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Looking for a Link: Testing the Relationship between Coral Reef Cover and Proximity to Humans



The purpose of this lesson is to explore the relationship between reef cover and human disturbance. Students will explore, manipulate, and test data on hard coral cover and human populations using a large, global dataset. Students will be given the opportunity to use R, an open-access statistical software, and consider how their analysis can inform worldwide conservation efforts.



Environmental Degradation

Students will explore how global climate change is impacting habitats, and specifically the dangers it poses to coral reefs.
Students will investigate whether local stressors play a significant role in coral reef degradation.



Data Analysis

Using data from a previously published study, students will test whether there is a relationship between hard coral cover and population density. They will explore a large dataset both descriptively and analytically.



Conservation

Putting it all together, students will discuss how the results inform reef conservation efforts around the world and what strategies scientists and policy makers should pursue.

Extra Resource:

Tim Flannery's TED Talk
"Can seaweed help curb
global warming?"

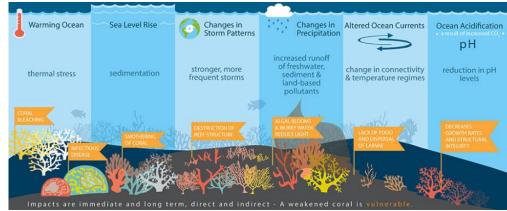
Coral Reefs

Coral reefs have served as litmus tests for the impacts of anthropogenic global warming, and news articles accentuate the consequences of rising ocean temperatures on reefs around the world (Cave, 2020). It is now clear that climate change is altering Earth's oceans, and these changes have robust effects on coral reef ecosystems. As the Earth's temperature rises and heats oceans, reef ecosystems have been harmed at an increasing rate. Mass coral bleaching and infectious disease outbreaks are becoming more common across the Earth's reefs and rising CO₂ levels have reduced calcification rates in reef-building organisms (National Ocean Service).

The infographic below outlines several ways in which climate change is already affecting coral reef ecosystems globally through warming oceans, sea level rise, changes to storm and precipitation patterns, new ocean currents, and ocean acidification.

Extra Resource:

NOAA's "The Coral Reef Economy" – everything you need to know about the coral reef economy in under two minutes.



"How does climate change affect coral reefs?"; Published by the National Ocean Service, 2021.

The dangers posed to coral reefs due to a changing climate can have consequences on global biodiversity and human activity. Healthy coral reefs are home to thousands of unique fish and invertebrate species that do not live anywhere else on Earth. Some ecologists suggest that reefs are home to over 4,000 fish species and 800 hard coral species and that there may be millions of undiscovered types of organisms living in and around reefs worldwide (National Ocean Service).

"Coral reefs are some of the most diverse and valuable ecosystems on Earth. Coral reefs support more species per unit area than any other marine environment."

-National Ocean Service

They protect coastlines from storm surges and erosion and play an important role in buffering shores. Along many coastlines, for instance, coral reefs can absorb as much as 97% of the energy from waves, storms, and floods, and the absence of these natural barriers can leave coastal communities at an increased risk of damage (National Ocean Service). For humans, coral reefs represent important sources of economic activity as a food source and for recreation. They also hold cultural importance to many Indigenous peoples around the world (NOAA). Given the key ecological role that coral reefs play, it is important to develop effective conservation and restoration policies to continue to protect them. In the remainder of this lesson, students will use global reef cover data to identify the links between reef cover—a proxy for overall reef health—and human disturbances. The results of their analysis will inform how students, conservationists, and policy makers approach coral reef protection in the future.

Human Disturbance

Humans place intrinsic value on natural beauty like coral reefs, yet human industry and activity have caused serious harm to these ecosystems around the world. The Great Barrier Reef, located off Australia's coast, for example, is designated as a UNESCO World Heritage site given the biodiversity that it supports and its aesthetic value. The organization states that "the GBR is of superlative natural beauty above and below the water, and provides some of the most spectacular scenery on Earth" (UNESCO, 2020). However, over half of the world's coral reefs have already been lost or severely damaged and some scientists predict that by 2050 all remaining coral reefs will be threatened and three-quarters of them will face critical threats (The World

Extra Resource:

National Geographic video
"Exploring Oceans | Great
Barrier Reef"

Results of overfishing and bleaching on portion of the GBR, considered an "accessible" reef:



Colorful and thriving reef at Palmyra Atoll National Wildlife Refuge, considered a less "accessible" reef and thus less affected by human activity:



"Considering that people are an integral part of the seascape in most reefs globally, we have to change this mentality. We need to better understand the human dimensions of reefs if we are to effectively manage them-this includes understanding people's values, aspirations, and needs and how these include the ways they use and manage reefs." -Dr. Joshua Cinner, James Cook

University

Counts). Ocean scientists attribute anthropogenic threats to coral reefs as the primary driver of this degradation and continued destruction of reefs globally. Pollution, over-fishing, destructive fishing, coral harvesting, coral mining, and warming oceans all damage reefs all over the world every day (National Ocean Service).

The U.S. Environmental Protection Agency considers threats to coral reefs to come from *both* local and global sources. Local or direct threats have the most obvious connection with coral reef degradation and offer clear avenues for policy intervention. Unsustainable fishing, pollution, and habitat destruction can all be mitigated by local policy and enforcement (Coral Reef Alliance). Global threats are more difficult to address directly given Earth's integrated systems and the feedback loops that regulate (or exacerbate) harmful byproducts of these systems. For example, global warming has been recorded to increase ocean temperatures to a depth of at least 700 meters and anthropogenic carbon dioxide has decreased pH levels and disturbed the natural concentration of ions in seawater (Hoegh-Guldberg, Jacob, and Taylor, 2019). Because so many communities rely on ocean habitats for survival, both human and natural, the cascading effects that global warming has on ocean habitats is particularly concerning.

Local Threats Global Threats Physical damage or destruction from Increased ocean temperatures and coastal development, dredging, changing ocean chemistry caused by quarrying, destructive fishing increasing atmospheric practices or boat anchors, and temperatures and more carbon recreational misuse dioxide in seawater Point-source pollution that finds its Warming oceans kill the microscopic way into coastal waters, including algae that produce food that corals sedimentation from coast need, eventually leading to coral development, urban stormwater bleaching runoff, agricultural nutrient runoff, Ocean acidity has increased by about and other toxic substances 30% since the Industrial Revolution Overfishing and scientists expect it to increase Coral harvesting for the aquarium by another 40% by the end of the trade, jewelry, and curios century

"Threats to Coral Reefs"; Adapted from the Environmental Protection Agency.

Research suggests that the further a coral reef is from human civilization, the better it is for its health. As one scholar puts it, "distance may be a good thing" (Cirino, 2016). In a study examining the relationship between coral reefs' proximity to people—measured in travel time to major marketplaces—and reef health, a team of scientists based in Australia concluded that the closer a reef is to a high-density human population center, the less likely large and diverse fish populations are to live there. In the study, they found that 58% of the world's reefs are within 30 minutes of human activity and thus face significant threat from local stressors like those outlined above (Maire et al.,

2016). Not only do reefs close to human populations face threats from direct sources such as overfishing, but these reefs are also less likely to be protected under strict marine conservation laws.



Extra Resource: NOAA's Ocean Today video series on fixing the ocean "Restoring Coral Reefs"

Reef Restoration and Protection

Given the threats and ongoing degradation faced by coral reefs, national and global actors have begun aggressively pursuing restoration and conservation programs to help support reef growth. NOAA's Coral Reef Conservation program, for example, spearheads the reef conservation efforts in the United States through research, conservation, and restoration efforts. Its strategic plan envisions "thriving, diverse, resilient coral reefs that sustain valuable ecosystem services for current and future generations." It is founded on four core principles for reef conservation: (1) increase resilience to climate change, (2) improve fisheries' sustainability, (3) reduce land-based sources of pollution, and (4) restore viable coral populations (NOAA, 2018).

Restoration strategies encompass a wide range of solutions, including planting nursery-grown corals back into reefs, making sure habitats are suitable for natural coral growth, and building coral resilience to threats such as climate change. Removing invasive algae species, which proliferate from runoff that contains high amounts of nitrifying substances, is also a key priority for reef conservationists (NOAA, 2019). Artificial reefs are another solution to restore coral reefs globally. These man-made reefs, which can be developed with 3D printers, steel, cement, glass, and other secured structures provide stable growing areas for corals and habitats for fishes that would make a home on natural reefs (New Heaven Reef Conservation Program).

Data Analysis

The data that students will use for this lesson come from a previous study published by Bruno and Valdivia in 2016. Their study sought to test whether the commonly held idea that coral reefs in more isolated areas are healthier than those located in waters closer to human disturbance. Essentially, they were investigating whether local stressors play as important of a role in reef degradation as many people think. Given what we have learned about local versus global threats to reefs, students will be able to test whether and to what extent human disturbances really impacts reef health.



The dataset contains over 1,700 observations of hard coral and macroalgae cover from across the world collected between 1996 and 2006. They provide information on percent of reef covered as well as the region and subregion that the data come from. The data also provide information on human population residing within 25 km, 50 km, and 100 km of the reefs.

This dataset offers several unique elements that will expose students to working with new types of data. It is longitudinally collected and collated from many different sources, sacrificing consistent time-of-collection information



Meet the lead researcher: Dr. John Bruno

Dr. Bruno is a marine ecologist in the Department of Biology at the University of North Carolina at Chapel Hill. His research focuses on marine biodiversity and coral reef ecology and conservation.

His research is conducted primarily in the Galápagos and the Caribbean.



"I support the search for short-term solutions for coral reefs. But the only way this ends well is if we radically reduce our carbon emissions." -Dr. John Bruno

Read the reference paper:

Bruno, J.F. & Valdivia, A. (2016). Coral reef degradation is not correlated with local human population density. Sci. Rep. 6, 29778. 10.1038/srep29778. to increase the geographic scope and sample size of the study. It is one of the few global coral cover studies completed, as most studies like this focus on one reef at a single point in time, thus reporting much smaller sample sizes. It contains geographic information – through regional codes and longitude and latitude data – as well as empirical data points for reef cover and human population. In their paper, Bruno and Valdivia assume that healthy baseline reef cover is between 50-75% and that observed cover at time of observation represents a snapshot of loss over time. For example, a cover value of 25% would indicate an absolute 25-50% decline in cover.

Research Questions:

Keeping in mind what we know about Earth as an integrated system and the key threats to reef health, what impact do <u>local</u> stressors have on coral reef degradation? Are coral declines correlated with reef isolation?

Students will use the data collected by Bruno and Valdivia to analyze the relationship between human population density (the **predictor variable**) and coral reef cover (the **response variable**). Nearby human population density is used as a proxy for local stressors (e.g., point-source pollution, over-fishing, tourism, etc., as explained above) while percentage of hard coral and macroalgae cover represents broader reef health. We will focus on two variables in particular: (1) human population within 50 km and (2) percentage of reef covered in hard coral.

Bruno and Valdivia's Hypothesis:

If local impacts such as sedimentation, pollution, and fishing are measurably affecting reefs, coral reef degradation should increase across sites as local population density increases.

To test their hypothesis, the researchers used generalized additive mixed-effect models (GAMM) to analyze the relationship between coral and macroalgae cover with human population. They considered this relationship across different ocean basins and regions of the world to determine if there were any significant disparities globally.

Methods

Students will conduct several statistical tests on the reef cover data to determine its relationship with human population density.

Data Transformation

The first thing that students will be asked to do is to test their data and evaluate it for normality. In statistics, assumptions of normality are important and should be taken seriously, as it is impossible to draw accurate and reliable conclusions about the real world without using the right statistical tests for the data that is available. The distribution of a dataset can be tested in several ways, such as through visual inspection or by using significance tests (Ghasemi and Zahediasl, 2012). In this lesson, students will be asked to explore the

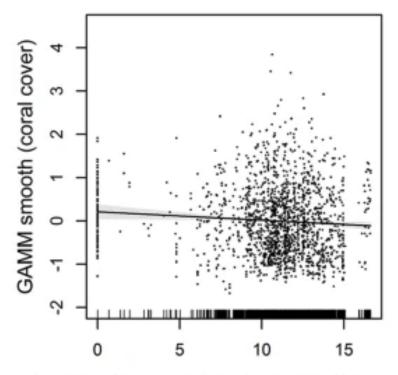
Extra Resource:

See YouTube video

"Testing for Normality —
Clearly Explained" for a
quick overview of why
distributions matter and
how to test for normality
using graphs and normality
tests.

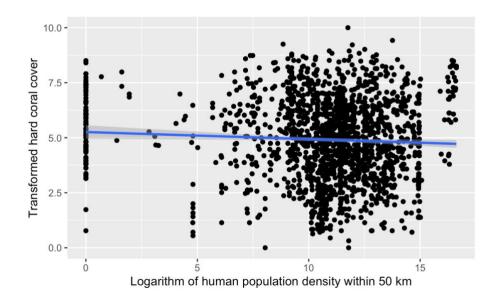
normality of the data in both ways through histogram plots and a Shapiro-Wilk normality test. After showing that the original data are not normally distributed, students will transform hard coral cover and human population data to better ascribe to assumptions of normality, which will help to validate the results of later statistical relationship testing. Bruno and Valdivia came to similar conclusions.

→ PAUSE → Compare Bruno and Valdivia's data (top chart) with the data produced in this lesson (bottom chart). Did we do a good job of matching their output?



Logarithm of human population density within 50 km





Extra Resource:

YouTube video "The Correlation Coefficient Explained in Three Steps"

Correlation Coefficient

Once the data are appropriately transformed, students will run a simplified version of Bruno and Valdivia's analysis using a Pearson's product-moment correlation test. Correlation tests are used to assess a possible linear relationship between two continuous variables, and a correlation offers students a simple method to calculate and interpret this relationship. A Pearson's test is appropriate here because students have transformed the two variables to adhere to assumptions of normality (Mukaka, 2012). Bruno and Valdivia's conclusions use correlation, so it is important for students to compare how their simplified iteration of Bruno and Valdivia's methods approximates the researchers' findings.

→ PAUSE → Consider the key statistics reported in the R output and what they say about the relationship tested. P-value and the correlation coefficient are central to interpreting the results.

Pearson's product-moment correlation

Extra Resource:

YouTube video "An Introduction to Linear Regression Analysis"

Linear Regression

After seeing and interpreting the results of the correlation test, students will then run a simple linear regression model. Linear regression is another method of testing the relationship between two or more variables and examining whether a predictor variable (or variables) does a good job of predicting an outcome and, if it does, the magnitude of that relationship (Statistics Solutions, 2013). A simple regression model tests the relationship between a single independent and a single dependent variable, making it an appropriate method for this lesson.



→ PAUSE → Consider the key statistics reported in the R output and what they say about the relationship tested. Estimate coefficients and R-squared values are central to interpreting the results.

```
Call:
lm(formula = transformed_HARD_CORAL ~ transformed_HUMAN_50km)
Residuals:
   Min
            10 Median
                            3Q
                                   Max
-4.9993 -1.2876 0.0298 1.3893 5.1208
Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
                                                   <2e-16 ***
(Intercept)
                                  0.15523 33.882
                       5.25948
transformed_HUMAN_50km -0.03234
                                  0.01380 -2.344
                                                   0.0192 *
Signif. codes: 0 '*** 0.001 '** 0.01 '* 0.05 '.' 0.1 ' '1
Residual standard error: 1.855 on 1706 degrees of freedom
Multiple R-squared: 0.003211, Adjusted R-squared: 0.002626
F-statistic: 5.495 on 1 and 1706 DF, p-value: 0.01919
```

Interpreting the Results

After running the correlation test and regression models, students should have a good understanding of the possible relationship between hard coral cover and human population. As students consider their results, it is important to compare their output to Bruno and Valdivia's conclusions.

Bruno and Valdivia's Conclusions:

Coral reef degradation is <u>not</u> correlated with human population density and thus any impacts of local stressors are undetectable at a geographic scale.

→ PAUSE → Students will find a different result. As you go through the assignment and lesson questions, consider how and why the results differ from the source material, and what that says about the potential impacts of local vs. global threats on coral reef health.

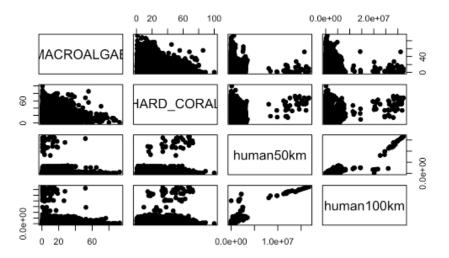
Extra Work: T-Tests

For some additional practice manipulating data and testing relationships, students can explore differences in coral cover between isolated and non-isolated reefs using a Welch's two sample t-test. This test introduces students to another method of comparing two groups of data and better understanding the relationship.

Assignment

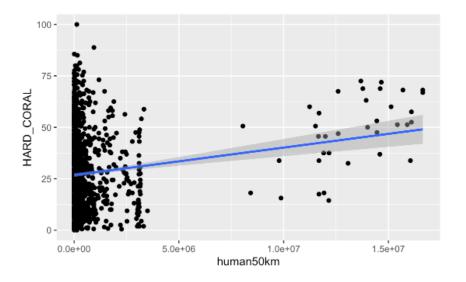
As a scientist, you have been given access to data on global reef cover and human population. Using R, you will configure, explore, and analyze these data to draw conclusions about the relationship between the two variables of interest. Follow along in the R code and answer the questions as you go.

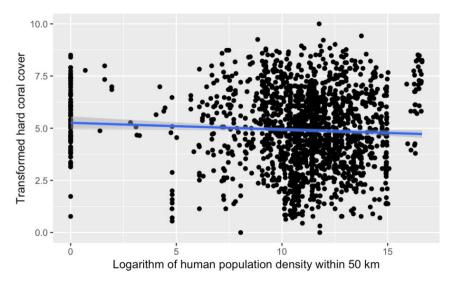
- 1. Look at a summary of the data. Do they look correct? What variables will you be using for the analysis?
 - It is important to make sure that the data were correctly imported into RStudio. A few things that students should verify are sample size and that they understand what the variables mean. We see that the sample size is 1708, which is correct. Students should make sure that variables are behaving in a way that makes sense. The human population variables are a good way to confirm this; there are generally lower numbers in the `human25km` variable than the `human50km` or `human100km` variables. Hard coral and macroalgae cover are both percentages, and we can see that the data range from 0 to 100. These are some ways of verifying and exploring the data from the get-go.
- 2. What do the pairwise plots suggest about the relationship between reef cover variables (macroalgae and hard coral) and population variables (humans within 50 km and 100 km)?
 - Pairwise plots are a useful way to describe a pattern of mean differences between groups of variables. Students should consider the plots between indicators of reef health (hard coral and macroalgae cover) and indicators of human population. There is no clear directionality to the plots at the intersection of `MACROALGAE` x `human50km` or `HARD_CORAL` x `human50km` for example. The same lack of pattern is observable with `human100km`. This suggests that there may be no clear linear relationship between reef health and nearby human population. Students should discuss how this initially confirms Bruno and Valdivia's findings.



3. Compare the point plots showing the relationship between the original hard coral cover and human population data with the transformed data. Explain why using the transformed data is appropriate here. What initial conclusions does the transformed point plot suggest?

The plot using the original data shows a high concentration of observations along the y-axis. These data are heavily skewed with fewer data points observed along higher population densities. By contrast, the plot that uses transformed data shows that the data points are more evenly distributed, and that the regression line appears to fit more evenly between them. This more normal distribution of the transformed data allows us to use a correlation test with more certainty, rather than using a different method (such as spearman's rho), as well as a simple regression model. Looking at the transformed plot, students should discuss the relative flatness of the regression line, and consider what it may suggest about the data that the original data's regression line is positive in slope while the transformed line is negative in slope. Overall, the transformed regression line suggests a weak or nonexistent relationship between the two variables.





4. Explain the correlation results. What do the p-value and correlation coefficient suggest about the relationship between hard coral cover and population density?

The correlation results suggest that there is a weak, but statistically significant, negative relationship between hard coral cover and population density. A p-value of 0.019 indicates that the null hypothesis can be rejected within a 95% confidence level, further validated by the fact that the 95% confidence interval does not cross zero. However, this relationship is very weak, with a correlation coefficient of only -0.057. Because correlation coefficients range from -1 to 1, a coefficient close to zero is quite weak.

- 5. Do the results of the simple linear regression support the findings from the correlation test? What do they explain about the significance and magnitude of the relationship between hard coral cover and human population?
 - Like the correlation test, the regression signals that there is a statistically significant relationship between coral cover and human presence. Though the magnitude is relatively low, especially considering the results are in transformed, rather than absolute, units, the results confirm that the two variables are statistically related with a high degree of certainty at a 95% confidence threshold.
- 6. Do isolated reefs demonstrate different percentages of hard coral cover than reefs in closer proximity to humans? Is this different statistically significant?
 - The results of the t-test between isolated and disturbed reefs suggest that hard coral cover does differ significantly between the two groups. A p-value of less that 0.05 (0.007) suggests that this difference is statistically significant. Isolated reefs have an average coral cover of 32.5% compared to disturbed reefs' cover of 27.3%. These means align with Bruno and Valdivia's findings.
- 7. Our results suggest that there *is* a statistical relationship between hard coral cover and human population density, which differs from Bruno and Valdivia's findings. Given your exploration (both descriptive and analytic) of the data, what would you recommend to conservationists given your findings? Consider statistical vs. biological significance in your answer and the role that local vs. global threats may play in reef destruction.

Students should discuss how their results differed from Bruno and Valdivia's results, where the authors found no correlation between reef cover and population density. Students should consider how their results differ from the study's findings. For example, Bruno and Valdivia do not transform coral cover data while we do in this lesson. Our findings conform more to the common understanding of human disturbance on reef health and the impacts the local threats have on reef degradation such as overfishing and point-source pollution. The Maire et al. (2016) study is a good counterpoint to Bruno and Valdivia that aligns with the findings in this lesson.

Although there are differences in the statistical outcomes of the two analyses, students should also discuss the practical/biological significance of the results. The extremely weak correlation suggests that coral reefs across different levels of human disturbance are still disturbed and it does not give conservationists a clear idea of if/how to prioritize certain reefs for conservation efforts. The relationship is likely not strong enough in practical ways to be able to "rank" reefs on their level of endangerment. Likewise, although there is a significant difference in means between isolated and non-isolated reef cover, we still find that isolated reefs have lost anywhere between 17.5-42.5% of their cover (based on the baseline assumption that healthy reefs are 50-75% covered), which has important biological implications regardless of its difference from disturbed reefs. Nonetheless, our results indicate that local stressors play an important role in reef degradation and support conservation efforts that aim to reduce human disturbance of reefs to protect them. Bruno and Valdivia's results, on the other hand, would advocate for a global treatment rather than a local one.

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