**Relating Late Quaternary Plant and Animal Distributions to Past and Future Climate**

In this activity, you will work in teams of 2-3 students to explore the relationships between the geographic distribution of organisms and climate during the late Quaternary (*i.e.,* about the last 130,000 years).

During the late Quaternary, our planet experienced large, rapid changes in climate associated with the growth and retreat of continental ice sheets. These changes were associated with wholesale reorganizations of terrestrial habitats, especially in the northern hemisphere. Ice age mammals like the classic mammoths and mastodons had to cope with these changes, as did our own species *Homo sapiens* as we expanded out of Africa during this time.

Because plant and animals species often have specific climate requirements, we can use the geographic distribution of fossil species to reconstruct ancient climate parameters and document how these parameters changed over time. First, though, we must understand the relationship between living species and climate. Then we can apply these observations to the fossil record—a great example of **uniformitarianism**, or using the present to help explain the past.

In Part 1 of this activity, you will use online databases to document the geographic distributions of selected *modern* plant and animal species and connect them to temperature and precipitation data. How does the species occupy a **climate space**? In Part 2, you will use an online database of *fossil* occurrences to track changes in species distributions over time. You will then apply your knowledge of climate parameters associated with these species today to describe likely climate changes in the past. Finally, in Part 3, you will consider what *future* species distributions may be like given continuing anthropogenic global warming.

Throughout this activity you will have the opportunity to explore several large online databases. More and more researchers are using “big data” to investigate complex problems. **Online databases** like the Neotoma Paleoecology Database provide a user-friendly web interface that enables you to locate, visualize, synthesize, and interpret large amounts of data very quickly. These are very powerful tools to have at your fingertips!



A herd of mastodon

Painting by Charles R. Knight

(public domain)

**PART 1 — Modern Plant and Animal Distributions and Their Relationships to Temperature and Precipitation**

**Step 1. Exploring modern plant distributions and plant-climate relationships**

Use the online resources listed to investigate the modern range distributions for the following plant and tree species.

Trees: Use the USGS Climate-Vegetation Atlas of North America website (Professional Paper 1650: <http://pubs.usgs.gov/pp/p1650-a/>).

Note there is one atlas for conifers and a separate atlas for hardwood trees. In the univariate plots for each species’ atlas entry, the top line of data shows where that species is present while the bottom line shows all the datapoints in the dataset where the species is absent. In the bivariate plots, the black dots show the species data while the grey dots show the total dataset including all species. Hence, you can see where that species falls relative to all the species in the dataset.

* *Pinus strobus* (eastern white pine, a conifer)
* *Picea mariana* (black spruce, a conifer)
* *Tsuga canadensis* (eastern hemlock, a conifer)
* *Quercus alba* (white oak, a hardwood)

Other Plants: Use BONAP's North American Plant Atlas (<http://bonap.net/NAPA/Genus/Traditional/State>) and/or the USDA NRCS PLANTS Database (<http://plants.usda.gov/java/>)

The two genera of interest have many species. Note that you are interested in the *native* species (shown in green in the BONAP maps). You will need to explore a bit more in the databases to find the information you will need.

* *Artemisia* spp*.* (sagebrush, mugwort, wormwood); some good species to consider are *A. arbuscula*, *A. cana*, *A. nova*,and *A. tridentate.*
* *Ambrosia* spp. (ragweed)

For each species/genus above, you will need to describe:

1. **Where geographically it occurs**, listing states and provinces or general regions (e.g., New England, upper Great Lakes, Southwest) as you deem appropriate.
2. **Its modern temperature and precipitation ranges**. The USGS atlas will provide this information for you for the four tree species, but the two non-tree taxa will require a little investigation on your part (try an advanced search in the USDA database). Think about what information you need for these climate parameters. For example, given that you want to capture the climate requirements of the species, does it make more sense to record summertime (July) highs or lows? What about wintertime (January)?

You can record your answers to questions 1 and 2 for each species below:

*Pinus strobus* (white pine)

*Picea mariana* (black spruce)

*Tsuga canadensis* (eastern hemlock)

*Quercus alba* (white oak)

*Artemisia* spp*.* (sagebrush, mugwort, wormwood)

*Ambrosia* spp. (ragweed)

**Step 2. Using Neotoma to explore modern animal ranges and animal-plant-climate relationships**

**Access the Neotoma Database.** Go to <http://www.neotomadb.org/>. Click on the ‘Explorer’ picture. Change the zoom so that your window is centered on North America, including all of the lower 48 states and the southern half of Canada.

Once in the Neotoma Explorer we will look at the modern distribution of several animal species and see how they compare to the plant distributions we examined above.

To find the modern distribution of select vertebrate species click on the red polygon button (4th from the left) in the Neotoma Explorer window. In the Modern Ranges pop-up window examine the modern distributions of the following species:

* *Antilocapra americana* (pronghorn antelope)
* *Martes americana* (pine marten)
* *Didelphis virginianus* (opossum)

For each of the three mammal species describe:

1. Where geographically they occur
2. What type of vegetation each animal is associated with, drawing upon the plant taxa you investigated above

You can record your answers to questions 3-5 below:

*Antilocapra americana* (pronghorn antelope)

*Martes americana* (pine marten)

*Didelphis virginianus* (opossum)

**PART 2 — Examining Past Distributions of Plant and Animal Species in Response to Quaternary Climate Change**

We will now look at how the distributions of the plant taxa we examined in Part 1 have changed over the past 21,000 years in response to climate change.

We will start with *Picea* (spruce).

1. First, predict how you think the distribution of this tree taxon has changed over the last 21,000 years. Do you think it has remained in the same position or has it migrated through time?

Now, let’s test your predictions using the Neotoma Database.

Instead of using a specific species we will look at the whole genus. Because these records are based upon fossil pollen, it is not always possible for scientists to distinguish among individual species based on pollen grain morphology, so we will aggregate the data.

Click on the search tool (binoculars). In the pop-up search window click on the Advanced tab to open the Advanced Taxa Selection window. For dataset type, select “pollen”. Click on the gear symbol next to the Taxon name box. For Taxa group, use the pull down menu to select “Vascular plants.” In the Search For window type “Picea” and click Go. Click on the top Taxon box to select all. Click Close. Back in the Search window, set Abundance to >20% and set the age range to 21,000 (oldest) to 18,000 (youngest) yr BP. Click Search.

Observe the spruce distribution on the map.

Now, repeat the search for spruce using the following time ranges. You will only need to specify the age ranges in the search window, you do not need to reselect the taxon.

* 15,000 to 12,000 yr BP
* 10,000 to 7,000 yr BP
* 5,000 to 1,000 yr BP

Observe the patterns for spruce at each time slice on the map. You can change the symbols and colors, rearrange the plotting order, and turn layers on and off using the View Current Search Layers tool (2nd from the left).

1. Describe the distribution through time for spruce.
2. Which climate parameters (temperature and/or precipitation) are driving the spruce distribution through time? Why do you think this? Explain your reasoning.

Let’s observe the relationship of spruce to the position of the North American ice sheets through time from 21,000 yr BP to the present.

Click on the white polygon in the center of the tool bar. In the Ice and Lake window set the time to 21,100 yr BP and press Play. You can pause the animation at points in time.

1. How does the position of spruce relate to the position of the ice sheets through time?

You will now need to observe the past distributions of the plant and animal taxa below using the same four time steps as you did with spruce. *[Note: we may assign each group to a subset of these taxa]*

* *Pinus strobus* (white pine)
* *Quercus* spp. (oak*)*
* *Tsuga* spp ( hemlock)
* *Artemisia* spp*.* (sagebrush, mugwort, wormwood)
* *Ambrosia* spp. (ragweed)
* *Antilocapra americana* (pronghorn antelope)
* *Martes americana* (pine marten)
* *Bison* sp. (bison)
* *Phloeotribus piceae* (bark beetle)

When doing searches for the above plant taxa you will need use the same Advanced Taxa Selection window that you used to select spruce. The one exception is *Pinus strobus:* for this taxon you can simply type *Pinus strobus* in the Basic Search window under Taxon. For all of the above plant species use >5% as the abundance.

For the above animal species, simply type the species name in the Basic Taxon search window. With the animal species, use **50,000 to 18,000 yr BP** instead of 21,000 to 18,000 yr BP, for the first age bracket.

In order to clear your previous searches, click on Remove All in the Current Searches window or reload the Neotoma Explorer page. However, it may be useful to be able to observe the species in tandem, so you may not want to delete your previous searches but rather just toggle the layers on and off as needed.

1. Describe how the distribution of each species changes over time.
2. What climate variables do you think are controlling the distribution of each species? Why?
3. Do some species appear to be more sensitive to climate change than others? Based on what evidence?
4. Can you detect any relationships between your species? For example, do some species consistently co-occur or appear mutually exclusive?
5. Do you notice species that move in synch with each other? Are some species’ responses to climate change more individualistic? Support your answers with specifics from your data!

**PART 3 — Exploring Potential Future Changes in Species Distributions**

How will the distribution of the above species change in the future? Let's take a look at how tree species distributions are expected to change in the coming century in response to anthropogenic climate change. The [USDA Climate Change Atlas](http://www.fs.fed.us/nrs/atlas/) illustrates the future potential ranges of 134 eastern North American tree species based upon climate model predictions of temperature, precipitation and a number of other variables related to tree growth.

Because the atlas only illustrates tree species distributions in the eastern United States, we will look at potential future pine, oak and hemlocks ranges and think about how animal species distributions might change in response in this part of North America.

**Open the Climate Change Atlas:** [USDA Climate Change Atlas](http://www.fs.fed.us/nrs/atlas/) (<http://www.fs.fed.us/nrs/atlas/>), and click on the large box at top that says “Explore the Climate Change Atlas.” (NOTE: As of this writing the box cycles through several pictures, so wait until it says “Explore the Climate Change Atlas” before clicking, otherwise it may take you to a different page.) You will notice that the default map is for the current distribution of red maple (*Acer rubrum*). The three tabs above the map illustrate the current distribution, the projected future habitat and predictor maps of the climate and soil factors that determine where red maple grows. Click on the Predictor Maps tab. You will see a map of average May-September precipitation for the eastern US. This is the climatic variable that best determines the distribution of red maple. Above the map is a pull-down menu where you can see a ranked list of the other climatic and edaphic (soil) variables that help determine where red maple grows. Next, click on the Projected Future Habitat tab. The default map shows where red maple habitat will be under a worst-case (high – harsh) climate change scenario (A1F1) as predicted by the Hadley Climate Model 3 (HadleyCM3). Under the pull-down menu you can look at other future habitat projections based on worst-case (A1F1) and best-case (B1) global warming scenarios as predicted by three different climate models. You can also see averages from all three climate models. The future climate scenarios (A1F1 and B1) are from the IPCC AR4 Synthesis Report. You can read more about these and other future climate scenarios as these links:

* <https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html>
* <http://www.esrl.noaa.gov/psd/ipcc/extremes/scenarios.html>
* <http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/029.htm>

Let’s take a look at four of the tree species that you have already worked with:

* *Pinus strobes* (eastern white pine)
* *Picea mariana* (black spruce)
* *Tsuga canadensis* (eastern hemlock)
* *Quercus alba* (white oak)

In the lower left of the atlas page there is a species search window where you can type in either the English or Latin name for the species. You can also select the tree from a sortable list (link is below the search window). Once the tree is selected click on the new link provided below the search window to load the map (the map does not automatically load).

For each of the four tree species, observe current and future projected ranges under a worst-case scenario (A1F1) as predicted by the average of the three climate models, then answer the following.

1. Describe how the geographic range of each species shifts in response to future climate change. Does it move north or south, east or west, or does it disappear from the eastern US altogether? If the latter, where do you think it will move to? Be descriptive.
2. Which climate (not soil) variable best predicts optimal species distribution? In some cases it may be the second variable on the list.
3. Which of the following animal species that you looked at previously will be most affected by the future range shifts of these three tree species? Why? (For the bark beetle, you may want to use the modern *Phloeotribina* genera distribution map at this link: <http://bugguide.net/node/view/360318/data>)

* *Antilocapra americana* (pronghorn antelope)
* *Bison* spp. (bison)
* *Didelphis virginianus* (opossum)
* *Martes americana* (pine marten)
* *Phloeotribus piceae* (bark beetle)

NOTE TO INSTRUCTOR. If students would like to observe maps of future climate change to help with this portion of the exercise, here are a couple of options.

The Center for Climatic Research at the University of Wisconsin-Madison has visualizations of future climate change in eastern North America <http://nelson.wisc.edu/ccr/resources/LCC/index.php>

The USGS maintains an interactive viewer where you can see CMIP5 (Climate Model Intercomparison Project version 5) output for the entire world and averaged data for each country. Follow the link below and accept the “Terms of Use.” <http://regclim.coas.oregonstate.edu/visualization/gccv/cmip5-global-climate-change-viewer/index.html>