Climate Browser: An Introductory Data Tool For Ecology Students

Authors: Elizabeth Clive, Benjamin Kimball, Jacob Jensen, Louisa Dayton.

Abstract:

Data literacy is an important skill for ecology students, but it is frequently underdeveloped. Ecology students and educators need a tool which can help students learn how to understand, analyze, and visualize real-world ecological data. We solve this problem with Climate Browser, an R Shiny application tailored to the needs of ecology students. It gives students an easy way to analyze and visualize ecological data in a way that would ordinarily require programming experience. Climate Browser allows students to tidy data, calculate species diversity indices, graph and map their data, and run statistical tests on their data or a preloaded dataset.

Introduction:

Data analysis skills have become increasingly crucial for professionals in life science fields. Unfortunately, many life science students obtain their degrees with inadequate data literacy, leaving them ill-equipped to enter the workforce (Auslander & Rosenne, 2016) (Fellers & Kuiper, 2020) (Li, 2020). Enabling students to be data literate without learning a programming language is especially essential for sustained growth in the field of ecology (Langen et al., 2014)(Cooke, et al., 2020). Therefore, educators desperately need new and creative ways to help students learn to understand and convey information derived from data. Studies indicate that using visual graphing applications to interact with data contributes significantly to learning outcomes by deepening perspective, increasing motivation, improving grades, encouraging students to use cutting-edge techniques in their data analyses, improving learning results of data analysis methods, and helping students retain important concepts through a hands-on learning approach (Neumann, Hood, & Neumann, 2013) (Fawcett, 2018) (Williams & Williams, 2017) (Doi, Potter, & Wong, 2016) (Hovardas & Korfiatis, 2010). Dynamic visualizations, such as those made with R Shiny, allow students to learn at a significantly faster rate by allowing students to interact with the data to see a clearer picture of what it conveys, unlike static visualizations which are currently being used in the classroom (Rolfes, Roth, & Schnotz, 2020). Students themselves generally evaluate these resources positively (González, López, Cobo, & Cortés, 2018) (Fawcett, 2018) (Fellers & Kuiper, 2020). Accordingly, instructors need graphing applications to equip students with essential major-specific expertise and experience.

While an application for data manipulation and visualization would be invaluable in an ecology class, there is currently no such tool for ecology students. A sufficient tool would need to include the ability to plot ecological data on graphs such as the Walter-Lieth climate diagram and geospatial data on a map. Ecology students would also need an easy means of calculating biodiversity indices, performing standard statistical tests, and graphing results. Finally, such a tool would need to be understandable and easily maintained, which would allow the integration of real, current data into classroom and real-world applications.

Currently existing tools have significant limitations. Microsoft Excel has been used to create graphs by ecologists, but these are not interactive and are poor quality when made with default settings (Su, 2008). Very few tools are able to produce Walter-Lieth climate diagrams or map user supplied data on a map. Some instructors use tools such as plotly or D3.js to produce charts, but both of these have steep learning curves, making them impractical for student use in most cases. Additionally, Java applets popular among educators in the late 90's and early 2000's are quickly becoming obsolete (González, López, Cobo, & Cortés, 2018) (Roberts, 2007). Shiny apps such as PlotTwist (Goedhart, 2020) have been made to address these concerns, but none are suitable for ecological data as they can not display geospatial data. Our goal was to make it easy for users with limited data analysis experience to make high quality interactive data visualizations with their own data.

R Shiny fills the need in undergraduate courses for a graphing and data manipulation tool. Shiny is an open source R package that provides a framework for web applications that harness the computational power of R (Antonelli & Olivieri, 2020). Shiny applications can be deployed and accessed for free on shinyapps.io. These apps are interactive, dynamic, user-friendly, and visually appealing (Ellis & Meridian, 2015) (McGuiness & Higgins, 2020) (Abhilash & Sheeba, 2019). R Shiny also offers specific educational advantages. Students without any coding training can easily access the full functionality of R through these applications. Shiny apps can easily be tailored to fit a specific course without using Javascript, HTML, CSS, or any other languages commonly used in web design (Doi, Potter, & Wong, 2016). Additionally, extensive documentation exists for R Shiny, as well as scientific papers detailing the structure of similar Shiny apps (Wojciechowski et al, 2015) (Holland-Letz & Kopp-Schneider, 2020) (Smith & Schneider, 2020) (McGuiness & Higgins, 2020) (Goedhart, 2020).

In light of these benefits, we created the Climate Browser using R Shiny. Our goal was to create a platform to allow students to graph ecological data and depict data and produce meaningful diversity indices that can be mapped or included in final analyses. This interactive browser gives ecology students the ability to create, manipulate, and compare various visual plots to analyze data, including regressions, bar charts, or violin plots without having to learn advanced programming techniques. Our group used two primary types of ecological data about the physical environment and ecological community, allowing students to gain experience specific to their field of study. Our tool allows users to select variables or categories based on column titles and then quickly visualize them with sophisticated looking graphs. Additionally, for data that contains geospatial coordinates, the application includes a map overlay with appropriate controls for data exploration, allowing users to come to a deeper understanding of geospatial data (Schweinberger, 2020) (Dierauer et al., 2020). This website is publicly available through a shinyapps.io website and has several pre-loaded datasets along with the option for users to upload their own datasets. To assist with student learning, the site also includes guidance as to which plot types are most appropriate for categorical, continuous, and time series data. Further capabilities for understanding and analyzing data were implemented using commonly used statistical tests such as various types of t-tests, log transformations, and

ANOVA(du Prel, 2010) (Wadhwa, 2020). We assessed our success in creating this tool through student surveys and robust testing.

Methods:

We wanted to create an application that students can use to see a clearer picture of specific ecological datasets. To do this, we created an interactive data browser using R-shiny that enables ecology students to create, manipulate, and compare various visual plots to analyze data without having to learn advanced programming techniques. We included climate diagrams, geospatial plotting, and other common statistical plots, as well as functionality to allow users to tidy their data before doing any graphing.

The first diagram we created was a Walter-Lieth climate diagram, which shows a summary of climate conditions for a place over a specific time period. To initially model our diagrams and provide a default dataset for users, we used the Mt. Larkins climate dataset, which is publicly available for free with an account on New Zealand's National Climate Database (https://cliflo.niwa.co.nz/). We made this dataset available as a default option for users not uploading their own data. We used diagwl, a function from the climatol package, to create an accurately scaled and colored climate diagram that would be consistent with the accepted standard for these diagrams. To gather the correct data from users, we created a short section in the sidebar that requires users to select the various variables necessary, such as altitude and hemisphere.

We wanted users to be able to display geospatial data over a map, which helps with distribution visualizations. We used the Whole Watershed Vascular Plant Dataset to model this function which was collected from the New Zealand Vegetation Survey. This data is publicly available, but requires an account (https://cliflo.niwa.co.nz/). We also used this data to test data manipulation functions and also provided it as a default data option for users. To plot geospatial data, we used mapview, a package which allowed us to plot data points onto a set of background maps. Once the user has uploaded their data, we require them to select the latitude and longitude columns as well as which column they would like to color their points by. Once we have that information, we can correctly plot a geospatial map.

Other diagrams we implemented for data visualization include scatterplots, violin plots, line graphs, box plots, and histograms. To depict these graphs, we used ggplot2, a data visualization package that neatly graphs data with some customizability. For each of these graphs, we require users to select the x and y axis. On some plots, we also require additional data such as line thickness and color, which allows users to customize the look of their graph.

Shiny apps contain scripts for the UI and server which allows us to have remote persistent data storage and facilitates the continuation of data between different tabs for users. We also wanted users to be able to manipulate and tidy their own data as the datasets they are uploading aren't necessarily tidied, which would result in inaccurate modeling. To do this, we utilized R's tidyverse library to build out functionality for pivoting, selecting columns, and filtering within columns. This allows users to perform most standard tidying functions without complicating the app. The dataset we used for this was Utah County Climate Data. This was the last dataset we provided to users as a default option.

We wanted users to be able to calculate biodiversity indices, so we implemented a number of diversity index functions which include species richness and the Shannon-Wiener, Menhinick, Margalef, and McIntosh indices. We implemented a number of functions that would compute and return these values based on the standard index calculations.

We wanted users to be able to not just graphically visualize data, but use common statistical tests to learn more about their datasets. To do this, we implemented one- and two-sample t-tests as well as ANOVA. R and R-tidyverse have built in functionality for these tests so no additional packages were used. For these tests, we require the user to select one or both variables to be analyzed. For the one-sample t-test, we require null hypothesis mean, and for a two-sample t-test, we require them to select if it's a paired test and an equal variance test.

Results:

We created a climate browser that allows users to upload, manipulate, and visualize data all from one application. This application can be accessed here: https://bio350browser.shinyapps.io/climate_browser, and is currently up and running. Users can upload, tidy, test, and graph their data using the corresponding tabs, and can also calculate diversity indices if their data contains the necessary columns. Full descriptions for each of these functionalities are detailed below.

Data Upload:

Climate Browser includes functionality for a user to upload their own data (Figure 1). If they do not have data to supply, they can pick from one of the three pre-uploaded datasets currently available. This allows users to learn the functionality of the application without being required to supply their own data, and simplifies the tasks a student would be expected to complete for an assignment. Because of the simple way pre-uploaded datasets are added to Climate Browser, future administrators can easily replace or add datasets.

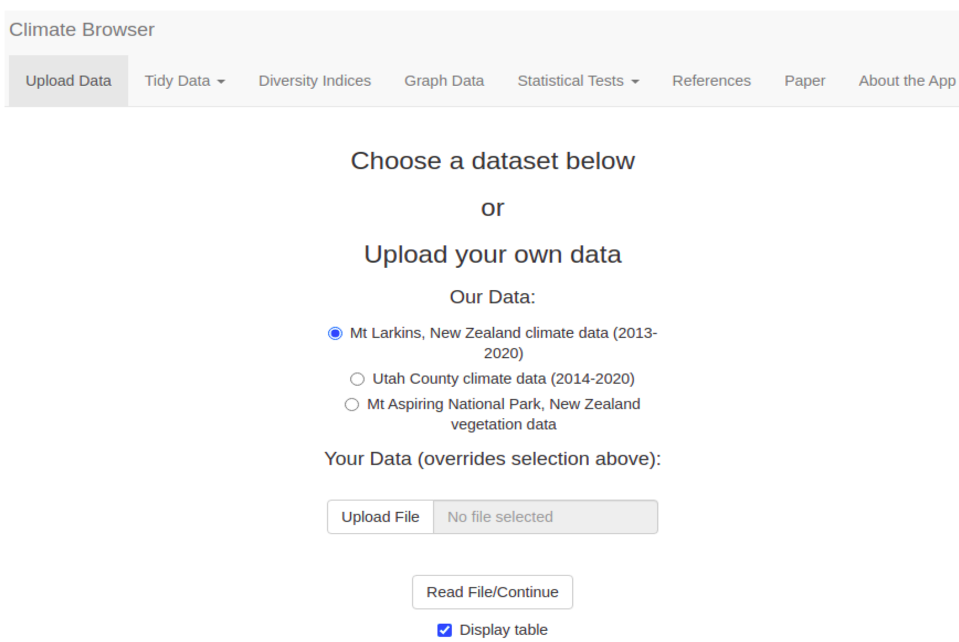
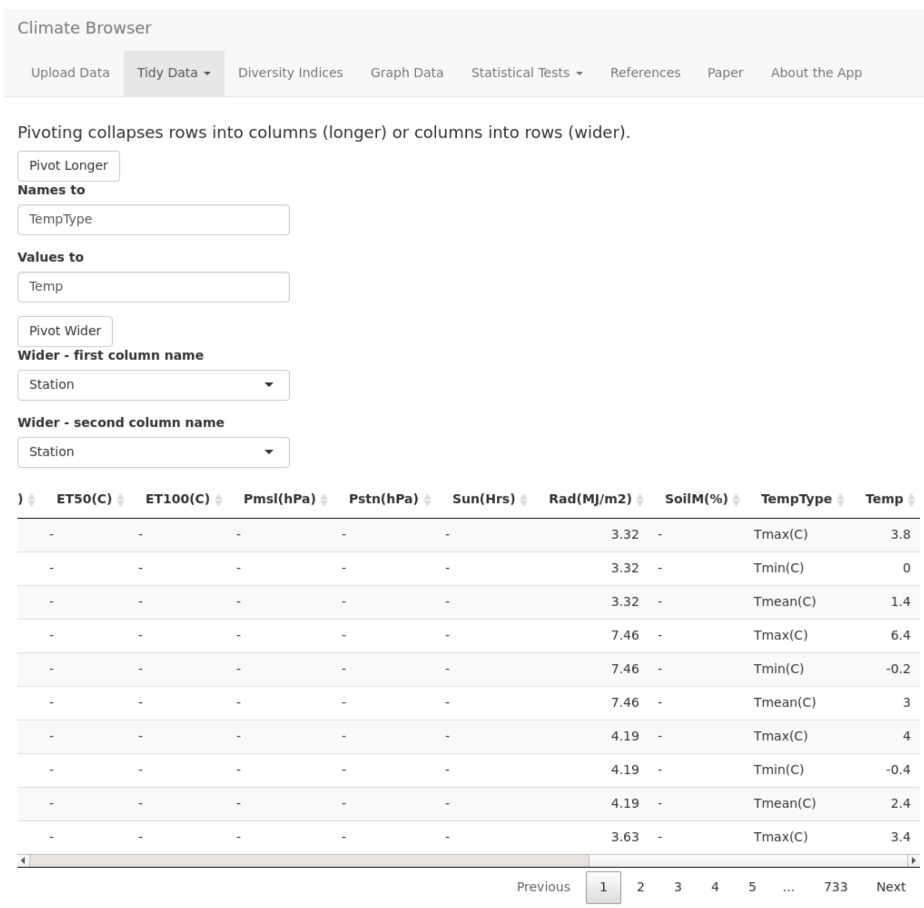


Figure 1: Home Page: Data Upload
This is the home page of Climate Browser, where users can select one of our three pre-uploaded datasets or upload their own. After making their selection and clicking the "Read File/Continue" button, the data will be available for

analysis.

Data Tidying:

Climate Browser allows users to tidy their data if desired as shown in Figure 2. This is important as their datasets may be in layouts which are not easy to run analyses on, or may have much more information than they care to analyze. Users are able to select columns which contain data of interest, and can filter rows based on values. If their data is in an unusable layout, they are able to pivot their data wider or longer. Users have the option to remove N/A values if any were present in the dataset or were added during pivoting.



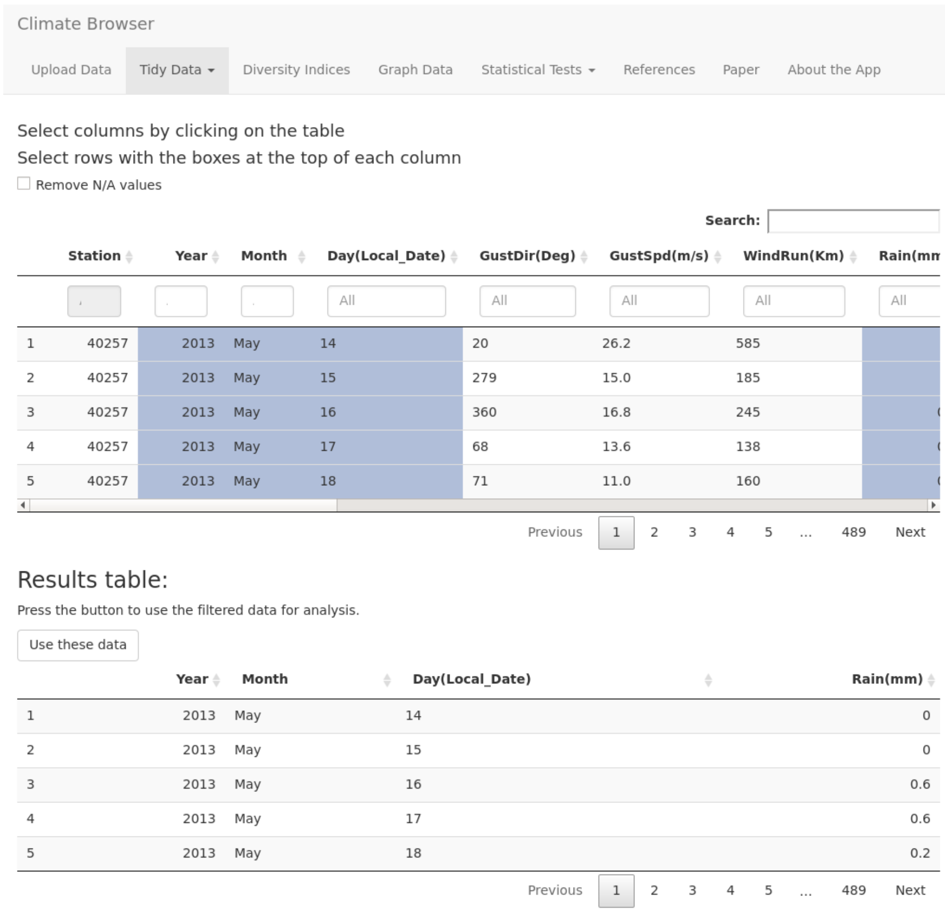
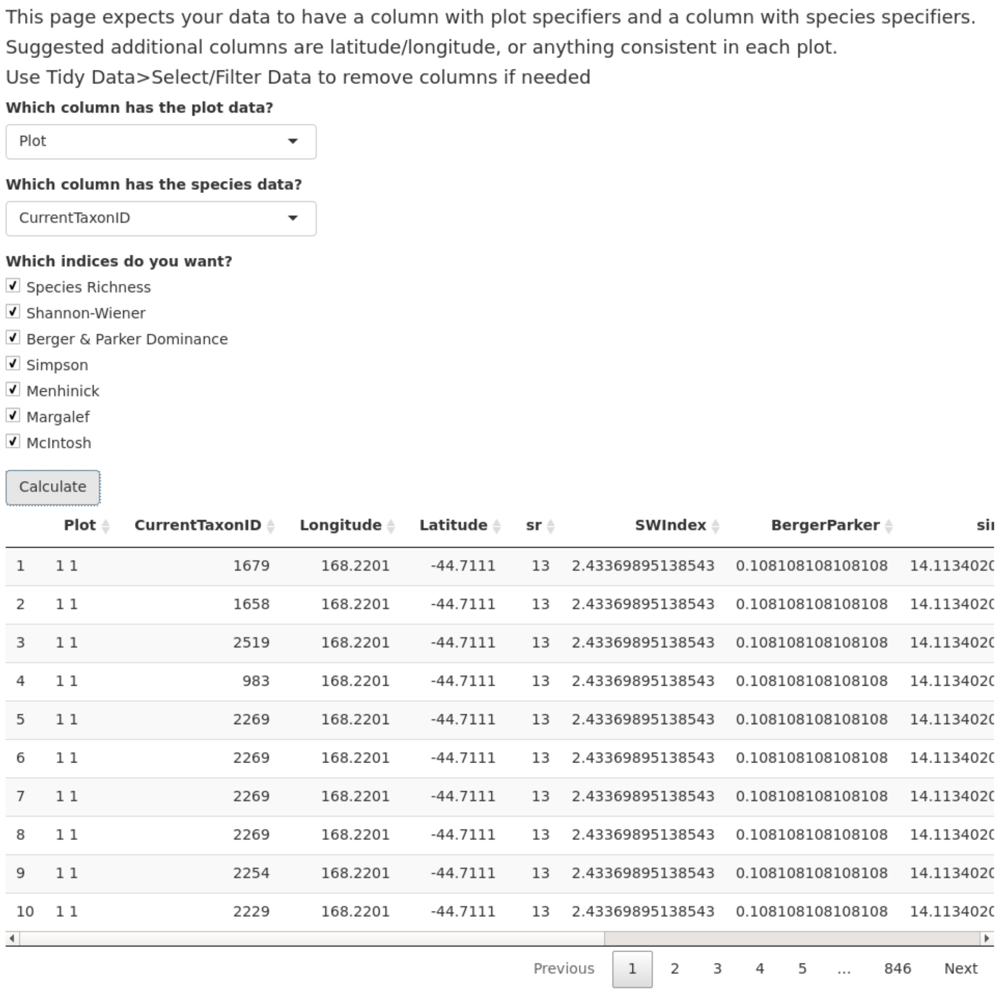


Figure 2: Data Tidying
Tidying functionality allows users to upload data in various layouts and use it for analysis. As shown in the top screenshot, users can pivot their data wider or longer if the layout is problematic. As shown in the bottom screenshot, users can filter rows and columns.

Diversity Indices:

Climate Browser includes functionality to calculate biodiversity indices (Figure 3), which are critical in ecology to quantify biodiversity in and between areas or regions. We implemented species richness, the Shannon-Wiener index, the Berger & Parker Dominance index, the Simpson index, the Menhinick index, the Margalef index, and the McIntosh index. More indices could be added in the future as desired by educators. Users can easily calculate these indices by selecting which column contains plot or region data, which column contains records of observed species, and the indices they would like to calculate. To assist with further analyses, users can choose to continue in the app using a dataset filtered to contain one row per plot. This functionality will allow students to compare ecosystems using full datasets from the real world, as opposed to oversimplified test datasets.



	Plot	CurrentTaxonID	Longitude	Latitude	sr	SWIndex	BergerParker	si
1	1 1	1679	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
2	1 1	1658	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
3	1 1	2519	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
4	1 1	983	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
5	1 1	2269	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
6	1 1	2269	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
7	1 1	2269	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
8	1 1	2269	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
9	1 1	2254	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020
10	1 1	2229	168.2201	-44.7111	13	2.43369895138543	0.108108108108108	14.1134020

Figure 3: Calculating Diversity Indices
Diversity indices are the primary way of quantifying the amount of diversity in an ecosystem. Students expect to learn how to calculate these, but they typically are hesitant to calculate them for large datasets unless they can program. This panel allows users to easily calculate these indices for large datasets.

Graphing:

Visually displaying data and understanding the patterns shown through different types of plots is a vital component of data literacy, so we ensured that the Climate Browser included this functionality. Separate pages were created for the Walter-Lieth climate diagram, line graph, scatter plot, box plot, violin plot, and histogram.

One graphing function in the app created especially to help with visualizing ecology data is the Walter-Lieth climate diagram page. With the Walter-Lieth climate diagram plotting feature (Figure 4), students can display a summary of climate data over time. The information that students need to input include columns of the year and month in which the data was recorded, as well as the precipitation, maximum temperature and minimum temperature over that time period. This information is displayed on the y axis as the mean daily precipitation and mean daily precipitation, with the x axis representing months over the year. Users also have the option to enter the name and exact location of the climatological station, including latitude, longitude, and altitude. The years in which the data was recorded is derived from the year column, and the graph title includes these years along with the station information. Walter-Lieth climate diagrams allow students to observe patterns in temperature and precipitation in certain climates, as well as commonalities between similar climates in different geographical areas.

For line graphs, scatter plots, box plots and violin plots, users only need to input columns that can be used as x and y axes. With line graphs, users also have the option to plot multiple lines by grouping data by another column, adjust line thickness and choose an appropriate color palette. When using the histogram page, users simply need to select a column to use as the x axis and the number of bins to use in displaying this continuous data. These different types of graphs will enable students to glean different types of information from their raw data.

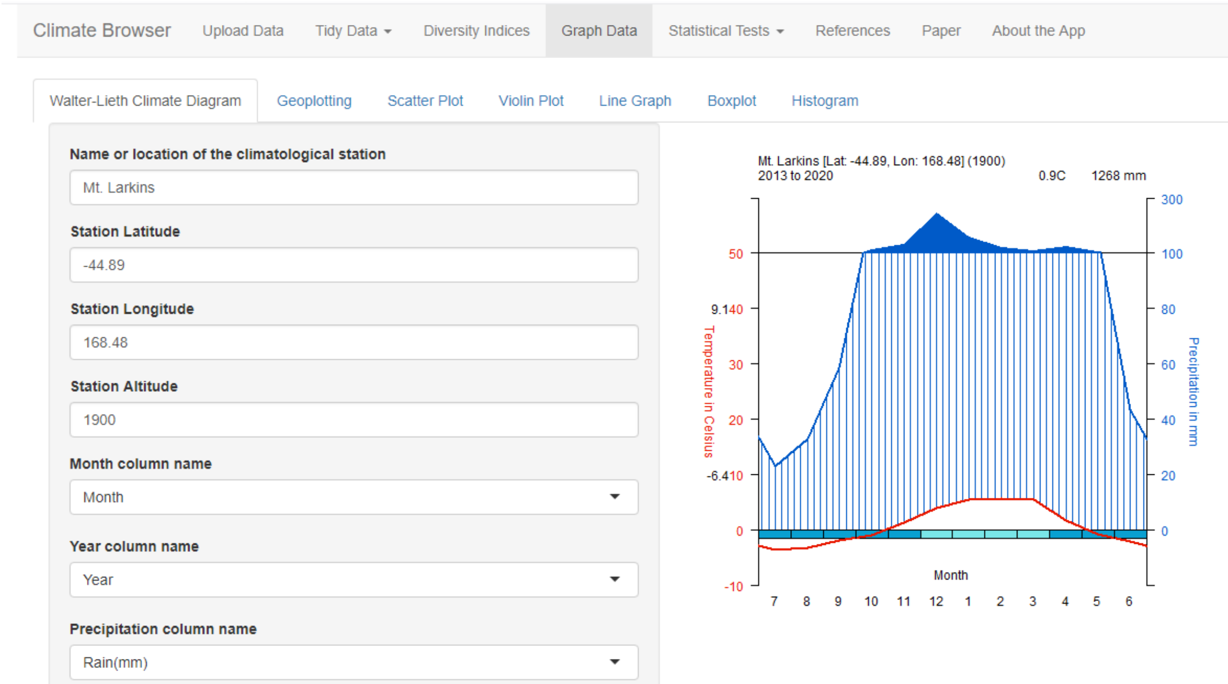


Figure 4: The Walter-Lieth Climate Diagram Page
Climate diagrams show monthly precipitation and temperature in an area, with temperature in red and precipitation in blue. Walter-Lieth climate diagrams summarize climate conditions for an area, and are especially useful for classifying an environment's climate type. These climate diagrams also show wet, dry, and humid periods which are useful for understanding a climate. In order to create the diagram, users must first have a file with daily precipitation levels, minimum and maximum temperature, along with the month and year in which these variables were recorded. Users can upload their climate data file, choose the appropriate columns using the dropdown menus, and specify other adjustments that will need to be made in plotting the diagram using the checkboxes. For example, standard Walter-Lieth climate diagrams show temperature in Celsius, so the user will need to note if the temperature is in Fahrenheit so the appropriate conversion can be made by the app. Users can also choose whether to display the table they upload. The table and graph are both displayed dynamically. Overall, this app is designed to be easy to use for ecology students without a coding background.

Geoplotting:

Figure 5 showcases the geoplotting functionality of our application. Users are able to use their previously uploaded and tidied data to select the correct latitude and longitude columns, allowing them to plot their data on an interactive map. Students are also given the option to choose a color which colors their data according to whichever category (another column) they decide. Once plotted, each individual point is clickable and allows users to see the data associated with it, allowing users to view their data in a map-view context. This geoplotting feature enables students to deepen their understanding of data in such a way that would be impossible through simply viewing a table or spreadsheet.

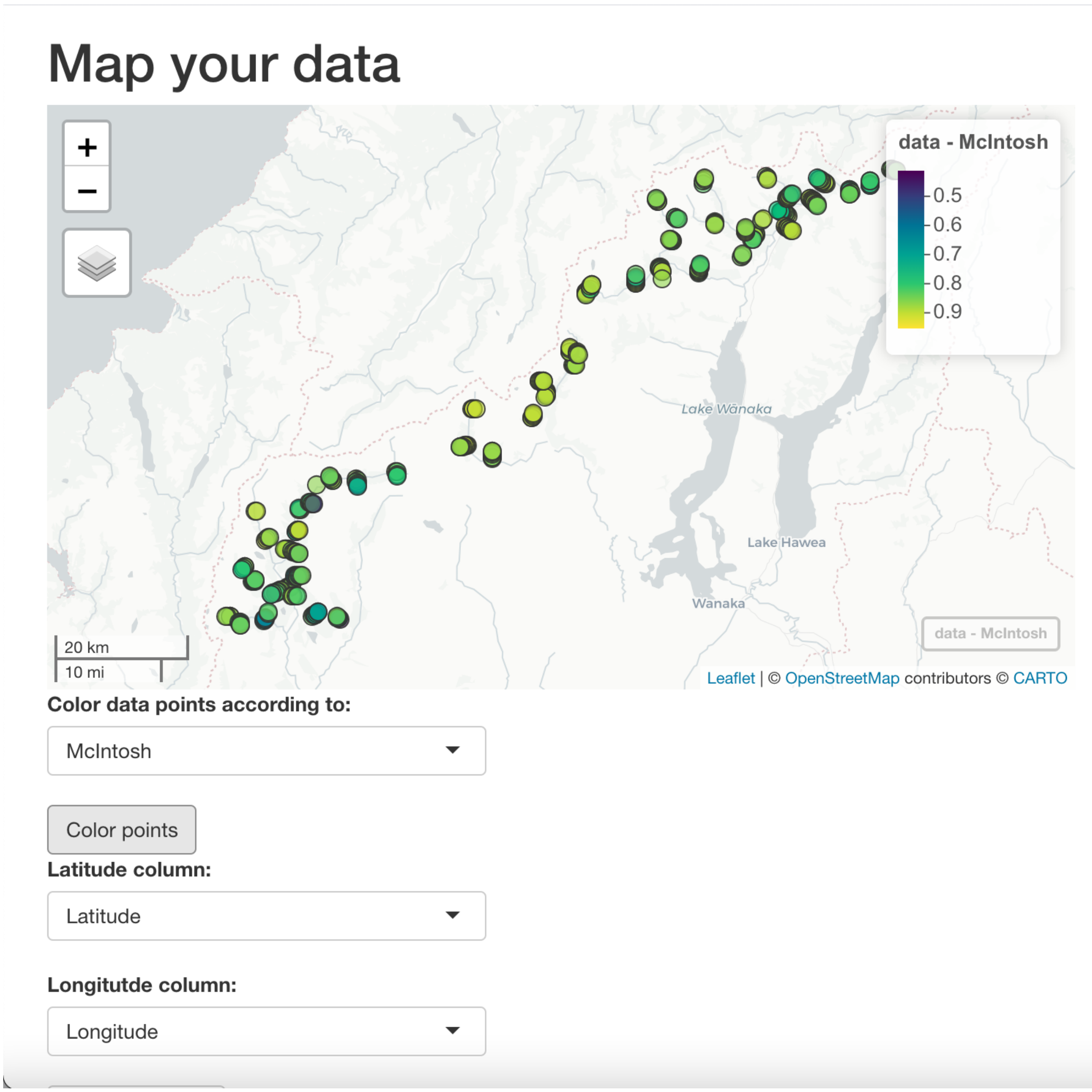


Figure 5: Plotting Geospatial Data
Users can use the geo-plotting tab in the application to plot data corresponding with latitude/longitude coordinates. Users can also select a column of their data to be used to determine the color of different data points on the map. The color shown here comes from the McIntosh species diversity index. Clicking on the map allows users to zoom in and out and pan over the plotted area, as well as click individual data points to show their corresponding data not shown on the map itself.

Statistical Tests:

While the information shown in various types of graphs will help students visualize and understand their data better, we also wanted to implement some functionality for testing hypotheses on their data using statistical tests. These tests include one and two-sample t-tests, as well as ANOVA tests for the comparison of means. Figure 6 showcases one example of how a user would compare the means of two columns in their uploaded data. Also included under the tab labeled “Statistical Tests” is a tab that allows users to log-transform certain parts of their uploaded data, if desired, in order to have their data more closely resemble the normal distribution.

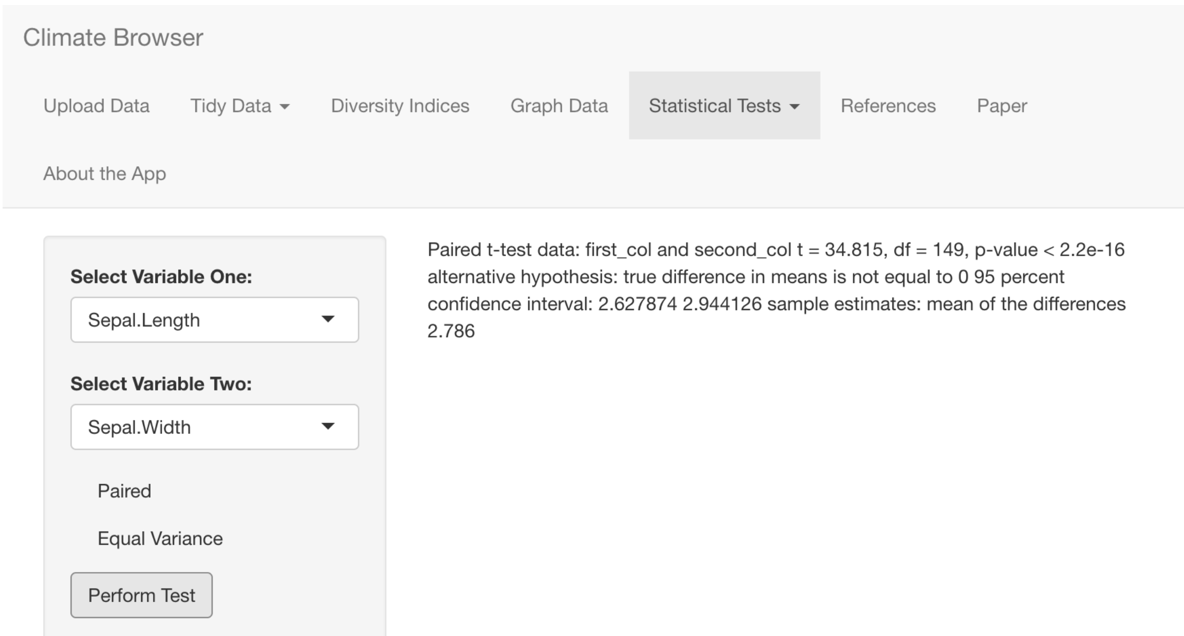


Figure 6: Two-Sample T-Test
Users under this tab select two different columns from their data in order to compare their means. They then select whether their data is paired and/or has equal variance. Upon clicking the “Perform Test” button, users are able to see the results of their t-test, including a p-value, a confidence interval, and the mean of differences.

Discussion:

Our goal in creating a climate browser was to help ecology students with limited exposure to programming languages learn to work with meaningful data. Our product does exactly that. It is easily accessed by both students and educators through our URL (https://bio350browser.shinyapps.io/climate_browser). While it is possible for students, through extensive searching, to find other sites and tools for them to create graphs and perform tests on data, there is no site that makes all of these tools so accessible to ecology students. This is especially true for calculating diversity indices and creating Walter-Lieth climate diagrams, both of which are incredibly important to ecologists. Our climate browser provides a powerful, easy to use interface that gives ecology students the ability to produce them quickly.

Moving forward in developing the Climate Browser, there is still much work to be done. The desire to help students become data literate is not limited to ecology. In a data-driven world, students from many other backgrounds would benefit from the ability to work with real-world data. Our browser is catered mostly towards ecology students, but the concepts in it can and should easily be applied to other fields. Furthermore, there is much more that can be done to optimize our browser's functionality in the field of ecology. The optimization of memory usage, for example, would allow bigger groups of students to access our browser at a time while still being hosted on a free server. More statistical tests and graphing types could be added. In suggesting these future modifications and adaptations to our browser, our hope is for data literacy to become the standard for students and professionals in ecology and all other scientific fields.

References

Abhilash, L., & Sheeba, V. (2019). *RhythmicAlly: Your R and Shiny–Based open-source ally for the analysis of biological rhythms* Sage Journals.

Antonelli, T. M., & Olivieri, A. C. (2020). Developing and implementing an R shiny application to introduce multivariate calibration to advanced undergraduate students. *Journal of Chemical Education, 97*(4), 1176-1180. doi:10.1021/acs.jchemed.9b00850

Auslander, G. K., & Rosenne, H. (2016). Data mining for social work students: Teaching practice-based research in conjunction with a field work placement. *Journal of Teaching in Social Work, 36*(1), 52-69. doi:10.1080/08841233.2016.1125731

Cooke, J., Araya, Y., Bacon, K. L., Bagniewska, J. M., Batty, L. C., Bishop, T. R., . . . Dougherty, L. R. (2021). Teaching and learning in ecology: A horizon scan of emerging challenges and solutions. *Oikos, 130*(1), 15-28.

Dierauer, J. R., Zhu, C., Gong, L., Walsh, A., Pamidighantam, S., Wang, J., . . . Abeysinghe, E. (Jul 26, 2020). FutureWater indiana: A science gateway for spatio-temporal modeling of water in wabash basin with a focus on climate change. Paper presented at the 252-261. doi:10.1145/3311790.3396651 Retrieved from http://dl.acm.org/citation.cfm?id=3396651

Doi, J., Potter, G., & Wong, J. (2016). *UCLA technology innovations in statistics education title web application teaching tools for statistics using R and shiny journal publication date*

du Prel, J., Röhrig, B., Hommel, G., & Blettner, M. (2010). Choosing statistical tests: Part 12 of a series on evaluation of scientific publications. *Dtsch Artztebl Int.,* Retrieved from https://pubmed.ncbi.nlm.nih.gov/20532129/

Ellis, D. A., & Merdian, H. L. (2015). Thinking outside the box: Developing dynamic data visualizations for psychology with shiny. *Frontiers in Psychology, 6*, 1782.

Fawcett, L. (2018). Using interactive shiny applications to facilitate research-informed learning and teaching. *Journal of Statistics Education, 26*(1), 2-16. doi:10.1080/10691898.2018.1436999

Fellers, P. S., & Kuiper, S. (2020). Introducing undergraduates to concepts of survey data analysis. *Journal of Statistics Education, 28*(1), 18-24. doi:10.1080/10691898.2020.1720552

Feng, D.*Interact with your data and create interactive plots with R shiny*

Funk, D., & Zahadat, N.R shiny as an effective tool for reproducible dissemination of public health data.

Goedhart, J. (2020). PlotTwist: A web app for plotting and annotating continuous data. *PLoS Biology, 18*(1), e3000581. doi:10.1371/journal.pbio.3000581

Goedhart, J., & Luijsterburg, M. S. (2020). VolcaNoseR is a web app for creating, exploring, labeling and sharing volcano plots. *Scientific Reports, 10*(1), 20560. doi:10.1038/s41598-020-76603-3

González, J. A., López, M., Cobo, E., & Cortés, J. (2018). Assessing shiny apps through student feedback: Recommendations from a qualitative study. *Computer Applications in Engineering Education, 26*(5), 1813-1824. doi:10.1002/cae.21932

Goto, E., Clarke, K., & Keller, E. (Nov 06, 2018). A tool to compute the landslide degree of risk using R-studio and R-shiny. Paper presented at the 1-7. doi:10.1145/3284103.3284122 Retrieved from http://dl.acm.org/citation.cfm?id=3284122

Greenhalgh, T. (1997). How to read a paper: Statistics for the non-statistician. I: Different types of data need different statistical tests. *BMJ (Clinical Research Ed.),* Retrieved from https://doi.org/10.1136/bmj.315.7104.364

Guo, W., Tzioutziou, N. A., Stephen, G., Milne, I., Calixto, C. P., Waugh, R., . . . Zhang, R. (2020). *3D RNA-seq: A powerful and flexible tool for rapid and accurate differential expression and alternative splicing analysis of RNA-seq data for biologists* Informa UK Limited. doi:10.1080/15476286.2020.1858253

Holland-Letz, T., & Kopp-Schneider, A. (2021). An R-shiny application to calculate optimal designs for single substance and interaction trials in dose response experiments. *Toxicology Letters, 337*, 18-27. doi:10.1016/j.toxlet.2020.11.018

Hovardas, T., & Korfiatis, K. (2011). Towards a critical re-appraisal of ecology education: Scheduling an educational intervention to revisit the ‘balance of nature’ metaphor. *Science & Education, 20*(10), 1039-1053.

Konrath, A. C., Aparecido Da Silva, S., Henning, E., Mulazani, L., Santos, D., Gabriel De Miranda, R., & Samohyl, R. W. (2017). *Desenvolvimento de aplicativos web com R e shiny: Inovações no ensino de estatística ⇤ development of web applications with R and shiny: Innovations in teaching statistics*

Langen, T. A., Mourad, T., Grant, B. W., Gram, W. K., Abraham, B. J., Fernandez, D. S., . . . Rodriguez, J. (2014). Using large public datasets in the undergraduate ecology classroom. *Frontiers in Ecology and the Environment, 12*(6), 362-363.

Li, Y. (2020). Towards fast prototyping of cloud-based environmental decision support systems for environmental scientists using R shiny and docker. *Environmental Modelling & Software, 132*, 104797.

Mcguinness, L. A., Higgins, J. P. T., & Mcguinness, L. A.*Risk-of-bias VISualization (robvis): An R package and shiny web app for visualizing risk-of-bias assessments*

Morshed, S. M., MPH, Tornetta, P. I. M., & Bhandari, Mohit MD, MSc, FRCSC. (2009). Analysis of observational studies: A guide to understanding statistical methods. *Jbjs, 91*(Supplement 3) Retrieved from https://pubmed.ncbi.nlm.nih.gov/19411500/

Neumann, D. L., Hood, M., & Neumann, M. M. (2013). Using real-life data when teaching statistics: Student perceptions of this strategy in an introductory statistics course. *Statistics Education Research Journal, 12*(2)

Qian, J., & Ming, S. (Nov 06, 2018). Centroid-amenities. Paper presented at the 616-617. doi:10.1145/3274895.3282798 Retrieved from http://dl.acm.org/citation.cfm?id=3282798

Roberts, E. (Mar 07, 2007). Resurrecting the applet paradigm. Paper presented at the 521-525. doi:10.1145/1227310.1227488 Retrieved from http://dl.acm.org/citation.cfm?id=1227488

Rolfes, T., Roth, J., & Schnotz, W. (2020). Learning the concept of function with dynamic visualizations. *Frontiers in Psychology,* Retrieved from https://pubmed.ncbi.nlm.nih.gov/32425845/

Schweinberger, M. (2020). Displaying geo-spatial data with R. Retrieved from https://slcladal.github.io/maps.html

Smith, R., Schneider, P., & Feenstra, T. L. (2020). *Making health economic models shiny: A tutorial [version 2; peer review: 2 approved] report report*

Su, Y.S. (2008). It’s easy to produce chartjunk using Microsoft® Excel 2007 but hard to make good graphs. *Computational Statistics & Data Analysis*, *52*(10), 4594-4601.

Větrovský, T., Kohout, P., Kopecky, M., Machac, A., Man, M., Bahnmann, B. D., . . . Baldrian, P. (2019). A meta-analysis of global fungal distribution reveals climate-driven patterns. *Nat Commun.,* Retrieved from https://pubmed.ncbi.nlm.nih.gov/31723140/

Wadhwa, R. R., & Marappa-Ganeshan, R. (2020). T test. *StatPearls,* Retrieved from https://pubmed.ncbi.nlm.nih.gov/31971709/

Whitworth, G.Shiny and geo-spatial visualization. Retrieved from https://rna.wlu.edu/bio297/04-shiny-geo.html

Williams, I. J., & Williams, K. K. (2018). Using an R shiny to enhance the learning experience of confidence intervals. *Teaching Statistics, 40*(1), 24-28. doi:10.1111/test.12145

Wojciechowski, J., Hopkins, A., & Upton, R. (2015). Interactive pharmacometric applications using R and the shiny package. *CPT: Pharmacometrics and Systems Pharmacology, 4*(3), 146-159. doi:10.1002/psp4.21

Yu, Y., Ouyang, Y., & Yao, W. (2018). shinyCircos: An R/shiny application for interactive creation of circos plot. *Bioinformatics, 34*(7), 1229-1231. doi:10.1093/bioinformatics/btx763