Evolution Study of Vermont Goldenrod (*Solidago spp.*)[1]

Sarah Cuprewich

6 October 2016

Abstract[2]

The Vermont Goldenrod population is quite diverse and plentiful. There are over 40 different species of Goldenrod found in the northeastern US and even more found elsewhere in the world. But they were once all one species before diverging into their modern day counterparts. It was hypothesized that there are differences between species in height of the plant and stem diameter[3], as well as a relationship between height and diameter. Taller plants need thicker stems for transport and support. These data were obtained in Centennial Woods using a meter stick and calipers and an identification key to ID species in the field. The computer program R was used to run an analysis of variance, ANOVA, to test for significance in the difference between the masses and the correlation coefficient (r) was found to test

---

[1] Notice how the title includes the common and scientific name of the study organism, as well as the location and general objective of the experiment.

[2] The abstract is a place to summarize the entirety of the report that follows. Each section of the report should be represented here with a sentence or two, and the major findings and conclusion should end the section.

[3] I should have explained why this was hypothesized here like I did for the next prediction.

for a relationship. It was found that there is a significant difference in plant height and diameter, with the *Solidago gigantea* species being the largest. The p-value for height was 0.000168 and for diameter was 2.41x10^-6, with which the null hypothesis can be rejected. This could aid scientists monitoring evolution in plant communities and can help predict what future plant populations will look like.

Introduction

There are over 100 species of Goldenrod (species *Solidago*) around the world, however only about 45 can be found in the northeastern United States. The species can often be difficult to differentiate, but enough phenotypic variation is seen to determine whether evolution is occuring in these species.[4] The purpose of this experiment is to determine the nature of variation in the *Solidago* species found in Centennial Woods. *Solidago canadensis*, *Solidago rugosa*, and *Solidago gigantea* can be found with various heights and diameters and the question being asked is if there is a correlation between those two variables.

It was hypothesized that there is a difference in height between the three species. It was predicted that because crowding could cause certain species to grow taller to

---

[4] More background information on the mechanisms and effects of evolution should have been included here before providing information on the study system. The introduction should move from broad to specific, general background information to specifics on the study organism.

outcompete another species for sunlight as a resource.[5] Growing taller, however, comes with its drawbacks because taller plants must invest more energy in stem construction and maintenance and less energy on reproduction (Falster and Westoby 2003).[6]

It was also hypothesized that there is a difference in diameter between the species, with the taller plants predicted to have thicker stems. It was predicted because crowding could cause species to try to outcompete each other for resources like water and soil nutrients. No two species occupying the same stable ecosystem can healthily occupy the same niche, so niche differentiation must be occuring if two species are too similar (Whittaker 1965).

There is a hypothesized relationship of correlation between the height and diameter for the Goldenrod species. Taller plants need thicker stems to support their height, and more vascular tissue to transport water and nutrients farther as the plant grows taller. However, species may take a while to reach their equilibrium phenotypic ratios in nature, and if evolution is currently occuring these species may not yet show a relationship between height and diameter (Lande 1976).

If height and diameter measurement differences are statistically significant between species, then we can reject the null hypotheses that the values are the same and the assumption that no evolution between the species is occurring. This is important

---

[5] Notice that I did not use H_0, H_a, or H_b to describe my hypothesis, allowing this paragraph to flow much better. Following the hypothesis, the prediction is stated.

[6] Also notice how I provided a previous study's conclusion as evidence to support my own hypothesis. This structure is also followed in the next two paragraphs.

because we can observe evolution as it is occurring in nature and see how the phenotypic ratios are changing over time to monitor the process.[7]

Methods[8]

Data Collection[9] Goldenrod species *Solidago canadensis* (SC), *Solidago rugosa* (SR), and *Solidago gigantea* (SG) were located at random in Centennial Woods[10]. They were first identified …[omitted]…. Then the height, in cm, …[omitted]…. A meterstick was used for the height measurement and calipers were used for the diameter. This process was repeated until thirty plants were surveyed.

Data Analysis[11] The data[12] were entered into a computer program called R. R made it possible to represent data using histograms to show distributions, boxplots to display variance, and scatterplots to show correlation. Tests of statistical significance were also run using R. The test used was Analysis of Variance (ANOVA) because …[omitted]…. The r correlation coefficient was also obtained to show

---

[7] A brief explanation of why this study is important is necessary, otherwise why else would the reader care?

[8] This section is broken up into data collection and data analysis, which is preferred for organizational purposes but not necessary. It is written in past tense and passive voice with enough detail for other researchers to repeat the procedure.

[9] Discusses how the data were obtained from the study system.

[10] I should have also added the site's city and state here.

[11] How were the data analyzed to get the results you obtained? Include which tests were run (and why) and any relevant equations.

[12] I should have stated how many total data points were included.

correlation between height and diameter for each of the species. Correlation is necessary in this experiment …[omitted]….

Results[13]

The median height and diameter values (in cm) for *Solidago canadensis* …[omitted].... SC and SR species have similar median values while SG is considerably larger. The minimum and maximum height and diameter values …[omitted]…. The minimum height and diameter for SR is 80 cm and 0.28 cm, while the maximum height and diameter is 182 cm and 1.01 am. However, the minimum height and diameter for SG …[omitted]…..[14]

The differences between the height of the species can be seen in Figure 1.[15] The SC population is skewed to the left, as is the SG population, but the SR group is fairly uniform in distribution. SG is fairly unimodal, while SC and SR have a few peaks in their distribution.[16] Figure 2 displays the variation in diameter between the species. All three species are skewed to the right, but the SC and SR species contain visually

---

[13] This section should include the major findings on the experiment in the form of tables or figures, but no conclusions or interpretations made about them. Try to vary the sentences describing the visuals so it does not turn into simply listing numbers.

[14] These numbers should have been listed in association with figures, like the histograms or box plot, instead of waiting for the second paragraph.

[15] Each figure in the results section should be described in a few sentences and referenced here.

[16] Where are these peaks? Be specific when describing the visuals, but be sure to make no assumptions here!

lower minimum values than SG. A positive correlation can be seen between height and diameter for each species in Figure 3. SC has an r value of 0.64, SR has a value of 0.70, and SG's r value is 0.65. Figures 4 and 5 are boxplots to show the data range of height and diameter for each species. SC and SG both have outliers on the low end for height, and all three species have outliers on the high end for diameter. Figure 4 also displays that the median value for SG is much higher than that of either SC or SR. The same is true for diameter in Figure 5. The ANOVA test for height produced a p-value of 0.000168 and the ANOVA for diameter revealed a p-value of 2.41x10^-6.[17]

Discussion[18]

After obtaining and analyzing the local Goldenrod population for evidence of evolution, the hypotheses tested were focused on finding differences in height and diameter between three Goldenrod species. It was predicted that taller plants would also have thicker stems because plants with more height need a better support and vascular system. To test this, measurements were gathered from three species and analyzed using ANOVA to test for a difference in height and diameter. The

---

[17] End this section with the major findings, like the calculated p-value values or correlation coefficients.

[18] Now is the time to interpret your results. Start with the specific and end on a broader note. Quickly summarize the experiment and hypotheses, and then interpret the results. Each figure or table should again be discussed and referenced in this section as well. After the results are discussed, state any possible errors and how to make the experiment better. End the section with the implications of this research and if there is anything specific that further research should investigate.

correlation coefficient for each species was also calculated to test for a relationship between the data. The p-value obtained for height from the ANOVA was 0.000168; this means there is not even a 1 in 1000 chance of these results just being due to random chance. The p-value obtained for diameter was 2.41x10^-6, considerably smaller than the already small p-value for height.[19]

The median height and diameter values for *Solidago gigantea* were much higher than the values for *Solidago canadensis* and *Solidago rugosa*, which can be seen in the very small p-values and throughout the figures. Figure 1 displays SG with a higher frequency of larger height values compared to smaller height values, and especially when compared to SR and SC. The same is true for diameter data displayed in Figure 2. SG did not have the same minimum extension as the other two species did, so it has a visibly larger average diameter when viewing the histogram.

The r-values, correlation coefficients, displayed in Figure 3 show the type of correlation between diameter and height for each species. The value for SC is 0.64, giving it a fairly strong positive correlation. This means that as height increases, so does diameter.[20] This is the weakest correlation coefficient between the species, however, meaning there is more variation of height and diameter values within SC than seen in the other species. The r-value for SR was the strongest positive

---

[19] Repeat some results which are going to be interpreted if they are not included in a figure or table. Note that the test which gave the result is mentioned and what that result means for the experiment is discussed.

[20] Not only should the r value be repeated here, but it should be discussed. Is it positive or negative? What does that mean for the variables analyzed?

relationship seen here, at 0.7, meaning most of the variation in the y variable is explained by the x variable. This is also evident in Figures 1 and 2 because SR often had a unimodal or fairly normal distribution.[21] SG also had a fairly strong positive relationship with a correlation coefficient of 0.65, meaning as the diameter increased in size so did the height.

Figures 4 and 5 also show the variation between and within species. There are outliers present for both height and diameter, meaning there is considerable variation within species that may have affected and skewed the median values. The SG species also has a visibly higher median for both the height and diameter, so it is probably the reason such low p-values were obtained.[22]

With these data, we can reject all the null hypotheses because data strongly support the alternative hypotheses. The p-values are far too small for these results to be due to chance, so there is a significant difference between height and diameter between species. The correlation coefficients are also all fairly strong and positive, meaning there is a positive correlation between height and diameter within species.[23]

---

[21] Compare different figures to each other. Can the same conclusions be drawn from each of them or are there some conflicting results?

[22] Try to explain your quantitative results, if you can, by describing your figures and tables.

[23] This paragraph is extremely important! It is the main idea of the discussion section: what do these results mean? State whether or not the null hypothesis is rejected, and state why using p-values or correlation coefficients to quantitatively back up your statements.

Errors could have accumulated throughout the study due to errors in measuring the plants during data collection. Errors could have also been made during data manipulation by the computer or when the data were first input into the system. The species could have also been misidentified in the field since they are notoriously difficult to differentiate between.[24]

This research can display evolution occurring in the present day and make it much easier to study than looking at fossil records. Scientists can monitor the rate at which alleles and phenotypes are changing in a population, and can see how niches are differentiated in plant communities. This research could also help farmers or other ecological growers when deciding where to plant crops, because plants of the same height will compete for resources and one will eventually win unless they both change their current niche. These data could also help scientists predict species that are likely to differentiate because of shared resources and decide whether a species is endangered or not.[25]

---

[24] Don't forget to discuss any errors that you know occurred during any point in this experiment, but also hypothesize about any other places in your experimental design where error could have occurred. These error statements are important because they show that the researcher is aware their experiment is not perfect and that there is always room for improvement and repetition of experiments.

[25] Discuss the big-picture implications of this study. How can the results of this experiment relate to researchers all over the world? How could this type of research impact the scientific community? In general, why is this important in the real world? Another source could have been useful here to connect previous research to the implications of this experiment.

Literature Cited[26]

- Falster, D.S. and M. Westoby. 2003. Plant Height and Evolutionary Games. Trends in Ecology and Evolution **18**: 337-343.

- Lande, Russell. 1976. Natural Selection and Random Genetic Drift in Phenotypic Evolution. Evolution **30**: 314-334.

- Whittaker, R.H. 1965. Dominance and Diversity in Land Plant Communities. Science **147**: 250-260.

[26] References are cited here and in the text using Ecology format. Only include the sources that are cited in the report.

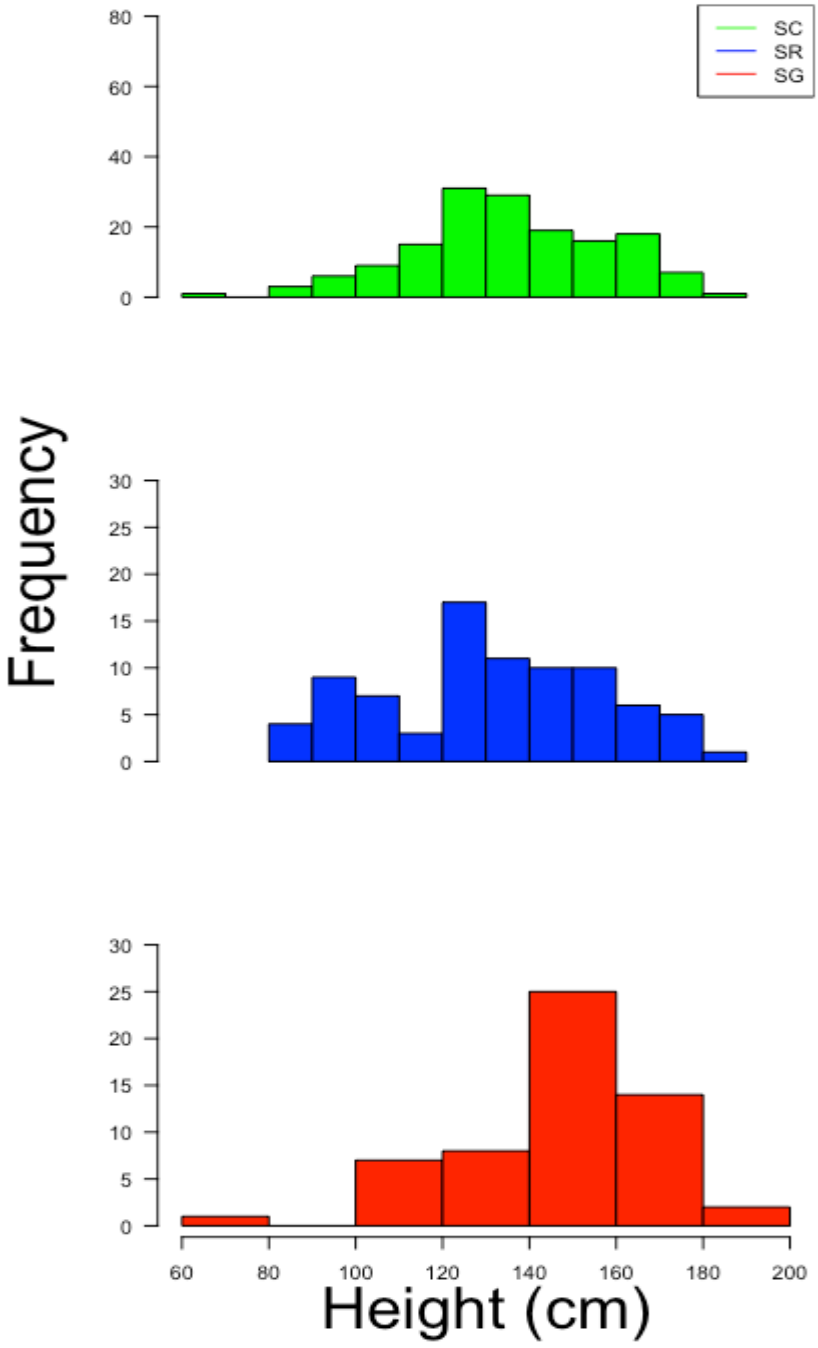

Figure 1 Goldenrod height (cm) distribution of SC, SR, and SG (top to bottom).[27]

[27] This figure and caption are here as an example (other figures are omitted). Note the descriptive caption.