A Spatial Analysis of Benthic Habitat and Coral Bleaching Severity on Guam Reefs

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I. INTRODUCTION

Coral reefs are one of the most diverse and valuable ecosystems on Earth. Unfortunately, coral reefs globally are being negatively impacted by a variety of physical and chemical stressors including ocean acidification, unsustainable overfishing, pollution, damage caused by vessels, coastal development, coral bleaching, and invasive species (Hoegh-Guldberg et al. 2007). Coral bleaching has been the major issue which has been reported in reefs in every part of the globe for decades with more intense and frequent bleaching events occurring more recently. The environmental stresses linked to coral bleaching include long exposure to sunlight and high sea surface temperatures (Brown 1997). Coral face non-global stressors and a common local stressor that has a large impact to corals on reefs is algae. Algae competes with coral for area on the reef and several algae species have a variety of ways to deter coral growth and settlement on available substrate. On reefs experiencing algae phase shifts or temporary algal blooms, the restocking of adult coral populations may be slowed due to recruitment inhibition. This causes reduced coral cover and limiting coral community recovery over time (Kuffner et al. 2006). Fortunately, presence of sufficient grazing fish populations may increase coral recovery since herbivorous fish consume the macroalgae that may otherwise out-compete coral recruits for space on the reef (West and Salm 2003). This is easily implemented by establishing a Marine Preserve Area over a desired reef. Marine Preserve Areas (MPAs) are coastal areas where fishing activity has been restricted in response to decreasing reef fish stocks and have been put in place across the globe. MPAs can vary in strength, size, and specific requirements (fish restrictions, certain seasons, etc.).

Present coral research can include a variety of environmental examinations such as benthic assessments, fish surveys, reef health monitoring, and others. Through these research methods, scientists have been documenting changes in coral reef composition, structure, size and health. There has been coral research conducted in many parts of the world with highly studied areas including the Great Barrier Reef in Australia, Hawaii's reefs, Belize Barrier Reef, and other Caribbean coral reefs. Relative to other islands, Guam has not been on the forefront of coral reef research. Guam, a US Territory, is the southernmost island of the Mariana Archipelago and the largest and most populated island in Micronesia but small in comparison to other islands. Small islands are likely to be disproportionately impacted by climate change-related stressors, as their high reef-to-land area and heavy dependence on shallow marine ecosystems increase their vulnerability to the decline and loss of these ecosystems (Raymundo et al. 2019). In the past few decades, there have been several studies that analyze the reef health on different reefs around Guam. Unfortunately, Guam coral reefs have also faced detrimental effects of climate change and local anthropogenic stressors. For the integrity of the island and the human population on Guam that depend on the reef, it is imperative to conduct research and assess the reef health.

Project Scope and Future Research Application:

In my graduate research, I will combine assessments of reef geometry with investigations of cryptobenthic fish communities and their contribution to coral reef energy fluxes to examine how changes in coral reef complexity will affect the biodiversity and functioning of reefs from first principles. My field research will take place in Guam and I will have several sites off the Eastern and Western coastlines. The overall goal of my research is to analyze the reef structural complexity in areas that were severely impacted during recent bleaching events. Another objective will be a benthic habitat assessment coupled with cryptobenthic fish surveys along several sites along the island. For this GIS project, the objective was a preliminary assessment of reefs since I wanted to find out where severe bleaching occurred as well as the benthic habitat in order to select my study sites.

In Guam, there are benthic surveys and habitat assessment as well as bleaching analyses conducted but we do not know the extent of bleaching on areas of known benthic cover. Yet, despite a recent increase in research on benthic composition and coral bleaching, the two components have not been extensively linked quantitatively. This project aims to 1) analyze the spatial variation in coral bleaching severity and benthic habitat of reefs within and outside Marine Protected Areas. Given more MPAs are located on the Western coasts, a secondary objective is to examine the bleaching severity and benthic habitat on the Eastern and Western coasts for comparison. Proposed methods to complete these objectives are to extract quantifiable data from benthic habitat from the desired study areas as well and create rasters from bleaching point data for analysis.

II. DATA COLLECTION

Downloaded Data:

I started this project by utilizing readily available open source data for the foundation of my research. My first step was simply inputting features of the island of Guam. I imported:

1. **Guam boundary**

   A boundary of the island of Guam was needed. I used the island's boundary polygon from ArcGIS Online which was accessed directly from the site (Source: Esri, USGS, US Census https://ut-austin.maps.arcgis.com/home/item.html?id=3c73f55f402241e7b36f9596710c516d)

2. **Coral Bleaching Point data**

   Coral bleaching data from Guam collected during the 2017 Global Coral Bleaching Event. Data includes location of point, date, depth, bleaching severity code, percent coral bleached, percent mortality, and more fields which is seen in the Value Attribute Table (Figure 1). Source: Data provided by NOAA Coral Reef Watch (CRW) https://coralreefwatch.noaa.gov/satellite/index.php

Table

Guam_Coral_Bleaching_data

LATITUDE	LONGITUDE	DATE	MONTH	YEAR	MAX_DEPTH	BLEACHING_SEVERITY_CODE	PERCENT_BLEACHED	MID-POINT_OF_RANGE_(% BLEACHING)	MORTALITY_CODE	PERCENT_MORTALITY	MID-POINT_OF_RANGE_(% MORTALITY)	MORTALITY_TIME_ADJUST	DATE_BLEACHING_YEAR_DHW_MAX	OBS_TIMING	DHW_TO_USE	DAILY_D
13.470001	144.690792	11	10	2017	12	3	60	N/A	1	4.5	N/A	0	10/11/2017	1	10.09	1
13.470001	144.690792	11	10	2017	5	3	64.351852	N/A	1	6.94	N/A	0	10/11/2017	1	10.09	1
13.387777	144.652738	12	10	2017	12	3	62.561576	N/A	1	6.9	N/A	0	10/12/2017	1	9.76	
13.387777	144.652738	12	10	2017	5	3	56.050955	N/A	2	20.06	N/A	0	10/12/2017	1	9.76	
13.540587	144.804559	17	10	2017	12	3	58.832117	N/A	1	8.91	N/A	0	10/11/2017	2	8.98	
13.540587	144.804559	17	10	2017	5	3	59.925558	N/A	2	10.92	N/A	0	10/11/2017	2	8.98	
13.241692	144.693527	31	10	2017	12	3	62	N/A	2	11.33	N/A	0	10/11/2017	2	10.18	
13.241692	144.693527	31	10	2017	5	2	45.522388	N/A	1	9.7	N/A	0	10/11/2017	2	10.18	
13.640854	144.88577	31	10	2017	12	3	62.982005	N/A	2	30.33	N/A	0	10/8/2017	2	8.09	
13.640854	144.88577	31	10	2017	5	3	80.18018	N/A	2	41.33	N/A	0	10/8/2017	2	8.09	
13.23221	144.647746	31	10	2017	12	3	60.9375	N/A	2	18.75	N/A	0	10/11/2017	2	10.38	
13.23221	144.647746	31	10	2017	5	3	68.248175	N/A	2	29.56	N/A	0	10/11/2017	2	10.38	
13.571862	144.823485	17	10	2017	12	3	62.251656	N/A	2	20.31	N/A	0	10/8/2017	2	8.36	
13.571862	144.823485	17	10	2017	5	3	72.984441	N/A	2	31.26	N/A	0	10/8/2017	2	8.36	
13.329143	144.647933	1	11	2017	12	3	53.846154	N/A	2	10.77	N/A	0	10/11/2017	2	9.67	
13.329143	144.647933	1	11	2017	5	2	44.375	N/A	2	20	N/A	0	10/11/2017	2	9.67	
13.601356	144.949811	31	10	2017	12	3	68.267223	N/A	2	34.03	N/A	0	10/8/2017	2	8.14	
13.601356	144.949811	31	10	2017	5	3	57.731959	N/A	2	24.74	N/A	0	10/8/2017	2	8.14	
13.446069	144.618272	12	10	2017	12	3	73.239437	N/A	2	31.69	N/A	0	10/12/2017	1	10.53	1
13.446069	144.618272	12	10	2017	5	3	77.55102	N/A	2	29.85	N/A	0	10/12/2017	1	10.53	1
13.47832	144.7243	23	9	2017	N/A	2	18.2	N/A	0	0	N/A	0	10/11/2017	0	7.66	
13.4784	144.72426	23	9	2017	N/A	1	10.116	N/A	0	0	N/A	0	10/11/2017	0	7.66	
13.4785	144.72412	23	9	2017	N/A	1	8.589	N/A	0	0.31	N/A	0	10/11/2017	0	7.66	
13.47832	144.7243	29	10	2017	N/A	2	12.012	N/A	0	0	N/A	0	10/11/2017	2	9.28	
13.4784	144.72426	29	10	2017	N/A	2	35.561	N/A	0	0	N/A	0	10/11/2017	2	9.28	
13.4785	144.72412	29	10	2017	N/A	1	4.301	N/A	0	0	N/A	0	10/11/2017	2	9.28	
13.38358	144.65363	23	9	2017	N/A	3	51.686	N/A	1	4.5	N/A	0	10/12/2017	0	8.3	
13.38363	144.65337	23	9	2017	N/A	2	49.366	N/A	3	56.96	N/A	0	10/12/2017	0	8.3	
13.38365	144.6532	23	9	2017	N/A	3	53.631	N/A	3	52.51	N/A	0	10/12/2017	0	8.3	
13.35543	144.77219	22	9	2017	N/A	2	29.649	N/A	0	0	N/A	0	10/11/2017	0	7.77	
13.35547	144.77238	22	9	2017	N/A	2	21.875	N/A	0	0	N/A	0	10/11/2017	0	7.77	
13.355444	144.772056	27	10	2017	N/A	2	23.271	N/A	0	0	N/A	0	10/11/2017	2	9.35	
13.35543	144.77219	27	10	2017	N/A	2	24.504	N/A	0	0	N/A	0	10/11/2017	2	9.35	
13.35547	144.77238	27	10	2017	N/A	2	22.353	N/A	0	0	N/A	0	10/11/2017	2	9.35	
13.365889	144.771028	22	9	2017	N/A	2	41.985	N/A	1	0.76	N/A	0	10/11/2017	0	7.77	
13.36585	144.77126	22	9	2017	N/A	2	28.001	N/A	1	1.33	N/A	0	10/11/2017	0	7.77	
13.36565	144.77179	22	9	2017	N/A	2	39.395	N/A	0	0	N/A	0	10/11/2017	0	7.77	

Figure 1: Portion of Value Attribute Table for 2017 Coral Bleaching data.

3. **Benthic habitat**

    Benthic habitat from 2017 for the nearshore, shallow (< 30 m) coastal waters of the island of Guam was downloaded as well. NOAA's National Centers for Coastal Ocean Science (NCCOS) produced these data to support coral reef research and management. Habitat regions were digitally identified using visual interpretation of orthorectified satellite imagery with a minimum mapping unit (MMU) of approximately 1 acre. Source: Data provided by PacIOOS (www.pacioos.org), which is a part of the U.S. Integrated Ocean Observing System (IOOS®), funded in part by National Oceanic and Atmospheric Administration (NOAA)
    http://www.pacioos.hawaii.edu/metadata/gu_noaa_all_benpthic_habitats.html?format=fgdc
4. **Hydrology**

    Major rivers in addition to minor streams and creeks were compiled. Source: The geospatial data were derived from the National Hydrography Database (NHD) by the United States Geological Survey (USGS) in collaboration with Bureau of Statistics and Plans (BSP) and the Water and Environmental Research Institute of the Western Pacific (WERI). Island Research & Education Initiative (iREi).
    https://www.oc.nps.edu/CMSP/Guam/rivers_major.shp.xml
    Discharge points were downloaded as well. Source: John M. Jocson and John W. Jenson, University of Guam (WERI)
    http://www.weriguam.org/reports/item/numerical-modeling-and-field-investigation-of-infiltration-recharge-and-discharge-in-the-northern-guam-lens-aquifer.html
5. **Marine Protected Areas**

    Polygon Coverage of Guam Marine Protected Areas. This includes Achang Reef Flat Marine Preserve, Piti Bomb Holes Marine Preserve, Sasa Bay Marine Preserve, Tumon Bay Marine Preserve, Pati Point Marine Preserve. Source: Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources (DAWR) and NOAA Pacific Islands Project
    https://www.oc.nps.edu/CMSP/Guam/index.html

III. DATA & ARCGIS PROCESSING

Data Pre-Processing

Once downloaded, some of the mentioned files were compressed and zipped which were inaccessible unless they were extracted. To have access to the files, Windows File Explorer was used in order to “Extract All” the files within the zipped files. Then I loaded data onto a new ArcGIS map. I ensured all files that were inputted matched the same projection and coordinate system.

- Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
- Projection: Mercator Auxiliary Sphere
- Datum: WGS 1984

In order to use Spatial Analysts later on, at the beginning I turned on Spatial Analyst from Extensions (Figure 2).

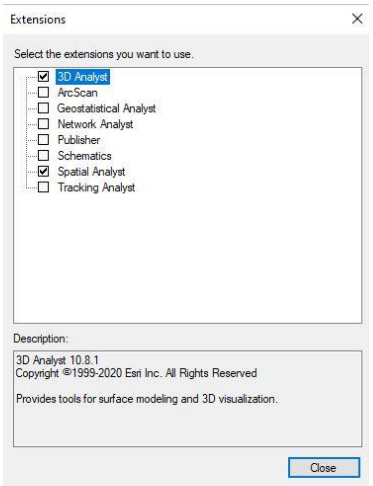

Figure 2: Spatial Analysis turned on under "Extensions".

Data & ArcGIS Processing

Step 1: I imported the downloaded data as mentioned above. I started with the Guam island boundaries as well as the MPAs (Figure 3a) which I labeled using "Label features". Then I added coral bleaching points, hydrology (major rivers, streams, creeks), and benthic habitat data (Figure 3b). For simple data visualization as I worked on the following steps, I symbolized the points for **coral bleaching severity** accordingly as seen in Figure 3b below.

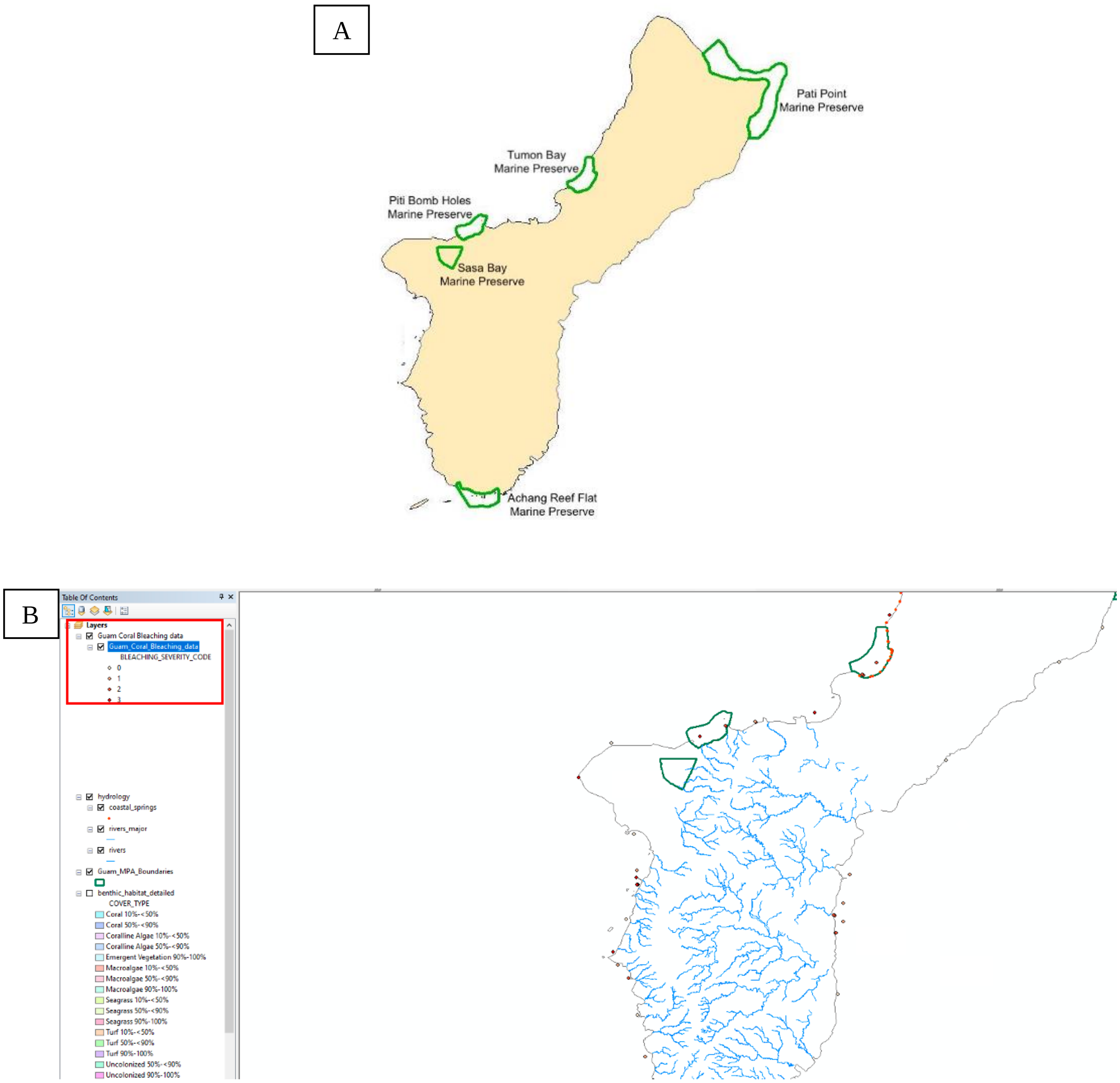

Figure 3 (A) Map of Marine Protected Areas and their titles
(B)Coral Bleaching points symbolized based on severity code (derived from percent bleached) boxed in red in Table of Contents.

Step 2: For ease of processing, I joined features in hydrology. Since I wanted to visualize freshwater streams generally, I joined the major rivers to the minor rivers, streams, and creeks. This was done by right clicking on the rivers layer and "Join Data" (Figure 4).

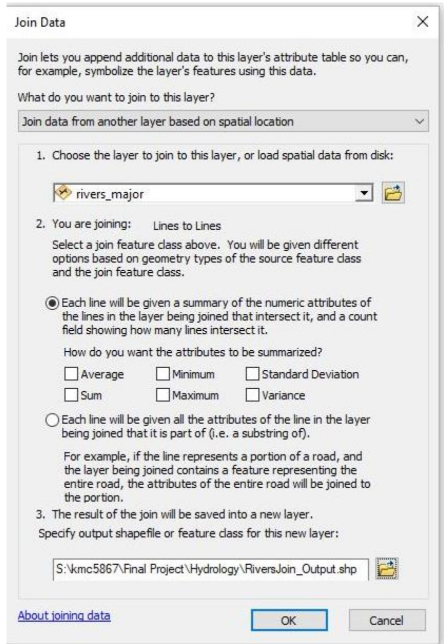

Figure 4: 'Join Data' window showing the joining between the river data layers resulting in one shapefile showing all rivers.

Step 3: From there my goal was to interpolate the point data from the 2017 Coral Bleaching Event to create a raster surface over the entire coast of Guam. In order to create a raster from points, I utilized the spatial interpolation method Inverse Distance Weighting (IDW). Geoprocessing Tools > Spatial Analyst toolbox > Interpolation toolset > IDW. Inverse distance weighted interpolation determines cell values using a linearly weighted combination of a set of sample points. My input was the Guam Coral bleaching data/Z value field: percent bleached/ Output cell size 148.97 (default parameters) /Search radius – variable (12 points)/Output surface raster: percbleach1 (percent bleached) as seen in Figure 5. The result from using this tool can be seen in Figure 6 which shows the interpolation between each point.

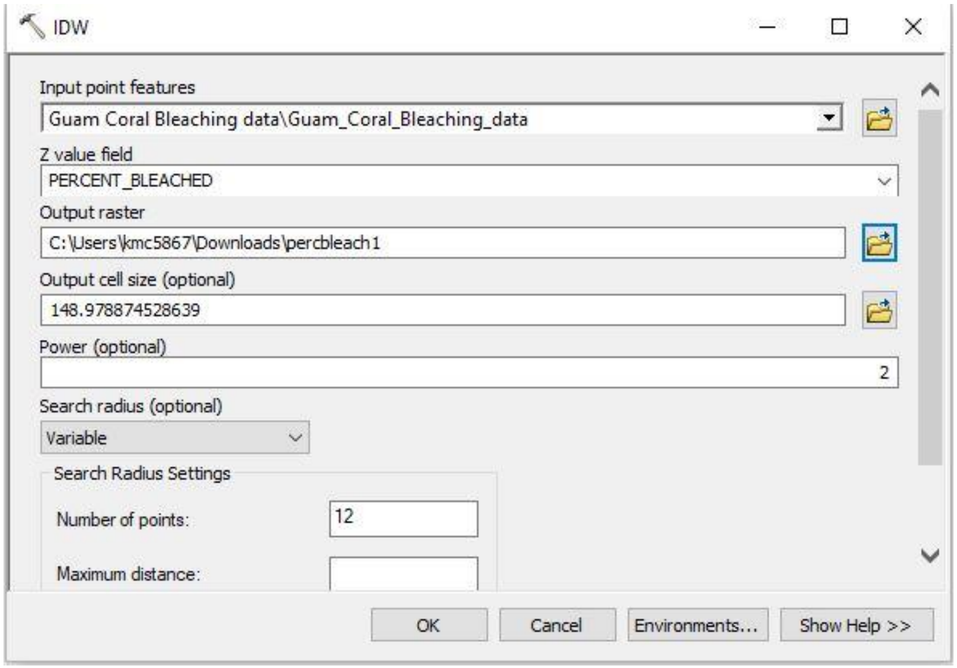

Figure 5: IDW window to interpolate coral bleaching points by percent bleached to create a raster surface.

Figure 6: Raster of percent coral bleached after IDW (before symbolizing properly).

Step 4: After successfully creating a raster surface using IDW, the next objective is to only use the interpolated values that are the shallow coastal areas of the island. To do this, I used "buffer", a geoprocessing tool which creates buffer polygons around input features to a specified distance. (Analysis Tools > Proximity > Buffer). My input feature was the Guam boundary layer / Distance: 2150m / Side type: outside only / End type: round / Dissolve type: all / Method: planar/ and my output feature class was named: buff_coast2km as seen in Figure 7. The result is a ~ 2 km buffer around the island (Figure 8).

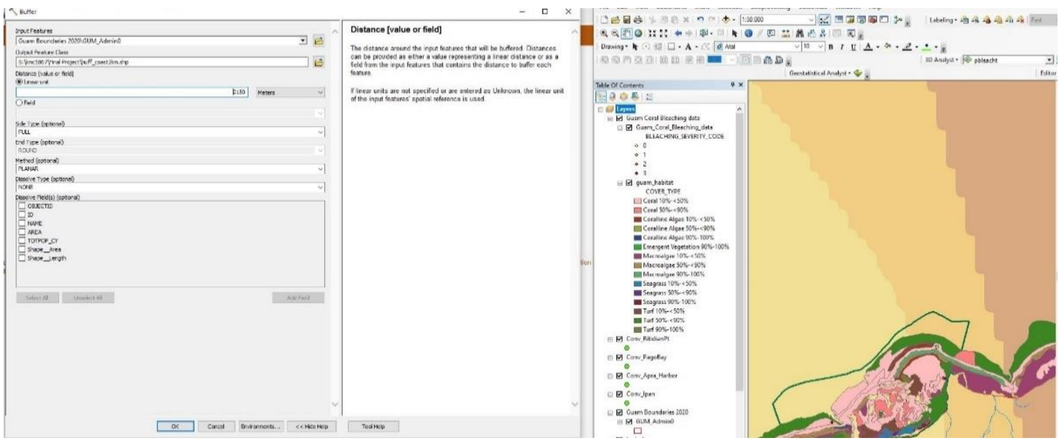

Figure 7: Window showing the buffer creation (around the coastline of Guam). The right window shows a zoomed-in view of the map with the raster before the buffer is created.

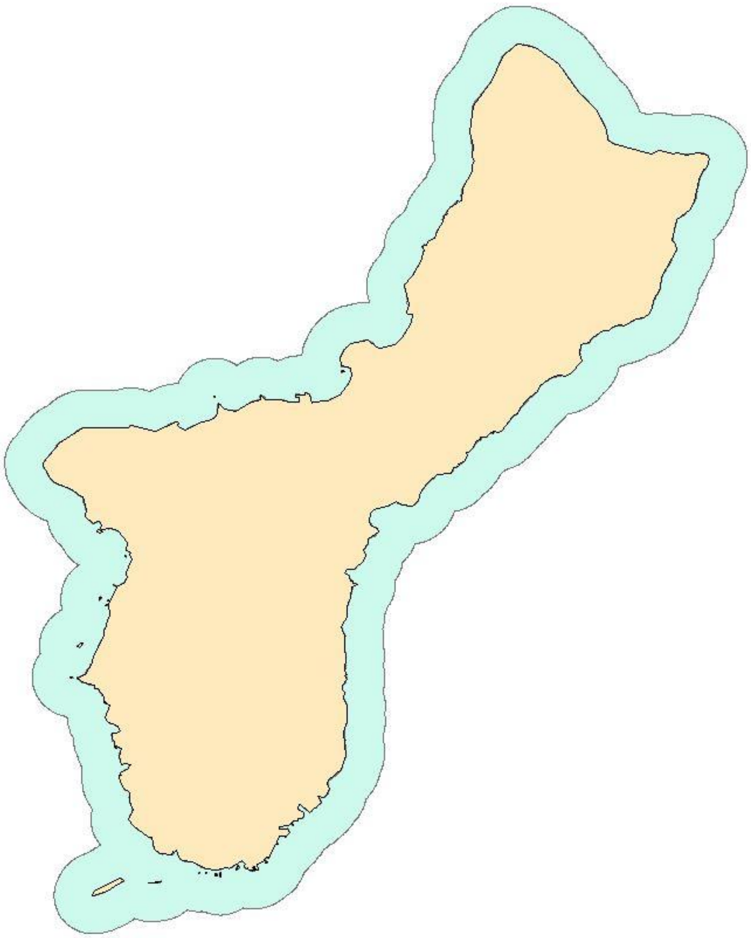

Figure 8: Light blue shape around the island is the created ~ 2km buffer of entire coastline

Step 5: To reiterate, the goal at this phase was to use the interpolated values that are the shallow coastal areas of the island. In order to use the buffer as a way to 'cut' the interpolated bleaching raster, I used "Extract by mask" which is a Spatial Analysis tool that extracts the cells of a raster that correspond to the areas defined by a mask (Spatial Analyst toolbox > Extraction toolset > Extract by Mask). My input raster was the interpolated percent bleached raster that I made in Step 3 (percbleach1) and my input raster mask data was the buffer I made in Step 4 as seen in Figure 9. Once completed, I symbolized the raster with red being the highest percent bleaching and yellow being the lowest (Figure 10).

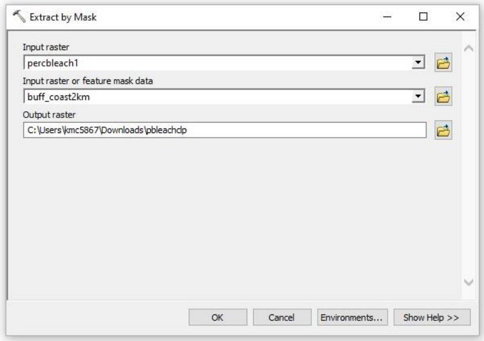

Figure 9: Window of "extract by mask" tool to extract the percent bleached raster using the buffer as a mask.

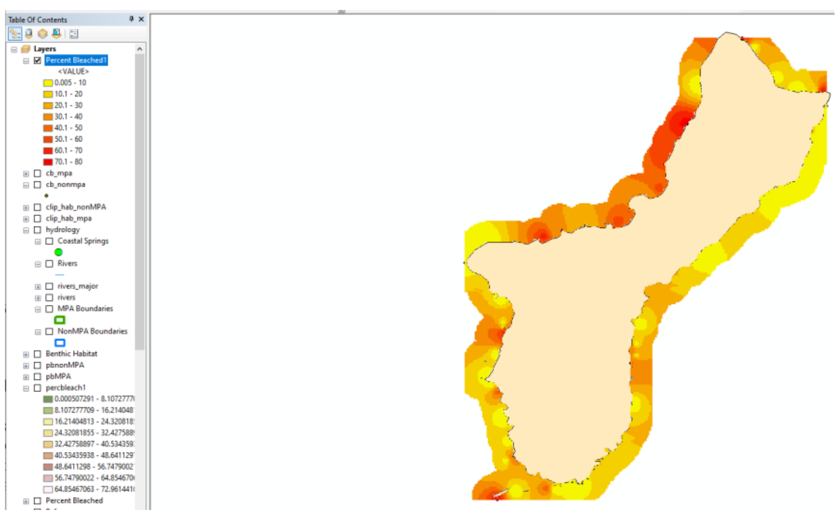

Figure 10: Severity of coral bleaching (after symbolization) after Extract by Mask to the 2 km buffer along the coast of Guam.

Step 6a: In order to have a spatial analysis of benthic habitat between MPAs and non MPAs, then next step was to isolate and extract benthic habitat within MPAs and non MPA areas. In order to calculate the amount of cover for each the benthic habitat type, I created randomly spaced non MPA areas (polygons) that were the average size of the MPAs (excluding the Pati Point Marine Reserve in order to keep the sizes consistent and to not skew the data) since I already had the MPAs downloaded. I started by simply drawing polygons the average size of MPAs. The placement was randomly selected to avoid any sampling bias. In the table of contents, I right-clicked the data frame containing the non MPA polygons and clicked "Convert Graphics To Features" which I symbolized in blue as seen in Figure 11 below.

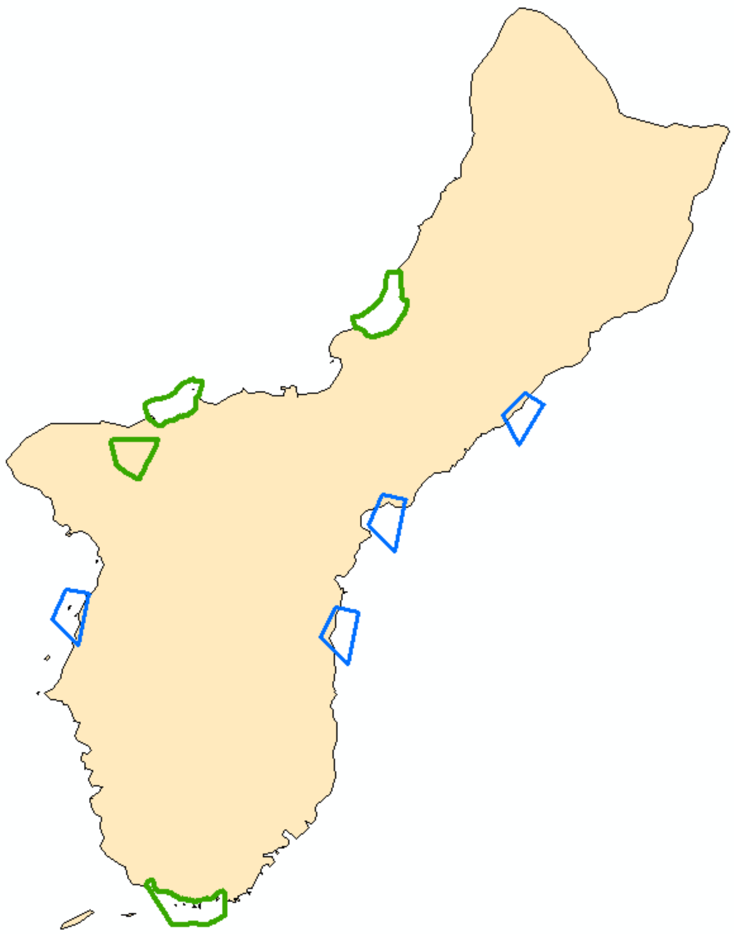

Figure 11: Map showing MPAs (in green) and non MPA areas (blue)

Step 6b: With a similar process as Step 5, I clipped (Analysis toolbox > Extract toolset) the benthic habitat to the MPAs. My input was the benthic habitat data / clip feature was the MPAs layer/ output named clip_hab_mpa. By using the Selection tool, I selected the benthic habitat data inside the MPAs and exported the selected data I needed by right-clicking the layer in the table of contents and clicked Data > Export Data. I exported selected records and outputted the table to an organized personal data folder for future analysis (Figure 12a). All Benthic data was exported from the following MPAs: Sasa Bay Marine Preserve, Achang Reef Flat Marine Preserve, Piti Bomb Holes Marine Preserve, and the Tumon Bay Marine Preserve (see Figure 3a for reference).

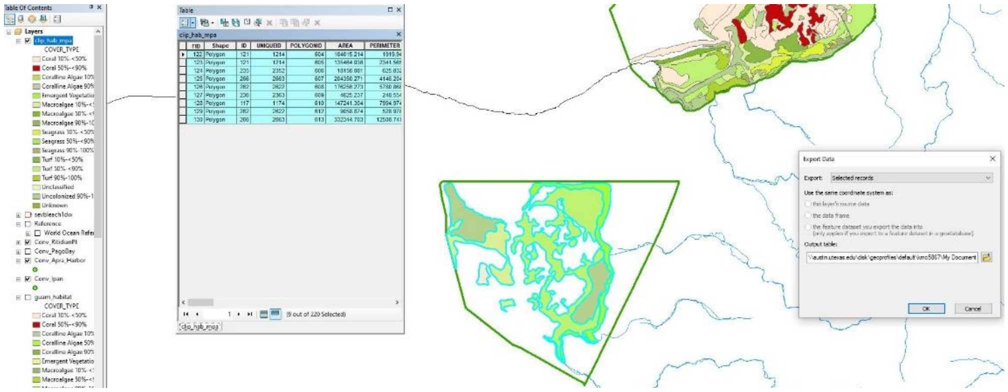

Figure 12: VAT of selected benthic habitat data and "Export Data" window from the Sasa Bay Marine Preserve [as an example].

Step 7: The same procedure for Step 6b was repeated for the non MPA areas by selecting benthic habitat inside the blue polygons that were constructed in Step 6a. My input was the benthic habitat data / clip feature was the non MPAs layer/ output named clip_hab_nonmpa.

Step 8a: At this point, the benthic data had been successfully clipped to the MPA and non MPA areas. The next objective was to analyze the severity of bleaching in these specific areas. In order to do this, I used "Extract by Mask" again for the percent bleached raster I made in Steps 3-5 but based in MPAs vs non-protected areas as seen in Figure 13.

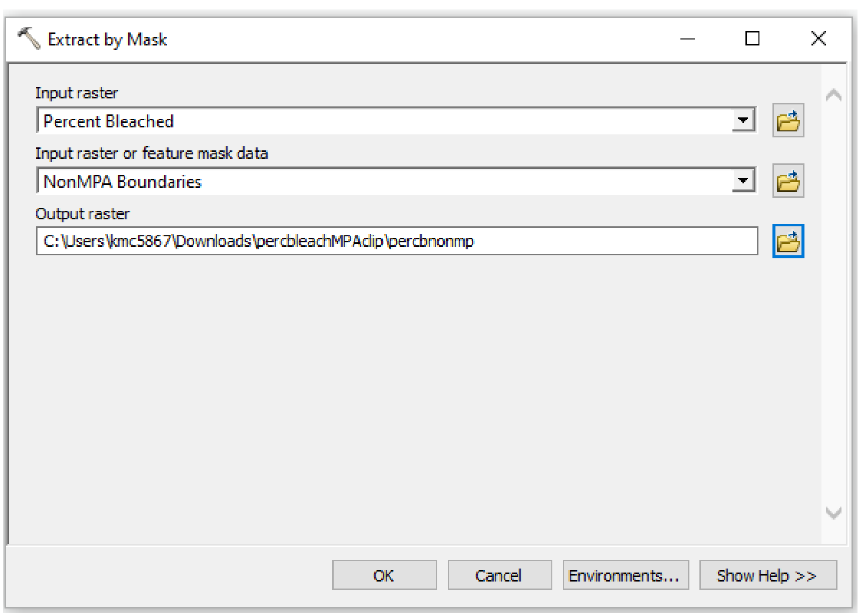

Figure 13: Extract by Mask for percent bleached for non MPA areas.

Step 8b: In order to get the mean percent bleached within MPAs, Layer Properties > Source > Statistics > Mean (Figure 14).

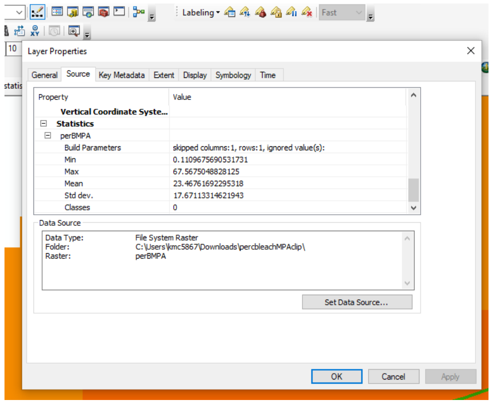

Figure 14: Window showing statistics for the extracted by mask raster of bleaching severity to the MPAs (in order to find the average/max/min percent of bleaching).

Step 8c: The step above (8b) was repeated with non MPAs for comparative analysis.

Step 9: For further analysis, the next goal was to see if there was a difference in the benthic habitat between the Eastern and Western Coasts. By using the polygons (MPA and non MPA) on both coastlines, I selected the benthic data on both sides – Eastern selection is seen in Figure 15. Then I exported the data as done in Step 6b. Step 8 was repeated for Eastern and Western sites to also get the Minimum, Maximum, and Mean percent bleached based on areas on either coast.

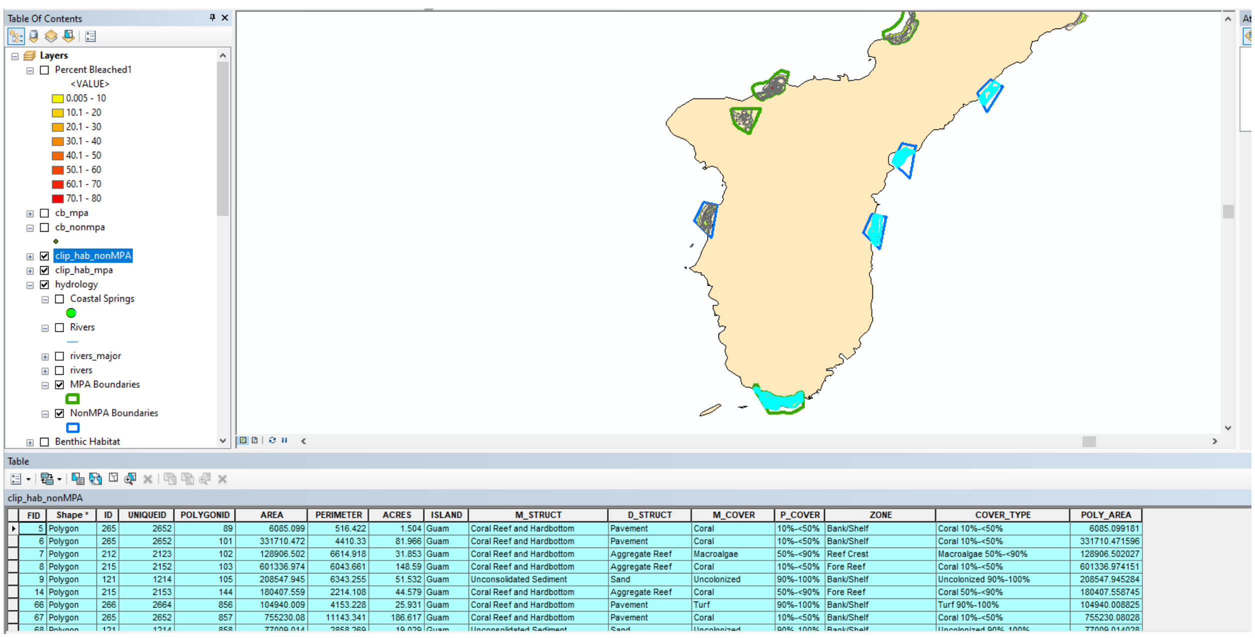

Figure 15: Benthic data extracted by mask for non MPA and MPA areas can be seen on the map and the table shows all Eastern sites selected (highlighted in blue on map and VAT).

Step 10: Focus Locations – for optimal visualization in Layout View.
Due to the fact I have multiple areas of interest around the island of Guam, I wanted to show the details of each location while displaying the general location on the island. To do that I first

created another Data Frame and then connected the two data frames. I connected them and added an extent indicator as seen in the window in Figure 16 below.

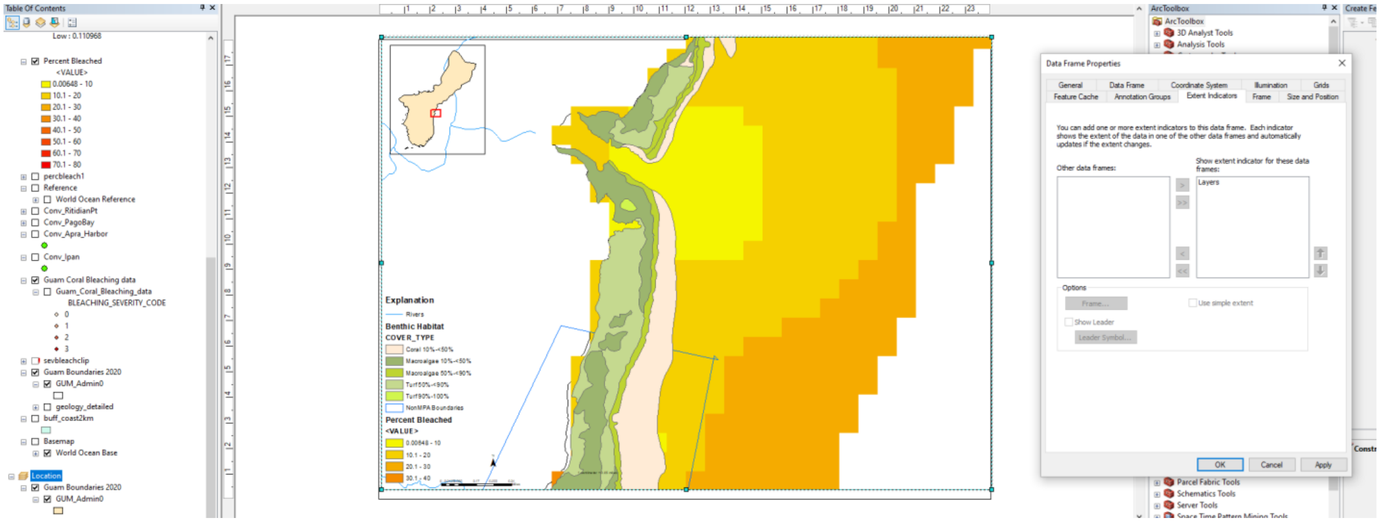

Figure 16: Data Frame Properties window to show extent indicator for the connected data frame. As seen on map in Layout View, the upper left corner shows the location of this area on the island.

IV. DATA PRESENTATION

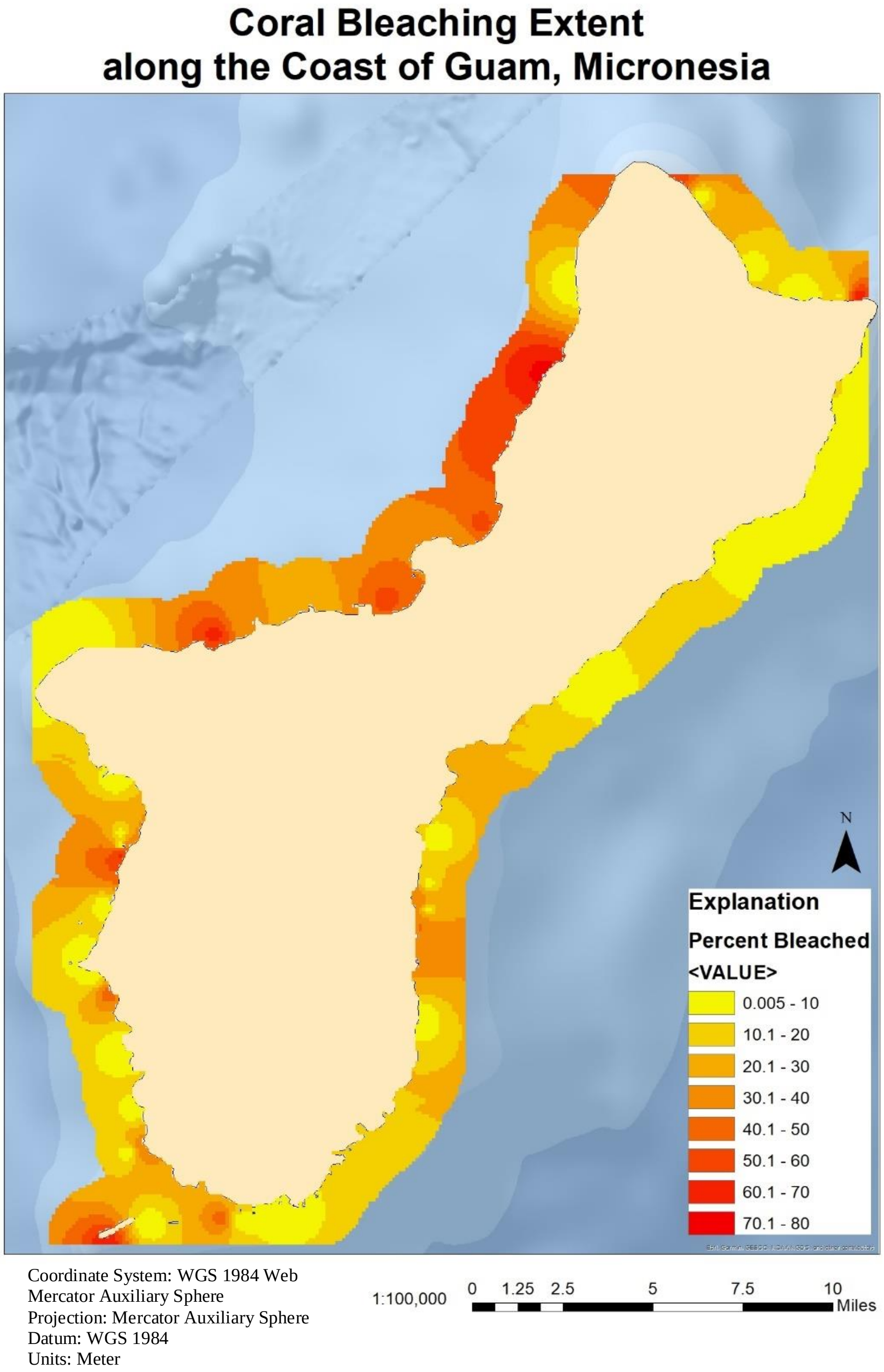

Figure 17: Map of Coral Bleaching along the entire coast of Guam

Table 1: Minimum, Maximum, and Mean percent coral bleached within Marine Protected areas and Non-protected areas

	MPA	Non MPA
Min Percent Bleached	0.11	0.93
Mean Percent Bleached	23.47	22.3
Max Percent Bleached	67.57	61.15

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Table 2: Minimum, Maximum, and Mean percent coral bleached for Eastern and Western Coast.

	East	West
Min Percent Bleached	0	0
Mean Percent Bleached	27.82	38.22
Max Percent Bleached	76.15	92.74

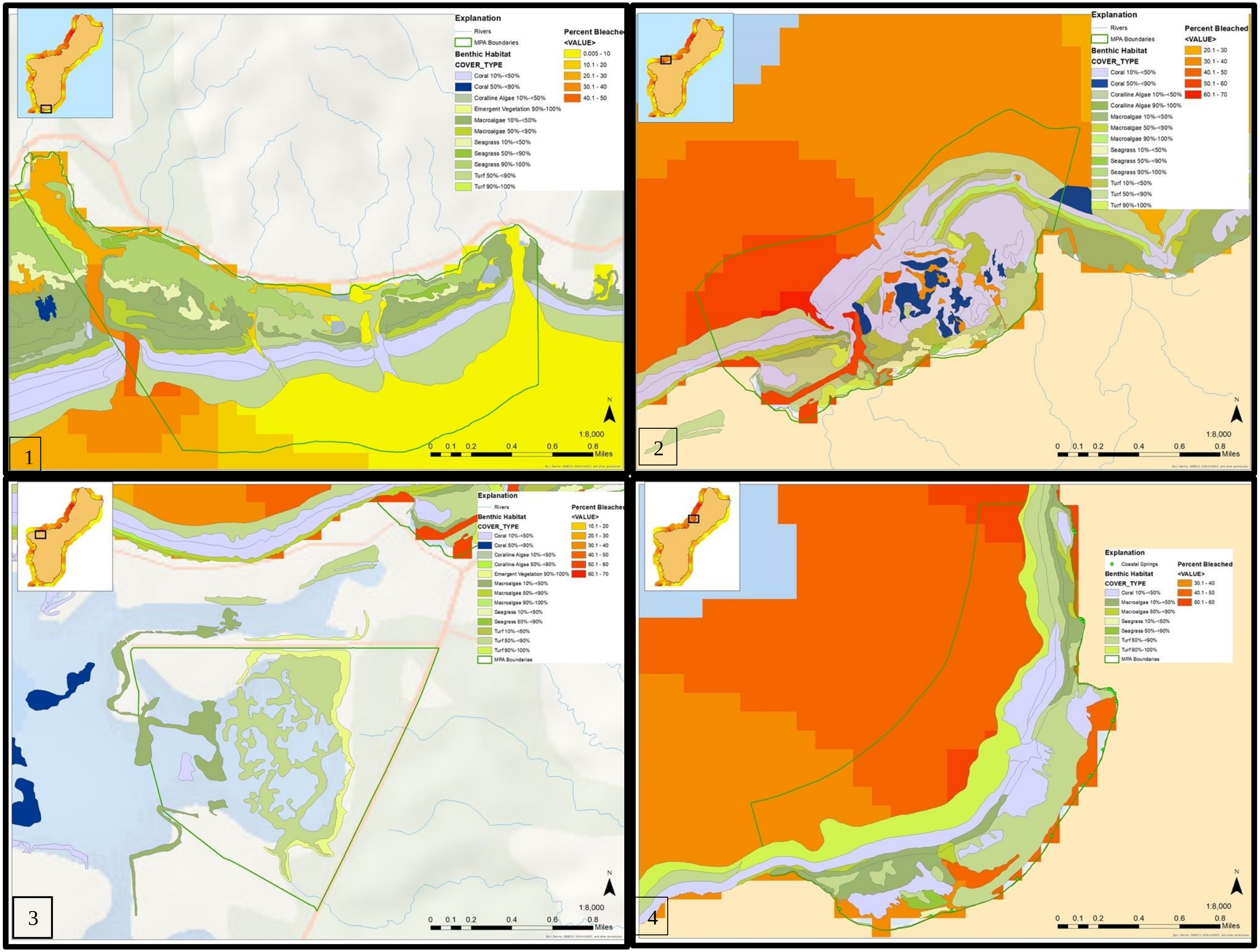

Figure 18: Benthic Habitat and Coral Bleaching Severity within MPAs (1) Achang Reef Flat Marine Preserve (2) Piti Bomb Holes Marine Preserve (3) Sasa Bay Marine Preserve (4) Tumon Bay Marine Preserve. Hydrology is included.

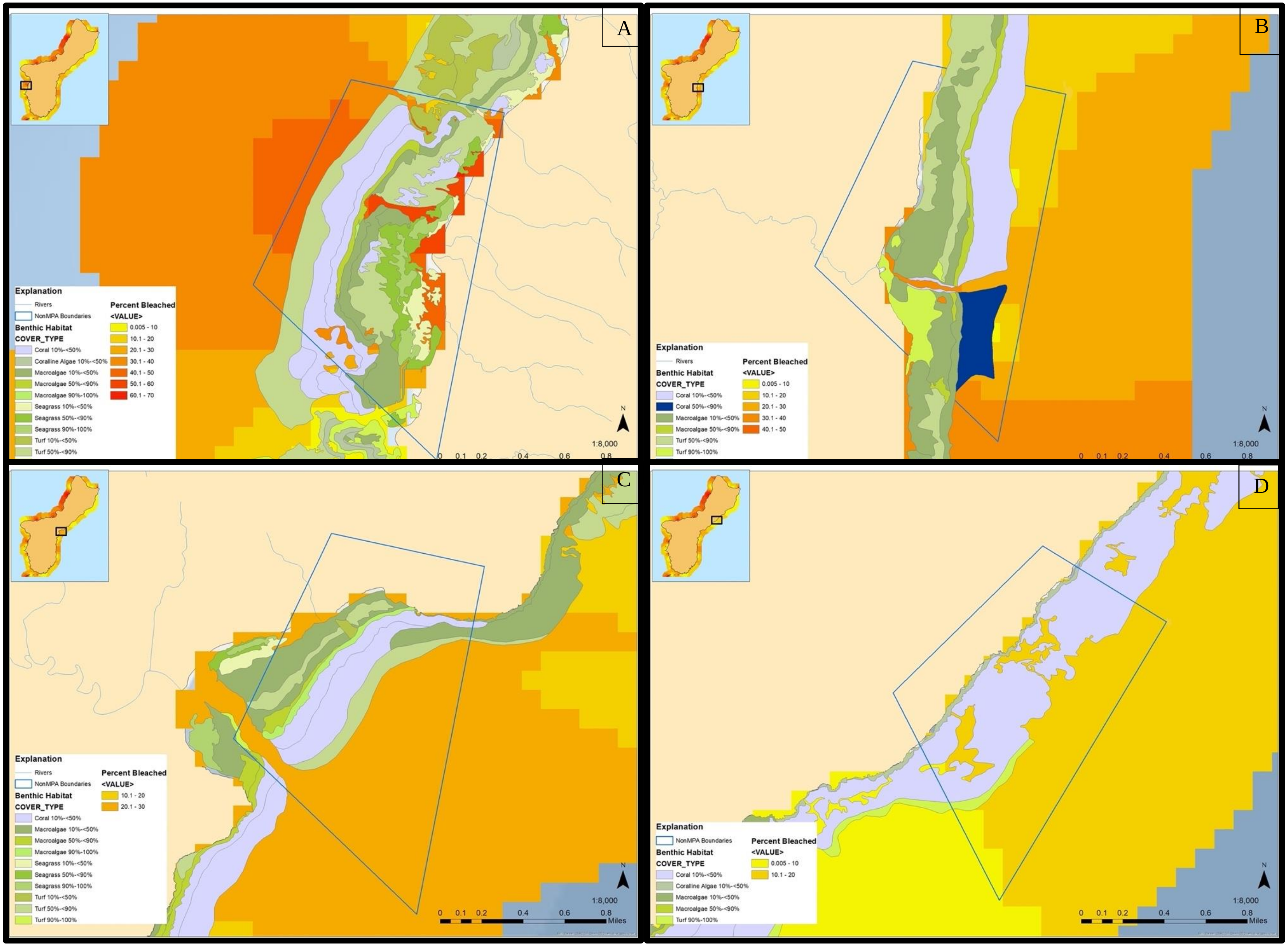

Figure 19: Benthic Habitat and Coral Bleaching Severity at non-protected areas (A-D). Hydrology is included.

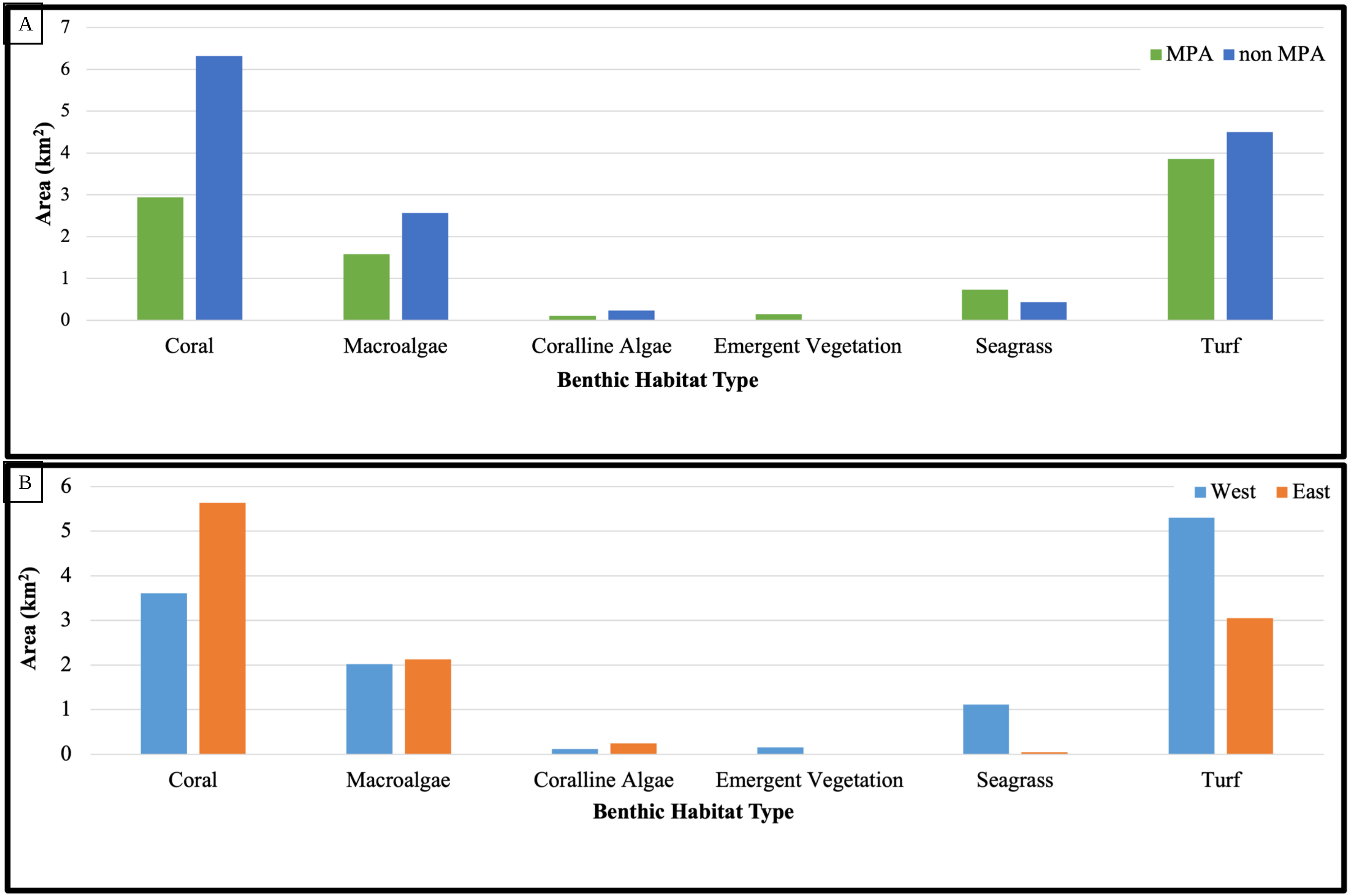

Figure 20. Benthic habitat type, a) Area (km2) of shallow benthic habitat in MPAs & non- protected areas, b) Area (km2) of shallow benthic habitat on the Eastern & Western coasts.

V. CONCLUSION

Maps displaying benthic habitat type and bleaching severity show that, overall, non-protected areas had less severe bleaching (Figure 19) in comparison to areas within MPAs (Figure 18). Maximum percent bleached corals within MPAs was 67.57% while the maximum percent bleached in non-protected area was 61.15 % (Table 1). I also found the mean percent bleached higher in MPAs than non-protected areas (23.47 and 22.3 respectively; Table 1). The non-protected areas that had less severe bleaching were C and D (Figure 19) and had relatively high coral overall cover which is positive in regards to coral reef health in those areas (Figure 19; Figure 20a). In regards to bleaching and presence of algae, the areas of highest concern area were non-protected area A, Achang Reef Flat Marine Preserve and Tumon Bay Marine Preserve (Figure 18; Figure 19). For this study, although it is unfortunate that there was severe bleaching along the island, the fact that reefs within MPAs had the most severe bleaching overall does have a silver lining. By reducing fishing pressure, there is an increase in the number of seaweed-eating fish, and they decrease the cover of harmful algae and seaweed, which makes it easier for larval corals to settle and thrive on the reef. Stresses on reef corals from climate and atmospheric changes are serious and beyond direct management control. However, local management measures can bolster the recovery of corals after damaging events and, eventually, improve their overall condition. A recent 2018 study in the Caribbean found that local fisheries management resulted in a 62% increase in juvenile coral density, improving the ecosystem's recovery potential from major disturbances (Steneck et al. 2018). In order to solidify this in Guam, there should be more detailed surveys including juvenile coral densities and larval settlement. This study can be used as a baseline to assess if the Marine Protected Areas in Guam are an effective means to promote local health and improve the ecosystem's ability to recover from major impacts including coral bleaching.

In regards to the Eastern and Western coast comparison, maximum percent bleached on the Western coast of Guam was 92.74% while the maximum percent bleached on the Eastern coast was 76.15 % (Table 2). An important thing to note is for the one non-protected area that had severe bleaching was located on the western side. A major question that was proposed during analysis is: Was there more intense bleaching on the western coast due to the bleaching event or due to the fact there is more coral there? As seen in Figure 20b, there is actually more coral on the Eastern coast where there was less severe bleaching. Thus, this study's results showing high bleaching severity is not due to the high presence of coral. Overall the reef health on the Eastern coast is higher than the Western Coast since there is more coral cover and there is less bleaching severity overall on the Eastern coast versus the Western coast (Figure 17). Overall, this study's findings suggest that Guam needs more MPAs on Eastern coast to maintain the Eastern reefs' health. Although Achang Reef Flat Marine Preserve and Pati Point Marine Preserve are large in comparison to the other three MPAs, more MPAs around the same latitude on the opposite coast of Guam would be beneficial for juvenile coral growth and larval settlement to extend further along the coast.

In regards to freshwater rivers, streams, and creeks, they were present near area of high and low bleaching thus no general significant relationship can be made from this study. However, with relating hydrology to bleaching, there is a big role that poor water quality plays in lowering the thermal tolerance (i.e. bleaching 'resistance') of symbiotic reef corals (Wooldridge 2009). This coastal discharge areas such as the area near Tumon Bay Marine Preserve (Figure 18) should be closely regulated and observed.

There were limitations within this study which can be eliminated with several modifications in the future. This study could be greatly improved with data from additional sampling sites that match previously sampled sites to allow for better spatial and temporal comparisons. In addition, further analysis on percent mortality would be beneficial. This project intended to use mortality data but there were many gaps in the dataset. Future surveys should include accurate measures of percent mortality due to the varying resilience of corals from bleaching. Also, documenting bleaching with specific coral growth forms would be extremely valuable since certain types, such as branching type corals (Acroporids) may be less resilient to environmental stressors. Other environmental stressors for future studies should include water quality, physical impacts from hurricanes, and outbreaks of *Acanthaster planci*, a corallivorous starfish. Additionally, measuring bleaching severity coupled with protected areas with varying fishing restrictions as well as herbivorous fish surveys would be worthwhile. Observing these same areas after bleaching events in the future to measure their potential recovery is imperative.

In regards to my proposed research, I will be studying structural complexity and cryptobenthic fish and now that I know where there are areas of high bleaching, I can choose my study sites and examine reef functioning in those areas specifically. Understanding and monitoring the structure and functioning of reefs is critical for the conservation of their services. Spatial analyses like this project help increase effectiveness in the development of strategies for marine ecosystem conservation including local fisheries management. Therefore, I hope that this research can be applied to future studies and conservation efforts in the Guam and elsewhere moving forward.

References:

Brown BE (1997) Coral bleaching: causes and consequences. Coral reefs 16(1):S129-138

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N (2007) Coral reefs under rapid climate change and ocean acidification. Science 1737-42

Kuffner IB, Walters LJ, Becerro MA, Paul VJ, Ritson-Williams R, Beach KS (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Marine Ecology Progress Series 323:107-17

Raymundo LJ, Burdick D, Hoot WC, Miller RM, Brown V, Reynolds T, Gault J, Idechong J, Fifer J, Williams A (2019) Successive bleaching events cause mass coral mortality in Guam, Micronesia. Coral Reefs 38(4):677-700

Steneck RS, Mumby PJ, MacDonald C, Rasher DB, Stoyle G (2018) Attenuating effects of ecosystem management on coral reefs. Science Advances 4(5): DOI: 10.1126/sciadv.aao5493

West JM, Salm RV (2003) Resistance and resilience to coral bleaching: implications for coral reef conservation and management. Conserv Biol 17(4):956-67

Wooldridge SA (2009) Water quality and coral bleaching thresholds: Formalizing the linkage for the inshore reefs of the Great Barrier Reef, Australia. Marine Pollution Bulletin. 58(5):745-51

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