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Abstract

There are many hypotheses that attempt to explain patterns of species diversity in different environments. Deserts are a great place to study changes in species richness because they are relatively nutrient bare and exhibit low precipitation. This barebones environment means that slight shifts in climate and geography may lead to clear changes in species richness. We investigate how temperature, precipitation, water and light availability, latitude, elevation and other variables affect plant species richness in 20 deserts.

Keywords: biogeography, ecology, deserts, plants, botany, richness, R, multiple regression

Introduction

There are an abundance of hypotheses that attempt to explain factors that affect species richness across the globe (Channel and Lomolino 2000). These hypotheses vary drastically, and many are conflicting. For example, one purports that species richness increases in a habitat with a stable environment (Fordham et.al 2012) while another suggests that it increases in a stochastic environment (Yachi and Loreau 1999). Gaining a better understanding of what exactly affects plant species richness is important for conservation efforts as we face human-induced climate change. Our planet is continuing to experience an increasing extinction rate, and a population's probability of extinction is directly correlated with its variability in species richness (Channell and Lomolino 2000). We believe it is imperative to understand the variables that affect richness so that this knowledge can be used to preserve and increase richness.

Deserts are ideal for the study of species biodiversity patterns because richness varies greatly across desert regions (Vetaas and Grytnes 2002). They are also relatively nutrient bare and their climates are associated with high temperatures and limited precipitation year-round (Tucker et al. 2001). Because of these conditions, minor changes in climate variables can lead to clear shifts in species richness. Previous research suggests that temperature, precipitation, latitude, elevation, and sunlight are strongly implicated in affecting plant species richness. However, prior research seems unable to reliably isolate the magnitude of the impact that each variable has on richness. Additionally, because climatic variables are often correlated with one another, it is difficult to tease out the relative importance of each one. The objective of our study is to determine which climatic and geographical characters most significantly influence plant species richness in desert biomes. We predicted that water and light availability would have a significant effect on richness, as both variables are primary energy sources for plants. Our results, however, indicate that predicting plant species richness is explained by a much more complex model, explained in greater detail below.

Table 1. Variables that we collected and analyzed for each desert in the stepwise regression and description.

Variables Analyzed Per Desert	Description of Variable
HighT	Average High Temperature
LowT	Average Low Temperature
AvgT	Average Average Temperature
Months_Below_Freezing	Average Months in a Year Below Freezing
HighPrecip_inmon	Average High Precipitation (Inches/Month)
LowPrecip_inmon	Average Average Precipitation (Inches/Month)
AvgPrecip_inmon	Average Low Precipitation (Inches/Month)
HighDaylight_hrsday	Average High Daylight (Hours/Day)
LowDaylight_hrsday	Average Low Daylight (Hours/Day)
Latitude	Latitude
HighElevation	Highest Elevation
LowElevation	Lowest Elevation
ElevationDelta	Elevation Change
DesertSize	Size in Square Miles
PlantSpeciesQuantity	Number of Individual Plant Species

Methods

Data Collection

Research was conducted using publicly available online data from NOAA, national, state and regional park websites, and other available sources (Appendix). We researched 20 deserts across the globe, though many were in the United States (Appendix). We used the national park boundaries instead of the entire desert because plant inhabitants are better documented in the national parks. All plants present were counted towards our plant richness measure, including native, introduced, and invasive species. We measured nine variables (Table 1) that we hypothe-

Table 2. Desert size indices that were used for analysis

Desert Size (Square Miles)	Index Value
0-100	1
101-500	2
501-1,000	3
1,001-2,500	4
2501-10,000	5
10,001+	6

sized would most influence plant species richness in a desert ecosystem. Because desert size was so variable, we used indices to bucket groups of like-sized deserts together. This prevented the Desert Size variable from having an outsized effect on our model. For example, if the actual value of desert size was used for deserts such as the Gobi with 500,000 square miles of area, that variable would have an outsized effect on the model compared to smaller deserts, such as Carlsbad Cavern National Park with 73 square miles of area. The index allows us to consider desert size in our model but to not skew the results based on the big differences in area between our deserts. This was particularly important because our smaller deserts are the national parks that are often specifically protected because of their ecological importance, regardless of their small size. Therefore, it is not fair to compare 73 square miles of national park to 500,000 square miles of non-specific desert without an index.

Data Analysis: Stepwise Regression

To analyze the data we collected, we ran a stepwise regression analysis using the statistical program R (R Core Team 2013). Stepwise regression is a method of fitting regression models in which the choice of predictive variables is carried out by an automatic procedure. In each step, a variable is considered for addition to, or subtraction from, the set of explanatory variables known as a model. We compared our measured variables against plant species richness in our stepwise regressions, and Akaike information criterion (AIC) scores determined which combination of variables most significantly affects plant species richness. AIC is a measure of the quality of a model relative to each of the other models. It is used to compare models against one another by determining the relative amount of information lost by using one model instead of another. A model with a lower AIC value should be more efficient at producing the true probability distribution than a model with higher AIC value (Busemeyer and Diederich 2014). We used the model with the lowest AIC value to determine the best predictor of plant species richness. After we determined the best model, we ran linear regressions on each of the variables in the model.

Results

Table 3 shows our best-fit models along with the associated AIC values for each. This table shows the different combinations of variables that best explain plant species richness. Our best-fit model had an AIC value of 241.45 and included the following variables: average temperature, months below freezing, high precipitation, low precipitation, average precipitation, high daylight hours, latitude, high elevation and desert size.

Table 4 shows the results from the individual linear regressions for each variable from our best-fit model. This data explains the degree to which each variable is correlated to plant species richness (coefficient) and its significant (p-value) when viewed from outside the model. Variables that were positively correlated with plant species richness (in order from greatest to least) were: average precipitation, latitude, and high elevation. Variables that were negatively correlated with plant species richness (in order from least to greatest) were: low precipitation, high precipitation, months below freezing, and average temperature.

Table 3. AIC value model results from stepwise regression

Model	AIC
Model 1 (Plant Species Richness~AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + Latitude + HighElevation + DesertSize)	241.45
Model 2 (Plant Species Richness~AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + LowDaylight_hrsday + Latitude + HighElevation + DesertSize)	242.33
Model 3 (Plant Species Richness~HighT + AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + LowDaylight_hrsday + Latitude + HighElevation + DesertSize)	243.66
Model 4(Plant Species Richness~HighT + LowT + AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + LowDaylight_hrsday + Latitude + HighElevation + DesertSize)	245.26
Model 5(Plant Species Richness~HighT + LowT + AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + LowDaylight_hrsday + Latitude + HighElevation + LowElevation + DesertSize)	246.41
Model 6(Plant Species Richness~HighT + LowT + AvgT + Months_Below_Freezing + HighPrecip_inmon + LowPrecip_inmon + AvgPrecip_inmon + HighDaylight_hrsday + LowDaylight_hrsday + Latitude + HighElevation + LowElevation + ElevationDelta + DesertSize)	246.41

Discussion

While our prediction that water and light availability would have the most significant effect on richness was correct in part, our analysis shows that a much more complex model is required to explain richness. Our best-fit Model 1 (Table 3) is the best predictor of plant species richness in the deserts that we studied and contains variables related to both light and water availability. Many of the variables included in this model exhibit intuitive results with regards to the magnitude and

Table 4. Linear regression results from top variables in our best-fit stepwise regression model with coefficients, standard error, test statistic, and p-values for each.

Variable From Stepwise Regression	Coefficient	Std. Error	t value	p-value
DesertSize	0.00	0.00	4.77	0.00
Latitude	28.88	6.74	4.28	0.00
Months_Below_Freezing	-167.60	44.04	-3.80	0.00
HighElevation	0.10	0.03	3.14	0.01
LowPrecip_inmon	-1380.00	667.40	-2.07	0.07
AvgT	-11.76	5.69	-2.07	0.07
AvgPrecip_inmon	1315.00	729.80	1.80	0.10
HighPrecip_inmon	-441.50	278.60	-1.59	0.14

direction of their effect on richness. For example, months below freezing and average temperature were negatively correlated with richness and average precipitation was positively correlated with richness. The negatively correlated variables behave as one might expect: the more months below freezing and/or the higher the temperature, the lower species richness in a desert. With more months below freezing, there is less water availability throughout the year. With higher temperatures in an already hot environment, conditions become inhospitable to life. Similarly, the higher the average precipitation in a desert is, the greater the species richness tends to be. Because deserts are water poor, having a higher baseline average precipitation probably allows for more favorable conditions for life.

In addition to these expected results, there are a few surprising findings. Most notably is that in our study deserts, having a higher average 'high precipitation' month every year and having a higher average 'low precipitation' month every year, are negatively correlated with plant species richness. This suggests that the greater our desert's lowest month of precipitation is—*and* the greater its highest month of precipitation is—the lower its species richness should be. In other words, the more precipitation there is in the desert's lowest and highest months of precipitation, the lower its richness is. Why would more rain during a desert's most extreme high and low precipitation months equate to lower richness? We hypothesize that with low amounts of precipitation and energy, the landscape would be dominated with smaller, less water-intensive plants. In these landscapes, there would be no big, dominant plants that consume most of the resources in the area (think redwood trees in a coastal forest). Without these dominant plants, a wider variety of species can compete for survival. This suggests that in conservation efforts aimed at maximizing species diversity, one should consider how undisturbed growth of dominant species might negatively affect overall richness.

Additionally, we found that although desert size did get incorporated into our model (and therefore was an important variable in predicting plant species richness), it did not present a coefficient when analyzed in isolation. This would suggest that desert size may not be a good predictor of plant species richness on its own. This is surprising because, intuitively, more area means more room for a greater diversity of plants to potentially grow. Instead, desert size is a useful predictor only in conjunction with all the other environmental variables incorporated in a model. In biogeographic literature pertaining to species conservation, there are two fundamental approaches to consider in terms of area of habitat: single large or several small plots (Järvinen, 1982). Our research seems to support the idea, as do many other studies, that smaller noncontiguous habitats are just as good at retaining high species richness numbers as larger contiguous habitats. To confirm findings from our research, we would like to see similar analyses performed in different biomes to see how the variables affected plant species richness differ in different environments.

In conclusion, predicting plant species richness in deserts is complex and is influenced by a host of potentially interconnected variables. The possibility of variables being influenced by each other makes definitive analysis in this complex environment even more difficult. In each of our deserts, though, we see the same variables playing similar crucial roles in determining species richness and overall production of the ecosystem.

While deserts are a wonderful environment that showcase an incredibly diverse array of adaptations, they are also harsh climates that are difficult to survive in. Currently, a phenomenon called desertification, or the spread of deserts to regions that were not previously desert, is a growing threat (Darkoh 1998). As such, it is important to better understand deserts and the variables that govern and influence plant life within them. In addition to illuminating factors affecting biodiversity in general, our research also provides valuable information that can help us understand the variables that govern the deserts in our study. In turn, this information can help us to better prepare for hotter environments and desertification caused by increasingly rapid climate change. With a better understanding of these crucial factors, we as humans can better protect and restore the planet and allow life to flourish.

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Appendix

Table 1A. List of deserts used in study.

Desert Name
Carlsbad Caverns National Park
Nambung National Park
Arches National Park
Great Basin National Park
Saguaro National Park
Petrified Forest National Park
Zion National Park
Capitol Reef National Park
Little Desert National Park
Organ Pipe Cactus NM
Canyonlands National Park
Joshua Tree National Park
Big Bend National Park
Grand Canyon National Park
Kobuk Valley National Park
Death Valley National Park
Atacama
Thar
Kalahari
Gobi

Steps to Collecting Data

1. Determine latitude via google.
2. Get temperature and precipitation data from NOAA, google aggregated data.
    a. Look at the months, pick out the lowest of the low temp value
    b. Look at all the months, pick out the highest of the high temp value
3. Get precipitation via US climate data, also aggregated by google.
    a. Look at the months, pick out the lowest
    b. Look at all the months, pick out the highest
    c. Here is a good source for precipitation data: https://www.timeanddate.com/weather/@5536441/climate
4. Google monthly high precipitation, or high annual divided by 12.
5. Google monthly low precipitation, or low annual divided by 12.
6. Google monthly average temperature, or average annual divided by 12.
7. Get daylight hours data
    a. https://www.timeanddate.com/sun/

   b. Slide the line on the graph and determine the high, low, and average *Daylight Total* for the year 2018, this is shown below the graph in the middle.
8. Look on the National Park Service website for elevation
   a. If you don't find it there, record on the *Sources* google doc where you found the elevation data
9. Look under the *Plants* page on the National Park Service website for the number of plant species

Data Sources

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