Chapter 11

Paleoecology: Documenting Long-term Environmental Variability

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Contents

Introduction

Long-term perspectives on climate and biological variability are essential to understanding the natural variability of ecosystems. The documentation of past ecosystem response to environmental change is particularly relevant under present models of global change. By documenting the frequency, magnitude, and rate of past environmental and biological change, the fossil record provides a sound basis for predicting future biological responses to natural and human-induced environmental changes.

This laboratory exercise provides students with an overview of paleoecology and paleoecological techniques. Specifically it demonstrates how these techniques are used to document local environmental changes in peat-accumulating wetlands over long time-scales (centuries to millennia). The lab also shows how long-term perspectives on environmental variability aid in our interpretation of recent environmental changes. This exercise was designed for non-majors in an introductory biology course that meets in two three-hour blocks of time each week. The lecture and laboratory components of the course are not separated, thus lecture and laboratory course material are highly integrated. As written, the exercise takes about three hours; however, if the lecture and laboratory portions of the exercise were separated the lab could be completed in less than two hours.

This exercise is based on paleoecological records from the Upper Peninsula of Michigan; however, similar labs could be designed for other regions. The record could also be modified to include other relevant ecological issues (*e.g.*, fire ecology, wetland succession). To design a lab for other regions, we suggest examining the paleoecological literature of the particular region. If little paleoecological literature exists, a lab could still be designed with knowledge of the local wetland plant species, and the relationships between plant species distribution patterns and environmental parameters (e.g., hydrology, salinity, pH).

Materials

- Petri dishes containing the "macrofossils" for each time period
- one dissecting microscope for every two students
- one compound microscope for every two students (optional)
- Prepared microscopic slides of wetland sediments showing microfossils (optional)
- Actual plant macrofossils collected from wetland sediments (optional)
- Coring equipment and sediment core for demonstration (optional)

Notes for the Instructor

Lecture and introductory material

The exercise is broken in two portions. In the first portion, lecture material is presented on why and how fossils become preserved in the sediments of wetlands and lakes, how radiocarbon dating works, and how sediment cores are collected. The types of fossils that are commonly encountered in wetland and lake sediments are discussed, with specific attention given to what types of environmental information these fossils can provide. The students then observe actual fossils that were collected from wetland sediments. Appendix A shows some photographs of the more common fossil types encountered so that the instructor can help the students make identifications. Some suggested further reading on paleoecological methods includes Warner (1990), Warner and Bunting (1996), and Bradley (1999).

Obtaining "macrofossils" for the plant macrofossil record

We created our hypothetical plant macrofossil record by collecting seeds, fruits, and needles from live plants. Collections from herbarium specimens could also be used. A predetermined number of seeds, fruits, and needles of each species were placed in petri dishes, with each sample representing what might be found in a 1-cm wide slice from a sediment core. Thus, each petri dish contains the "macrofossils" that accumulated in the wetland during a particular time period. Appendix B shows the number of "macrofossils" that are placed in each petri dish, and Appendix C shows the actual macrofossil diagram produced by the students. The macrofossil record could easily be changed by altering the numbers and/or types of plants in the samples. Seeds, fruits, and needles are the best plant organs to use, as these are commonly preserved in wetland sediments and are usually easily identifiable. We caution against using two species that have fruits, seeds, or needles that are morphologically similar, as it creates frustration for the students. If fruits, seeds, or needles of a particular species are not accessible, plant fragments from a similar species could be substituted.

Interpretation of the plant macrofossil record is relatively straightforward, because the concentration of macrofossils in closed basins (*i.e.,* wetlands and lakes with no inflow or outflow streams) generally corresponds to the local abundance of the plant species that produce them (*e.g.,* Birks 1980; Dunwiddie 1987). Thus, for the purpose of this exercise, large increases or decreases in macrofossils should be interpreted as changes in the abundance of those species. Appendix D contains answers to the interpretation questions posed to the students. It should be noted that alternate interpretations do exist, and the purpose of the exercise is to get the students to critically think about environmental variability.

Student Outline

Questions to be considered

1. Why do scientists study past environments?
2. How do scientists study past environments?
3. How have changes in climate affected hydrology, fire frequency, and vegetation? How are these factors related to each other?
4. What is natural variability?
5. How have human activities influenced vegetation, hydrology, and fire frequency?

Global change and environmental variability

The earth is a dynamic place. Think about what the weather is like today. Is today's weather different from yesterday's weather? Was the weather this week different from the weather last week? Is this year's winter different from last year's winter? How different was the weather of the last 10 years compared with the weather of the previous decade? How about comparing the last hundred or even thousand years?

Ecologists typically study the relationship between organisms and their environment on short temporal scales (years to decades). Paleoecologists study these relationships on longer time scales, typically ranging from centuries to millennia. Understanding the long-term natural variability of ecosystems is critical to understanding the relationships between climate, hydrology, fire, and organisms. Understanding the long-term natural variability of ecosystems is also important to assessing the effects of humans on the environment. In other words, are the changes we observe in the environment today due to human actions, or are they part of a longer cycle of natural change?

Relationships among climate, vegetation, hydrology, and fire

Some definitions (*students fill in*):

- Climate –
- Vegetation –
- Hydrology –
- Fire -

How might a change in climate affect vegetation, hydrology, or fire? How might a change in fire frequency affect vegetation? Could vegetation ever affect climate? Can you describe all of the interactions shown in Figure1?

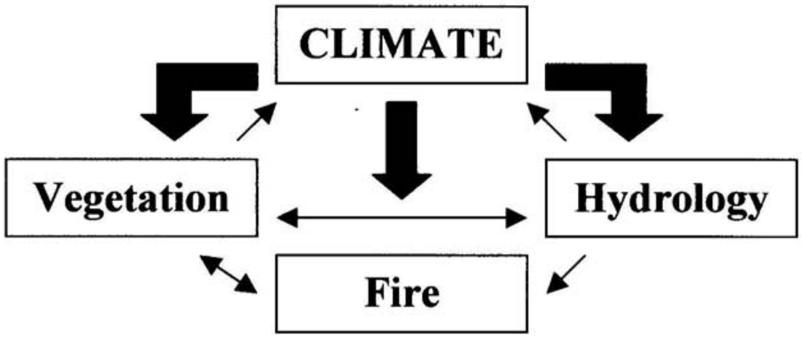

Figure 1. Possible relationships among climate, vegetation, fire, and hydrology at a particular location. The arrows show the potential interactions among the different factors that take place over time.

Documenting long-term environmental variability

Sources of environmental information

The most common source of information on past environments comes from sediments preserved in lakes, ponds, and wetlands. Sediments gradually accumulate in these systems, and the oxygen-poor water slows decomposition of organic matter. Virtually every organism living in or around a wetland or lake has the potential to be preserved in the sediment record, although organisms with decay-resistant parts are found more often. Some common types of organisms found as fossils in lake and wetland sediments are shown in Table1.

Table 1. Everything living in or around a wetland or lake has the *potential* to get preserved; however, organisms with decay-resistant parts are most common (modified from Warner and Bunting 1996).

Organism	Part most often preserved
Algae	Cells, valves, frustules, stratospheres, cysts, and scales
Fungi	Hyphae, spores, and macrofossils
Plants	Pollen, spores, macrofossils, charcoal
Amoebae	Amoeba tests
Sponges	Gemmules and spicules
Flatworms	Turbellaria egg capsules
Rotifers	Bdelloidea egg capsules
Bryozoa	Floatoblasts and statoblasts
Annelids	Egg capsules
Cladocera	Exoskeleton
Ostracodes	Exoskeleton/shell
Copepods	Spermatophores
Molluscs	Shells
Chironomids	Larval head capsules and jaws
Beetles	Wing cases
Vertebrates	Bones and teeth

Fossils incorporated into the sediments record changes in the environment within and surrounding the lake, pond, or wetland. Different fossil types record different aspects of the biota and physical environment at different spatial scales (Figure 2). When reconstructing past environments, it is very important to know the size of the geographic area that different fossil types represent.

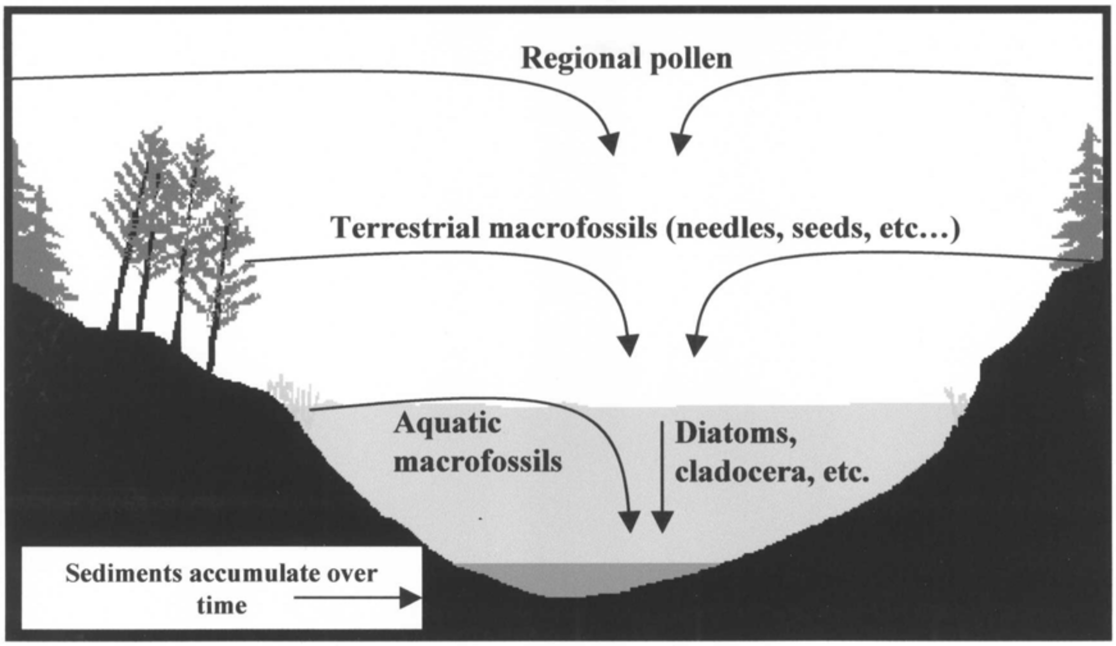

Figure 2. Diagram showing the spatial area represented by several common fossil types that are found in lake and wetland sediments.

Using the microscope and the samples provided, find and draw examples of pollen and plant macrofossils in Table 2. Also, find, identify, and draw at least two other common fossil types (*e.g.*, diatoms, cladocera, testate amoebae). Your instructor will help you with the identifications.

Table 2. Some example fossil types commonly used to reconstruct characteristics of past environments.

POLLEN GRAINS	PLANT MACROFOSSILS
________________ (*fill in blank*)	________________ (*fill in blank*)

Questions:
What fossil type(s) might tell you about the vegetation of an entire region?

What fossil type(s) might tell you about the vegetation growing locally around a lake or wetland?

What fossil types(s) might tell you about the past chemistry or water level of a lake or wetland?

What fossil type(s) might tell you about the past occurrence of fires?

Dating the fossils

There are several ways to determine the age of the fossils preserved in sediments. The most commonly used method is radiocarbon dating. Radiocarbon dating is based upon the measurement of radioactive carbon molecules, or isotopes. If you remember your chemistry, normal carbon molecules have a molecular weight of 12. This means there are 6 neutrons (neutral charge) and 6 protons (positive charge). An isotope is a molecule that has added neutrons. In radiocarbon dating, we are concerned with a radioactive carbon molecule with a molecular weight of 14. These molecules are formed high in the atmosphere as solar energy knocks a proton from a Nitrogen molecule and adds a neutron. These molecules become radioactive during this process and then slowly "decay" over time, emitting what are called beta particles. We can use these molecules for dating purposes because we know how long it takes for half of these beta particles to be lost. The "half-life" of Carbon 14 is 5568 years. By measuring the number of Carbon 12 and Carbon 14 molecules in a sample, we can determine the age of the sample. More carbon 14 molecules indicate a young sample whereas few carbon 14 molecules would be found in an old sample.

How do scientists collect the data?

Because sediments in lakes, ponds, and wetlands can preserve a rich fossil history of an area, paleoecologists have developed techniques for obtaining sediment samples so they can be analyzed. Most commonly, sediment cores are taken from lakes and wetlands using a device called a piston corer. A long, hollow tube with an internal rubber-lined piston is the main part of the piston corer. A metal cable or rod is attached to the piston so it can be moved inside the tube. To begin coring, the piston is located at the bottom of the tube and is firmly secured to a coring platform so it stays at the same horizontal point as coring takes place. As the coring tube is pushed down into the sediments, the piston is held in place by the cable and will act as the suction device which holds the sediments in the coring tube as it is pulled up out of the lake. In short, the piston acts like your finger when you put a straw into your soda (pop, carbonated beverage), place your finger over the top, and pull it up.

Using plant macrofossils to reconstruct past environments

The exercise you are going to do is partially based on actual sediments recovered from a small pond (or lake) in northern Michigan. In groups of two, you will randomly be given a sample of macrofossils that were isolated from a 1-centimeter slice of the sediment core recovered from this pond. You will identify and count all the macrofossils in your sample and enter your data onto the sheet on the next page. Also, tally all the pieces of charcoal.

The following dichotomous key will help you identify the different macrofossils in the sample. You may need to verify some of your identifications using the dissecting microscope.

1. A linear needle
   - A. Needle distinctly half-moon shaped in cross section…………………..….Jack pine
   - B. Needle not half-moon shaped in cross section
     - 1) Needle slightly rounded and four-sided in cross section.……....Spruce
     - 2) Needle triangular in cross section with one side rounded.....….White pine

2. Not a linear needle
   - A. Branchlet consisting of scale-like leaves……………………………….Cedar
   - B. Not a branchlet
     - 1) Small oval-shaped seed with a fine reticulate pattern on surface……………………………………………………Water lily
     - 2) Not oval in outline
       - a) Small fruit (called an achene) covered with an external sheath (called a perigynium)………………Aquatic sedge
       - b) No perigynium present ……………………...…Purple loosestrife

After completing the analysis of your sample, write your results in Table 3 and on the board or overhead. When the entire class is finished, copy the class data onto Table 3 and graph the entire data set on the included sheet.

Table 3. Class plant macrofossil data.

Sample Age (Years B.P.)	# Jack pine	# White pine	# Spruce	# Cedar	# Water Lily	# Aquatic Sedge	# Purple loosestrife	# Charcoal Fragments
0								
50								
100								
150								
200								
300								
400								
500								
600								
700								
800								
900								
1000								
1100								
1200								
1300								
1400								
1500								
1600								
1700								
1800								
1900								
2000								

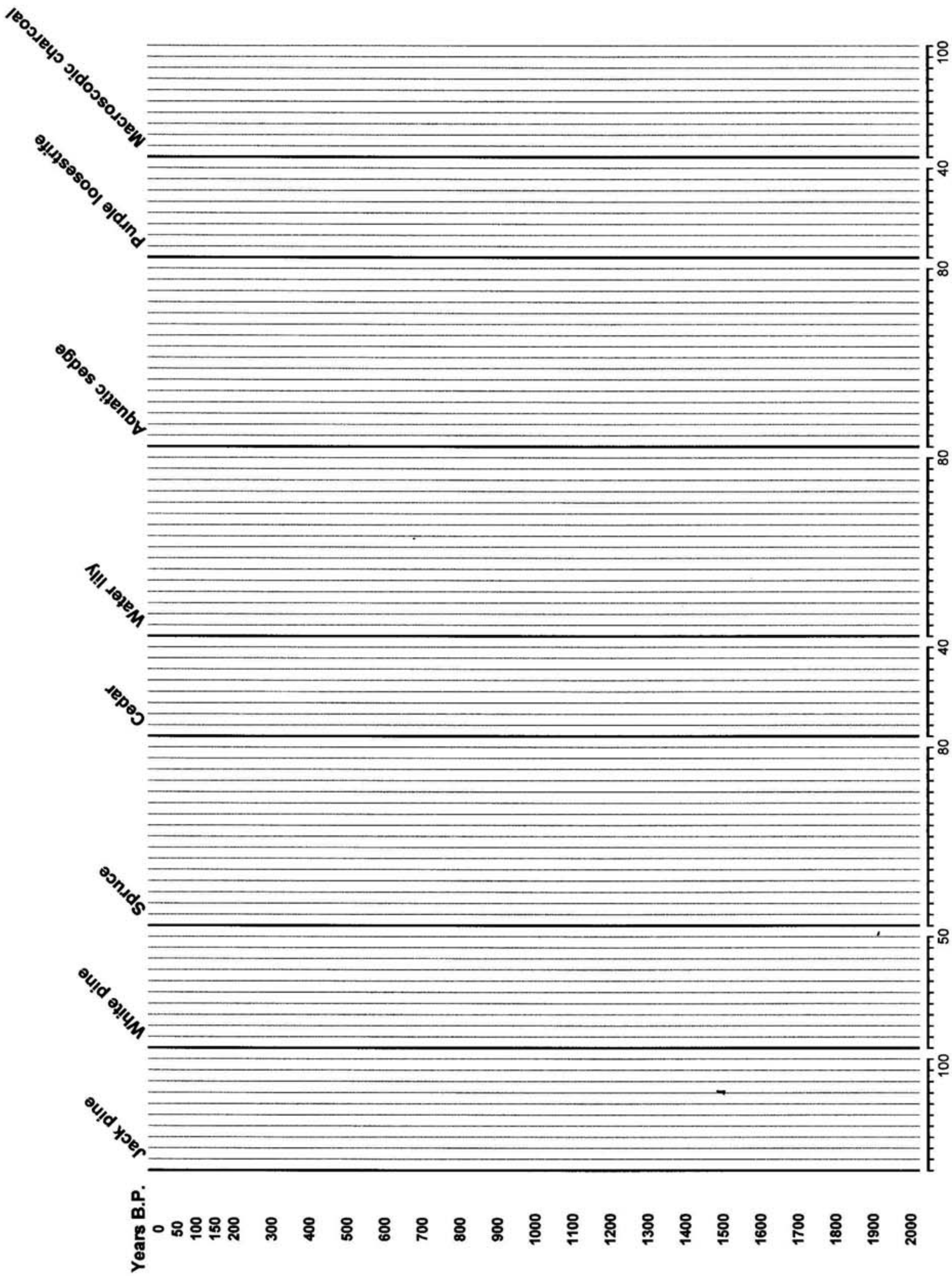

Figure 3. Plant macrofossil diagram for class data.

Interpretation of paleoecological data

In order to correctly interpret your macrofossil record many things must be considered. Three things that are critical to your interpretation include:

1. The characteristics of plants in your macrofossil record (Table 4).
2. Some general climate and historical changes of the last 4000 years in the region (Table 5).
3. The pond's geomorphology (shape and depth) (Figure 4).

Table 4. Some ecological characteristics of the plant species in the macrofossil record.

SPECIES	SOME CHARACTERISTICS
Jack pine	Has serotinous cones (cones that release their seeds after a fire), mostly found on sandy soils
White pine	Heavily logged when European settlers colonized Michigan.
Black spruce	Found in cool, moist areas
Cedar	Often found along the edge of ponds and lakes. Extreme dryness or prolonged flooding will kill them.
Water lily	A plant that lives in water usually less than 1.5m deep
Aquatic sedge	A plant that lives in water usually less than 1m deep
Purple loosestrife	A wetland plant that is not native to the North American continent

Table 5. Some general climate and historical changes of the last 4000 years in the region (documented by other studies and the historical record):

YEAR B.P.	HISTORICAL AND CLIMATIC EVENTS
150 yr B.P.	European colonization of Upper Michigan
700-200 yr B.P.	Generally cooler than today (Little Ice Age)
4000-2000 yr B.P.	Generally warmer and/or drier than today

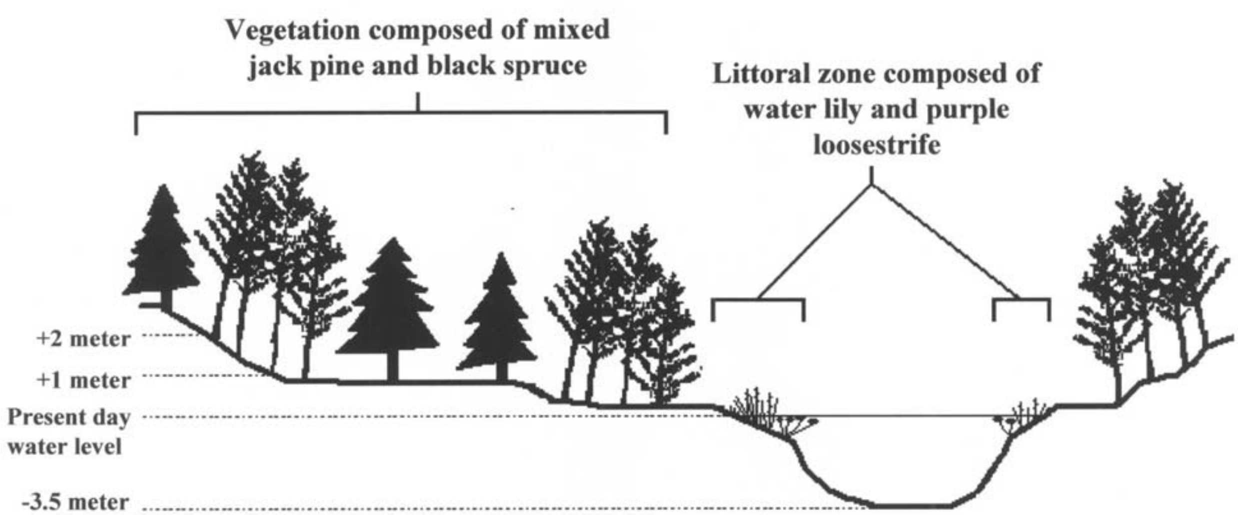

Figure 4. Elevational cross section of the pond showing the present water level and vegetation. The scale on the left indicates the elevation of the pond if water levels rose or fell (HINT: imagine what would happen to the amount of aquatic plant habitat if the water level goes up or down by 0.5-3 meters).

Questions

1. Draw a cross section of the pond depicting what the water level and surrounding vegetation might have been like 400 years ago.
2. Draw a cross section of the pond depicting what the water level and surrounding vegetation might have been like at the time of the pond's formation 2000 years ago. Why do you think this pond formed at that time?
3. Interpret the changes you see in your macrofossil diagram. To do this, turn your diagram into a narrative using words. Start from the time of the pond's formation and work your way to the present, describing the various changes that have occurred. Be sure to discuss each species, and what you think caused the various changes (e.g., climate, hydrology, fire, vegetation, relationships between these factors, something else?).
4. When was there the most water in the pond? When was there the least? What type of climate would have been associated with these water levels? Why?
5. What type of climate was probably associated with greatest amount of forest fires? Why?
6. Which species were most affected by fire? Why?
7. Which species were probably most affected by hydrological changes? Why?
8. Name at least two ways that human activities have influenced the present day vegetation around the pond (plus 1/2 point extra credit for each additional way that humans have influenced the vegetation).

Literature Cited

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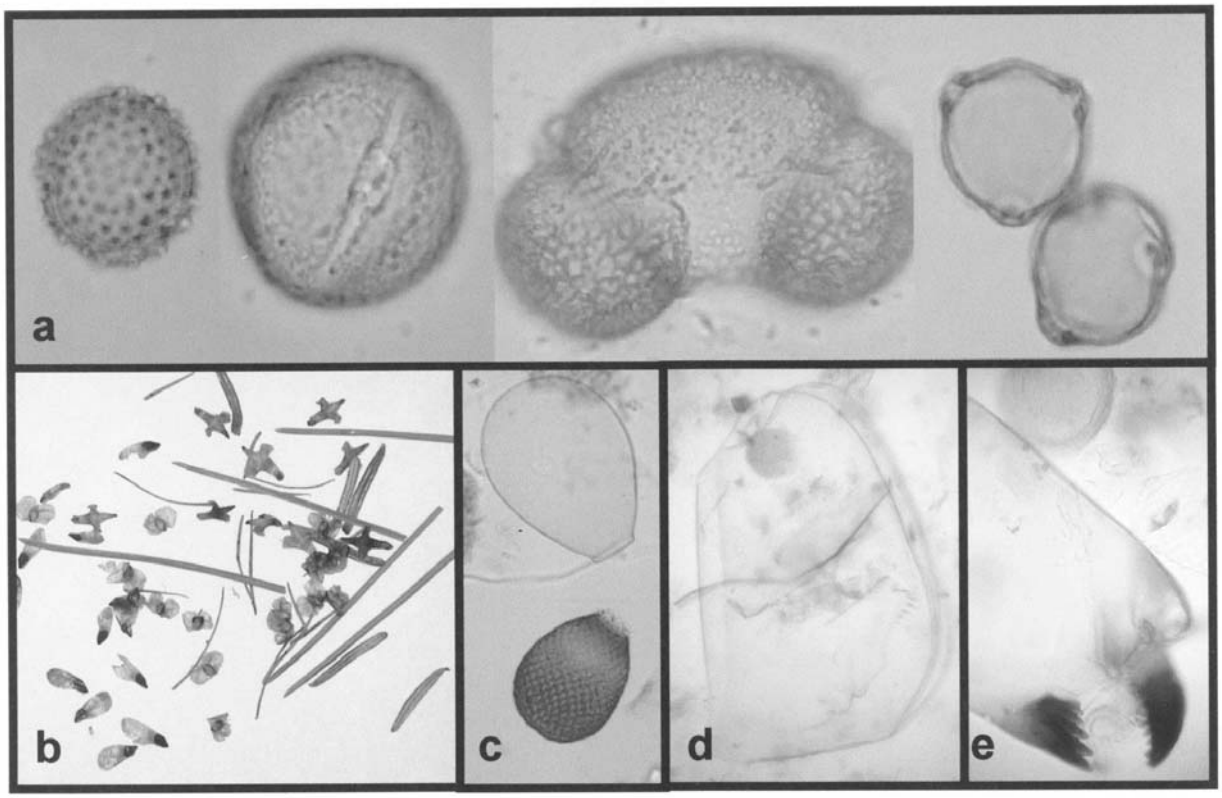
Appendix A

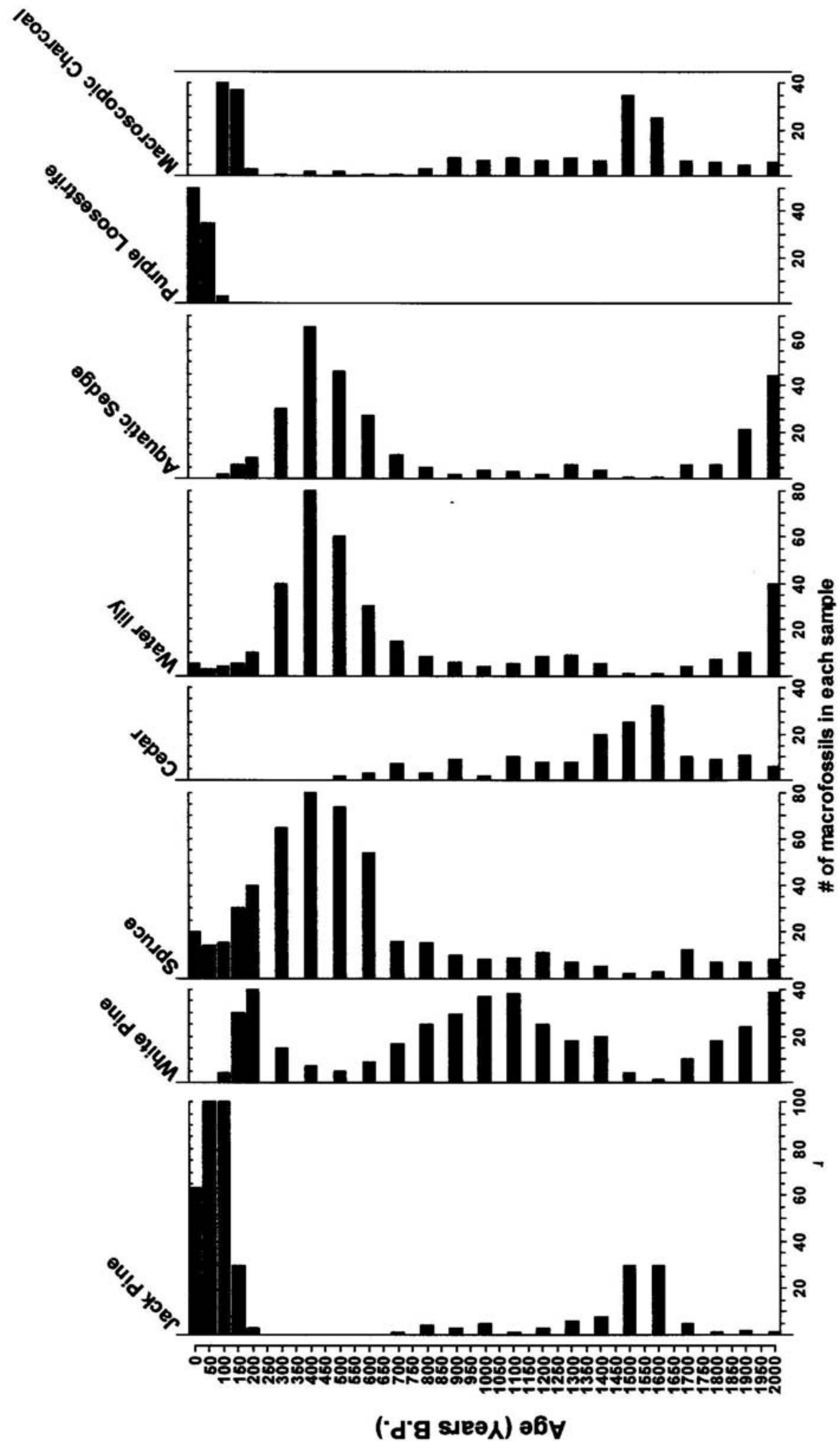
Photographs of some fossil types commonly encountered in wetland sediments: a) pollen (frome left to right: ragweed, beech, pine, birch), b) plant macrofossils (needles and seeds), c) testate amoebae, d) cladocera exoskeleton, e) chironomid head capsule



Appendix B
The number of plant "macrofossils" in each sample

Sample Age (Years B.P.)	# Jack pine	# White pine	# Spruce	# Cedar	# Water Lily	# Aquatic Sedge	# Purple loosestrife	# Charcoal Fragments
0	63	0	20	0	5	0	50	0
50	100	0	14	0	3	0	35	0
100	100	4	15	0	4	2	3	40
150	30	30	30	0	5	6	0	37
200	3	40	40	0	10	9	0	3
300	0	15	65	0	40	30	0	1
400	0	7	80	0	80	65	0	2
500	0	5	74	2	60	46	0	2
600	0	9	54	3	30	27	0	1
700	1	17	16	7	15	10	0	1
800	4	25	15	3	8	5	0	3
900	3	29	10	9	6	2	0	8
1000	5	37	8	2	4	4	0	7
1100	1	38	9	10	5	3	0	8
1200	3	25	11	8	8	2	0	7
1300	6	18	7	8	9	6	0	8
1400	8	20	5	20	5	4	0	7
1500	30	4	2	25	1	1	0	35
1600	30	1	3	32	1	1	0	25
1700	5	10	12	10	4	6	0	7
1800	1	18	7	9	7	6	0	6
1900	2	24	7	11	10	21	0	5
2000	1	39	8	6	40	44	0	6

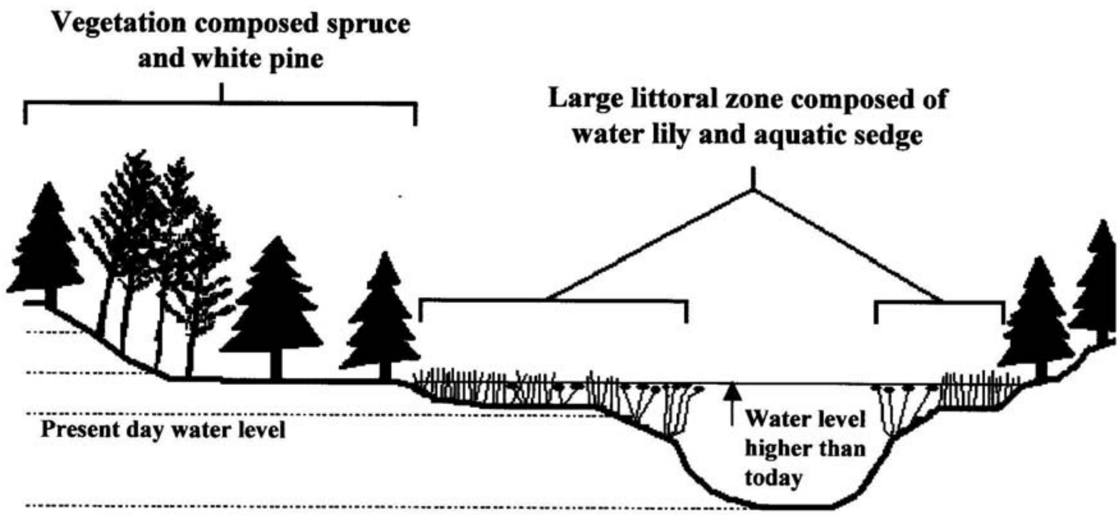
Appendix C
The resulting plant macrofossil diagram produced by the students



Appendix D

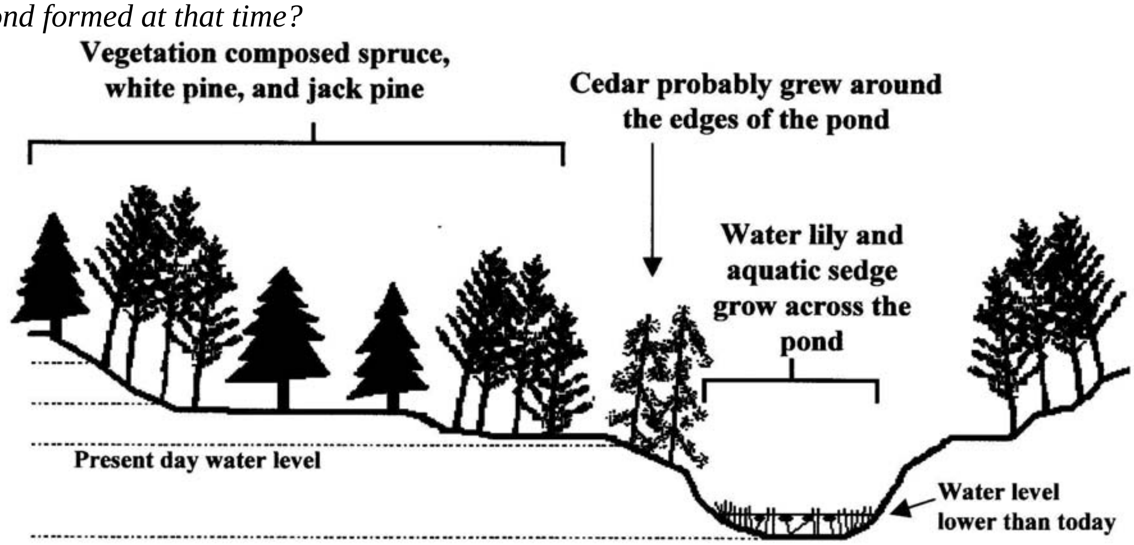
Answers to questions

1. *Draw a cross section of the pond depicting what the water level and surrounding vegetation might have been like 400 years ago.*



The drawing should show the water level of the pond higher than it is today. The Little Ice Age had a cooler climate than today. Cooler temperatures would have decreased the amount of evaporation, so the water level of the pond rose. The increase in aquatic plant macrofossils (because of increased shallow-water habitat around the edge of the pond) and black spruce are also consistent with higher water levels and a cooler climate. Macroscopic charcoal is very low during this time, which also suggests that there was a cooler and wetter climate.

2. *Draw a cross section of the pond depicting what the water level and surrounding vegetation might have been like at the time of the pond's formation 2000 years ago. Why do you think this pond formed at that time?*



Drawing should show the pond water level lower than today. Water level was low enough to allow aquatic plants to grow across its entire surface (increasing the number of aquatic plant macrofossils). Climate became moist enough (slightly cooler) to allow water to remain standing in this depression, which created the pond.

3. *Interpret the changes you see in your macrofossil diagram. To do this, turn your diagram into a narrative using words. Start from the time of the pond's formation and work your way to the present, describing the various changes that have occurred. Be sure to discuss each species, and what you think caused the various changes (e.g., climate, hydrology, fire, vegetation, relationships between these factors, something else?).*

   2000 - 1700 BP: The pond formed approximately 2000 BP as the climate became slightly cooler (it was warmer from 4000-2000 BP). Vegetation around the pond was characterized by abundant white pine. Black spruce, jack pine, and cedar were also present. Water lilies and aquatic sedges were abundant because the pond water level was low enough to allow lots of shallow-water habitat.

   1600 – 1500 BP: This period of time was characterized by abundant or intense forest fires. Jack pine expanded as a result of these fires, because it is very fire-resistant and has serotinous cones. Cedar is also quite abundant during this time. White pine decreases in abundance, possibly because of the jack pine expansion. Pond water levels were probably slightly lower than today.

   1400 – 700 BP: White pine expands and Jack pine decreases. This probably occurred as the climate started becoming a bit cooler and moister. Water levels in the pond probably started increasing.

   700 – 200 BP: The climate becomes much cooler during the Little Ice Age. Less evaporation probably resulted in higher water levels in the pond. This created a large habitat for aquatic plants in the littoral zone of the pond. The higher water levels probably flooded the area occupied by cedar, leading to its local extinction. Spruce expanded as a result of the cooler and moister conditions. There were less frequent or less intense fires during this time.

   150 – 0 BP: The time of European colonization was associated with decreased white pine, probably because this species was heavily logged. Intense and/or frequent fires also occurred during this time. These may have been purposely set by humans, or they may have happened as a result of the accumulation of dry wood and debris left from logging. Jack pine expanded after these fires. Purple loosestrife, an exotic plant, was probably brought to the area by humans.

4. *When was there the most water in the pond? When was there the least? What type of climate would have been associated with these water levels? Why?*
   ~400 BP = most water = climate cool and moist, so there was less evaporation
   ~2000 BP (or 1600 BP) = least water = climate was warm and dry

5. What type of climate was probably associated with greatest amount of forest fires? Why?

Warm, dry climates were associated with more forest fires, because of drier fuel.

6. *Which species were most affected by fire? Why?*
   Jack pine was because of its serotinous cones (releases seeds after fires).

7. *Which species were probably most affected by hydrological changes? Why?*
   Aquatic plants and Cedar. The habitat of these plants is dependent upon the water- level of the pond.

8. *Name at least two ways that human activities have influenced the present day vegetation around the pond (plus 1/2 point extra credit for each additional way that humans have influenced the vegetation).*
   Logging (mostly white pine)
   Fire suppression and/or fire initiation by people
   Transportation of exotic plants (Purple loosestrife) to the area