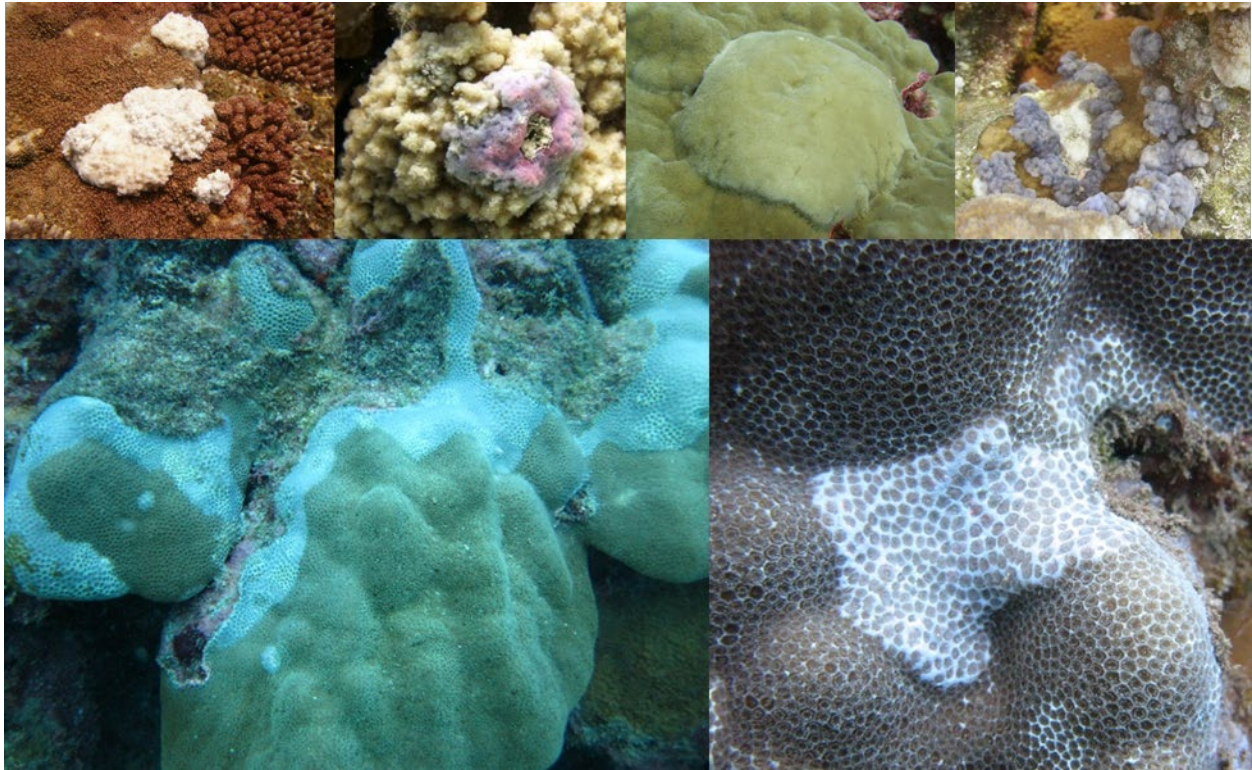
An endolithic fungal infection is characterized by irregular, patchy, dark discoloration of coral live tissue (Figure 40). The discoloration can be identified by multifocal or diffuse areas of brown, reddish brown, or purple colored tissue discoloration. FUG is commonly observed on a variety of encrusting taxa including: *Montipora*, *Pavona*, *Porites*, *Leptastrea*, and *Cyphastrea*. Histologically, the upward migration of fungal hyphae into the thecal cavity is generally associated with disruption of the polyp body wall and sloughing of gastrodermis. Distribution and abundance: common but not abundant, with cases reported in the main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Guam, the CNMI, and Line Islands.



**Figure 40. Example of endolithic fungal infection (FUG).**

### ***Skeletal growth anomalies (SGA)***

Skeletal growth anomalies are characterized by focal to multifocal and circular to irregularly shaped lesions comprising abnormally arranged, enlarged skeletal elements (Figure 41). These anomalies typically protrude above the colony surface and the surface texture visibly differs from healthy tissue. Corallites may be enlarged or remain normal size, but the spacing between corallites may increase. The pigmentation of the anomalies may be normal, slightly pale or discolored (e.g., pigmentation response).

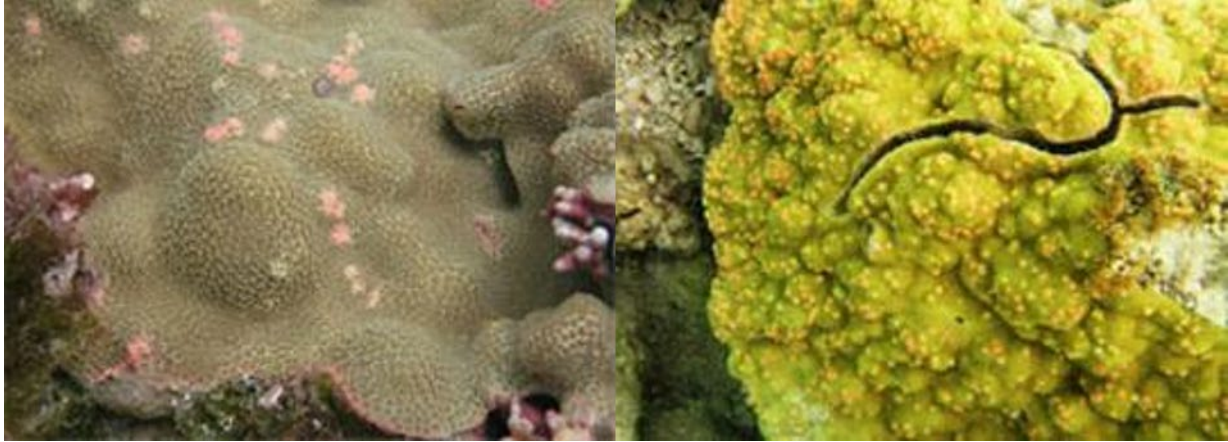


**Figure 41. Examples of skeletal growth anomalies (SGA).**

### ***Porites trematodiasis (PTR)***

*Porites trematodiasis* is characterized by multifocal, distinct pink to white small (~5 mm) areas of tissue swelling (Figure 42). The swelling of one or few polyps is in response to encysted parasitic trematodes. These trematode cysts are often clustered. The extent reflects the amount of colony surface area covered by the pink patches, (i.e., swollen and hyperpigmented). The main host for this disease is the genus *Porites*. Distribution and abundance: Infected colonies are occasional to abundant in the main and Northwestern Hawaiian Islands; absent elsewhere. This disease can be easily be confused with pigmentation responses around tiny spirobid worm burrows, which have tiny tubes coming out of center of hyperpigmented lesions.





**Figure 42. Examples of *Porites* trematodiasis (PTR).**

***Pigmentation response (PRS)***

Pigmentation response is characterized by bright pink patches of discolored, swollen tissue, often occurring in irregular shapes, scattered on the surface of the colony or adjacent to the sediment/algal margins of a colony (Figure 43). Often these lesions appear to be associated with small areas of tissue loss or filamentous algal infections. As some PRS is fairly common on coral colonies, only record if the extent is greater than 10%. Distribution and abundance: Lesions are found on *Porites* and common in the main Hawaiian Islands, Guam, and the southern CNMI; occasional elsewhere.

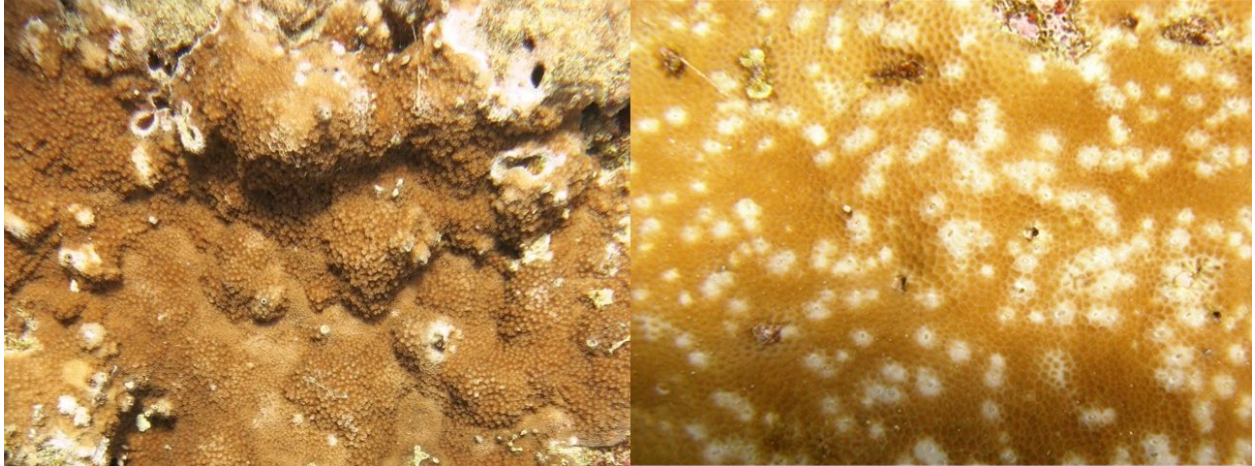


**Figure 43. Examples of pigmentation response (PRS).**



***Barnacle and/or tube worm infestation (IIN)***

Barnacle infestations are characterized by numerous barnacles embedded in a coral colony, resulting in noticeable white spots. Tube worm infestations are characterized by numerous tubeworms embedded in a coral colony (Figure 44). There are often noticeable white spots or protruding tubes. Only record INN if the extent of tube worm and barnacle infestation combined is greater than or equal to 10%.



**Figure 44. Examples of tube worm and barnacle infestations (INN).**

### ***Bleaching (BLE)***

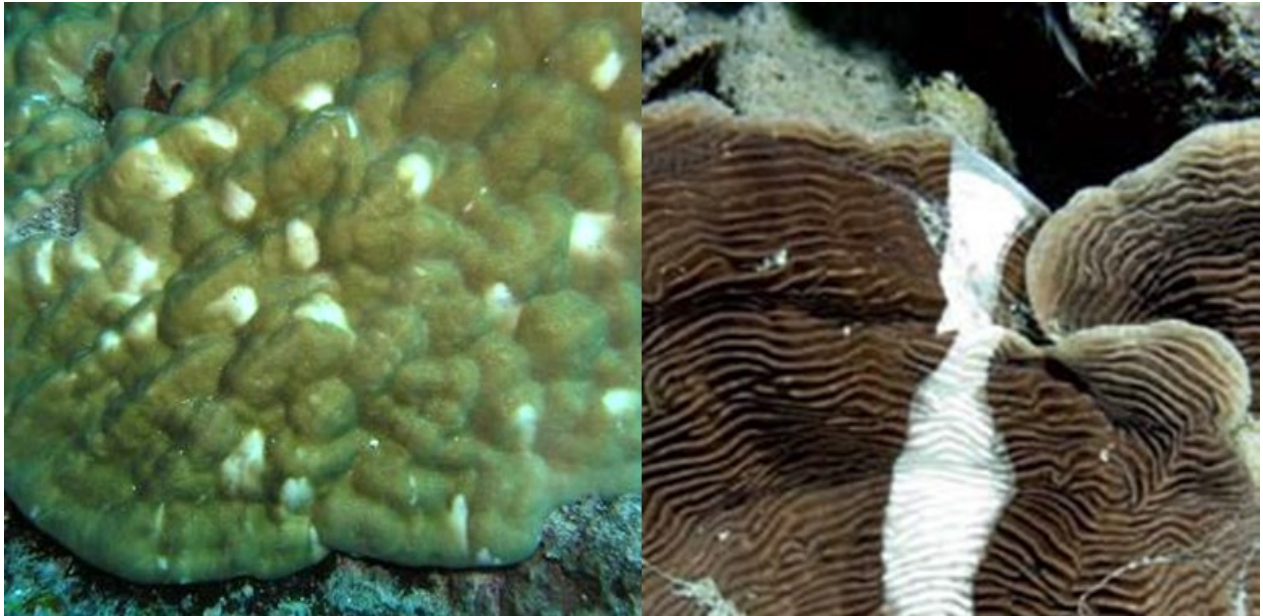
Coral bleaching is characterized by a reduction or absence of coloration within coral tissues due to the loss of zooxanthellae (Figure 45). Severe bleaching is usually associated with environmental stress, such as unusual levels of temperature, light, and/or salinity. However, coral tissue is still alive, and the polyps are visible. Both the extent (% of colony with reduced pigmentation) and severity (range: 1 = slight paling; 3 = stark white skeleton) should be recorded if the severity is greater than 1. If varying severity of bleaching is observed (i.e., a gradient of paling to bleached), score as the average severity observed over the entire colony. Note: as colonies can naturally vary in color and be misinterpreted as “bleaching - slight paling,” only score bleaching for severity of 2 or 3.



**Figure 45. Examples of coral bleaching (BLE).**

### ***Patchy bleaching (BLP)***

Patchy bleaching is characterized by unusual, diffuse patterns of bleaching that do not appear to be a specific response to thermal or other environmental stress (Figure 46). This condition may be caused by intercellular bacterial pathogens. The coral tissue is still alive, and the polyps are visible. Both extent and severity are recorded if severity is greater than 1. Margins between bleached and unbleached tissue are typically very distinct, while BLE is typically characterized by a gradient with paling present.

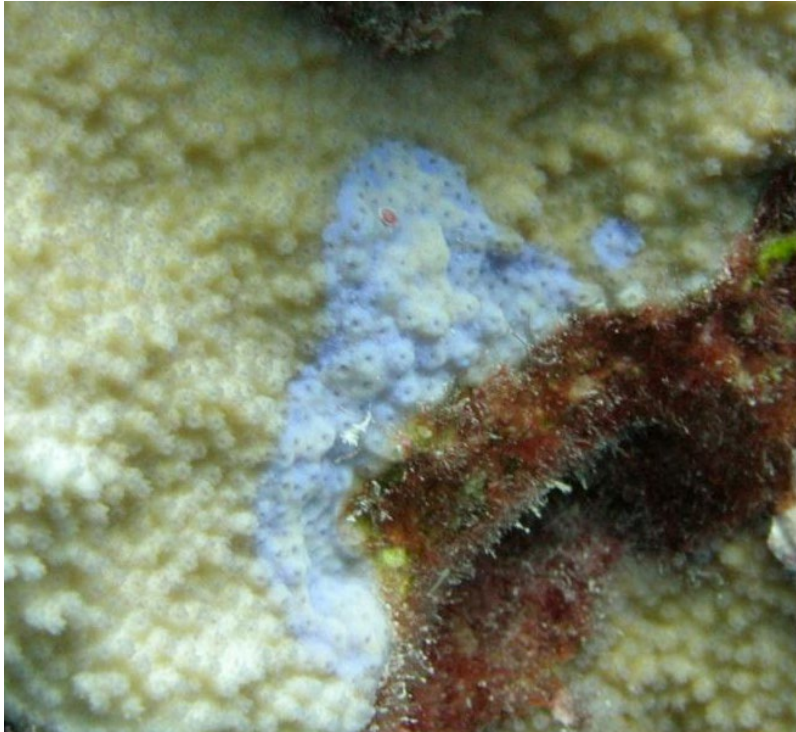


**Figure 46. Examples of patchy coral bleaching (BLP).**



### ***Discoloration other than bleaching or pigmentation response (DIS)***

Discoloration lesions (other than bleaching and pigmentation responses) are characterized by abnormally colored patches that are often bright and occurring in irregular shapes and patterns. Patches are scattered on the surface of the colony or adjacent to the sediment/algal margins of a colony (Figure 47). Often these lesions appear to be associated with small areas of tissue loss or filamentous algal infections.



**Figure 47. Examples of discolorations other than bleaching (DIS).**

### ***Sedimentation (SEDI)***

Suspended sediment can settle over coral tissue, and is at times accompanied by mucus secretion and pigmentation response. As some sediment on a colony is fairly normal, only score SEDI when the area covered by sediment is greater than or equal to 10%. Note: if area under a pocket of sediment/sand is dead coral tissue, this should be included in the percent old mortality estimate for the colony.

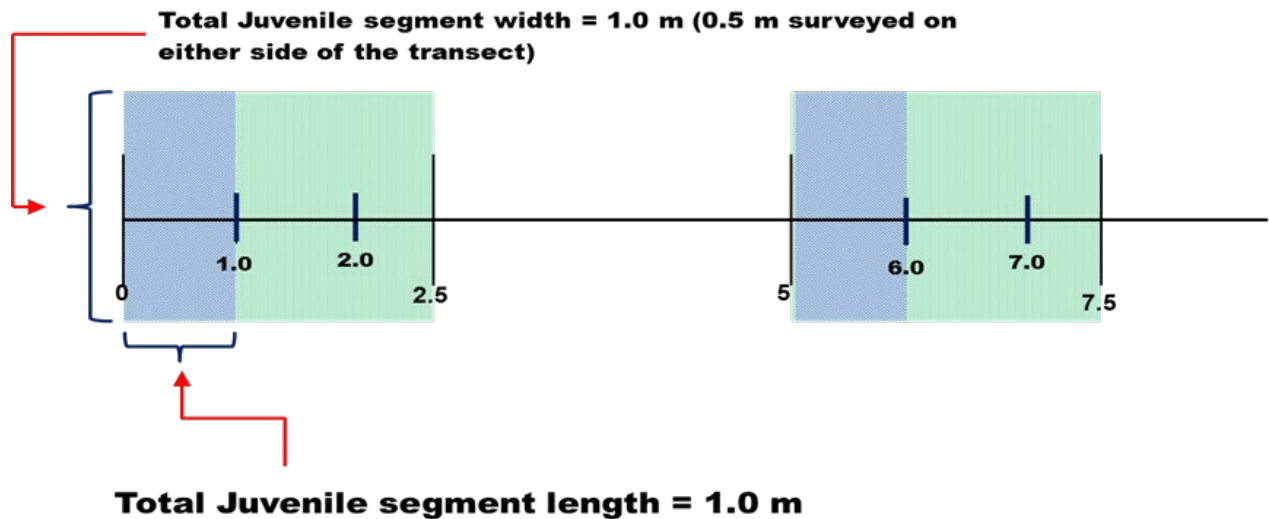
### ***Juvenile coral surveys***

Surveys of juvenile coral colonies ( $\geq 0.5$  mm,  $< 5$  cm) are conducted within three 1 m  $\times$  1 m segments centered along the 30 m transect (

Figure 48), where each segment is numbered as follows: **Segment 0** = 0–2.5 m; **Segment 5** = 5.0–7.5 m; **Segment 10** = 10–12.5 m. No juvenile coral survey is performed from 15.0 m to 16.0 m along the transect line.



As with adult colonies, the center of the juvenile colony must be within the boundaries of the segment to be included in the survey. Juvenile colonies should be distinguished in the field by a distinct tissue and skeletal boundary (not a fragment of larger colony). Each colony is measured for size by recording the maximum diameter to the nearest 5 mm.

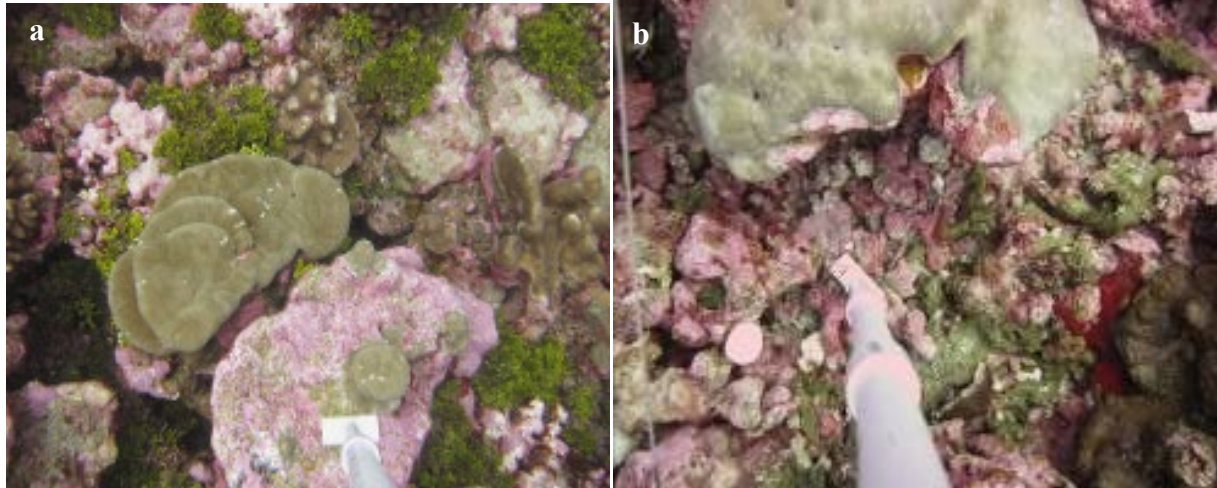


**Figure 48. Diagram of two juvenile coral survey segments (blue) in relation to those surveyed for adult corals (green).**

### *Benthic photo surveys*

Photoquadrats (photoquads) are used to derive estimates of benthic cover. The gear used to collect photoquadrats consists of a high-resolution digital camera mounted on a 1m pole. Prior to collecting photoquads, review the latest camera settings that are standardized across ESD, and make sure you know how to use the cameras. Prior to each cruise there should be a photoquad refresher meeting to make sure everyone is up to speed. It is extremely important that we take quality imagery so that we have the ability to use CoralNet to automatically classify benthic features accurately. All images should be shot in JPEG. The first photo taken at each REA site is a photo of the slate with the dive site ID. The diver uses a gray card to white balance the camera at this time, then takes a photo of the gray card for potential color balancing in the future. The diver should take proper care to photograph the image perpendicular to the reef and not at an angle (

Figure 49a). The photographer can look at the camera viewfinder during and after taking pictures to ensure that orientation of the monopod is correct and that the images are not blurry. Thirty photoquadrat images are collected along one side of the 30 m transect implemented for coral surveys at 1 m intervals, starting at 1 m and progressing to the 30 m mark (images are not collected at the 0 m mark).



**Figure 49. Examples of (a) ideal and (b) incorrect monopod placements.**

If the meter stick is crooked (Figure 49b), an object is in the way, or the image is blurry, replace the original with a new photo. If the bad photo is not deleted in the field, make sure it is done once the camera is downloaded.

## **Data Entry and Quality Control Measures**

Once data collection is complete, rinse all data sheets with fresh water and dry in preparation for data entry into the Mission Data Application. Initial data entry and quality control is the responsibility of the diver who collected the data. Quality control should include error checking the entered data against the data sheet once data for all sites surveyed that day have been entered. Contact [Courtney.s.couch@noaa.gov](mailto:Courtney.s.couch@noaa.gov) for access to QC scripts written in R.

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