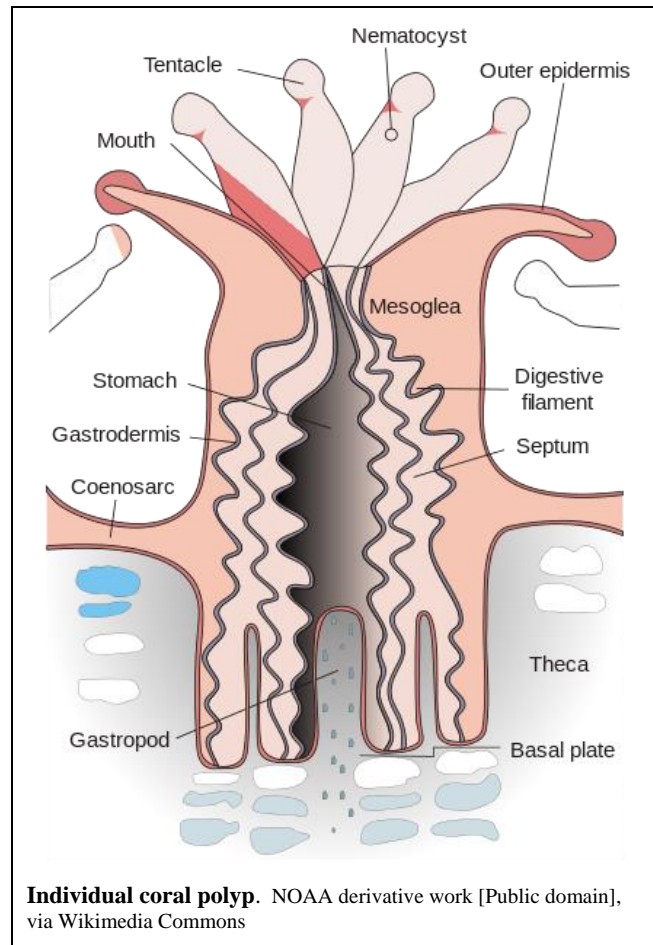## Corals and Their Zooxanthellae

Corals are invertebrates in the phylum Cnidaria. Corals reefs are made up of individual corals -- called polyps – that are very small animals resembling tiny sea anemones. The living part of a coral reef is actually a colony of identical, individual reef-building coral polyps, connected to each other laterally to form a community. The lateral connections between polyps (the coenosarc in the diagram at right), makes up most of the tissue that covers the stony, calcium carbonate-containing foundation of the reef. Therefore, the coral colony is analogous to a thin layer of skin that overlies a calcium skeleton that is secreted by the corals themselves.

Corals feed on plankton that they capture with their tentacles, but this does not provide all of their nutrition. Unlike most animals, corals also contain microscopic algae, called zooxanthellae, within their tissues. The relationship between the coral polyps and the zooxanthellae is a **mutualistic symbiosis**, which means that each organism benefits. As with all other algae, the zooxanthellae are photosynthetic, and each coral polyp is a host that gives its zooxanthellae

Individual coral polyp. NOAA derivative work [Public domain], via Wikimedia Commons

a safe habitat, including providing CO_2 and access to sunlight. In exchange, the zooxanthellae provide the host coral with sugars and other nutrients derived through photosynthesis. Corals can only survive for a short time without zooxanthellae, but it appears that at least some of the zooxanthellae species can survive and reproduce outside the polyps.

Coral Bleaching

Certain stressful conditions can cause the coral polyps to lose their zooxanthellae. Because the photosynthetic pigments of zooxanthellae give corals their characteristic brownish color, when many or all polyps in a coral reef lose their zooxanthellae, the corals lose their color. At that point you can see through the thin layer of coral to the white calcium carbonate skeleton underneath. This is known as coral bleaching. Coral polyps can sometimes reacquire zooxanthellae, but it is not uncommon for the polyps to remain bleached until they die.

This incidence of coral bleaching has been increasing in recent years, and it may soon become so severe that it threatens the survival of entire coral species and the ocean ecosystems that depend on them. Coral bleaching is associated with a number of environmental factors, such as high and low temperatures, high solar irradiation, low salinity, high levels of sediment in the water, pollutants and herbicides, and possibly even tiny concentrations sunblock lotion. The most well-studied of these effects

on corals is high temperature, in part because global climate change is associated with a gradual increase in sea surface temperatures, including in coral reef habitats.

When Does Coral Bleaching Occur?

As noted above, exposure to high temperature makes corals vulnerable to bleaching, presumably because the high temperature causes "heat stress" in the coral. Therefore, one method to determine whether a specific coral is at risk of bleaching is to identify when the **sea surface temperature** (SST) at the coral's location gets so high that it puts the coral into heat stress.

Continuously monitoring the SST at all coral reef sites around the world would be very challenging. Fortunately, the National Oceanographic and Atmospheric Agency (NOAA) operates satellites that view most of the Earth's surface every day. These satellites have infrared radiation sensors that can measure the SST. These data are continuously transmitted back to NOAA, which combines the satellite data with data from monitoring stations and makes it all available in real-time on a publically-accessible website called the Coral Reef Watch: http://coralreefwatch.noaa.gov/satellite/vs/. This information is intended to be used by scientists and resource managers who want to learn to predict when corals in a particular region are at risk of bleaching.

In the following activity you will examine the available SST data since January 1, 2000 to look for trends that can predict coral bleaching events.

PROCEDURE

You will be assigned to examine one of four coral reef regions:
- Bermuda
- U.S. Virgin Islands
- Puerto Rico
- Bahamas

1) Go to NOAA's database for the Coral Reef Watch: http://coralreefwatch.noaa.gov/satellite/vs/
2) Find the dropdown menu labeled "Choose a region to zoom in:" (below the map) and select the "Caribbean" option.
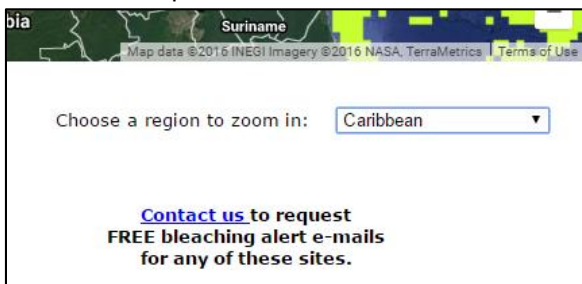

3) Acquire the Data
   a. Use the zoom and pan tools (or drag with your mouse) to find your location
   b. Click on the map pin icon to open the dialog box for that location. Note that you can open boxes for multiple locations.
   c. Click on Time Series Graphs and Data
   d. Find your location and click on the pin icon to bring up the current data box.

    e.   Right-click on "time series data", select "Save Link As...", and save the file to your desktop (or any preferred folder). This will save the time-series data as a text file.

4) Import your data to Excel:

    a.   Start Excel

    b.   Browse for the file to open. Note that you must browse for all files, not just Excel files (since your data is currently a text file)
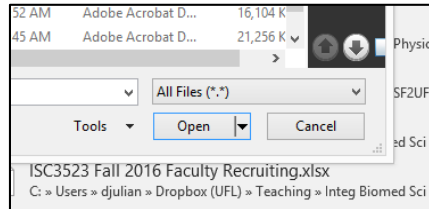

    c.   Open the desired data file.

    d.   You should see the Text Import Wizard (if you don't, notify your instructor). This allows you to import the into columns in a spreadsheet. Note that the data in each row of the text file are separated (delimited) by spaces. Excel should recognize this and default to an appropriate data importing strategy, but just to be sure you can tell Excel to use the spaces to "parse" the data into columns. (Other types of common text files separate the data by commas or tabs). To do this, select "Delimited" on the Import Wizard, then select Next. In the second window of the Text Import Wizard select Space as the delimiter and look at the preview window to make sure the columns are being separated correctly. Note that this will also separate the reef name into separate columns, but you don't need to worry about that for this table. If the columns otherwise look good, click "Finish".
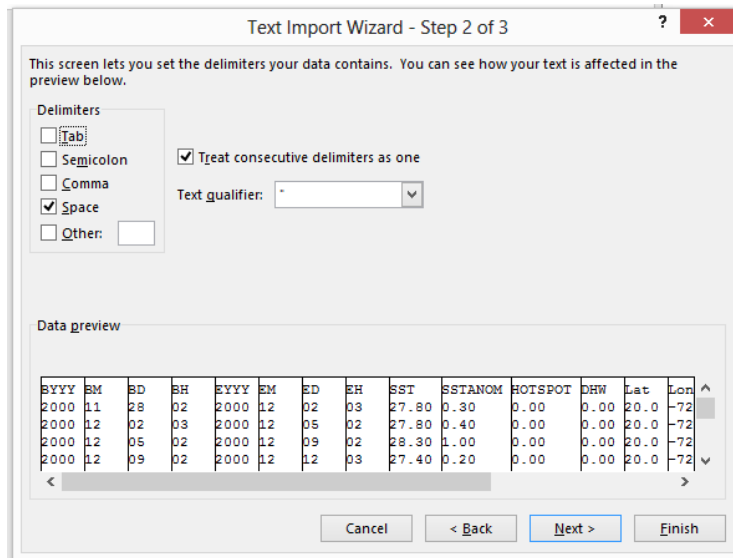
5) Save the resulting file as an Excel Workbook (xls or xlsx).

6) Open the View menu, click on Freeze Panes and then Freeze Top Row. This will keep the column headings visible as you scroll down through the spreadsheet.
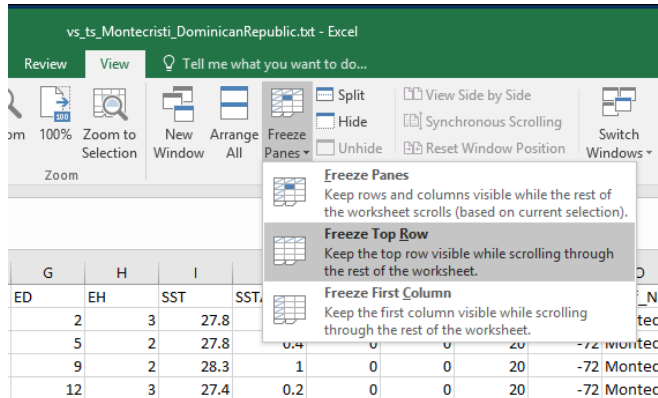
7) The time series data are extracted in four-day composites from the monitoring stations. The beginning and end times for each measurement are represented in the first eight columns:
   - BYYY, BM, BD, BH = year, month, day, and hour of the beginning time point
   - EYYY, EM, ED, EH = year, month, day, and hour of the ending time point

8) To plot the data conveniently, you will need to combine the beginning date data into a single column that can be the X-axis.
   a. Insert a new column at column "I" and give it the column title of "B-Date" in cell I1.
   - In cell I2, enter "=Date(A2, B2, C2)", where BYYY is located in cell A2, BM is located in cell B2, and BD is located in cell C2 (remember that starting a cell entry with "=" tells Excel to read it as a formula).
   - Copy the formula down to the last data row.

9) Now examine the next few columns, starting with the SST.
   - SST = Sea surface temperature, represented as composite value that is obtained twice weekly.
   1) SSTANOM = Anomaly (difference) between the SST and the daily climatological SST

10) Plot the data for your site
   a) Select the Date and SST columns and insert a line chart.
   b) Use the formatting options to enhance the ability of the chart to convey the desired information. For example, you may want to alter the Y-axis range.
   c) Examine the resulting chart. What trends are immediately obvious?

Generalizing about the amount of heat stress that corals can withstand is complicated because they are adapted to local environments and are somewhat able to acclimate to changing environments. Therefore, predicting when a coral is at risk of bleaching must take into consideration the normal maximum temperatures historically experienced by that coral population. The benchmark for the normal maximum temperature for a given location is the **maximum monthly mean** (MMM). This the mean SST of the warmest month in that location over previous decades (or for as far back as reliable data are available). The MMM varies with latitude and local conditions. For example, it is 33.5 °C in the Gulf of Oman, 30.3 °C in the Florida Keys, and 27.5 °C in the Galapagos Islands.

The **bleaching threshold temperature** for a coral is considered to be 1 °C above the MMM for that location (i.e., MMM + 1 °C). Locations that have reached this threshold temperature are called Hot Spots.

11) If the coral reef site represented in your table reaches the bleaching threshold temperature during a sampling period, this is represented in column L of your table, which has the heading of HOTSPOT. This value is greater than zero when the conditions are predicted to cause thermal stress. Scroll through the table to examine some events when the site reached the hot spot condition.

The bleaching threshold temperature by itself is not sufficiently accurate for assessing coral risk, because bleaching is due to both how high the temperature reaches and the duration of exposure to the elevated temperature. That is, the risk depends on the accumulation of heat stress over time.

To represent the accumulation of heat stress over time, coral biologists calculate **degree heating weeks** (DHW). This is a cumulative measurement of the intensity and duration of heat stress above the bleaching threshold temperature over a 12-week period (which is roughly equivalent to a season). The units are °C-weeks. For example, 10 DHWs could result from any of the following:

- 1 °C above MMM for 10 weeks
- 2 °C above MMM for 5 weeks
- 0.5 °C above MMM for 20 weeks
- 0.5 °C above MMM for 5 weeks plus 1.5 °C above MMM for 5 weeks

A DHW of 4 °C-weeks or greater typically results in significant bleaching, whereas a DHW of 8 °C-weeks or greater typically results in widespread bleaching and significant coral mortality.

12) DHW is represented in the next column (column M). As noted above, this represents thermal stress accumulated over a 12-week period). Note that The remaining columns do not vary for your table. These are Lat, Lon, and Reef_Name, which represent the latitude and longitude of the center of the pixel with the monitoring station, and the name of the reef represented.
13) To help you do a graphical analysis of the bleaching risk, it would be helpful to add a to indicate the bleaching threshold temperature. Recall that the bleaching threshold temperature is estimated as MMM + 1 °C. When a region reaches this value it is identified as a "hot spot" on the data table. Use the information in your data table to determine the bleaching threshold value for that region.
   a. Enter this bleaching threshold temperature value into a new column and copy it down the entire length of the dataset.
   b. Copy the column and paste it into your existing line chart to add it as a second data series. This will allow you to visualize when the SST exceeded the hot spot threshold temperature in relation to the variation in SST.
14) Are there any years in which the risk was especially high?
15) In a blank cell, calculate the total DHW over the two-year period of 2004-2005.
16) Work with other students in your class to compare the data for the four regions during that period. Based on the data, rank the four regions in terms of bleaching risk during the 2004-2005 period.
17) When you have completed your ranking, notify your instructor, who will provide you with field survey data over the same period in which researchers went to the coral reefs at the four sites to measure the extent of coral bleaching.

[This page should be provided to students after they've made their coral bleaching predictions.]

1) Examine the data below to determine whether your predictions were accurate.
2) The data show that a catastrophic coral bleaching event occurred in some regions in 2005.
3) Now go back to your chart and examine the current and most recent data. Many coral biologists are concerned that some regions are currently at high risk of another widespread bleaching event. Do you see evidence of this in the recent satellite data?
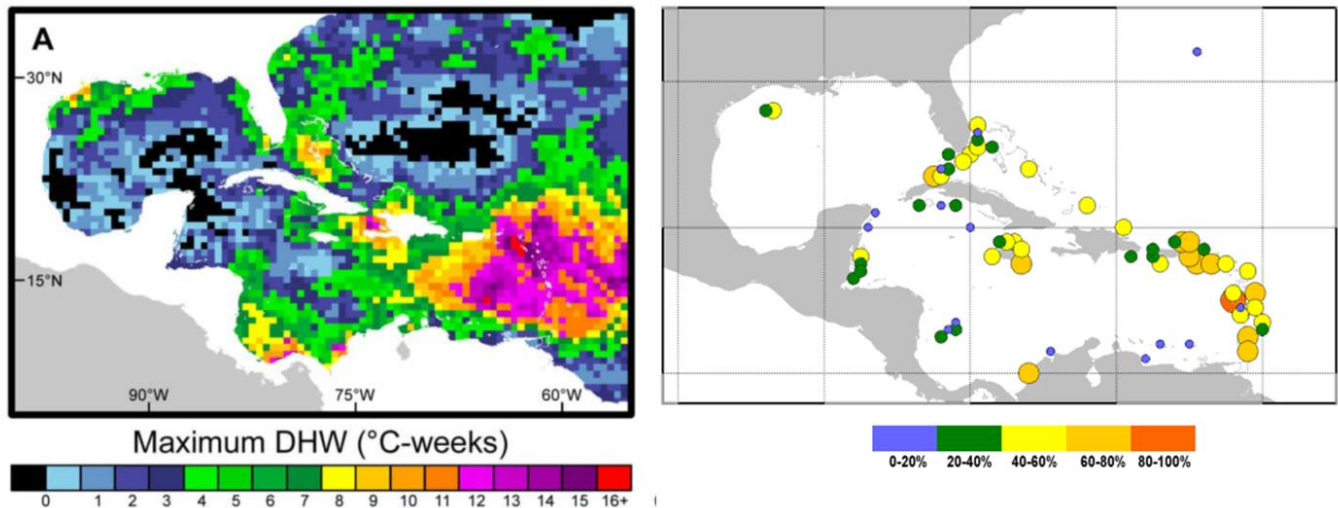
Figure 1. Thermal stress and bleaching during the 2005 Caribbean bleaching event. (A) Maximum NOAA Coral Reef Watch Degree Heating Week (DHW) values showing the highest thermal stress recorded at each 0.5-degree pixel during 2005. Values ≥4°C-weeks typically resulted in significant bleaching; ≥8°C-weeks typically resulted in widespread bleaching and significant mortality. (B) Jurisdictional means of coral bleached; marker color and size denote the severity measured as either percent live coral colonies (circles) or cover (diamonds). doi:10.1371/journal.pone.0013969.g001
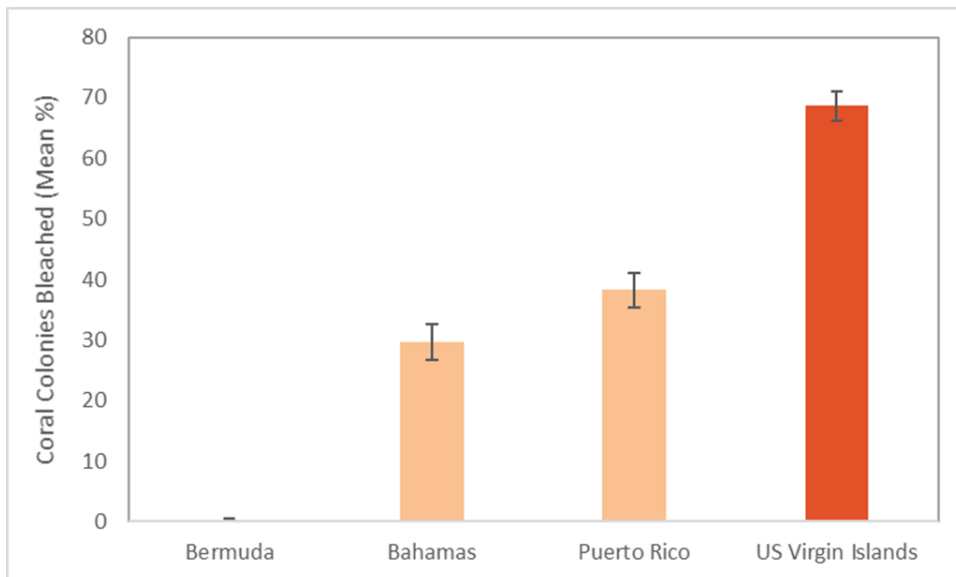
Data from: Eakin et al. (2010). Caribbean Corals in Crisis: Record Thermal Stress, Bleaching and Mortality in 2005. PLoS ONE 5(11), e13969