Teaching California Climate and Vegetation Change Over Long Timescales: An NGSS-Aligned Unit Using CalFlora and the Neotoma Paleoecological Database

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Abstract

This paper introduces an inquiry-based classroom unit titled "California Climate and Vegetation Change," a set of place-based exercises that utilize real data from California. NOAA climate data at four locations throughout the state are provided to create climatographs. Students then use Neotoma Explorer to find and evaluate past vegetation change from fossil pollen sites, and use CalFlora to research the environmental tolerances and distribution of plant taxa that seem most sensitive to climate change. Synthesis at the end of the classroom task includes writing a summary of what we can discern about California climate change over the past 10,000 years from vegetation records, and proposing and defending a new collection site for a palynological study. The unit is appropriate for high school and college coursework that cover topics such as climate, vegetation, range shifts, and the fossil record in physical geography and biogeography. Both databases employ graphical user interfaces that reinforce the spatial thinking central to geography. The unit is aligned with the Earth Sciences and Life Sciences content criteria of the Next Generation Science Standards, the latest set of scientific standards that stress active learning, use of technology, interpretation of real datasets, and connections across disciplines. While this approach to learning may put students into the uncomfortable territory of complex data sets and no simple "right answer," there is potential for student practice and skill-building. These skills include data visualization, interpretation, synthesis, evaluation, and evidence-based proposal writing, all essential for real-life problem solving and finding solutions to environmental challenges in California.

1. Motivation

California is on the front lines of twenty-first century climate and ecosystem change. The effects of such change are already evident in recent warming and statewide drought,[1] longer wildfire seasons,[2] tree mortality in alpine zones,[3] and thermophilization (i.e., the northward migration of plants colonizing disturbed areas.[4] Educating our state citizenry to meet the challenges that rapid climate and landscape change present to society is of utmost importance, and geospatial skills are a key component of this climate literacy.[5] Retrospective studies are also crucial to understand the range of possible variation in moisture availability, rates of change, vegetation turnover, and past wildfire regime.

This paper briefly describes an educational unit I developed from California-based climate, vegetation, and pollen data. The urgent need for inquiry-based, local course content was apparent while I was teaching biogeography as a general education course at UCLA. Students struggled to connect with traditional teaching paradigms of ecosystem function, which often assume knowledge of landscape history and successional models in deciduous biomes (e.g., old-field succession, primary succession after ice sheet retreat). Palynology, one of the key techniques in biogeography for discerning vegetation change through time, also has its roots in the deciduous hardwood forests of Europe[6] and the U.S. Northeast and Midwest[7]. Interactive online exercises that illustrate palynology offer excellent visualization of deposition, coring, and analyses (e.g.,[8]), but include a large proportion of arboreal taxa not native to the U.S. West. Deciduous forests, ice sheet glaciation, and the natural regrowth of forest on abandoned farmland remain abstract concepts to a large proportion of students in California's secondary and higher public-education systems. Pedagogical research has shown that student motivation tends to be higher when curricula and problems are derived from their community and region.[9]

The exercises presented here comprise a classroom task designed to supplement these teaching models. This task aims to explore the environmental and vegetation dynamics in California, starting with its winter-wet, summer-dry Mediterranean climate. Pollen data from California that span the past 10,000 years are explored, with a focus on how vegetation change can inform hydroclimatic change, rather than changes in the vegetation community as a whole. Students also gain familiarity with accessible public databases on California vegetation at CalFlora,[10] and fossil pollen data archived at the Neotoma Paleoecological Database.[11]

2. Classroom Task Components and Skills Addressed

In this unit, students examine and graph climate data from four disparate regions of the state, explore and evaluate the available pollen records near these areas, then develop a working plant list of most-sensitive taxa that yield information on past climate change. The following task components then ask students to summarize climate change over the past 10,000 years in California, and design and defend a new fossil pollen study. Worksheets and formatted tables for documenting notes and observations are available in the unit, allowing flexible adaptation for education level, and time available. Designed for three to five hours of class time, the unit is available at http://serc.carleton.edu/dev/neotoma/activities/174249.html, and formatted and aligned with Next Generation Science Standards (NGSS) at the high school level.[12] Table 1 shows a shorter summary of all task components, skills reinforced, and high school standards satisfied with this alignment.

Table 1. Summary of classroom task on California Climate and Vegetation Change, including skills and Next Generation Science Standards (NGSS) satisfied by each component. See classroom task for further detail on each NGSS.

Task Component	Skills	NGSS alignment
A. Compare monthly climate data from 2010 at four locations to 20-year averages	• comparison and evaluation of real data	
B. Plot climatographs for each location	• graphing and plotting, including setting appropriate scale	
C. Find and evaluate fossil pollen data that shows vegetation change over the past 10,000 years	• data evaluation and comparison • scientific observation • spatial thinking	HS-LS2-6 HS-LS4-C HS-LS4-3
D. Develop a list of most-sensitive plant taxa in California pollen studies	• evaluate plant characteristics and spatial distribution/range • consider taxonomic rank of plants	
E. Summarize the past 10,000 years of climate change in California	• consider and evaluate shortcomings of real datasets • synthesis in writing and/or oral presentation • effective communication of results	HS-ESS2.E HS-LS4-C
F. Propose a new pollen research project that addresses gaps in the fossil record	• persuasive writing and/or oral presentation • integrating supporting evidence	HS-LS2-6 HS-ESS2-7

3. Standards Alignment

NGSS are the latest K–12 content standards for science, with a focus on understanding the interconnectedness of Earth systems and actively practicing science and engineering methods.[12] Earth Science content standards underwent the most substantive changes when NGSS was developed, particularly in applying science and engineering methods to real problems and building connections to other disciplines via cross-cutting concepts.[13] While I initially designed this lesson (i.e., classroom task) with my student population in mind, using these K–12 standards as the primary framework has broader appeal for the following reasons:

- NGSS emphasizes several of the components and skills in this task. These include integration of technology[14] to access and analyze real datasets, examining the interconnectedness between modern plants and their fossil record, and effectively communicating these often-complex topics.
- NGSS alignment allows one to create a classroom task that is flexible across several courses (e.g., life sciences, earth sciences, environmental science, and geography) and grade levels.
- The NGSS emphasis upon cross-cutting connections allows space for geographical thought[15] an inherently interdisciplinary subject.
- NGSS is the first set of science standards to explicitly include climate change.[14]

This task addresses four of the NGSS crosscutting concepts: **patterns**, **cause and effect, scale**, and **stability and change. Patterns** in nature lead to classification, a concept this exercise addresses through the use of plant taxonomy. Elucidating process from pattern, or vice versa, is also a key component in biogeography.[16] One of the overarching objectives of this unit is asking students to examine **cause and effect**, e.g., how does climate change drive vegetation in California's environment? Differences of **scale** are introduced as students move from monthly average climate data to examining records on longer timescales, with time steps on the order of decades, centuries, or millennia. Finally, students confront differences in landscape **stability and change** as they encounter pollen records that may show relative staticity in one area or vegetation group, compared to others that demonstrate significant change.

NGSS at the high-school level does not include explicit standards for the English Language and Mathematics skill-building incorporated into the unit (Table 1); these are satisfied through California's Common Core State Standards.[17] This task does include integrating information with different formats, writing arguments with valid reasoning and citing supporting evidence to communicate complex ideas, writing a sensible and well-supported narrative on California's past climate change, and representing and interpreting data.

One challenge to implementing this unit, and NGSS-aligned curricula in general, is shifting the focus and expectations of students toward more integrative concepts, practice, and the messiness often inherent with real datasets. Earth Science secondary-school curriculum has long focused on objective testing and categorization,[15] with binary "right" and "wrong" answers. Suggestions at the beginning of the task address this somewhat, but instructors may need support and training to effectively guide and assess students in what will likely be a new mode of science education.[18, 19]

4. Differentiation and Scaffolding

Worksheets and graphic organizers for tasks B–D are included as options for lesson structure and scaffolding. Higher-level synthetic tasks E–G can be assigned to groups or as oral presentations, or omitted altogether, depending on level and instructional time available. Advanced students can determine the format of their final assignment as appropriate, with the option of completing all work electronically, including use of graphing software.

More-advanced students in upper-division or masters-level university courses can work on the assignment independently, particularly if the goal is to acquire background knowledge for future research that involves familiarity with California's plants, available pollen records, use of the CalFlora and Neotoma platforms, and/or original palynological research. Neotoma's more-advanced features were not employed for this lesson, but offer opportunities for powerful integration and synthesis of large datasets with R packages that can quickly extract pollen data for analysis.[20]

5. Summary

This paper describes components and rationale for a newly developed classroom task that employs California climate, vegetation, and paleoecologic data. The content spans geography, biogeography, earth science, ecology, and environmental science coursework. Available at http://serc.carleton.edu/dev/neotoma/activities/174249.html, the unit's flexible format includes worksheets and templates that can be provided to match course goals and student level. It satisfies several standards in the NGSS-HS framework that focus on interdisciplinary connections of scale, pattern, cause and effect, and stability and change. The unit also focuses on evaluating, drawing connections between, and synthesizing real (and often incomplete) vegetation and fossil pollen datasets. This satisfies core goals of NGSS, providing essential practice in problem-solving and inquiry necessary for an educated citizenry. Such skills are crucial to develop in the next generation as we consider solutions to climate change effects, including stress upon California's ecosystems, water and food supply, and infrastructure.

6. References

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