Analysis of Benthic Survey Images via CoralNet: A Summary of Standard Operating Procedures and Guidelines (2022 update)

Public Version

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May 2022

NOAA Administrative Report
H-22-03
https://doi.org/10.25923/nhx2-6j45

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Recommended citation

Lamirand M, Lozada-Misa P, Vargas-Ángel B, Couch C, Schumacher BD, Winston M. 2022. Analysis of benthic survey images via CoralNet: a summary of standard operating procedures and guidelines. PIFSC Administrative Report, H-22-03, 129 p. doi:10.25923/nhx2-6j45

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Introduction

This is a reference document that provides guidelines for training and the analysis of images on CoralNet from surveys conducted by the Ecosystem Sciences Division (ESD), formerly known as the Coral Reef Ecosystem Division (CRED), of the NOAA Pacific Islands Fisheries Science Center (PIFSC). The user documentation outlined in this report applies to the analysis of photoquadrat images collected by ESD and its partners. The images were collected in the coral reef ecosystems of about 40 primary islands, atolls, and shallows banks in the Hawaiian Archipelago, including the Papahānaumokuākea Marine National Monument; the Mariana Archipelago (Guam and the Commonwealth of the Northern Mariana Islands, including the Marianas Trench Marine National Monument); American Samoa; and the Pacific Remote Islands Marine National Monument (Wake, Johnston, Palmyra, and Kingman Atolls; and Howland, Baker, and Jarvis Islands).

Background

Estimates of benthic cover and community composition are fundamental components of coral reef monitoring programs. Typically, benthic habitat is characterized by percent cover. Several available approaches may be used to derive this metric, each with differing levels of accuracy, effort, and efficiency (Ohlhorst et al. 1988; Jokiel et al. 2015). ESD, through the National Coral Reef Monitoring Program (NCRMP) in the Pacific and its predecessor, the Pacific Reef Assessment and Monitoring Program (Pacific RAMP), has implemented three different protocols to derive estimates of benthic percent cover at different spatial scales:

1) Visual towed-diver surveys (TDSs) that cover approximately 15,000–25,000 m^2 per survey (Kenyon et al. 2006) were conducted between 2000 and 2017.
2) Line-point-intercept (LPI) surveys (Loya 1978) were conducted from 2005 to 2012.
3) Photoquadrats as part of TDSs, or as part of fish and coral demographic surveys at long-term fixed or stratified-random sites, have been conducted since 2010 (Brainard et al. 2008).

In 2012, ESD adopted the image analysis tool Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006) as the standard procedure to extract benthic data from photoquadrats. Benthic cover data was identified to the functional or morphological group level (e.g., encrusting coral, upright macroalgae, sand). This level of identification is referred to as Tier 2 and can be integrated into broader categories under Tier 1 (e.g., coral, macroalgae, sediment).

In 2013, ESD began to classify benthic composition from images at a finer level of taxonomic resolution: Tier 3 was created to include several algal and coral genera. Tier 3b was later added to include additional coral taxa and morphological designations, and combines some rare algal groups.

In 2015, ESD transitioned to the web-based annotation tool, CoralNet. It allows the user to manually annotate imagery and uses machine-learning algorithms to fully- or partially-automate classification of benthic imagery once sufficient data are available (Beijbom et al. 2015).

In 2018, ESD made three important updates to the methods used to assess benthic cover. First, considerable improvements were made to photoquadrat image acquisition: camera model, settings, and white balancing technique. The Canon PowerShot S110 was replaced with the Canon PowerShot G9 X and Canon PowerShot G9 X Mark II. The Canon Powershot S110's slow shutter speed resulted in blurry photos. The PowerShot G9 X provides several settings that ESD has configured for improved images: "Custom" mode for image quality is set to the highest setting, "ISO Auto" is set to "Fast," and the exposure is set to "–1/3." ESD previously used dive slates to white balance, but found that this technique produced photos with inconsistent exposure levels. ESD now uses 18% grey cards, which consistently produce white-balanced images with proper exposure. These updates have improved the sharpness and color of the photoquadrat imagery.

Second, with better image quality, CoralNet's alleviation tool can reduce the time spent on manual annotation. To accomplish this, ESD manually annotated 8,000 – 10,000 images with the CoralNet classifier's confidence threshold set at 100%. After annotation was completed, we then used the CoralNet classifier to generate annotations, lowering its confidence threshold by increments of 10% to determine the lowest viable threshold for accurate machine-generated annotations.

Third, we defined Tier 3c by adding two new coral genera (*Astrea* and *Phymastrea*) and removing *Montastraea* (dissolved). The category "Unknown Soft Coral" was also merged with Octocoral to become "Octocoral/Wire coral." All Tier 3c categories fall within the Tier 2 and Tier 1 classification levels (see Appendix 6 and Appendix 7 for details).

1. This manual provides detailed instructions for the following steps:
2. Setting up an account on CoralNet
3. Conducting CoralNet pre-analysis calibration exercise
4. Uploading images to CoralNet
5. A CoralNet image analysis user guide

The associated guides are provided in the appendices.

FIRST TIME ESD USER GUIDE

Setting Up Your CoralNet Account

1. Launch CoralNet[1] on your web browser
2. For first-time users, request a new user account by clicking Sign Up[2]

Complete the following fields:

First Name

Last Name

Email — *use your email account*

Username — *for ease in tracking, use the suggested formats: "firstnamelastname" (e.g., janesmith); "firstname_lastname" (jane_smith); "firstand/middlenameinitialslastname" (e.g., jksmith)*

Affiliation — *e.g., NOAA PIFSC Ecosystem Sciences Division*

Reason for requesting an account — *e.g., Analyze ESD's optical data (primarily photoquadrat images) via CoralNet*

Project description — *e.g., One of the aims of the National Coral Reef Monitoring Program in the Pacific is to collect data on coral population and reef community structure. While coral demography, partial mortality, and conditions are surveyed and assessed via belt transects, benthic community structure and percent cover are derived from photoquadrat images (Winston et al. 2019).*

How did you hear about us — *e.g., Oscar Beijbom*

3. Check the "Agree to data policy" box
4. Type the text that you see on the reCAPTCHA™ image
5. Click "**Submit**"
6. You will receive a confirmation email from "noreply@coralnet.ucsd.edu" containing a link to activate your account and a temporary password. You may also receive a welcome email from Oscar Beijbom with links to the CoralNet instructional videos[3] on Vimeo. Review this video series before attempting to use the program.
7. Once your account is activated, change your user password and sign in.
8. If working with a benthic image analysis coordinator, immediately inform them of your CoralNet username so they can add you as a user to the source page where all of the analysis will take place.

Analyst Inter-Calibration Process

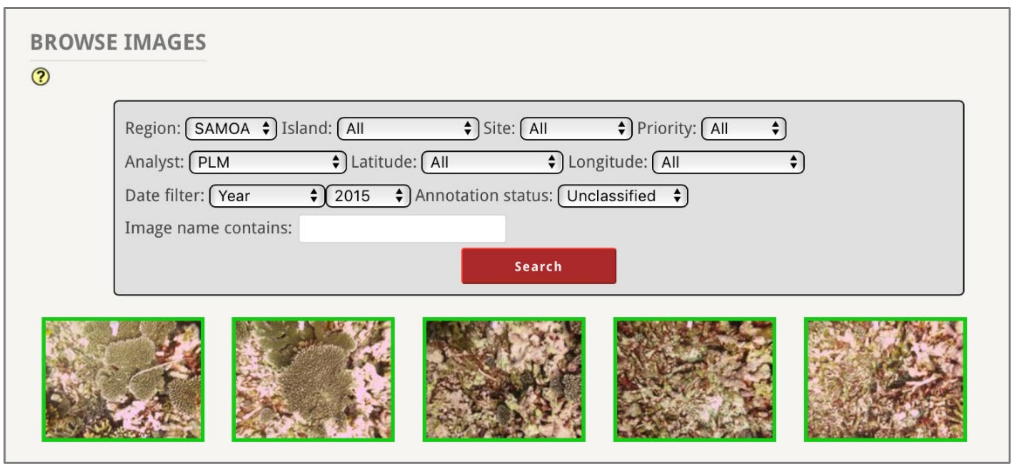
Prior to each ESD benthic image analysis (BIA) production series, all analysts must participate in an inter-calibration process to check for inter-observer variability and bias. This inter-calibration begins with a pre-calibration exercise: a few images (3−5) with points already projected are distributed for analysis using CoralNet. The results of the pre-calibration exercise are compiled and all analysts meet to discuss the images. Problematic identification categories (e.g., crustose coralline algae (CCA), turf algae, blue-green macroalgae) and points are highlighted to ensure analysts achieve a consensus identification for each point. This process

[1] http://coralnet.ucsd.edu
[2] http://coralnet.ucsd.edu/requests/accounts/
[3] http://vimeo.com/channels/coralnet

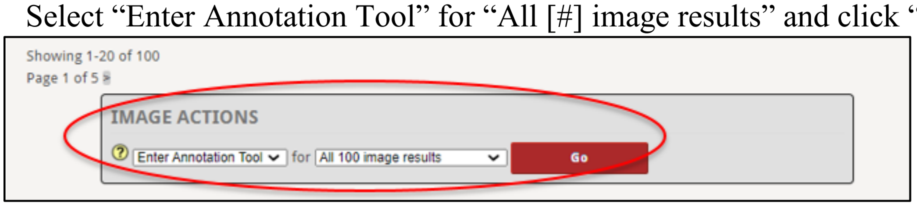
builds consistency among analysts to discern trends and patterns in benthic cover across space and time. The analysts will then annotate a series of 100 images with points already projected. The results of this exercise will be analyzed using multivariate statistics to assess similarities and discrepancies among analysts. Analysts who differ markedly will repeat the exercise. Analysts who exhibit a reasonable degree of similarity and consistency will proceed and begin the benthic image analysis series. For a new calibration source or to upload new images to the calibration source, see Appendix 2.

1. **Selecting your assigned images**
   a. Launch CoralNet and sign in.
   b. Under "Your Sources," select the name of your calibration source.
   c. On the source page, select "Images."

   d. Use the dropdown menus to specify any filters you wish to apply.
   "**Annotation status**" — "All," "Unclassified," or "Unconfirmed," depending on your viewing preference.
   Most importantly, choose your initials under "**Analyst.**"



   e. Click "**Search**" to display your selection.
   Note: The image border color indicates the image's annotation status:
   red *needs annotation*
   green *has been annotated and confirmed*
   orange *has been machine-annotated but still needs analyst confirmation.*
   f. Scroll to the bottom of the page to "IMAGE ACTIONS"
   g. Select "Enter Annotation Tool" for "All [#] image results" and click "**Go**"



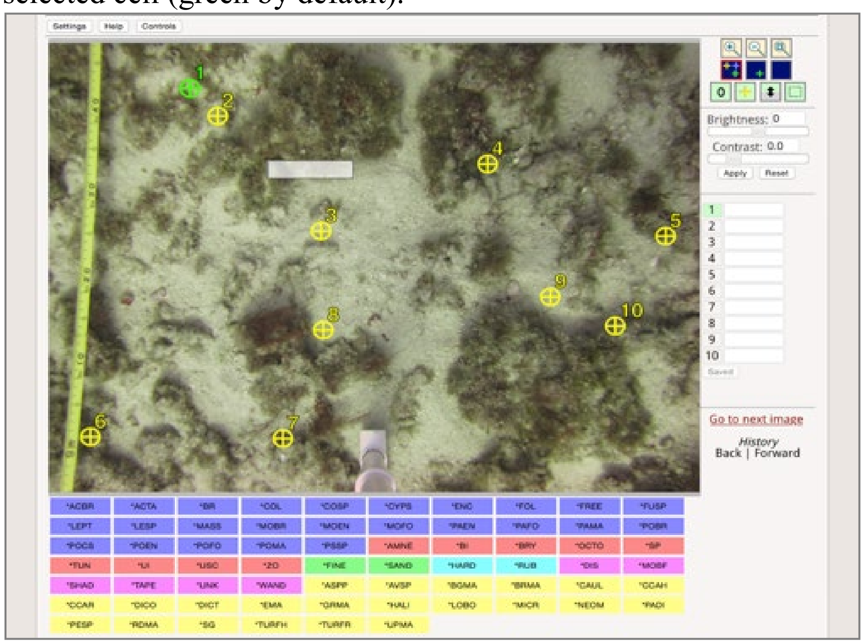
2. **CoralNet Calibration Annotation Settings**

The following recommended settings ***only* apply to calibration exercises**:

a. Click "Settings" on the upper left side of the image.
b. In the "Settings" pop-up box, select the following:
   Point marker: Crosshair and circle
   Point marker size: 12
   Point marker is scaled: *check*
   Point number size: 28
   Point number is scaled: *check*
   Point colors: *user's preference*
   Show machine annotations: ***uncheck***
c. Click "Save settings."
d. Click the X in the upper right corner to exit.

3. Image Analysis

a. Click on the first cell (#1) in the ID column on the right side of the screen. The point (#1) on the image will change to the color designated in settings for the selected cell (green by default).



b. Identify the benthic category/label the point's cross-hair is covering: Decide which benthic category lies directly beneath the point's cross-hair and choose it from the label grid at the bottom of the screen. The cell will populate with the category label, and the data point changes to the color designated in settings for the confirmed data point (blue by default).
Note: If all 10 cells have been populated with suggested annotations (in grey text), go back to step 2.b (Annotation Settings) to uncheck the machine annotations.

c. After selecting a category, the cursor will automatically advance to the next point. For guidance on selecting the correct category, see Appendix 6: Identification Guides.
   Note: Click "*Help*" *above the image for further guidance on using the annotation tool. Click* "*Controls*" *for navigation tips and keyboard shortcuts.*

d. Repeat steps c−d until all points on the image are classified.

e. Click on "Save Progress" to save your annotations. "ALL DONE" will display at the bottom of the column to indicate that the annotations for all points have been saved and confirmed.

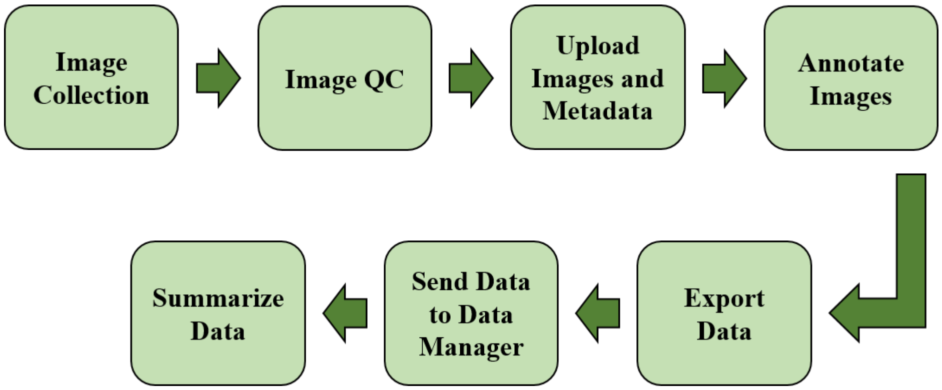
f. Click "Next" to advance to the next image.

g. Repeat steps a−g until all images are analyzed.

h. Inform the BIA coordinator and they will export the annotations.

CoralNet IMAGE ANALYSIS USER GUIDE

The following section will walk through the process ESD uses to analyze our benthic imagery. Our image analysis guide outlined below consists of 4 main steps: imagery quality control, imagery and metadata upload, annotation, and data exportation.



Data Management and Imagery Quality Control (QC)

Since CoralNet classifiers are trained from the source annotated imagery, it is fundamental that images are sharp with good color contrast and proper white balance. This will make manual annotation easier and provide high-quality source data for the classifiers to automate annotation. Image quality can be affected by several factors: the make and model of the camera, the settings on the camera (i.e., ISO, shutter speed, and exposure), and proper white balancing technique (non-ESD users can feel free to reach out to the ESD CoralNet team for the most recent guidance on camera use and settings). All imagery should be rigorously checked for quality control before it is uploaded to CoralNet. This quality control check is outlined below.

For ESD Users*:* After each day's field operations, benthic images are uploaded to the data server and stored in a specific file folder format. REA imagery are saved in a series of hierarchical folders that include the mission/cruise name, island, which team collected the imagery, and site name. Keeping the folder structure consistent across survey locations and years is essential for efficient QC and data management. It is the divers' responsibility to ensure there are 30 images per site in each PHOTO_QUAD folder, as well as discarding any poor or inadequate photoquadrat images, including, blurry, dark, washed, inappropriate angle or distance. Sometimes, discarding poor images will put the total image count below 30 for a site. This is okay, however we want to avoid this as much as possible and emphasizes the importance of high quality image collection in the field. Adobe Lightroom can be used to color correct images if needed (see Suka et al. 2019 for detailed methods on color correction).

For non-ESD Users: Develop a file naming convention and folder structure that is consistent. This allows you to ensure you have the intended number of images per site (e.g., that there aren't any extras or any sites missing photos) and remove any poor quality or blurry imagery.

Uploading Images and Metadata

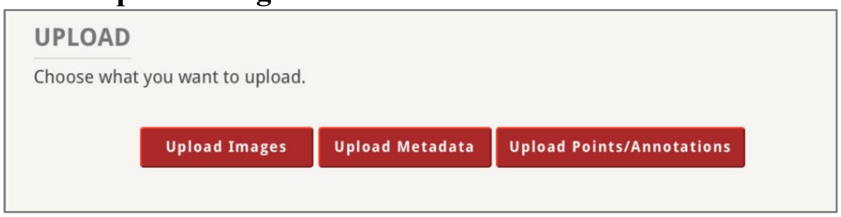
The upload process is conducted in the following order:

1. Upload the image files

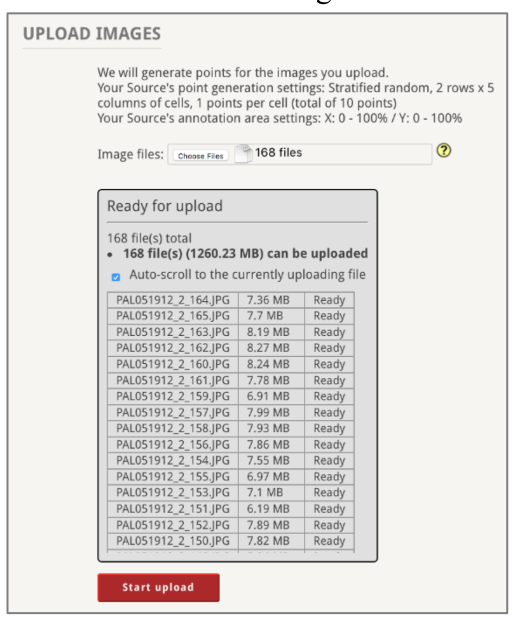
2. Upload the metadata files.

Below are the guidelines for each uploading step:

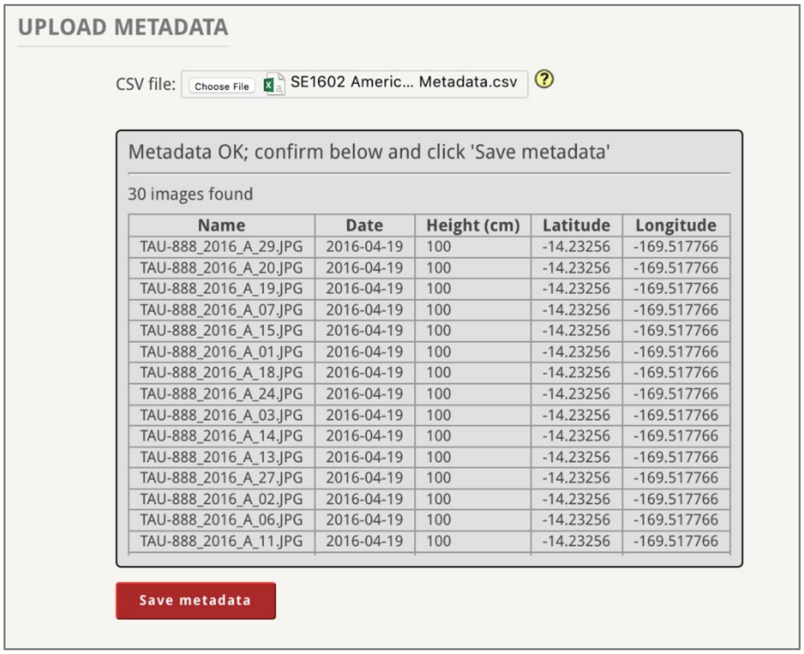
1. Open the source to which you will upload the image(s).
2. From the source home page, click the blue "**Upload**" button.
3. Upload the images
    a. Click "**Upload Images**."



    b. Under "**Images files**," click "**Choose files**," navigate to the image folder, and select the files.
    c. Click "**Start Upload**." Once upload is complete, if necessary, click "**Upload more images**" to upload another batch of images.



4. Upload the metadata
    a. From the source home page, click the blue "**Upload**" button and click "**Upload Metadata**."
    b. Under "**CSV file,**" click "**Choose files**," navigate to the appropriate folder, and select the CSV file.
    c. Click "**Save metadata**," then click the blue "**Upload**" button to upload more images/metadata, or click on the source name to return to the home page.



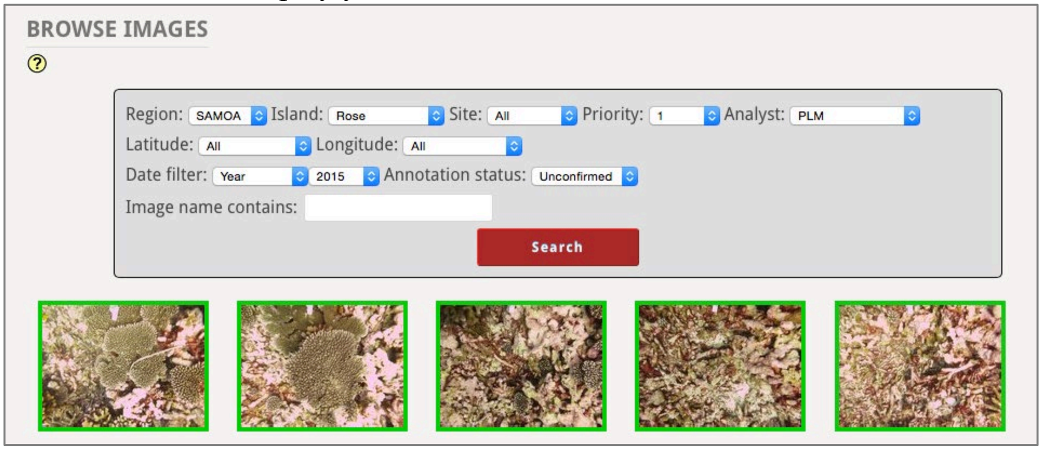
Name	Date	Height (cm)	Latitude	Longitude
TAU-888_2016_A_29.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_20.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_19.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_07.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_15.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_01.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_18.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_24.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_03.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_14.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_13.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_27.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_02.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_06.JPG	2016-04-19	100	-14.23256	-169.517766
TAU-888_2016_A_11.JPG	2016-04-19	100	-14.23256	-169.517766

Analyzing Rapid Ecological Assessment (REA) Images

1. **Selecting your assigned images**
   a. Under "Your Sources," select "CREP-REA [REGION]" (e.g., "CREP-REA SAMOA" or "CREP-REA HAWAII").
   b. On the source page, select "Images."

   c. Use the dropdown menus to specify the "**Region**" and/or "**Island**" from which the images originated. Under "**Date filter: Year**," select the corresponding year the images were collected. Set the "**Annotation status**" to either "All," "Unclassified," or "Unconfirmed," depending on your viewing preference. Then, *most importantly*, choose your initials under "**Analyst**."

d. Click “**Search**” to display your selection.



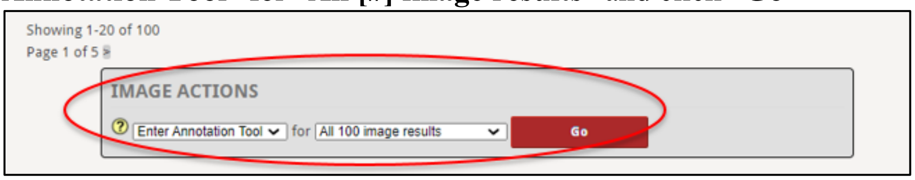
Note: The image border color indicates the image's annotation status:

red needs annotation

green has been annotated/confirmed

orange has been machine-annotated[4] *but still needs analyst confirmation.*

e. Scroll to the bottom of the page to “**IMAGE ACTIONS**,” select “**Enter Annotation Tool**” for “**All [#] image results**” and click “**Go**”



2. CoralNet Annotation Settings

The following recommended settings will ***only need to be applied once*** during the image analysis process:

a. Click “Settings” on the upper left side of the image.

b. In the “Settings” pop-up box, select the following:

Point marker: Crosshair and circle
Point marker size: 12
Point marker is scaled: *check*
Point number size: 28
Point number is scaled: *check*
Point colors: *user's preference*
Show machine annotations: ***check***

e. Click “Save settings.”

f. Click the X in the upper right corner to exit.

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[4] *At 12:03 AM HST (3:03 AM PST), CoralNet will read all annotations provided by the analysts and the robot will then provide annotations to the remaining images in the source. From this point on, all images that have not been previously analyzed by a human analyst will have an orange border and the analyst will have to confirm all suggested annotations in the next session.*

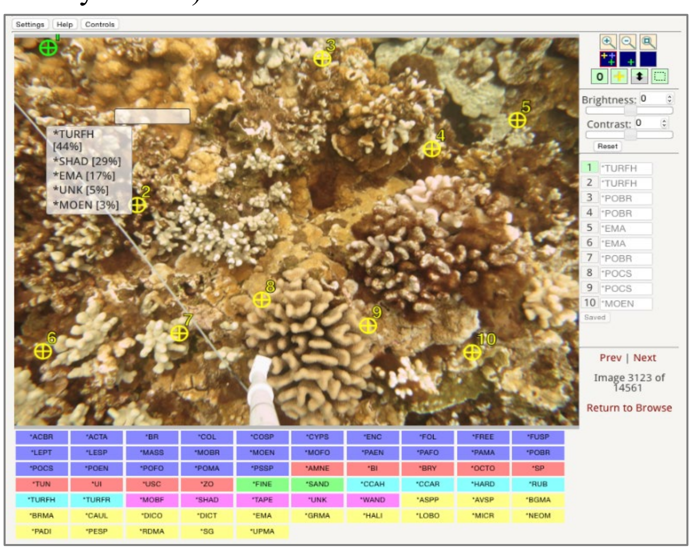
3. Image Analysis Process

Navigation Tips

- **Adjust the view** under an active point using the zoom buttons (zoom in, zoom out, zoom to fit). Alternatively, left click on an image or SHIFT + ↑. To zoom out, right click, CTRL + left click or SHIFT + ↓.
- **Hide or view** the points on an image by using the point display buttons (display all, display selected, display none). You can turn off all the random points except one by using "isolation mode" (middle icon).
- **To select multiple points**: Use (select all, click on image to select, draw on image to select). Alternatively, you can hold CTRL (Windows) or CMD (Mac) and left click on the numbers that you would like to assign the same category. Each point must be carefully assessed prior to assigning them to a group to ensure that they should all be assigned to the same category.
- **To deselect all**: Click the 0 (deselect all) button.
- If you need to **clear all the annotations on an image**, click "Image Details" above the upper-right corner of the image. Scroll down to the bottom below the image and click "Clear Annotations." Scroll up and click "Annotation Tool" to return to the annotation page.

a. Click on the first cell (#1) in the ID column on the right side of the screen.

b. The point (#1) on the image will change to the color designated in settings for the selected cell (green by default).



c. Identify the benthic category/label the point's cross-hair is covering.

Note: If the image has been machine-annotated and "show annotations" is checked in the settings box, all 10 cells will contain suggested annotations (in gray text) that will need confirmation. Click on the cell and select the correct category label on the field list (if available, probability scores that correspond to each of the suggested labels will be visible). If the correct category label is not among those on the field list, select the correct one from the label grid at the *bottom of the screen. The annotation font color on the ID column will turn black once confirmed.*

d. After selecting the correct category, the cursor will automatically advance to the next point. For guidance on selecting the correct category, see Appendix 6: Identification Guides.

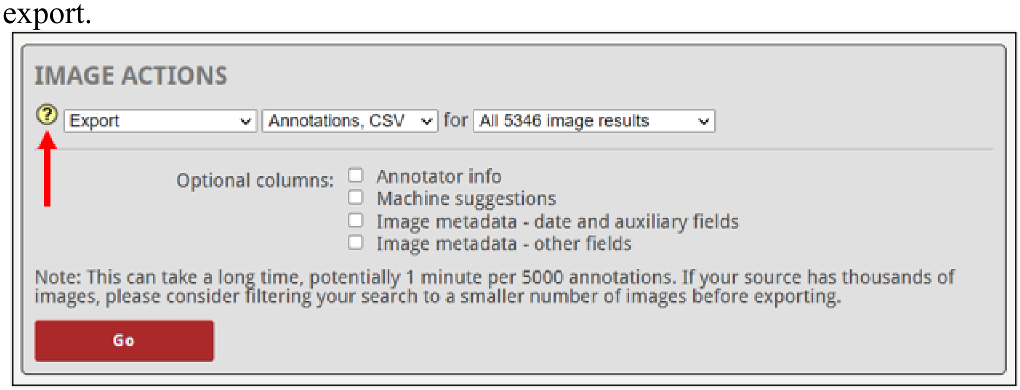
   Note: Click "Help" above the image for further guidance on using the annotation tool. Click "Controls" for navigation tips and keyboard shortcuts.

e. Repeat steps c–d until all points on the image are classified.
f. **If you are uncertain about a point**, follow the protocols in the "Common Questions and Troubleshooting" section on page 14.
g. Click "Save Progress" to save your annotations. "ALL DONE" will display at the bottom of the column to indicate that the annotations have been saved and confirmed.
h. Click "Next" to advance to the next image.
i. Repeat steps a–h until all images are analyzed.
j. Inform the BIA coordinator and they will export the annotations.

Exporting Annotation Data

1. Select images to export their data

a. On your source's main page, click the blue "**Images**" button.
b. Select your desired images using any of the specific filters and press "**Search**."
c. Once the search has loaded, scroll down to the "**IMAGE ACTIONS**" section.
d. Click the first drop down menu and select "**Export**."
e. A second drop down menu will appear. From there, select the data you want to export.



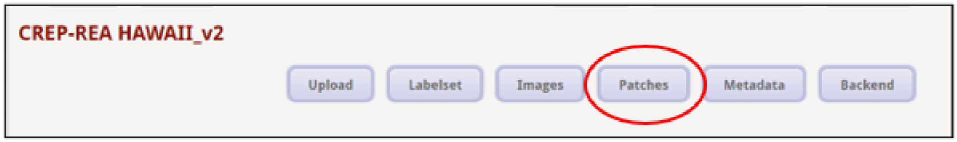
   Note: For more information on each of the export options, click on the yellow circle button with a question mark in the middle. A pop-up box will open, detailing the specifics for each of the options.

f. ESD uses an R-script to summarize the benthic cover data exported from CoralNet. More information about this is in Appendix 5.

Common Questions and Troubleshooting

When in doubt

- Leave the point blank until you can consult with an expert or colleague who is familiar with the area.
- **Do not guess** if you are not able to confidently classify the point.
- Utilize CoralNet's "Patches" tab
  - On each source page, users can use the patches tab to look at previously annotated imagery to assist with point identification.



  - It allows users to filter by various options depending on the metadata that are available. It can be extremely helpful when trying to decide what coral genera is beneath a point.
  - This feature is available on *all* sources shared with you regardless of permissions (i.e., Admin, Edit, or View). If you wish to have access to another group/organization's sources, contact their CoralNet data manager or admin to request permission for viewing access.
- If the area under the point is blurry or in a shadow, but you think you can still identify it, use the **Unclassified** or **Shadow** categories. We are increasingly relying on CoralNet's machine learning infrastructure to assist with point annotation. As such, it's important to train the classifier with good imagery and points.

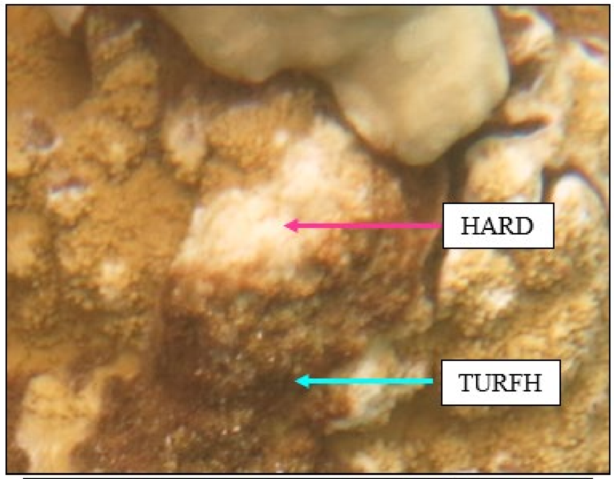
Using Unclassified, Shadow, Water Column

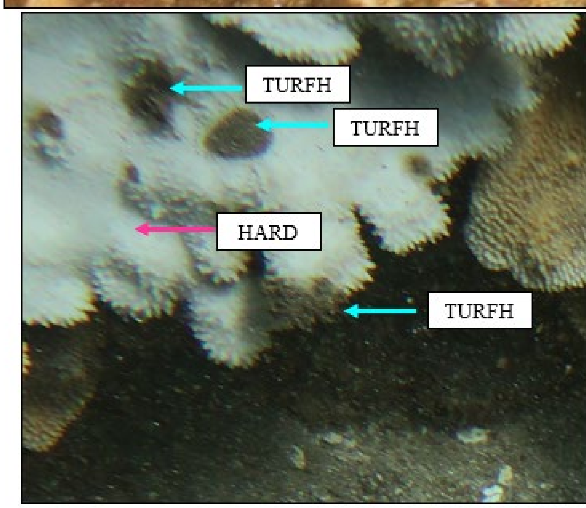
- ESD recommends minimizing the use of labels that result in null categories (ie Unclassified and Shadow), however below are examples of instances where we use the labels Shadow and Unclassified.
- The category **Shadow** should be used when the point falls on an area that is dark and the nature of the benthos cannot be assessed due to diminished light.
- The category **Unclassified** should be used when the nature of the benthos cannot be determined due to image quality or unfamiliarity with the type of benthos.
- In rare cases when the point falls on the water column, classify the point as **Tape** to remove it from the benthic cover estimate. (Note: the categories Tape and Wand are excluded from percent cover estimates).

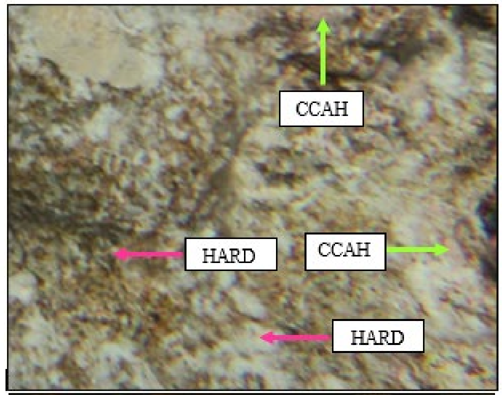
Differences between hard substrate and turf growing on hard substrate:

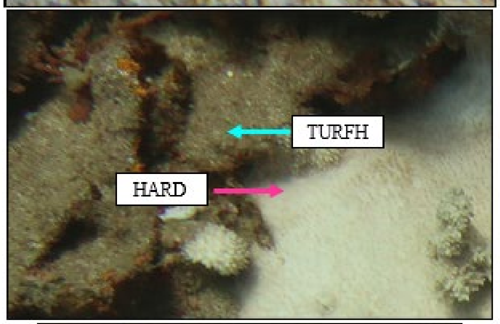
- Hard substrate (**HARD**) is classified by ESD as substrate that is newly exposed and/or only has a very thin lining of turf (most often not visible in the photograph). Some examples include: fish bites or scrapes that leave bare carbonate surface behind, areas of recently dead coral, or basalt formations.
- We classify a point as Turf growing on hard substrate (**TURFH**) when there are visible turf algae filaments in the photograph. Often times turf mats can have granules of sand mixed in, but should not be classified as Sand or Fine.

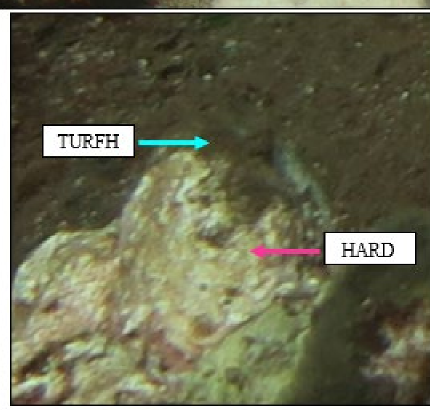
- It can be tricky to decide whether a point is HARD or TURFH when the substrate has the coloration of turf algae, but no filaments are visible. REMEMBER: If you are unsure, consult with an expert or colleague that is more familiar with the area. Below are some examples to help with some confusion:











What if the point falls on a coral colony with multiple growth morphologies?

- Classify the point based on the morphology directly under the point rather than the overall colony morphology. For example, *Porites rus* may have both "branching" and "foliose" (POBR, POFO; Tier 3c) morphologies on the same colony.
- If the observed morphology is not in the Tier 3c labelset, choose the closest morphology.

What if the point lands between two growth forms or categories?

- If a point falls precisely between multiple coral growth morphologies or on the border between multiple benthic categories (e.g., coral-algae), the benthic category occupying the greatest area within the symbol (circle wrapping the cross-hairs) will be classified.
- If the multiple benthic categories occupy an equal space within the symbol, the benthos falling on the top left quadrant within the point symbol will be classified.

Acknowledgments

We would like to thank former and current staff and partner agencies of the Ecosystem Science Division who were instrumental in formulating the Program's original image analysis protocols: Jesse Abdul, Jeffrey Anderson, Jacob Asher, Vivienne Blyth-Skyrme, Rusty Brainard, Annette DesRochers, Emily Donham, Matthew Dunlap, Jamie Gove, Jason Helyer, Brittany Huntington, Erin Looney, Mark Manuel, Kaylyn McCoy, Danny Merritt, Faith Knighton, Kerry Reardon, Cristi Richards, Benjamin Richards, John Rooney, Stuart Sandin, Jennifer Smith, Jeremy Taylor, Molly Timmers, Amanda Toperoff, Peter Vroom, Ivor Williams and Gareth Williams. We thank ESD team members Hatsue Bailey, Marie Ferguson, Andrew Gray, Thomas Oliver, Jennifer Samson, Rhonda Suka, Dione Swanson, and Jesse Tootell for their participation and feedback; the Data Management team members Michael Akridge, Troy Kanemura, Brooke Olenski, and Kevin Trick for their technical support; and CoralNet's application developers Stephen Chan, Oscar Beijbom and David Kriegman for their continuing guidance and support as we fully integrate CoralNet into our image analysis efforts. We would also like to thank the Automated Image Analysis Strategic Initiative (AIASI) and the Coral Reef Conservation Program (CRCP) for funding this project.

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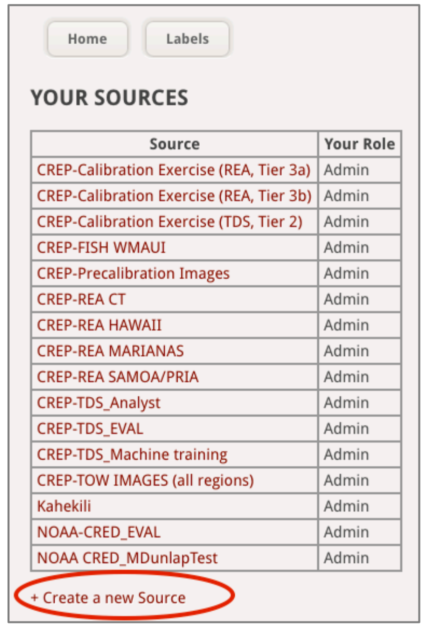
Winston M, Couch C, Ferguson M, Huntington B, Swanson D, Vargas-Ángel B. 2019. Ecosystem Sciences Division Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Benthic Surveys, 2018 Update. NOAA Tech. Memo. NOAA-TMNMFS-PIFSC-92, 66 p. doi:10.25923/w1k2-0y84

Appendices

APPENDIX 1: Creating a new source

1. Log in to your CoralNet user account.
2. On your Home page, click on **+ Create a New Source link** found at the bottom of the Source list box.
3. In the CREATE A NEW SOURCE page, fill in the necessary Source information. For ESD image analysis purposes, we use the following information:



<u>**General Information**</u>

- **Name**: ESD-*region* (previously CREP-*region*, e.g. "CREP-REA SAMOA")
- **Visibility**: Private
- **Affiliation**: Ecosystem Sciences Division
- **Description**: Coral reef surveys by the Ecosystem Sciences Division at the US National Oceanic and Atmospheric Administration (NOAA), Pacific Island Fisheries Science Center (PIFSC)

<u>**Location Keys**</u>

- **Key 1**: Region
- **Key 2**: Island
- **Key 3**: Site
- **Key 4**: Analyst

<u>**Image Annotation**</u>

- **Default image height**
  Default image height coverage (centimeters): 100
- **Default image annotation area**
  Left boundary X: 2.5% Right boundary X: 97.5%
  Top boundary Y: 2.5% Bottom boundary Y: 97.5%
- **Point generation method**
  Point generation type: Stratified Random (Random within a cell of the annotation area)
  Number of cell rows: 2
  Number of cell columns: 5
  Points per cell: 1
- **Level of alleviation**
  Confidence threshold (%): 100

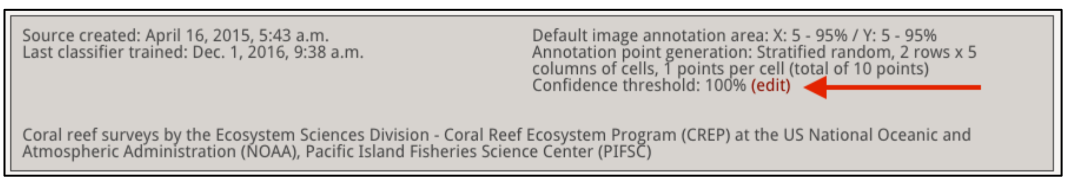
Note: The confidence threshold level can be changed (i.e., decreased) after an adequate number of images have been manually annotated to satisfactorily *train the classifier. This will allow the robot to help with more annotations. For ESD that number of images was between 8,000 and 10,000; see Appendix 4 for more guidance on adjusting the confidence threshold.*

- **Feature extractor**
  Feature extractor: EfficientNet (default) (legacy sources were created with the VGG16 extractor).

  Note: In 2021, the CoralNet development team released their new their computer vision backend in CoralNet 1.0 (formally CoralNet Beta). This new backend uses a more modern neural network architecture that is faster and 2-3% more accurate than its predecessor.

World Location
Latitude: *region dependent*
Longitude: *region dependent*
You can also search the region/area's coordinates from latlong.net

4. Click on **Save Changes**. You will be redirected to your newly created Source.
5. On the Source page, check that the entered Source information is correct. The Source page information and annotation settings can be modified by clicking on the **(edit) link** next to "Confidence threshold".



APPENDIX 2: Creating a calibration source

1. Create a Source page strictly for Calibration Exercises. To do so, follow Appendix 1 on "Creating a Source."
2. To upload a calibration exercise **with fixed points and annotations** from a previous calibration exercise photoset:
   a. Copy all the images where the calibration exercise was based, to a folder on your local drive. This photoset is typically 100 randomly-selected images from a region or a set of islands.
   b. Using a batch file renaming program (e.g., Bulk Rename Utility), rename each set of 100 images by adding a suffix of the analyst's 3 or 2-letter initials (e.g., "PLM").

      Example:
      ROS-03_A_13_**PLM**.JPG
      ROS-23_A_07_**PLM**.JPG
      ROS-409_A_15_**PLM**.JPG
      ROS-422_A_25_**PLM**.JPG
      ROS-427_A_03_**PLM**.JPG

      Repeat this process until each analyst, who participated (or will participate) in the calibration exercise has annotated their own set of images. That is, if there are 100 calibration images and 5 analysts, you will be uploading 500 images to CoralNet, with each image file renamed with each of the analysts' initials (image file names uploaded to the same Source page on CoralNet must be unique).

   c. Create the associated **image metadata file.**

      Note: For ESD, the Data Manager generates the image metadata file. This file contains 10 metadata values, 4 of which correspond to the Location Keys specified when entering the Source information. For non-ESD users, refer to CoralNet's <u>upload instructions</u> to obtain information on manually entering image metadata values or automating metadata fields based on the image file names.

   d. Create a points/annotations CSV file based on the data copied from the results of each of the analysts' previous calibration exercise using the following guidelines:

      The CSV file should have one row per point. The first row must contain column headers that specify which column is which.
      Example:

Name	Row	Column	Label
ROS-03_A_13_**PLM**.JPG	853	486	*CCAH
ROS-03_A_13_**PLM**.JPG	1646	465	*MOBR
ROS-03_A_13_**PLM**.JPG	325	1011	*TURFH
ROS-03_A_13_**PLM**.JPG	1619	1176	*TURFH

ROS-03_A_13_**PLM**.JPG	1013	1743	*ACBR
ROS-03_A_13_**PLM**.JPG	1333	1300	*MOBF
ROS-03_A_13_**PLM**.JPG	374	2251	*UNK
ROS-03_A_13_**PLM**.JPG	1760	1984	*UNK
ROS-03_A_13_**PLM**.JPG	900	2577	*TURFH
ROS-03_A_13_**PLM**.JPG	1126	2534	*POEN

Name is the image name. *Row* is the pixel row of the point. *Column* is the pixel column of the point. *Label* is the label code used to annotate the point. (Label is optional. If specified, both a point and an annotation will be created. If not specified, only a point will be created).

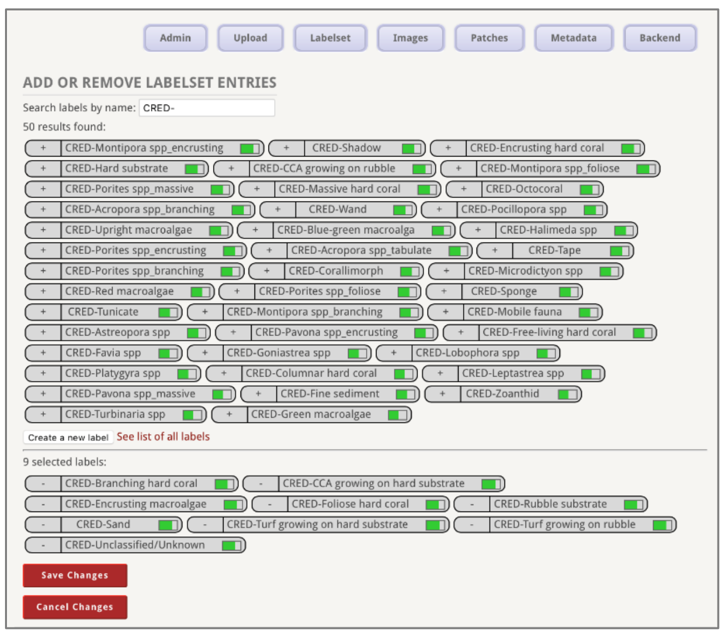
e. When all the image files, metadata, and points/annotations CSV files are ready, click on the blue "**Upload**" button to upload the images and metadata (See upload steps in section IV. CoralNet Image Analysis User Guide: Uploading Images and Metadata on page 8.
f. Return to the main Upload page by clicking on the blue "**Upload**" button.
g. Click on the "**Upload Points/Annotations**" button
h. Under "**CSV file**," click on the "**Choose files**" button, navigate to the folder where the points/annotations CSV file is stored, and select the CSV file.
i. Click on "**Save points/annotations**," then click on the blue "**Upload**" button to upload more images/metadata, or click on the Source name to return to the home page.

APPENDIX 3: Creating a labelset

CoralNet has a table with over 5,500 labels (as of 2021) created by users of different public and private CoralNet Sources. Each label is currently categorized among 7 functional groups (e.g. Other Invertebrates, Hard Coral, Soft Substrate, Hard Substrate, Other, Algae, Seagrass). For consistency with the ESD's historical benthic image analysis-derived data, new labels were created on CoralNet that afforded a one-to-one match with the program's previous image analysis benthic categories. Each ESD label name includes a "CRED" or "CREP" prefix (e.g., "CRED-Isopora"), and its corresponding short code includes an asterisk (*) prefix (e.g., "*ISSP").

1. From your Source home page, click on the blue "**Labelset**" button.

2. Click on "**Choose labels for your labelset**".
3. Type "CRED" or "CREP" on the search bar, and select (click on the + sign) any or all of the pre-made labels.



4. When all the labels have been selected, scroll down to the bottom of the table and click on the "**Create Labelset**" button. You will be redirected to a table containing your Source's Labelset.
5. To edit your Labelset, scroll down to the bottom of the table and click on the "**Add/Remove labels**" button. Select or deselect the appropriate labels and when done, scroll down to the bottom of the table and click "**Save Changes**" button. Once the LabelSet has been finalized, click on the Source's name to return to the home page.

Full list of ESD-CREP Tier 3c labels and shorts codes (to see all of the ESD's Tiers see Appendix 7):

Name	Short Code	Functional Group
CRED-Acanthastrea spp	*ACAS	Hard coral
CRED-Acropora spp_branching	*ACBR	Hard coral
CRED-Acropora spp_tabulate	*ACTA	Hard coral
CRED-Astrea spp	*ASTS	Hard coral
CRED-Astreopora spp	*ASSP	Hard coral
CRED-Branching hard coral	*BR	Hard coral
CRED-Columnar hard coral	*COL	Hard coral
CRED-Coscinaraea spp	*COSP	Hard coral
CRED-Cyphastrea spp	*CYPS	Hard coral
CRED-Diploastrea spp	*DISP	Hard coral
CRED-Echinophyllia spp	*ECHL	Hard coral
CRED-Echinopora spp	*ECHP	Hard coral
CRED-Encrusting hard coral	*ENC	Hard coral
CRED-Euphyllia spp	*EUSP	Hard coral
CRED-Favia spp	*FASP	Hard coral
CRED-Favites spp	*FAVS	Hard coral
CRED-Foliose hard coral	*FOL	Hard coral
CRED-Free-living hard coral	*FREE	Hard coral
CRED-Fungia spp	*FUSP	Hard coral
CRED-Galaxea spp	*GASP	Hard coral
CRED-Goniastrea spp	*GONS	Hard coral
CRED-Goniopora/Alveopora spp	*GOAL	Hard coral
CRED-Heliopora spp	*HCOE	Hard coral
CRED-Hydnophora spp	*HYSP	Hard coral
CRED-Hydrocoral	*HYCO	Hard coral
CRED-Isopora spp	*ISSP	Hard coral
CRED-Leptastrea spp	*LEPT	Hard coral
CRED-Leptoria spp	*LPHY	Hard coral
CRED-Leptoseris spp	*LESP	Hard coral
CRED-Lobophyllia spp	*LOBS	Hard coral
CRED-Massive hard coral	*MASS	Hard coral
CRED-Merulina spp	*MESP	Hard coral
CRED-Millepora spp	*MISP	Hard coral
CRED-Montipora spp_branching	*MOBR	Hard coral
CRED-Montipora spp_encrusting	*MOEN	Hard coral
CRED-Montipora spp_foliose	*MOFO	Hard coral
CRED-Oulophyllia spp	*OUSP	Hard coral
CRED-Pachyseris spp	*PACS	Hard coral
CRED-Pavona spp_encrusting	*PAEN	Hard coral
CRED-Pavona spp_foliose	*PAFO	Hard coral
CRED-Pavona spp_massive	*PAMA	Hard coral
CRED-Phymastrea spp	*PHSP	Hard coral

Name	Short Code	Functional Group
CRED-Platygyra spp	*PLSP	Hard coral
CRED-Plerogyra spp	*PLER	Hard coral
CRED-Pocillopora spp	*POCS	Hard coral
CRED-Porites spp_branching	*POBR	Hard coral
CRED-Porites spp_encrusting	*POEN	Hard coral
CRED-Porites spp_foliose	*POFO	Hard coral
CRED-Porites spp_massive	*POMA	Hard coral
CRED-Psammocora spp	*PSSP	Hard coral
CRED-Stylophora spp	*STYS	Hard coral
CRED-Symphyllia spp	*SYSP	Hard coral
CRED-Turbinaria spp	*TURS	Hard coral
CRED-Anemone	*AMNE	Other Invertebrates
CRED-Bivalve	*BI	Other Invertebrates
CRED-Bryozoan	*BRY	Other Invertebrates
CRED-Corallimorph	*CMOR	Other Invertebrates
CRED-Giant clam	*GC	Other Invertebrates
CRED-Octocoral/Wire coral	*OCTO	Other Invertebrates
CRED-Sponge	*SP	Other Invertebrates
CRED-Tunicate	*TUN	Other Invertebrates
CRED-Unclassified sessile invertebrate	*UI	Other Invertebrates
CRED-Zoanthid	*ZO	Other Invertebrates
CRED-Fine sediment	*FINE	Soft Substrate
CRED-Sand	*SAND	Soft Substrate
CRED-Hard substrate	*HARD	Hard Substrate
CRED-Rubble substrate	*RUB	Hard Substrate
CRED-CCA growing on hard substrate	*CCAH	Hard substrate
CRED-CCA growing on rubble	*CCAR	Hard substrate
CRED-Turf growing on hard substrate	*TURFH	Hard substrate
CRED-Turf growing on rubble	*TURFR	Hard substrate
CRED-Mobile fauna	*MOBF	Other
CRED-Shadow	*SHAD	Other
CRED-Tape	*TAPE	Other
CRED-Unclassified\Unknown	*UNK	Other
CRED-Wand	*WAND	Other
CRED-Asparagopsis spp	*ASPP	Algae
CRED-Avrainvillea spp	*AVSP	Algae
CRED-Blue-green macroalga	*BGMA	Algae
CRED-Brown macroalgae	*BRMA	Algae
CRED-Caulerpa spp	*CAUL	Algae

Name	Short Code	Functional Group
CRED-Dictyopteris\Dictyota spp	*DICO	Algae
CRED-Dictyosphaeria spp	*DICT	Algae
CRED-Encrusting macroalgae	*EMA	Algae
CRED-Green macroalgae	*GRMA	Algae
CRED-Halimeda spp	*HALI	Algae
CRED-Lobophora spp	*LOBO	Algae
CRED-Microdictyon spp	*MICR	Algae
CRED-Neomeris spp	*NEOM	Algae
CRED-Padina spp	*PADI	Algae
CRED-Peyssonnelia spp	*PESP	Algae
CRED-Red macroalgae	*RDMA	Algae
CRED-Seagrass	*SG	Algae
CRED-Upright macroalgae	*UPMA	Algae

*Note: You can also import a premade labelset (Tier 3c) by clicking on "**Import a labelset from a CSV file**."*

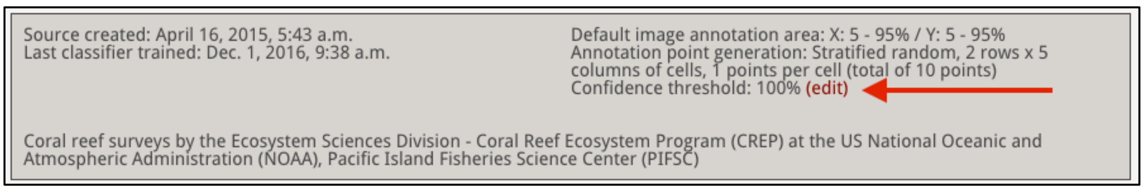
APPENDIX 4: Adjusting confidence threshold

During annotation, the CoralNet classifier automatically provides annotation suggestions with a level of confidence displayed in light grey. The Source Administrator is tasked to regularly check the classifier's performance by clicking on backend tab to periodically assess the accuracy of automated annotation and the percent confidence of those suggestions, before adjusting the classifier's confidence threshold for automated annotation. For ESD, the number of images that were manually annotated to provide an acceptable Tier 1 cover estimate was 8,000 – 10,000 images. To adjust the confidence threshold for a source, follow the steps below:

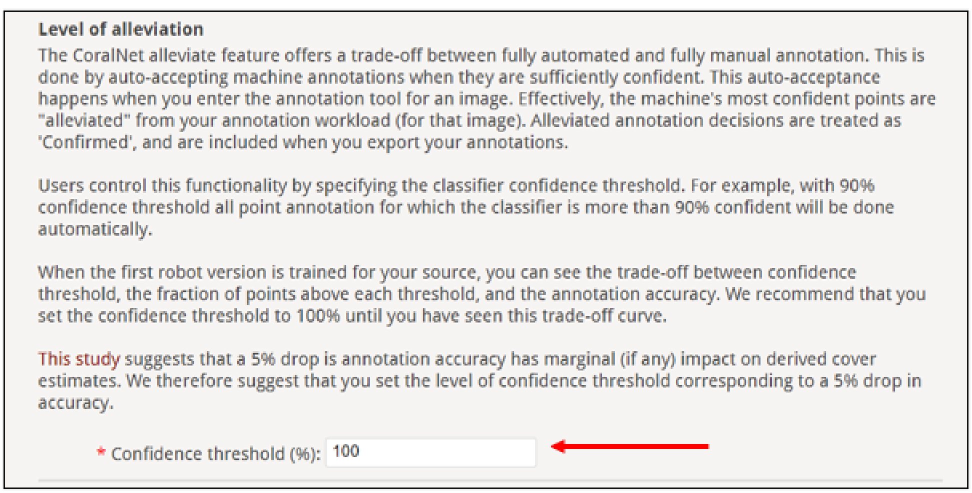
1. Open the source homepage that you wish to edit

2. Edit the source settings by clicking the red "**edit**" button next to "**Confidence threshold**"

   *Note: Editing the source can only be done by a user that has been designated as an "**Admin**" for that source. If you are not the Admin, contact the Data Manager to discuss adjusting the confidence threshold.*



3. Scroll down to the "**Level of alleviation**" section and set the "**Confidence Threshold**" to your desire percentage.



4. Scroll to the bottom of the Edit Source page and click "**Save Changes**"

APPENDIX 5: Summarizing CoralNet Data

The Ecosystem Sciences Division uses an R code that summarizes raw CoralNet annotations into benthic cover estimates at both Tier 1 and Tier 3c levels of resolution. Benthic cover is computed at the photo level by estimating the proportion of each benthic category to the total number of points annotated per photo, excluding those points falling on TAPE or WAND. The code output includes photo-level benthic cover estimates for Tier 1 and Tier 3c categories. If you are interested in the code ESD uses to summarize their data, contact their CoralNet data manager to request access.

APPENDIX 6: Identification Guides

Classification Guide (Tier 3c) for Rapid Ecological Assessment (REA) Images

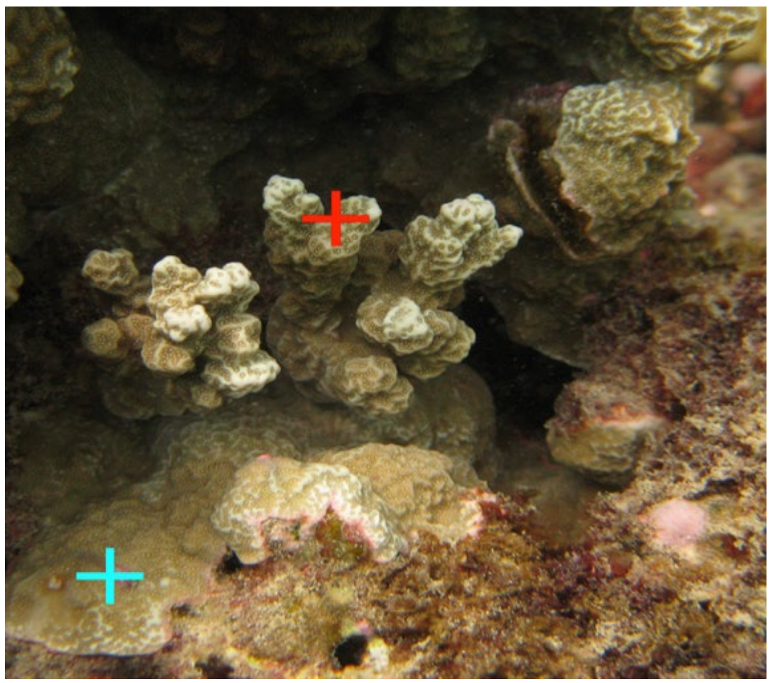
ESD uses a hierarchical system to classify benthos. This system has three different levels, or 'Tiers' (see Appendix 7). **Tier 1** is the most general level, with categories such as Coral, Sediment, Invertebrate, and Macroalgae. **Tier 2** subdivides these groups into a mix of taxonomic and ecological functional designations. For example, Invertebrate is divided into taxonomic groups such as Anemone, Bivalve, and Sponge. Corals are divided functionally by growth form, into categories such as Branching, Encrusting, and Massive. **Tier 3** was developed to further divide Tier 2 groups into more specific categories such as coral and algal genera, and some combined taxon-functional group designations (e.g. *Porites* spp. massive/non-massive, *Montipora spp.* encrusting/non-encrusting.). Some Tier 2 functional groups were retained in the Tier 3 classification in instances where a precise identification was not possible. Tier 3 classification was implemented by the ESD's benthic team from 2013 to 2015. It was the result of the merging of numerous disparate yet similar benthic image analysis classification strategies that were used historically within the program and its research partners. After practical experience, Tier 3 was refined, and **Tier 3b** was developed and used during 2016 and 2017. Some coral genera and mid-level taxonomic groups for coral (e.g., *Porites* massive, *Pavona* encrusting) and algae (e.g., red algae (*Rhodophyta*) were added and unused algal genera were removed from Tier 3b.

In 2018, **Tier 3c** was implemented with the addition of two new coral genera (*Astrea* and *Phymastrea*) and removal of the coral genera *Montastraea* (dissolved). The category "Unknown Soft Coral" was also merged with Octocoral to become "Octocoral/Wire coral."

This classification guide provides a comprehensive list of benthic categories (Tier 3c) specific to image analysis (corresponding functional/morphological Tier 2 group mappings are presented in Appendix 7). The list includes a summary of category definitions and sample photos. Categories are presented as groups per their Tier 1 designation (i.e., Coral, Soft Coral, Invertebrate, Macroalgae, Crustose Coralline Algae, Turf Algae, Sediment, Mobile Fauna, Unclassified, and Tape/Wand). Within each designation, groups are presented with generic groups first, followed by functional or broad taxonomic groups if applicable. Within those categories, groups are presented alphabetically. This is the labeling system ESD has established for our program; however, we suggest identifying the taxonomic identification level that works best for your program or project.

CORAL

a) The taxa classified under this category include all Scleractinian corals, the blue octocoral *Heliopora coerulea* and hydrozoans such as *Millepora* because they form carbonate skeletons that contribute to coral reef formation and accretion.
b) If possible, corals should be identified to genera (e.g., *Pocillopora, Favia*). If it is not possible to identify a coral to this level, identify it by its growth form (e.g., branching, encrusting). Also, under Tier 3c classification, three genera (*Montipora, Pavona,* and *Porites*) are further subdivided into growth forms (e.g., *Montipora* spp. branching, encrusting, and foliose). Descriptions below provide details about these categories.
c) If a point falls on a colony that has multiple growth forms, classify the point based on the morphology directly under the point rather than the overall colony morphology.



NOAA

Coral Genera

The codes given for categories in this section are used to identify them at the Tier 3c. The corresponding functional/morphological Tier 2 group mappings are presented in Appendix 7.

***Acanthastrea* spp. (ACAS)**

Colonies most often occur in shallow reef environments and they have encrusting or massive morphologies and are usually flat. Colonies have thick “fleshy-looking” tissue over skeleton. Corallites are cerioid or subplocoid, monocentric, either circular or angular in shape. Septo-costae are thick near the corallite wall, thinning near the columella, and have tall mussid teeth. Polyps are thick-walled, and tentacles are extended only at night. These corals are common.

guamreeflife.com

***Acropora* spp._branching (ACBR)**

Colonies are most often found in shallow reef environments, reef flats, and upper reef slope habitats. This category includes staghorn, bushy, and digitate colonies. Branch tips often have a different shade/color than the rest of the colony. Polyp tentacles are usually only extended at night. These corals are common and include: *A. intermedia*, *A. abrontanoides*, *A. globiceps*, and *A. retusa*.

guamreeflife.com; aims.gov.au

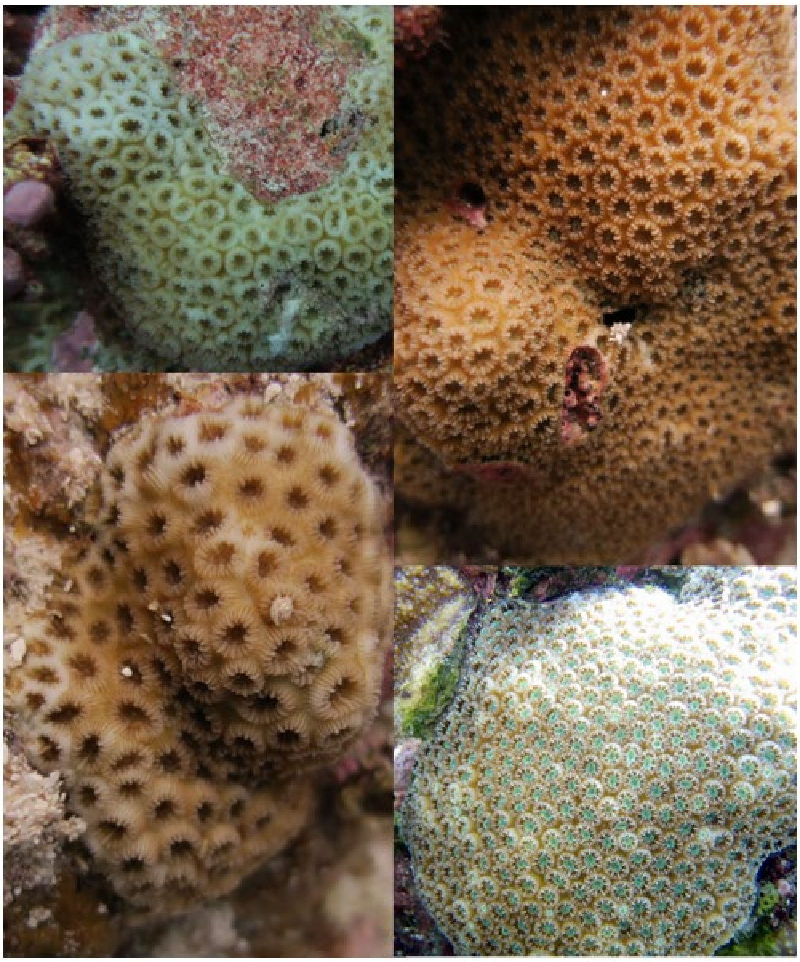
Acropora spp._table (ACTA)

Colonies are most often found in shallow reef environments, reef flats, and upper reef slope habitats. Plate-like or table-like morphology with encrusting bases encompass this category. Plate edges often appear lighter in color than the rest of the colony. Polyp tentacles are usually extended only during the night. These corals are common and include: *A. cytherea*, A. hyacynthus, *A. paniculata.*

aims.gov.au; guamreeflife.com; NOAA photos

***Astrea* spp. (ASTS)**

Formerly grouped in the genus *Montastraea,* these corals tend to form mounding or encrusting colonies. Corallites are small, circular, have well developed paliform lobes, and do not share walls. Extra-tentacular budding is often observed and the corallites are more exsert than *Phymastrea* sp. Colonies are usually pale in color.



NOAA Photos

***Astreopora* spp. (ASSP)**

Found in many reef environments including protected water areas, these colonies have massive, laminar, or encrusting morphology. Corallites are generally conical — they can be evenly spaced and uniform or face different directions with mixed sizes yielding a "chaotic appearance." These corals are abundant.

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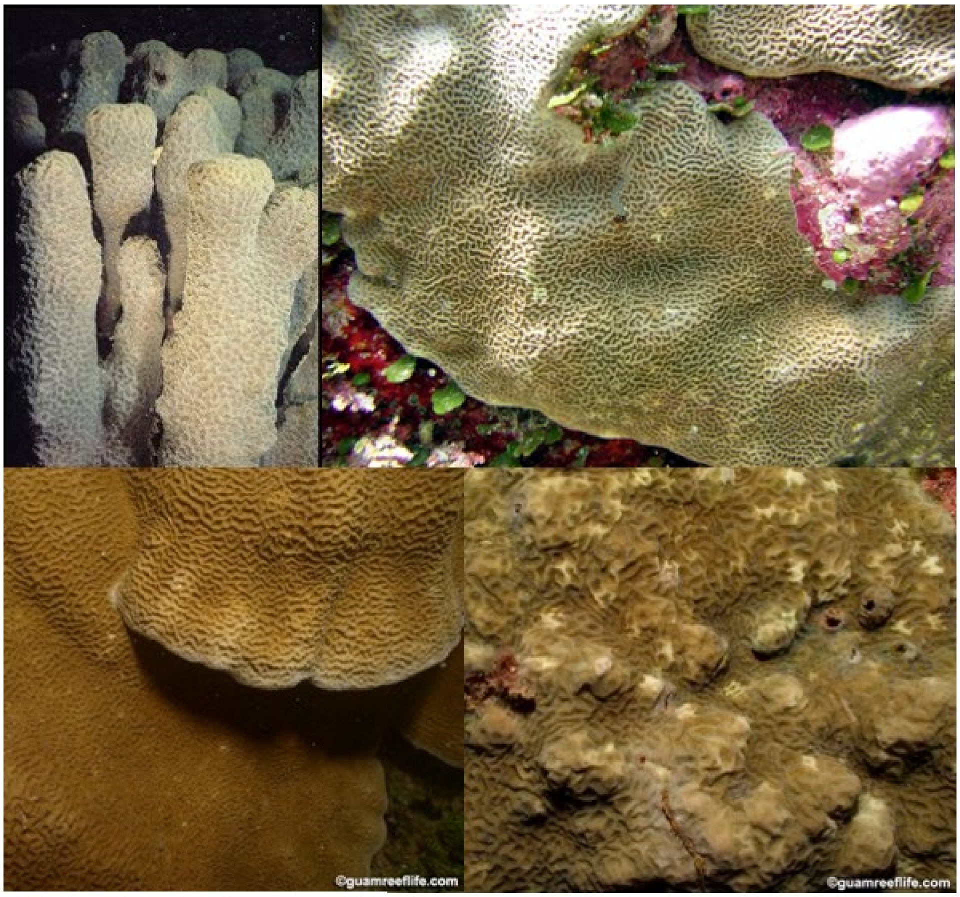
Coscinaraea **spp. (COSP)**
Colonies are often found in shallow reef habitats. Colonies have columnar, massive, encrusting, or laminar morphologies. Corallites are in short shallow valleys and have indistinct walls. Tentacles are often extended during the day, yielding a “fuzzy” appearance. Color is typically dark grey or brown. These corals are uncommon.



guamreeflife.com; aims.gov.au; NOAA photos

***Cyphastrea* spp. (CYPS)**

Colonies are found in nearly all reef environments, including rocky foreshores. Colonies have massive and encrusting morphologies. Corallites are conical or round and often have strongly alternating costae which are easily visible. Corallites may be widely spaced and are common.

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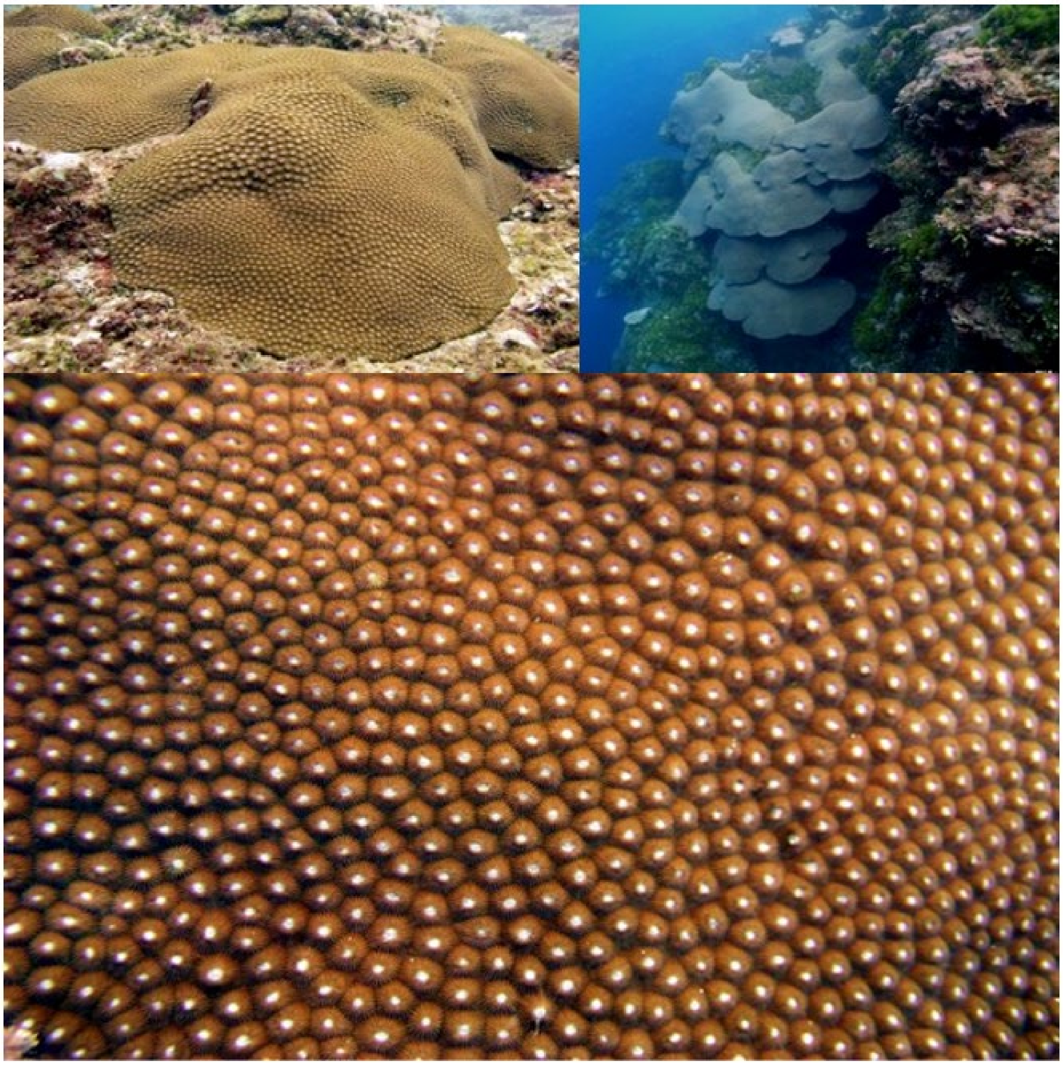
Diploastrea **spp. (DISP)**

Colonies are found in both exposed and protected reef environments. Colonies have massive and sub-massive morphologies. Massive colonies are often dome-shaped. Colonies can be very large (> 5 m diameter). Corallites are large, thick walled, and form low cones with small openings. Corallites are very uniform and tightly spaced. Colony skeleton is very dense. These corals are uncommon.



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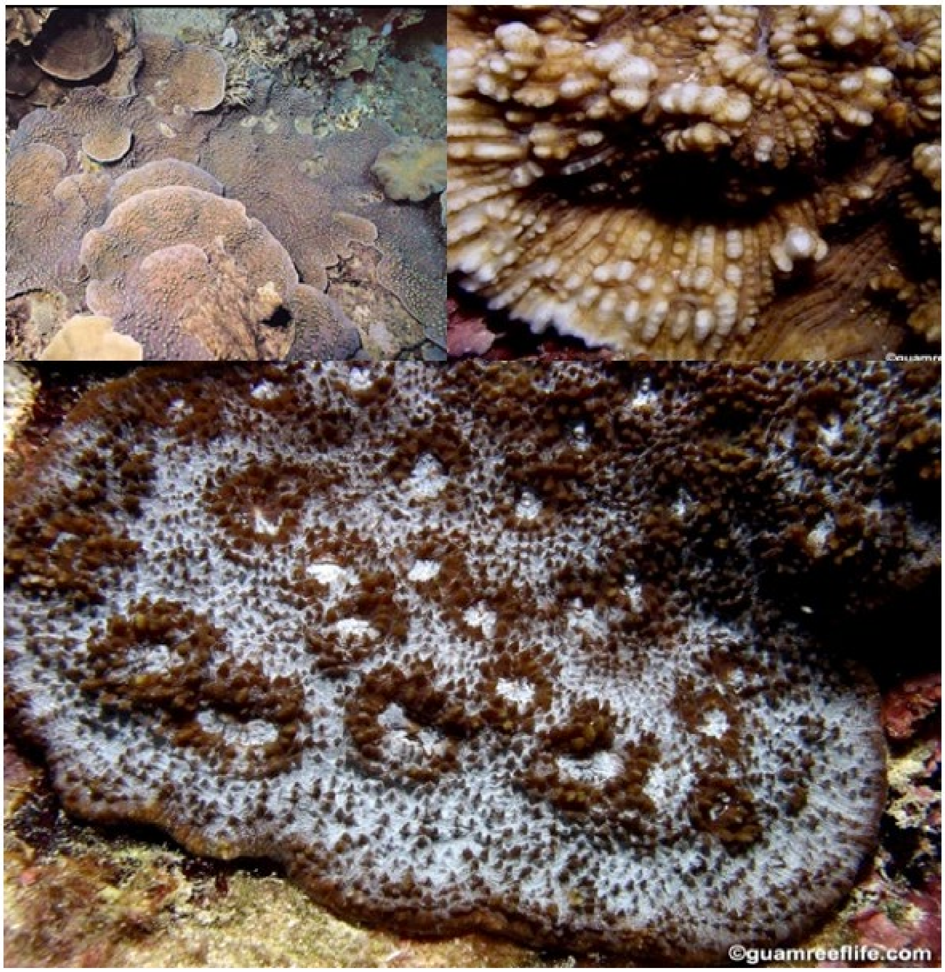
Echinophyllia* spp. (ECHL*)

Colonies are found in most reef environments, particularly on lower reef slopes and in lagoons. Colonies have encrusting or laminar morphologies, and may form whorls or have central parts that are hillocky. Corallites have toothed costae. Brown, green, and red color morphs are most common, with polyps usually having a red or green oral disc. These corals are common.



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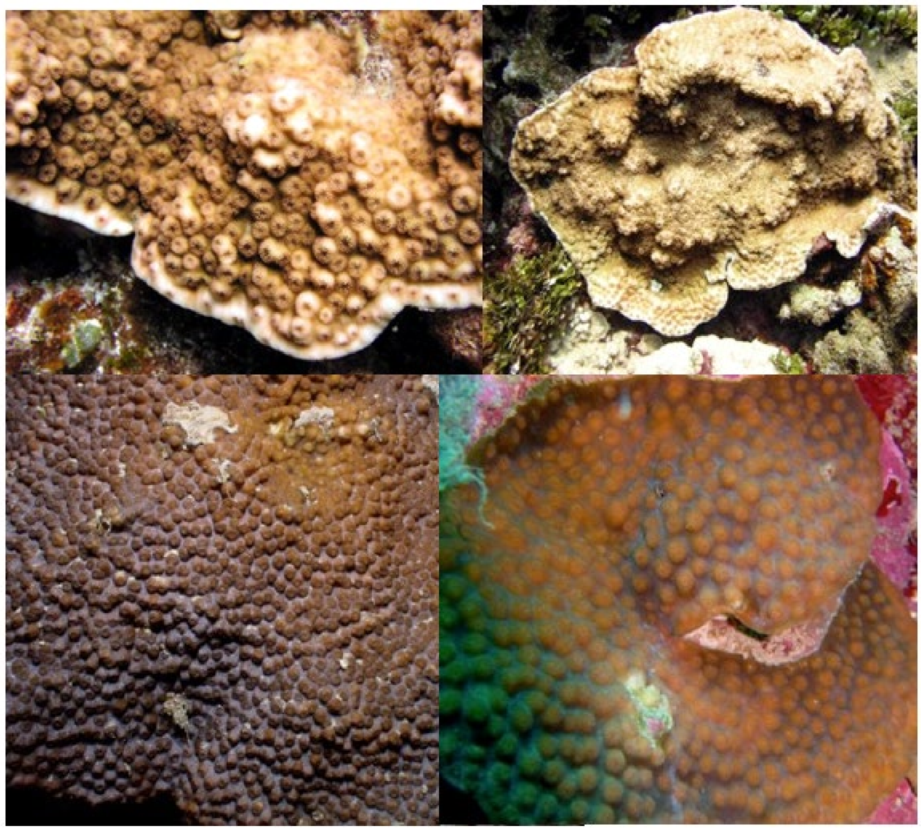
Echinopora spp. (ECHP)

Colonies are found in shallow reef environments. Colonies have encrusting, laminar (forming whorls or tiers), massive, or arborescent (tree-like) morphologies. Colonies may form large stands > 5 m across. Corallites are thin-walled and small. Coenosteum is often granulated, with a "sand-paper" like appearance; often amber, pale to dark brown, or greenish in color with darker brown or green calices. These corals are common.



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***Euphyllia* spp. (EUSP)**

Colonies have phaceloid or flabello-meandroid morphologies. Corallites are large (20 to 30 mm diameter) and widely spaced (15 to 30 mm apart). Corallites have thin walls with septa not exert and lacking columellae. Corallite structure cannot be seen with tentacles extended. Polyps have large tubular tentacles with knobby tips giving it an appearance similar to an anemone. These corals are relatively uncommon.

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***Favia* spp. (FASP)**

Colonies are found in most reef environments. Colonies typically have massive morphologies and can be flat or dome shaped. Corallites are usually monocentric and plocoid (not sharing walls). Corallites can vary in size between species from small (< 8 mm diameter), to medium (8 to 12 mm diameter), or large (> 12 mm diameter). Oral discs may have a similar or contrasting color to the rest of the polyp. These corals are common and abundant, such as *Favia stelligera*. They can appear similar to *Favites* or *Astrea* spp.

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***Favites* spp. (FAVS)**

Colonies are found in most reef environments. Colonies typically have massive morphologies and can be flat or dome shaped. Corallites are usually monocentric and ceroid, occasionally sub-plocoid. Corallites can vary in size between species, from very small (< 6 mm diameter), to small (6 to 10 mm diameter), medium (10 to 14 mm diameter), or large (> 14 mm diameter). Corallites usually have thick, shared walls. They are most similar in appearance to *Favia* spp. These corals are common.

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***Fungia* spp. (FUSP)**

Corals are often found on reef slopes and in lagoons. Corals are free-living/solitary, can be circular or elongate, and domed or flattened. They often have pits between costae on the lower surface. Primary septa begin with a tall tentacular lobe. Usually brown, blue, or yellow in color, they may have brighter tentacular lobes. These corals are common.

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***Galaxea* spp. (GASP)**
Colonies are found in protected reef environments. Colonies have massive, sub-massive, columnar, and encrusting morphologies. Colonies of some species can be very large: > 2 – 5 m across. Corallites do not share walls and can be elongated. Polyps have a "flower-like" appearance. Tentacles are usually extended during day. These corals are abundant.

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***Goniopora/Alveopora* spp. (GOAL)**

Colonies of both genera are found in many reef environments. *Goniopora*, which is more common, can be found in sub-tidal areas, lagoons, and protected reef slopes. Colonies have massive, branching, or encrusting morphologies and are irregular in shape. Polyps are large and fleshy, often extended both day and night. *In-situ*, the two genera can be distinguished by the number of tentacles: *Alveopora* (12) and *Goniopora* (24). It is often difficult to confidently distinguish *Alveopora* from *Goniopora* in images collected for photoquadrats; thus, both genera are classified under the same category.

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***Goniastrea* spp. (GONS)**

Colonies occur in shallow-water habitats, including the intertidal. Colonies usually have a spherical, massive morphology, but may form thick plates. Corallites are monocentric and ceroid to polycentric and meandroid. Corallites are round or four to six sided. Corallites may form ridges and valleys creating a “brain coral” like appearance. These corals are abundant, *Goniastrea edwardsi* is a good example.

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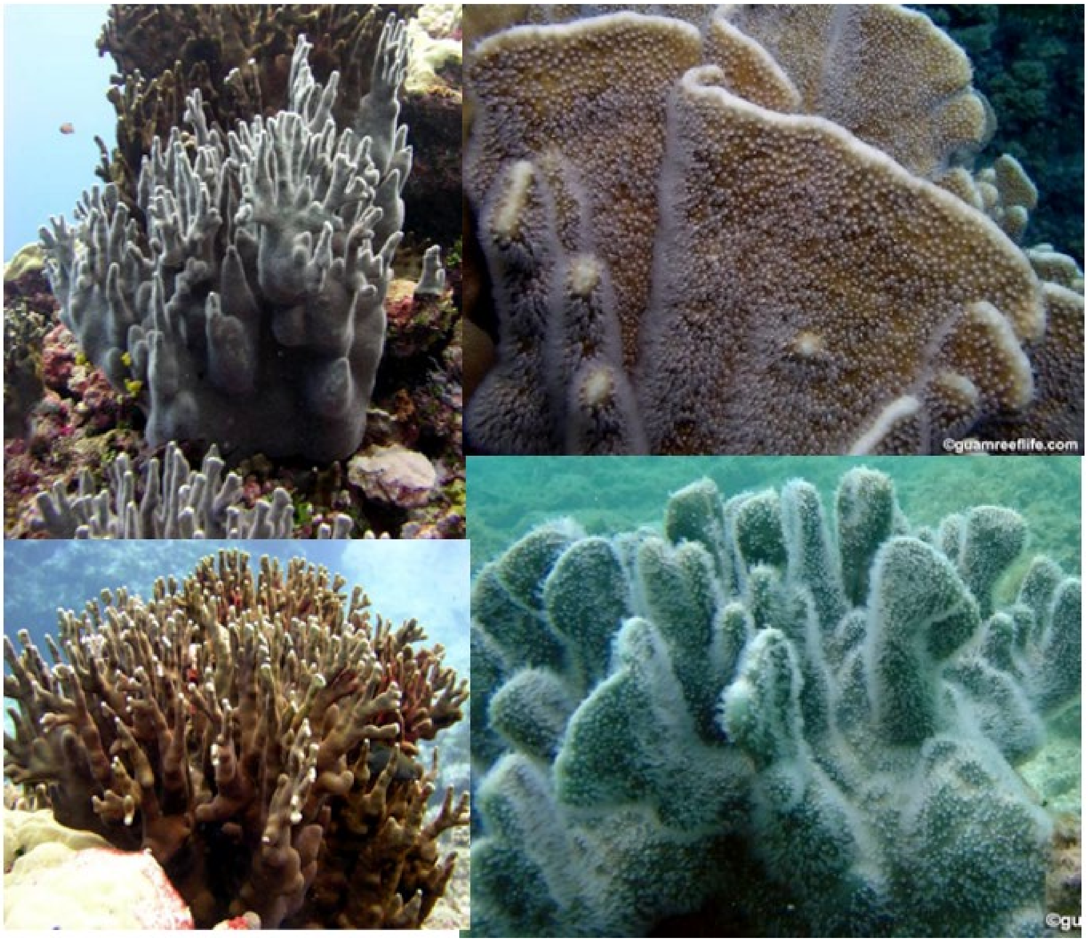
Heliopora spp. (HCOE)

This octocoral is commonly called Blue Coral. It is found in intertidal and subtidal environments with branching (flattened lobes) and columnar morphologies. It is brown to blue in color with a powder blue internal skeleton.



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Hydnophora spp. (HYSP)

These corals can be found in all reef habitats, but primarily occur in lagoons and protected areas. Colonies have massive, sub-massive, encrusting, or sub-arborescent morphologies. Characterized by the presence of monticules, hydnophores formed where sections of common wall between corallites intersect and develop into conical mounds. Short tentacles surround the base of each monticule and, in some species, may be extended both day and night. These corals are relatively common, including *H. microconnos*, *H. excesa*, and *H. rigida*.

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Hydrocoral (HYCO)

The category includes two genera that are a part of Class Hydrozoa, *Distichopora* and *Stylaster*. These small branching “lace corals” are azooxanthellate and are generally found in shaded areas, such as in crevices and around ledges.

arkive.org

***Isopora* spp. (ISSP)**

These corals were considered a subgenus of *Acropora* until recently. Colonies have branching or encrusting morphologies. Individual species can be distinguished only based on coenosteum microstructure. Polyps resemble those of *Acropora* species, but *Isopora* colonies lack the apical polyp on branch tips that is characteristic of *Acropora*. Skeleton is very heavy and dense with robust branches. The robustness is similar to the Atlantic *A. palmata* and they can be locally common; particularly, the ESA-listed *I. crateriformis*.

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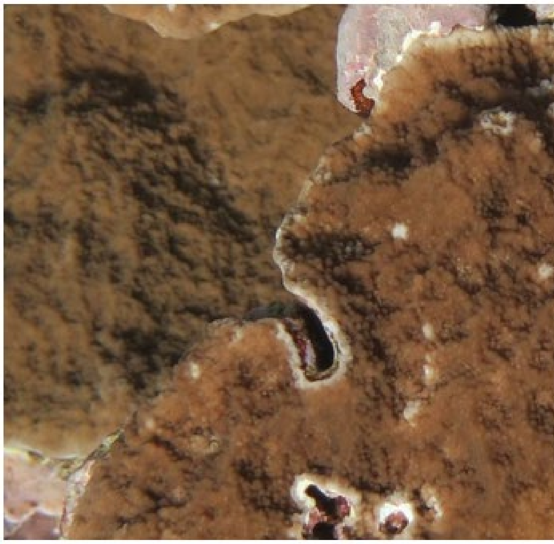
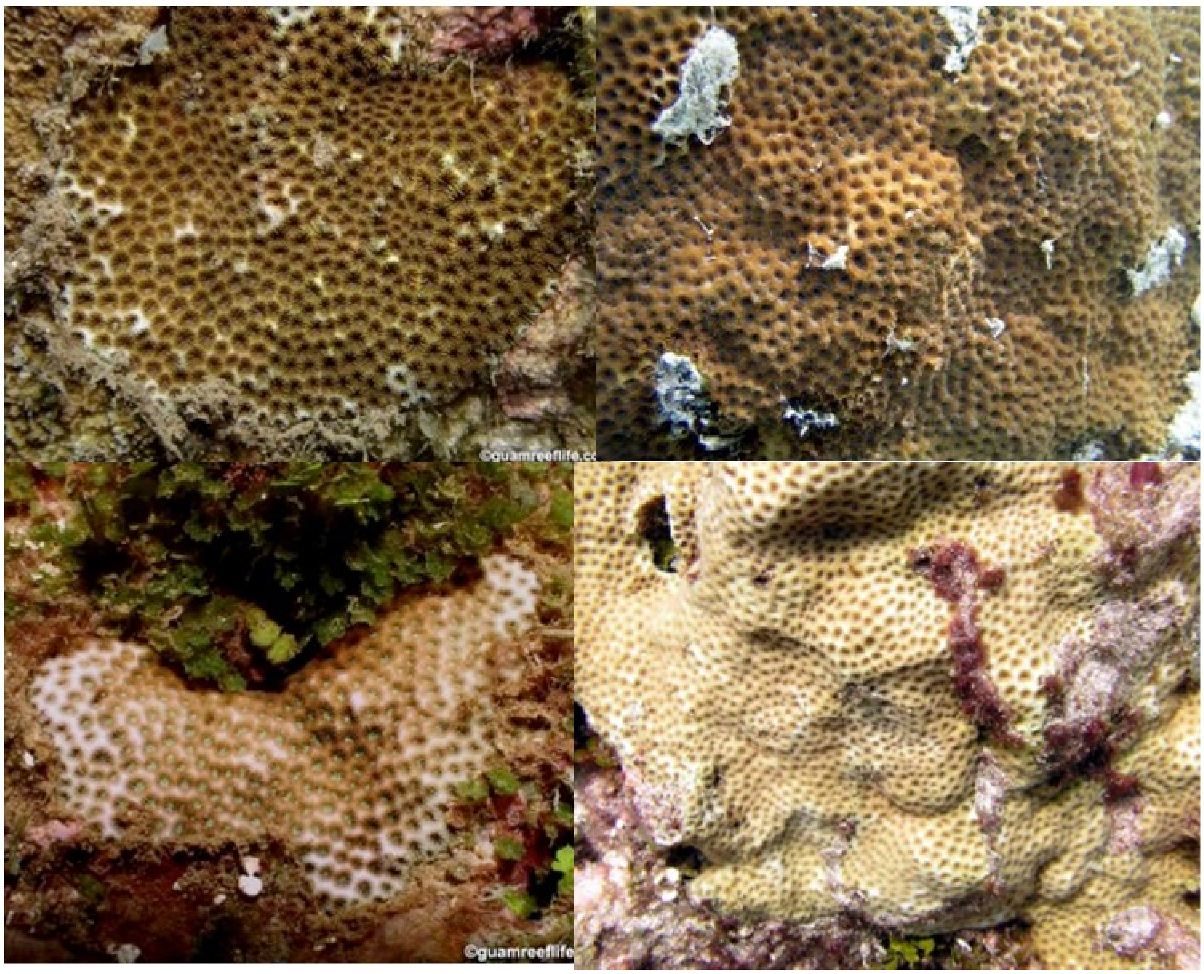


***Leptastrea* spp. (LEPT)**
Colonies are found in a wide variety of reef environments. Colonies are encrusting and are usually flat or dome-shaped. Corallites are small and cylindrical, separated by only a fine groove. Septa have inward projecting teeth. Tentacles may be extended during the day. Upper surfaces of intertidal colonies are usually pale. Surface has a “golf ball” like appearance. These corals are common. The most common species are *L. purpurea, L. pruinosa, L. bewikensis, and L. transversa.*



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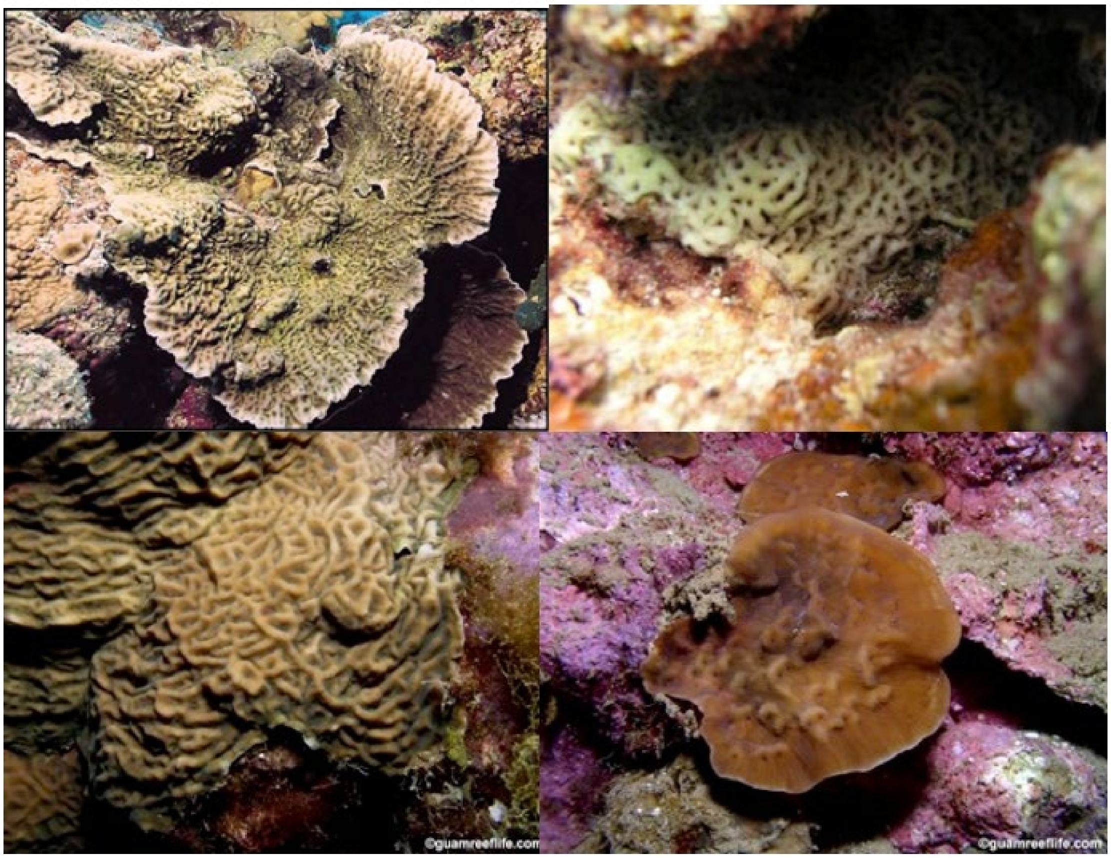
***Leptoseris* spp. (LESP)**

Colonies are found in many reef environments but are most often seen in shallow areas and on walls/overhangs. Colonies typically are unifacial and have laminar or encrusting morphologies. Corallites are shallow depressions with poorly defined walls. Septo-costae are thin and usually and radiate outward giving the colony a pin-striped appearance. Some laminar colonies have radiating ridges. These corals are common; corals in the genus *Pavona* can look morphologically similar.



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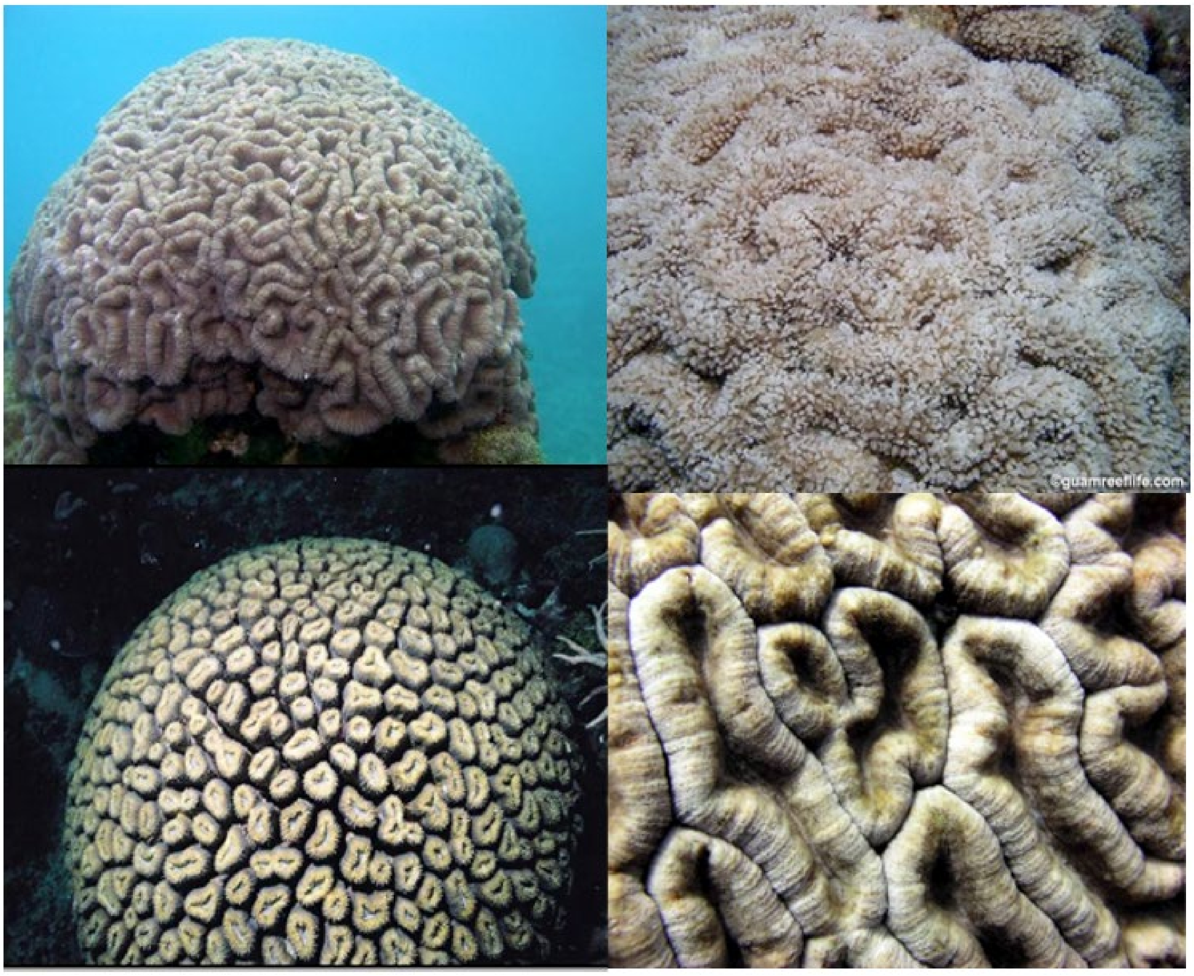
***Lobophyllia* spp. (LOBS)**

These corals are found in most reef environments. Colonies are usually monocentric and rarely polycentric; polyps are solitary and do not share walls. Septa slope up from columella to an indistinct wall, then costae slope down to the perimeter, giving the fleshy looking tissue a concentric pattern. Primary septa have large, regular, blunt teeth.



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***Leptoria* spp. (LPHY)**

Colonies are found in most reef environments including upper reef slopes and non-turbid areas. Colonies are massive to encrusting and exhibit sinuous valleys and neatly arranged, with equal septa. Collumnellae do not form centers. Colonies are cream, brown, or green in color with walls and valleys of contrasting colors; colonies have a "brain coral" appearance. These corals can be common; *L. phrygia* is the only coral in this genus.

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Merulina spp. (MESP)

Colonies are found in many reef environments, but predominantly in lagoons and forereefs. Colonies have laminar and sub-arborescent morphologies, which often occur simultaneously in large colonies. They have short, straight valleys which radiate from the center outward fan out before dividing. Flat surfaces often have concentric growth lines. They are often pale brown or bluish in color and are uncommon.

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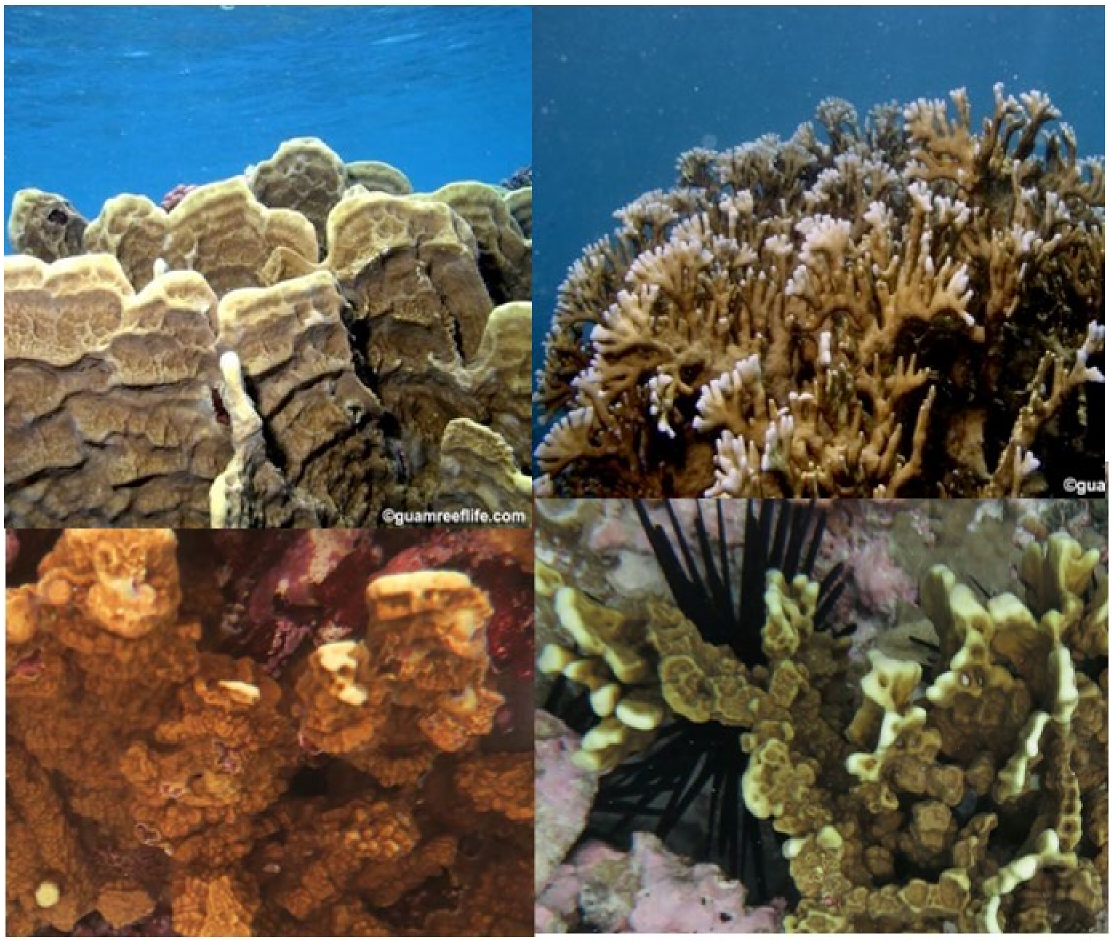
***Millepora* spp. (MISP)**

These hydrozoans are commonly called Fire Coral and are found in many reef environments. They have encrusting, branching, columnar, and sub-massive morphologies and are orange, tan, brown, or pale in color. Branch tips and edges are sometimes lighter in color or white. They will “burn” (sting) skin if touched and leave welts.



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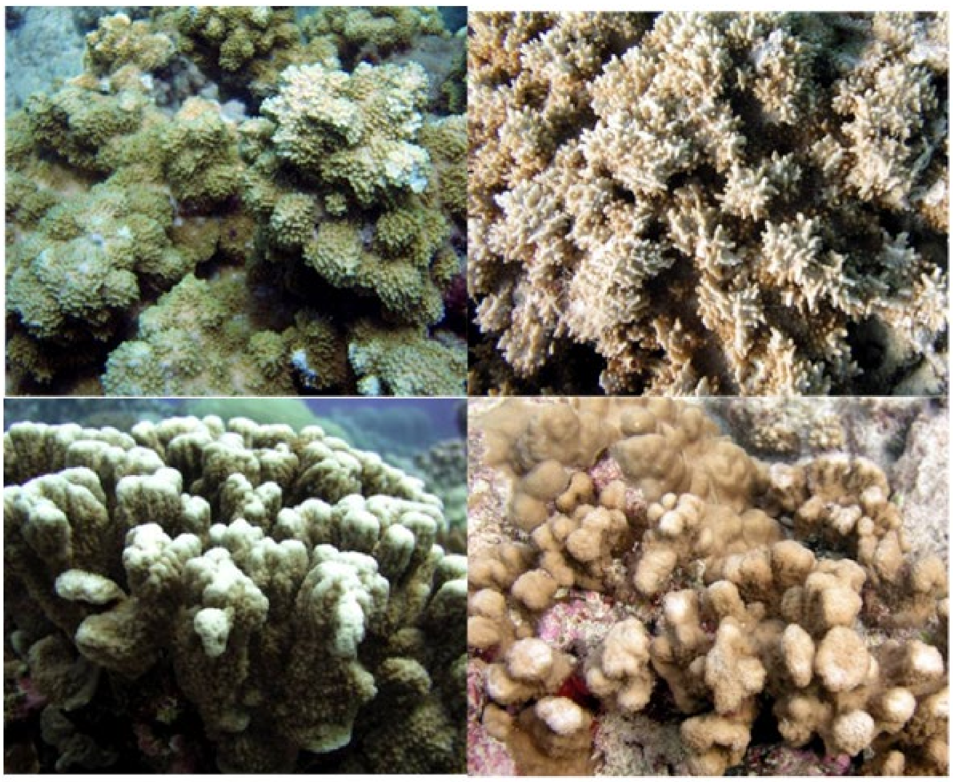
***Montipora* spp._branching (MOBR)**
Found in most reef environments including upper reef slopes, under overhangs and within crevices. Colonies in this category exhibit a branching/arborescent morphology. May have smooth or knobby surface with immersed corallites. Some species have tuberculae (Rice-Krispy looking bumps). Commonly brown and cream colors, but may be blue or purple. Some brown colonies will have polyp tentacles that are blue/purple. Abundant. This category includes the following species: *M. capitata*, *M. incrassata,* and *M dilatata.*



***Montipora* spp._encrusting (MOEN)**

These corals are found in most reef environments including upper reef slopes, under overhangs, and within crevices. Colonies in this category exhibit an encrusting morphology. They may have a smooth or knobby surface with immersed corallites. Some species have tuberculae (Rice-Krispy looking bumps). Though commonly brown and cream colors, they may also be blue or purple. Some brown colonies have polyp tentacles that are blue/purple. This type of coral is abundant. This category includes the following species: *M. grisea, M. capitata, M. flabellata, M. patula, M. caliculata,* and *M. dilatata.*

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Montipora spp._foliose (MOFO)

These corals are found in most reef environments including upper reef slopes, under overhangs, and within crevices. Colonies in this category exhibit a foliose or laminar morphology. They may have a smooth or knobby surface with immersed corallites. Some species have tuberculae (Rice-Krispy looking bumps). Though commonly brown and cream colors, they may also be blue or purple. Some brown colonies will have polyp tentacles that are blue/purple. This type of coral is abundant, including *M. capitata.*

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Oulophyllia spp. (OUSP)

Colonies are found in most reef environments, especially lagoons and forereefs. Colonies generally have a massive morphology and are monocentric to meandroid. Colonies may be large, > 1 m diameter, and have broad valleys with widely spaced "ragged" septa and thin walls. They are similar in appearance to "Brain coral". Valleys are V-shaped and have sharp upper margins. Tentacles extend only at night, and when retracted, the polyps have a coarse "reptilian" texture. These corals are common.

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***Pachyseris* spp. (PACS)**

Colonies are unifacial or bifacial laminae, usually horizontal, but may develop upright ridges or columns. More than one row of corallites may occur between ridges. Columnellae are absent. These corals are pale brown to deep grey in color and abundant over a wide range of habitats. Colonies are seldom over 2 m in diameter.

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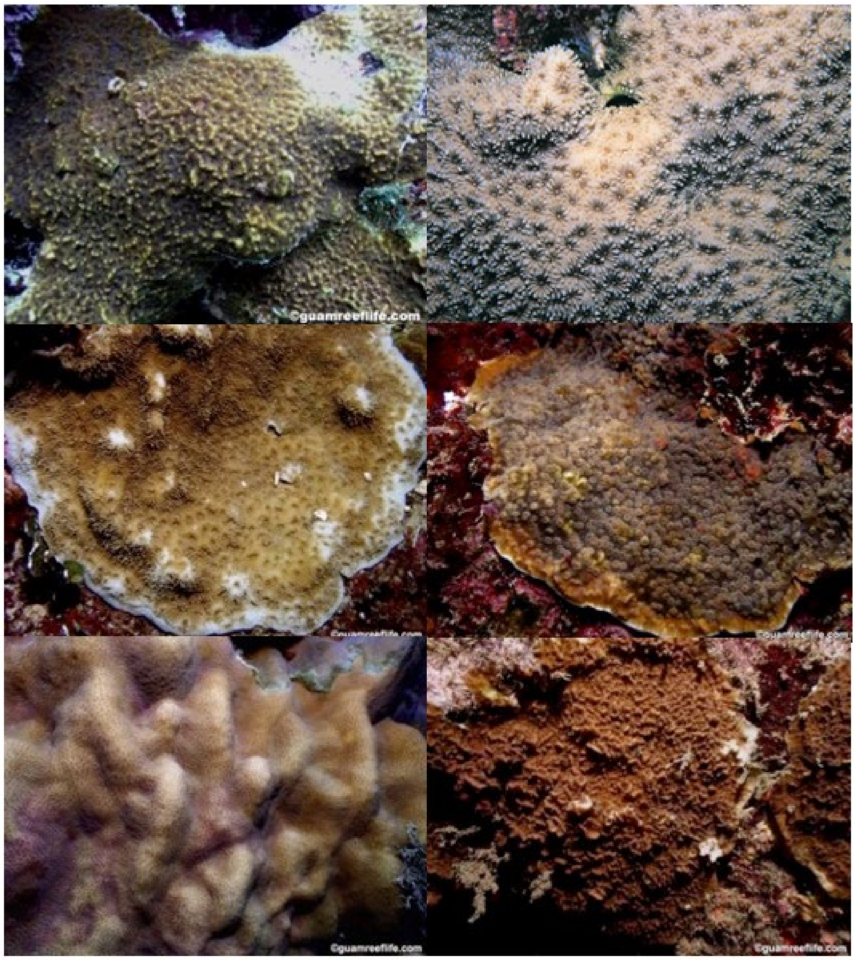
***Pavona* spp._encrusting (PAEN)**

Colonies are found in many reef environments including shallow, high current, and strong wave action areas. Colonies in this category exhibit an encrusting morphology. Corallites are deep and often have a “star-like” appearance. Primary septa are very exsert. These corals are abundant. Common species in this category are *P. chiriquiensis, P. maldivensis,* and *P. varians.*



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***Pavona* spp._foliose (PAFO)**

Colonies are found in many reef environments including shallow, high current, and strong wave action areas. Colonies in this category exhibit a laminar or foliose morphology. Corallites are deep and often have a “star-like” appearance. Primary septa are very exsert. These corals are abundant.

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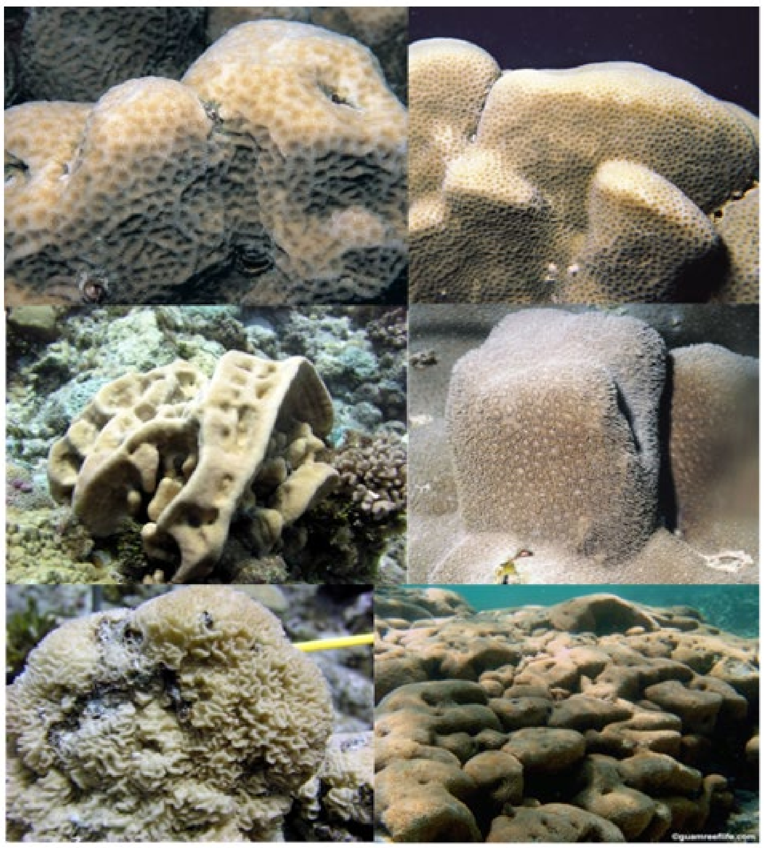
***Pavona* spp._massive (PAMA)**
Colonies are found in many reef environments including shallow, high current, and strong wave action areas. Colonies in this category exhibit massive and sub-massive morphologies. It is important to note that massive does not necessarily describe the *size* of the colony; it is a description of the *growth form.* PAMA is used for parts of colonies that possess a solid, thick shape that is neither encrusting nor foliose. Corallites are deep and often have a "star-like" appearance. Primary septa are very exsert. These corals are abundant, including *P. duerdeni.*



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***Phymastrea* spp. (PHSP)**

These corals were formerly grouped in the genus *Montastrea* and are found in most reef environments. Colonies are typically mounding or encrusting and may be flat or dome-shaped. Corallites are monocentric and plocoid, and are formed by extra-tentacular budding. *Phymastrea* corallites tend to be larger than *Astrea*, and often have bright green oral discs with contrasting septa.

aims.gov.au; NOAA Photos

***Platygyra* spp. (PLSP)**

Colonies are found in most reef environments. They generally have a massive morphology and may be flat or dome-shaped. Corallites are usually meandroid; septa are uniformly exsert and evenly spaced. Colonies have contrasting valley floors and may be pale along the ridge tops. They are similar in appearance to "brain coral" and are abundant.

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***Plerogyra* spp. (PLER)**
These corals are found in shallow, protected reef environments, particularly in turbid water. Colonies are either branching, forming phaceloid colonies, or flabello-meandroid with valleys connected by a light blistery coenosteum. Living parts of colonies may be separated by dead basal parts. Vesicles are approximately the size of grapes and often the same shape, but may be tubular, bifurcated, or irregular, depending primarily on the state of inflation. These corals are uncommon.

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***Pocillopora* spp. (POCS)**

Colonies are found in many reef environments. Colonies have branching morphologies and are covered with verrucae with immersed corallites. Tentacles are most often extended at night. These corals are abundant. The most common species are *P. damicornis*, *P. grandis*, *P. meandrina*, *P. verrucosa,* and *P. ligulata.*

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***Porites* spp._branching (POBR)**

Colonies can be found in many reef environments including along fringing reefs, reef slopes, back reef areas, and lagoons. Colonies in this category exhibit a branching morphology. Colonies can grow to be very large (>5 m diameter). Corallites are generally small and immersed. These corals are often yellow to gold to brown in color and are abundant. The most common species in this category are *P. compressa, P. cylindrica, P. lichen, P. rus.*

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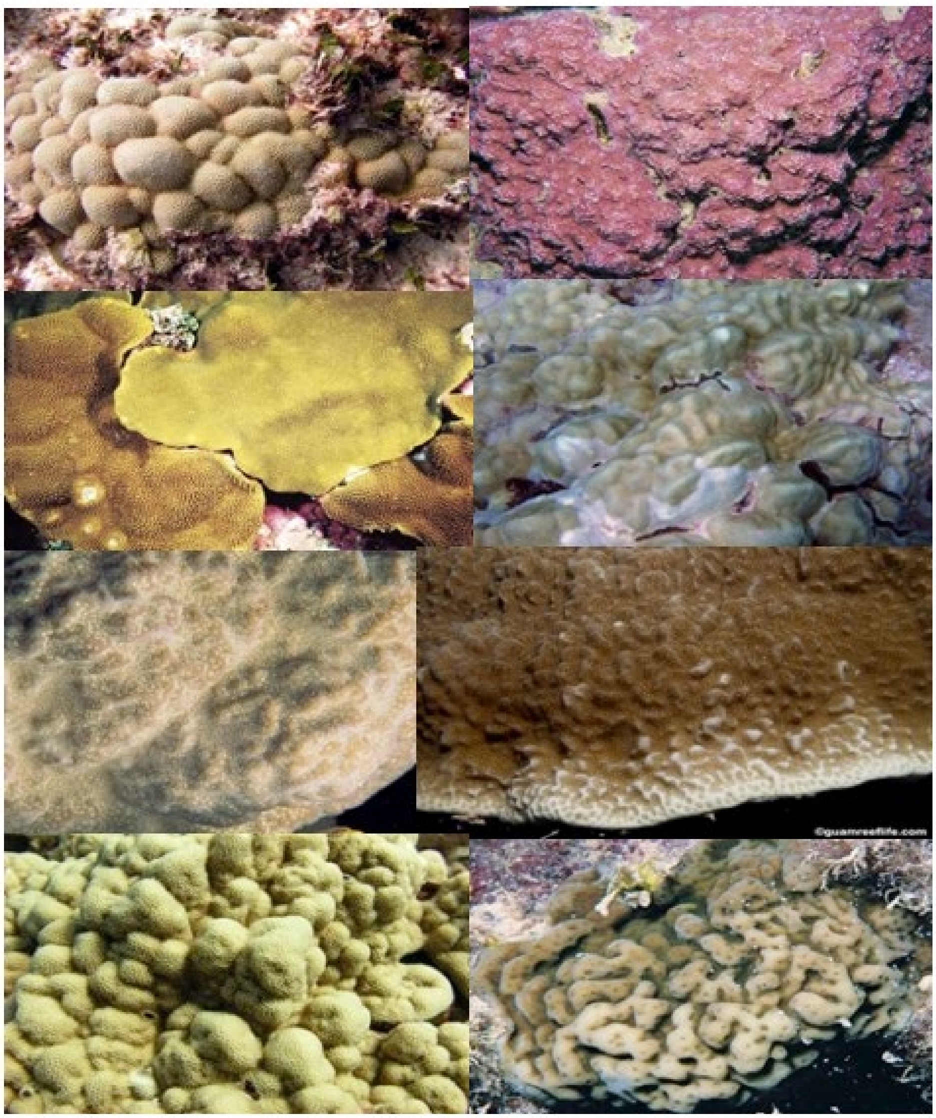
***Porites* spp._encrusting (POEN)**

Colonies can be found in many reef environments including along fringing reefs, reef slopes, back reef areas and lagoons. Colonies in this category exhibit an encrusting morphology. Colonies can grow to be very large (> 5 m diameter). Corallites are generally small and immersed. These corals are often yellow to gold to brown in color and are abundant. The most common species in this category are: *P. lobata, P. lutea, P. lichen, P. monticulosa,* and *P. rus.*



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***Porites* spp._foliose (POFO)**

Colonies can be found in many reef environments including along fringing reefs, reef slopes, back reef areas and lagoons. Colonies in this category exhibit a laminar or foliose morphology. Colonies can grow to be very large (> 5 m diameter). Corallites are generally small and immersed. These corals are often yellow to gold to brown in color and are abundant. The most common species in this category are: *P. monticulosa* and *P. rus*.

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***Porites* spp._massive (POMA)**

Colonies can be found in many reef environments including along fringing reefs, reef slopes, back reef areas and lagoons. Colonies in this category exhibit massive and sub-massive morphologies. Colonies can grow to be very large (> 5 m diameter). Corallites are generally small and immersed. Surface may be knobby. These corals are often yellow to gold to brown in color and are abundant. The most common species in this category are: *P. lobata* and *P. lutea.*

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***Psammocora* spp. (PSSP)**

Colonies are found in shallow reef environments particularly ones exposed to strong wave action. Colonies have massive, columnar, laminar, or encrusting morphologies. Corallites are often situated at the bottom of depressions/short valleys or can be distributed independently of valleys. Colony surface often has a "rough" or "pocked" appearance. These corals are often grey or brown in color but can also be brightly colored, and they are common. The most common species are *P. profundacella, P. nierstraszi,* and *P. stellata.*

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***Stylophora* spp. (STYS)**

Colonies are most commonly found in shallow reef environments including areas exposed to strong wave action. Colonies have branching to sub-massive morphologies. Corallites can be immersed, hooded, or conical. Colonies are uniform in color and can be cream, pink, blue, or green. These corals resemble a "smooth *Pocillopora* sp." and they are abundant.

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***Symphyllia* spp. (SYSP)**

Colonies are found on reef slopes and fringing reefs. They have meandroid morphology and are generally flat or dome shaped. Ridges and valleys are large and wide (>10 mm). A groove usually runs along the top of the walls. Septa are large with long teeth. Ridges/walls and valleys are usually contrasting in color and resemble "brain coral."

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***Turbinaria* spp. (TURS)**

Often found in shallow fringing reef environments, rocky foreshores, and upper reef slopes, these colonies have laminar or encrusting morphologies. Laminar morphologies can be irregular, forming whorls and cups. Corallites are widely spaced and can be immersed to conical. These corals are common to abundant.

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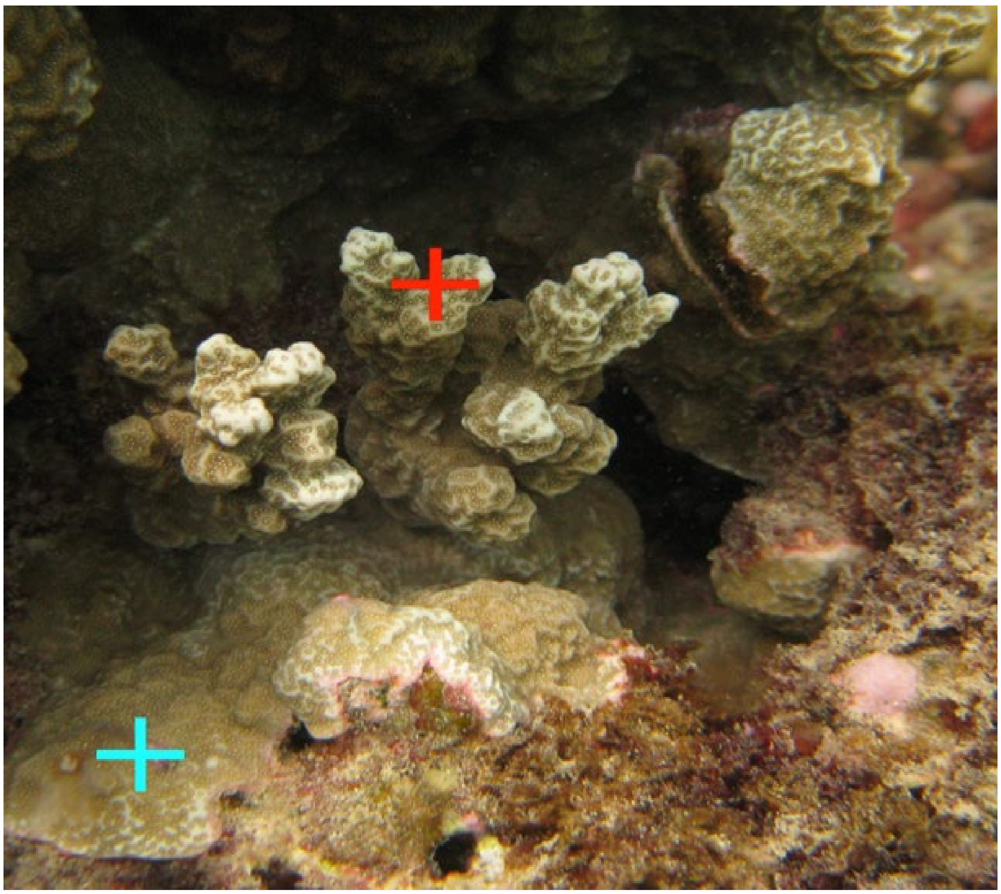
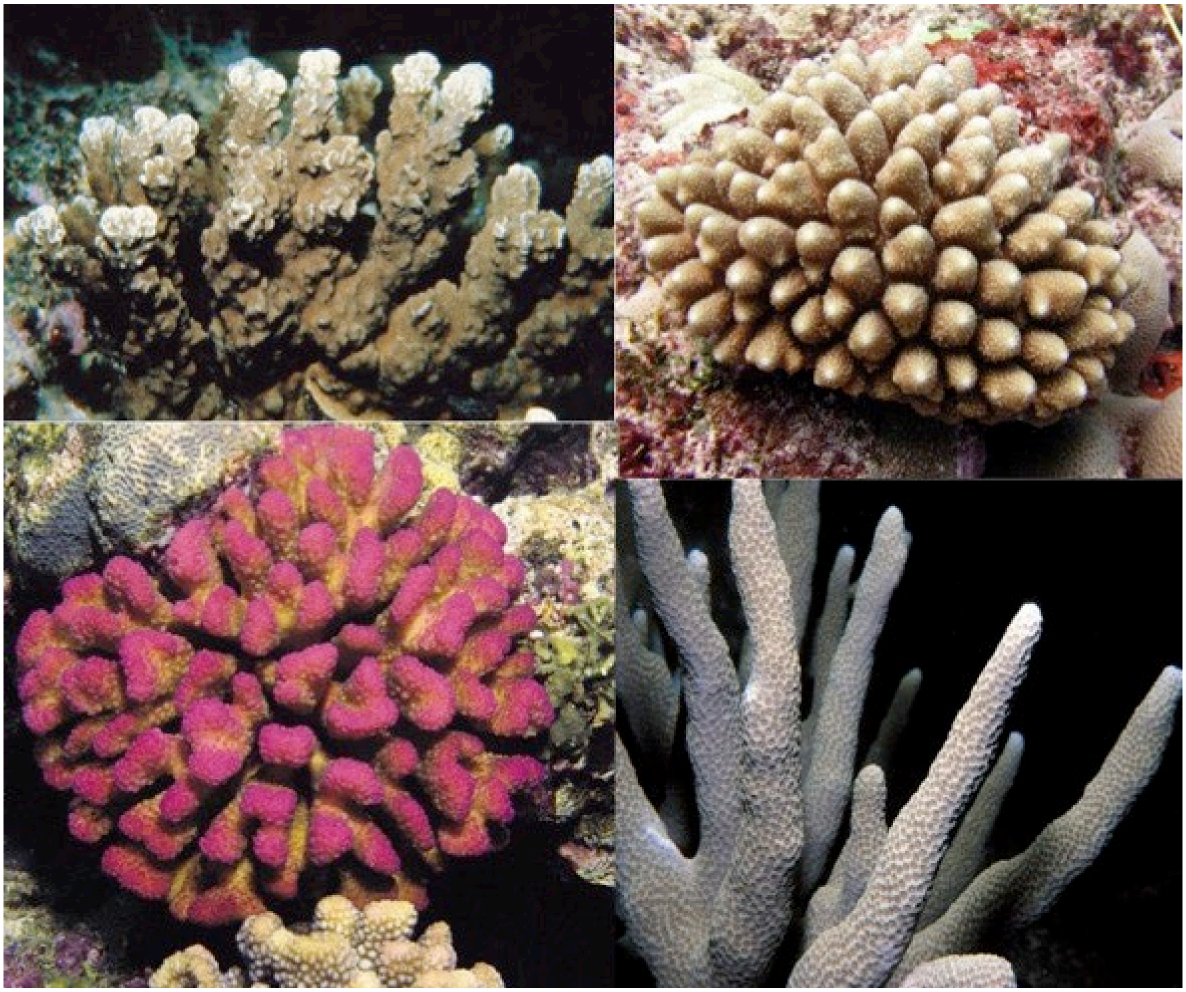
CORAL FUNCTIONAL GROUPS

If a point falls on a coral colony that cannot be identified to its genus, it should be identified by the growth form underneath that point. Some colonies may have different growth forms in different areas. If this occurs, you should identify the growth form underneath each point that falls on the colony. Thus, identifications of points from an individual colony may differ. For example, in the image below, if the coral underneath the red marker cannot be identified to genus, it would be recorded as BR, while the blue marker would be recorded as ENC.



NOAA photos

Branching hard coral (BR)
This group consists of corals that form large, arborescent (tree-like) colonies which exhibit elongated branched projections; corals with smaller, stubby and compact branches with finger-like (digitate) protrusions should also be classified as branching morphology.



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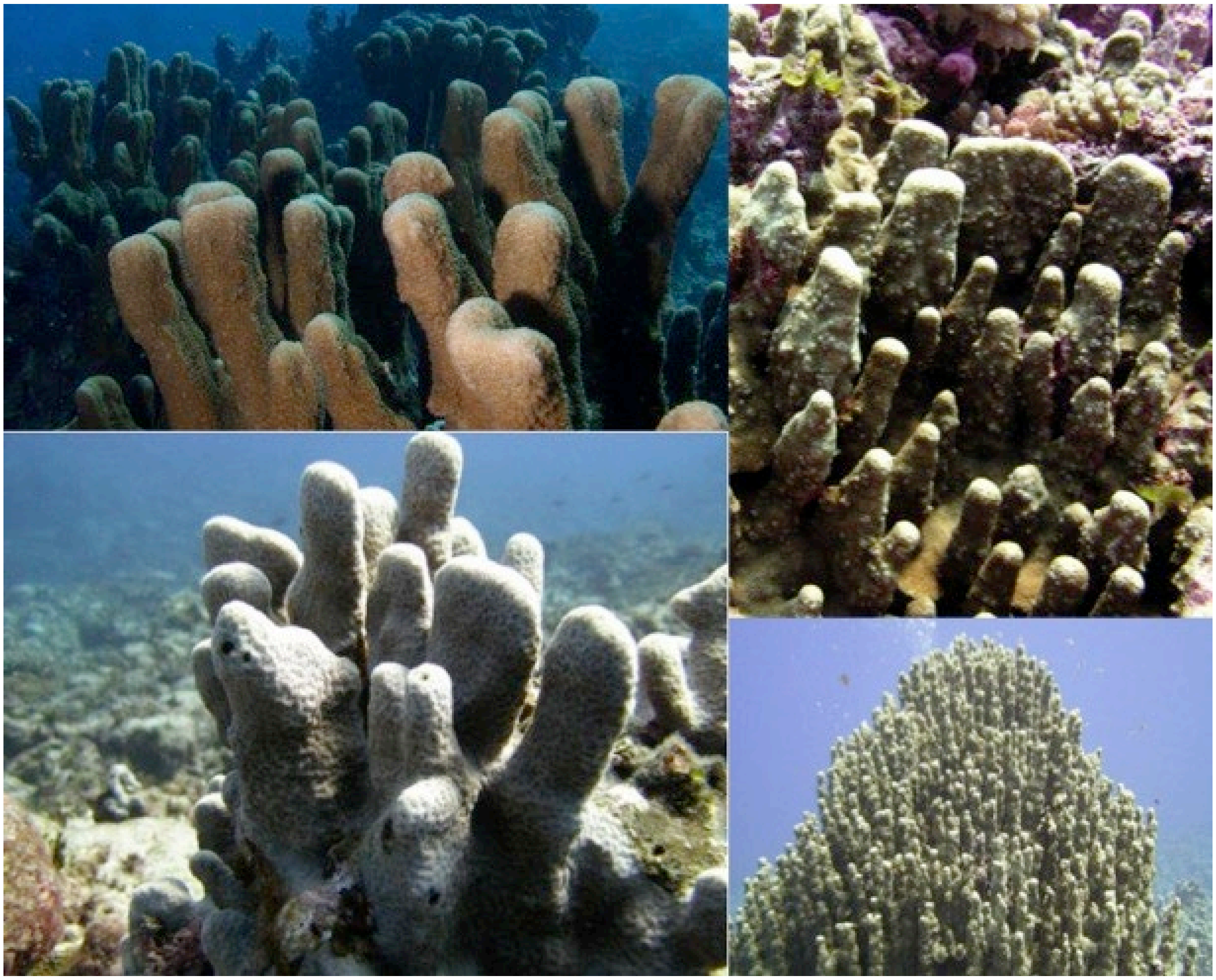
Columnar hard coral (COL)
Some coral colonies, generally massive- and encrusting-looking, can exhibit club-like or column-like up-growths; these colonies should be classified as having a columnar morphology.



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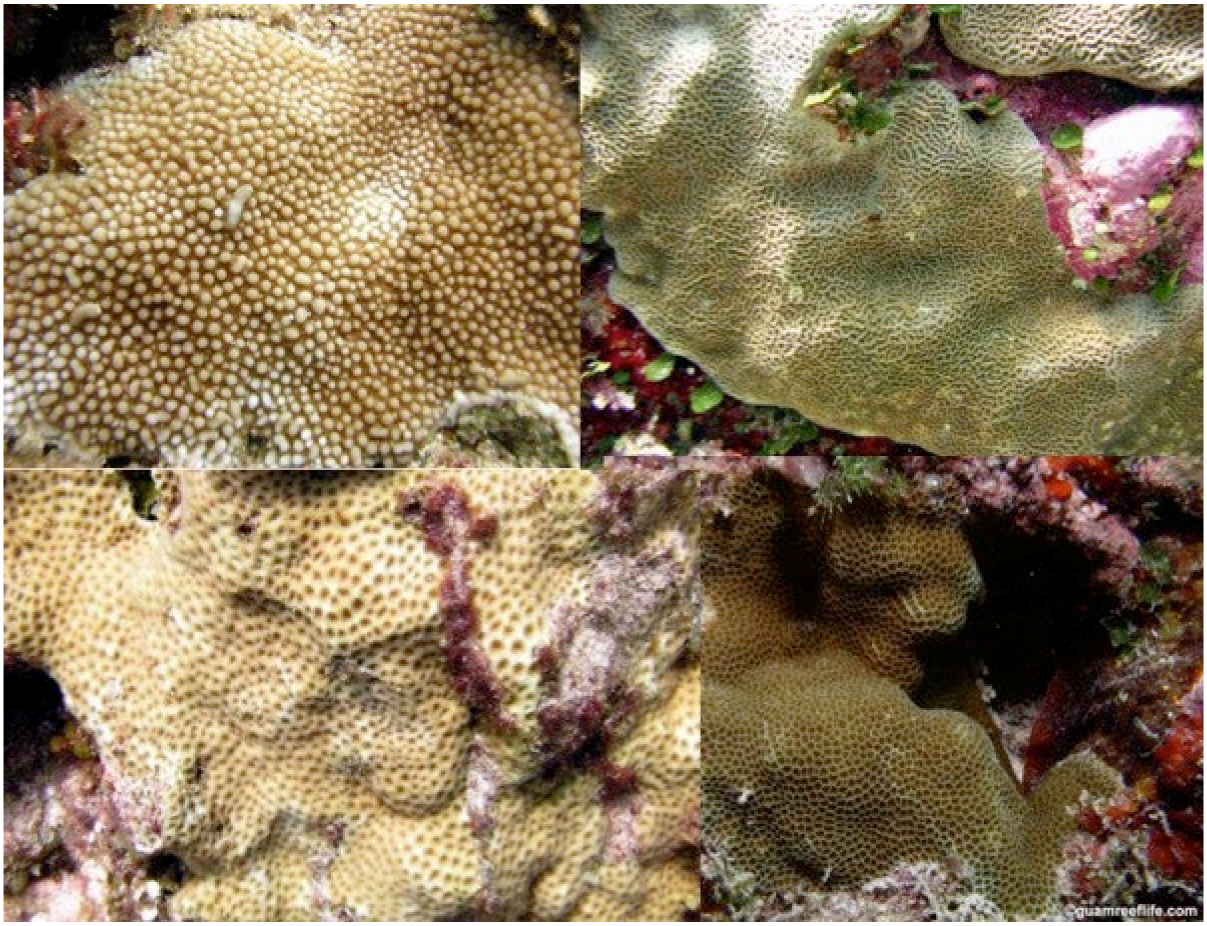
Encrusting hard coral (ENC)

Coral colonies with encrusting morphology are those with flattened, thick or thin sheets/plates that adhere to and follow the contour of the substrate. Colony surfaces often range from smooth to rough, bumpy, knobby, or crinkled, with some specimens exhibiting raised colony edges, giving them a plating/foliose appearance.



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Foliose hard coral (FOL)

Coral colonies with foliose morphology include those that form flattened sheets or plates where a substantial portion of the colony is detached and elevated from the substrate. These corals often form shingle-like rows or tiers of overlapping plates, fused or convoluted whorls, vases, or leafy/lettuce-like stands. Note that growth forms used during classification of colonies in the field such as "plating" and "laminar," are not available in the classification scheme used for images. Therefore, plating and laminar colonies are included in the foliose category for BIA.

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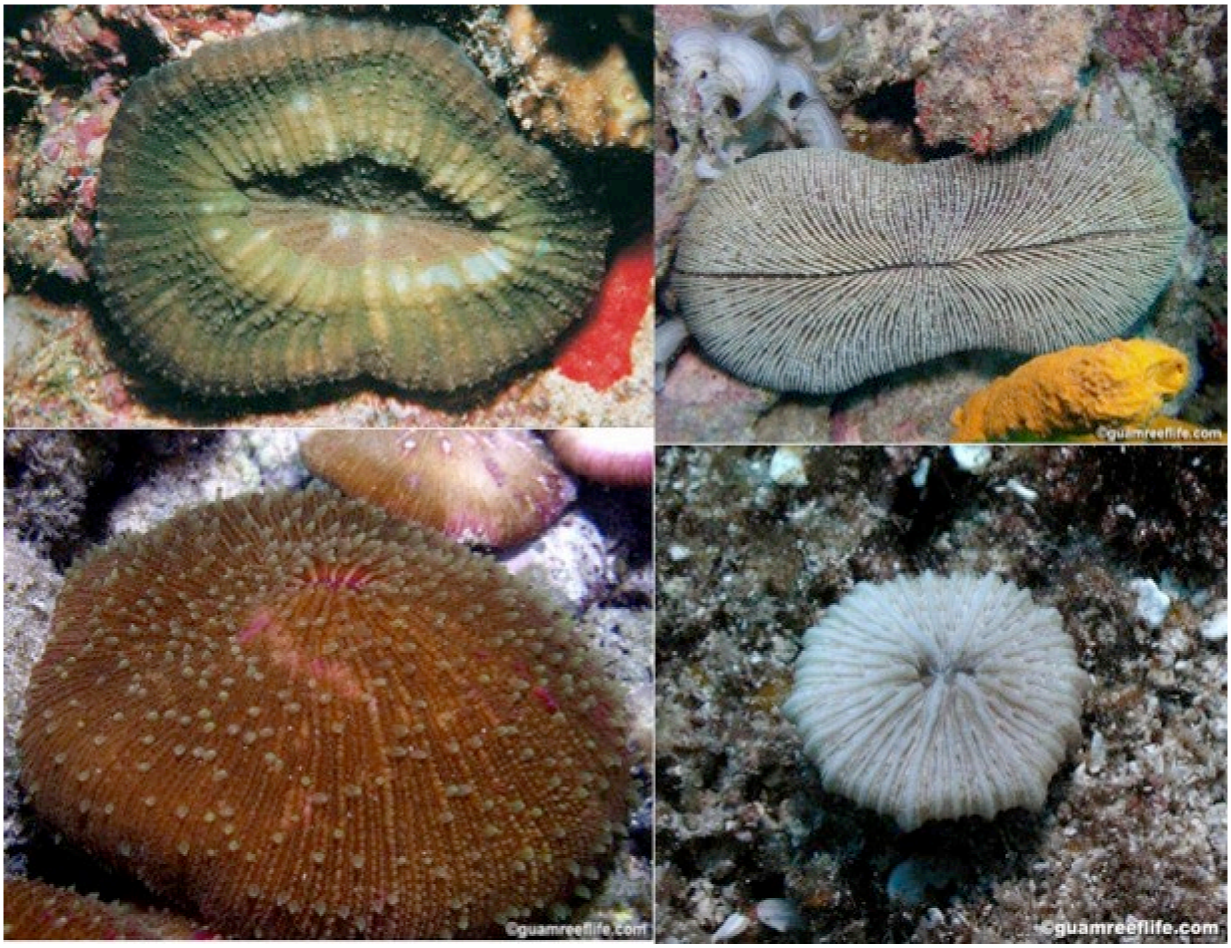
Free-living hard coral (FREE)
Use the free-living morphology for coral colonies that live unattached from the substrate. This excludes broken-off colony branches or other products of fragmentation that are still alive. Free-living corals are conspicuous; most develop as flattened, dome-shaped disks, with a central mouth and apparent, radiating ridge-like structures. Includes the following genera: *Cycloseris, Diaseris, Fungia, Halomitra, Herpolitha, Sandalolitha,* and occasionally *Scolymia.*



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Massive hard coral (MASS)

Massive corals are those characterized by forming raised mounds or rounded heads with hemispherical to sub-hemispherical morphologies. It is important to note that massive does not necessarily describe the *size* of the colony, it is a description of the *growth form.* This growth form may also be referred to as 'mounding.' Large colonies are distinct and boulder-like; small ones have more of a dome or cushion-shape silhouette. It is not unusual for massive colonies to exhibit a bumpy or knobby surface, but for the most part all possess a solid, thick shape.

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SOFT CORAL

The codes given for categories in this section are used to identify soft corals at the Tier 3c level.

Octocoral/Wire Coral (OCTO)
Refers to gorgonian corals, wire corals, black coral, sea fans, sea whips, sea pens, and other members of Subclass Alcyonaria (octocorals), except blue coral *Heliopora coerulea* (Order Helioporacea), which is classified as 'HCOE'. All members of this classification category produce skeletal elements made of protein and calcium carbonate that give the colony sufficient soft support and the flexibility to sway with the ocean waves and currents.

guamreeflife.com; aims.gov.au; NOAA photos

isprambiente.gov.it; NOAA photos

INVERTEBRATE

This group includes organisms from very different phyla, including Porifera (sponges), Cnidaria (anemones, corallimorphs, zoanthids), Mollusca (giant clams, other bivalves), Bryozoa/Ectoprocta (bryozoans), and Chordata (tunicates). The categories are arranged taxonomically according to these groups.

PORIFERA

Sponge (SP)

Sponges (Phylum Porifera) have numerous species and growth morphologies, many of which can be confused with other benthic organisms. Sponges have porous tissue for filter feeding and many have large openings through which expelled water flows (excurrent openings). To help identify sponges, zoom-in on the photograph and examine the surrounding tissue. In general, sponges are more colorful than tunicates are “rougher” around the edges due to a lack of a “tunic” and being composed of spicules. Most sponges, unlike tunicates, are not able to close their excurrent openings. Sponges can also protrude/extend upwards off the benthos from their encrusting state, whereas tunicates tend to grow along the contours of the substrate underneath them.

guamreeflife.com

CNIDARIA

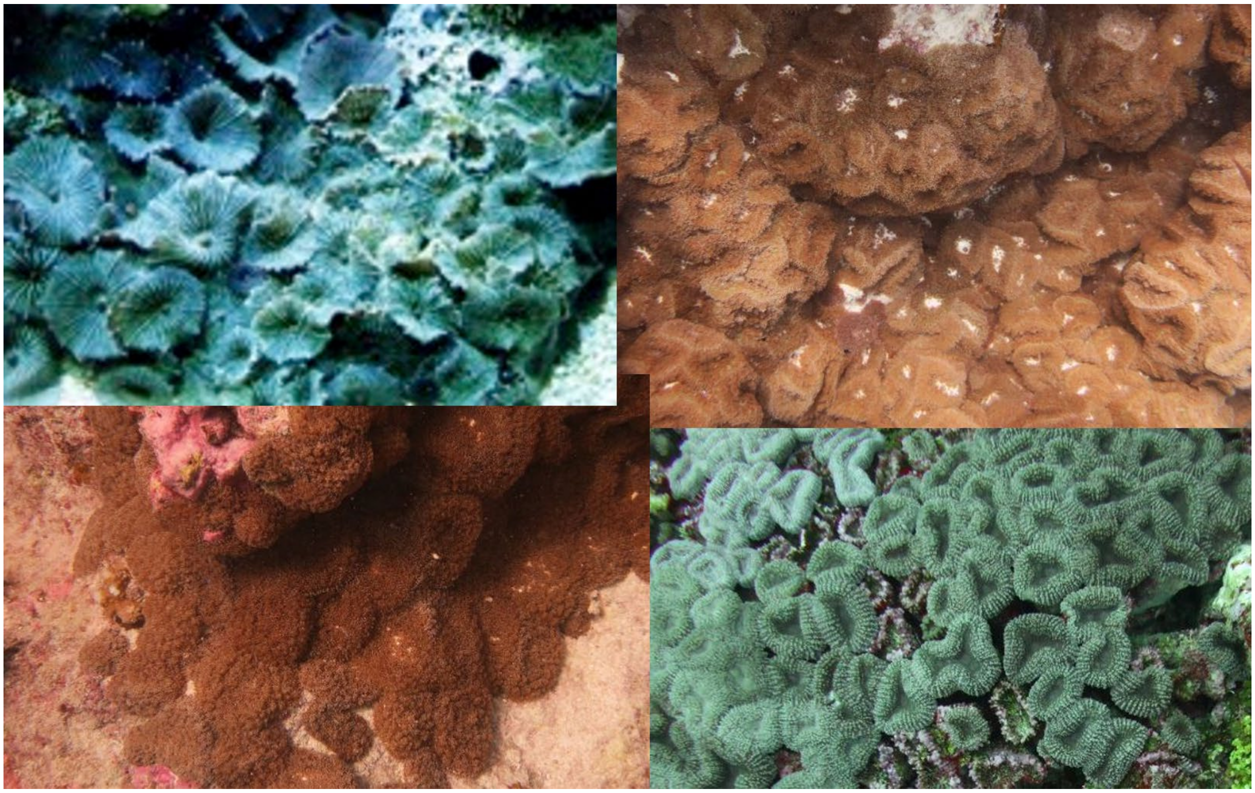
Anemone (AMNE)

Anemones include members of Order Actinaria (anemones) and Order Ceriantharia (tube-dwelling anemones).

A.Petrusek; reefcorner.com; uniprot.org

Corallimorph (CMOR)

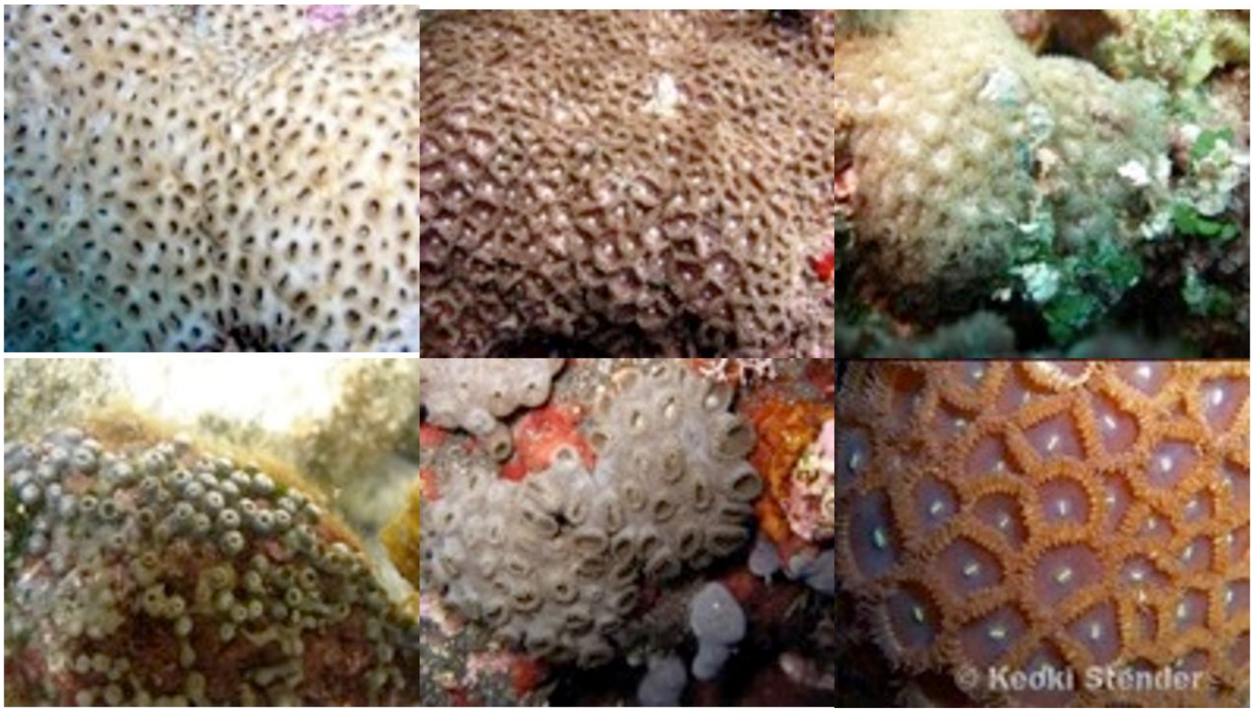
Corallimorphs (Order Corallimorpharia) are anemone-like animals that are found either solitary or in colonies. Their tentacles are generally much shorter than those of true anemones. They can be invasive and at this stage resemble a fuzzy carpet.



midlandsmarinelighting.com, NOAA photos

Zoanthids (ZO)

Zoanthids (Order Zoanthidea) are colonial anemone-like animals having smooth, flat, broad oral disks with tentacles that radiate outward from their margins. Tentacles are found in two nearby rows and are always found in a multiple of six. The polyp's mouth has a ciliated groove at one or both ends. Zoanthids are connected by runners (called stolons) and they lack the hard skeletons of scleractinian corals. The following genera are included in this group: *Palythoa*, *Protopalythoa*, *Zoanthus*.

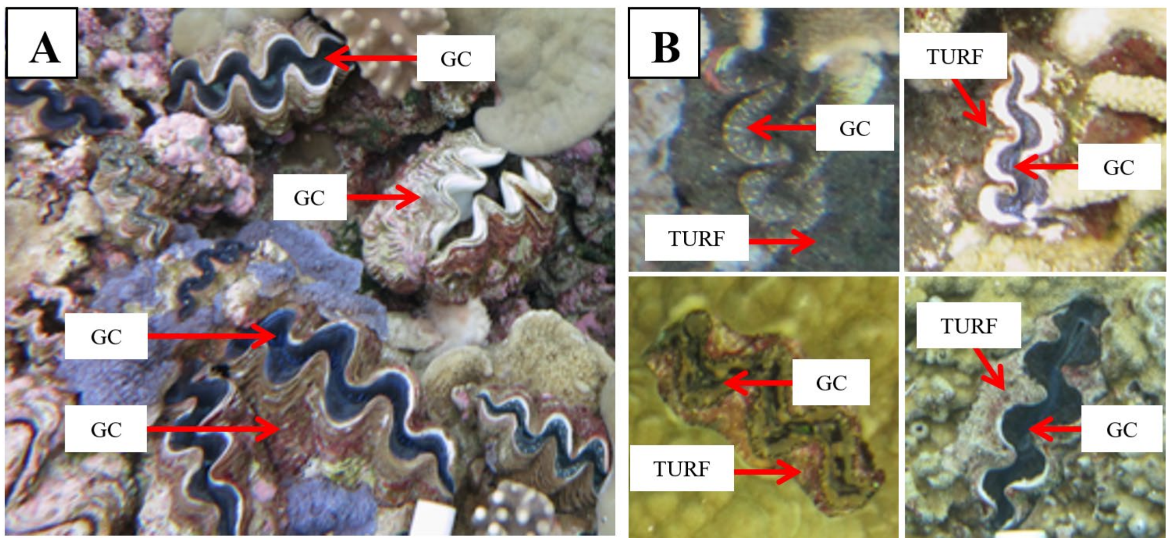


guamreeflife.com; marinelifephotography.com; NOAA photos

MOLLUSCA

Giant clam (GC)

Giant clams may have shells that are drab in color and/or colonized by algae or other sessile organisms, but the mantle can be colorful and can grow from 0.25 m to more than 1 m in diameter. Giant clams with completely exposed shells (Figure A) should be classified as "GC," regardless of whether the point falls on the mantle or the algae-covered shell. If the giant clams are buried, classify only as "GC" if the point falls on the mantle (Figure B). For all other bivalves (clams, oysters, and mussels) in Class Bivalvia, use the Bivalve category (BI).



NOAA photos

Bivalve (BI)

Clams, oysters, and mussels are common examples of bivalves (Class Bivalvia). Giant clams (Family Tridacnidae) are a special case and have their own classification category (GC). For all other bivalves, use this category.

NOAA photos; guamreeflife.com

BRYOZOA/ECOPROCTA

Bryozoan (BRY)

These colonial animals are early colonizers of bare surfaces on coral reefs. Most attach to solid surfaces but some live in sand. Each “member” lives in a zooid, or house, and has lophophores which are “tentacles” that extend out of the house to filter feed. The lophophores are ciliated and very “regular” in appearance. However, unless the image is clear, it will be hard to detect the lophophores and use them to distinguish between a tunicate and a sponge. Individual zooids attach to other neighboring zooids forming bushy, branching, fanlike, or encrusting colonies that may be rigid or flexible. Most bryozoans have a lace-like appearance and can be confused with algae or sponges. However, unlike sponges and tunicates, you will not see incurrent and excurrent openings. This is because the lophophores in bryozoans are used for feeding. In general, bryozoans will not appear smooth like a tunicate and their upright structure will appear to be “flower” and “plant”- like.

guamreeflife.com

CHORDATA

Tunicate (TUN)

Tunicates (Class Ascidiacea) are made up of numerous species and growth morphologies, many of which can be confused with other benthic organisms. They can grow as solitary individuals or in colonies. Their soft body is surrounded by a thick test, or tunic, often transparent or translucent and varying in consistency from gelatinous to leathery. In general, if the organism has multiple holes (which are the individual incurrent siphons of the zooid) with a few larger holes (the shared excurrent siphons) spread out, it is probably a tunicate. Tunicates can close their siphons rather quickly, whereas sponges are for the most part unable to close their siphons at all. Thus, if some of the openings of the sessile organism appear to be closed in the photograph, it is likely a tunicate. One final generalization is that tunicates tend to grow with the contours of the substrate, whereas sponges can grow upwards from the encrusting state.

guamreeflife.com; NOAA photos

OTHER OR UNIDENTIFIABLE SESSILE INVERTEBRATES

Unclassified sessile invertebrate (UI)

This category refers to sessile invertebrates that do not fall within one of the other categories, or should be used in situations when a sessile invertebrate cannot be distinguished, for example, differentiating between an encrusting sponge or tunicate.

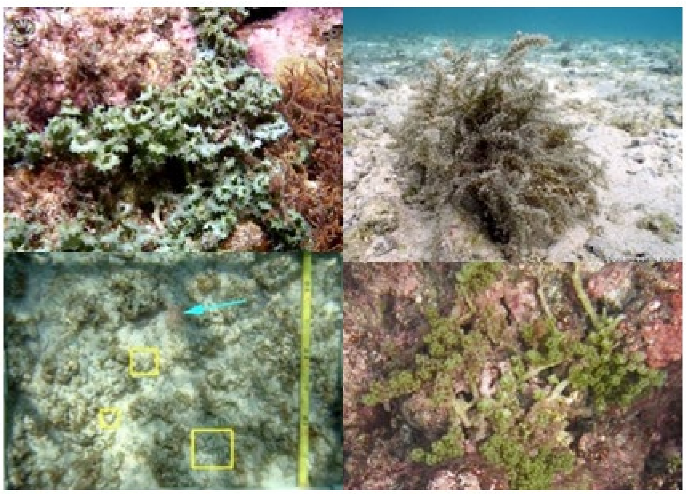
NOAA photos

MACROALGAE

Upright macroalgae (UPMA)

As is the case with corals, it is preferable to identify algae to genus if possible. Broader categories (e.g. green, brown, red, encrusting macroalgae) are also available if the genus cannot be determined with confidence or if the correct genus is not included in the Labelset. If it is not possible to identify algae to one of these groups, it should be assigned to upright macroalgae. The algae categories are presented here as “Fleshy” (e.g. green, brown, red) and “Other” forms because that is how they will likely be considered when identifying substrate during analysis.

Note that although Crustose Coralline Algae (CCA) is taxonomically red algae, the associated categories are classified differently because of their unique ecological role. CCA remains separate from UPMA and Macroalgae at higher tiers.



guamreeflife.com; NOAA photos

FLESHY MACROALGAE

DIVISION CHLOROPHYTA

Green macroalgae (GRMA)

This category is used for green upright macroalgae (Chlorophytes) that cannot be identified to genus. The typical color of plants in this category, resulting from the dominant chlorophyll pigments, is some shade of apple or grass green, although certain species may appear yellow-green or blackish-green due to the presence of carotenoid pigments or high concentrations of chlorophyll.

guamreeflife.com

***Avrainvillea* spp. (AVSP)**

This category contains spongy, blade-like green macroalgae, which are generally fan-shaped and rare. Recorded species are: *A. lacerata, A. amadelpha*, which is invasive in Hawai'i and forms dense aggregations that trap sediment.

guamreeflife.com

Caulerpa spp. (CAUL)

These macroalgae are typically bright green and have horizontal creeping stolon with upright fronds of various forms. They are uncommon.

guamreeflife.com

Dictyosphaeria spp. (DICT)

These macroalgae have a firm and tough texture consisting of visible large bubble-shaped cells. They grow close to the substrate. Forms vary from cup-like and hollow to closed and solid and are usually green to grey in color. They are common.

guamreeflife.com

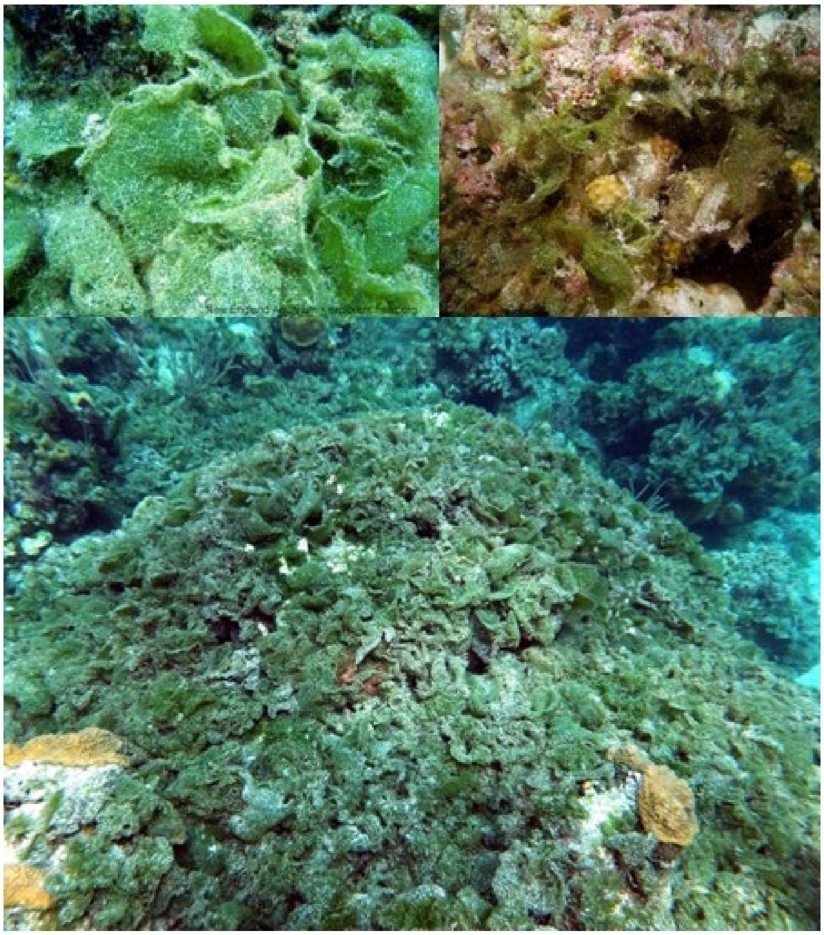
***Halimeda* spp. (HAL)**

These are green alga with segmented, calcified branches. Plants can be erect or sprawling and are commonly found.

guamreeflife.com

Microdictyon spp. (MICR)

These are green alga with flattened fronds. Primary filaments have several lateral branches that attach to other nearby filaments forming a net-like structure. They are relatively common in some areas like Swains Island.



zonkil.gmu.edu; explorers.neaq.org

***Neomeris* spp. (NEOM)**

These green alga appear “wormlike”, erect, usually growing in groups; white because of heavy calcification. They are netlike, forming template through which branches protrude. Individual plants may be bright green at apices when young, with conspicuous hairs protruding in annular rows.

guamreeflife.com

DIVISION OCHROPHYTA

Brown macroalgae (BRMA)

This category is used for brown upright macroalgae (Class Phaeophytes) that cannot be identified to genus. The colors of brown algae (predominantly due to the brown accessory pigment fucoxanthin) cover a spectrum from pale beige to yellow-brown to almost black. In tropical seas, they range in size from microscopic filaments to several meters in length.

guamreeflife.com

***Dictyopteris and Dictyota* spp. (DICO)**

Dictyota and *Dictyopteris* species are brown macroalgae that have flattened, divided thalli. In *Dictyota*, branch tips form a Y-shape and do not have a midrib. *Dictyopteris* have a prominent midrib and thin lateral wings, and the branches are generally uniform. It is often difficult to confidently distinguish *Dictyopteris* from *Dictyota* in images from photoquadrats. Thus, both genera are assigned to the same category.

guamreeflife.com; biol.tsukuba.ac.jp; waikikiaquarium.org

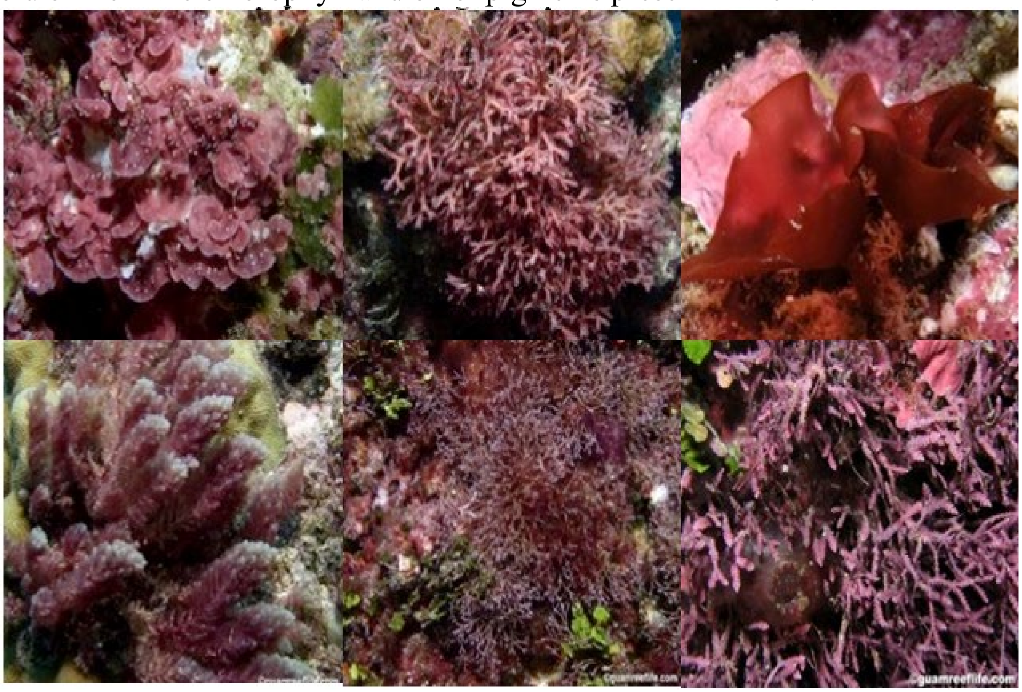
Padina spp. (PADI)
This is brown alga with a fan-shaped thallus with leading edge that is typically inrolled. It often appears striped in coloration and is uncommon.

guamreeflife.com

DIVISION RHODOPHYTA

Red macroalgae (RDMA)

This category is used for red upright macroalgae that cannot be identified to genus. Rhodophytes contain the pigment phycoerythrin; this pigment reflects red light and absorbs blue light. Because blue light penetrates water to a greater depth than light of longer wavelengths, these pigments allow red algae to photosynthesize and live at somewhat greater depths than most other algae. Some rhodophytes have very little phycoerythrin (especially in shallower or very clear waters) and may appear green or bluish from the chlorophyll and other pigments present in them.



guamreeflife.com

***Asparagopsis* spp. (ASPP)**
These are red macroalgae with creeping stolons. Upright axes are fluffy and pink to gray in color. Ultimate branches are fine and taper to filaments just a few cells long. They are relatively common.

guamreeflife.com

OTHER MACROALGAE GROUPS

Blue-green macroalga (BGMA)

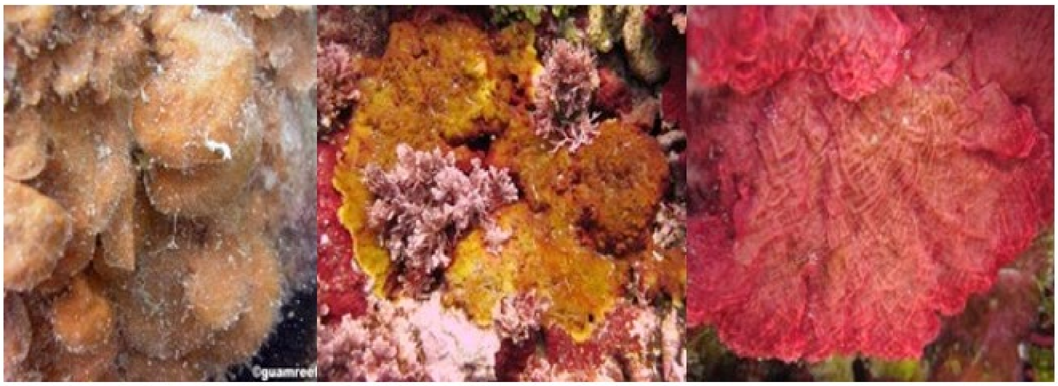
Blue-green algae, also known as Cyanophytes or cyanobacteria are photosynthetic and essentially aquatic prokaryotic organisms closely related to bacteria. They often form deep purple to black filamentous tufts or mats that may stretch for multiple centimeters in length, and therefore look different from turf algae. They may also form mucilaginous masses that are white or pale yellow in color.

guamreeflife.com

ENCRUSTING MACROALGAE

Encrusting macroalgae (EMA)

Encrusting macroalgae can be either completely attached to the substrate, attached at one margin and lifting off the substrate in a blade-like form. This blade can either be uncalcified like the brown EMA *Lobophora* spp. or calcified like red *Peyssonnelia* spp. If encrusting macro algae are calcified, they are calcified on the undersurfaces of the blade and this process can often indicate direction of growth by forming subtle growth rings that are visible through the blade (CCA do not have these ridge/rings form).



guamreeflife.com

Lobophora spp. (LOBO)

This is encrusting brown alga with thin, fan-shaped blades encrusting the substrate, often overlapping in a shingle-like pattern, and it comes in shades of green-brown to tan to brown. It grows in most reef environments, encrusting great areas of shaded, rocky substrates. It is especially abundant on undercut wall faces along deep drop-offs. Blades' surfaces are often covered with sediment and encrusted with epiphytes.

guamreeflife.com; Magruder and Hunt

***Peyssonnelia* spp. (PESP)**

Plants are crust-like, mostly prostrate, relatively thin, composed of erect filaments arising from distinct basal layer, frequently calcified across its ventral surface. Surface is smooth and varies from scarlet, dark rose, wine red, to maroon in color. Historically, this was often lumped with “Encrusting Macroalgae”. Identify PESP when possible.

guamreeflife.com; university.uog.edu

SEAGRASS (SG)

Seagrasses are flowering plants from one of four plant families (Posidoniaceae, Zosteraceae, Hydrocharitaceae, or Cymodoceaceae), which grow in marine, fully-saline environments.

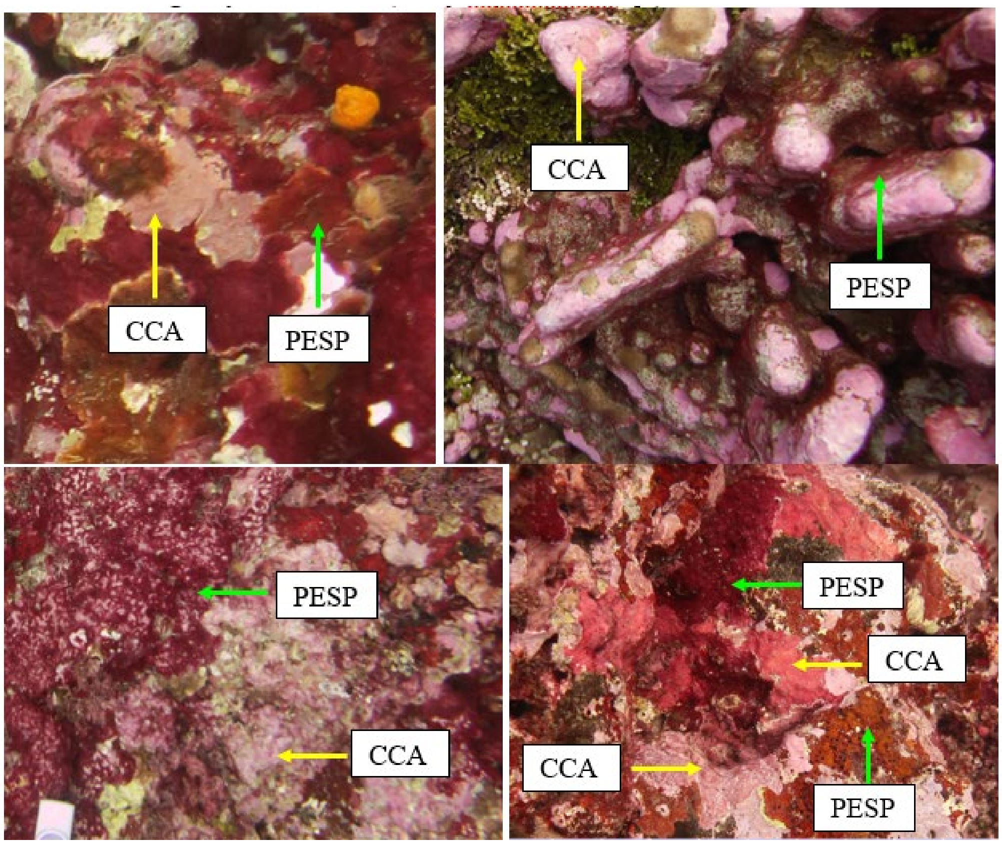
guamreeflife.com; M.Heckman

CRUSTOSE CORALLINE ALGAE

Crustose coralline algae (CCA) is a type of calcified encrusting red macroalgae. It is classified separately from other red algae due to its importance as carbonate producer, reef builder, and substrate for coral larval settlement. Tallus commonly grows in patches on hard substrates, forming hard pink/lavender crusts.

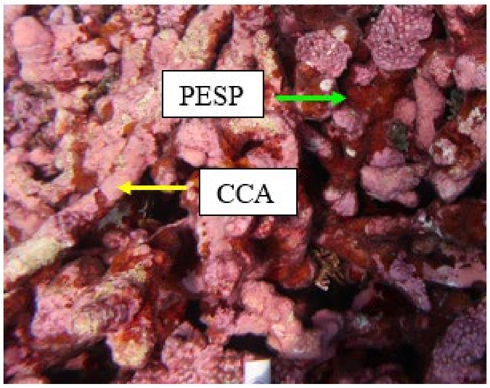
Crustose coralline algae on hard substrate (CCAH)

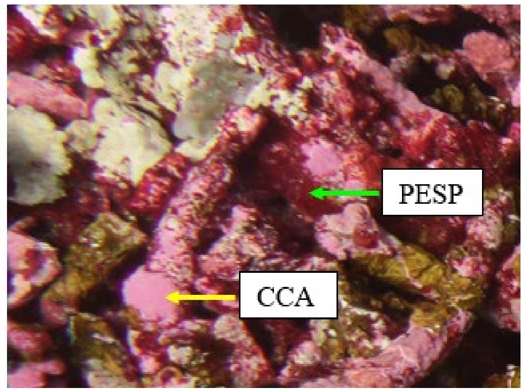
Hard substrates range from pavement flats to basalt formations to bare carbonate (i.e., coral skeleton) structures. The pink and lighter red substrate in the images below is CCA; the darker, burgundy red is EMA (likely *Peyssonnelia* sp.).



NOAA photos

Crustose coralline algae on rubble substrate (CCAR)
CCAR commonly grows on rubble, which is defined as hard fragments (e.g., rocks, pebbles, pieces of dead coral) typically gravel (>5 mm) to cobble (baseball) size with finer and coarser sediments mixed in patches. The pink and lighter red substrate in the images below is CCA; the darker, burgundy red is EMA (likely *Peysonnelia* sp.).

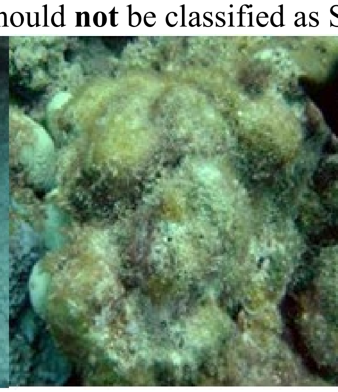
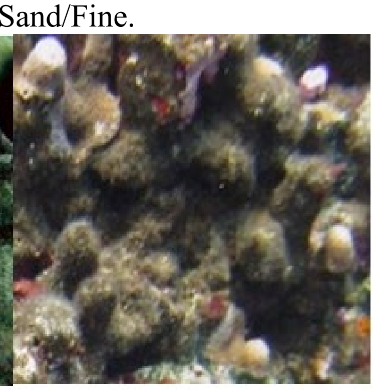




NOAA photos

TURF ALGAE

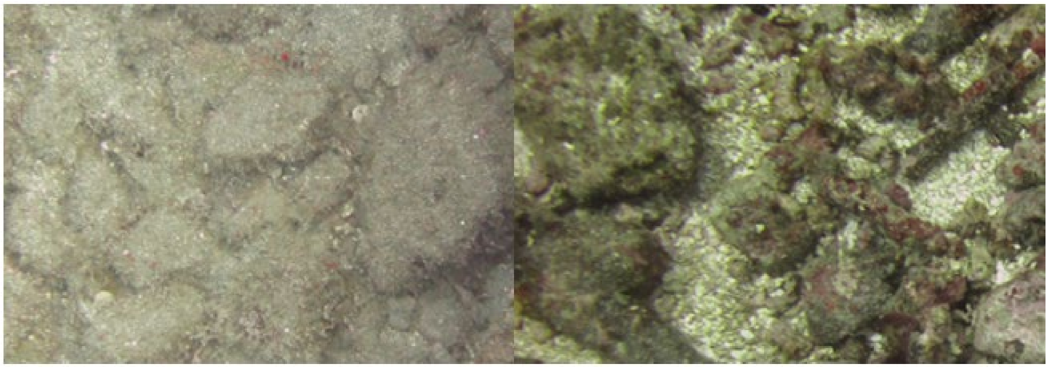
Turf growing on hard substrate (TURFH)
Turf algae often appear as fuzzy carpets growing across hard substrates. Hard substrates range from pavement flats to basalt formations to bare carbonate (i.e., coral skeleton) structures. Note that turf algae tends to trap a fine layer of sediment; this still constitutes a turf covered surface and should **not** be classified as Sand/Fine.

NOAA photos

Turf growing on rubble substrate (TURFR)

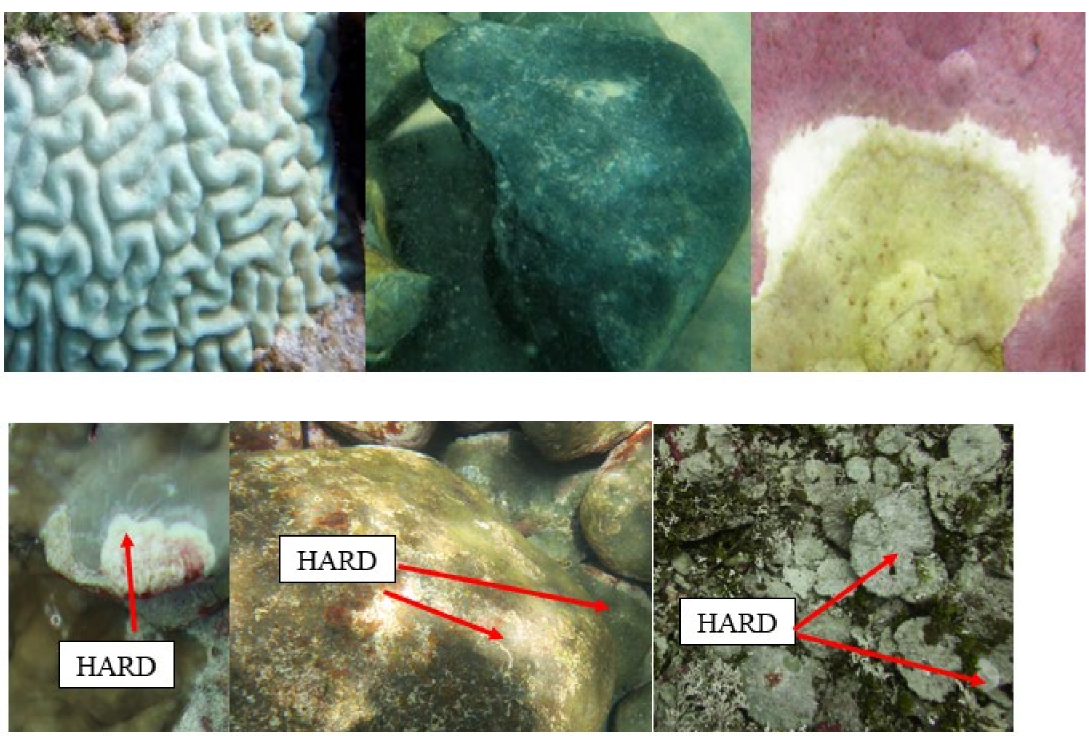
Turf algae often cover rubble, giving the fragments a fuzzy appearance. Rubble is defined as hard fragments (e.g. rocks, pebbles, pieces of dead coral), typically gravel (> 5 mm) to cobble (baseball) size with finer and coarser sediments mixed in.



NOAA photos

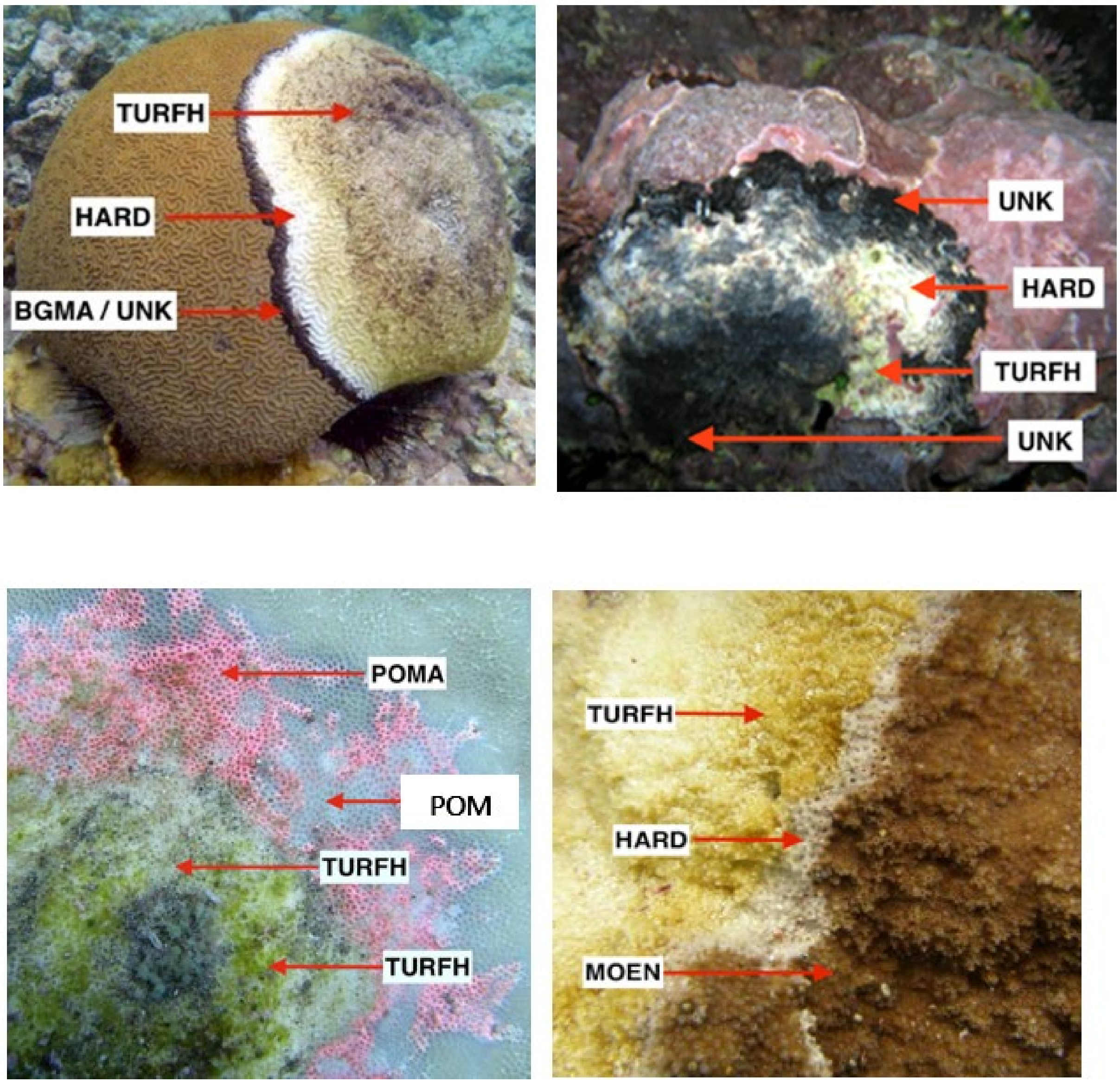
Hard substrate (HARD)

While most hard surfaces are colonized by microscopic turf algae within days of being placed in the water, meaning that nearly all hard substrates are covered by turf algae, we distinguish newly exposed substrate and substrates with a thin patina from thicker turf. Substrates classified as HARD are limited to cleanly scoured pavement flats, basalt formations, bare carbonate structures or substrates that have a very thin (few mm) green patina. Very fine turf algae may be present but isn't visible by the naked eye- this should be classified as HARD. These are substrates that coral larvae could easily settle on.



NOAA photos

The following serves as a guideline for cases in which a disease or predation pattern is visible on corals and CCA. If the point falls directly on the active disease band (if present), the area underneath the point should be classified as the appropriate causative agent (e.g., blue green macroalgae in Black Band Disease), but only if the analyst is certain of the nature of the disease, otherwise, the point should be classified as UNK. If the point falls on the stark-white/recently-dead area, this area should be classified as HARD. If the point falls on the algae-covered skeleton/old-dead area, this area should be classified as TURFH.



NOAA photos; clarku.edu

Rubble substrate (RUB)

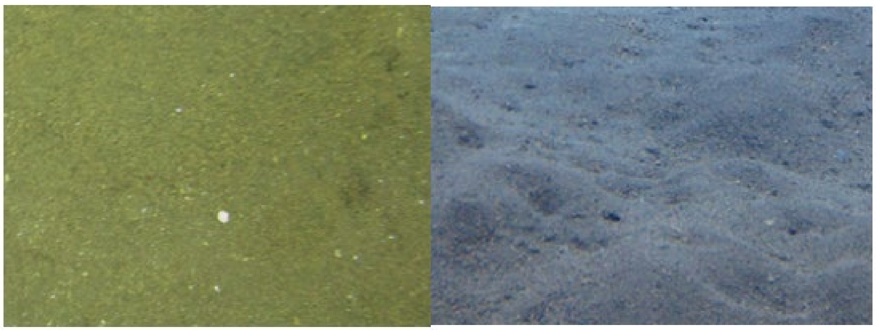
All rubble, which is defined as hard fragments (e.g., rocks, pebbles, pieces of dead coral), typically gravel (> 5 mm) to cobble (baseball) size with finer and coarser sediments mixed in, are covered by turf algae even though these small organisms might not be visible in a photograph. Similar to HARD, rubble (RUB) is defined as substrates that is constantly scoured or has a very thin patina with no visible turf algal filaments.

NOAA photos; youwarke.files.wordpress.com

SEDIMENT

Fine substrate (FINE)

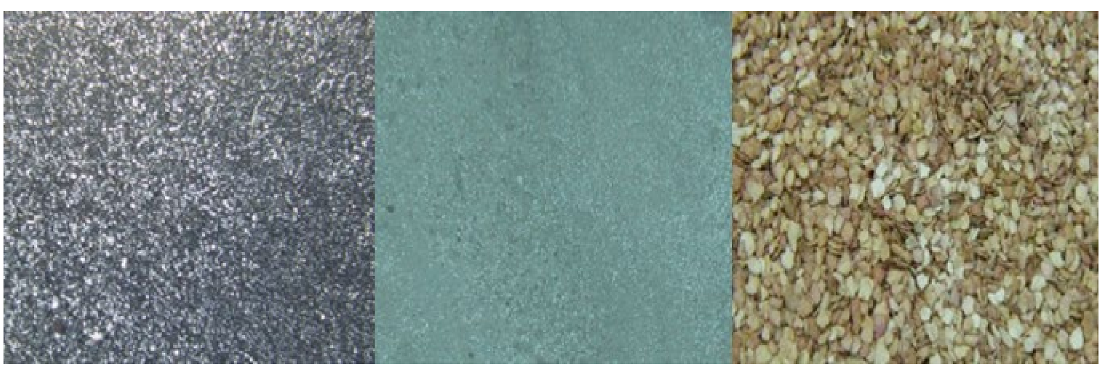
Fine sediment is defined as sediment with a grain size of < 1/16 mm. A thin dusting of fine sediment over a turf-covered surface is not sufficient to be called FINE habitat. Although it can be difficult to judge from a planar photograph, substrate is generally classified as FINE when it is > 1 cm deep.



NOAA photos

Sand (SAND)

Sand is defined as sediment with a grain size between 1/16 mm and 5 mm. This can include silica sand, fine calcium carbonate sand, lava sand, and/or *Halimeda* spp. blade sand. A thin dusting of sand over a turf-covered surface is not sufficient to be called Sand habitat. Although it can be difficult to judge from a planar photograph, substrate is generally classified as SAND when it is >1 cm deep.



NOAA photos; scripps.ucsd.edu

MOBILE FAUNA

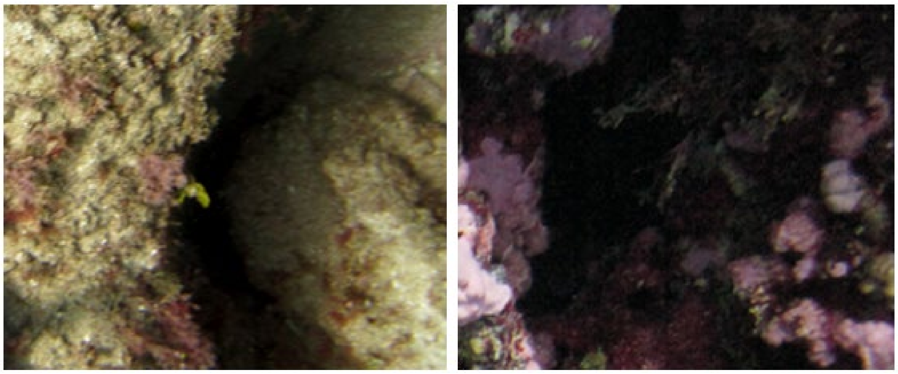
Mobile fauna (MOBF)
This category is appropriate to use for classification when the point falls on fauna that are not permanently affixed to a single location on the sea floor (e.g., sea cucumbers, seastars, sea urchins, fish, marine mammals, etc.).

guamreeflife.com

UNCLASSIFIED

Shadow (SHAD)

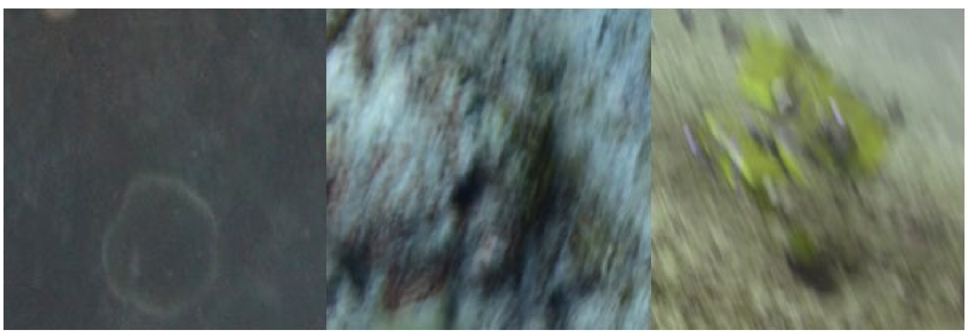
This category is appropriate when the point falls on a shadow cast by natural or anthropogenic features that prevent organism classification.



NOAA photos

Unclassified/Unknown (UNK)

This category is appropriate when the point falls on an area that is obscured or blurry and/or the substrate cannot be identified with confidence.



NOAA photos

TAPE/WAND

Since these categories are artificial and not part of the substrate, they are removed from the results prior to analysis.

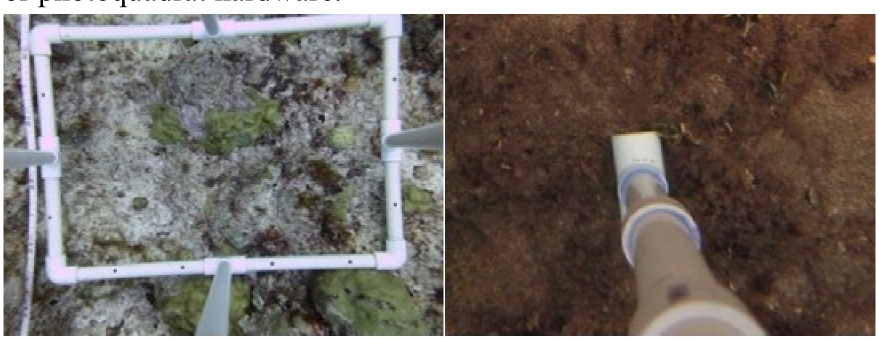
Tape (TAPE)

This category is appropriate when the point falls on the transect tape/line or tape hardware. It may also be used in the rare occasion that the point falls on the water column.

NOAA photos

Wand (WAND)

This category is appropriate when the point falls on the photoquadrat frame/spacing wand or photoquadrat hardware.



NOAA photos

APPENDIX 7: Table of the ESD classification tiers

Below is a table of the classification tiers that ESD uses for labeling and calculating benthic cover data. **Tier 1** is the most general functional level, **Tier 2** subdivides those groups into morphological designations, **Tier 3** further divides Tier 2 groups into more specific genus categories, and lastly Tier 3 was refined to **Tier 3b** and **Tier 3c**, each more specific to ESD's needs and reflective of new coral genera.

Taxon Name	**Tier 3c**	**Tier 3b**	**Tier 3**	**Tier 2**	**Tier 1**
Branching hard coral	BR	BR	BR	BR	CORAL
Columnar hard coral	COL	COL	COL	COL	CORAL
Encrusting hard coral	ENC	ENC	ENC	ENC	CORAL
Foliose hard coral	FOL	FOL	FOL	FOL	CORAL
Free hard coral	FREE	FREE	FREE	FREE	CORAL
Massive hard coral	MASS	MASS	MASS	MASS	CORAL
Tabular hard coral	ACTA	ACTA	ACTA	TA	CORAL
Non-scleractinian hard coral	MISP, HCOE, HYCO	MISP, HCOE, HYCO	NS	NS	CORAL
Astrea spp.	ASTS	MASS	MASS	MASS	CORAL
Acanthastrea spp	ACAS	ACAS	ACAS	ENC, MASS	CORAL
Acropora cytherea	ACTA	ACTA	ACTA	TA	CORAL
Acropora hyacinthus	ACTA	ACTA	ACTA	TA	CORAL
Acropora paniculata	ACTA	ACTA	ACTA	TA	CORAL
Acropora spp_tabulate	ACTA	ACTA	ACTA	TA	CORAL
Acropora abrotanoides	ACBR	ACBR	ACBR	BR	CORAL
Acropora intermedia	ACBR	ACBR	ACBR	BR	CORAL
Acropora globiceps	ACBR	ACBR	ACBR	BR	CORAL
Acropora retusa	ACBR	ACBR	ACBR	BR	CORAL
Acropora spp_branching	ACBR	ACBR	ACBR	BR	CORAL
Alveopora spp.	GOAL	GOAL	GOAL	ENC	CORAL
Astreopora spp.	ASSP	ASSP	ASSP	ENC	CORAL
Barabattoia spp.	ENC	ENC	NEW	ENC	CORAL
Caulastrea spp.	ENC	ENC	NEW	ENC	CORAL
Cladopsammia spp.	ENC	ENC	ENC	ENC	CORAL
Coeloseris spp.	MASS	MASS	MASS	MASS	CORAL
Coscinaraea spp.	COSP	COSP	COSP	ENC	CORAL
Cycloseris spp.	FREE	FREE	FREE	FREE	CORAL
Cyphastrea spp.	CYPS	CYPS	CYSP	ENC	CORAL
Diaseris spp.	FREE	FREE	FREE	FREE	CORAL
Diploastrea heliopora	DISP	DISP	MASS	MASS	CORAL
Echinophyllia spp.	ECHL	ECHL	ECHL	ENC	CORAL
Echinopora spp.	ECHP	ECHP	ECHP	ENC	CORAL
Euphyllia spp.	EUSP	EUSP	ENC	BR	CORAL
Favia spp.	FASP	FASP	FASP	MASS	CORAL
Favites spp.	FAVS	FAVS	FAVS	MASS	CORAL
Fungia spp.	FUSP	FUSP	FREE	FREE	CORAL
Galaxea spp.	GASP	GASP	GASP	ENC	CORAL
Gardineroseris spp.	MASS	MASS	MASS	MASS	CORAL
Goniastrea spp.	GONS	GONS	GONS	MASS	CORAL
Goniopora spp.	GOAL	GOAL	GOAL	ENC	CORAL
Halomitra spp.	FREE	FREE	FREE	FREE	CORAL
Heliopora spp.	HCOE	HCOE	NS	NS	CORAL

Taxon Name	**Tier 3c**	**Tier 3b**	**Tier 3**	**Tier 2**	**Tier 1**
Herpolitha spp.	FREE	FREE	FREE	FREE	CORAL
Hydnophora spp.	HYSP	HYSP	HYSP	MASS	CORAL
Isopora spp.	ISSP	ISSP	ISSP	ENC	CORAL
Leptastrea spp.	LEPT	LEPT	LEPT	ENC	CORAL
Leptoria spp.	LPHY	LPHY	PLLE	MASS	CORAL
Leptoseris spp.	LESP	LESP	LESP	ENC	CORAL
Lobophyllia spp.	LOSY	LOSY	LOSY	MASS	CORAL
Merulina spp.	MESP	MESP	FOL	FOL	CORAL
Millepora spp.	MISP	MISP	NS	NS	CORAL
Montipora caliculata	MOEN	MOEN	MOEN	ENC	CORAL
Montipora capitata	MOBR, MOEN, MOFO	MOBR, MOEN, MOFO	MOBR, MOEN, MOFO	BR, ENC, FOL	CORAL
Montipora flabellata	MOEN	MOEN	MOEN	ENC	CORAL
Montipora incrassata	MOBR	MOBR	MOEN	BR	CORAL
Montipora patula	MOEN	MOEN	MOEN	ENC	CORAL
Montipora grisea	MOEN	MOEN	MOEN	ENC	CORAL
Montipora dilatata	MOBR, MOEN	MOBR, MOEN	MOBR, MOEN	BR, ENC	CORAL
Montipora spp_branching	MOBR	MOBR	MOBR	BR	CORAL
Montipora spp_encrusting	MOEN	MOEN	MOEN	ENC	CORAL
Montipora spp_foliose	MOFO	MOFO	MOFO	FOL	CORAL
Mycedium spp.	FOL, ENC	FOL, ENC	FOL, ENC	FOL, ENC	CORAL
Oulophyllia spp.	OUSP	OUSP	MASS	MASS	CORAL
Oxypora spp.	FOL	FOL	ENC	FOL	CORAL
Pachyseris spp.	PACS	PACS	FOL	FOL	CORAL
Pavona chiriquiensis	PAEN	PAEN	PAVS	ENC	CORAL
Pavona clavus	PAMA	PAMA	PAVS	MASS	CORAL
Pavona duerdeni	PAMA	PAMA	PAVS	MASS	CORAL
Pavona maldivensis	PAEN	PAEN	PAVS	ENC	CORAL
Pavona spp_encrusting	PAEN	PAEN	PAVS	ENC	CORAL
Pavona spp_foliose	PAFO	PAFO	PAVS	FOL	CORAL
Pavona spp_massive	PAMA	PAMA	PAVS	MASS	CORAL
Pavona varians	PAEN	PAEN	PAVS	ENC	CORAL
Pectinia spp.	FOL	FOL	NEW	FOL	CORAL
Platygyra spp.	PLSP	PLSP	PLLE	MASS	CORAL
Plerogyra spp.	PLER	PLER	ENC	BR	CORAL
Plesiastrea spp.	ENC	ENC	MASS	ENC	CORAL
Pocillopora spp.	POCS	POCS	POCS	BR	CORAL
Pocillopora damicornis	POCS	POCS	POCS	BR	CORAL
Pocillopora grandis	POCS	POCS	POCS	BR	CORAL
Pocillopora ligulata	POCS	POCS	POCS	BR	CORAL
Pocillopora meandrina	POCS	POCS	POCS	BR	CORAL
Pocillopora verrucosa	POCS	POCS	POCS	BR	CORAL
Podabacia spp.	FOL	FOL	FOL	FOL	CORAL
Porites compressa	POBR	POBR	PONM	BR	CORAL
Porites cylindrica	POBR	POBR	PONM	BR	CORAL
Porites lichen	POBR, POEN	POBR	POMA	BR	CORAL
Porites lobata	POEN, POMA	POEN, POMA	POEN, POMA	ENC, MASS	CORAL

Taxon Name	**Tier 3c**	**Tier 3b**	**Tier 3**	**Tier 2**	**Tier 1**
Porites lutea	POEN, POMA	POEN, POMA	POEN, POMA	ENC, MASS	CORAL
Porites monticulosa	POEN, POFO	POEN, POFO	POEN, POFO	ENC, FOL	CORAL
Porites rus	POBR, POEN, POFO	POBR, POEN, POFO	PONM	BR	CORAL
Porites spp_branching	POBR	POBR	PONM	BR	CORAL
Porites spp_encrusting	POEN	POEN	PONM	ENC	CORAL
Porites spp_foliose	POFO	POFO	FOL	FOL	CORAL
Porites spp_massive	POMA	POMA	POMA	MASS	CORAL
Porites vaughani	POEN	POEN	POMA	ENC	CORAL
Psammocora spp.	PSSP	PSSP	PSSP	ENC	CORAL
Psammocora nierstraszi	PSSP	PSSP	PSSP	ENC	CORAL
Psammocora profundacella	PSSP	PSSP	PSSP	ENC	CORAL
Psammocora stellata	PSSP	PSSP	PSSP	ENC	CORAL
Phymastrea spp.	PHSP	MONS	MONS?	MASS, ENC	CORAL
Sandalolitha spp.	FREE	FREE	FREE	FREE	CORAL
Scapophyllia spp.	ENC	ENC	ENC	ENC	CORAL
Seriatopora spp.	BR	BR	NEW	BR	CORAL
Stylaster spp.	HYCO	HYCO	NS	NS	CORAL
Stylocoeniella spp.	ENC	ENC	ENC	ENC	CORAL
Stylophora spp.	STYS	STYS	STYS	BR	CORAL
Symphyllia spp.	SYSP	SYSP	LOSY	MASS	CORAL
Tubastraea spp.	ENC	ENC	ENC	ENC	CORAL
Turbinaria spp.	TURS	TURS	TURS	FOL	CORAL
Black coral - Antipatharia	USC	USC	USC	USC	SC
Cladiella spp.	OCTO	OCTO	OCTO	OCTO	SC
Dendronephthya spp.	OCTO	OCTO	OCTO	OCTO	SC
Lobophytum spp.	OCTO	OCTO	OCTO	OCTO	SC
Octocoral/Wire coral	OCTO	OCTO	OCTO	OCTO	SC
Pachyclavularia spp.	OCTO	OCTO	OCTO	OCTO	SC
Sarcophyton spp.	OCTO	OCTO	OCTO	OCTO	SC
Sinularia spp.	OCTO	OCTO	OCTO	OCTO	SC
Soft Coral	OCTO	OCTO	OCTO	OCTO	SC
Stereonephthya spp	OCTO	OCTO	OCTO	OCTO	SC
Wire coral - Antipatharia		USC	USC	USC	SC
Anemone	AMNE	AMNE	AMNE	AMNE	INV
Bivalve	BI	BI	BI	BI	INV
Bryozoan	BRY	BRY	BRY	BRY	INV
Corallimorph	CMOR	CMOR	CMOR	CMOR	INV
Giant clam	GC	GC	GC	GC	INV
Palythoa spp.	ZO	ZO	ZO	ZO	INV
Protopalythoa spp.	ZO	ZO	ZO	ZO	INV
Rhodactis spp.	CMOR	CMOR	OCTO	CMOR	INV
Sponge	SP	SP	SP	SP	INV
Tunicate	TUN	TUN	TUN	TUN	INV
Unclassified sessile invertebrate	UI	UI	UI	UI	INV
Zoanthus spp.	ZO	ZO	ZO	ZO	INV
Asparagopsis spp.	ASPP	ASPP	ASPP	UPMA	MA
Avrainvillea spp.	AVSP	AVSP	AVSP	UPMA	MA
Blue-green macroalga	BGMA	BGMA	BGMA	BGMA	MA

Taxon Name	**Tier 3c**	**Tier 3b**	**Tier 3**	**Tier 2**	**Tier 1**
Brown macroalgae	BRMA	BRMA	UPMA	UPMA	MA
Caulerpa spp.	CAUL	CAUL	CAUL	UPMA	MA
Dictyopteris spp.	DICO	DICO	DICO	UPMA	MA
Dictyosphaeria spp.	DICT	DICT	DICT	UPMA	MA
Dictyota spp.	DICO	DICO	DICO	UPMA	MA
Encrusting macroalgae	EMA	EMA	EMA	EMA	MA
Green macroalgae	GRMA	GRMA	UPMA	UPMA	MA
Halimeda spp.	HALI	HALI	HALI	HALI	MA
Lobophora spp.	LOBO	LOBO	LOBO	EMA	MA
Microdictyon spp.	MICR	MICR	MICR	UPMA	MA
Neomeris spp.	NEOM	NEOM	NEOM	UPMA	MA
Padina spp.	PADI	PADI	PADI	UPMA	MA
Peyssonnelia spp.	PESP	PESP	PESP	EMA	MA
Red macroalgae	RDMA	RDMA	UPMA	UPMA	MA
Seagrass	SG	SG	SG	SG	MA
Upright macroalgae	UPMA	UPMA	UPMA	UPMA	MA
CCA growing on hard substrate	CCAH	CCAH	CCAH	CCAH	CCA
CCA growing on rubble	CCAR	CCAR	CCAR	CCAR	CCA
Turf growing on hard substrate	TURFH	TURFH	TURFH	TURFH	TURF
Turf growing on rubble	TURFR	TURFR	TURFR	TURFR	TURF
Hard substrate	HARD	HARD	HARD	HARD	TURF
Rubble substrate	RUB	RUB	RUB	RUB	TURF
Fine sediment	FINE	FINE	FINE	FINE	SED
Sand	SAND	SAND	SAND	SAND	SED
Mobile fauna	MOBF	MOBF	MOBF	MOBF	MOBF
Shadow	SHAD	SHAD	SHAD	SHAD	UC
Unclassified benthos	UNK	UNK	UC	UNK	UC
Tape	TAPE	TAPE	TAPE	TAPE	TW
Wand	WAND	WAND	WAND	WAND	TW