Module description and purpose:

The AIMS project was founded on the idea that students don't often care much about statistical analysis until they care about the research questions at hand. Most faculty didn't love stats either until they had data they worked hard to collect, and desperately wanted to know what those data meant. We can't have every undergraduate collect a dissertation's worth of data, but we can provide opportunities for them to decide what investigative path to take, and maybe they will subsequently care a bit more about learning and applying statistical approaches in the same way that we did.

Setting:

The setting for this research experience is the dendroclimatological research of Dr. Stockton Maxwell and colleagues, conducted in the forests of the eastern US. Stockton works to reconstruct climatological records from examining tree rings, and especially to understand the relative roles of ecological and long-term climate factors in tree growth.

**Modifying the activities**

This activity has been designed to be modular - you can take pieces and parts that are relevant to your course and build your own lab experience. For example, there are instructions and guidance for fieldwork if you'd like to include local sampling, and there is a primer on regression analyses if your students haven't yet been exposed or will need a reminder of those concepts.

We present two levels of analysis and student post-lab assignment, depending on what students are ready for, but the complexity can ratchet up from here. Dendroclimatology as practiced by experts in the field gets pretty quantitatively sophisticated, so if you and your students are ready for that, dive in. Moreover, there are lots of accessory videos and resources that you can pick and choose from - not all of them will fit into a single lab experience. We encourage you to cut, paste, rework, improve, **and repost** the lab - the changes you make might be just what others need, and your work can save them time, and **you could become famous**.

Learning Objectives:

The realized learning objectives will of course vary depending on how the materials are modified, but at the core the objectives are for students to:

* Be able to conduct and interpret simple linear regression analyses, including interpretation of p-values, R2, and the equation for the line of best fit.
	+ Success could be defined as a student being able to at least get the dichotomous "are these variables related" or "is there a significant relationship" correct, given an analysis, and being able to make predictions based on the regression equation.
* Be able to implement and understand the necessity of standardizing data by a covariate (e.g., adjusting raw ring widths for the relationship between ring width and tree size)
	+ Success could be defined as a student being able to adjust a data set for body size and then conduct a linear regression on the adjusted data (e.g., look at the relationship between metabolic rate and temperature, adjusted for body size)
* Gain appreciation for the utility of image analysis in biology, and gain some experience with simple data collection from images (linear measurements).
	+ Success could be defined as a student being able to identify research problems where image analysis would or would not be useful.
* Be able to describe the basic procedures and purposes of dendrochronology, including how cores are obtained and prepared for observation, what measurements are routinely taken, how data are treated, and identify some scientific questions that can be addressed.
	+ Success could be defined as a student being able to properly describe dendrochronology methods used here in a post-lab experiment, or answering specific questions about the process.

Additional learning objectives that could be added:

* Data manipulation and management
	+ Depending on the source of climate data, and the variables that the students define to be of interest, there may be significant data manipulation to get the data in a useful form (e.g., taking daily precipitation measurements and aggregating them over different time frames, or looking for minimums or maximums, etc.)
* Review the basics of plant growth and morphology
* Discuss the impact of measurement error on scientific studies and analyses

**Alignment**

**AP Biology:**

Learning objective 4.14: The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy. [See SP 2.2; Essential knowledge 4.A.6]

[**Next Generation Science Standards**](http://www.nextgenscience.org/hsls-ivt-inheritance-variation-traits)**:**

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### Science and Engineering Practices: [Planning and Carrying Out Investigations](http://www.nap.edu/openbook.php?record_id=13165&page=59): Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-LS1-3)

Science and Engineering Practices: Using Mathematics and Computational Thinking: Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)

Science and Engineering Practices: Constructing Explanations and Designing Solutions: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-6), HS-LS2-3)

### Science and Engineering Practices: [Obtaining, Evaluating, and Communicating Information](http://www.nap.edu/openbook.php?record_id=13165&page=74): Communicate scientific information (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-LS4-1)

Science and Engineering Practices: Asking Questions and Defining Problems: Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)

Science and Engineering Practices: Developing and Using Models: Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS3-3)

[**Common Core ELA Standards for Science and Technical Subjects**](http://www.corestandards.org/ELA-Literacy/RST/11-12/)**:**

[CCSS.ELA-LITERACY.RST.11-12.3](http://www.corestandards.org/ELA-Literacy/RST/11-12/3/)
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

[CCSS.ELA-LITERACY.RST.11-12.7](http://www.corestandards.org/ELA-Literacy/RST/11-12/7/)
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

[CCSS.ELA-LITERACY.RST.11-12.9](http://www.corestandards.org/ELA-Literacy/RST/11-12/9/)
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

[**Common Core Mathematics Standards for Statistics and Probability**](http://www.corestandards.org/Math/Content/HSS/introduction/)**, Algebra:**

[CCSS.MATH.CONTENT.HSS.ID.A.1](http://www.corestandards.org/Math/Content/HSS/ID/A/1/)
Represent data with plots on the real number line (dot plots, histograms, and box plots).

[CCSS.MATH.CONTENT.HSN.Q.A.1](http://www.corestandards.org/Math/Content/HSN/Q/A/1/)
Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

[CCSS.MATH.CONTENT.HSN.Q.A.2](http://www.corestandards.org/Math/Content/HSN/Q/A/2/)
Define appropriate quantities for the purpose of descriptive modeling.

[CCSS.MATH.CONTENT.HSA.CED.A.2](http://www.corestandards.org/Math/Content/HSA/CED/A/2/)
Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

[CCSS.MATH.CONTENT.HSA.REI.D.10](http://www.corestandards.org/Math/Content/HSA/REI/D/10/)
Understand that the graph of an equation in two variables is the set of all its solutions plotted in the coordinate plane, often forming a curve (which could be a line).

[CCSS.MATH.CONTENT.HSF.IF.C.7.A](http://www.corestandards.org/Math/Content/HSF/IF/C/7/a/)
Graph linear and quadratic functions and show intercepts, maxima, and minima.

[CCSS.MATH.CONTENT.HSF.LE.B.5](http://www.corestandards.org/Math/Content/HSF/LE/B/5/)
Interpret the parameters in a linear or exponential function in terms of a context.

**Instruction level**: Introductory or advanced undergraduate biology courses, high school, AP biology

**Prerequisite knowledge:** This module is designed to fit into a study of ecology, evolution, plant anatomy, or the like. Alternatively, it could be used in a biostatistics course as an interesting context for analysis. Previous experience with image analysis is not required for either the instructor or the students.

**Keywords**: data visualization, graphing, linear regression, dendrochronology, tree rings, climate, standardization

**Where might this lab fit**

This activity has also been designed to be self-explanatory - that is, **if** students actually read the instructions, watch tutorial videos, then they should be able to work their way through with little trouble. Thus, it may be possible to assign the entire experience as homework, rather than hosting it in a lab period, allowing adoption in courses without lab periods, online classes, etc. That being said, it is really nice to be able to work with students to develop meaningful hypotheses and to overcome technical glitches, face to face. For courses with outdoor labs, this is a great one to keep "on the shelf" in case of inclement weather.

**Potential Research Questions - openness of the inquiry**

Students are being asked todevelop their own research hypotheses, and this can be challenging for both them and the instructor. Some instructors may prescribe a hypothesis to investigate, others may want to host a whole-class discussion of the types of questions that can be addressed and that are biologically meaningful, and then choose one for the whole class to collaboratively work on. Other instructors might have individuals or small groups choose their own hypotheses. The degree of open-inquiry is up to you, but one of the advantages that we tried to build into these materials is the possibility for student-driven inquiry. We anticipate that students who craft their own questions should have greater engagement and care a bit more about the answers that the analyses provide.

Just a few example questions:

*Intro Level*

1. Do all trees grow at the same annual rate?
2. What is the narrowest (and widest) ring in the chronology? What was the climate like that year?
3. What is the relationship between a trees age and its diameter?

*Advanced Level*

1. Are average monthly climate values more important to tree growth than average annual climate values?
2. Does the previous year’s climate affect the current year’s growth?
3. Has the relationship between tree-growth and climate changed over time (correlations in different time periods)?

If you or your students come up with an interesting research question to address, let Jeremy know... we can add it to this list (with attribution)!

*Super-advanced Level*

You could collect more local data in the field, look for other tree core images in online data bases, get data from published papers or data repositories, or find other climate data to expand the frame of inference.

**Data quality**

Included in the instructor resources (links below) for this lab are professionally measured tree ring widths for each core image. These can be used by instructors in several ways:

* As a quality check on your students - you can have them submit their data, regress it against the "correct" data, and use the R2 as a metric of how well they did collecting their data. This could even be part of their grade.
* As part of a lesson on data quality - you can have students compare their data with the "correct" data, and have them include an assessment or discussion of measurement error in their post-lab reports. Data quality/measurement error is a topic of great importance that is very rarely explicitly examined in undergraduate education, and having students do the analysis also gives them practice with another regression.
* If you have small student groups all investigate the same hypothesis, but collect their own data from the images, you could even do a "meta-analysis" of sorts looking at whether data quality cascaded to determine whether the student groups found meaningful patterns between climate and tree growth. Presumably sloppy data going in would mean one would be less likely to find significant relationships between climate and growth. This could be quite an interesting discussion especially as it applies to Type-I and Type-II error rates, and situations where industries or agencies want or don't want to find significant differences (i.e. environmental monitoring, side effects from pharmaceuticals, etc.)

**Useful Web Sources:**

The Science of Tree Rings – a detailed resource for dendrochronology (<http://web.utk.edu/~grissino/>)

Dr. Henri Grissino-Mayer’s Youtube Channel – tree coring and cutting demonstrations (<https://www.youtube.com/channel/UC9RszazKr-3iJ4SANr0lXyg/videos>)

Ohio University Tree-Ring Laboratory – Introduction to Dendrochronology (<https://www.ohio.edu/plantbio/staff/mccarthy/dendro/body.htm>)

Crossdating and Skeleton Plotting – how to accurately date trees (<http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm>)

International Tree-Ring Data Bank – open access to tree-ring collections around the world (<http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring>)

PRISM Climate Group – climate data for the United States (<http://www.prism.oregonstate.edu/>)

National Centers for Environmental Information – source for climate, paleoclimate, and environmental data (<https://www.ncdc.noaa.gov/cdo-web/>)

North American Dendroecological Fieldweek – training tree-ring scientist from the novice to professional level (<https://sites.google.com/site/northamericandendrofieldweek/>)

TRADER Package in R – used to analyze raw ring width data for forest disturbance (<https://github.com/pavel-fibich/TRADER>). Reading in folder.

dplR Package in R – Dendrochronology Program Library in R can perform tree-ring analyses such as detrending, chronology building, and cross dating. Read and write standard file formats used in dendrochronology (<https://cran.r-project.org/web/packages/dplR/index.html>). Reading in Folder.

**Associated resources/files:**

* [Worksheet activities on dendrochronology from other sources](http://www.radford.edu/~jmwojdak/AIMS_Dendro/Instructor_resources/worksheets)
* [Readings related to dendrochronology](http://www.radford.edu/~jmwojdak/AIMS_Dendro/Instructor_resources/readings)
* [Expert measurements: raw ring widths, adjusted ring widths, and DBH](http://www.radford.edu/~jmwojdak/AIMS_Dendro/Instructor_resources/expert_data)
	+ Raw ring widths are the direct observations from the cores
	+ A "chronology" in dendro speak is the adjusted ring widths, using the negative exponential relationship between tree size and tree ring width described in the module to adjust raw ring widths
	+ DBH is diameter at breast height, a common forestry metric of tree size.
* [More photos, to set scene in powerpoint pre-lab, etc.](http://www.radford.edu/~jmwojdak/AIMS_Dendro/Instructor_resources/photos)
	+ file names are reasonably descriptive