FEATURE ARTICLE

A Class Project for Investigating Possible Future Local Effects of Global Climate Change through Student Analysis of Fossil Faunas

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Abstract

A common question posed to environmental scientists by nonscientists, particularly policymakers, is the following: In a world that is globally warmer, what will the new climate be like in specific geographical regions? This question has been and continues to be addressed by computer modeling, a technique that is out of reach for vast majority of students. However, an alternate approach to investigating this issue exists that is more practical for students. Past climates can be inferred for specific regions from fossils, utilizing climate tolerances of related modern organisms. When these inferred past climates correspond to periods of the Earth's history where levels of carbon dioxide were as high or higher than today, these data can be used to extrapolate possible future local climates in a globally warmer world. The last Pleistocene interglacial period (known as the Eemian), which occurred approximately 120,000 years ago, is an ideal time period for studies of this kind for the following reasons. First, carbon dioxide levels were elevated at this time to levels approximating modern global conditions, and the world was warmer as evidenced by a much higher sea level than exists today. Secondly, most Eemian-age animals (especially mollusks) still exist, have known climate tolerances, and are relatively common as fossils. Students examining fossil mollusk faunas have applied this methodology to infer the Eemian climates of South Florida and coastal Virginia and found unexpectedly that for both regions the Eemian climate did not greatly differ from the modern one. The methodology described here can be used to address other important questions and puts such authentic and potentially valuable scientific research within practical reach of student scientists.

Key Words: *climate change; paleontology; fossils; Pleistocene.*

Analysis of fossil assemblages from past geological periods with climates plausibly representative of a near-future warm Earth should allow scientists (and student researchers) to project likely future regional climate changes independent of computer modeling.

○ Introduction

One of the major themes of current science pedagogy is experiential learning, in which students learn both scientific concepts and practices through direct scientific investigation (e.g., American Association for the Advancement of Science, 1993; Lehane, 2020). Ideally, such investigations would involve subjects that are clearly relevant to the majority of students. One such subject could be anthropogenic global climate change (usually referred to in the vernacular as global warming), which is widely publicized in popular media and considered by most scientists to be one of the most pressing environmental problems facing the modern world (e.g., Oreskes, 2004; Marlon et al., 2019). Unfortunately, most professional research on this topic requires techniques and/or resources that are beyond the reach of middle and high school students, and even typical undergraduates (e.g., examination of oceanic uptake of carbon dioxide (CO_2) [Tsunogai et al., 1999; Ballantyne et al., 2012], computer modeling of climate change [Edwards, 2001; Hausfather et al., 2022], and satellite monitoring of glacier change [various papers in Chuvieco, 2007; Kimothi et al., 2022]).

Though environmental scientists and climatologists can make plausible large-scale projections about effects that could be produced by global climate change (e.g., rising sea levels leading to coastal flooding, an increase in the frequency of severe weather events, changes in rainfall distribution, etc.), unfortunately current models do not yield reliable predictions on how these effects could be manifested on a regional scale (e.g., will the increased warmth be sufficient to allow commercial citrus agriculture in the United States to expand to the northern Gulf Coast or even farther north; Monier et al., 2015). Unfortunately, this uncertainty about plausible future regional environmental change is problematic for policymakers, who

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may have to plan infrastructural projects spanning decades on the basis of poor information. One method for addressing this problem is continued refinement of the models. However, paleontology offers an alternate possible avenue for investigating this issue, one that is surprisingly accessible in terms of techniques and required resources to both middle/high school students and undergraduates.

The traditional methodology for reconstructing ancient climates in paleontology is relatively straightforward and requires two pieces of information: (1) a faunal/floral list for a fossil site and (2) information about the climatic preferences/tolerances of modern organisms that are closely related to organisms from the fossil assemblage under consideration. In this methodology, clear patterns of inferred climatic preference in the fossil organisms are assumed to reflect the past climate of the fossil locality (e.g., Eberle & Greenwood, 2012; Thiel et al., 2012; Bolikhovskaya & Makshaev, 2020, among many others). To use an extreme example, alligators living in northern Canada near the Arctic 55 million years ago are a clear indication that the regional climate was much warmer at that time than today. Thus, going back to the issue of modern global climate change, analysis of fossil assemblages from past geological periods with climates plausibly representative of a near-future warm Earth should allow scientists (and student researchers) to project likely future regional climate changes independent of computer modeling.

The Eemian, the period name given to the last major global warming event (interglacial) before the advent of the Recent, occurred approximately 130,000–110,000 years ago and is a good candidate for this kind of analysis for a number of reasons (note that in North American literature, the Eemian is commonly referred to as the Sangamon). The Eemian global climate was clearly warmer than that of the modern world based on a number of lines of evidence, with sea levels roughly 7 m higher than the current one and exceptionally high CO_2 levels (350 ppm; Hansen et al., 2015) compared to the norm for the Quaternary, though not as high as those currently observed (412 ppm circa 2020; Le Quere et al., 2020). However, the Eemian was not as warm as the hyper-thermal early–middle Eocene, or early Pliocene (which apparently had CO_2 levels of 400 ppm, much like those currently found in the atmosphere; Wilson et al., 2007; IPCC, 2001, 2007; Kunzig, 2013; Eberle & Greenwood, 2012). In addition, just as valuable for the purposes of this analysis, Eemian-age marine beds are abundant worldwide and commonly very fossiliferous, with Eemian-age terrestrial fossil localities also being fairly common and well documented (Klotz et al., 2003; Kurten & Anderson, 1980; Kurten, 1968; Richards, 1974). Finally, because of their relatively young geological age, many if not most of the species represented in these fossil localities still exist (this is especially true for the marine invertebrates), with the result that climate preferences of the fossil species can be reliably determined on the basis of the preferences of their living relatives. Thus, by obtaining faunal (or in some cases possibly floral) lists for different Eemian localities and compiling modern climate preference data for the taxa based on modern counterparts, student researchers can deduce the likely climate of that region during the Eemian, and then on the basis of that finding plausibly project what the climate of that region might look like in a near-future, globally warmer world.

○ Sources of Eemian Faunal Data for Student Analysis

Possible sources of Eemian data for research projects of this type vary considerably and depend in part on both student geographical location and available literature resources. Ideally, the students would both collect and identify fossils to create their own faunal list for analysis. In most instances, this requires the students to have access to Eemian invertebrate-bearing marine sites (terrestrial vertebrate-bearing fossil sites are impractical to collect from on the needed scale in most instances, with the difficulty of specimen identification being a compounding logistical problem). This in turn requires access to coastal regions, since this is where nearly all Eemian marine sediments are located. Eemian-age invertebrate fossils are actually easily accessible and relatively common through much of the Atlantic and Gulf coasts (e.g., see Gore & Witherspoon, 2013) and in some cases make up significant component of the topsoil (because they are ubiquitous, these specimens are commonly not recognized as fossils). There are certainly Eemian-age invertebrate fossil localities on the Pacific coast of North America as well as the Gulf and Atlantic coasts (e.g., Lindberg et al., 1980). However, unfortunately they are not well documented in the literature, possibly because of complex geological settings, and may be difficult to locate.

In situations where directly collecting fossils is not a practical option, then analysis of metadata is a reasonable alternative. A number of literature sources provide Eemian-age invertebrate faunal lists for North American localities, including Petuch and Roberts (2007) (Florida), Coach (1971) (Virginia), and Lindberg et al. (1980) (Baja California, Mexico). Though not North American, Muhs et al. (2002) provide Eemian-age invertebrate faunal lists for Hawaii and Bermuda that could possibly allow for interesting comparisons with North American faunas. An unpublished Eemian-age mollusk species list from South Florida, based on specimens that were both collected and identified by high school biology students at the Oxbridge Academy of the Palm Beaches, is provided in the Appendix and could be used in a class project.

Eemian North American vertebrate paleofaunas, particularly those of mammals, may also be useful in studies of this type (in this context, the Eemian period is typically referred to as the Sangamon), though there are added complications that do not generally apply to invertebrate faunas. First, with regard to mammals, broad thermal tolerance can result in many extant species occupying a wide range of zones (e.g., raccoons are found across most of North America, ranging from central Canada to the Neotropics; Kays & Wilson, 2009), potentially making climate zone assessment for a location difficult. Second, a considerable number of the species in most Pleistocene mammal faunas are typically extinct, reducing the number of species that can be compared with extant counterparts. Admittedly, however, many students are likely to be more interested in mammals than mollusks, which may compensate for the aforementioned complications. The following sources provide detailed mammal faunal information for Eemian locations: Ray (1967) (Georgia); Webb (1974) (Florida); Van Devender et al. (1985) (northern Mexico); and Kurten and Anderson (1980) (multiple locations across North America).

Finally, paleofloras, particularly in the form of fossil pollen (palynoflora) assemblages, can be extremely useful tools in reconstructing paleoclimates (probably more so than mammal or even mollusk assemblages), and have been widely used for this purpose (see Steele & Warny, 2013; Wing, 1998). Unfortunately, while Eemian paleofloras have been widely studied in Europe (e.g., Bolikhovskaya & Makshaev, 2020), there is little literature available on paleofloras of this age for North America. European papers including palynofloral assemblages may be useful for teachers interested in projects that deal with Eemian climates outside of North America.

Analysis of the Biotic Data

Interpretation of the faunal data discussed above requires modern counterparts of the fossil species to be assigned to climate categories, which in turn requires a useful system for classifying climate. A number of different classification schemes can be used for this purpose, either student-invented or preexisting. One system that my students created and successfully used to analyze mollusk faunal data from the U.S. Atlantic and Gulf of Mexico coastlines, with broad temperature trends across the range subdivided into five relatively simple zones, is presented in Table 1 (of course, students could just as well produce other, equally workable climate classification systems). Another possible option is to use a preexisting classification system. One such system, which uses zones based on the lowest temperatures experienced during a typical winter, was created by the United States Department of Agriculture (USDA; for the details of this system, see popular gardening books such as Ray, 2015, or the government website at www.usda.gov). Though convenient to use, the USDA system has the disadvantage of focusing only on winter conditions and ignoring summer ones, hiding important information. For example, in this system both southern England and East Texas are found in the same climate zone (8), despite these locations clearly having vastly different overall climates. It is conceivable that innovative students could modify the USDA system so as to incorporate summer heat as a factor in addition to winter low temperatures.

In most modern and Eemian biotas, the taxa are likely to exhibit a range of geographic distributions, equating to climatic tolerances, with some species having such broad ranges as to be effectively useless in climate interpretation (e.g., the northern quahog, *Mercenaria mercenaria*, which extends from the Gulf of St. Lawrence in Canada to Texas; Rehder, 1981). In a study of this type, students may want to consider eliminating species with broad thermal tolerances from the data set and focus on those with relatively narrow climatic ranges. Ideally, interpretation of data such as these should involve statistical analysis. However, this is clearly beyond the scope of most high school students, and in my experience most graphic presentations produced in these studies (usually bar or pie charts) can be visually interpreted reasonably easily (e.g., see Figure 1).

Table 1. Geographical scheme used to classify climate ranges of modern marine mollusks found on the Atlantic and Gulf coasts of the United States.

Climate Designation	Geographic Range
1. Subarctic	Maine northward
2. Cold Temperate	New Hampshire-Maryland
3. Warm Temperate	Virginia–Georgia, northern Gulf Coast
4. Subtropical	Peninsular Florida, southern Texas
5. Tropical	Southeast Florida, West Indies, Mexico–Brazil

An Example of Student Research: Reconstructing the Eemian Climate of Southeast Florida

Highly fossiliferous Eemian-age marine sediments are ubiquitous in the southern half of Florida, most belonging to a geological unit referred to as the Fort Thompson Formation (Petuch & Roberts, 2007). As part of a class project, students at the Oxbridge Academy of the Palm Beaches (West Palm Beach) collected large samples of fossil marine mollusks (totaling well over a thousand specimens) from easily accessible localities in Palm Beach County. Once collected, the students used a guidebook of modern marine mollusk shells (Rehder, 1981) to identify the specimens down to species and

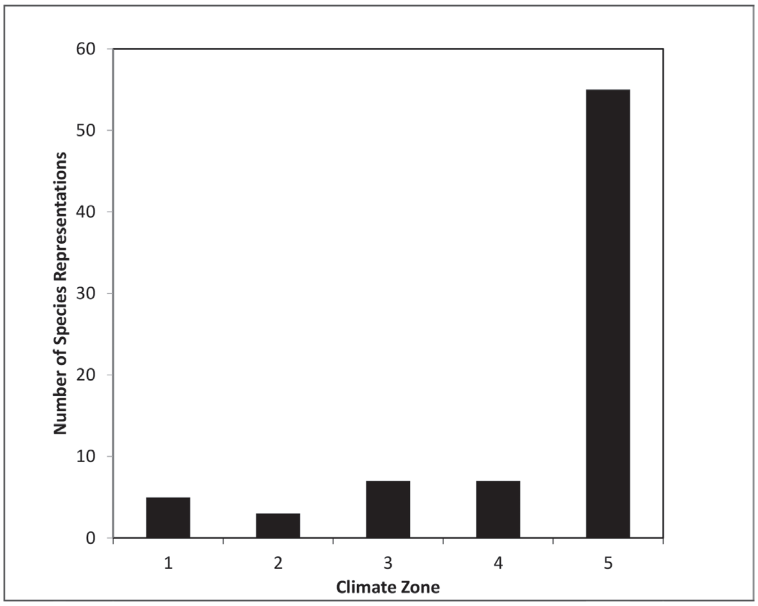

Figure 1. Student-produced histogram of modern climate ranges for Eemian-age mollusks found in Palm Beach County, South Florida (see Table 1 for explanation of climate zone categories). The *Y*-axis represents the number of times a given climate zone is represented in the collective faunal data.

create a faunal list (see Table 2 and Appendix). Once the faunal list was created, students looked up and tabulated the modern geographic range of the species in the fossil fauna (see Table 2) and did a numerical and graphical analysis of the data to deduce the likely climate of South Florida during the Eemian (Figure 1). Though not done in this instance because of time limitations, it would have been useful for the students to do an equivalent analysis of modern shells collected from a local beach in order to form a comparative baseline. Based on their analysis, the students concluded the regional climate of South Florida was not greatly warmer than that found today during the Eemian, and therefore that future global warming might not necessarily cause the climate of South Florida to warm appreciably.

Table 2. Representative partial, student-produced, faunal list for Eemian invertebrates collected from Palm Beach County, South Florida, with modern geographical ranges (see Table 1 for an explanation of the geographical range categories).

Common Name	Scientific Name	Geographical Range
Thick lucine	*Phacoides pectinatus*	3, 4, 5
Verrill's diplodon	*Diplodonta verrilli*	2, 3
Atlantic lucine	*Lucinoma atlantis*	3
Blood ark	*Anadara ovalis*	3, 4, 5
Double-barred venus	*Chione cancellata*	3, 4, 5
Southern quahog	*Mercenaria campechiensis*	4, 5
Empress venus	*Circomphalus strigillinus*	4, 5
Trigonal tivela	*Tivela mactroides*	5
Yellow cockle	*Papyridea soleniformis*	4, 5
Lady-in-waiting venus	*Chione intapurpurea*	3, 4, 5
Maritime marsh clam	*Polymesoda maritima*	4
Cross-hatched lucine	*Divaricella quadrisulcata*	2, 3, 4, 5
King venus	*Chione paphia*	5
Arctic wedge clam	*Mesodesma angliforum*	2
Shark's eye	*Polinices duplicatum*	3, 4
Transverse ark	*Anadara transversa*	3, 4
Alternate tellin	*Tellina alternata*	3, 4
Tiger lucine	*Codakia orbicularis*	4
Giant heart cockle	*Dinocardium robustum*	3
Northern lucine	*Lucinoma filosa*	1, 2, 3, 4

Additional Student Research Possibilities

A faunal analysis of the kind demonstrated above creates potential for student research that addresses a number of additional questions. For example, in a separate study in which metadata was used to analyze Eemian-age mollusk fossils from around coastal Virginia, using faunal data from Coach (1971), students at Holy Innocents Episcopal School (Atlanta) concluded that the Eemian climate of this region was also much like that found in the region today (warm temperate), and cooler than that of Southeast Florida. This finding surprised the students, who expected that the Eemian Virginia climate would more closely resemble that of tropical Southeast Florida given the evidence (e.g., the high sea level) that the world as a whole was warmer at that time. This seemingly counterintuitive finding led the students to wonder where the excess Eemian warmth was, and some students proposed that the excess warmth might have been concentrated northward, a hypothesis that could be tested by analyzing Eemian fossil faunas (either marine or terrestrial) from relatively high latitudes, possibly from Europe. This hypothesis, if supported by the evidence, could have important implications for future regional climate changes produced by modern global warming (there is already abundant evidence that current effects of global change are most prominent at high latitudes [e.g., Appenzeller, 2015]). Testing this and similar hypotheses represents real and important scientific work that lies within practical reach of student scientists with the use of this methodology.

Appendix

Faunal list of Eemian-age mollusk species from Palm Beach County, Florida, showing both common and scientific names. Students both directly collected and identified the fossil specimens used to create this list.

Thick lucine	*Phacoides pectinatus*
Verrill's diplodon	*Diplodonta verrilli*
Atlantic lucine	*Lucinoma atlantis*
Double-barred venus	*Chione cancellata*
White triphora	*Triphora melanura*
West Indian chank	*Turbinella angulata*
Princess venus	*Periglypta listeri*
Southern quahog	*Mercenaria campechiensis*
Empress venus	*Circomphalus strigillinus*
Incongruous ark	*Anadara chemnitzi*
White pygmy venus	*Chione pygmaea*
False cerith	*Batillaria minima*
Trigonal tivela	*Tivela mactroides*
Lady-in-waiting venus	*Chione intapurpurea*
Shark's eye	*Polinices duplicatum*
Maritime marsh clam	*Polymesoda maritima*
Yellow cockle	*Papyridea soleniformis*

Cross-hatched lucine	*Divaricella quadrisulcata*
King venus	*Chione paphia*
Artic wedge clam	*Mesodesma angliforum*
Alternate tellin	*Tellina alternata*
Cut-ribbed ark	*Anadara floridana*
Broad-ribbed cardita	*Carditamera floridana*
Tiger lucine	*Codakia orbicularis*
Giant heart cockle	*Dinocardium robustum*
Northern lucine	*Lucinoma filosa*
Ponderous ark	*Noetia ponderosa*
Perverse whelk	*Busycon perversum*
Gray Atlantic auger	*Terebra cinerea*
Fly-specked cerith	*Cerithium muscarum*
Cancellate risso	*Rissoina cancellata*
Crest oyster	*Ostreola equestris*
Sponge oyster	*Cryptostrea permollis*
Atlantic diplodon	*Diplodonta punctata*
Turton’s wedge clam	*Mesodesma deauratum*
Pennsylvania lucine	*Lucina pensylvanica*
Florida lucine	*Pseudomiltha floridana*
Eared ark	*Anadara notabilis*
Waxy Gould clam	*Gouldia cerina*
Alternate bittium	*Bittium alternaturn*
Lettered olive	*Oliva sayana*
Imperial venus	*Chione latilirata*
Stearn’s cone	*Conus jaspideus*
Pat’s cone	*Conus patae*
West Indian prickly cockle	*Trachycardium isocardia*
Florida cone	*Conus floridanus*
Coffee bean trivia	*Trivia candidula*
Florida fighting conch	*Strombus alatus*
Magnum cockle	*Trachycardium magnum*
Egg cockle	*Laevicardium laevigatum*
Atlantic gray cowrie	*Cypraea cinerea*
Lightning whelk	*Busycon contrarium*
Greenland cockle	*Serripes groenlandicus*
Iceland cockle	*Clinocardium ciliatum*
False quahog	*Pitar morrhuanus*
White venus	*Pitar albidus*
Lightning venus	*Pitar fulminatus*
Purple venus	*Pitar circinatus*
Texas venus	*Agriopoma texasiana*
Decussate bittersweet	*Glycymeris decussata*
Mitchell’s wentletrap	*Amaea mitchelli*

Mauger’s erato	*Erato maugeriae*
Banded tulip	*Fasciolaria lilium*
Channeled whelk	*Busycotypus canaliculatus*
Costellate dipper shell	*Cardiomya costellata*
Dall’s little abra	*Abra aequalis*
Buttercup lucine	*Anodontia alba*
West Indian dwarf olive	*Olivella mutica*
Little white trivia	*Trivia candidula*
Northern rough periwinkle	*Littorina saxatilis*
Stimpson’s surf clam	*Spisula polynyma*
Northern cardita	*Polymesoda caroliniana*
Ravenel’s egg cockle	*Laevicardium pictum*
Waved astarte	*Astarte undata*
Left-handed jewel box	*Pseudochama radians*
Rigid venus	*Ventricolaria rigida*
Southern surf clam	*Spisula solidissima*
Gaudy asaphis	*Asaphis deflorata*
Colorful Atlantic natica	*Natica carena*
Common American auger	*Terebra dislocate*
Queen venus	*Ventricolaria rugatina*
Sozon’s cone	*Conus delessertii*
Caribbean spiny jewel box	*Arcinella arcinella*
Sunray venus	Macrocallista nimbosa
Turnip whelk	*Busycon coarctatum*
Florida rock shell	*Thais haemastoma*
Atlantic cylinder sundial	*Heliacus cylindricus*
Little surf clam	*Mulinia lateralis*
Ribbed mussel	*Geukensia demissa*
File yoldia	*Yoldia limatula*
Oval corbula	*Varicorbula operculata*
Chestnut astarte	*Astarte castanea*
Short-tailed laitrus	*Latirus angulatus*
Adams’ miniature cerith	*Seila adamsi*
White-spotted periwinkle	*Littorina meleagris*
Pointed venus clam	*Anomalocardia auberiana*
Dwarf Atlantic planaxis	*Angiola lineata*
Northern rosy margarite	*Margarites costalis*
West Indian dosinia	*Dosinia concentrica*
Disk dosinia	*Dosinia discus*
Doc Bales’ ark	*Barbatia tenera*
Rough scallop	*Aequipecten muscosus*
Southern bay scallop	*Argopecten irradians*
Blake’s lucine	*Lucinoma blakeana*
Eroded turret shell	*Tachyrhynchus erosus*

Filose turban	*Turbo cailletii*
Krebs' sundial	*Phillipia krebsi*
Dwarf cerith	*Cerithium lutosum*
Custate lucine	*Codakia costata*
Gaudy asaphis	*Asaphis deflorata*
Green-base tegula	*Tegula excavata*
Orbigny's sundial	*Heliacus bisulcatus*
Pear whelk	*Busycon spiratum*
Lentil astarte	*Astarte subaequilatera*
Decussate risso	*Rissoina decussate*
Varicose alaba shell	*Alaba incerta*
Variable bittium	*Bittium varium*
Gray pygmy venus	*Chione grus*
Boring petricola	*Petricola lapicida*
Common northern lacuna	*Lacuna vincta*
Adele's top shell	*Calliostoma adelae*
Florida auger	*Terebra floridana*
Florida prickly cockle	*Trachycardium egmontianum*
False tulip mussel	*Modiolus modiolus*
Filose turban	*Turbo cailletii*
Florida horse conch	*Triplofusus giganteus*
Poulsen's triton	*Cymatium cingulatum*
Dogwinkle	*Nucella lapillus*
Broad-ribbed cardita	*Carditamera floridana*
Yellow cowrie	*Cypraea spurca*
Striate coquina	*Donax striatus*
Wavy clam	*Liocyma fluctuosa*
Angel wing	*Cyrtopleura costata*
Mauve-mouthed drill	*Calotrophon ostrearum*
Morocco natica	*Natica marochiensis*
Lamarck's carinaria	*Carinaria lamarcki*
Eroded turret shell	*Turritella variegate*
Milk conch	*Strombus costatus*
Common periwinkle	*Littorina littorea*
Beau's vitrinella	*Cyclostremiscus beauii*
Common Atlantic oyster	*Crassostrea virginica*
Jingle shell	*Anomia simplex*
Sentis scallop	*Caribachlamys sentis*
Adam's miniature ark	*Arcopsis adamsi*

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