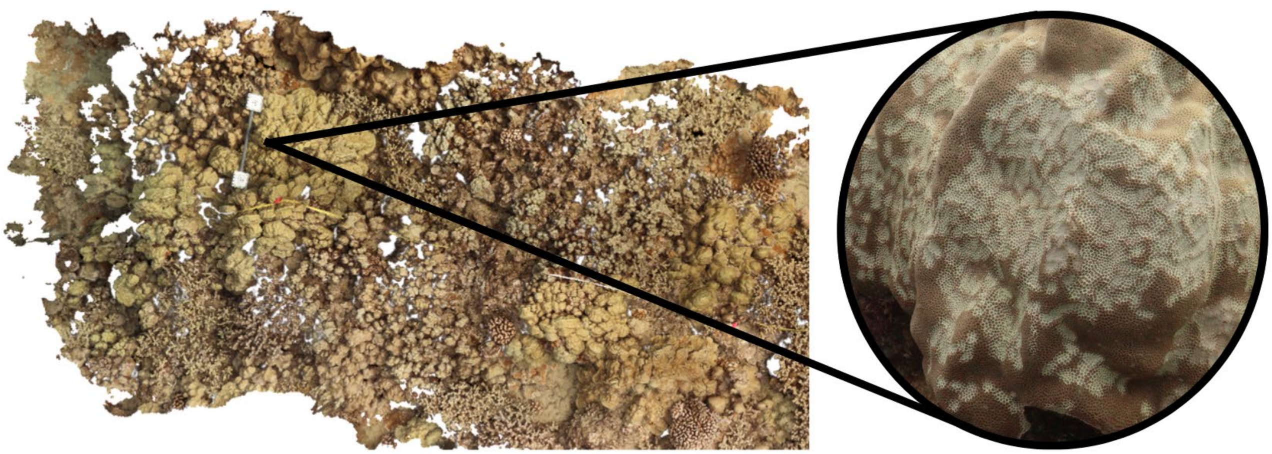
Quantifying Corallivory from Structure-from-Motion Models

Daniela Escontrela Dieguez, Roseanna Lee, Tye L. Kindinger, Courtney S. Couch, Jonathan Charendoff



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

NOAA Technical Memorandum NMFS-PIFSC-149
https://doi.org/10.25923/c64k-gh75

September 2023

Quantifying Corallivory from Structure-from-Motion Models

Daniela Escontrela Dieguez[1], Roseanna Lee[2,3], Tye L. Kindinger[3], Courtney S. Couch[2,3], Jonathan Charendoff[2,3]

[1]University of Hawaiʻi at Mānoa
Department of Biology
Edmondson Hall 418
2538 McCarthy Mall
Honolulu, HI 96822

[2]Cooperative Institute for Marine and Atmospheric Research, University of Hawaiʻi at Mānoa, Honolulu, HI, USA

[3]Pacific Islands Fisheries Science Center
National Marine Fisheries Service
1845 Wasp Boulevard
Honolulu, HI 96818

NOAA Technical Memorandum NMFS-PIFSC-149
September 2023

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., NOAA Administrator

National Marine Fisheries Service
Janet Coit, Assistant Administrator for Fisheries

About this report

The Pacific Islands Fisheries Science Center of NOAA's National Marine Fisheries Service uses the NOAA Technical Memorandum NMFS-PIFSC series to disseminate scientific and technical information that has been scientifically reviewed and edited. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

Recommended citation

Escontrela Dieguez D, Lee R, Kindinger TL, Couch CS, Charendoff J. 2023. Quantifying corallivory from Structure-from-motion models. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-PIFSC-149, 8182 p. doi: 10.25923/c64k-gh75

Copies of this report are available from

Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at

https://repository.library.noaa.gov/

Table of Contents

List of Tables v

List of Figures vi

Abstract 1

1. Introduction 2

2. Materials needed 4

3. Model generation 5

    3.1 Image Collection 5

    3.2 Data Management and Quality Control 6

    3.3 Generating 3D Models and 2D Orthomosaics 6

4. Setting up ArcGIS Pro for Model Annotation 7

    4.1 Creating the Geodatabase 7

    4.2 Importing 2D Orthomosaics into ArcGIS Pro 16

    4.3 Adding Transects and Quadrats to an Orthomosaic in ArcGIS Pro 21

    4.4 Adding Geodatabase to ArcGIS Pro Projects 27

5. Extracting Corallivory Data Using ArcGIS Pro 29

    5.1 Extracting Coral Area by Species 29

    5.2 Annotating Fish Predation 29

        5.2.1 Getting ready to annotate 30

        5.2.2 Annotating fish predation 33

    5.3 Annotating Sea Star and *Drupella* Predation 38

    5.4 Extracting Data from ArcGIS Pro 39

6. Literature Cited 40

7. Appendix 43

    Appendix 1. Corallivory Annotation Descriptions (Hawai‘i) 43

        Coral species 43

        Corallivory categories 50

        Bite mark condition 60

        Overlap scores 63

    Appendix 2. Extracting orthoblocks 66

List of Tables

Table 1. Column name and type along with field type information to complete steps 14 and 15. For columns without drop-down options, leave the 'Field Domain' blank. For columns with drop-down options, fill in the 'Field Domain' with the column name. 16

List of Figures

Figure 1. A spray-painted fishing weight is used to mark where quadrats will be drawn in ArcGIS Pro. ... 5
Figure 2. Excel table of GDB domains. Once imported into ArcGIS Pro, columns C, E, F, G, and I will have corresponding drop-down options. Columns A, B, D, H, J, and K will need to be manually filled in using ArcGIS Pro. ... 8
Figure 3. Open an ArcGIS Pro file. (1) Under the 'Analysis' tab, select 'Tools'. (2) On the right side of the screen, search for and select 'Create File Geodatabase'. ... 9
Figure 4. Fill in the parameters in the 'Create File Geodatabase' and select 'Run.' ... 10
Figure 5. (1) Under the 'Analysis' tab, select 'Tools'. (2) On the right side of the screen, search for and select 'Table to Domain'. ... 11
Figure 6. Fill in the parameters in the 'Table to Domain' window as follows and select 'Run'. ... 12
Figure 7. (1) Under the 'Analysis' tab, select 'Tools'. (2) On the right side of the screen, search for and select 'Create Feature Class'. ... 13
Figure 8. Fill in the parameters in the 'Create Feature Class' window as follows and select 'Run'. ... 13
Figure 9. (1) Under the 'Analysis' tab select, 'Tools'. (2) On the right side of the screen, search for and select 'Add Field'. ... 14
Figure 10. Fill in the parameters in the 'Add Field' window as follows and select 'Run' for columns (A) without drop-down options and (B) with drop-down options. The 'Field Type' will vary depending on the input values or drop down options (Table 1). 'Field Domain' should remain blank for columns without drop down options and it should match the 'Field Name' for columns with drop down options. ... 15
Figure 11. Open ArcGIS Pro and select the 'Map' icon (boxed in red). ... 16
Figure 12. Screenshot of the pop-up window that appears after the 'Map' option is selected along with how to complete it. ... 17
Figure 13. Removing the 'World Topographic Map'. ... 17
Figure 14. Use the 'Add Folder' option to add the folder to the document. ... 17
Figure 15. Use the 'Add Data' option (boxed in red) to import the orthomosaic. The error message can be seen on the upper right hand corner in the blue box. ... 18
Figure 16. Use the 'Zoom to Layer' option on the left side of the screen if the model is not visible. ... 18
Figure 17. (A) Go to the 'Tools' section under the 'Analysis' tab (boxed in red). On the right side of the screen, search for and select 'Define Projection'. (B) Fill in the parameters as described above. ... 19
Figure 18. (1) Select the 'Raster Layer' tab, then (2) then navigate to 'Stretch Type' and select 'None' to color correct the model. ... 20
Figure 19. Use the 'Measure' tool (boxed in red and under the 'Map' tab) to measure an object in the model to ensure it is correctly scaled. In the figure above, the scale bar was measured and has a length of 0.5 meters. Note:scale bars may be different lengths. Become familiar ahead of time with the scale bar(s) used for proper scaling and orientation. This project used both 0.25 and 0.5 meter scale bars (target to target). ... 20
Figure 20. Click the 'Catalog Pane' option (boxed in red) under the 'View' tab. A 'Catalog' window will appear. Drag and drop to the right of the screen to pin it into place. ... 21
Figure 21. (A) Right click on the 'ARC' folder in the Catalog and select 'New' → 'Shapefile'. (B) Fill in the 'Creature Feature Class' fields as previously described. ... 22
Figure 22. (1) In the 'Edit' tab, first select 'Edit' and (2) then click on 'Create.' ... 22

Figure 23. (A) First make sure the 'line' option is selected in the 'Create Features' pane on the right side of the screen. (B) Change the type of line by (1) double clicking on the line under the transect name on the left side of the screen and (2) clicking the 'Highway' option on the right side of the screen. 23
Figure 24. Turn on the 'Dynamic Constraints' option at the bottom of the screen (boxed in red). 23
Figure 25. For each transect line, click at the pink weight, follow the transect line for 3.28 ft (1 m) and double click to fix the line into place. 24
Figure 26. Once all the 1-m segments have been drawn, zoom out to ensure seven are visible. (1) Go to the 'Edit' tab and hit 'Save.' (2) Lastly, go to the 'Map' tab and select 'Explore.' 24
Figure 27. Right click on the transect layer on the left side of the screen then press 'Selection' and 'Select All' from the drop down menus. 25
Figure 28. Select the 'Buffer' option (boxed in red) in the 'Analysis' tab. Then fill in the 'Buffer' pain on the right side of the screen as previously described. 26
Figure 29. After step 11, quadrats will be drawn around the transect lines. To fix the shading and outline, (1) double click on the site#_segments layer on the left side of the screen and (2) select the 'Black Outline' option on the right. 26
Figure 30. With the model open in ArcGIS Pro, (1) navigate to the 'Insert' tab and (2) select 'Add Folder' 27
Figure 31. After navigating to the Geodatabase in the Catalog, (A) (1) click on the arrow to the left of the Geodatabase name, (2) right click 'template' and (3) select 'Copy.' (B) Go back to the Geodatabase, (1) right click and (2) select 'Paste.' 28
Figure 32. When project is open, zoom into the quadrat and turn the check mark on for the multipoint feature on the left side of the screen (boxed in red). 30
Figure 33. Select the 'Edit' option under the 'Edit' tab. 30
Figure 34. (A) Click on the right pointing arrow next to the feature name on the right side of the screen (boxed in red). (B) Fill in the 'SITE' and 'ANNOTATOR' fields as described above and optionally the rest of the fields for each new annotation combination. 31
Figure 35. Turn on the multipoint annotation tool by clicking on the icon boxed in red. 32
Figure 36. Right click on the name of the multipoint feature on the left side of the screen and select 'Attribute table' 32
Figure 37. To turn on the cameras, select 'cams' on the right side of the screen (boxed in red). The small 'ON' will appear once 'cams' has been clicked. Then select 'none' on the bottom left of the screen (boxed in blue). 33
Figure 38. Drop a point (Point A) on the first coral along the search pattern. 34
Figure 39. Create a new row in the attribute table for each new combination of coral species, bite category, and condition in each quadrat. Then fill in the information in each column as described above. 36
Figure 40. To view a new colony, drag the green point to the desired spot and select 'snap' (boxed in blue). Alternately, if the new underlying imagery isn't showing up correctly, delete the point (boxed in red) and drop a new point. 36
Figure 41. (A) Once all rows have been selected, right click on the 'number_bites' column and select 'Calculate Geometry,' (B) fill in the pop up window as shown. 37
Figure 42. (A) Colony-level and (B) close up images of *Pocillopora damicornis.* 43
Figure 43. (A) Colony-level and (B) close up images of *Pocillopora meandrina.* 44

Pocillopora grandis (uncommon, PGRA)—this is the largest of the Pocillopora species, and its size is one of the main defining characteristics, sometimes reaching a few feet in height. The branches are tubular and upright, sometimes flattened and forked at the tips. Smaller individuals may look similar to P. meandrina but P. grandis has larger spaces between the branches and branches typically don't have the "c" shape (Figure 44).Figure 44. A) Colony-level (Photo by Erik Brush) and (B) close up images of *Pocillopora grandis*. 44
Figure 45. (A) Colony-level and (B) close up images of *Montipora capitata*. 45
Figure 46. (A) Colony-level and (B) close up images of *Montipora patula*. 45
Figure 47. (A) Colony-level and (B) close up images of *Montipora flabellata*. 46
Figure 48. (A) Colony-level (Photo by Keoki Stender) and (B) close up images of *Porites compressa*. 46
Figure 49. (A) Colony-level (Photo by Keoki Stender) and (B) close up images of *Porites lobata*. 47
Figure 50. (A) Colony-level and (B) close up images of *Porites evermanni* (Photos by Keoki Stender). 47
Figure 51. (A) Colony-level and (B) close up images of *Pavona duerdeni*. 48
Figure 52. (A) Colony-level and (B) close up images *of Pavona varians*. 48
Figure 53. (A) Colony-level and (B) close up images of *Lobactis scutaria*. 49
Figure 54. (A) Colony-level and (B) close up images of *Cyphastrea ocelina*. 49
Figure 55. (A) Colony-level and (B) close up images of Leptastrea bewickensis (Photo by Keoki Stender). 50
Figure 56. (A) Colony-level and (B) close up images of *Leptastrea transversa*. 50
Figure 57. (A) Shortbodied blenny, (B) close up of a blenny bite mark, high density and overlapping blenny bite marks on (C) massive *Porites* and (D) *M. capitata* 52
Figure 58. (A) Crown-of-thorns, (B) cushion star, (C) massive *Porites* consumed by a crown-of-thorns sea star (Photo by NOAA), and (D) a juvenile *Pocillopora* consumed by a cushion star. 54
Figure 59. (A) *Drupella* snail and *Drupella* predation on (B) *Porites compressa*, (C) *Montipora capitata*, and (D) *Pocillopora damicornis*. 55
Figure 60. (A) Parrotfish (Photo by Reef Guide), (B) close up of a parrotfish bite mark, (C) high density of overlapping parrotfish bite marks on massive *Porites*, and (D) a parrotfish bite mark on *Montipora patula*. 56
Figure 61. (A) Barred filefish (Photo by Reef Life Survey) and (B) spotted pufferfish (Photo by Wikipedia Commons). Excavator bite marks on *Porites compressa*, (C) new and (D) healing. Examples of excavator bite marks on (E) *Montipora capitata*, (F) *Pocillopora meandrina* and (G) massive *Porites*. 58
Figure 62. (A) Scattered scraper bite marks on the branches of *Pocillopora meandrina.* (B) Different conditions of scraper bite marks on *Pocillopora meandrina* (blue box is a healing scraper mark with a light tip and some verrucose missing, green box is a new scraper bite mark, and red box is not a bite mark as it is a light branch tip without missing verrucose). Scraper bite marks on (C) *Porites compressa* and (D) *Montipora patula*. 60
Figure 63. Examples of new bite marks across different bite mark categories and coral species. (A) Excavator on massive *Porites*, (B) scraper on *Montipora patula*, (C) *Drupella* on *Porites compressa*, (and D) sea star on *Pocillopora meandrina*. 61
Figure 64. Examples of healing bite marks across different bite mark categories and coral species. (A) Excavator on *Porites compressa*, (B) scraper on *Pocillopora meandrina*, (C) blenny bites on massive *Porites*, and (D) parrotfish on massive *Porites*. 62

Figure 65. Examples of old bite marks across different bite mark categories and coral species. (A) An excavator bite wound on *Porites compressa* and (B) *Drupella* bite wound on *Montipora capitata*. 63
Figure 66. Examples of different overlap scores for (A-D) SCSP, (E-H) EXBR, and (I-L) SCRAP bite mark categories. Numbers on the bottom left corner of each image represent the overlap score............... 65
Figure 67. (1) Double click on the current orthomosaic, then right click and (2) deselect the 'Set as Default' option. 66
Figure 68. On the left contents pane, deselect the multipoint tool, transect lines, and orthomosaic tiff; leave only the quadrat outlines selected. 67
Figure 69. (A) (1) Go to the 'Map' tab, (2) select 'Add Data,' (3) navigate to the high resolution ortho, and (4) select 'OK.' (B) Once uploaded, the high resolution tiff will appear in the navigation pane. 68
Figure 70. (1) From the 'Analysis' tab, (2) select 'Tools.' Search for and select 'Define Projection' (not pictured). (3) In the 'Define Projection' pane, fill in the 'Input Dataset' and 'Coordinate System' fields as described above and select 'Run' 68
Figure 71. With the high resolution tiff selected on the left pane, (1) go to the 'Raster Layer' tab, (2) select 'Stretch Type' and then 'None' from the drop down menu. 69
Figure 72. (1) Select the 'Map' tab, (2) then click on the 'Select' tool, and (3) lastly click on the first segment. 70
Figure 73. Fill in the fields in the 'Clip Raster' pane as indicated and select 'Run'. 71
Figure 74. For all the layers, (1) select the raster layer on the left pane, (2) go to the 'Raster Layer' tab, (3) select 'Stretch Type,' and (4) click on 'None.' 71
Figure 75. Right click on the raster layer, select 'Data,' and click on 'Export Raster.' Fill in the pop up window as described in step 10. 72
Figure 76. Open the PNG of the quadrat in Paint3D, (1) click on the 'Select' tool, (2) use it to highlight the whole quadrat, (3) rotate until the quadrat is square with the screen, (4) and select 'Crop.' 73

Abstract

This document provides a detailed standard operating procedure (SOP) for identifying, annotating, and extracting estimates of corallivory, or coral predation, observed on coral reefs using Structure-from-Motion (SfM) techniques. These procedures were developed by the Ecosystem Sciences Division (ESD) at the NOAA Pacific Islands Fisheries Science Center (PIFSC) in collaboration with the University of Hawaiʻi at Mānoa. This workflow, applied to coral reefs around Oʻahu, Hawaiʻi, consists of five key steps: (1) image collection, (2) data management and quality control, (3) generation of 3D models and 2D orthomosaics, (4) setting up ArcGIS Pro for model annotation, and (5) annotating procedures for corallivory. Steps one through three have previously been outlined in other SOPs; therefore, they will not be described in detail here. This SOP focuses on steps four and five which include setting up a Geodatabase specific to corallivory annotations, preparing models in ArcGIS Pro for annotation, the methodology used for annotation, and a description of different annotation categories. This SOP is the result of comprehensive methodological testing, both underwater and using different annotation tools within ArcGIS Pro. While the following procedures are designed to provide a foundation for future uses that meet ESD needs, we primarily use commercially available cameras and software, making these methods adaptable based on programmatic capacity and needs.

1. Introduction

Coral reefs are important undersea oases that provide innumerable goods and services for humanity (Moberg and Folke 1999). For example, global coral reef tourism is estimated to produce U.S. $36 billion in annual revenue (Spalding et al. 2017), and shoreline protection by reefs substantially reduces costs associated with erosion and flooding (Beck et al. 2018). Coral reefs are also ecologically important. Although they cover only 0.1% of the ocean floor, they are among the most species-rich ecosystems on Earth (Knowlton et al. 2010). But despite our heavy reliance on coral reefs and their ecological importance, there has been a 30 to 50% reduction in global coral reef cover due to increasing anthropogenic stressors at both local and global scales (Birkeland 2019; National Academies of Sciences, Engineering, and Medicine 2019). These combined effects have caused a decline in coral cover around the main Hawaiian Islands (MHI) since at least the late 1990s (Friedlander et al. 2005). Because of the many socioeconomic and ecological goods and services coral reefs provide worldwide, their protection is imperative. Addressing global stressors, such as ocean warming due to climate change, will take time and cooperation at the international level. However, evidence suggests that local management can help offset global changes or at least buy reefs time until carbon emissions are stabilized (Kennedy et al. 2013; Anthony 2016; Donovan et al. 2021).

Corallivory, or coral predation, is an important ecological process on coral reefs, but at high levels, can lead to coral decline (Rotjan and Lewis 2008; Rice et al. 2019). Moreover, corallivory can act synergistically or additively with other stressors, further exacerbating the threats corals face. Corallivores encompass a variety of taxa such as annelids, mollusks, crustaceans, echinoids, and fishes, which consume the mucus (mucus eaters), polyp tissue (browsers), and/or skeleton of corals (scrapers and/or excavators) (Cole et al. 2008; Rotjan and Lewis 2008). Direct and indirect corallivore-coral interactions are known to affect corals at the colony level in Hawai‘I (Jayewardene et al. 2009; Counsell et al. 2019). The removal of coral tissue and/or skeleton can lead to mortality (direct effect). Additionally, because corals are limited by metabolic resources, corallivory can inhibit overall growth, sexual reproduction, and alter morphology (indirect effects) while energy is directed to wound healing (Henry and Hart 2005; Lenihan HS and Edmunds PJ 2010; Palacios et al. 2014; Pratchett et al. 2020). Lesions caused by predators do not always heal, making them more susceptible to disease (Bak and Steward-Van Es 1980). Moreover, outbreaks of corallivores can result in mass mortality of corals. This phenomenon has been well documented on the Great Barrier Reef and French Polynesia, where predation by the crown-of-thorns sea star (*Acanthaster planci*), a voracious corallivore, was the leading source of coral mortality prior to recent bleaching events (De’ath et al. 2012; Kayal et al. 2012). Further reducing coral reef recovery after disturbance events is some corallivores, such as the cushion sea star (*Culcita novaeguineae*) in Hawai‘i, preferentially feeding on juvenile coral colonies (Glynn and Krupp 1986).

Having tools to rapidly monitor and document threats over large reef areas is imperative for management interventions, as some corallivores may be increasing in abundance around some of the MHIs (Escontrela unpublished data). With increasing predator numbers, coral mortality will likely increase along with reductions in coral reproduction and growth. Moreover, as coral cover decreases due to anthropogenic threats, coral predation may intensify. Such was the case on Florida coral reefs where predation rates by parrotfishes were documented to increase in areas where coral cover was low and preferred coral species were rare (Burkepile 2012). Quick assessments for changes in predation pressure will allow managers to enact management interventions, such as corallivore removals, in a timely manner which could increase the probability of success. For example, in the Great Barrier Reef, one of the best management interventions in the face of increasing crown-of-thorns abundances is removal at the onset of population outbreaks(Bos et al. 2013). Additionally, because corallivory can be an important determinant of coral outplant success during restoration efforts, coral reefs should also be monitored for corallivory prior to and during coral outplanting. In the Red Sea, corallivory rates on *Stylophora* spp. transplants were 2.2-fold higher than those experienced by naturally occurring corals of the same species (Horoszowski-Fridman et al. 2015). Given that corallivory rates can be an important determinant of coral reef health and that it can greatly affect the success of coral restoration efforts, tools to quantify corallivory rapidly and accurately are needed. Although in-water corallivore surveys can be time consuming, a growing number of projects are using imagery-based methods from which corallivore estimates could also be extracted.

Past monitoring techniques for corallivory have included in situ surveys and analysis of 2D benthic imagery collected via photoquadrats. While in situ surveys provide the most accurate way to document corallivory, they tend to be expensive because they require extended boat use and underwater time. Alternately, analysis of 2D photoquadrats tends to be inaccurate because quantifying metrics from a 2D image captured from a 3D environment often misses cryptic bite marks which may be hidden under overhangs or within crevices (Bonaldo and Bellwood 2011; Rice et al. 2020). Structure-from-Motion (SfM) is a photogrammetric method used to create 3D models from a collection of hundreds to thousands of 2D images. Large-area imaging techniques and SfM technologies are increasingly being used by reef managers to collect coral reef imagery more efficiently and to collect data on multiple metrics at the same time (e.g., coral cover, rugosity, and coral growth) (Bryson et al. 2017; Ferrari et al. 2017; House et al. 2018; Lange and Perry 2020; Kornder et al. 2021). SfM surveys drastically reduce the amount of time needed underwater and different observers can consistently and accurately annotate models with minimal training. This technology allows for the surveying of a broader spatial extent as underwater time can be reallocated from conducting surveys at one location to gathering images for different models at different sites. It is important to note, however, that post-processing time can be high. SfM technologies allow researchers to visualize the reef in 3D which could allow for more accurate estimates of corallivory than 2D photoquadrats, with the option to extract a whole suite of complementary reef metrics.

In this standard operating procedure (SOP), we document the workflow for extracting corallivory estimates from SfM models of coral reefs. The pipeline consists of five steps: (1) image collection, (2) data management and quality control, (3) generation of 3D models and 2D orthomosaics, (4) setting up ArcGIS Pro for model annotation, and (5) annotating corallivory on SfM models. Steps one through three have previously been outlined in other SOPs, therefore they will not be described in detail here. This SOP focuses on steps four and five which include setting up a Geodatabase, preparing models in ArcGIS Pro for annotation, and the methodology used for annotation. This SOP is the result of comprehensive methodological testing. The methodology along with in-water surveys was applied at coral reefs around the island of O‘ahu, Hawai‘i. Ten coral reef sites that encompass a variety of coral habitat types, corallivore abundances, and percent coral cover were selected. It is our hope that the workflow discussed in this SOP can be easily adapted to other coral reef and marine ecosystem monitoring programs, while considering local coral species and types of corallivory.

2. Materials needed

To use this SOP the following materials are needed:

- For in-water image collection:
  - Dive slate with pencil
  - SfM datasheet
  - 20-meter transect, weighted down at both ends
  - Ground control points (3+)
  - Canon SL2 or SL3 with Ikelite housing
  - 18% gray card to white balance at depth
  - Optional: fishing weights spray painted in bright color (i.e., neon pink)
- For model processing and annotation:
  - Agisoft Metashape
  - ArcGIS Pro
  - Viscore
  - Mouse with a middle scroll bar wheel (required for Viscore)
  - Optional: a tablet with an electronic pencil and/or an external monitor

3. Model generation

This section goes over the general steps required to create SfM models, from image collection to building models in Agisoft. The "Processing Photomosaic Imagery of Coral Reefs Using Structure-from Motion Standard Operating Procedures" SOP will be referenced throughout this section and contains detailed, step-by-step directions for each of the broad steps described below. It will be referred to throughout this document as the "SfM SOP." The sections below refer to specific sections of the SfM SOP (linked above) and detail ways in which these methods deviate from the earlier SOP.

3.1 Image Collection

The first step in the pipeline will be to collect underwater imagery for the SfM models. Refer to section 2.1 of the SfM SOP which covers camera setup and settings, scale bars and markers, and underwater survey methodology. At the time of this writing, an updated version of the SfM SOP was created with new camera settings. However, during method development for this SOP, the camera settings from the older SfM SOP (linked above) were used. It is also important to note that most digital cameras can be used to generate SfM models.

Optional: If the surveyor is trying to monitor specific areas along a transect, such as surveying quadrats at specific meter marks, it is recommended that they place something highly visible, such as a spray-painted fishing weight, in those areas before image collection (Figure 1).

When time is available, we recommend collecting additional close-up images of coral heads with excess predation or that may be difficult to annotate in the orthomosaic. It is also a good idea to take note of corallivorous fishes (i.e., parrotfish, triggerfish, blennies, and pufferfish) and invertebrates (i.e., snails, cushion stars, and crown-of-thorns) in the area. These notes can be helpful when figuring out the likely sources of coral predation while annotating.

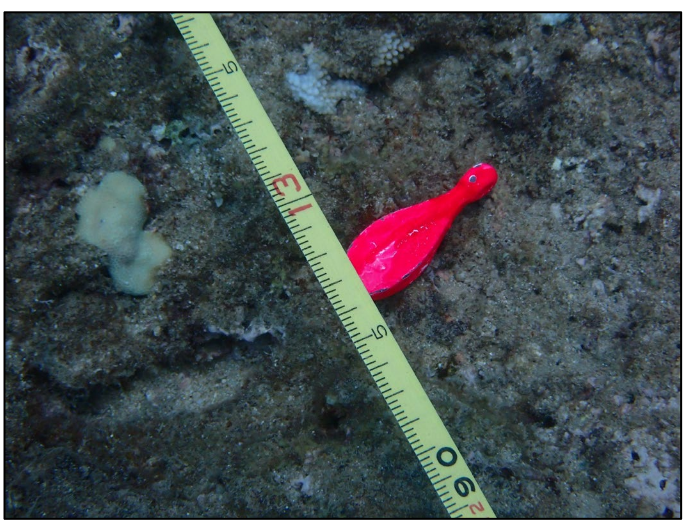


Figure 1. A spray-painted fishing weight is used to mark where quadrats will be drawn in ArcGIS Pro.

3.2 Data Management and Quality Control

The images gathered for the SfM models will need to be stored and undergo quality control procedures. Refer to section 2.2 of the SfM SOP which covers camera download, saving images to site folders, quality control, and, if necessary, using Adobe Lightroom to adjust image exposure.

3.3 Generating 3D Models and 2D Orthomosaics

Once images have been stored in the proper folders and undergone quality control, they can be used to create 3D models and 2D orthomosaics. Refer to section 3 of the SfM SOP for instrustions on how to generate 3D point clouds and 2D orthomosaics in Agisoft and how to visualize 3D point clouds and underlying imagery using Viscore. Viewing the 3D structure and underlying imagery is crucial to generating quality annotations. If Viscore is not available, Agisoft can also be used to view underlying imagery. The SfM SOP describes this process. Contact courtney.s.couch@noaa.gov for the most recent version of the Suka et al. (2019) SOP.

4. Setting up ArcGIS Pro for Model Annotation

ArcGIS Pro (v2.8.0 or later) should be used to annotate orthomosaics created in Agisoft. This section describes how to upload orthomosaics to ArcGIS Pro, add transect lines and quadrats for annotation boundaries, and create a geodatabase to record data. Creating an original geodatabase (section 4.1) only needs to be done once per project. Every step in sections 4.2, 4.3, and 4.4 needs to be replicated before annotating each individual site or orthomosaic. This section assumes a very limited working knowledge of ArcGIS Pro.

4.1 Creating the Geodatabase

Before annotations can begin, a Geodatabase must be created. The Geodatabase will be used to create the attribute domains which will provide annotators with standard drop down menus from which to choose. The following section outlines the steps for creating the Geodatabase and the specific column headers and codes for each column. Descriptions of each column and all the codes are covered in more detail in Appendix 1. This step only needs to be completed once for the whole project (i.e., it is unnecessary to create a new geodatabase for each new site/transect that is being annotated).

Adapted from the SfM SOP Appendix.

1. Create a table in Excel (e.g., Figure 2). This will later be converted to attribute domains in the Geodatabase (GDB) in ArcGIS Pro. Attribute domains are rules in a GDB used to constrain the values allowed in any particular attribute for a table or feature class within, which will let the analyst utilize a standard drop down menu. Short codes make conversion into data clouds easier, although full names can be used according to what is surveyed.
    a. Each column in the Excel file will later be a column in the attribute table in ArcGIS Pro. All cells filled in below the header row will be a confined drop-down option in the attributes table. For no confinements in a given column, leave the cells under the header column blank.
    b. Note: the CORAL_CODE column in the figure below is cut off and does not contain a complete list of coral species. A description of O‘ahu’s most common species can be found in Appendix 1. However, it is best to include all the coral species likely found in the region of interest, even if they are rare, as it is difficult to edit the GDB later.

	A	B	C	D	E	F	G	H	I	J	K
1	SITE	ANNOTATOR	QUAD_N	METER_MARK	CORAL_CODE	BITE_CATEGORY	CONDITION	NUMBER_BITES	OVERLAP_SCORE	BITE_LOCATION	COMMENTS
2			1		UNKN	EBRE	New		1 (<25%)		
3			2		ACYT	EXCAV	Old		2 (25 - 50%		
4			3		APAN	SCSP	Healing		3 (50 - 75%)		
5			4		AGEM	SCRAP			4 (>75%)		
6			5		AHUM	DRUP					
7			6		ACSP	STAR					
8			7		CWEL	NONE					
9					CYSP						
10					CAGA						
11					COCE						
12					CVAU						
13					DIAS						
14					FGRA						
15					FSCU						
16					FUSP						
17					GPLA						
18					LBEW						
19					LPRU						

Figure 2. Excel table of GDB domains. Once imported into ArcGIS Pro, columns C, E, F, G, and I will have corresponding drop-down options. Columns A, B, D, H, J, and K will need to be manually filled in using ArcGIS Pro.

2. Name this table (e.g., Corallivory_MHI_codes) and save in a GDB folder (located generally within the project folder) as an .xlsx file.
3. Convert the Excel file to CSV (comma delimited) following the same naming convention as the Excel file.
4. Open an existing ArcGIS Pro file.
5. Go to Analysis → Tools. On the right side of the screen, search and select 'Create File Geodatabase (Data Management)' (Figure 3).

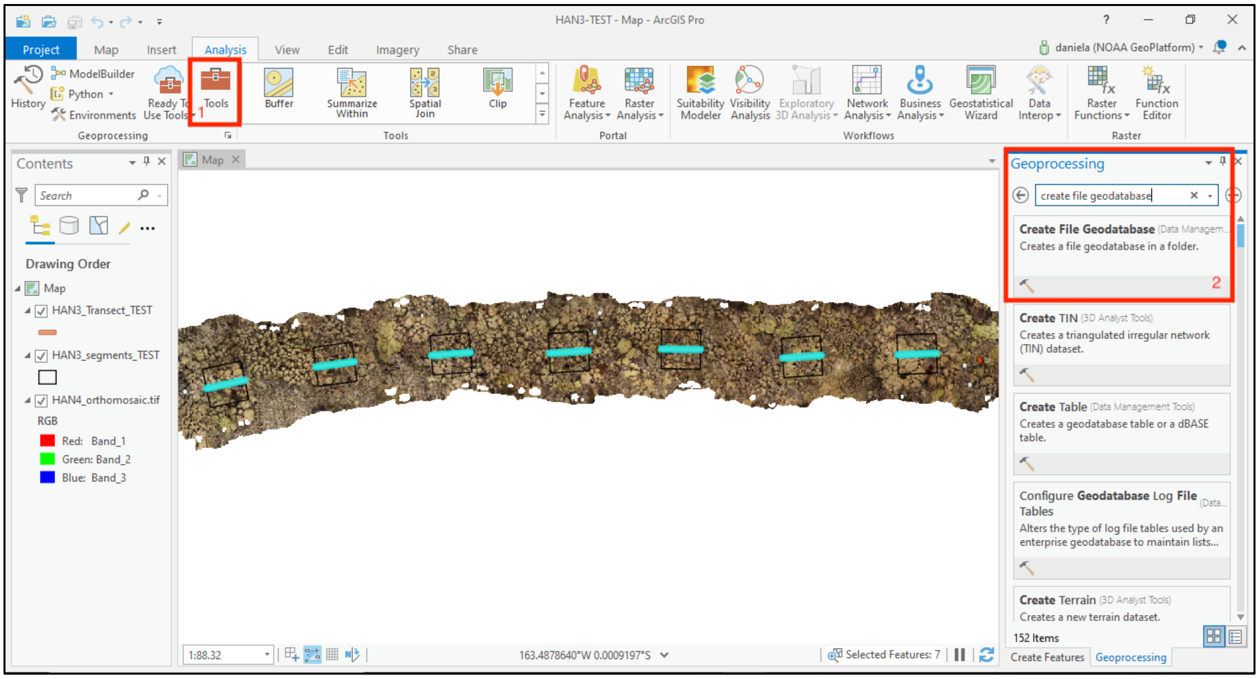


Figure 3. Open an ArcGIS Pro file. (1) Under the 'Analysis' tab, select 'Tools'. (2) On the right side of the screen, search for and select 'Create File Geodatabase'.

6. Fill in the following parameters and press the 'Run' button (Figure 4):
    a. File Geodatabase Location: Path to the folder where the GDB will be stored (the same folder where the Excel and CSV files are located, e.g., M:\Corallivory_MHI\Corallivory_MHI_GDB_v2).
    b. File GDB Name: Name of geodatabase.
    c. File Geodatabase Version: Current.

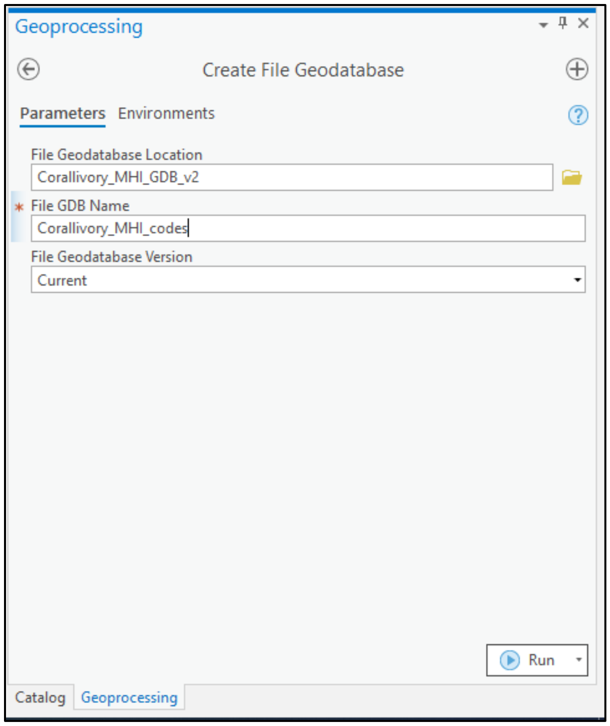


Figure 4. In the 'Create File Geodatabase' pop up window, fill in the 'File Geodatabase Location' field with the path to where the GDB will be store, the 'File Geodatabase Name' field with the name of the GDB, and select 'Current' in the 'File Geodatabase Version' drop down meni. Once all fields are filled out, select 'Run' on the bottom right of the pop up window.

7. Go to Analysis → Tools. On the right side of the screen search for and select 'Table to Domain (Data Management)' (Figure 5).

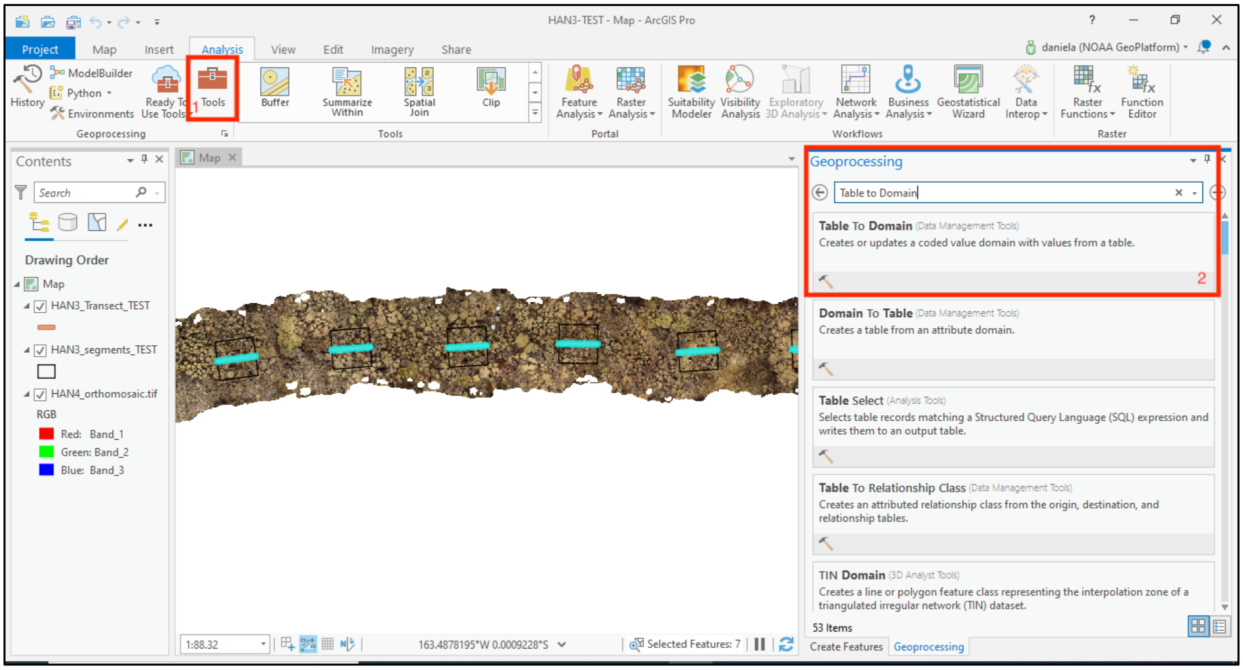


Figure 5. (1) Under the 'Analysis' tab on the top of the screen, select 'Tools' icon. (2) On the right side of the screen, search for and select 'Table to Domain'.

8. Fill in the following parameters and press the 'Run' button (Figure 6):
   a. Input Table: Table containing coded field values and description field values (the CSV file from step 1).
   b. Code Field: Header name of the first column of the CSV file (e.g., if looking at figure 2, type 'SITE').
   c. Description Field: Same field as above (i.e., 'SITE').
   d. Input Workspace: The path to geodatabase created in step 6a.
   e. Domain Name: Same as 'Code Field' (i.e., 'SITE').
   f. Domain Description: Same as 'Code Field' (i.e., 'SITE').
   g. Update Option: Append the values.

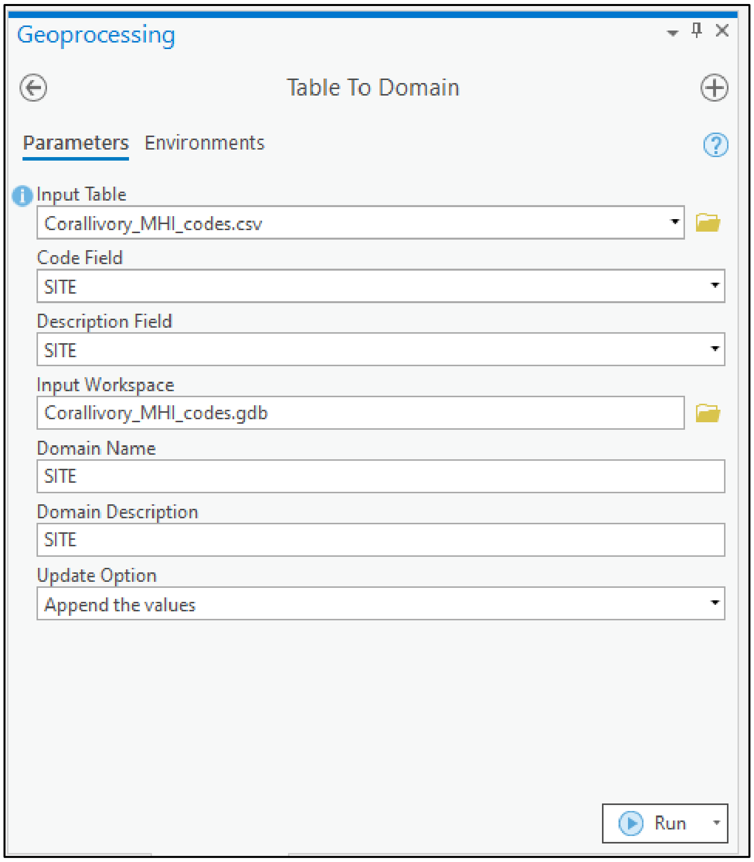


Figure 6. Fill in the parameters in the 'Table to Domain' window as follows and select 'Run'.

9. Repeat steps 7 and 8, the 'Table to Domain' tool, for all attribute domains per column.
10. Once all list domains are added, go to Analysis → Tools. On the right side of the screen search for and select 'Create Feature Class (Data Management)' (Figure 7).

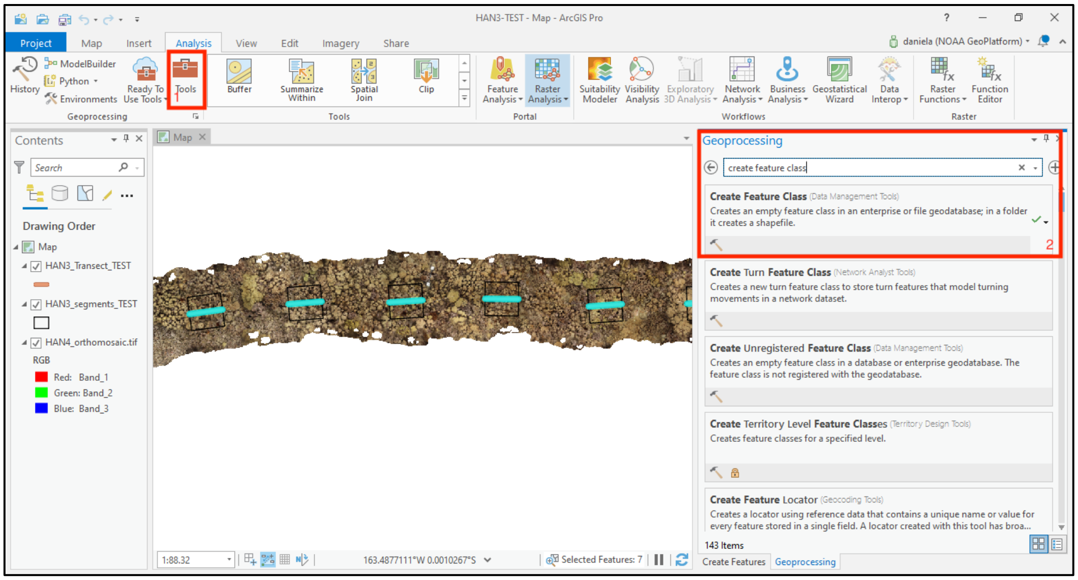


Figure 7. (1) Under the 'Analysis' tab, select 'Tools'. (2) On the right side of the screen, search for and select 'Create Feature Class'.

11. Fill in the following parameters and press the 'Run' button (Figure 8):
    a. Feature Class Location: Path to geodatabase created in step 6.
    b. Feature Class Name: Template.
    c. Geometry Type: Multipoint.
    d. Template Feature Class (optional): Leave blank.
    e. Has M (optional): No.
    f. Has Z (optional): No.
    g. Coordinate System (optional): WGS1984 UTM Zone 4N.
    h. Feature Class Alias: Leave blank.

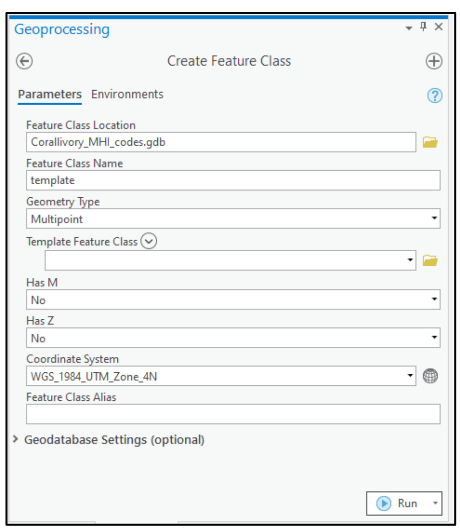


Figure 8. Fill in the parameters in the 'Create Feature Class' window as follows and select 'Run'.

12. The template feature class will automatically be dropped into the Table of Contents under the 'Map' drop down menu on the left side of the screen

([Figure 9](#)).

13. Go to Analysis → Tools. On the right side of the screen search for and select ‘Add Field (Data Management)’ ([Figure 9](#)).

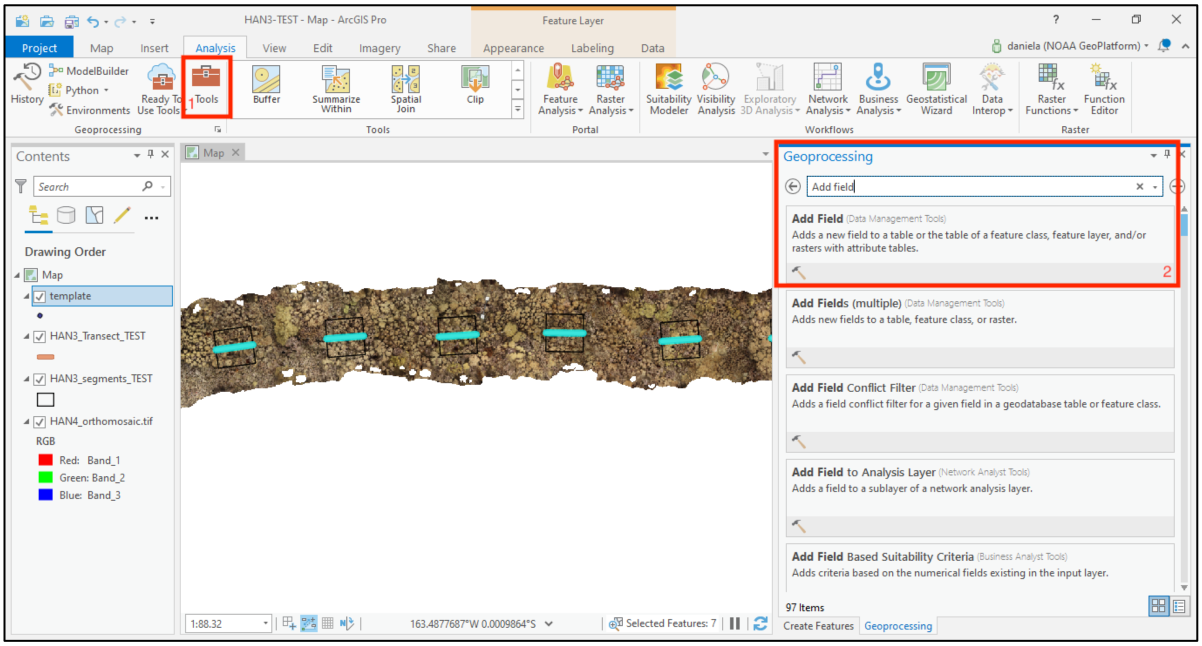


Figure 9. (1) Under the ‘Analysis’ tab select, ‘Tools’. (2) On the right side of the screen, search for and select ‘Add Field’.

14. ***Repeat this step for each column <u>without</u> drop-down options*** ([Table 1](#)). Fill in the following parameters and press the ‘Run’ button ([Figure 10a](#)):
    a. Input Table: Template.
    b. Field Name: Header name of the column in the CSV file (e.g., SITE).
    c. Field Type ([Table 1](#)):
        i. ‘Text’—if inputting letters OR letter and number combinations into field during annotation.
        ii. ‘Long (large integer)’—if inputting just numerical values into field during annotation.
    d. Leave remaining cells blank. Make sure to disable ‘Field IsNullable’ and ‘Field IsRequired’.
15. ***Repeat this step for each column <u>with</u> drop-down options*** ([Table 1](#)). Fill in the following parameters and press the ‘Run’ button ([Figure 10b](#)):
    a. Input Table: template.
    b. Field Name: Header name of the column in the CSV file (e.g., QUAD_N).
    c. Field Type ([Table 1](#)):
        i. ‘Text’ - if drop-down options include letters OR letter/number combinations.
        ii. ‘Long (large integer)’—if drop-down options are just numerical values.
    d. Field Domain: Same as Field Name (e.g., QUAD_N).
    e. Leave remaining cells blank. Make sure to disable ‘Field IsNullable’ and ‘Field IsRequired’.

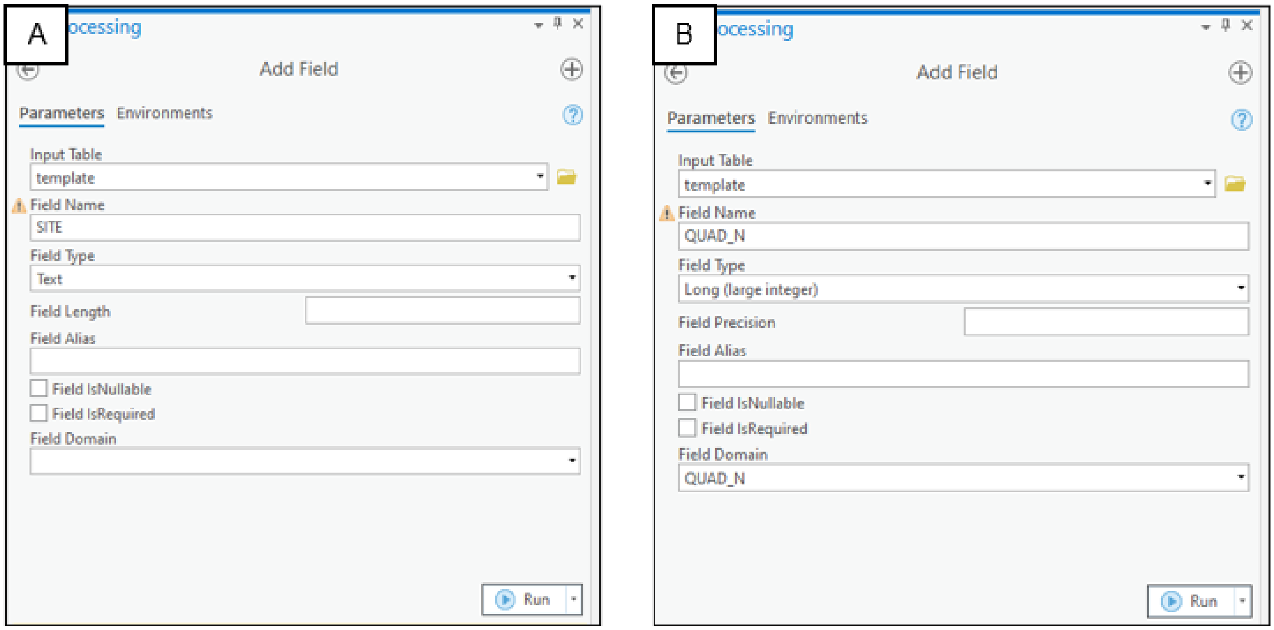


Figure 10. Fill in the parameters in the 'Add Field' window as follows and select 'Run' for columns (A) without drop-down options and (B) with drop-down options. The 'Field Type' will vary depending on the input values or drop down options (Table 1). 'Field Domain' should remain blank for columns without drop down options and it should match the 'Field Name' for columns with drop down options.

Table 1. Column name and type along with field type information to complete steps 14 and 15. For columns without drop-down options, leave the 'Field Domain' blank. For columns with drop-down options, fill in the 'Field Domain' with the column name.

Column name	**Column Type**	**Field Type**
SITE	**Without** drop-down options	Text
ANNOTATOR	**Without** drop-down options	Text
QUAD_N	**With** drop-down options	Long (large integer)
METER_MARK	**Without** drop-down options	Long (large integer)
CORAL_CODE	**With** drop-down options	Text
BITE_CATEGORY	**With** drop-down options	Text
CONDITION	**With** drop-down options	Text
NUMBER_BITES	**Without** drop-down options	Long (large integer)
OVERLAP_SCORE	**With** drop-down options	Text
BITE_LOCATION	**Without** drop-down options	Text
COMMENTS	**Without** drop-down options	Text

4.2 Importing 2D Orthomosaics into ArcGIS Pro

Adapted from the SfM SOP section 3.2.

1. Open a new ArcGIS Pro (v2.8.0 or later) file locally on computer.
2. Under 'Blank Templates,' select 'Map' (Figure 11).

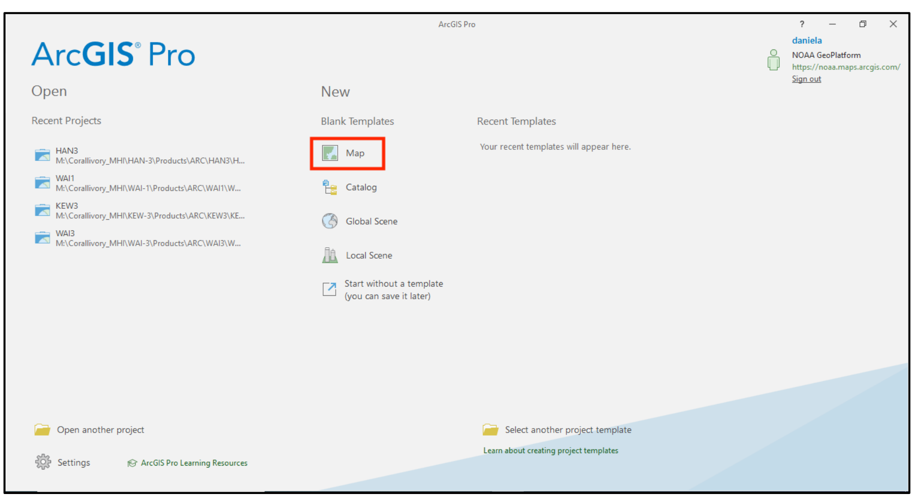


Figure 11. Open ArcGIS Pro and select the 'Map' icon (boxed in red).

3. Fill in the pop up window as follows (Figure 12):
    a. Name: Enter name of site being annotated (e.g., Site#).
    b. Location: Navigate to the ARC folder that contains the orthomosaic TIF file for that site (e.g., M:\Corallivory_MHI\HAN-3\Products\ARC).
    c. Check the box, 'Create a new folder'.
    d. Select 'OK'.

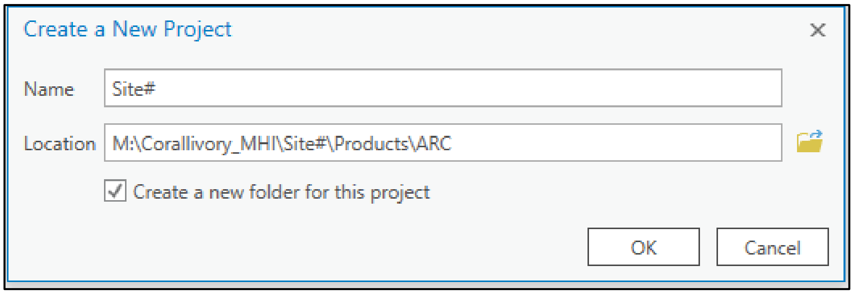


Figure 12. Screenshot of the pop-up window that appears after the 'Map' option is selected along with how to complete it.

4. Remove the 'World Topographic Map' by right clicking the name on the left side of the screen and selecting 'Remove' (Figure 13).

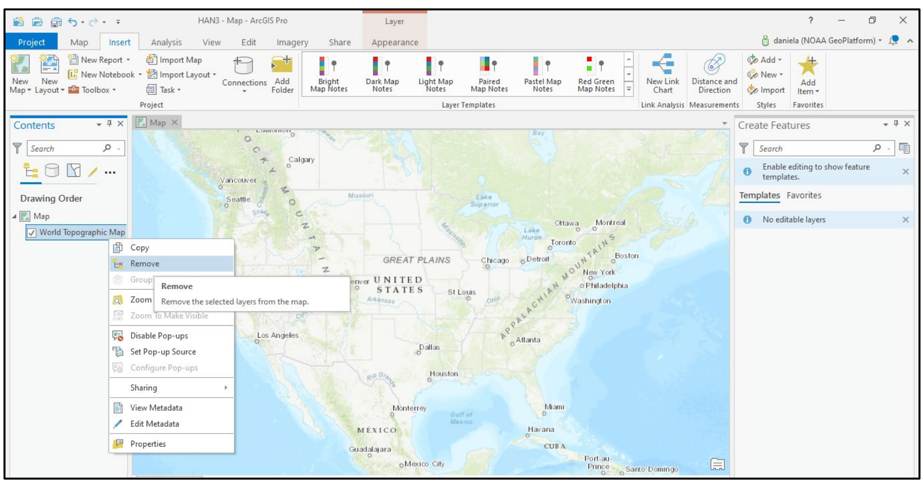


Figure 13. Removing the 'World Topographic Map'.

5. Use the 'Add Folder' option under the Insert tab to add the folder where the orthomosaic is located (e.g., M:\Corallivory_MHI\HAN-3\Products\ARC) (Figure 14).

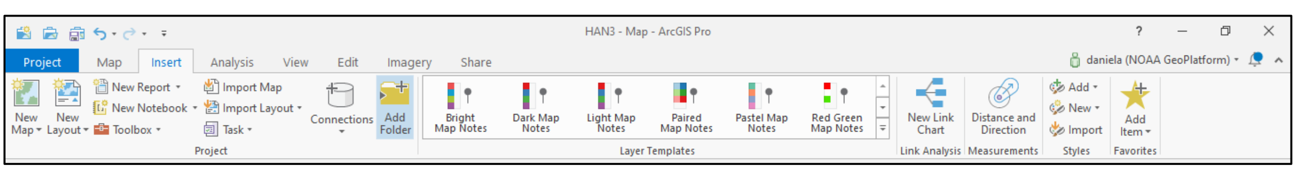


Figure 14. Use the 'Add Folder' option to add the folder to the document.

6. Upload the orthomosaic using the ‘Add Data’ option under the ‘Map’ tab (e.g., M:\Corallivory_MHI\HAN-3\Products2\ARC\HAN3_orthomosaic.tif) (Figure 15).
    a. An ‘Unknown Spatial Reference’ message will pop up in the upper right corner, ignore this (Figure 15).

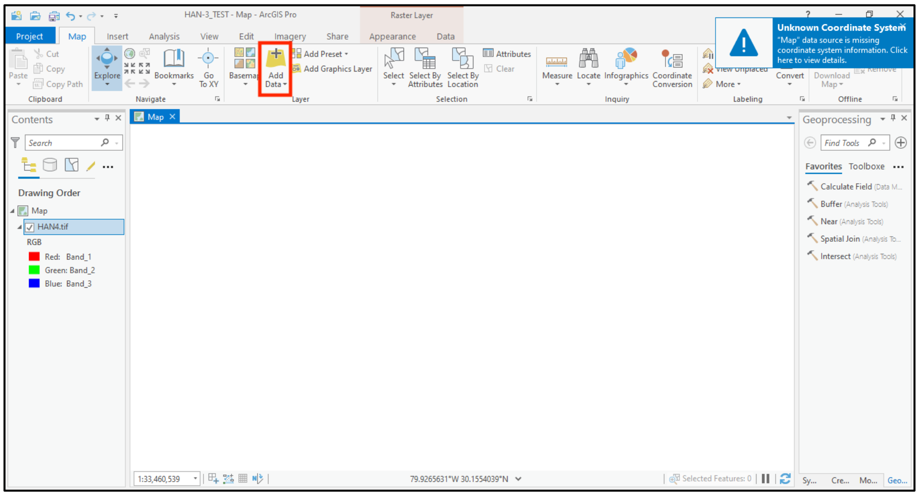


Figure 15. Use the ‘Add Data’ option (boxed in red) to import the orthomosaic. The error message can be seen on the upper right hand corner in the blue box.

    b. If the model does not appear on the screen, right click on the previously defined name (e.g., Site#) on the left of the screen under ‘Map’ and select ‘Zoom to Layer’ (Figure 16).

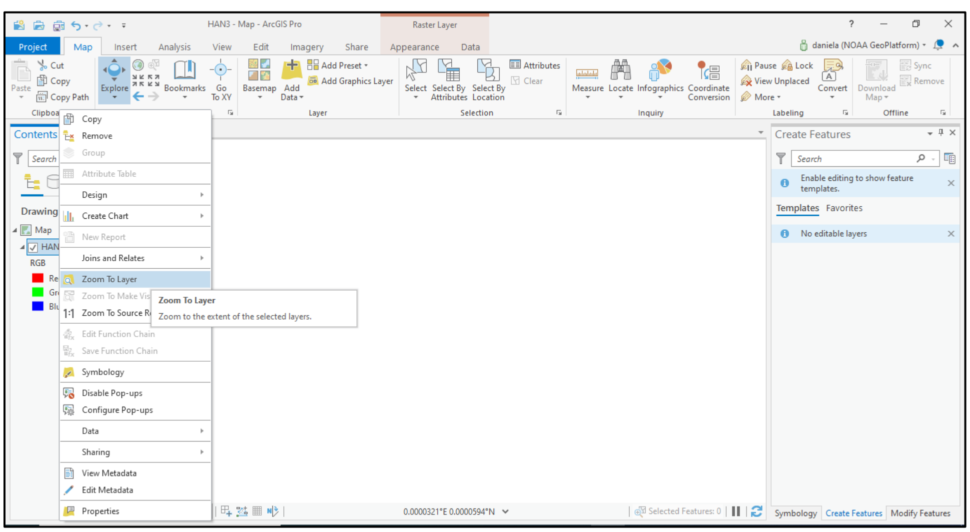


Figure 16. Use the ‘Zoom to Layer’ option on the left side of the screen if the model is not visible.

7. Go to Analysis → Tools (Figure 17a).
8. On the right side of the screen, search for and select ‘Define Projection’ (Figure 17a). Fill in the following parameters and press the ‘Run’ button (Figure 17b):

a. Input Dataset or Feature Class: Navigate to current orthomosaic (e.g., M:\Corallivory_MHI\HAN-3\Products2\ARC\HAN3_orthomosaic.tif).

b. Under 'Coordinate Systems,' set 'Current XY' to 'WGS 1984 UTM Zone 4N.' To do so, click on the globe next to the drop down menu ( ) and go to 'Projected Coordinate System' → 'UTM' → 'WGS 1984' → 'Northern Hemisphere' → 'WGS 1984 UTM Zone 4N.'

   i. The coordinate system will be the same regardless of geographical location.

   ii. If not previously done, right click to 'Add to Favorites.'

c. If the model disappears after hitting 'Run' and displays, 'Define Projection complete' on the bottom right, repeat step 6b and 'Zoom to Layer'.

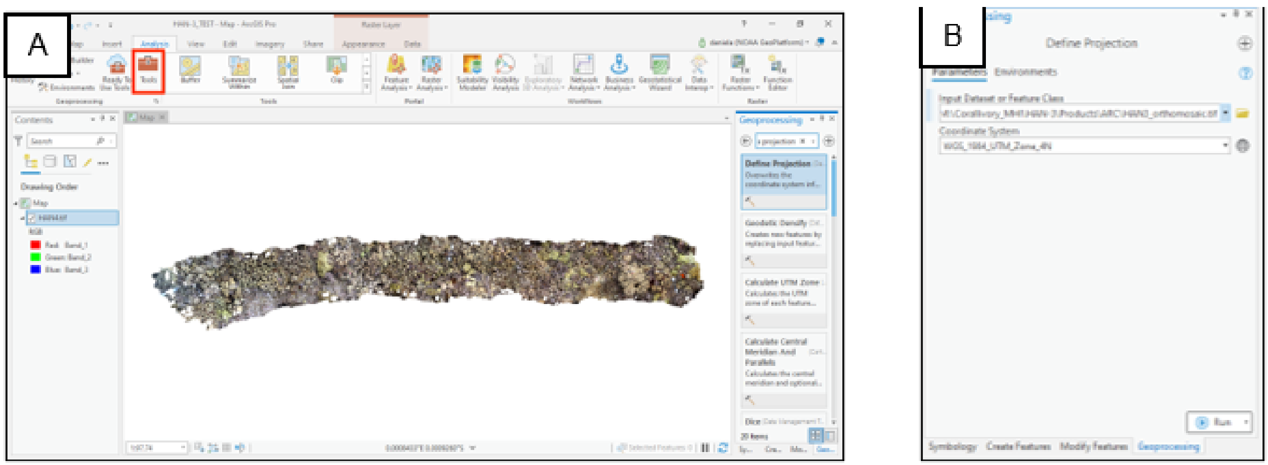


Figure 17. (A) Go to the 'Tools' section under the 'Analysis' tab (boxed in red). On the right side of the screen, search for and select 'Define Projection'. (B) Fill in the parameters as described above.

9. The model colors will likely be incorrect. Click the model layer, go to the 'Raster Layer' tab at the top, click on the drop down menu under 'Stretch Type' and change to 'None' (Figure 18).

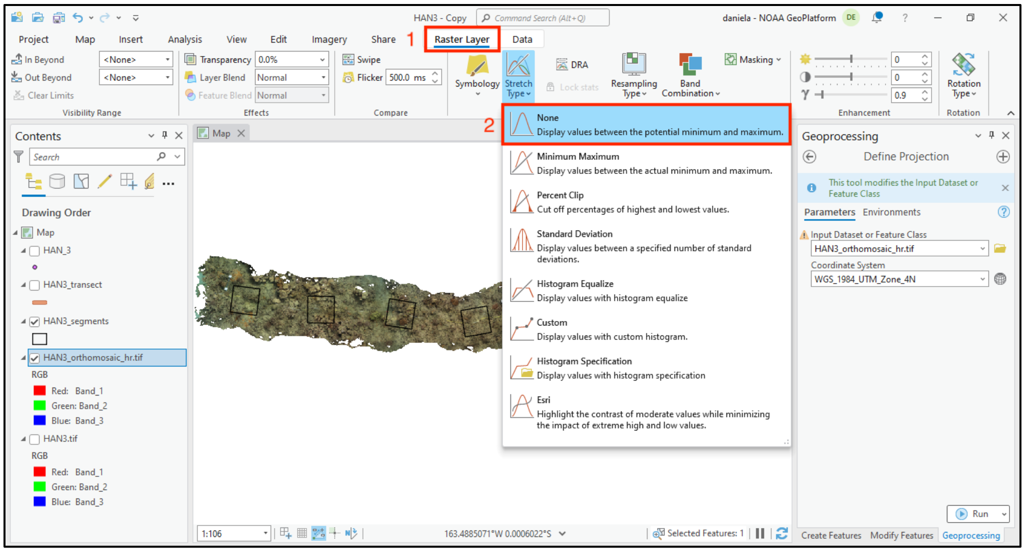


Figure 18. (1) Select the 'Raster Layer' tab, then (2) navigate to 'Stretch Type' and select 'None' to color correct the model.

10. The orthomosaic should already be properly scaled if it was scaled and oriented in Agisoft; however, confirm it is correctly scaled by using the 'Measure' tool under the 'Map' tab to measure an object of known length (e.g., a scale bar) (Figure 19).
    a. If the orthomosaic did not scale properly, revisit the SfM SOP (section 3.1E) to rescale the model and export a new orthomosaic.

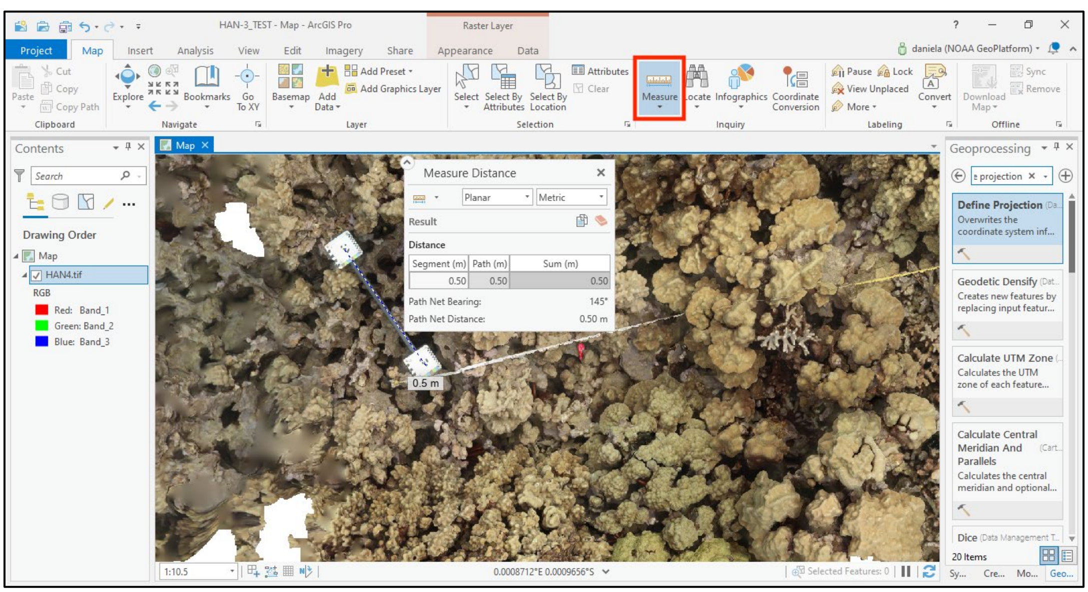


Figure 19. Use the 'Measure' tool (boxed in red and under the 'Map' tab) to measure an object in the model to ensure it is correctly scaled. In the figure above, the scale bar was measured and has a length of 0.5 meters. Note: scale bars may be different lengths. Become familiar ahead of time with the scale bar(s) used for proper scaling and orientation. This project used both 0.25 and 0.5 meter scale bars (target to target).

4.3 Adding Transects and Quadrats to an Orthomosaic in ArcGIS Pro

1. Under the 'View' tab on the top of the screen, click 'Catalog Pane.' Drag and drop the new window to the right side of the screen to pin it (Figure 20).

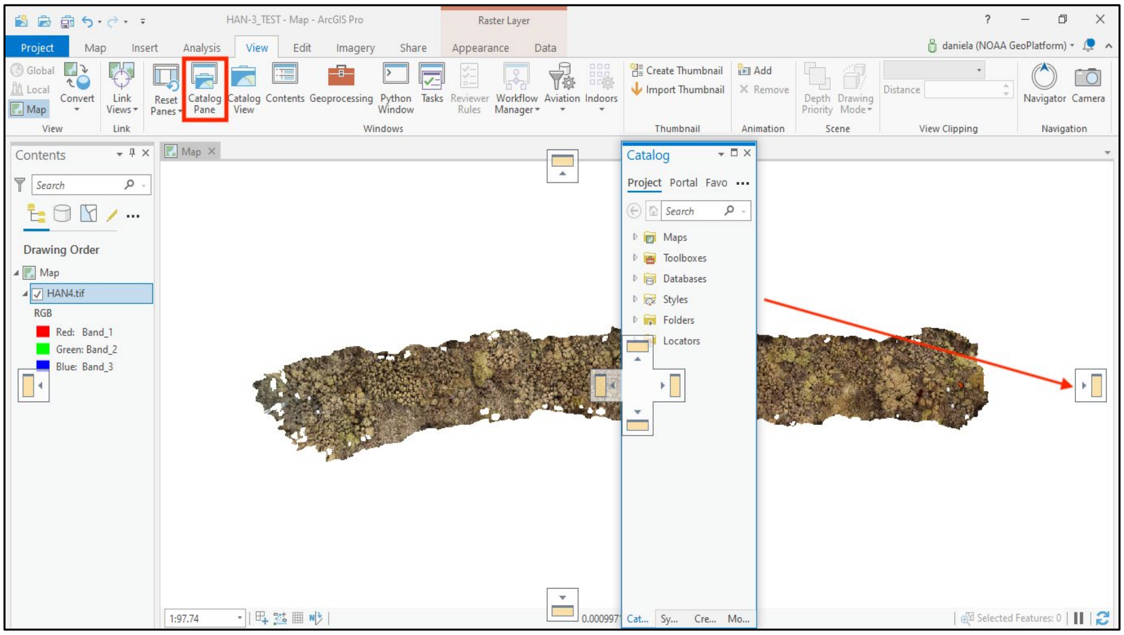


Figure 20. Click the 'Catalog Pane' option (boxed in red) under the 'View' tab. A 'Catalog' window will appear. Drag and drop to the right of the screen to pin it into place.

2. **To create the transect**, right click on the site's ARC folder in the Catalog and select New → Shapefile (Figure 21a). Fill in the pop-up window as follows and press the 'Run' button (Figure 21b):
   a. Feature Class Name: site#_transect.
   b. Geometry Type: Polyline.
   c. Coordinate system: WGS 1984 UTM Zone 4N (change as in step 8b from the previous section).
   d. Leave everything else as is.
   e. Note: transect length and location will vary depending on the project and research question. For the purposes of this SOP, we laid a 20-m transect over the reef and parallel to shore.

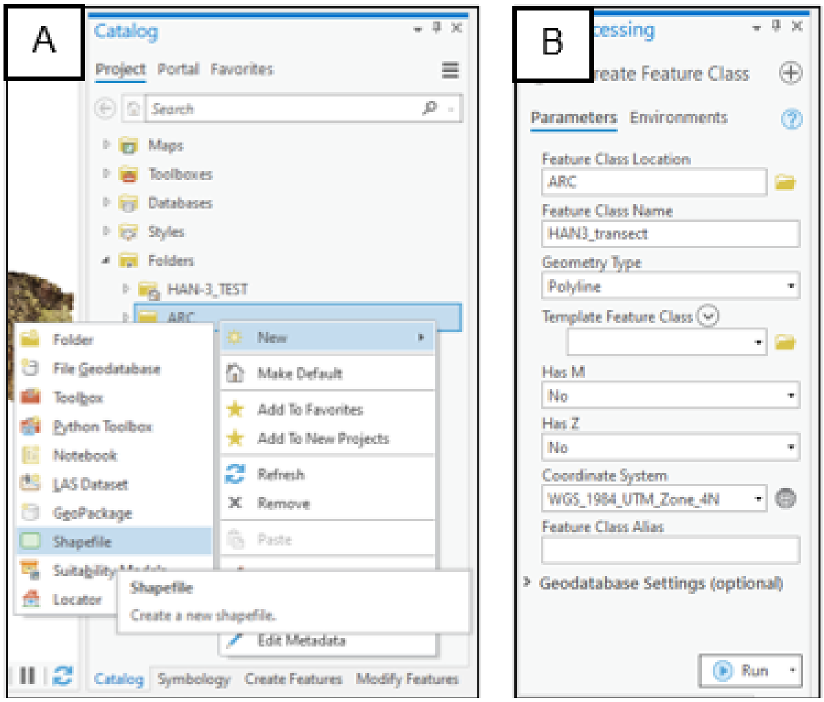


Figure 21. (A) Right click on the 'ARC' folder in the Catalog and select 'New' → 'Shapefile'. (B) Fill in the 'Creature Feature Class' fields as previously described.

3. In the 'Edit' tab, select 'Edit' → 'Create.' Drag the pop up window to the right side of the screen to pin it there, as was done in step 1 (Figure 22).

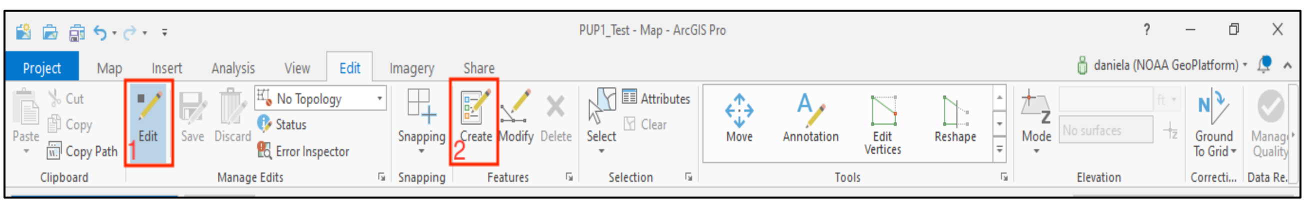


Figure 22. (1) In the 'Edit' tab, first select 'Edit' and (2) then click on 'Create.'

4. In the 'Create Features' window (on the right side of the screen), click on site#_transect and make sure the construction tool is the 'line' option (Figure 23a).
    a. To make the line a more vibrant color (which will make it easier to see on the dynamic background), double click on the line feature on the left side window under 'Map' → 'Site#_transect'. This will open a 'Symbology' window on the right side of the screen. Select 'Highway' for a highly visible transect line (Figure 23b).

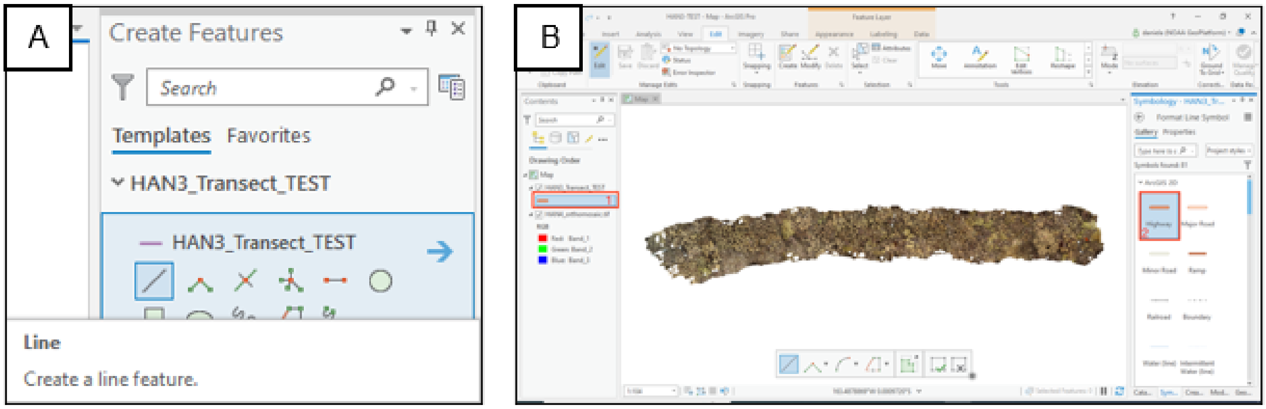


Figure 23. (A) First make sure the 'line' option is selected in the 'Create Features' pane on the right side of the screen. (B) Change the type of line by (1) double clicking on the line under the transect name on the left side of the screen and (2) clicking the 'Highway' option on the right side of the screen.

5. Turn on the 'Dynamic Constraints' option prior to drawing transects by clicking once on the icon, found at the bottom of the screen (Figure 24).

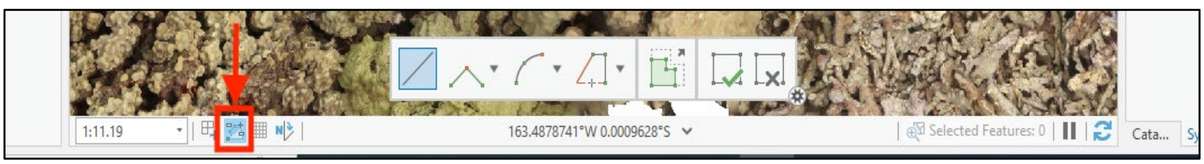


Figure 24. Turn on the 'Dynamic Constraints' option at the bottom of the screen (boxed in red).

6. Zoom into the layer 'site#_orthomosaic.tif' and click once at the designated starting point for the first quadrat of the transect. For this project, these points were marked with a pink/red fishing weight (if a fishing weight is not visible or was not used, refer to the project metadata to locate which meter marks were used for the quadrats) (Figure 25).
    a. Note: due to the resolution of the orthomosaic, it may be necessary to reference the raw imagery using Viscore/Iview to locate the fishing weights/meter markers.
7. After the first click, drag the mouse to draw a "best-fit" line along the transect tape visible in the orthomosaic. Drag the mouse exactly 1-meter (3.28-ft), then double click to fix the line into place (Figure 25).

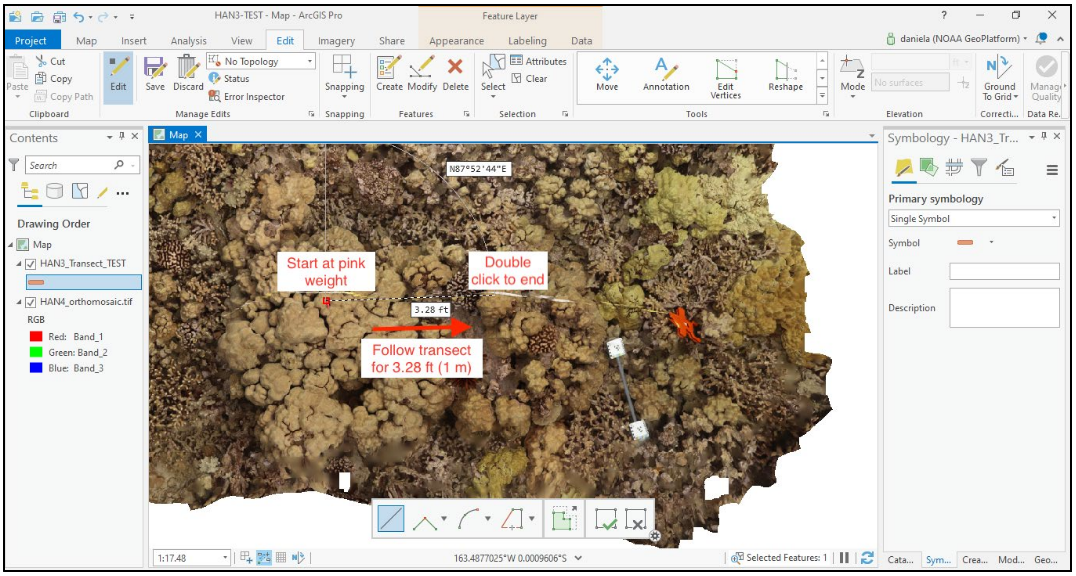


Figure 25. For each transect line, click at the pink weight, follow the transect line for 3.28 ft (1 m) and double click to fix the line into place.

8. Repeat steps 6 and 7 for all the quadrats along the transect (this project analyzed seven quadrats per transect).
    a. When done, zoom out. Seven same-length lines should be visible at equal intervals along the model (Figure 26) (distances between lines may vary *slightly* due to the curvatures of the transect line along the reef).
9. Once all 1-m transect lines are drawn, go to the 'Edit' tab and hit 'Save.' Then, go to the 'Map' tab and click 'Explore' to stop editing (Figure 26).

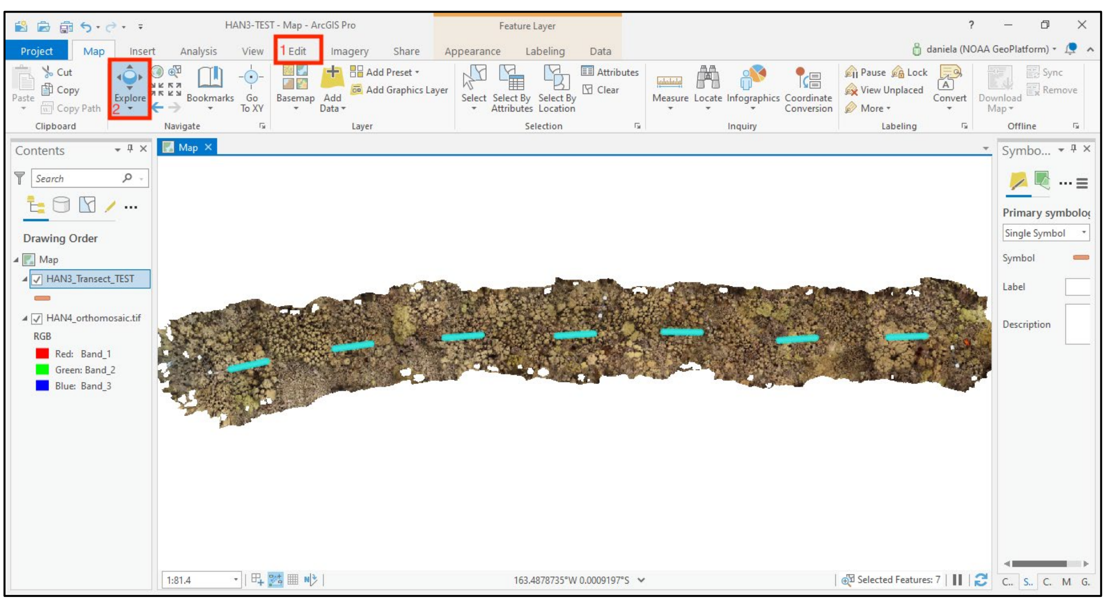


Figure 26. Once all the 1-m segments have been drawn, zoom out to ensure seven are visible. (1) Go to the 'Edit' tab and hit 'Save.' (2) Lastly, go to the 'Map' tab and select 'Explore.'

10. **To create the quadrats**, right click on the transect layer (Site#_transect) on the left side of the screen, click on 'Selection,' then click on 'Select All' (Figure 27).

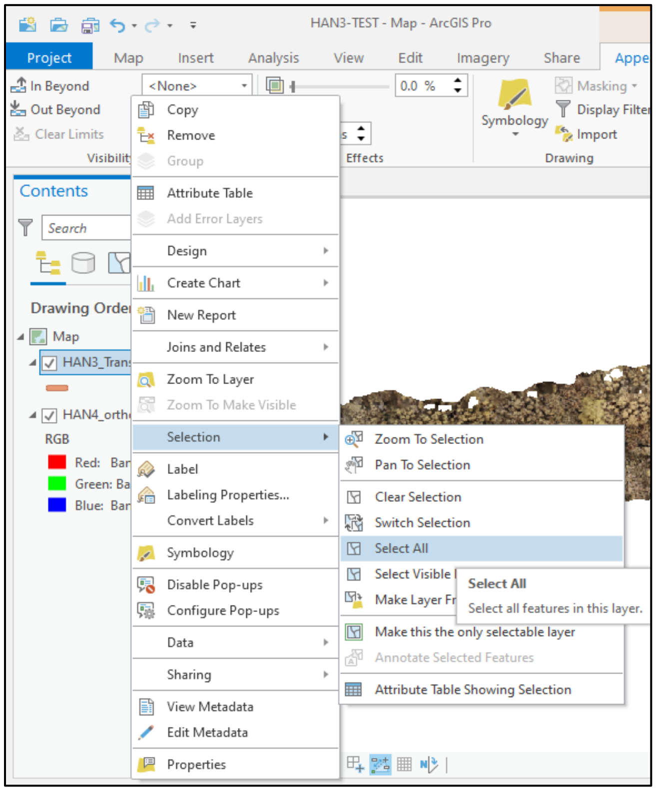


Figure 27. Right click on the transect layer on the left side of the screen then press 'Selection' and 'Select All' from the drop down menus.

11. Go to 'Analysis' → 'Buffer.' Fill in the 'Geoprocessing' pane on the right side of the screen as follows and press the 'Run' button (Figure 28):
    a. Input features: site#_transect.
    b. Output Feature Class: site#_segments.
    c. Linear Unit: 0.5 Meters.
    d. Side Type: Full.
    e. End Type: Flat.
    f. Method: Planar.
    g. Dissolve Type: No Dissolve.

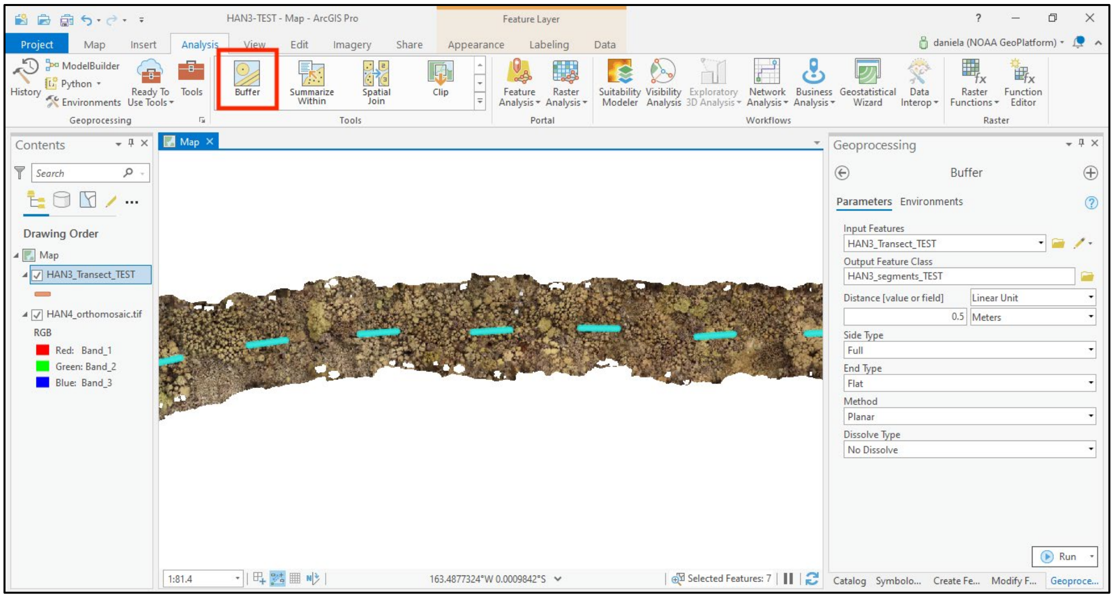


Figure 28. Select the 'Buffer' option (boxed in red) in the 'Analysis' tab. Then fill in the 'Buffer' pain on the right side of the screen as previously described.

12. Once step 11 is completed, segments (quadrats) will be drawn around the transect lines and should be exactly 1-m wide (Figure 29).
    a. At this point, the segments may be filled in. To correct the color and transparency of the segments, double click on the Site#_segments layer on the left window which will make the Symbology window reappear on the right. Use this window to choose the outline and fill color of the segments (Figure 29).

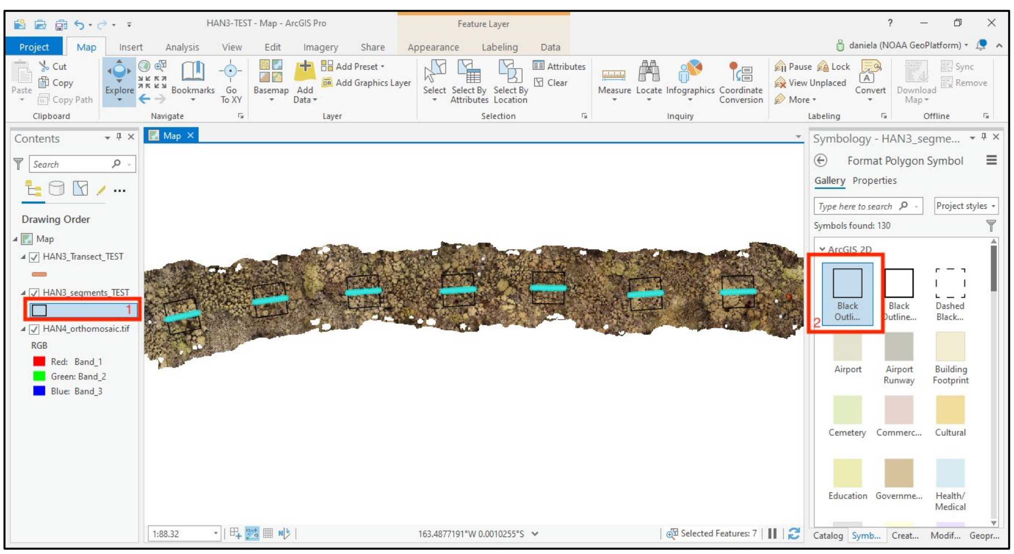


Figure 29. After step 11, quadrats will be drawn around the transect lines. To fix the shading and outline, (1) double click on the site#_segments layer on the left side of the screen and (2) select the 'Black Outline' option on the right.

4.4 Adding Geodatabase to ArcGIS Pro Projects

1. To view the project folder in ArcGIS Pro, navigate to 'Insert' → 'Add Folder' (Figure 30).

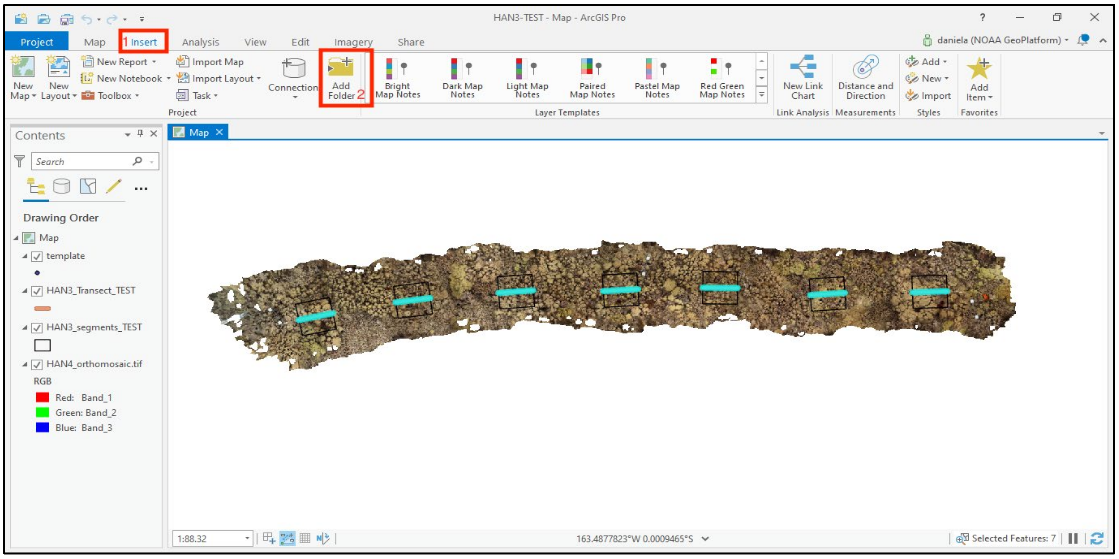


Figure 30. With the model open in ArcGIS Pro, (1) navigate to the 'Insert' tab and (2) select 'Add Folder'.

2. In the pop up window, select the project's parent folder that includes the geodatabase and the individual ArcGIS Pro files and click 'OK.'
3. In 'Catalog' (View → Catalog Pane), navigate to the project's most recent version of the Geodatabase.
    a. Folders: Corallivory_MHI → select the file in the folder with the most recent Geodatabase (i.e., M:\Corallivory_MHI\Corallivory_MHI_GDB_v2\Corallivory_MHI_v2.gdb).
4. Expand the drop down menu for the GDB (i.e., Corallivory_MHI_v2.gdb) by clicking on the arrow to the left of the file name (Figure 31a).
5. Right click on the 'template' feature class and select 'Copy' (Figure 31a).
6. Right click on the Geodatabase (in this case, 'Corallivory_MHI_v2.gdb') and click 'Paste' (Figure 31b). It will take a few moments for this to paste.

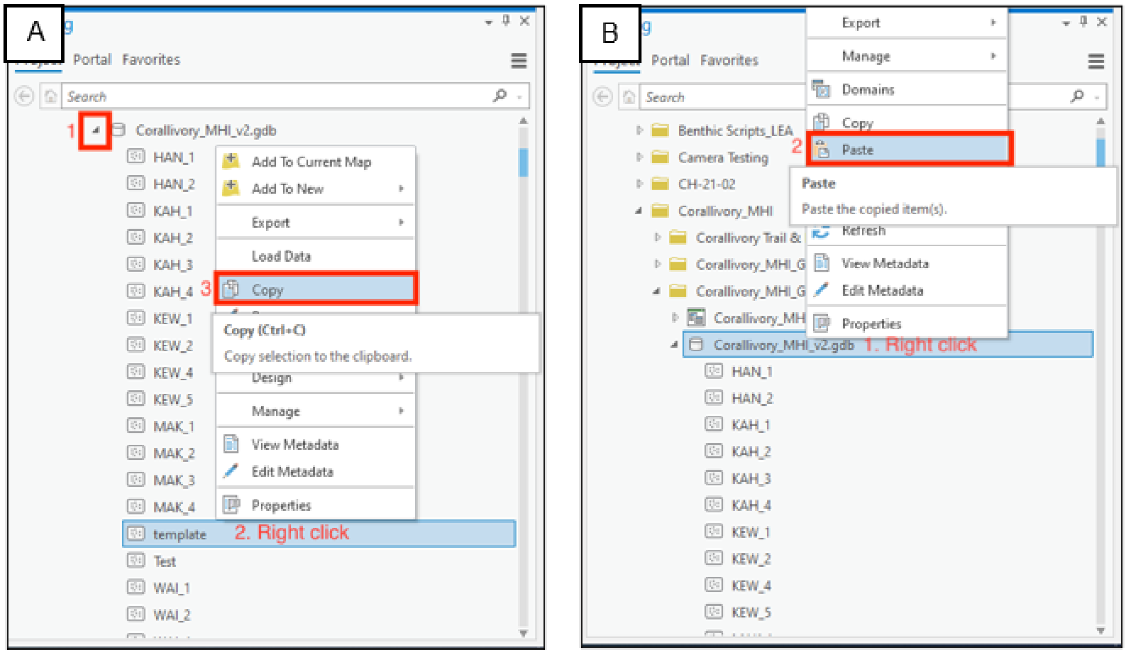


Figure 31. After navigating to the Geodatabase in the Catalog, (A) (1) click on the arrow to the left of the Geodatabase name, (2) right click 'template' and (3) select 'Copy.' (B) Go back to the Geodatabase, (1) right click and (2) select 'Paste.'

7. Right click on the new template copy (it will likely show up as 'template_1') and select 'Rename.'
    a. Rename feature to 'SITE_#.'
8. Drag the new template copy ('SITE_#') from the catalog pane to the contents tab and drop it under 'Map.'

5. Extracting Corallivory Data Using ArcGIS Pro

The following section outlines the annotation process and covers best practices and suggestions on the best way to look for corallivory bite marks. It also describes how to use ArcGIS and Viscore to annotate models for different types of corallivory. It is important to note that these surveys might not be as accurate during bleaching events, when browsing bite marks and bleaching could be confused with one another. Moreover, annotators should have some familiarity with coral conditions and diseases as some may be easily confused with corallivory. Appendix 1 reviews O‘ahu-specific codes used to annotate coral reef models for corallivory. For fish bite mark categories (e.g., EXBR, SCSP, EXCAV, and SCRAP), follow the methods outlined in section 5.2. For sea star and *Drupella* predation, follow the methods in section 5.3.

5.1 Extracting Coral Area by Species

Some types of predation (e.g., *Drupella,* sea stars) leave behind large swaths of white, dead skeleton which is used to estimate the percent cover of corallivory for these types of predators. This method could also be used in areas of concentrated fish predation when individual bites cannot be distinguished. In order to determine percent corallivory for these predators from SfM models, it is necessary to calculate coral area by species in each quadrat. This section discusses general steps used to extract the area of corals by species, while section 5.3 presents a general overview of how to use these data to calculate percentage of corallivory.

1) Extract orthblocks of the areas that will be annotated (reference Appendix 2).
2) Upload orthoblocks to CoralNet and annotate to the lowest taxonomic level (the “Analysis of Benthic Survey Images via CoralNet” SOP outlines the process of annotating in CoralNet).
3) Multiply the percentage coral cover of each species by the area of the orthoblock.
    a) For example, if the orthoblock area represents a 1m × 1m quadrat, the area of each coral species would be calculated by multiplying the percent coral cover of that species by 1m^2.

5.2 Annotating Fish Predation

It is recommended that the person annotating uses two monitors and/or a tablet. The following software are required for annotation:

- ArcGIS Pro—for annotation and initial inspection
- Viscore—for viewing underlying imagery
- GoogleChrome–for viewing underlying imagery

If Viscore is not available to the annotator, underlying imagery can be viewed using Agisoft. Information on how to use Agisoft for this purpose can be found in the SfM SOP. Contact courtney.s.couch@noaa.gov for the most recent version of the Suka et al. (2019) SOP.

Calibration among annotators is critical. A new annotator and a trained annotator should agree to annotate the same quadrats. They should choose a variety of sites with different topographies, coral composition and cover, and levels of predation. Once they have annotated the same quadrats, compare results. The new annotator is ready when there is greater than 90% agreement between the two users. For fish predation, the annotator will count the number of bite marks per corallivory category per coral species per condition per quadrat.

5.2.1 Getting ready to annotate

1. Open the project in ArcGIS Pro. Depending on the speed of the computer, it might take some time for the project to open.
    a. Site folder → products → ARC → site name → select the file with the ArcGIS Pro symbol ( ).
2. Zoom in to the quadrat that is being annotated.
3. On the left side of the screen, under the 'Map' drop down menu, make sure the multipoint feature is checked on (Figure 32).

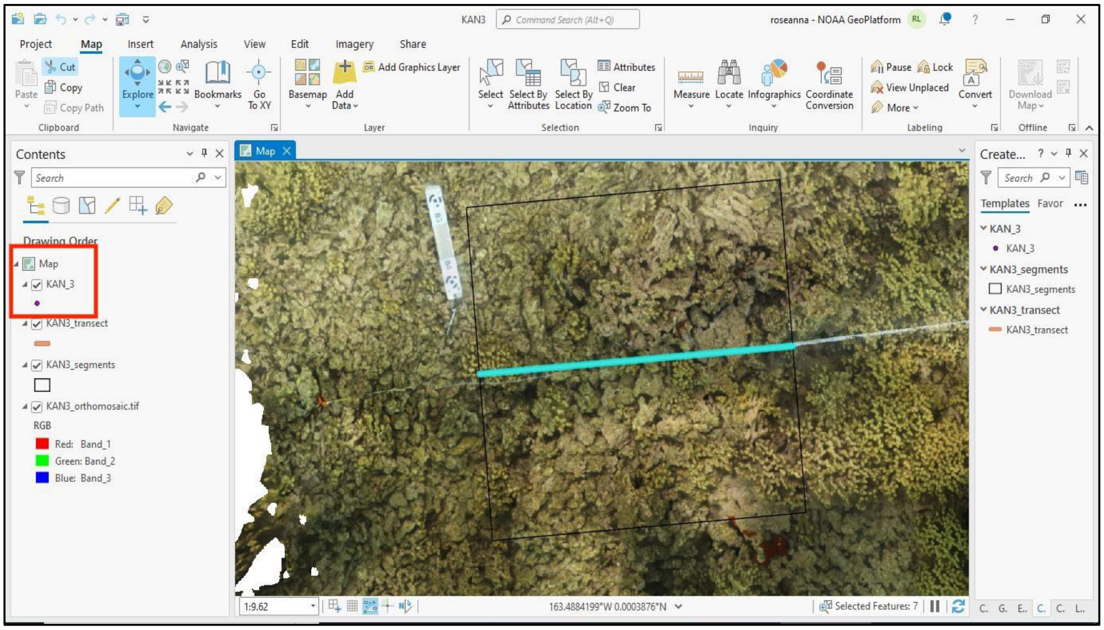


Figure 32. When project is open, zoom into the quadrat and turn the check mark on for the multipoint feature on the left side of the screen (boxed in red).

4. Go to 'Edit' tab → 'Edit' (Figure 33).

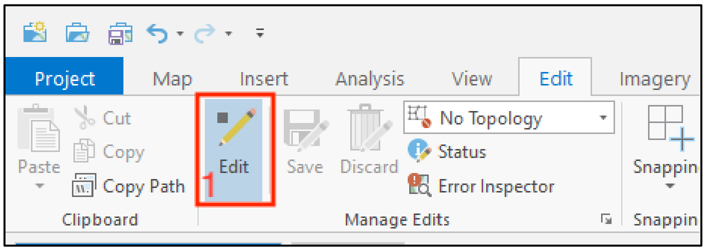


Figure 33. Select the 'Edit' option under the 'Edit' tab.

5. On the far right side of the screen, click on the right pointing arrow that appears next to the multipoint tool (Figure 34a). Fill in the site name and annotator fields (Figure 34b).

These fields will be the same for the whole transect, prefilling them will auto-fill them whenever a new row of annotations is created in the attributes table.

a. SITE—three letter code followed by the number transect at that site. This should match the site name and number on the SfM tracking sheet.
b. ANNOTATOR—the three letter initials of the annotator.
c. The rest of the fields can either be filled out here for each annotation or in the attribute table once the new row corresponding to the annotations is created (step 6 in the next section).

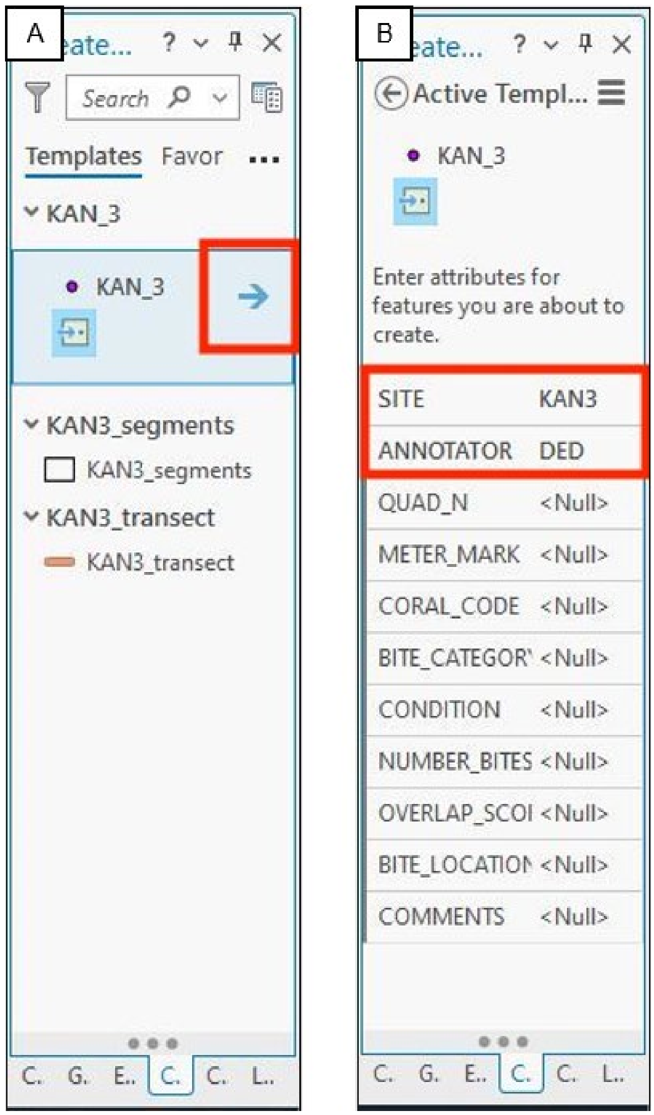


Figure 34. (A) Click on the right pointing arrow next to the feature name on the right side of the screen (boxed in red). (B) Fill in the 'SITE' and 'ANNOTATOR' fields as described above and optionally the rest of the fields for each new annotation combination.

6. To begin annotating, click on the icon under the multipoint feature that looks like a box with a dot inside and an arrow pointing into it on the right hand side of the screen. This will turn on the multipoint annotation tool (Figure 35).

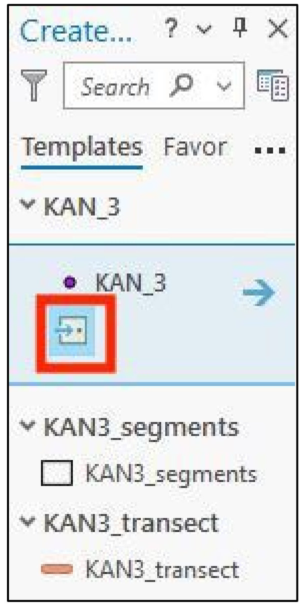


Figure 35. Turn on the multipoint annotation tool by clicking on the icon boxed in red.

7. Open the attribute table for the multipoint feature. On the left side of the screen, right click on the site name (immediately under the 'Map' drop down menu) and select 'Attribute Table' (Figure 36).

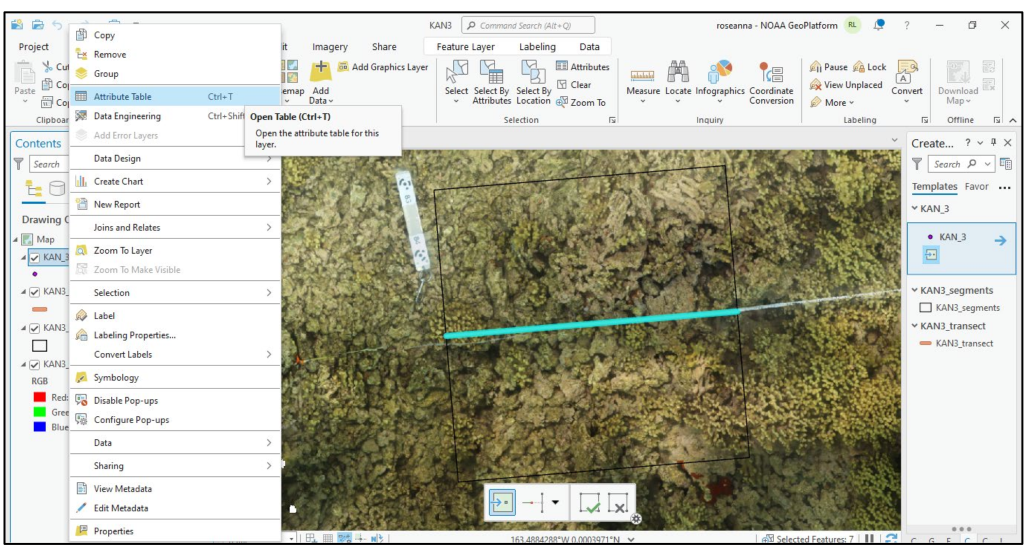


Figure 36. Right click on the name of the multipoint feature on the left side of the screen and select 'Attribute table'.

8. Navigate to the Viscore file for that site and double click to open.
    a. Site_folder → Products → Site_name file with Viscore symbol (⭐).
9. Turn on the cameras (Figure 37).
    a. Hover over the right side of the screen and select ‘Cams’ (once clicked, a small ‘ON’ symbol will show up next to ‘Cams’).
    b. On the bottom left, click on ‘none’ to the right of the word ‘cams.’ Once clicked, the symbol will change from ‘none’ to the site name and yellow camera paths will appear on the model. Consult the “Guide to Viscore” if the site name or camera paths do not appear.

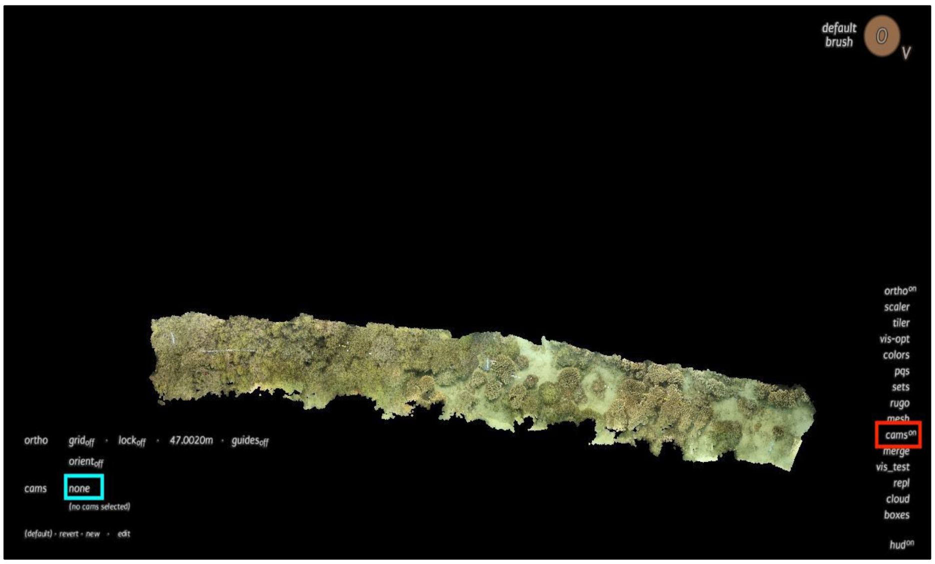


Figure 37. To turn on the cameras, select ‘cams’ on the right side of the screen (boxed in red). The small ‘ON’ will appear once ‘cams’ has been clicked. Then select ‘none’ on the bottom left of the screen (boxed in blue).

10. Zoom in to the part of the model that will be annotated.
    a. The pink weight marks the beginning of the quadrat.
    b. If necessary, rotate the model so it matches the orientation in ArcGIS Pro. This will make it easier to navigate within the models in both programs.
    c. Viscore controls:
        i. Right click and move mouse up and down to zoom in and out.
        ii. Left click and move mouse up and down to rotate the model.
        iii. Left and right click at the same time and move the mouse to move the model.

Now that ArcGIS Pro and Viscore are set up, the annotation process can begin.

5.2.2 Annotating fish predation

This section covers how to annotate fish predation; *Drupella* and sea star predation follows a different methodology (see section 5.3). However, any sea star or *Drupella* predation observed in a quadrat during these annotations should be noted on the SfM process tracking sheet (or whatever process tracking sheet is being used). Also, note any cushion stars, crown of thorns, and/or *Drupella* snails seen anywhere on the model or in the underlying imagery. For fish predation (codes: SCRAP, EXBR, EXCAV, SCSP; see Appendix 1), the annotator will count the number of bite marks per corallivore category per coral species per condition per quadrat.

1. Go to Viscore and drop a point on the first coral that will be inspected (Figure 38).
    a. To drop a point, select 'Alt' on the keyboard and click the middle wheel/button on the mouse.

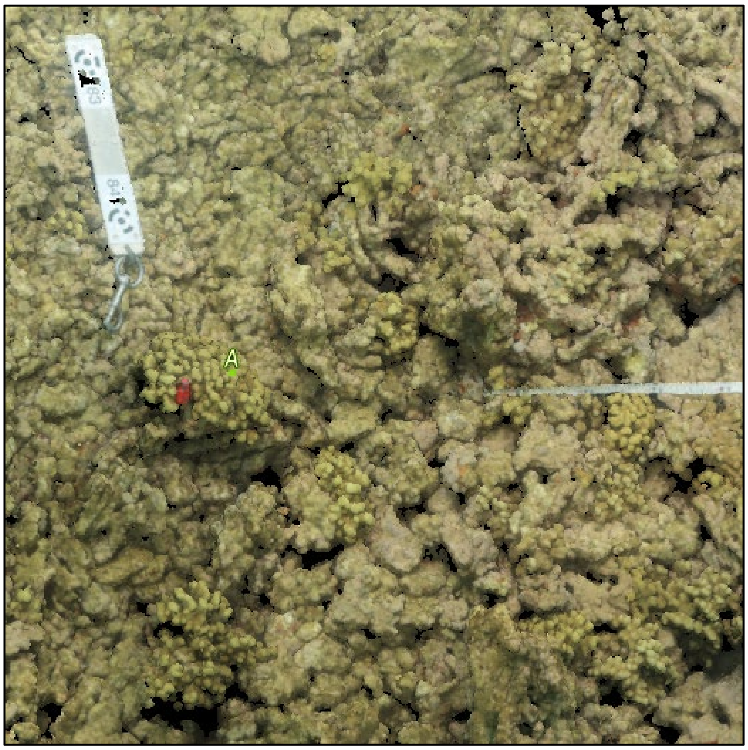
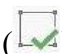


Figure 38. Drop a point (Point A) on the first coral along the search pattern.

2. After dropping the point, view the underlying imagery by opening Google Chrome.
    a. Enter localhost:9090/jsd/pq.xhtml in the URL bar and images containing that point should appear.
    b. To scroll through the images 'scroll + left click' with the mouse or use the up and down arrows on the keyboard.
    c. To zoom in or out, simply 'scroll' with the middle wheel on the mouse.
3. View as many images from as many angles as needed to identify corallivory scars.
    a. For colonies that fall both inside and outside the quadrat, only look at the live coral within the quadrat, ignore anything outside.
    b. Not all colonies may be visible on the ArcGIS Pro orthomosaic due to low resolution, especially smaller colonies, or those under overhangs or in crevices.

   When viewing underlying imagery for larger colonies, inspect the surroundings for colonies that might not be visible in ArcGIS Pro.
   c. For corallivore marks that fall on the quadrat line, count the bite mark as long as more than 50% of the bite mark falls within the quadrat.
4. When corallivory is found, go back to ArcGIS Pro and using the multipoint tool, drop point(s) wherever bite marks were spotted in the underlying imagery.
   a. If corallivory is not visible in ArcGIS Pro, try to match the location as closely as possible using the underlying imagery as a guide.
   b. Create a new line in the attribute table for each new coral species/bite category/condition combination.
      i. For example, scraper bite marks on *Pocillopora meandrina* that are new and scraper bite marks on *Pocillopora meandrina* that are old will each require their own line in the attribute table
      ii. Note: each coral colony does not need a new line, all colonies of the same species with the same bite category and condition can be lumped together.
   c. Once done dropping points for the specific coral species/bite category/condition combination in ArcGIS Pro, click the button that looks like a box with a check mark (). This will create a new row in the attribute table that is linked to the point(s) that were just created.
5. A new line in the attribute table will be generated for those points. Fill in the appropriate information for the point(s) in the attribute table (Figure 39). Alternately, the information could be filled in before completing step 5c (of this section) as described in step 5 of the previous section:
   a. Site and Annotator should automatically get filled in if step 5 in section 5.2.1 was completed correctly.
   b. Quad_N—quadrat number (drop down menu).
   c. Meter_mark—at what meter is the pink weight placed (approximate to nearest meter). Might need to view underlying imagery for this information (type in a number).
   d. Coral_code—first letter of genus name followed by first three letters of the species name, with some exceptions. See Appendix 1 for taxa list and example images (drop down menu).
   e. Bite_category—type of bite mark, see Appendix 1 for list and descriptions (drop down menu).
   f. Condition—at what stage of the healing process are the bite marks, see Appendix 1 for list and descriptions (drop down menu).
   g. Number_bites—there is no need to fill this in, see step 9 in this section.
   h. Overlap_score—the degree to which scars are overlapping (scores range from one to four), see Appendix 1 for list and descriptions (drop down menu).

i. The overlap score is a rough average per coral species per bite mark category per condition category per quadrat.

i. Comments—note anything unusual or of interest.

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	OBJECTID *	Shape *	SITE	ANNOTATOR	QUAD_N	METER_MARK	CORAL_CODE	BITE_CATEGORY	CONDITION	NUMBER_BITES	OVERLAP_SCORE
1	1	Multipoint	KAN3	DED	1	1	PCOM	SCRAP	Healing	<Null>	1 (<25%)
	Click to add new row.										

Figure 39. Create a new row in the attribute table for each new combination of coral species, bite category, and condition in each quadrat. Then fill in the information in each column as described above.

6. Repeat steps 3–6 until all the coral in the quadrat has been inspected.
   a. To move the point on Viscore to a new area, middle click on the point, drag to a new spot, and click on 'snap' on the bottom left (Figure 40). The new underlying imagery should automatically show up in Google Chrome.
   b. Alternatively, if the new imagery is not showing up, on Viscore, delete the point that was dropped by going to the bottom left hand side of the screen and selecting 'delete' (Figure 40). Drop a new point using the method described in step 1.

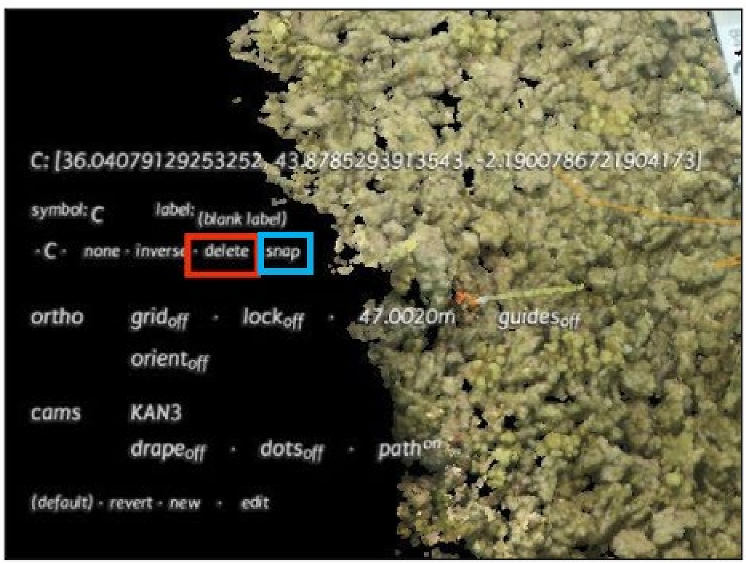


Figure 40. To view a new colony, drag the green point to the desired spot and select 'snap' (boxed in blue). Alternately, if the new underlying imagery isn't showing up correctly, delete the point (boxed in red) and drop a new point.

7. After each quadrat is annotated, indicate its completion in a tracking spreadsheet or whatever method is being used to track progress.
   a. As corallivory will be absent from some quadrats, tracking will allow users to ensure that all quadrats were surveyed and ensure that they do not repeat work that has already been completed.

b. Note on the tracking sheet if corallivory was absent from any quadrats, if a sea star or *Drupella* snail were found within the model, and/or if any of the quadrats had sea star or *Drupella* predation.

8. After completing all the annotations on a transect, fill in the 'number_bites' column following these steps:
    a. Select all the rows in the attribute table.
    b. Right click on the 'number_bites' column (Figure 41a).
    c. Select 'Calculate Geometry' (Figure 41a).
    d. In the pop up window (Figure 41b):
        i. Under 'Field (Existing or New),' select 'Number_bites'.
        ii. Under 'Property,' select 'Number of Parts'.
        iii. Click OK.
    e. Note: the 'Edit' option in the 'Edit' tab must be turned on in order to complete this step.

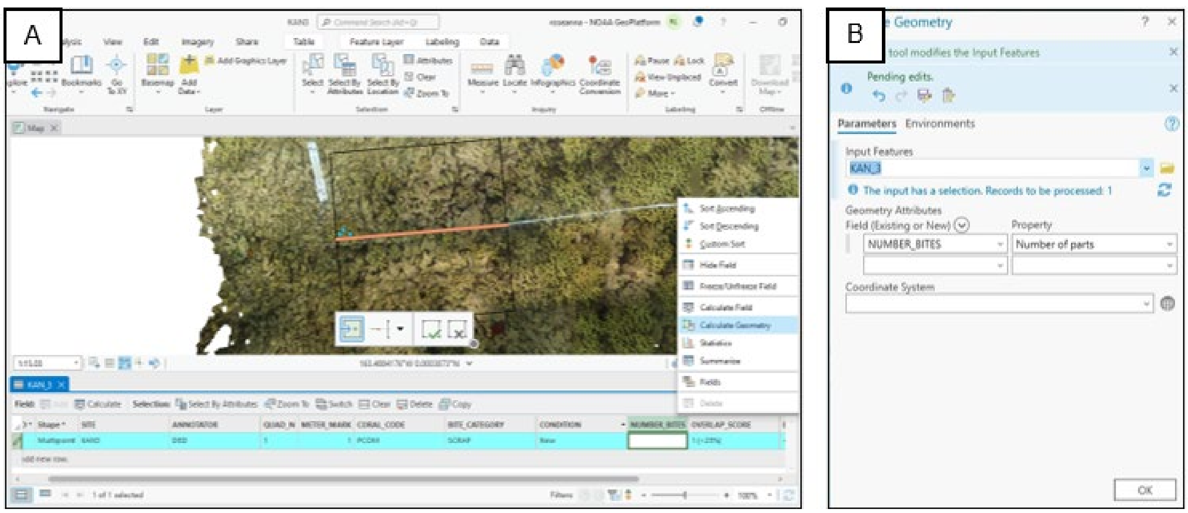


Figure 41. (A) Once all rows have been selected, right click on the 'number_bites' column and select 'Calculate Geometry,' (B) fill in the pop up window as shown.

9. Follow some of these extra recommendations while annotating:
    a. Define a search pattern ahead of time to help keep track of which colonies have already been inspected.
    b. For quadrats with a lot of coral, especially *Porites compressa* and "pieces" of massive *Porites*, upload a screenshot of the orthomosaic to something such as an iPad or tablet and use this to cross out previously inspected colonies; this will help keep track of progress.
    c. Similarly, rather than annotating on ArcGIS Pro as bite marks are encountered, mark them on a screenshot of the orthomosaic on the iPad or tablet. Wait until the whole quadrat has been inspected to transfer annotations to ArcGIS Pro.

i. Marking annotations on an iPad/tablet will also be helpful in case the annotator forgets to save changes and/or if ArcGIS Pro unexpectedly crashes.

d. If not using an iPad or tablet, it is best to annotate one colony at a time. An exception to this is when there are colonies of the same species in the surrounding area with the same type and condition of predation.

e. If an annotator is unclear about whether something is a bite mark or not, try to find it in at least 3–5 spaced out pictures. This can be especially useful when there is sand or other particles in the water column that might make it look like there is predation.

f. Underexposed pictures are better for finding bite marks as they provide much higher contrast between healthy and consumed areas.

g. Annotators must use an external mouse rather than the trackpad on the laptop in order to navigate in Viscore.

h. Have an external monitor and place ArcGIS Pro on one monitor and Viscore/ Google Chrome on the other monitor.

i. Use context clues when unsure about what might be predation. For example, if something looks like a parrotfish or blenny bite mark but the annotator is unsure, check the surrounding area as these two fishes usually leave several bite marks in one area. It may also be useful to check the notes from the image collector in case they noted whether they saw any corallivores.

j. If a sea star or *Drupella* snail is visible in the SfM model or the underlying imagery, note this in whatever tracking spreadsheet is being used for annotations. Similarly, make note of any predation from these animals in the tracking sheet.

k. Save work frequently!

5.3 Annotating Sea Star and *Drupella* Predation

Due to the low incidence of observed predation by *Drupella* snails and sea stars (crown-of-thorns and cushion stars) around O‘ahu, these types of corallivory were not annotated. Instead, a brief overview of the general methods that could be applied to quantify corallivory by these types of predators is described below. Since these corallivores leave behind large swaths of dead skeleton, the percent area of each coral species with a predation scar is estimated within each quadrat (the percent predation is out of live and recently dead coral tissue).

The general methodology requires the annotator to first set up a geodatabase in ArcGIS Pro to annotate using polygons. The quadrats are then inspected for *Drupella* and sea star predation and annotated using this tool. The SfM tracking data sheet can be used as a reference to determine where this type of predation was seen during the initial fish predation annotation round. As with fish predation, it is important to inspect the underlying imagery. Next, the area of each coral species within each quadrat is calculated using the methods in section 5.1. Lastly, to determine the percent predation by *Drupella* snails and sea stars, divide the area of predation from each coral predator (by coral species) by the total area of that coral species in the quadrat.

Because of the inconsistencies in this type of predation across sites and likely high variability, a method for comparing these types of predation was not conducted in this study. However, it is our hope that these methods are tested by other users as coral predation by these two types of predators has proven to be devastating to reefs around the world.

5.4 Extracting Data from ArcGIS Pro

Once annotations are complete, the final step is to export the annotations data from ArcGIS Pro. Refer to section 3.2 (F) of the SfM SOP which offers step by step instructions on how to extract annotations data from ArcGIS Pro.

6. Literature Cited

Anthony KRN. 2016. Coral Reefs Under Climate Change and Ocean Acidification: Challenges and Opportunities for Management and Policy. Annual Review of Environment and Resources. 41(1):59–81. https://doi.org/10.1146/annurev-environ-110615-085610

Bak RPM, Steward-Van Es Y. 1980. Regeneration of superficial damage in the scleractinian corals *Agaricia agaricites*, *F. Purpurea* and *Porites astreoides*. Bull Mar Sci. 30(4):883–887.

Beck MW, Losada IJ, Menéndez P, Reguero BG, Díaz-Simal P, Fernández F. 2018. The global flood protection savings provided by coral reefs. Nat Commun. 9(1):2186. https://doi.org/10.1038/s41467-018-04568-z

Birkeland C. 2019. Chapter 2 - Global Status of Coral Reefs: In Combination, Disturbances and Stressors Become Ratchets. In: Sheppard C, editor. World Seas: An Environmental Evaluation (Second Edition). Vol. III. Second Edition.: Academic Press; p. 35–56. https://doi.org/10.1016/B978-0-12-805052-1.00002-4

Bonaldo RM, Bellwood DR. 2011. Parrotfish predation on massive Porites on the Great Barrier Reef. Coral Reefs. 30(1):259–269. https://doi.org/10.1007/s00338-010-0669-3

Bos AR, Gumanao GS, Mueller B, Saceda-Cardoza MME. 2013. Management of crown-of-thorns sea star (Acanthaster planci L.) outbreaks: Removal success depends on reef topography and timing within the reproduction cycle. Ocean & Coastal Management. 71:116–122. https://doi.org/10.1016/j.ocecoaman.2012.09.011

Bryson M, Ferrari R, Figueira W, Pizarro O, Madin J, Williams S, Byrne M. 2017. Characterization of measurement errors using structure-from-motion and photogrammetry to measure marine habitat structural complexity. Ecol Evol. 7(15):5669–5681. https://doi.org/10.1002/ece3.3127

Burkepile DE. 2012. Context-dependent corallivory by parrotfishes in a Caribbean reef ecosystem. Coral Reefs. 31(1):111–120. https://doi.org/10.1007/s00338-011-0824-5

Cole AJ, Pratchett MS, Jones GP. 2008. Diversity and functional importance of coral-feeding fishes on tropical coral reefs. Fish and Fisheries. 9(3):286–307. https://doi.org/10.1111/j.1467-2979.2008.00290.x

Counsell CWW, Johnston EC, Sale TL. 2019. Colony size and depth affect wound repair in a branching coral. Mar Bio. 166(11):148. https://doi.org/10.1007/s00227-019-3601-6

De'ath G, Fabricius KE, Sweatman H, Puotinen M. 2012. The 27–year decline of coral cover on the Great Barrier Reef and its causes. Proc Nat Acad Sci. 109(44):17995–17999. https://doi.org/10.1073/pnas.1208909109

Donovan MK, Burkepile DE, Kratochwill C, Shlesinger T, Sully S, Oliver TA, Hodgson G, Freiwald J, Woesik R van. 2021. Local conditions magnify coral loss after marine heatwaves. Science. 372(6545):977–980. https://doi.org/10.1126/science.abd9464

Ferrari R, Figueira WF, Pratchett MS, Boube T, Adam A, Kobelkowsky-Vidrio T, Doo SS, Atwood TB, Byrne M. 2017. 3D photogrammetry quantifies growth and external erosion of individual coral colonies and skeletons. Sci Rep. 7(1):16737. https://doi.org/10.1038/s41598-017-16408-z

Friedlander A, Aeby G, Brown E, Clark A, Coles S, Dollar S, Hunter C, Jokiel P, Smith J, Walsh B, et al. 2005. The State of Coral Reef Ecosystems of the Main Hawaiian Islands.

Glynn PW, Krupp DA. 1986. Feeding biology of a Hawaiian sea star corallivore, *Culcita novaeguineae* Muller & Troschel. J Exp Mar Bio Eco. 96(1):75–96. https://doi.org/10.1016/0022-0981(86)90014-6

Henry L-A, Hart M. 2005. Regeneration from Injury and Resource Allocation in Sponges and Corals – a Review. Internat Rev Hydro. 90(2):125–158. https://doi.org/10.1002/iroh.200410759

Horoszowski-Fridman YB, Brêthes J-C, Rahmani N, Rinkevich B. 2015. Marine silviculture: Incorporating ecosystem engineering properties into reef restoration acts. Ecological Engineering. 82:201–213. https://doi.org/10.1016/j.ecoleng.2015.04.104

House JE, Brambilla V, Bidaut LM, Christie AP, Pizarro O, Madin JS, Dornelas M. 2018. Moving to 3D: relationships between coral planar area, surface area and volume. PeerJ. 6:e4280. https://doi.org/10.7717/peerj.4280

Jayewardene D, Donahue MJ, Birkeland C. 2009. Effects of frequent fish predation on corals in Hawaii. Coral Reefs. 28(2):499–506. https://doi.org/10.1007/s00338-009-0475-y

Kayal M, Vercelloni J, Lison De Loma T, Bosserelle P, Chancerelle Y, Geoffroy S, Stievenart C, Michonneau F, Penin L, Planes S, Adjeroud M. 2012. Predator Crown-of-Thorns Starfish (*Acanthaster planci*) Outbreak, Mass Mortality of Corals, and Cascading Effects on Reef Fish and Benthic Communities.Fulton C, editor. PLoS ONE. 7(10):e47363. https://doi.org/10.1371/journal.pone.0047363

Kennedy EV, Perry CT, Halloran PR, Iglesias-Prieto R, Schönberg CHL, Wisshak M, Form AU, Carricart-Ganivet JP, Fine M, Eakin CM, Mumby PJ. 2013. Avoiding Coral Reef Functional Collapse Requires Local and Global Action. Curr Bio. 23(10):912–918. https://doi.org/10.1016/j.cub.2013.04.020

Knowlton N, Brainard RE, Fisher R, Moews M, Plaisance L, Caley MJ. 2010. Coral Reef Biodiversity. In: Life in the World's Oceans: Diversity, Abundance and Distribution. Wiley-Blackwell Pub; p. 65–78.

Kornder NA, Cappelletto J, Mueller B, Zalm MJL, Martinez SJ, Vermeij MJA, Huisman J, de Goeij JM. 2021. Implications of 2D versus 3D surveys to measure the abundance and composition of benthic coral reef communities. Coral Reefs. 40(4):1137–1153. https://doi.org/10.1007/s00338-021-02118-6

Lange ID, Perry CT. 2020. A quick, easy and non-invasive method to quantify coral growth rates using photogrammetry and 3D model comparisons. Methods Ecol Evol. 11(6):714–726. https://doi.org/10.1111/2041-210X.13388

Lenihan HS, Edmunds PJ. 2010. Response of *Pocillopora verrucosa* to corallivory varies with environmental conditions. Mar Ecol Prog Ser. 409:51–63.

Moberg F, Folke C. 1999. Ecological goods and services of coral reef ecosystems. EcolEcon.

29(2):215–233. https://doi.org/10.1016/S0921-8009(99)00009-9

National Academies of Sciences, Engineering, and Medicine. 2019. A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs. Washington, D.C.: National Academies Press; [accessed 2023 Sep 21]. https://doi.org/10.17226/25279

Palacios MM, Muñoz CG, Zapata FA. 2014. Fish corallivory on a pocilloporid reef and experimental coral responses to predation. Coral Reefs. 33(3):625–636. https://doi.org/10.1007/s00338-014-1173-y

Pratchett MS, Messmer V, Wilson SK. 2020. Size-specific recolonization success by coral-dwelling damselfishes moderates resilience to habitat loss. Sci Rep. 10(1):17016. https://doi.org/10.1038/s41598-020-73979-0

Rice MM, Ezzat L, Burkepile DE. 2019. Corallivory in the Anthropocene: Interactive Effects of Anthropogenic Stressors and Corallivory on Coral Reefs. Front Mar Sci. 5. https://doi.org/10.3389/fmars.2018.00525

Rice MM, Maher RL, Correa AMS, Moeller HV, Lemoine NP, Shantz AA, Burkepile DE, Silbiger NJ. 2020. Macroborer presence on corals increases with nutrient input and promotes parrotfish bioerosion. Coral Reefs. 39(2):409–418. https://doi.org/10.1007/s00338-020-01904-y

Rotjan R, Lewis S. 2008. Impact of coral predators on tropical reefs. Mar Ecol Prog Ser. 367:73–91. https://doi.org/10.3354/meps07531

Spalding M, Burke L, Wood SA, Ashpole J, Hutchison J, Zu Ermgassen P. 2017. Mapping the global value and distribution of coral reef tourism. MarPol. 82:104–113. https://doi.org/10.1016/j.marpol.2017.05.014

7. Appendix

Appendix 1. Corallivory Annotation Descriptions (Hawai‘i)

This section describes the columns and codes that are in the attributes table commonly used for O‘ahu reefs. They can be applied to the other main Hawaiian Islands and provide a starting point for other Pacific regions. The attributes table is where annotation data are entered in ArcGIS Pro. The columns described below include: (1) coral species, (2) bite mark categories, (3) condition categories, and (4) overlap scores. Example images are provided for each description.

Coral species

There are over 30 coral species found around the island of O‘ahu. In this section, the most common 15 coral species are briefly described. More information can be found in:

- Hawai‘i’s Sea Creatures: A Guide to Hawai‘i’s Marine Invertebrates by John P. Hoover
- Marine Life Photography by Keoki Stander and Yuko Stender

The following section is organized by coral family. Each species is categorized as either “Very Common,” “Somewhat Common,” or “Rare.” “Very common” species can be found on almost every survey, “Somewhat Common” species can be found in about half of all surveys, and “Rare” species are encountered every once in a while. The code for each species is also provided. The code is made up of the first letter of the genus followed by the first three letters of the species.

1. Family Pocilloporidae—coral species in this family have a branching morphology. Branches are covered with bumpy verrucae.
   a) *Pocillopora damicornis* (somewhat common, PDAM)—usually found in shallow water, uncommon around most of O‘ahu, except in Kaneohe Bay. They form bushy heads with slender branches in wave protected areas and thicker branches in areas with wave action. Like all Pocilloporidae, it is covered with verrucae. Color varies from light brown to darker brown (Figure 42).

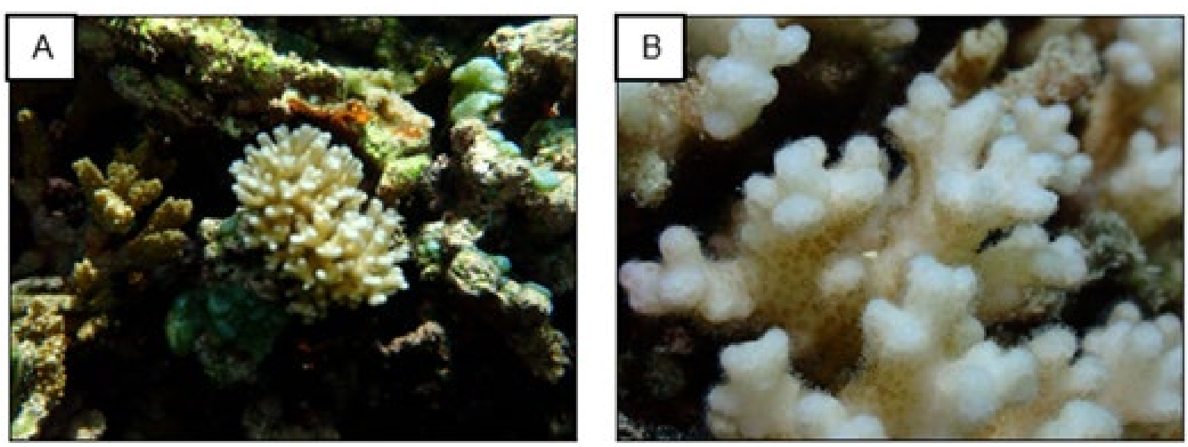


Figure 42. (A) Colony-level and (B) close up images of *Pocillopora damicornis.*

b) *Pocillopora meandrina* (very common, PMEA)—especially common in high energy environments. They form compact branching colonies. Branches look flattened and branch tips tend to curve into a "c" shape. Colors range from brown (most common) to green and rose pink. These species can attain very pale coloration (Figure 43).

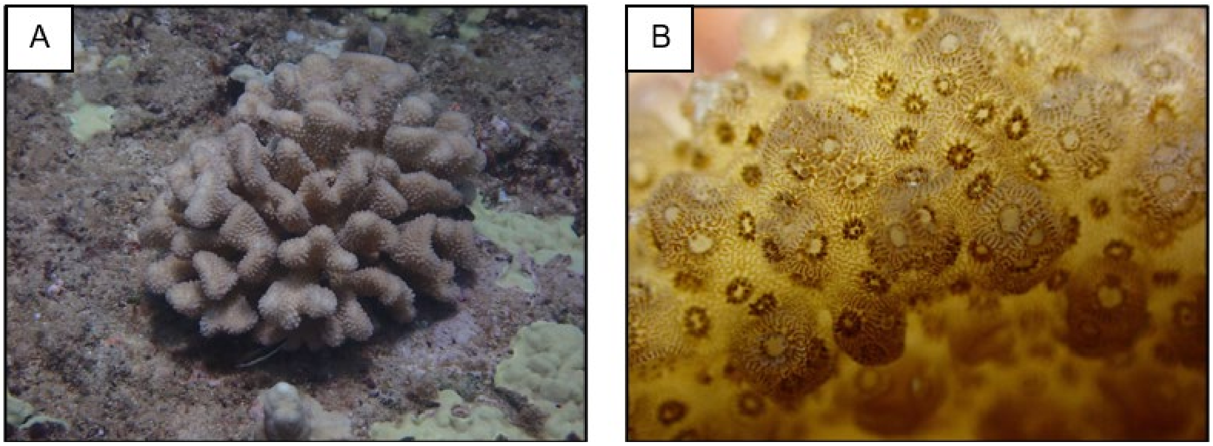


Figure 43. (A) Colony-level and (B) close up images of *Pocillopora meandrina.*

c) *Pocillopora grandis* (uncommon, PGRA)—this is the largest of the Pocillopora species, and its size is one of the main defining characteristics, sometimes reaching a few feet in height. The branches are tubular and upright, sometimes flattened and forked at the tips. Smaller individuals may look similar to P. meandrina but P. grandis has larger spaces between the branches and branches typically don't have the "c" shape (Figure 44).

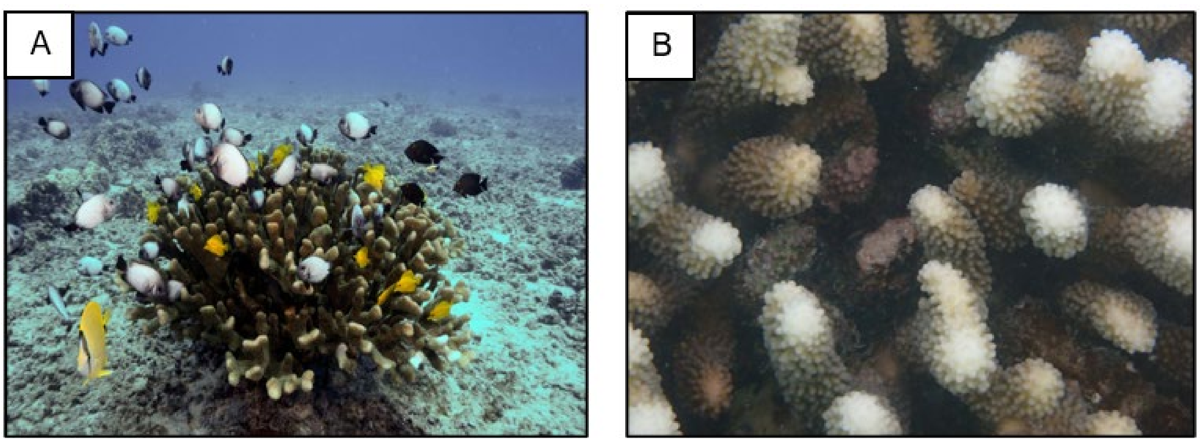


Figure 44. A) Colony-level (Photo by Erik Brush) and (B) close up images of *Pocillopora grandis.*

2. Family Acroporidae—species of the *Acropora* genus rarely occur around the main Hawaiian Islands. More common are members of the genus *Montipora*. This genus usually forms encrusting or platelike colonies. They have small calyces which are usually surrounded by projections which give the coral colonies a rough texture.

a) *Montipora capitata* (very common, MCAP)—the most common morphology for this coral species is encrusting. However, they can also form plates, cups, and branches in more protected environments. They have rounded, rice-like projections between calyces giving them a bumpy appearance. Color varies from dark brown to light beige or cream. The darker colonies usually have light edges and tips which do not necessarily indicate predation (Figure 45).

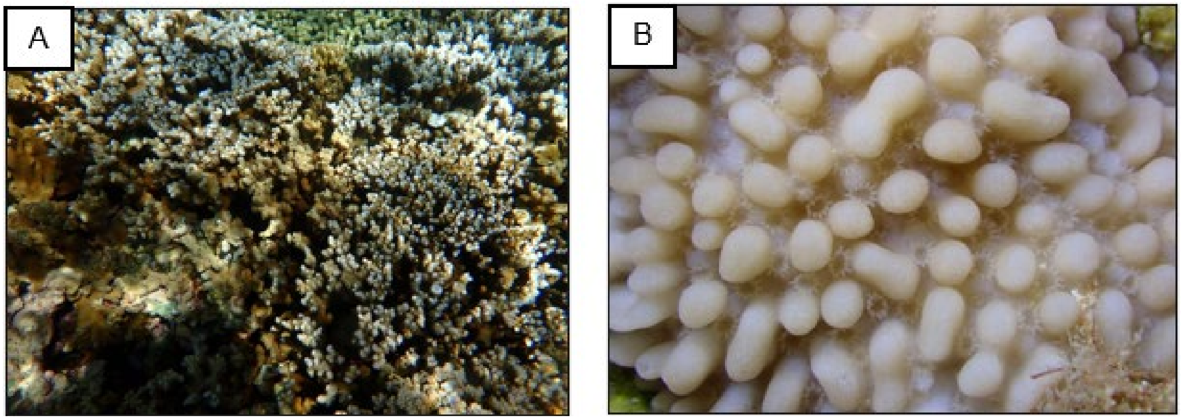


Figure 45. (A) Colony-level and (B) close up images of *Montipora capitata.*

b) Montipora patula (very common, MPAT)—this species grows in plates and encrusting colonies. The surface is covered by small projections which tend to cluster around the widely spaced calyces. When polyps are out, they appear purple or blue. Color varies from light tan to brown (Figure 46).

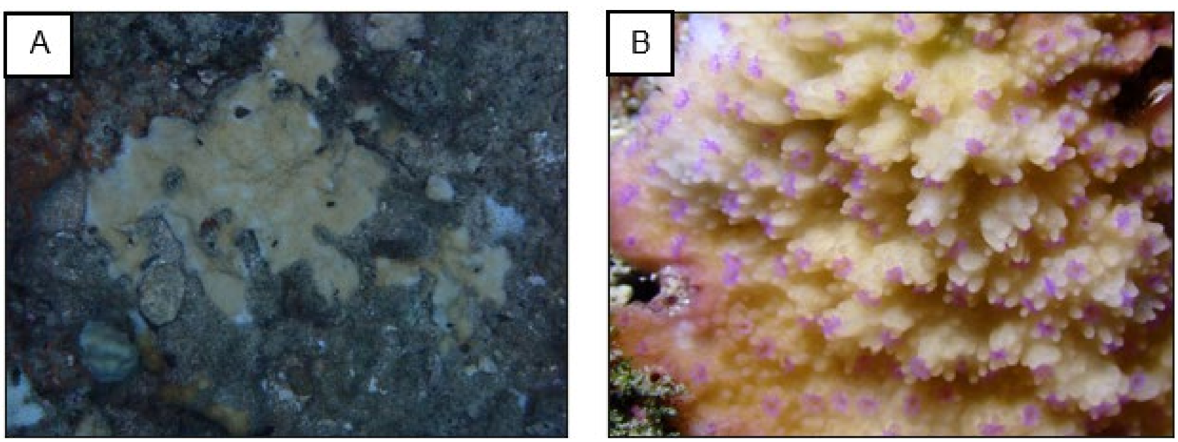


Figure 46. (A) Colony-level and (B) close up images of *Montipora patula.*

c) *Montipora flabellata (rare, MFLA)*—the most obvious characteristic of this species is its vivid fluorescent blue/purple color. They are found in high energy environments and form encrusting colonies. Like the other Montipora species, this one has a rough texture due to projections between the calyces (Figure 47).

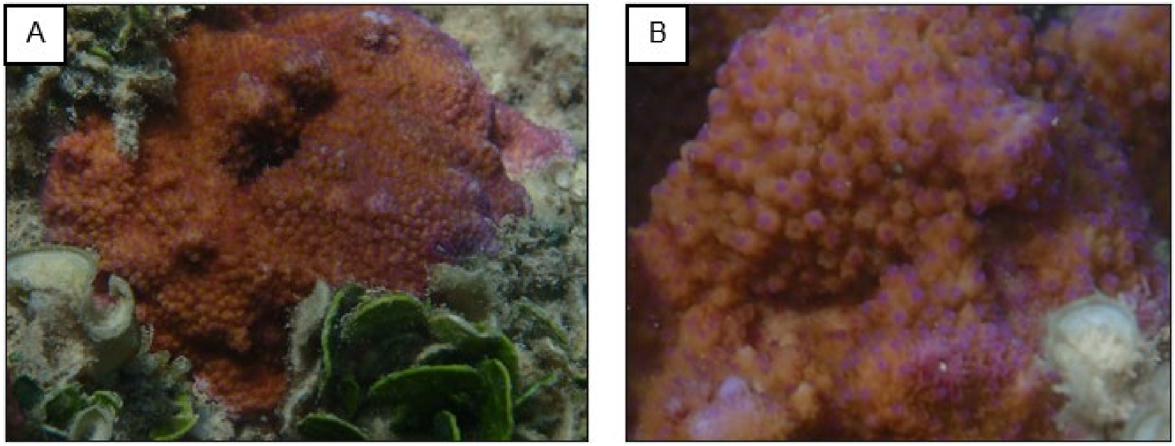


Figure 47. (A) Colony-level and (B) close up images of *Montipora flabellata.*

3. Family Poritidae—corals in this family have small, tightly packed calyces. The surfaces of the colonies are smooth with no projections. A few morphologies exist for species within this family such as mounding, lobes, encrusting, or branching fingers. Some *Porites* species can be hard to differentiate and for these surveys, some of them will be grouped together (see below).

a) *Porites compressa* (somewhat common, PCOM)—this species has a branching finger morphology. In shallow areas, they form rounded heads with fused branches. In deeper waters, branches are longer and more finger-like. *P. compressa* beds can be very large, especially in places like Kaneohe Bay. Color varies from light brown to sometimes yellowish or bluish gray (Figure 48).

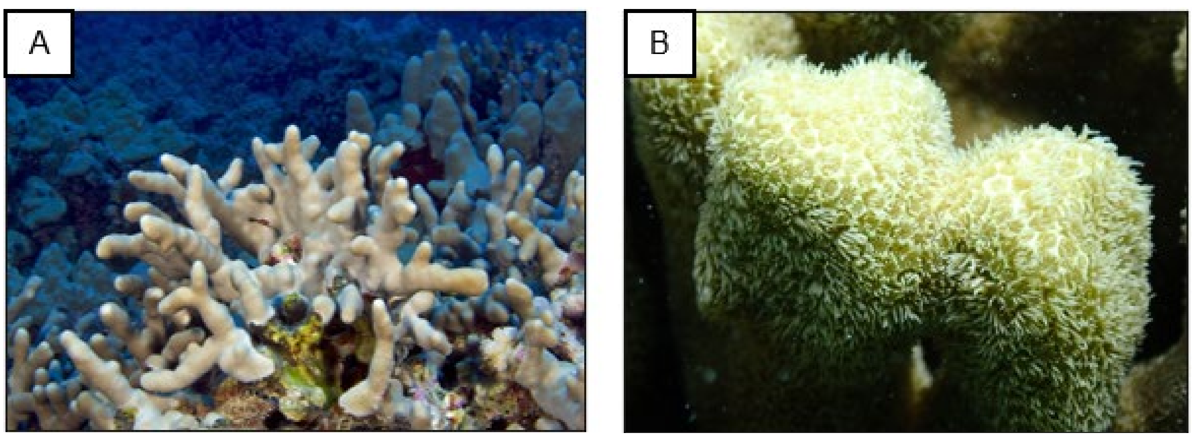


Figure 48. (A) Colony-level (Photo by Keoki Stender) and (B) close up images of *Porites compressa.*

b) *Porites lobata* (very common, PLOB)*—this species usually forms large, mounding colonies. In more energetic environments, they may form encrusting patches. This is Hawai‘i's most common massive coral. Color varies from yellowish brown to yellowish green (Figure 49).

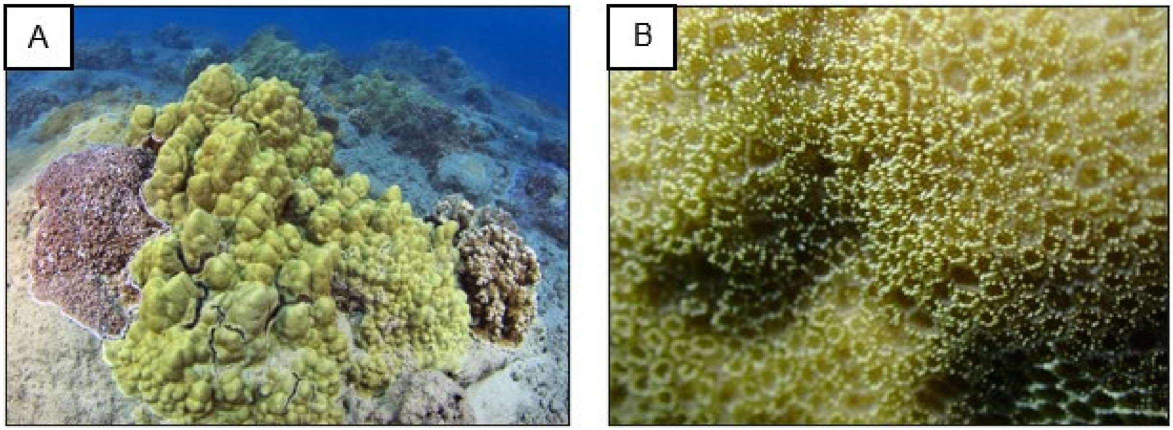


Figure 49. (A) Colony-level (Photo by Keoki Stender) and (B) close up images of *Porites lobata.*

c) *Porites evermanni* (somewhat common, PEVE)*—this species looks very similar to *P. lobata.* One of the main differences is that it is usually brownish to bluish gray and never has the yellowish color usually present in *P. lobata.* The polyps are often not retracted giving the colony a fuzzy appearance (Figure 50).

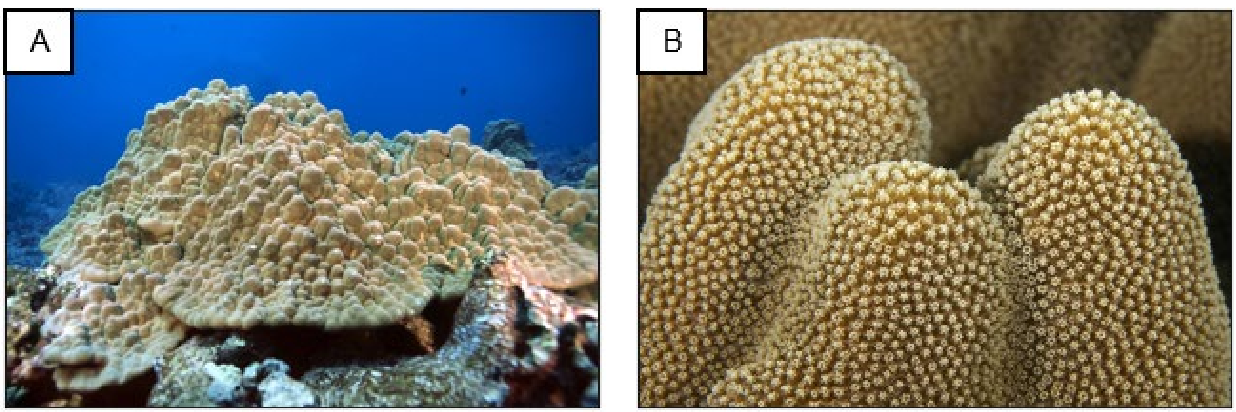


Figure 50. (A) Colony-level and (B) close up images of *Porites evermanni* (Photos by Keoki Stender).

* *P. lobata* and *P. evermanni* can be easily confused with each other. There are an additional three rare species (not described here) that also resemble these two species. For these surveys, *Porites lobata, Porites evermanni,* and the additional three rare species were aggregated into the code PMAS (*Porites* massive).

3. Family Agariciidae—narrow ridges connect the calyces. Corals in this family have very fine tentacles. Most species in this family form encrusting colonies although some form lobes.

a) *Pavona duerdeni* (uncommon, PDUE)—colonies of this species form lobes or thick upright disks. Younger colonies are encrusting. The surface is smooth and does not have distinct visible ridges like other species in this family. Their calyces form star-shaped patterns. They are usually a tan color (Figure 51).

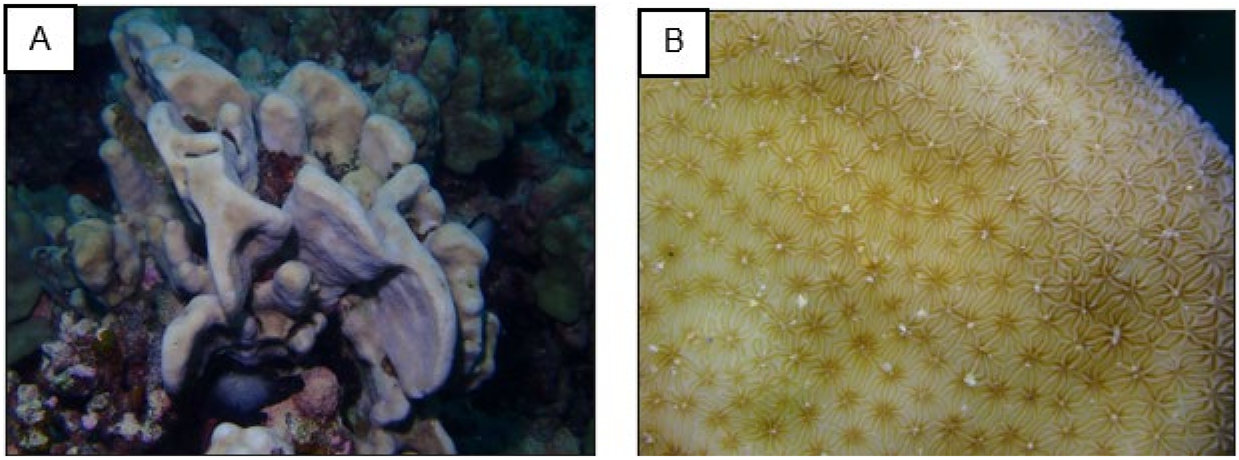


Figure 51. (A) Colony-level and (B) close up images of *Pavona duerdeni.*

b) *Pavona varians* (common, PVAR)—this species forms encrusting colonies. In protected areas, it can form thin plates. The calyces sit in valleys separated by sharp ridges. They vary in color from light yellowish tan to brownish gray, greenish or brown (Figure 52).

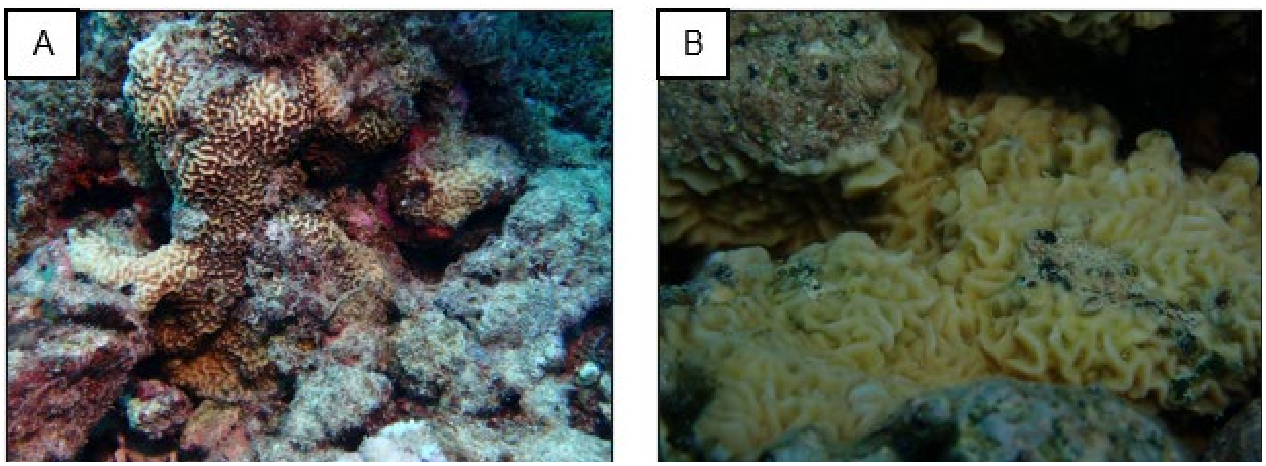


Figure 52. (A) Colony-level and (B) close up images of *Pavona varians.*

4. Family Fungiidae—this is a family of free living corals. They are composed of one solitary polyp which tends to be large, flattened, and unattached to the substrate.

a) *Lobactis scutaria* (uncommon, LSCU)—can be found shallow or deep but is often lodged in crevices or holes. They have an oval shape. Sharp ridges radiate from the central mouth. The ventral side also has projections, although not as sharp. Color is usually tan or brown dorsally and white ventrally (formally known as *Fungia scutaria*) (Figure 53).

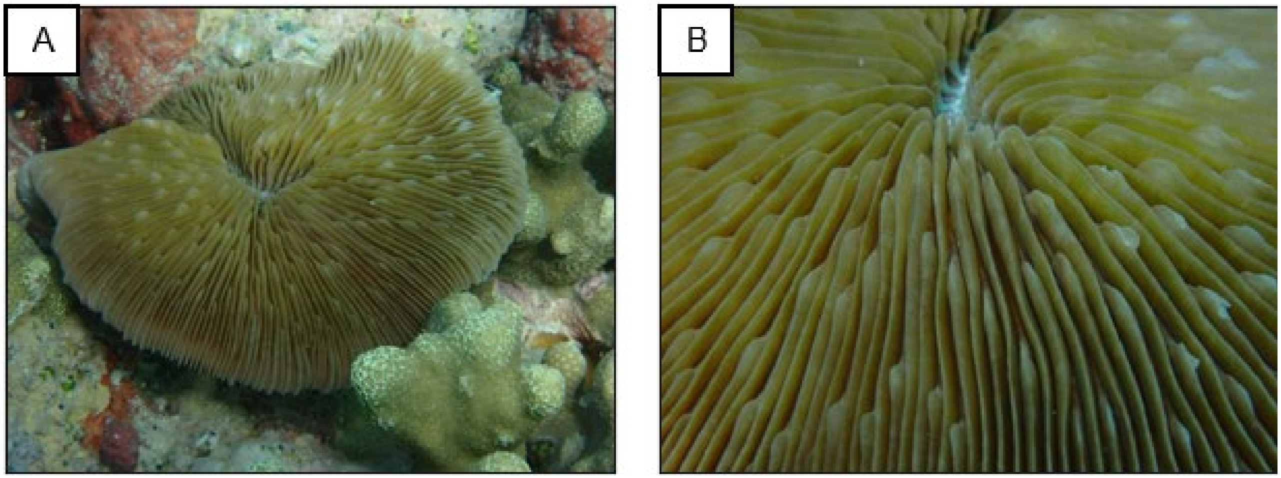


Figure 53. (A) Colony-level and (B) close up images of *Lobactis scutaria.*

5. Family Faviidae—species in this family in Hawai‘i are usually encrusting or domelike. They tend to have large, easily distinguished calyces.

   a) *Cyphastrea ocelina* (rare, COCE)—colonies of this species are usually small, encrusting, and clumpy. The calyces have sharply raised edges and are usually tightly packed, although they remain distinct. Color is usually light brown (Figure 54).

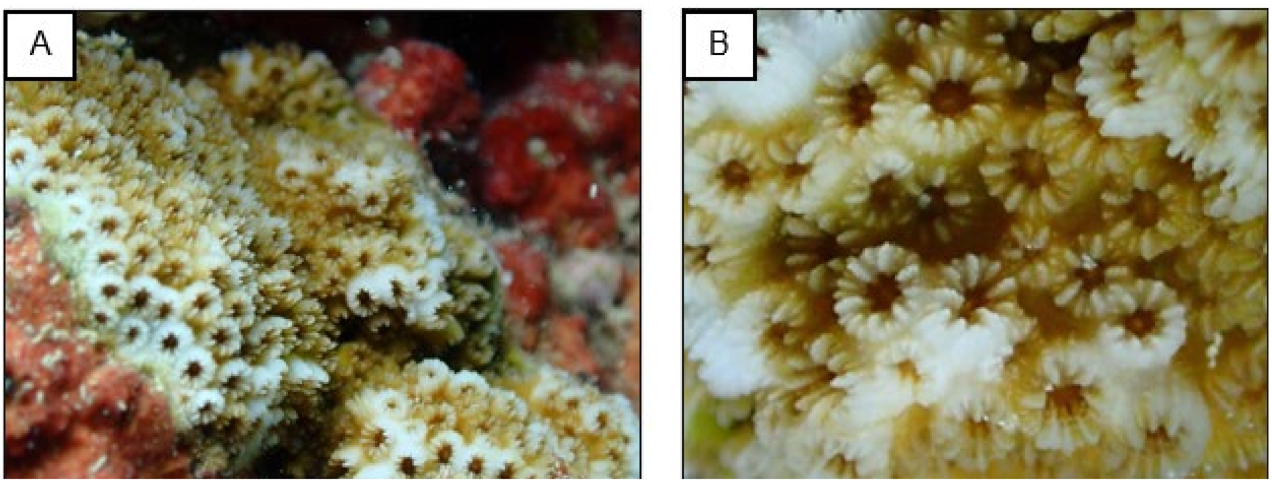


Figure 54. (A) Colony-level and (B) close up images of *Cyphastrea ocelina.*

   b) *Leptastrea bewickensis* (uncommon, LBEW)*—this coral usually forms flat, encrusting colonies. Calyces are brown and often with whitish centers and pale spaces between them (Figure 55).

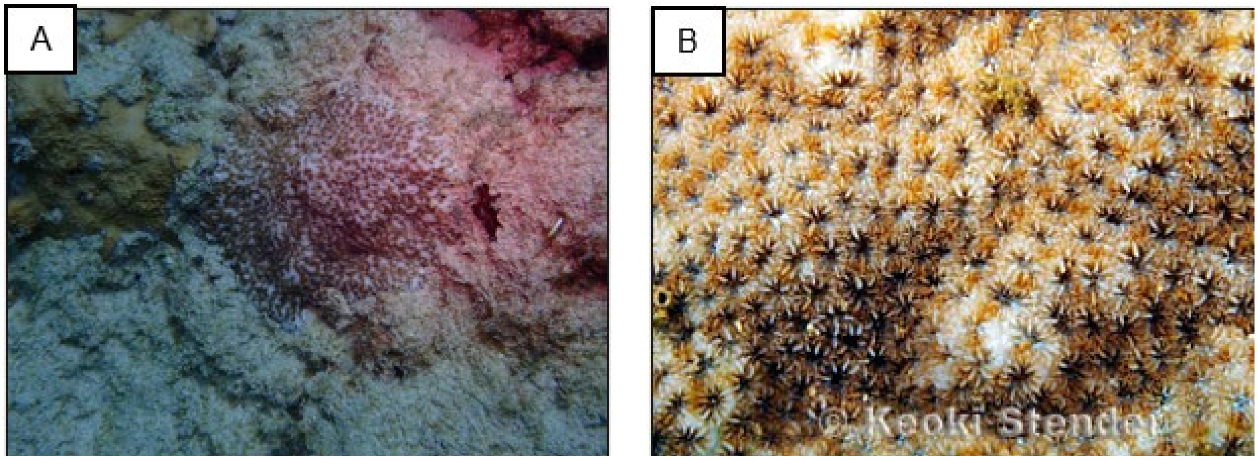


Figure 55. (A) Colony-level and (B) close up images of *Leptastrea bewickensis* (Photo by Keoki Stender).

c) *Leptastrea transversa* (rare, LTRA)*—this coral forms an encrusting colony, although not as flat as *L. bewickensis*. It sometimes has rounded lobes. The center of the calyces may be green. Color varies from brown to greenish brown to purplish brown (Figure 56).

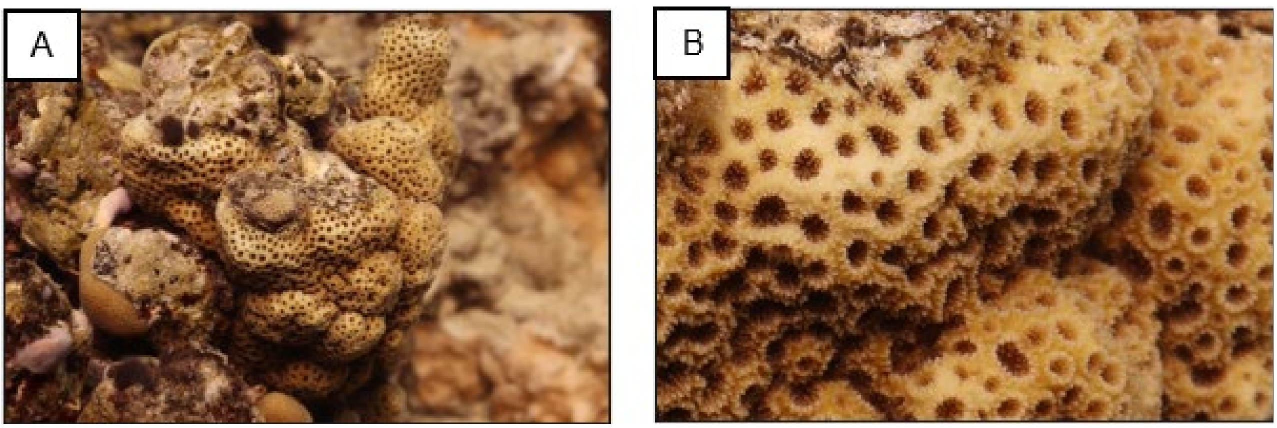


Figure 56. (A) Colony-level and (B) close up images of *Leptastrea transversa.*

* *L. transversa* and *L. bewickensis* can be easily confused with each other. There is an additional species (not described here) that also resembles these two species. For these surveys, all three species were aggregated into the code LESP (*Leptastrea* species).

Corallivory categories

Fish and invertebrates have different feeding modes which result in different types of predation wounds on coral. Mucus eaters, such as *Trapezid* crabs, consume only the mucus secreted by coral. Browsers, such as sea stars and butterflyfish, consume only coral tissue. Lastly, scrapers and excavators, which include fishes such as parrotfish and pufferfish, remove both coral tissue and skeleton to varying degrees. The categories described below were developed after extensive research into coral predation types around Oʻahu, Hawaiʻi. Due to the difficulty in distinguishing predation caused by certain species, most of these categories are broad; only two categories are species-specific. Importantly, predation by mucus eaters and butterflyfish cannot be annotated because of the lack of or very small size of those predation marks. There are six categories of coral predation described below; the code for each is in parentheses. It is important to note that bite mark categories will look slightly different depending on the coral species.

1. *Exallias brevis* predation (EXBR)

The shortbodied blenny (*Exallias brevis*) (Figure 57a) is frequently found on the reef and inflicts one of the most common corallivory bite marks on Oʻahu reefs. They only extract coral polyps, resulting in wounds that look like near-perfect circles (with some exceptions) (Figure 57b). There will usually be multiple bites within a coral colony or within a cluster of colonies (Figure 57c). Bite marks are still visible when they begin to heal and polyps begin to recolonize the wound (these should be marked as “healing,” see condition categories below). When there are high densities of overlapping blenny bite marks, the annotator should approximate how many bite marks are in a small, specific area and extrapolate to the rest of the areas that show similar signs of concentrated blenny predation. To estimate the number of bite marks in a small area, look at other images that have individual, well defined blenny bite marks to get a size approximation. Using this size approximation, estimate how many bite marks there are in the small, high-coverage area. The annotator should count the number of blenny bites per coral species per condition category per quadrat. Blenny bites are often found on *Porites* species and are easily distinguishable. At some sites, *Montipora patula* and *M. capitata* experience high levels of blenny predation; because of the irregular surface of this coral genus, blenny predation forms irregular/distorted circles that sometimes look like long, white tracks between ridges (Figure 57d). Lastly, blenny bites are sometimes found on the branch tips or base of *Pocillopora meandrina* and *P. grandis.*

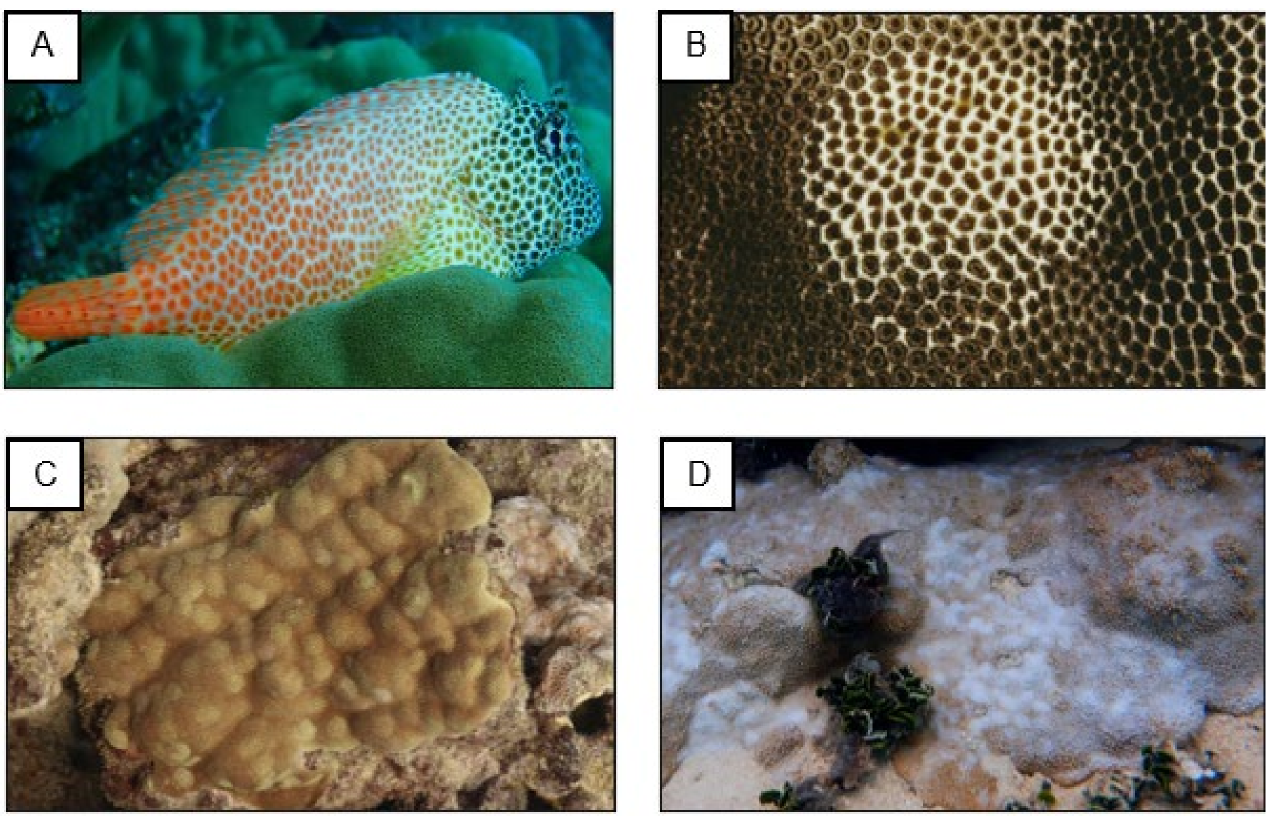


Figure 57. (A) Shortbodied blenny, (B) close up of a blenny bite mark, high density and overlapping blenny bite marks on (C) massive *Porites* and (D) *M. capitata*.

2. Sea star predation (STAR)

Sea star predation around O‘ahu is inflicted by either the crown-of-thorns sea star (*Acanthaster planci)* (Figure 58a) or the cushion sea star (*Culcita novaeguineae*) (Figure 58b). Both sea star species will climb onto a coral colony, expel their stomach to cover the colony, and secrete digestive enzymes which allows them to absorb the coral polyps. Crown-of-thorns predation on large coral colonies results in swaths of dead, bare, bright white skeleton (Figure 58c). However, they are also capable of causing complete colony mortality. Predation on smaller colonies will usually result in total coral mortality. Cushion stars tend to consume smaller colonies and will also leave behind a bare, white skeleton with no polyps (Figure 58d). For the purposes of our O‘ahu surveys, predation by crown-of-thorns and cushion stars was not distinguished and was grouped into the "STAR" category. However, sea stars can often be seen in the SfM models, and their presence should be noted in whatever tracking spreadsheet is being used for annotations. For STAR predation, percent area of each coral species with a predation scar is estimated within each quadrat. The percent predation is out of live and recently dead coral tissue. STAR predation looks very similar to bleached coral colonies; therefore, corallivory surveys are likely to be less accurate during bleaching events. It is recommended that surveyors wait two months after a bleaching event before trying to quantify this type of corallivory. Cushion stars are more selective predators and preferentially consume juvenile *Pocillopora* colonies. However, they have also been observed eating *Pavona varians, Pavona duerdeni, Montipora patula,* and larger *Pocillopora* colonies. The crown-of-thorns sea star is more of a generalist predator and is often found consuming *Pocillopora meandrina*, *Montipora patula*, massive *Porites* (i.e., *lobata and evermani*), and *Pavona* spp.

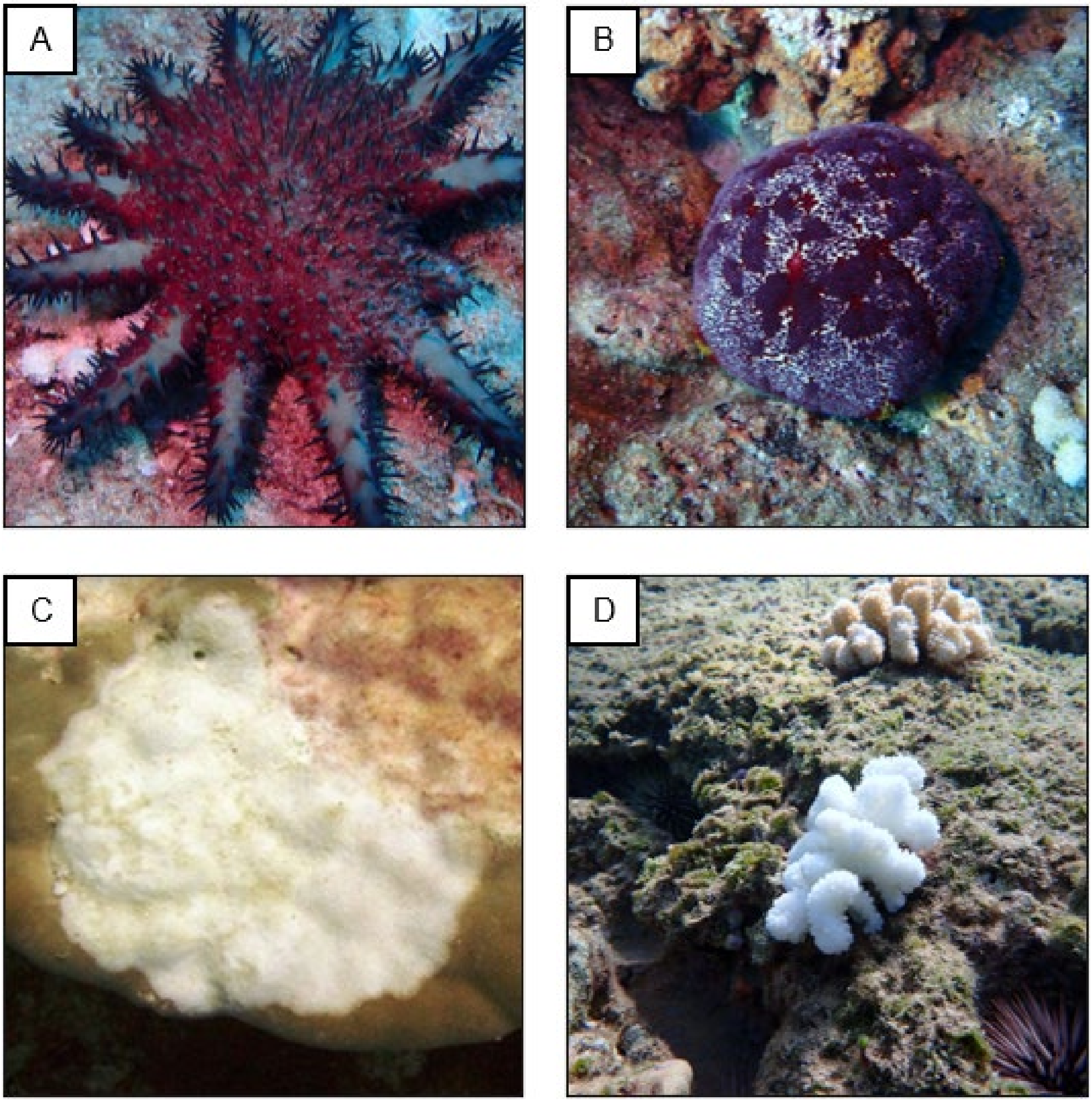


Figure 58. (A) Crown-of-thorns, (B) cushion star, (C) massive *Porites* consumed by a crown-of-thorns sea star (Photo by NOAA), and (D) a juvenile *Pocillopora* consumed by a cushion star.

3. *Drupella cornus* predation (DRUP)

Drupella is a genus of marine snail that specializes in consuming coral polyps (Figure 59a). Predation by this snail is not common around Oʻahu. Much like sea star predation, *Drupella* predation results in small swaths of dead, bare, bright white skeleton, often at the bases or boarders of colonies (Figure 59b-d). Large dead swaths only exist when there are multiple *Drupella* consuming the same colony. While *Drupella* are often nocturnal, they can sometimes be seen in the vicinity during the day and their presence should be noted. For *Drupella* predation, the percent area of each coral species with a predation scar is estimated within each quadrat. The percent predation is determined from both live and recently dead coral tissue. Similar to STAR predation, *Drupella* predation can resemble bleaching and the same recommendations should be followed. Although sea star and *Drupella* predation can look very similar, damage inflicted by *Drupella* usually affects much smaller portions of the coral colony when compared to sea star predation. This marine snail prefers corals in the genera *Pocillopora*, *Porites* and *Montipora*.

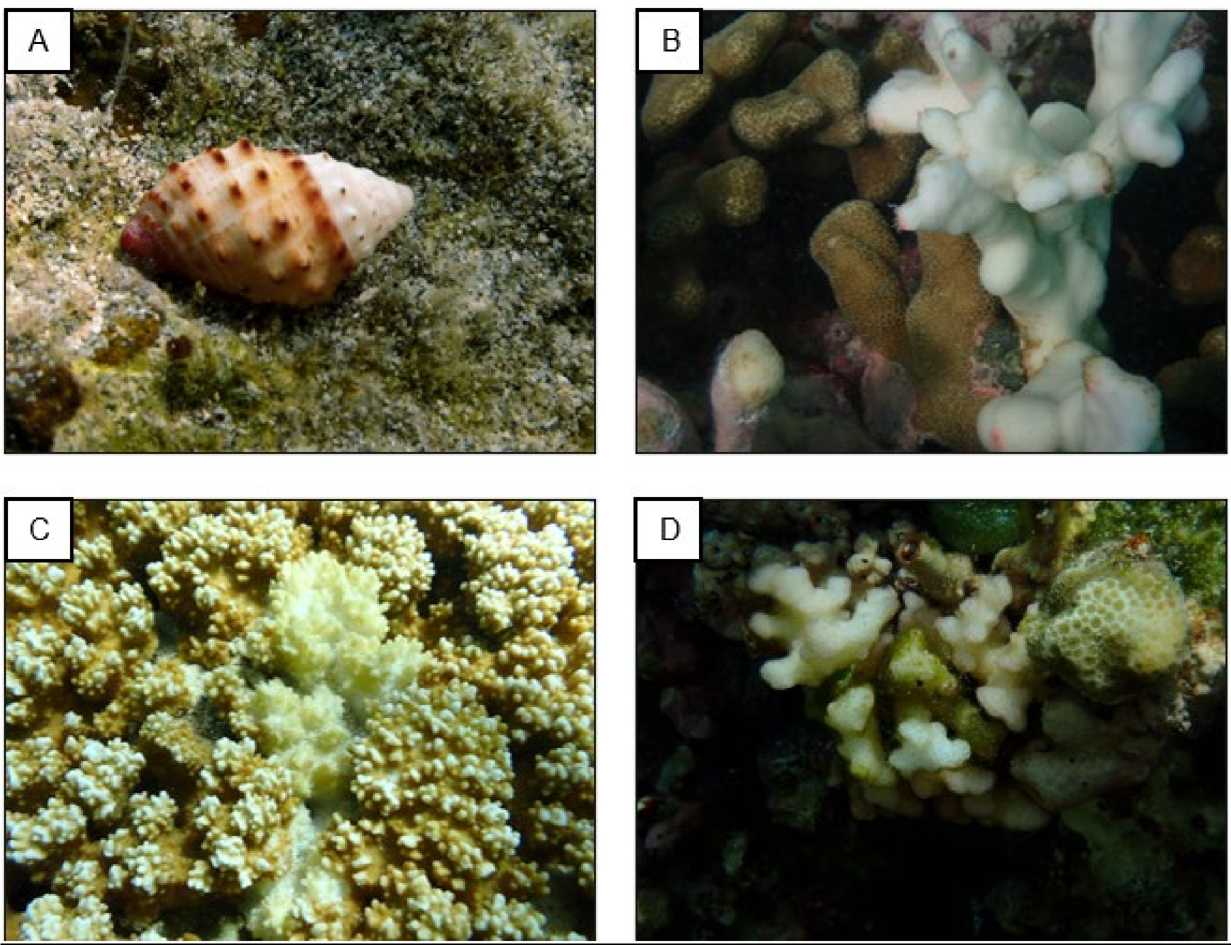


Figure 59. (A) *Drupella* snail and *Drupella* predation on (B) *Porites compressa*, (C) *Montipora capitata*, and (D) *Pocillopora damicornis.*

4. *Scaridae* species predation (SCSP)

The parrotfish (*Scaridae*) family are most commonly known for their herbivory, but they are also corallivores (Figure 60a). Because the parrotfish around O'ahu are usually small in size, their bite marks tend to be shallow (a few millimeters deep) as well as small. A parrotfish bite mark is made up of two ovals opposite one another, usually with a small gap between the two ovals (Figure 60b). Despite looking like two separate bite marks, each pair of ovals counts as a single bite mark. Larger parrotfish leave behind bigger, deeper bite marks but these still consist of paired ovals. Parrotfish can take part in focused predation, whereby they repeatedly bite the same coral, leaving behind a high density of overlapping marks (Figure 60c). When this is the case, the annotator should approximate how many bite marks are in a specific area and extrapolate to the rest of the areas that show signs of parrotfish predation (the same method as with blenny bite marks). The annotator should count the number of parrotfish bites per coral species per condition category per quadrat. Parrotfish bite marks are most often found on either massive *Porites* or *Porites compressa.* Less commonly they can be found on *Montipora patula* and *Montipora capitata* (Figure 60d).

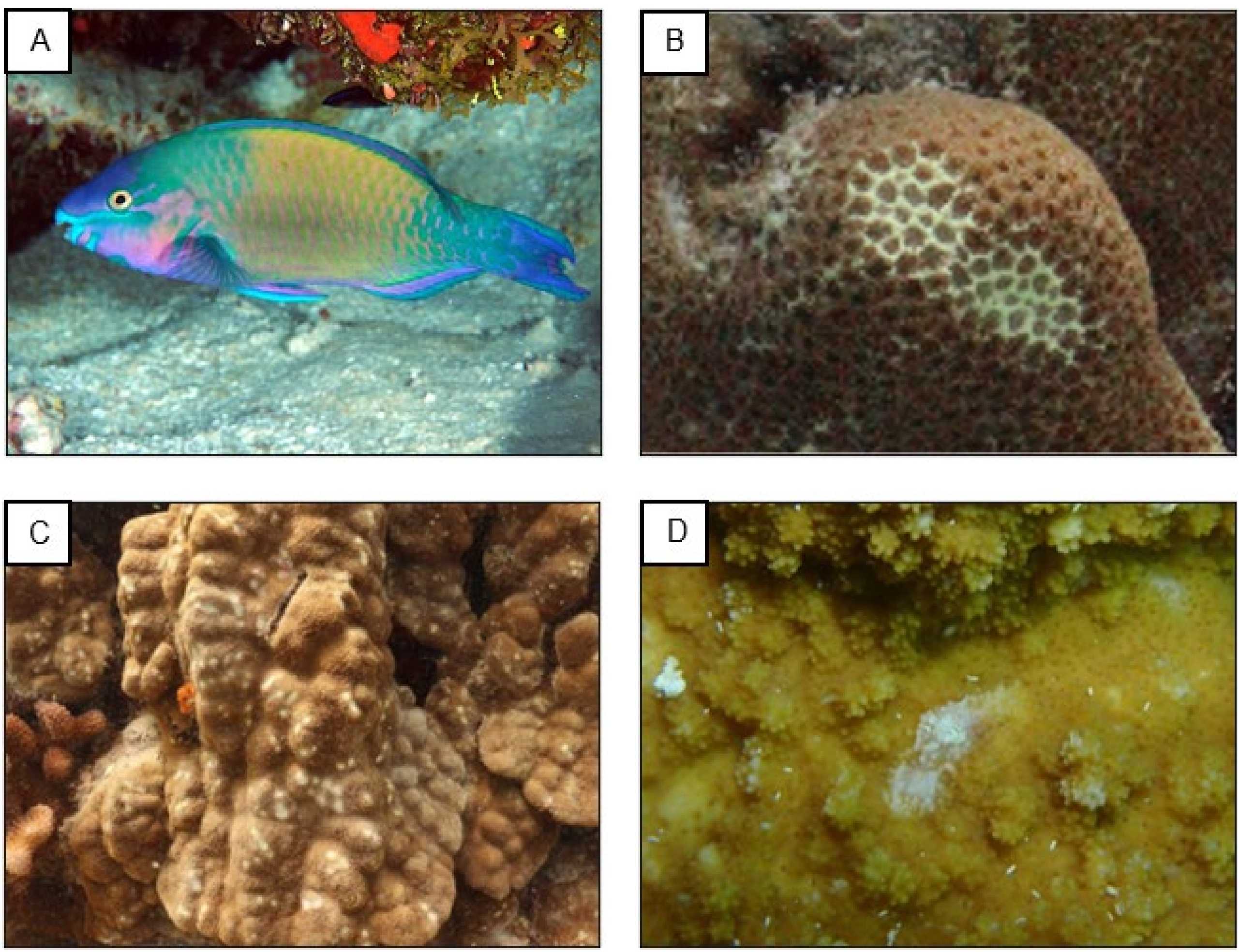


Figure 60. (A) Parrotfish (Photo by Reef Guide), (B) close up of a parrotfish bite mark, in this case without the gap between the two ovals, (C) high density of overlapping parrotfish bite marks on massive *Porites*, and (D) a parrotfish bite mark on *Montipora patula*.

5. Excavator (EXCAV)

Excavator bite marks around O‘ahu are caused by the barred filefish (*Cantherhines dumerilii*) (Figure 61a), spotted pufferfish (*Arothron meleagris*) (Figure 61b), and larger parrotfish (*Scaridae* spp.) (Figure 60a). Bite marks from these three fishes are grouped under the “EXCAV” category because of their similarity in appearance. In the case of parrotfish bite marks, they should be categorized as “SCSP” if they have the appearance described above; if it is a deep wound without any discernible shape, it should be categorized as “EXCAV.” These bite marks are very conspicuous. Corals with excavator marks have deep chunks missing (deeper than 0.3 cm) with bare skeleton clearly visible. When the bite mark is new, the edges are very sharp (Figure 61c). This bite mark type rarely overlaps with other excavator bite marks. The annotator counts the number of excavator bites per coral species per condition category per quadrat. It is most common on *Porites compressa* (Figure 61 c-d). However, keep in mind that *P. compressa* branches break off easily with disturbance, so look around the colony for broken branches before marking as an excavator bite mark. This coral species also tends to have pale branch tips, either as a result of a healing excavator bite mark or due to a broken branch tip. In this case, only count as an excavator bite mark if the top of the branch is clearly flattened with rounded edges and there are no broken branches in the vicinity; these would be considered to be in “healing” condition (Figure 61d). Massive *Porites* (Figure 61g), *Pocillopora meandrina* (Figure 61f), and *Pocillopora grandis* branch tips also experience excavator bites. Excavator bite marks on *Pocillopora* species are usually very large (the whole branch tip is removed) without defined margins along the branch tip edge. Because it can be nearly impossible to determine whether these represent more than one bite mark, count as a single bite mark and consider increasing the overlap score (Figure 61f). Excavator bite marks are less common on *Montipora capitata* (Figure 61e) and *Montipora patula,* but will appear as big chunks of bare white skeleton with clearly defined edges.

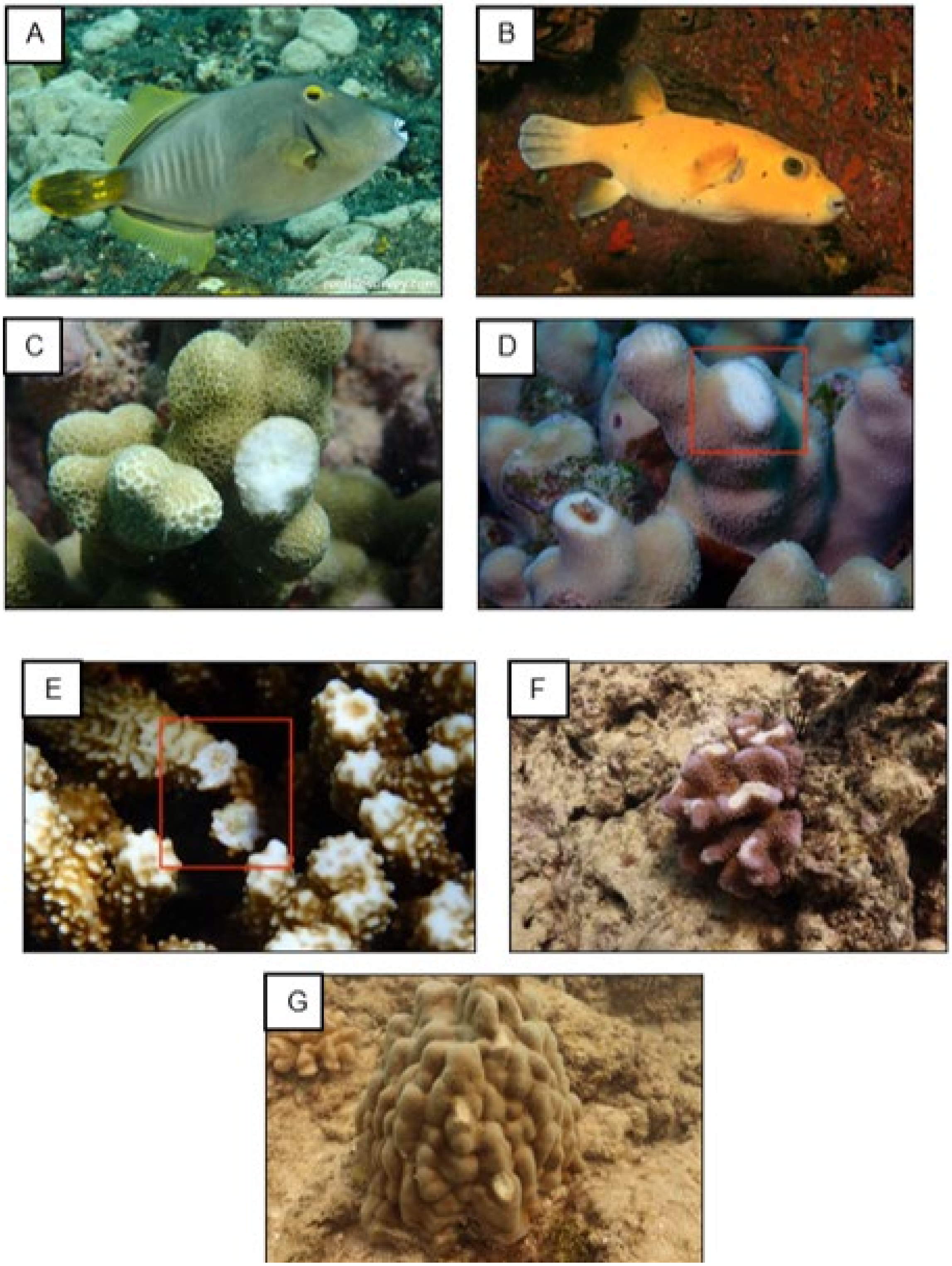


Figure 61. (A) Barred filefish (Photo by Reef Life Survey) and (B) spotted pufferfish (Photo by Wikipedia Commons). Excavator bite marks on *Porites compressa*, (C) new and (D) healing. Examples of excavator bite marks on (E) *Montipora capitata*, (F) *Pocillopora meandrina* and (G) massive *Porites*.

6. Scraper (SCRAP)

Scraper bite marks are also caused by the barred filefish (*Cantherhines dumerilii*) (Figure 61a) and the Spotted Pufferfish (*Arothron meleagris*) (Figure 61b). Bite marks for these two fishes are grouped under the "SCRAP" category because of their similarity. Scraper marks can be very similar to excavator marks; the main difference is the depth of the resulting bite wound. Scraper marks are shallower "nips" or "nibbles," less than 0.3 cm deep, that expose coral skeleton (Figure 62). As opposed to an individual parrotfish bite mark which has one pair of marks (one from their upper mouth beak on the top and one from the lower beak), scraper bite marks have two pairs of bite marks (two on the upper portion and two on the lower portion). However, the two pairs of bite marks are only visible on coral species with flat surfaces, such as massive *Porites*, and will appear as "nibbles" on other species, such as *Pocillopora meandrina* (Figure 62a). This is because the upper and lower teeth of the filefish and pufferfish are not fused like the beaks of parrotfish. The annotator counts the number of scraper bites per coral species per condition category per quadrat. Scraper bite marks are most common on *Pocillopora meandrina* branch tips. As with the excavator bite marks on this coral species, whole or large swaths of branch tips might appear to be missing without clear boundaries between bite marks. In that case, count as one bite mark and increase the overlap score. *Pocillopora meandrina* sometimes has very pale tips which may not necessarily be indicative of a healing bite mark. This is a fast growing coral species, and it may take time for *Symbiodinium,* a single celled algae that lives within coral tissue, to colonize the branch tips. In cases of pale branch tips, only count as scraper marks if the verrucose (the bumpy projections on the branch tips) are missing and consider these marks to be in "healing" condition (Figure 62b). This bite mark type is also seen on the massive *Porites* colonies and *Porites compressa* (Figure 62c). Scraper bite marks can sometimes be found on *Montipora patula* (Figure 62d) and *Montipora capitata* and will similarly look like a shallow bite mark with exposed skeleton. These are not to be confused with tube worm holes, which can expose a little bit of white skeleton, but have a black hole in the middle.

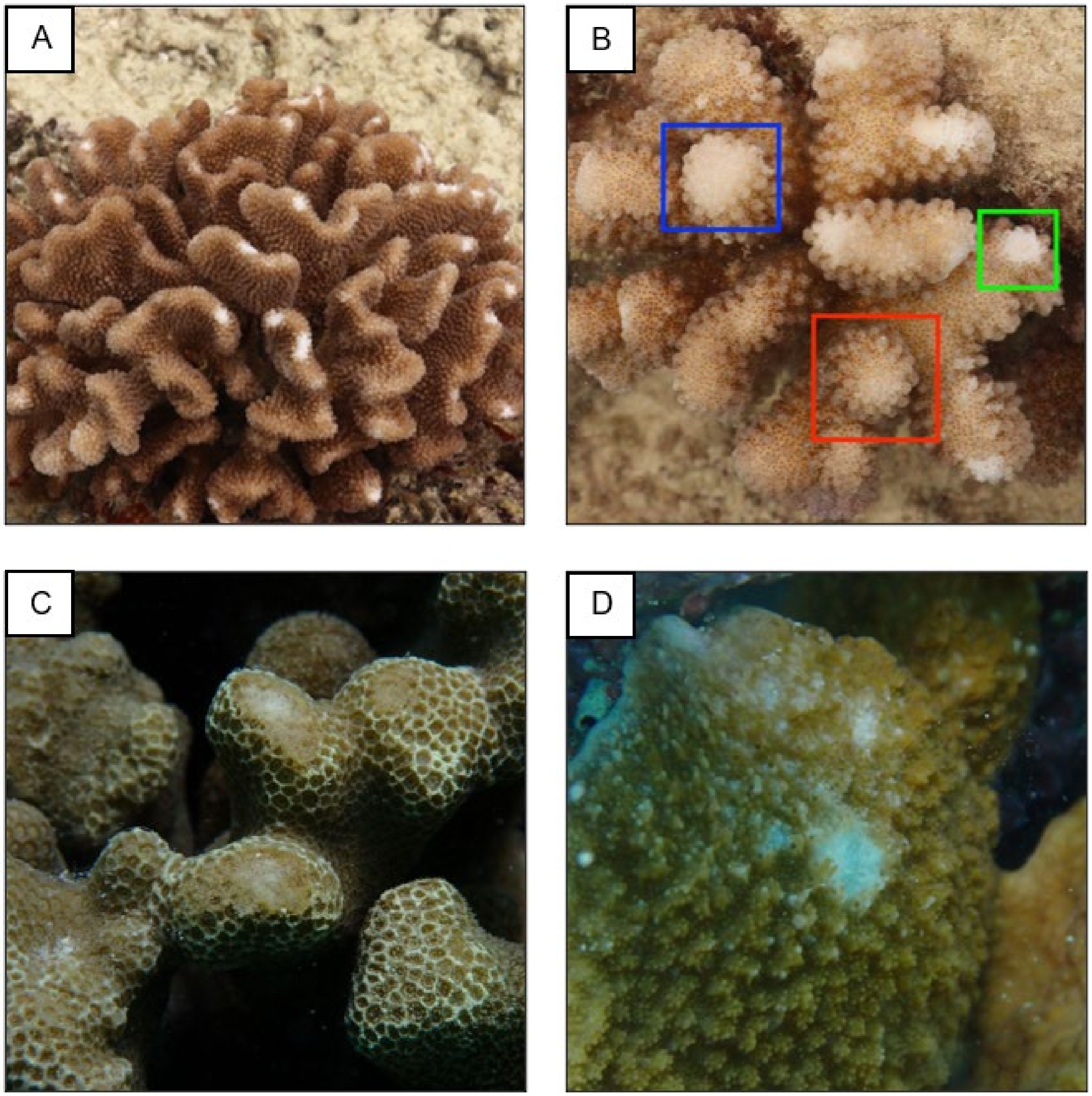


Figure 62. (A) Scattered scraper bite marks on the branches of *Pocillopora meandrina.* (B) Different conditions of scraper bite marks on *Pocillopora meandrina* (blue box is a healing scraper mark with a light tip and some verrucose missing, green box is a new scraper bite mark, and red box is not a bite mark as it is a light branch tip without missing verrucose). Scraper bite marks on (C) *Porites compressa* and (D) *Montipora patula*.

Bite mark condition

When these surveys were developed, it was difficult to determine which bite marks to count since they could be at different stages in the healing process. In order to be comprehensive and eliminate the need for annotators to decide which marks to quantify, it was decided that all bite marks should be included and assigned a condition score. Differentiating among conditions will provide useful information. For example, areas may be identified that have corals with high healing potential, are unable to recover from corallivory, or repeatedly exhibit new corallivory marks across multiple surveys. Different condition types will apply to some corallivory categories more than others due to the extent of damage imposed by different corallivores and the nature of wound recovery for different bite marks.

1. New (NE)

Bite marks categorized as "NE" are injuries that have been recently inflicted (days to weeks). For bite mark categories that include skeleton removal (SCSP, EXCAV, SCRAP), the skeleton is exposed and bright white, no polyps or algae growth is visible, and the bite mark edges are sharp (Figure 63a-b). For bite mark categories that only include polyp removal (EXBR, DRUP, STAR), the skeleton will look bright white with little to no algae present and without any polyps recolonizing the wound (Figure 63c-d). This category is common for EXCAV, SCRAP, DRUP, and STAR bite mark categories.

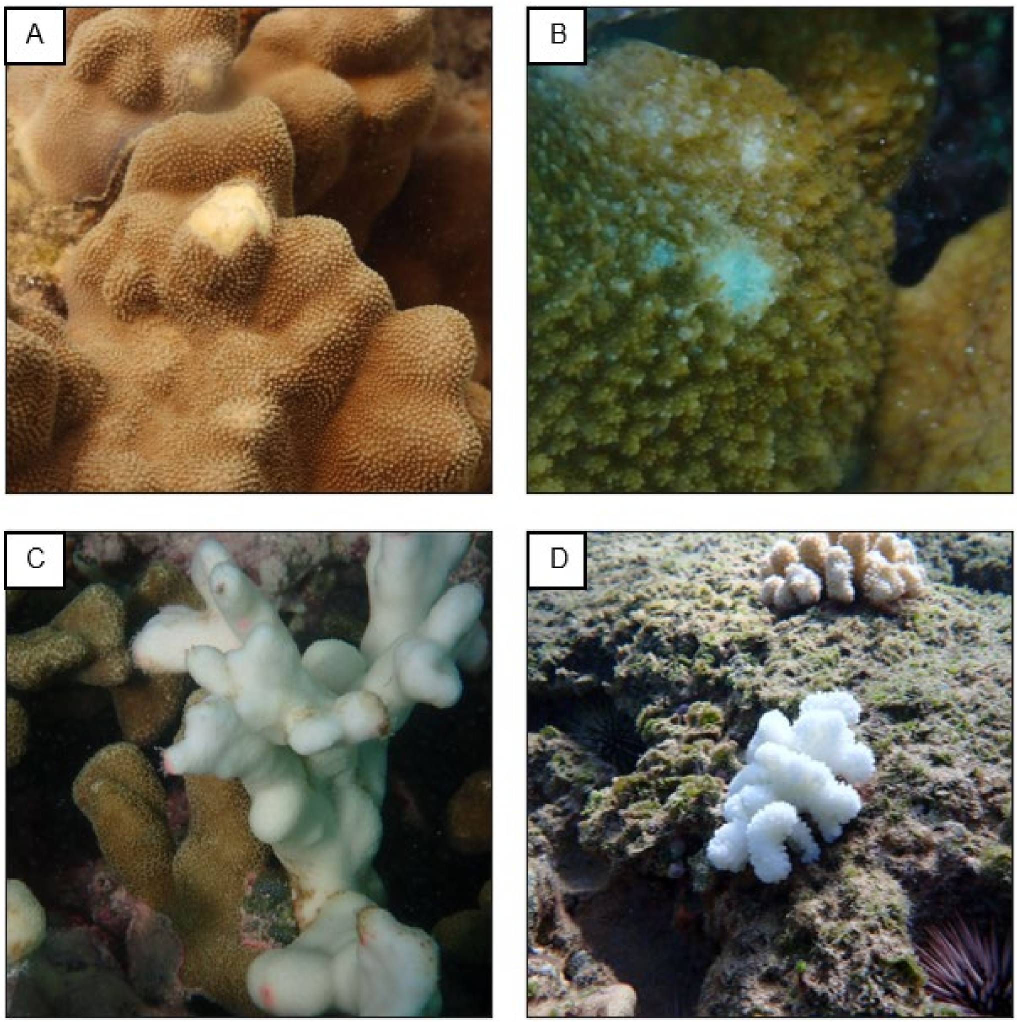


Figure 63. Examples of new bite marks across different bite mark categories and coral species. (A) Excavator on massive *Porites*, (B) scraper on *Montipora patula*, (C) *Drupella* on *Porites compressa*, (and D) sea star on *Pocillopora meandrina*.

2. Healing (HE)

Bite marks in this category were likely inflicted a few weeks before the survey was conducted and have had some time to heal. For bite mark categories that include skeleton removal (SCSP, EXCAV, SCRAP), the area will look pale compared to the rest of the colony, some polyps will be visible albeit usually still clear, parts of the skeleton will still be missing, and the edges of the bite marks will appear dull. For example, the top of the branch of *Porites compressa* will appear pale, flat and with rounded edges (Figure 64a). For scraper and excavator bite marks on *Pocillopora meandrina*, only mark as a healing corallivory bite mark if part of the skeleton and/or verrucose are missing (Figure 64b). The branch tips of *Porites compressa* and *Pocillopora meandrina* can often look pale, but only count as a healing bite mark if part of the skeleton is missing and it appears somewhat flattened. For bite mark categories that only include polyp removal (EXBR, DRUP, STAR), the bite mark will look paler than the rest of the colony, but polyps will be visible, although these might still look transparent (Figure 64c-d). Healing bite marks are uncommon with DRUP and STAR because these types of predation are often either extensive, preventing recovery, or they lead to complete colony mortality. This category is common for SCSP, EXCAV, SCRAP, and EXBR bite mark categories.

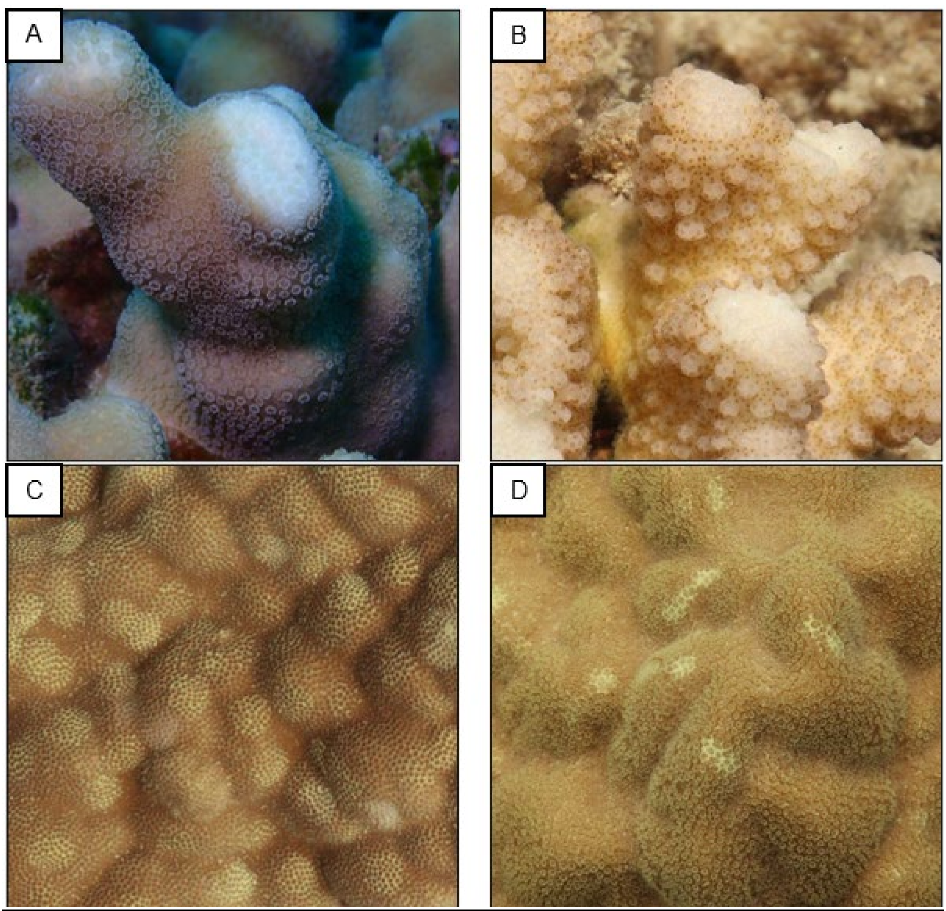


Figure 64. Examples of healing bite marks across different bite mark categories and coral species. (A) Excavator on *Porites compressa*, (B) scraper on *Pocillopora meandrina*, (C) blenny bites on massive *Porites*, and (D) parrotfish on massive *Porites*.

3. Old (OL)

Bite marks that are categorized as "OL" are probably weeks to months old. They have been covered with turf algae, or in some cases little "tufts" of cyanobacteria, but the identity of the scar underlying the algae is still recognizable. For bite mark categories that include skeleton removal (SCSP, EXCAV, SCRAP), the injury can look similar to a new or healing bite mark but will have medium to large tufts of algae growing on the wound (Figure 65a). This condition is not common among EXBR bite marks because they usually fully heal. DRUP and STAR bite marks may start to be colonized by large amounts of turf algae (Figure 65b). This category is most common with the EXCAV bite mark category.

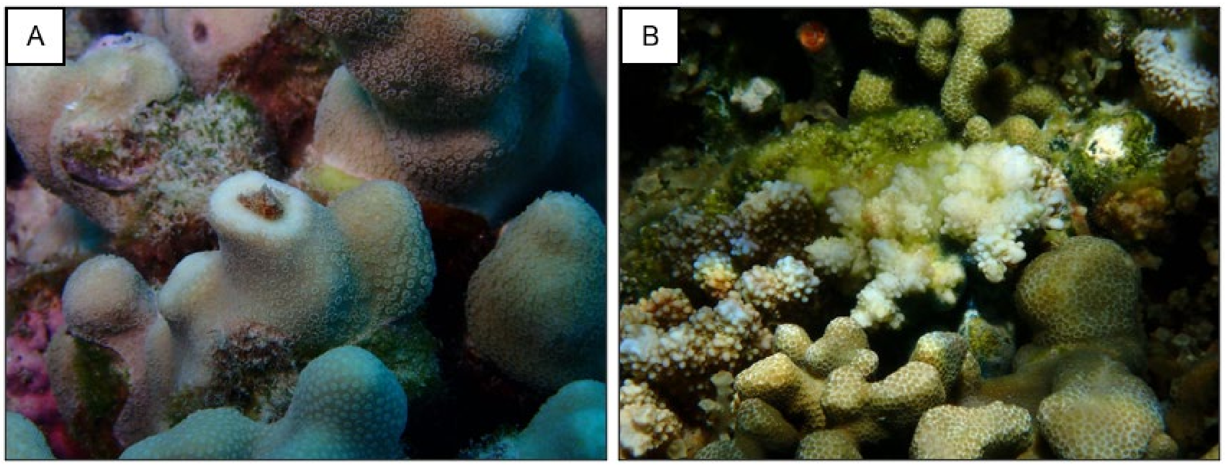


Figure 65. Examples of old bite marks across different bite mark categories and coral species. (A) An excavator bite wound on *Porites compressa* and (B) *Drupella* bite wound on *Montipora capitata*.

Overlap scores

There can be high levels of overlap between bite marks, especially with some of the categories such as EXBR and SCSP. The higher the overlap, the more difficult it is to accurately estimate the number of bite marks. Therefore, overlap scores are assigned in order to estimate how much corallivory may be undercounted. For example, the higher the overlap, the more likely corallivory is being undercounted because of the difficulty in distinguishing individual bite marks. Additionally, overlap scores help determine whether focused predation is occurring. When annotating, the overlap score is a rough average per coral species per bite mark category per condition category per quadrat. Keep in mind that colonies with few bite marks can have high overlap scores and colonies with many bite marks can have low overlap scores. Overlap is assumed any time multiple bite marks are touching. For example, EXBR bites may consist of two circles overlapping with each other or a large white area with only a few distinguishable circular shapes. Overlap scores are not assigned to DRUP and STAR predation because they leave behind large swaths of coral rather than inflicting multiple bite wounds. There are four overlap scores:

- Score 1: < 25% of bite marks overlap. These bite marks are easy to count as they are spaced out and have easily distinguishable edges (Figure 66 a, e, and i).

- Score 2: 26–50% of bite marks overlap. With this score, it becomes more difficult to count the number of bite marks individually, but it should still be possible to see a lot of bite marks edges (Figure 66 b, f, and j).
- Score 3: 51%–75% of bite marks overlap. With this score, it is likely that the number of bite marks will need to be estimated based on the size of individual bite marks and the extent of predation on the colony. This score is common for SCSP and EXBR bite mark categories and can also be common with SCRAP and EXCAV bite mark categories on the branch tips of *Pocillopora meandrina.* For example, when there are wounds that are large and cover the whole branch tip, count as one bite mark and increase the overlap score to account for the likely possibility that the wound is made up of more than one bite mark (Figure 66 c, g, and k).
- Score 4: 76%–100% of bite marks overlap. These bite marks are similar to category three but will appear as a large white mass of bite marks with hard to see edges, whereas category three the bite marks will be more spaced out. Similar to category three, this score is most common with SCSP and EXBR corallivory categories and with SCRAP and EXCAV categories on *Pocillopora meandrina* branch tips (Figure 66 d, h, and l).

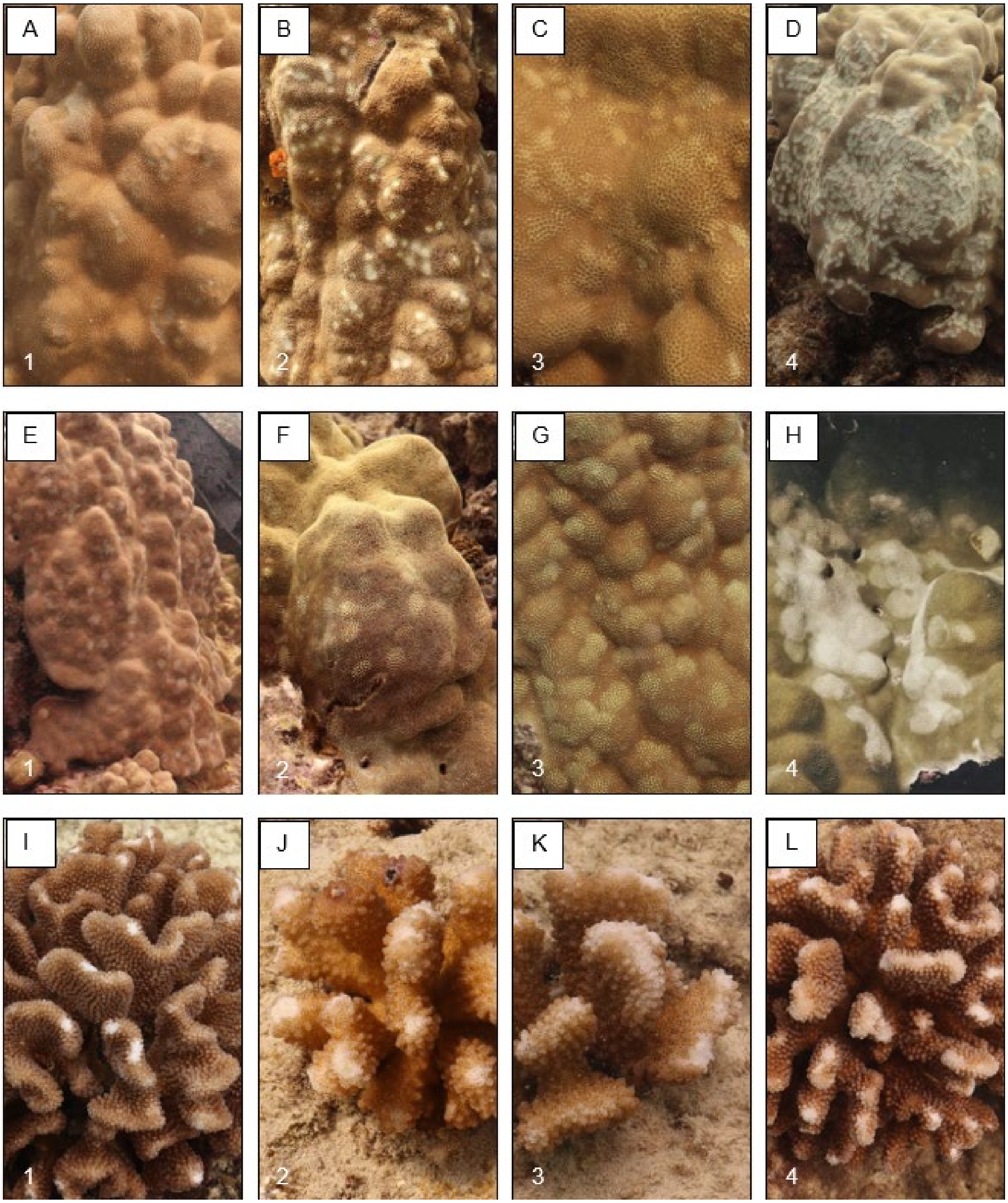


Figure 66. Examples of different overlap scores for (A-D) SCSP, (E-H) EXBR, and (I-L) SCRAP bite mark categories. Numbers on the bottom left corner of each image represent the overlap score.

Appendix 2. Extracting orthoblocks

After the orthomosaic is generated, the full mosaic can be divided into smaller chunks to be used for downstream image analysis. These chunks, henceforth referred to as "orthoblocks," capture the precise area of a quadrat, taken from a 2D orthomosaic and exported from ArcGIS Pro as a .PNG file to maintain high resolution. Orthoblocks, similar to photoquadrats, can be uploaded to CoralNet and annotated to determine percent benthic composition by coral species or substrate category.

<u>Generating high-resolution orthomosaics in Agisoft:</u>
If a project requires high-resolution orthomosaics, the most efficient process consists of building the original orthomosaics (section 3.3) at the default resolution and exporting two TIFF files (.tif) at higher resolutions (e.g., 1mm/pix and default mm/pix).

If only a low-resolution orthomosaic has been built:

1. Open the Agisoft file for the project (e.g., M:\Corallivory_MHI\HAN3\Products\HAN3.psx).
2. In the workspace, double click on the current orthomosaic (Figure 67).
3. Right click on the orthomosaic in the workspace and deselect 'Set as Default' (Figure 67).

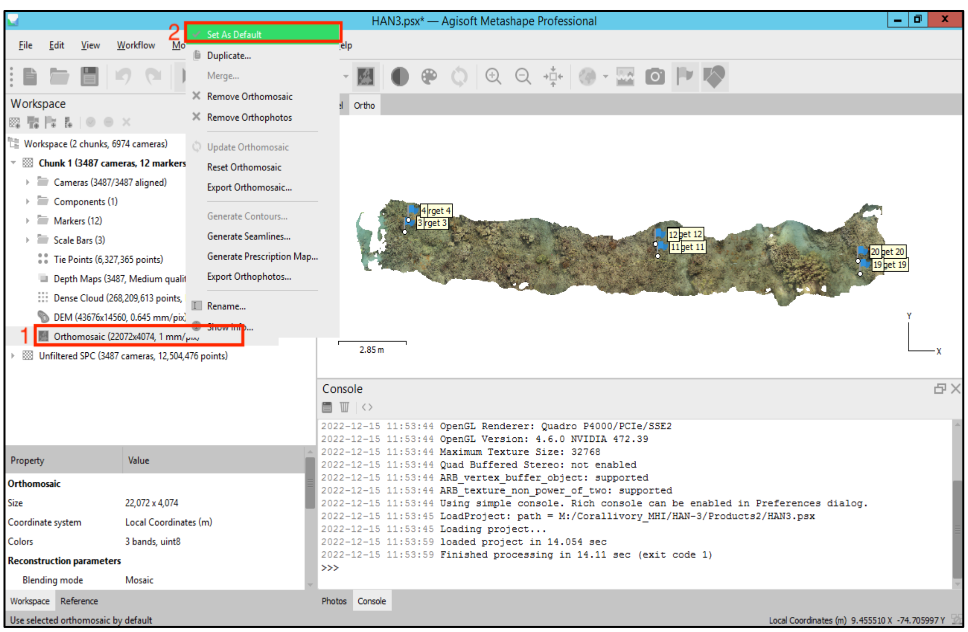


Figure 67. (1) Double click on the current orthomosaic, then right click and (2) deselect the 'Set as Default' option.

4. To build the high resolution orthomosaic go to 'Workflow' → 'Build Orthomosaic' and run using the default resolution (i.e., leave the 'Pixel (m)' setting to the default numbers).
5. Once complete, re-export the high resolution orthomosaic using the default resolution.
    a. Refer to step 7, section 3.1E of the SfM SOP.

Extracting PNGs for each quadrat in ArcGIS Pro:

1. Open the ArcGIS Pro file for the project (e.g., M:\Corallivory_MHI\HAN3\Products\ARC\HAN3\HAN3.aprx).
2. Deselect all layers in the contents pane except for the segments (i.e., the outlines of the quadrats) (Figure 68).

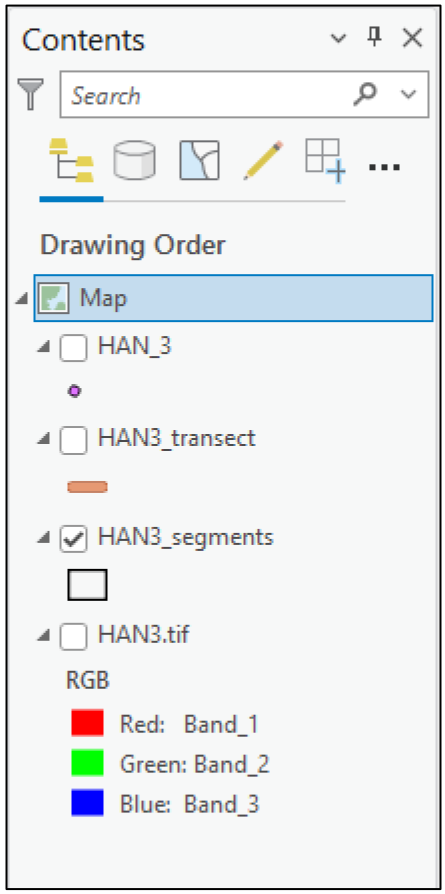


Figure 68. On the left contents pane, deselect the multipoint tool, transect lines, and orthomosaic tiff; leave only the quadrat outlines selected.

3. Import the high-resolution orthomosaic:
   a. 'Map' → 'Add Data' → Navigate to the high resolution ortho → 'OK' (Figure 69a).
   b. The ortho will not automatically appear, but it is loaded once the TIFF file shows up in the contents pane. (Figure 69b).

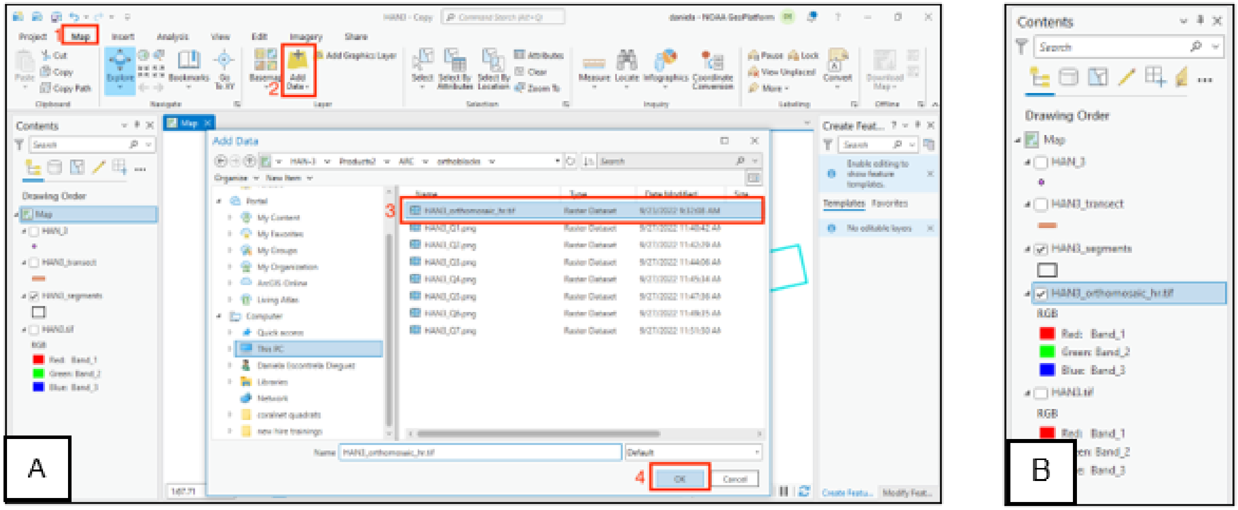


Figure 69. (A) (1) Go to the 'Map' tab, (2) select 'Add Data,' (3) navigate to the high resolution ortho, and (4) select 'OK.' (B) Once uploaded, the high resolution tiff will appear in the navigation pane.

4. Georeference the high-resolution orthomosaic (Figure 70).
   a. 'Analysis' → 'Tools' → 'Define Projection'.
      i. Input dataset: High resolution orthomosaic (SITE#_orthomosaic_hr.tif).
      ii. Coordinate System: WGS 1984 UTM Zone 4N.
      iii. 'Run'.

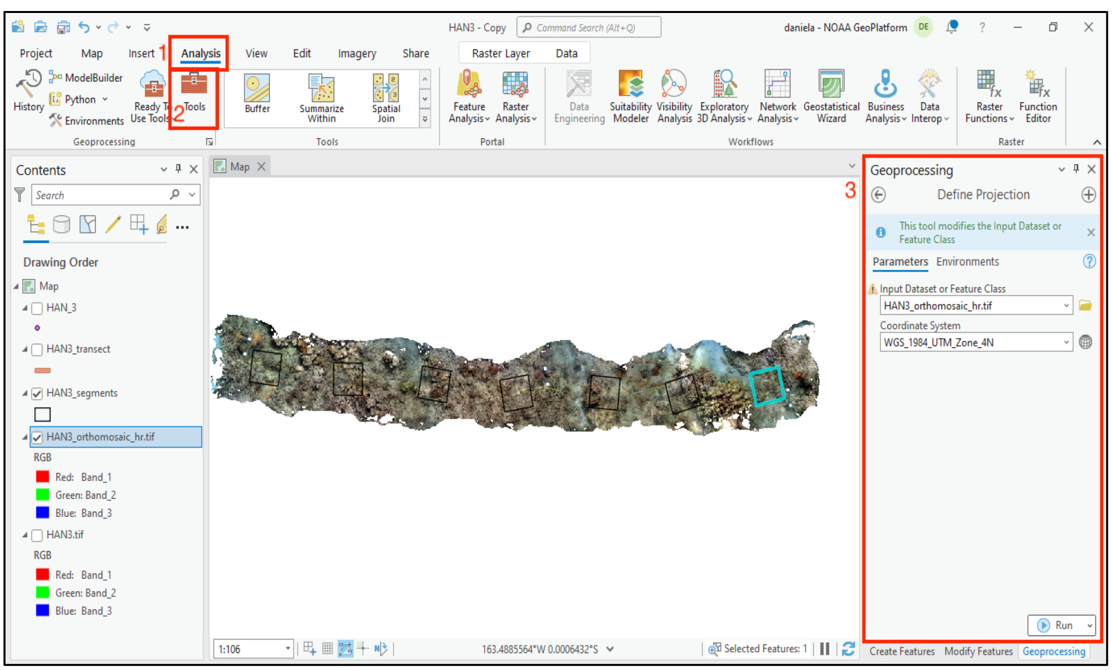


Figure 70. (1) From the 'Analysis' tab, (2) select 'Tools.' Search for and select 'Define Projection' (not pictured). (3) In the 'Define Projection' pane, fill in the 'Input Dataset' and 'Coordinate System' fields as described above and select 'Run'.

5. The coloration of the ortho will be off and will need to be corrected under the ‘Raster Layer’ tab.
    a. Make sure the high resolution TIFF is selected on the left side pane. Then go to ‘Raster Layer’ → ‘Stretch Type’ → ‘None’ (Figure 71).

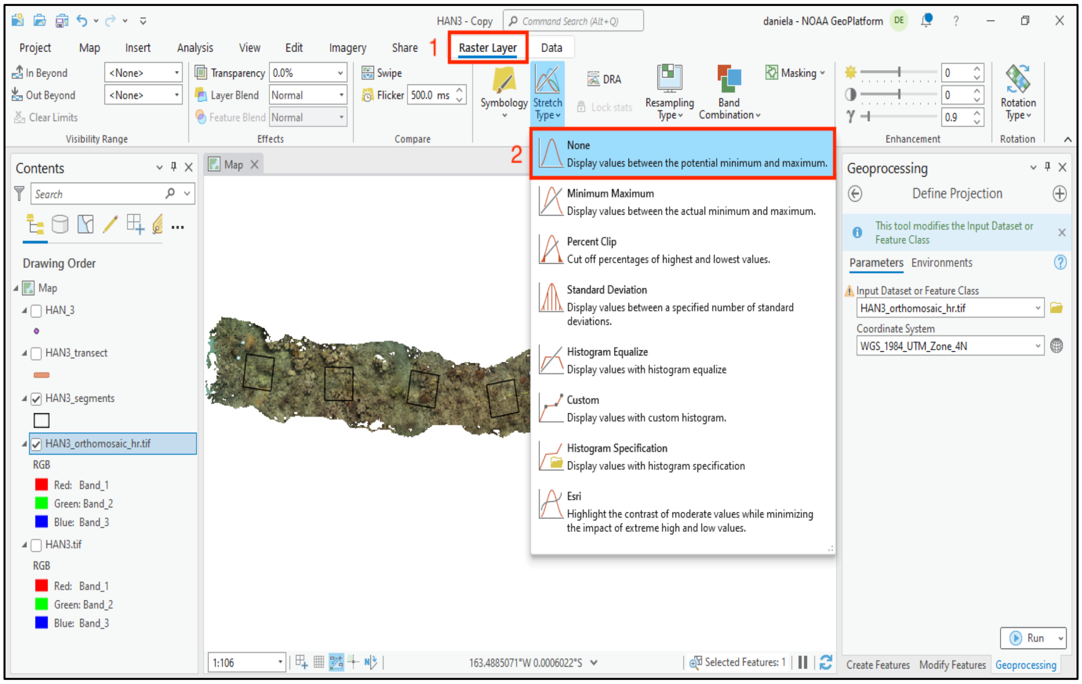


Figure 71. With the high resolution TIFF selected on the left pane, (1) go to the ‘Raster Layer’ tab, (2) select ‘Stretch Type’ and then ‘None’ from the drop down menu.

6. Click on the first segment overlaying the orthomosaic by using the ‘Select’ tool under the ‘Map’ tab (Figure 72).

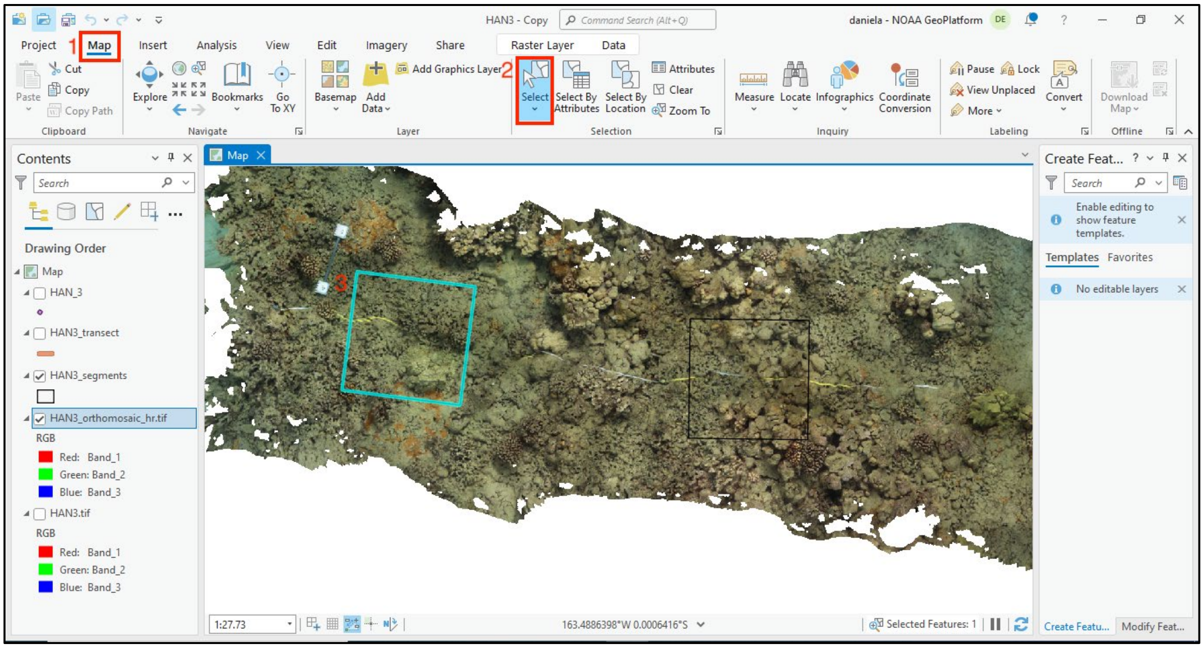


Figure 72. (1) Select the 'Map' tab, (2) then click on the 'Select' tool, and (3) lastly click on the first segment.

7. In the Geoprocessing pane (go to 'Analysis' tab → 'Tools'), search for 'Clip Raster' and fill in the fields as follows (Figure 73):
   a. Input Raster: SITE#_orthomosaic_hr.tif
   b. Output Extent: SITE#_segments
   c. Check 'Use Input Features for Clipping Geometry'
   d. Output Raster Dataset: Rename to SITE#_Q1 → 'Save'
   e. 'Run'

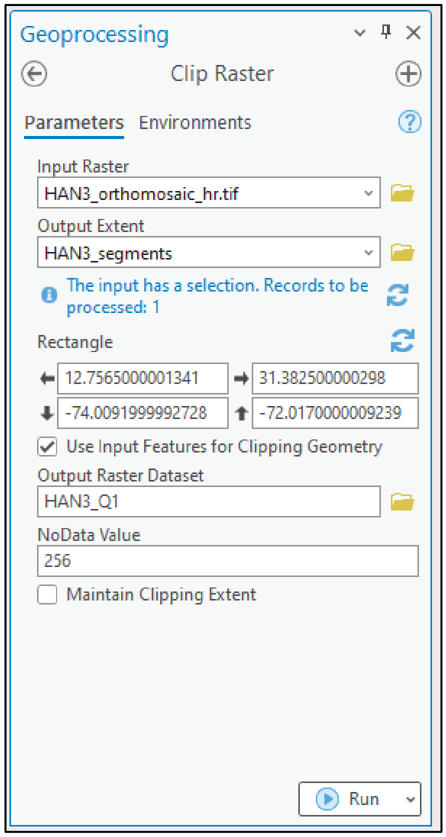


Figure 73. Fill in the fields in the 'Clip Raster' pane as indicated and select 'Run'.

8. Repeat step 7 for the remaining segments (i.e., quadrats) by selecting each segment and renaming the 'Output Raster Dataset' to the appropriate quadrat number (i.e., Q#). This will create a 'Raster Layer' on the left pane for each segment.
9. All new raster layers will be discolored. Individually select each raster layer in the contents pane (on the left) and navigate to 'Raster Layer' → 'Stretch Type' → 'None' ([Figure 74](#)).

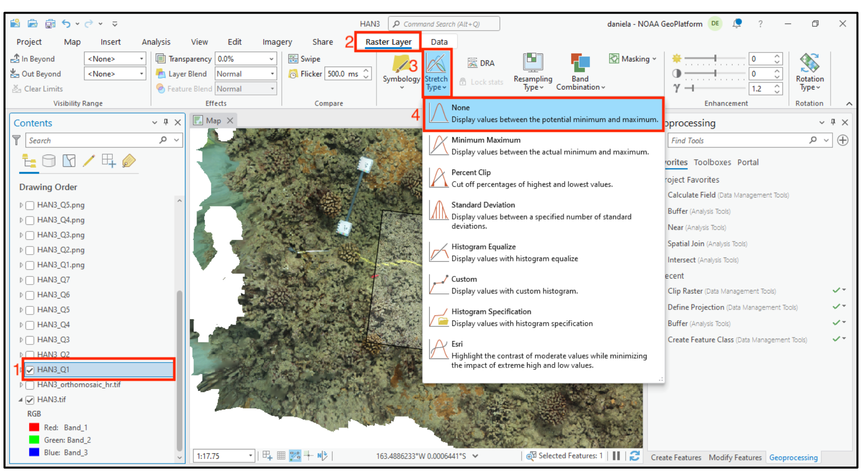


Figure 74. For all the layers, (1) select the raster layer on the left pane, (2) go to the 'Raster Layer' tab, (3) select 'Stretch Type,' and (4) click on 'None.'

10. To export a .PNG of each raster, right click on the raster layer (i.e., HAN3_Q1) in the contents pane (on the left) → 'Data' → 'Export Raster' (Figure 75).
    a. Output Raster Dataset: Navigate to the site's orthoblocks folder (i.e., M:\Corallivory_MHI\HAN-3\Products\ARC\orthoblocks) and save as SITE#_Q#.png
    b. Leave all other fields as default, but double check that the Output Format is PNG.

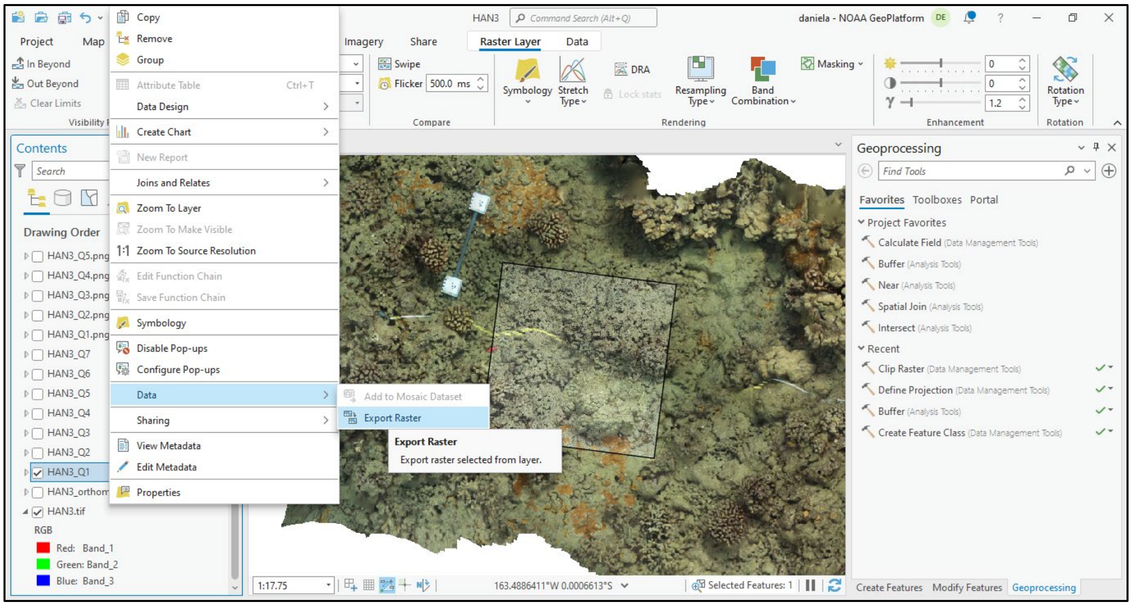


Figure 75. Right click on the raster layer, select 'Data,' and click on 'Export Raster.' Fill in the pop up window as described in step 10.

<u>Orienting the PNG and converting to JPG with photo editing software:</u>

1. Individually open each PNG with an editing software (e.g., Paint3D).
2. If using Paint3D (Figure 76):
    a. Use the select tool and highlight the whole quadrat.
    b. Rotate the image until it is squared with the computer screen.
    c. Using the crop tool, crop out the extra gray space around the quadrat.

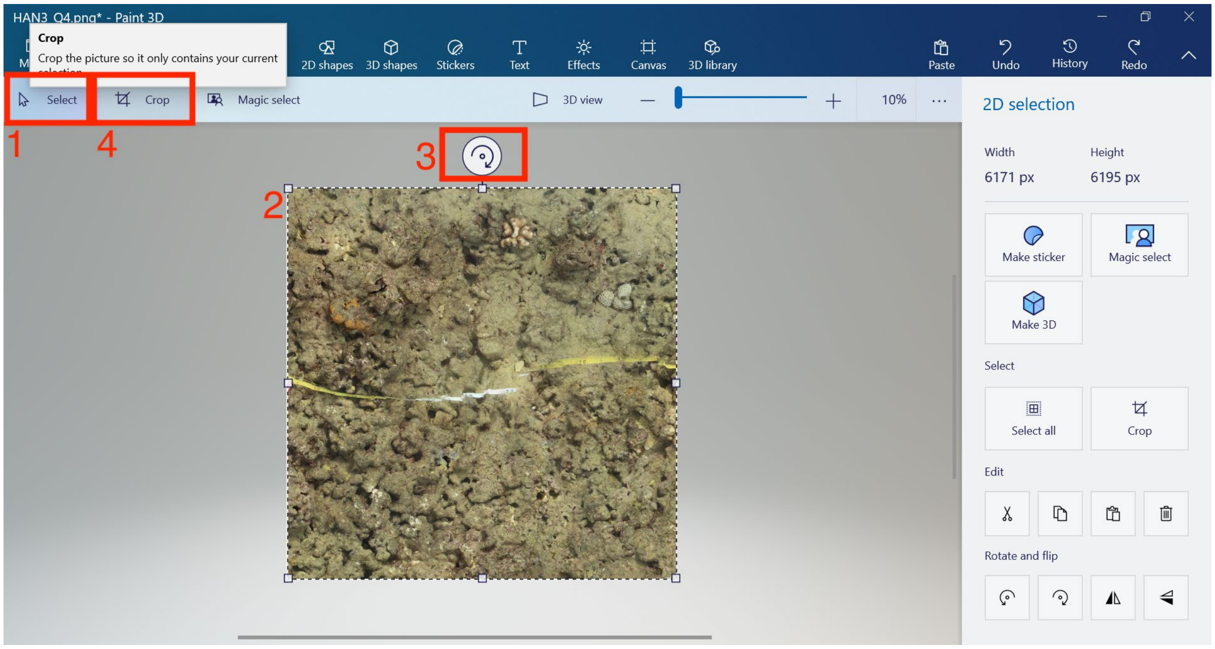


Figure 76. Open the PNG of the quadrat in Paint3D, (1) click on the 'Select' tool, (2) use it to highlight the whole quadrat, (3) rotate until the quadrat is square with the screen, (4) and select 'Crop.'

3. Save the rotated and cropped photoquadrat as a JPG in a new 'Photoquads' folder:
    a. e.g., M:\Corallivory_MHI\HAN-3\Products\Photoquads
    b. Save as SITE#_Q#