

How Do Upwelling and El Niño Impact Coral Reef Growth?

STUDENT ACTIVITY SHEET

Pre-Lab Activity

Compare the environmental conditions between the two gulfs in Pacific Panamá and record your observations from the lecture in Table S1. After completing the table, answer the discussion questions below.

TABLE S1. Complete this table describing the two study sites. Use information from the lecture material and/or an online scavenger hunt to compare the gulfs for each environmental parameter.

Condition	Environmental Parameter	Gulf of Chiriquí	Gulf of Panamá
Normal	Upwelling		
	Temperature		
	Nutrients		
	Turbidity		
	Tidal range		
El Niño	Upwelling		
	Temperature		
	Nutrients		
	Turbidity		
	Tidal range		

PRE-LAB DISCUSSION QUESTIONS

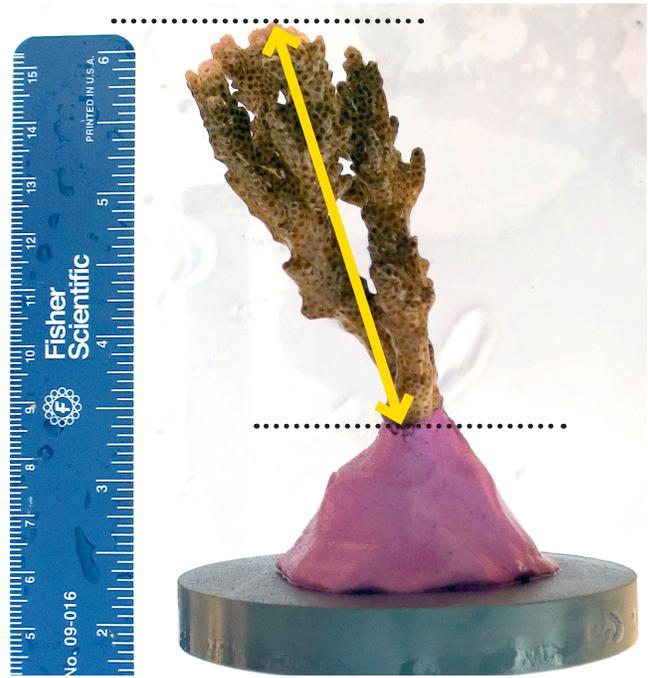
1. What are some similarities and differences in the environmental conditions between the two gulfs?

2. What environmental changes occur in each gulf during an El Niño event?

Activity 1. Determining Coral Growth in Upwelling and Non-Upwelling Environments

During this activity, pairs of students will measure the lengths of five independent experimental colonies of the cauliflower coral, *Pocillopora damicornis* (Handouts S1 and S2). The paired images were taken one-year apart, in 2016 and 2017, during a non-El Niño period. The difference in the lengths of the coral colonies between these two time points will provide students with an annual linear extension rate.

1. Measure each coral from the point of attachment at the base (lower dashed line in the figure to the right) to the furthest branch tip (upper dashed line in the figure) using string, a ruler, or calipers. Do not include the epoxy base (purple in the figure) in the measurement. The furthest branch for each coral may not be perpendicular to the base.
2. Measure the initial length of each of the corals (2016) and record your data in Table S2 on the next page. Then, measure the final lengths of the same corals (2017) and record your data. The photographs are labeled to identify the individual corals.
3. After measuring each coral, calculate total linear extension over a one-year period by subtracting the initial length from the final length.
4. Calculate the average yearly growth rate for all corals (cm yr^{-1}) from each gulf. Also calculate the standard deviation and standard error.
5. Create a bar graph with standard error bars to compare the average annual growth rate for each gulf.



An example of an individual coral colony. Linear measurements should be taken from the base to the furthest tip. The ruler is to provide scale.

DATA SHEET FOR ACTIVITY 1

TABLE S2. Data sheet for linear-extension measurements on corals in each gulf in 2016 and in 2017.

Replicate	Gulf	Coral ID	2016 Height (cm)	2017 Height (cm)	Change in Height from 2016 to 2017 (cm)	Mean Annual Growth Rate (cm yr ⁻¹)	Standard Deviation	Standard Error
1	Panamá	1L						
2	Panamá	4L						
3	Panamá	6L						
4	Panamá	10D						
5	Panamá	26L						
Summary Statistics:								
1	Chiriquí	36D						
2	Chiriquí	37L						
3	Chiriquí	38D						
4	Chiriquí	43D						
5	Chiriquí	44L						
Summary Statistics:								

Notes:

DISCUSSION QUESTIONS FOR ACTIVITY 1

1. What differences did you observe in the average linear extension between the two gulfs?
2. Did one gulf have more variable coral growth than the other?
3. What might be some reasons for the differences in linear extension? What evidence from the pre-lab activity supports your hypothesis?
4. How do you think sea surface temperature impacts coral linear extension?
5. Hypothesize how other factors like increased turbidity might impact coral linear extension. Explain.

Activity 2. Determining Percent Coral Cover in Each Gulf

1. Familiarize yourselves with the benthic-cover key ([Handout S3](#)) and the practice quadrat ([Table S3](#)), which classify the different types of seafloor components you may encounter, including the identification of live coral (which can have white tips) and coral overgrown with algae.
2. Each reef image is gridded to randomize the areas that each student pair will quantify. Use dry erase pens and number the grids on each image 1–36 ([Handout S4](#)).
3. Number pieces of paper 1–36 and place them in the envelope. Use the numbered papers to randomly select fifteen grid cells per image (see example on page 6). Estimate and record the percent coral cover that makes up each randomly selected grid cell in [Table S4](#) on page 7.

4. After estimating the total percent coral cover for all 15 selected grid cells, convert your measurements into percentages of coral cover for each image. For example, if image 1 resulted in 4 grid cells with 100% live coral, 1 grid cell with 50% live coral, and 10 grids with 0% live coral, then you would calculate and record coral cover as:

$$\frac{4.5}{15} \times 100 = 30\% \text{ coral cover,}$$

Repeat this procedure for each gulf. If time is limited, the instructor can use her/his discretion to reduce the number of randomly selected grid cells per image.

5. Upon completing your analyses, calculate the average percent coral cover in each gulf during each time period by averaging the measurements from the three images per gulf. Also, calculate the standard deviation and standard error for each gulf.
6. Create a bar graph of the average percent coral cover with standard error bars to compare the two gulfs. Data [Table S5](#) is provided on page 7.

EXAMPLE QUADRAT FOR ACTIVITY 2

Example of a quadrat that students can use for practice prior to the start of Activity 2. Examples of the specific substrate types are listed in Table S3. Students can use this quadrat as a model for distinguishing coral from other substrates they might encounter during Activity 2. Grids are numbered sequentially left to right. Note that the image mosaic of the quadrat didn't properly align with the PVC pipe. Students should be encouraged to comment on any error that might introduce.

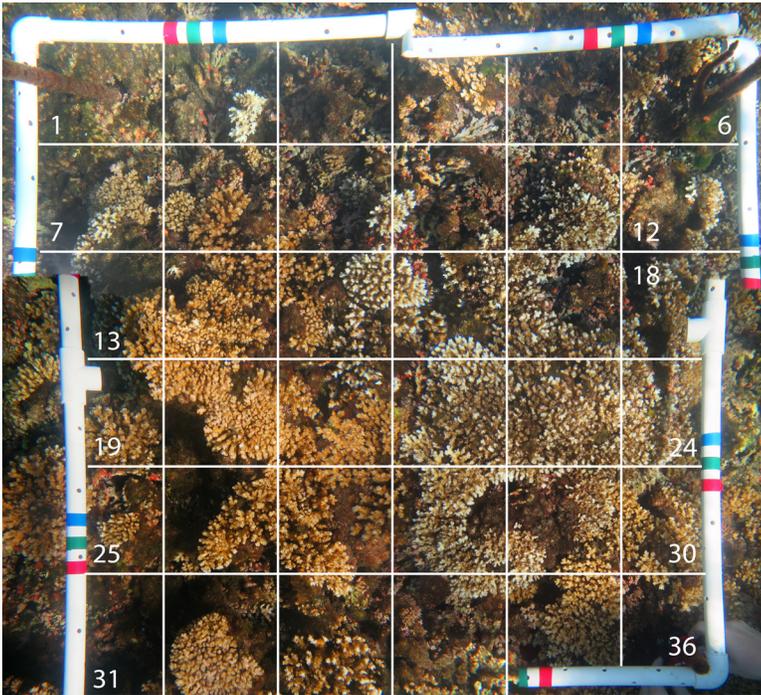


FIGURE S3. Example of a quadrat.

TABLE S3. A grid-specific benthic classifications guide.

Grid #	Estimated Composition
7	60% dead coral, 40% live coral
10	95% algae growing on dead coral, 5% live coral
14	95% live coral, 5% algae growing on dead coral
15	90% live coral, 10% algae growing on dead coral
20	75% live coral, 25% algae growing on dead coral
23	100% live coral
29	60% live coral, 40% algae growing on dead coral

DISCUSSION QUESTIONS FOR ACTIVITY 2

1. What differences did you observe in the average percent coral cover between the two gulfs? Did both gulfs show the same level of variability among quadrats?
2. What might be some reasons for the difference in percent cover in each gulf? What evidence from the pre-lab activity supports your hypotheses?
3. What are some sources of error and variability in the data that might have caused differences in the measurements among student pairs? How might those differences have been caused?
4. How could you minimize those errors if you were conducting the study for real?
5. If Panamanian reefs are hit by a strong El Niño in the future, how would you expect coral cover to change in each gulf? Discuss what this may mean for the future of coral reefs.

Activity 3. Estimating a Carbonate Budget for Panamanian Reefs

Estimating carbonate budgets for coral reefs gives researchers a measure of the potential for long-term reef growth and identifies where a particular reef falls on the spectrum from net accretion to net erosion. The carbonate production of a reef can be estimated using percent coral cover and linear growth rates (in cm yr^{-1}) of corals on a reef. Perry et al. (2012) developed an equation that students can use in simplified form to estimate yearly production (in $\text{kg m}^{-2} \text{yr}^{-1}$) of calcium carbonate, or CaCO_3 , for each reef explored in this lesson. The formula below has been modified to assume that rugosity, a measure of the topographical complexity of the reef, is similar between the two reefs. Total carbonate production (TCP) can be estimated as:

$$TCP_{year} = \left[\frac{x}{100} \times [(D \times G \times 10,000) \div 1,000] \right],$$

where x is the average percent coral cover estimated from the images (Activity 2), D is a skeletal density constant, assumed to be $2.0 \text{ g CaCO}_3 \text{ cm}^{-3}$ for both reefs (from Manzello, 2010), and G is the annual linear growth rate (in cm yr^{-1}) of *Pocillopora damicornis* (Activity 1). In this activity, the students should:

1. Calculate the total annual CaCO_3 production (TCP) for both gulfs.
2. Subtract an assumed rate of bioerosion (B) for each gulf to calculate the “net” carbonate production (NCP):

$$NCP_{year} = TCP_{year} - B.$$

Manzello et al. (2008) estimated the rate of bioerosion (B) as $26.1 \text{ kg CaCO}_3 \text{ m}^{-2} \text{yr}^{-1}$ for the Gulf of Panamá and $13.6 \text{ kg CaCO}_3 \text{ m}^{-2} \text{yr}^{-1}$ for the Gulf of Chiriquí. A positive value for net carbonate production indicates net accretion, whereas negative values indicate net erosion. Students should record the values for NCP in [Table S6](#) on the next page.

ADDITIONAL ANALYSES

1. Assume a 10% decline in coral growth and/or coral cover in only the Gulf of Chiriquí to see how bleaching during an El Niño event might influence carbonate production and reef accretion. Calculate the percent difference from the average annual accretion rate and record your data in [Table S6](#). Note that this lesson does not account for horizontal, or “lateral” coral growth, which is also an important component of reef accretion.
2. Attempt a sensitivity analysis by comparing how a decline of 20% or 30% in coral growth or percent cover and/or a 10%, 20%, or 30% increase in bioerosion in the Gulf of Chiriquí might affect the reef’s overall carbonate production. Note that the calculations for varying levels of bioerosion do not include physical processes, such as wave energy, that contribute to reef erosion. Calculate the percent difference from the original annual accretion rate that you calculated for the Gulf of Chiriquí and record your data in [Table S6](#).

DATA SHEET FOR ACTIVITY 3

TABLE S6. Data table to record the average net carbonate production in each gulf. The data table can be used for the additional analyses below. The sensitivity analyses should use the present-day rate of net carbonate production for the Gulf of Chiriquí.

	Net Carbonate Production (kg CaCO ₃ m ⁻² yr ⁻¹)	Percent Decrease in Net Carbonate Production
Gulf of Panamá (present day)		N/A
Gulf of Chiriquí (present day)		N/A
10% decrease in coral cover in Chiriquí		
20% decrease in coral cover in Chiriquí		
30% decrease in coral cover in Chiriquí		
10% decrease in linear growth in Chiriquí		
20% decrease in linear growth in Chiriquí		
30% decrease in linear growth in Chiriquí		
10% decrease in both coral cover and linear growth in Chiriquí		
10% increase in bioerosion in Chiriquí		
20% increase in bioerosion in Chiriquí		
30% increase in bioerosion in Chiriquí		

DISCUSSION QUESTIONS FOR ACTIVITY 3

1. What is the percent change in net carbonate production in the Gulf of Chiriquí due to a 10% change in coral cover? A 10% change in coral growth? Both?
2. Which factor, linear growth or percent cover, has a greater impact on net carbonate production in the Gulf of Chiriquí? Explain.
3. How might more intense and frequent El Niño events impact net carbonate production (and therefore reef accretion) in the Gulf of Chiriquí? Compare your sensitivity analyses to the estimates of net carbonate production for the Gulf of Panamá.
4. How do increases in bioerosion compare with decreases in percent coral cover or linear growth?

Glossary

Glossary of lesson-specific terms. Instructors should share the glossary with students prior to or during the activity.

Term	Description	Sources
Bioerosion	The removal of material by the action of living organisms including those that scrape, bore into, consume, or chemically degrade the coral skeleton.	Glynn, 1997 https://coralreefwatch.noaa.gov/satellite/oa/description/oaps_intro_oa_and_reef.php http://www.aoml.noaa.gov/keynotes/keynotes_0716_coral%20oa_bioerosion.html
Calcification	The process of deposition of calcium carbonate (CaCO ₃).	Cohen and Holcomb, 2009 http://www.aroundtheamericas.org/log/wp-content/uploads/2010/02/Teachers_GuideLess-1-CoralCO2Calcification.pdf
El Niño–Southern Oscillation (ENSO)	A naturally occurring cycle that is caused by the shifts in trade wind circulation and results in the warming of the sea in the central and eastern Pacific Ocean.	Garrison, 2013 https://www.esrl.noaa.gov/psd/enso/education/
Linear Growth/ Extension	Measurement of the change in a coral's height along its longest axis.	
Ocean Acidification	Surface waters absorb excess atmospheric CO ₂ , resulting in decreased oceanic pH via a series of chemical reactions.	Cohen and Holcomb, 2009 https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F
Percent Live Coral Cover	The percentage of the reef surface covered by living coral.	
Vertical Reef Accretion	A measure of the net upward growth of the reef over time that incorporates both calcification and erosion.	https://coastal.er.usgs.gov/crest/research-themes/holocene.html