TREE-RING RESEARCH, *Vol. 75(2), 2019, pp. 160–166*
DOI: http://dx.doi.org/10.3959/1536-1098-75.2.160

DENDRO-EDUCATION REPORT

TREE-RING EXPEDITIONS (TREX): ONLINE LABS THAT GUIDE UNDERGRADS TO THINK LIKE SCIENTISTS

NICOLE DAVI[1,2]*, PATRICK PRINGLE[3], JEFF LOCKWOOD[4], FRANCESCO FIONDELLA[5], and ROSE OELKERS[1,2]

[1]William Paterson University, Department of Environmental Science, Wayne, NJ, 07470 USA

[2]Tree-Ring Laboratory, Lamont-Doherty Earth Observatory, Palisades, NY, 10964 USA

[3]Centralia College, Centralia, WA, 98531 USA

[4]Curriculum Consultant, Durham, ME, 04222 USA

[5]International Research Institute for Climate and Society, Palisades, NY, 10964 USA

ABSTRACT

Here we describe five publicly available online labs, geared to undergraduate students, which focus on foundational tree-ring research. Students are introduced to basic dendrochronological concepts and practices (Lab 1) while learning about research that has implications for human well-being. Students learn about the way scientists use tree-ring records to reconstruct drought in the Hudson Valley in New York (Lab 2), how tree-ring science began through its utility in putting exact calendar dates on ancestral pueblos (Lab 3), how tree-ring records can be used to put drought into a long-term context, reconstruct streamflow, and better manage water resources (Lab 4), and how tree rings have been used to reconstruct temperatures in the northern latitudes (Lab 5). These labs have the dual aim of guiding students to use many of the same tools as tree-ring scientists, while also giving them a sense of the nature-of-science and how scientists work. Throughout the labs, students are guided to explore virtual field sites, navigate public databanks, observe and measure tree-ring samples, and describe trends and extremes in paleoclimate records. Labs are designed for a 2 to 3-hour lab class and have been classroom-tested and assessed by faculty teams and students.

Keywords: dendrochronology, paleoclimate, climate change, nature-of-science, science education, tree rings, science literacy, climate literacy, undergraduate education.

INTRODUCTION

Many aspects of dendrochronology are accessible to undergraduate students. Conceptually, tree rings are both visual and intuitive. Trees are part of the everyday experience of most students, and even non-experts can start to see patterns of climate variability through time just by looking at a cross-section of a tree. Many tree-ring scientists also travel to beautiful, remote regions across the world in search of long-lived, slow-growing trees that are capturing a climate signal in their annual growth rings. These remote field sites and scientific expeditions are of inherent interest to students and can be utilized to generate student interest in the nature-of-science and the methods scientists use to study past climate.

Here, we present five publicly-available online labs designed for undergraduate instructors and students. Within these labs students learn about fundamental concepts, such as how scientists conduct research and by what means authentic tree-ring data can be used, for example, to learn about temperature variability of the past two thousand years in the Northern Hemisphere (Wilson *et al.* 2016), to place exact calendar dates on ancestral pueblos in the U.S. Southwest (Douglass 1929), and to reconstruct streamflow estimates for the U.S. Colorado River (Woodhouse and Lucas 2006). In addition to being able to virtually explore tree-ring

*Corresponding author: ndavi@ldeo.columbia.edu

field sites, students can measure and evaluate tree-ring data, and use visualization tools to explore time-series in more detail.

For undergraduate students in science, a need exists for improved understanding as to how scientists work and how they develop the underlying data used in climate research. For example, a graph of a multi-proxy, collaboratively-developed paleoclimate reconstruction can provide insights about climate variability through time, but what it can't show is the extraordinary scientific effort that went into creating that dataset: the inspiration behind an idea, attempts (successful and unsuccessful) to get funding, launching a field expedition to collect data, processing and analyzing those data, publishing, and presenting results to peers at conferences. Helping students develop a deeper understanding of the nature-of-science, as well as how scientists work and evaluate evidence was our primary motivation in designing these labs. Each lab is briefly described below, along with classroom recommendations. Key questions, datasets and media used, and student tasks are described in Table 1. Learning objectives for each lab are listed in Table 2.

LAB DESCRIPTIONS

Lab 1. Launching an Expedition

In **Lab 1** we introduce students to the science of dendrochronology. They will see how tree-core samples are obtained, watch an animation about climate sensitivity in trees, virtually explore important field sites, and answer questions about why they think these sites are of interest to scientists. They hear from accomplished dendrochronologists who describe their career paths, the role serendipity has played in their careers, and offer advice to students interested in pursuing science as a career (**Video 1**). Students hear from dendrochronologist Rosanne D'Arrigo, discussing what it means to be a scientist). Students explore the tree-ring datasets available from The International Tree-Ring Databank (ITRDB) to search for data that is nearest to their home or university and are guided to use Google Scholar to see if they can find associated peer-reviewed articles. They are also guided to explore the National Science Foundation website to learn about the various directorates and to see what research has been recently funded.

Lab 2. Humpty Dumpty and Drought in the Hudson Valley, NY

Humpty Dumpty Talus Slope (https://goo.gl/maps/f8kDp8Y4KK42) is a tree-ring study site in southern New York State, marked by giant sandstone and conglomerate boulders, which is home to a forest of hemlock trees that have been growing for centuries. This site has some of the best examples of drought-sensitive trees in the northeastern U.S., and in the 1970s became the catalyst for tree-ring studies in the region (Cook 2014). In **Lab 2**, students virtually explore the Humpy Dumpty Talus Slope and learn the importance of finding sites where long-lived, climate-sensitive trees grow. Students examine high-resolution digital scans of samples taken from these trees, zoom in and out of the scans using virtual microscopes, and compare ring patterns to meteorological data that they have learned to download online. In **Video 2**, Ed Cook describes why the Humpty Dumpty Talus Slope site is valuable for studying past climate, and what drew him to the area in the 1970s.

This lab concludes with an optional assessment activity called "Meet the Challenge", where students can apply their newly acquired skills comparing tree-ring patterns to climate data, to a tree-ring site in a different part of the world—Central Asia.

Lab 3. Tree Rings and the Ancestral People of Pueblo Bonito

The science of dendrochronology began because of its utility in assigning exact calendar dates to ancestral pueblos in the US Southwest (Douglass 1929). In **Lab 3**, students virtually explore Pueblo Bonito, in Chaco Canyon, New Mexico, for wood samples that may be suitable for tree-ring sampling. They are guided to develop a skeleton plot using a high-resolution digital scan of one of the original samples taken from the site in the 1920s (Figure 1). Students then compare their skeleton plot to an original created by the founder of tree-ring science, A. E. Douglass, and to another skeleton plot of the same sample, created by

Table 1. TREX labs, key questions addressed, datasets/multimedia used in each lab, and student tasks.

TREX Labs:	Key Questions:	Datasets, Software, Platforms, and Media:	Student Tasks:
Lab. 1. Launching an Expedition: Introduction to dendrochronology and the nature-of-science.	• How do scientists take tree-core samples? • What site characteristics are important for tree-ring studies? • How do scientists learn about what has already been done? • How do scientists get funding for research?	• Virtual 360° field exploration • ITRDB • Google Scholar • Video: Scientist interviews[A] • NSF Research News • Animation: Identifying Climate Sensitive Trees • Video: Historical video	• Virtually explore and describe sites • Watch interviews • Explore NSF website • Search the ITRDB
Lab 2. Humpty Dumpty and Drought in the Hudson Valley: Focuses on a premier climate-sensitive site in the US Northeast and on how scientists use tree rings to develop a drought record of the region.	• What site characteristics are important for tree-ring studies? • Why are some trees more sensitive to climate than others? • How do you take tree-core samples? • Why are some rings narrow? • Do trees record climate?	• Virtual 360° field exploration • Video: Scientist interviews[B] • Video: Tree sampling • High-resolution scans of tree cores from the site • Meteorological databank (PDSI, KNMI Climate Explorer)	• Virtually explore and describe sites • Identify narrow rings • Find online meteorological data • Compare ring patterns to meteorological data.
Lab 3. Tree Rings and the Ancestral People of Pueblo Bonito: Focuses on the history of dendrochronology and how scientists calendar date historic structures.	• What site characteristics are important for tree-ring studies? • How do scientists assign exact calendar dates to tree-ring samples and historical structures? • How might have drought affected the ancient Puebloan people? • How could a drought affect your life?	• Virtual 360° field exploration • Video: History of dendrochronology[C] • High-resolution scans of tree samples. • NIH ImageJ software and tutorial • Drought reconstruction interactive	• Virtually explore and describe sites • Skeleton plot • Compare plots to historical work • Determine tree felling year • Measure tree rings • Evaluate drought reconstructions • Graphing
Lab. 4. Sharing a River: The Colorado River Story: Stresses the importance of the Colorado River as a resource and how tree-ring data informs water resource management.	• Who are entitlement holders and how is the Colorado River used? • What site characteristics are important for tree-ring studies? • How are tree rings used to reconstruct drought? • What information can we learn from tree rings about streamflow? • How do we better manage water resources?	• Virtual 360° field exploration • Video: Colorado River • Map interactives • Digital scans of tree cores • NIH ImageJ software and tutorial • National Weather Service drought maps • Reconstruction Interactive	• Virtually explore and describe sites • Evaluate current drought maps • Compare supply/demand data, snowmelt/streamflow • Measure samples • Compare work to published datasets • Evaluate streamflow reconstruction
Lab. 5. Warming and the Boreal Forests: Students learn how tree-ring records have been used to develop a temperature reconstruction, evaluate trends, and relate extreme years to major volcanic events.	• What are boreal forests? • What site characteristics are important for tree-ring studies? • How do you find previously published data and related science literature? • How do scientists develop long tree-ring records? • What do tree rings in the northern latitudes tell us about climate? • What role can serendipity play in science? • Can large-scale volcanic events affect climate?	• Virtual 360° field exploration • ITRDB • Google Scholar • Animation: Identifying Climate Sensitive Trees • Video: Scientist interview • Video: History of Dendrochronology • High-resolution scans of tree cores • NIH ImageJ software and tutorial • Temperature reconstruction interactive	• Explore the ITRDB • Research: peer-reviewed articles • Virtually explore and describe sites • Measure tree samples • Compare measurements to published data • Evaluate interactive temperature reconstruction • Identify short and long-term trends • Identify extreme years. • Research volcanic events

[A] https://d32ogoqmya1dw8.cloudfront.net/files/trex/students/rosanne_video_part_1.mp4
[B] https://d32ogoqmya1dw8.cloudfront.net/files/trex/students/ed_cook_part_2.mp4
[C] https://d32ogoqmya1dw8.cloudfront.net/files/trex/students/labs/brief_history_dendrochronology.mp4

Table 2. Student learning objectives.

Lab 1. Launching an Expedition. (https://serc.carleton.edu/trex/students/labs/lab1.html)
- describe what the science of dendrochronology is and what dendrochronologists typically do in terms of fieldwork.
- explain what types of trees give dendrochronologists the best chance to reconstruct past climate change.
- navigate and utilize a public scientific databank and identify peer-review publications associated with the data.
- explain how the peer-reviewed work of scientists shared collaboratively advances the body of scientific knowledge in dendrochronology.

Lab 2. Humpty Dumpty and Drought in the Hudson Valley. (https://serc.carleton.edu/trex/students/labs/lab2.html)
- describe the nature of dendrochronology and why it is important.
- explain why it is important to understand the ecological conditions of a site.
- observe and record ring patterns in digital samples and compare tree-ring growth to climate records.
- describe how the analysis of tree-ring data can be used to understand changes in past climatic conditions.

Lab 3. Tree Rings and the Ancestral People of Pueblo Bonito. (https://serc.carleton.edu/trex/students/labs/lab3.html)
- explain how scientists assign exact calendar dates to tree-ring samples and to a historic archeological structure such as Pueblo Bonito.
- construct a "skeleton plot" and measure and graph tree-ring data.
- describe how "proxy" data such as measurements of annual growth rings in trees reveal the nature, scale, and duration of extreme and extended droughts.
- explain the history behind the origin of the science of dendrochronology.

Lab 4. Sharing a River: The Colorado River Story. (https://serc.carleton.edu/trex/students/labs/lab4.html)
- describe how tree rings can be used to determine past stream flow and hydrological conditions in the Colorado River Basin.
- measure tree-ring data and compare those measurements to published work.
- explain how proxy data, such as measurements of annual growth rings in trees, reveal the nature, scale, and duration of past climate events like droughts.
- explain how the analysis of scientific data leads to a deeper understanding of the challenges we face as a society and helps to guide our decision making.

Lab 5. Warming and the Boreal Forests. (https://serc.carleton.edu/trex/students/labs/lab5.html)
- navigate and utilize a public scientific databank and identify peer-review publications associated with the data.
- virtually explore field sites in the boreal forests and describe why these are ideal places for conducting meaningful tree-ring research.
- measure tree samples and compare measurements to published data.
- identify short and long-term trends in a published temperature reconstruction, and research the potential cause of the extreme years identified.
- describe what we can learn about climate change from long tree-ring records growing in the northern latitudes.

Richard Warren in 1971. Using these plots, students are able to determine the date the tree was felled to build the pueblo (951 C.E.). In **Video 3** students watch historical footage of A. E. Douglass skeleton plotting a sample and are then guided to measure tree rings using NIH public-domain ImageJ software (Schneider *et al.* 2012) using a pre-marked sample from the pueblo. Students graph their data, discuss the long-term trends and extremes that they see, and learn about age-trends in samples, and about why there is a need for scientists to detrend data (Stokes and Smiley 1968).

Figure 1. A scan of an original sample (JPB31) from Pueblo Bonito used for analysis in Lab 3.

Using the El Malpais data from New Mexico (Stahle *et al.* 2009), students are guided to think about the implications of an extended drought for human wellbeing. They interactively zoom in and out of the El Malpais millennial-length precipitation reconstruction to identify decadal-scale droughts through time, and are asked to consider if drought may have been a contributing factor as to why the people of Pueblo Bonito abandoned their settlement in the 12th Century.

Lab 4. Sharing a River: The Colorado River Story

Students take a journey to the Colorado River Basin near Lees Ferry in **Lab 4**. They explore aspects of the Colorado River Basin using a variety of resources, interactive maps, and tools such as Google Maps. This journey gives them perspective on the scope of the watershed and how

Figure 2. Students learn how scientists combine living and dead trees to create millennial-length records of temperature, such as the buried forests emerging here from the wasting margin of Mendenhall Glacier (Credit: Jesse Wiles).

various stakeholders have siphoned the water from the river to serve seven western states' needs. Then they collect data concerning where the water comes from, who is using the water and how much they are using, and what the future may hold for the people living in the basin. In the final part of the lab, students virtually explore three tree-ring sites within the basin and work in groups to measure pre-marked cores. They produce a graph of the raw data and are asked to compare their measurements to a published millennial-length stream-flow reconstruction of the Colorado River (Woodhouse and Lukas 2006; Meko *et al.* 2007) and compare narrow rings in their sample and measurements to the same years in the reconstruction. In this lab, students are also introduced to basic tree-ring principles, such as locally absent rings, false rings, and age trends. Additionally, they are asked to think about how a millennial-length tree-ring reconstruction can add context to our understanding of streamflow, as well as how these records of climate and hydrology can support evidence-informed decision making.

Lab 5. Warming in the Boreal Forests

In **Lab 5**, students virtually explore some of the remote tree-ring sites scientists have sampled to develop a better understanding of warming in the northern latitudes over the past millennium. Students evaluate publicly-available tree-ring datasets from the ITRDB and research related peer-review publications in Google Scholar. They evaluate an interactive Northern Hemisphere temperature reconstruction (Wilson *et al.* 2016), based in-part on tree-ring records from the virtual sites that they have been asked to explore. They evaluate and measure tree-ring data from three sites and learn how scientists combine samples from living and dead trees to create very long records (Figure 2). Students are asked to research online for a potential cause for some of the extremely narrow rings (cold years) that they have identified (*i.e.* large-scale volcanic eruptions).

TREX IN THE CLASSROOM

TREX labs are free and available to instructors and the public. Each of the five labs has been field-tested in undergraduate classes. What we learned from running the TREX labs in the classroom is that students can miss important information in the instruction sections and that they sometimes needed to be pointed to the pertinent information in the webpage and asked to re-read it. Based on this, we simplified the text and instructions as much as possible. To make it easier, we also guide students to open two windows, one so they can follow the directions, and the other window for analysis. This helped them avoid losing their place. Student activity sheets have also been added at the beginning of each lab, so that they can easily fill them in as they go.

Materials were evaluated by graduate and undergraduate students and reviewed by independent faculty assessment teams affiliated with The National Association of Geoscience Teachers. We also ran instructor workshops and used feedback and all other assessments to develop and refine the materials. We developed the site to appeal to a variety of student populations and for broad adoption in existing courses. The site contains significant content geared to instructors in earth and natural sciences, including background materials, teaching notes and tips, downloadable student activity sheets, answer keys, and assessment options. Instructors can use any of the labs as stand-alone activities or all five can be combined to offer students a broad view of how tree-ring science can be applied to answer different questions. They are

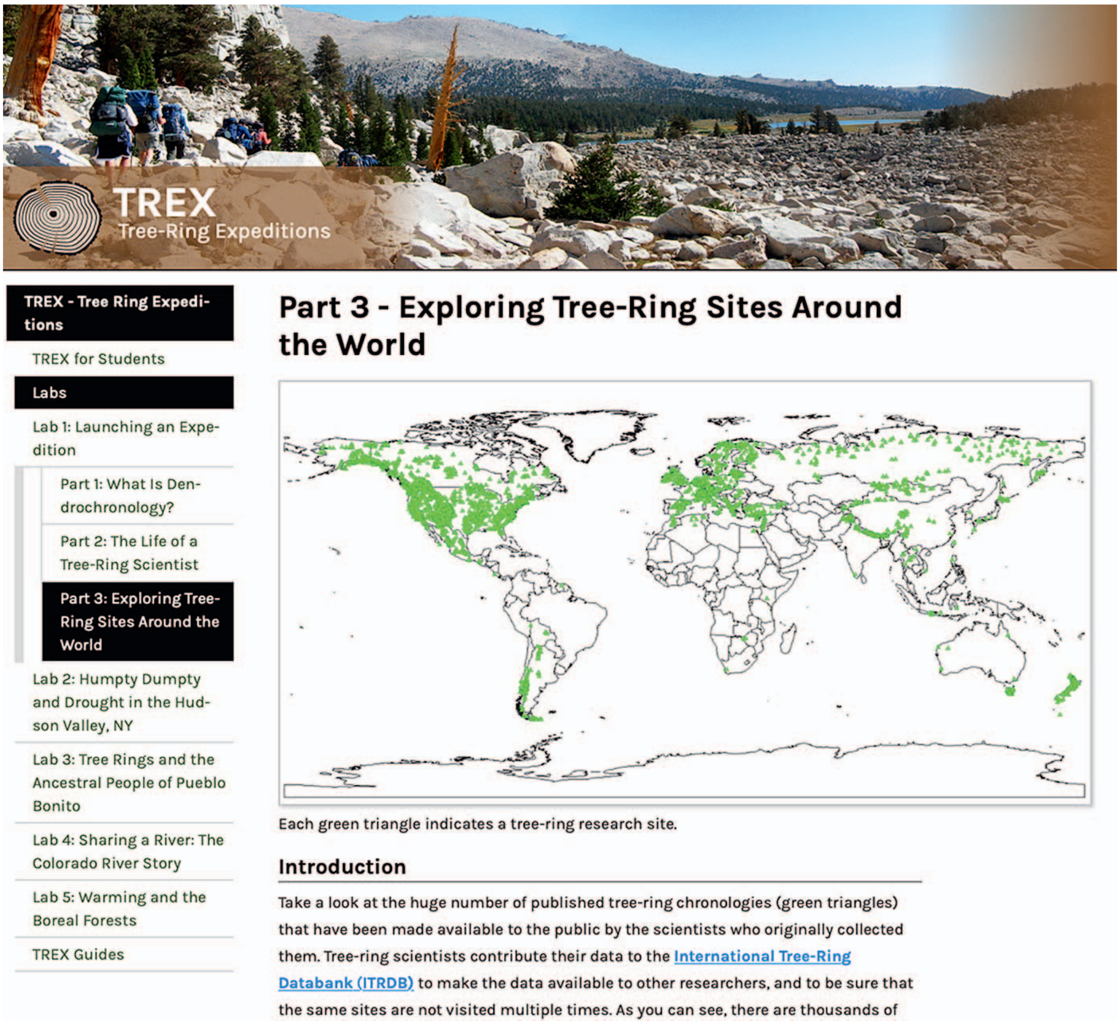

Figure 3. A snapshot of the TREX website, Lab. 1, Part 3. Note the navigation menu to the left and the TREX Guides section at the bottom left.

designed to be inserted into the lab of a wide range of undergraduate courses, including those on introductory geology, environmental science and sustainability courses, or more advanced courses in research methods, hydrology, and climate change science. Each one can be completed in a typical 2–3-hour lab period. Additional resources such as references, links to online datasets and/or relevant news articles are provided in the introductory section for each lab. To get access to the suggested answer keys for the labs, instructors will need to '**Request Instructor Access**', in the TREX Guides section (Figure 3). This is to ensure that students are not simply downloading answer keys.

ACKNOWLEDGMENTS

This project was funded by the National Science Foundation #DUE1405664. Thanks to faculty, staff, and student reviewers, and F. Wattenberg, I. Greidanus, C. Manduca, S. Fox, J. Wolfe, D. Dobbles, R. D'Arrigo, E. Cook, G. Wiles, C. Sinton, R. Wilson, N. Weisemburg, C. Leland, M. Rao, M. DaSilva, E. Klein, C. Cairns, and J. Daly. LDEO Contribution #8297.

REFERENCES CITED

Cook, E. R., 2014. Early days of dendrochronology in the Hudson Valley of New York: Some reminiscences and reflections. *Tree-Ring Research* 70(2):113–118.

Douglass, A. E., 1929. The secret of the Southwest solved by talkative tree rings. *National Geographic Magazine* 56(6): 736–770.

Meko, D. M., C. A. Woodhouse, C. A. Baisan, T. Knight, J. J. Lukas, M. K. Hughes, and M. W. Salzer, 2007. Medieval drought in the upper Colorado River Basin. *Geophysical Research Letters* 34(10):L10705.

Schneider, C. A., W. S. Rasband, and K. W. Eliceiri, 2012. NIH Image to ImageJ: 25 years of image analysis. *Nature Methods* 9:671–675.

Stahle, D. W., M. K. Cleaveland, H. D. Grissino-Mayer, R. D. Griffin, F. K. Fye, M. D. Therrell, D. J. Burnette, D. M. Meko, and J. Villanueva Diaz, 2009. Cool and warm-season precipitation reconstructions over western New Mexico. *Journal of Climate* 22:3729–3750.

Stokes, M. A., and T. L. Smiley, 1968. *An Introduction to Tree-Ring Dating*. University of Chicago Press, Chicago; 110 pp.

Wilson, R. J. S., K. J. Anchukaitis, K. R. Briffa, U. Büntgen, E. Cook, R. D. D'Arrigo, N. K. Davi, J. Esper, D. Frank, B. Gunnarson, G. Hegerl, S. Helama, S. Klesse, P. J. Krusic, H. W. Linderholm, V. Myglan, T. J. Osborn, M. Rydval, L. Schneider, A. Schurer, G. Wiles, P. Zhang, and E. Zorita, 2016. Last millennium northern hemisphere summer temperatures from tree-rings: Part I: The long term context. *Quaternary Science Reviews* 134:1–18.

Woodhouse, C. A., and J. J. Lukas, 2006. Multi-century tree-ring reconstructions of Colorado streamflow for water resource planning. *Climatic Change* 78(2):293–315.

Received 8 February 2019; accepted 12 April 2019.