Reconstructing Fire History: An Exercise in Dendrochronology

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ABSTRACT
Dendrochronology is used widely to reconstruct the history of forest disturbances. I created an exercise that introduces the use of dendrochronology to investigate fire history and forest dynamics. The exercise also demonstrates how the dendrochronological technique of crossdating is employed to age dead trees and identify missing rings. I assigned the exercise to upper-level undergraduate students in a field geography course during Fall 2003. Good student performance on the exercise indicates students were able to interpret the exercise and apply dendrochronological concepts to the problem of forest disturbance history. Strong evaluations of the exercise by students demonstrate its clarity and perceived usefulness. The exercise aligns with contemporary emphases in geographic education, including student-centered teaching, experiential learning, and constructivist pedagogy.

Key Words: *tree ring, disturbance, vegetation, biogeography*

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Disturbances strongly influence the species composition, diversity, structure, and spatial distribution of natural vegetation. Disturbances include fires, windstorms, ice storms, insect outbreaks, diseases, timber harvest, and other events that cause plant mortality (Huston 1994). Over the last three decades, plant geographers and ecologists have become increasingly aware of the importance of disturbances for vegetation (Huston 1994; Parker et al. 2001). Contemporary textbooks in introductory physical geography typically include at least a short discussion on disturbance and the related topic of succession (e.g., Strahler and Strahler 2002; Christopherson 2003; Gabler et al. 2004). Some textbooks geared toward upper-level undergraduate courses in biogeography and ecology devote considerable attention to these issues (e.g., Barbour and Billings 2000; Gurevitch et al. 2002; MacDonald 2003).

This paper presents an exercise on the use of dendrochronology, or tree-ring dating, to investigate disturbance history in a forest stand. Dendrochronology has been used extensively to obtain high-resolution records of disturbance history and stand dynamics (Frelich 2002). Moreover, dendrochronology is employed frequently in many other areas of geographic research, including climatology, geomorphology, and historical geography (Fritts 1976; Shroder 1980; Stahle et al. 1985). The exercise presented here would be appropriate for courses in these subjects, in addition to biogeography, because it introduces concepts that are fundamental to any dendrochronological investigation. In particular, students learn to apply the technique of crossdating, which is the basis of dendrochronology.

The exercise is aimed primarily at undergraduate students enrolled in advanced courses in physical geography, but it also could be used in introductory-level undergraduate courses if sufficient guidance were available (e.g., in a laboratory session). The exercise addresses three primary issues relevant to these courses. First, it demonstrates the application of dendrochronology for reconstructing fire history and forest stand dynamics. Second, it teaches basic crossdating skills. Third, it challenges students to reflect on the role of fire in natural ecosystems. In North America, fires commonly are viewed as undesirable and harmful events to be suppressed whenever possible (Pyne 1982). However, many plant species require periodic fire for reproduction and population maintenance, and the abundance of such species is declining as a result of fire suppression. The exercise presented here illustrates the beneficial role of fire in a pine forest.

I anticipate that the exercise will be most useful if it is introduced in the context of lectures, fieldwork, or other instruction about vegetation disturbance and dendrochronology. Undoubtedly, many physical geographers teach these topics and would find the exercise could fit readily into their courses. Moreover, if students read the chapter on disturbance in MacDonald's (2003) biogeography textbook, they would find my exercise a logical application of the dendrochronology discussion.

This exercise aligns with contemporary emphases in geographic education. In particular, it provides a student-centered approach (Burke 1978) that fits within the framework of experiential learning (Birnie and O'Connor 1998; Healy and Jenkins 2000). The project supplies a concrete experience that complements learning gained in more abstract forms (e.g., via lectures or reading assignments). It also supports constructivist pedagogy (Jenkins 1998; Scheurman 1998; Bransford et al. 1999) by building on pre-existing general awareness of tree growth and forest fire, and by permitting students to grapple on their own with disturbance and tree rings as a step in constructing knowledge about these topics.

Using Dendrochronology to Study Forest Disturbance History

Trees growing in many parts of the earth, particularly middle and high latitudes, add a new growth ring each year (Stokes and Smiley 1968). Dendrochronologists sample these growth rings by sawing cross-sections from a tree trunk or by coring the tree with an increment borer. An increment borer is a threaded hollow bit used to extract cores 4 to 5 mm in diameter from a tree. The increment borer permits the researcher to sample the annual growth rings without cutting the tree. Tree cores are dried, glued to mounts, and then surfaced with fine-grit sandpaper or a razor blade to make visible the boundaries between consecutive growth rings (Stokes and Smiley 1968). A mounted and sanded core is depicted in Figure 1.

In any tree-ring study, the dendrochronologist must assign a calendar date to each annual ring. Dating the rings hinges on sampling live trees in which the date of the most recent growth ring is known. Once these are dated, it is possible to date specimens from dead trees by matching patterns of interannual ring-width variability between the live and dead trees (Stokes and Smiley 1968). Such matching, or "crossdating," is the most important principle in dendrochronology (Fritts 1976), and distinguishes dendrochronology from simple ring counting. The exercise below describes the technique of crossdating more fully.

Properly dated tree-ring samples can yield several types of information about forest disturbances. Most fundamentally, they indicate tree ages, which are necessary for identifying pulses of tree establishment. New plants often become established in the high-resource environment that exists after the mortality of dominant plants. Numerous demographic studies of forest stands use dendrochronology to reveal the presence of tree cohorts that initiated after disturbances (e.g., Lorimer 1980; Mast et al. 1998; Taylor and Skinner 1998; Parker et al. 2001). The frequent occurrence of low-severity disturbances leads to a forest composed of multiple age-cohorts. In contrast, even-aged stands often develop in forests struck by major crown fires at relatively infrequent intervals (Heinselman 1973; Turner and Romme 1994; Parker et al. 2001).

In multi-aged stands, interannual changes in tree-ring width supply additional information about disturbance history. Abrupt and sustained increases in ring width often follow disturbances, because disturbances release resources (light, water, nutrients) that can be used by the surviving trees (Frelich 2002). Biogeographers and ecologists have conducted numerous analyses that use such growth increases to identify past disturbances (e.g., Lorimer 1980; Parker 2001; Lafon and Speer 2002; Ziegler 2002).

Fire scars provide further evidence of disturbance. Scars are typical in forests affected by surface fires that burn litter and understory vegetation. Surface fires usually do not kill the dominant trees, but often scar their boles. A scarred tree covers the wound gradually via the curling of wood over the scar from the sides. In forests characterized by surface fire regimes, the interval between burns is often too short for a scar to be covered completely before the next fire occurs. Consequently, an individual tree can bear multiple fire scars (Fig. 2). Geographers and other researchers have conducted numerous studies that use dendrochronological analyses of fire scars to reconstruct fire history (e.g., Sutherland et al. 1995; Mast et al. 1998; Taylor and Skinner 1998; Grissino-Mayer and Swetnam 2000). Some caution is required when interpreting studies of fire history, because additional fires of low intensity may have burned without scarring the trees, leaving no record of occurrence. Therefore, the length of the intervals between successive fires may be overestimated.

An exercise on dendrochronological investigation of forest disturbance

I created an exercise on the use of dendrochronology to reconstruct fire history and explore how fire disturbances influence tree establishment and growth. The exercise represents a mixed-severity fire regime—the forest is affected both by surface fires that scar the trees and by crown fires that kill many of them (Brown 2000). The exercise teaches basic crossdating skills, including the dating of specimens from dead trees and the identification of missing rings. The estimated time required to complete the project is two to three hours.

The photographs in Figures 1 and 2 should help students visualize the concepts addressed in the exercise without having to collect data in the field or prepare the wood samples. The Ultimate Tree-Ring Web Pages of Dr. Henri Grissino-Mayer (http://web.utk.edu/~grissino/) also provide many excellent photographs that illustrate

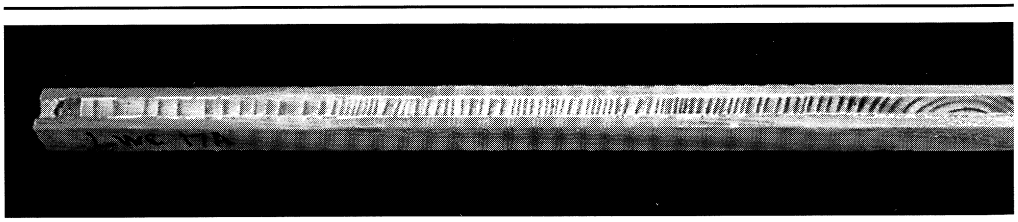
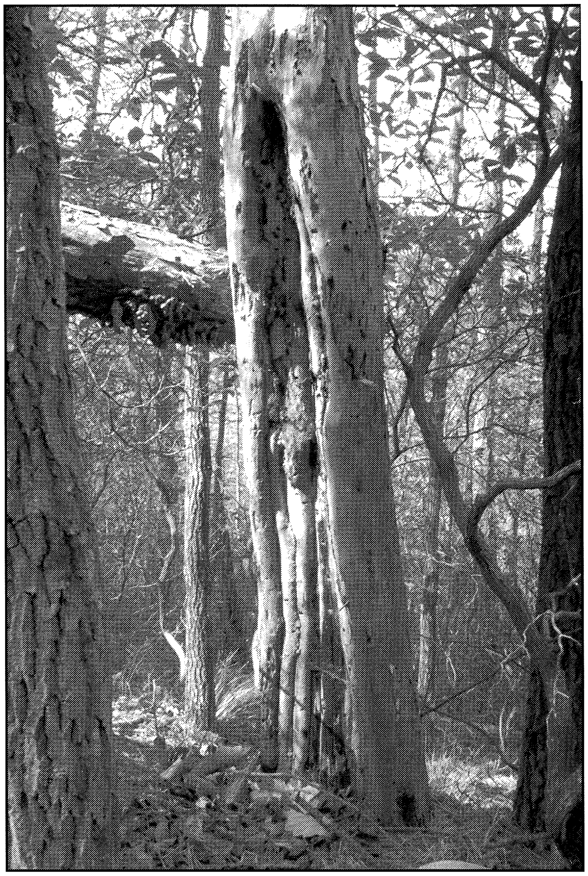


Figure 1. A tree core that has been mounted and sanded. The core was extracted from a Table Mountain pine tree, which, like other pines, exhibits distinct annual rings. The inner (earliest) rings are at the right end of the core, and the outer (recently grown) rings are at the left end.

dendrochronological concepts, including the use of fire scars to reconstruct fire history.

The exercise is on the following pages. The graphics for completing the assignments are at the end of the exercise. An evaluation of the exercise follows the graphics.



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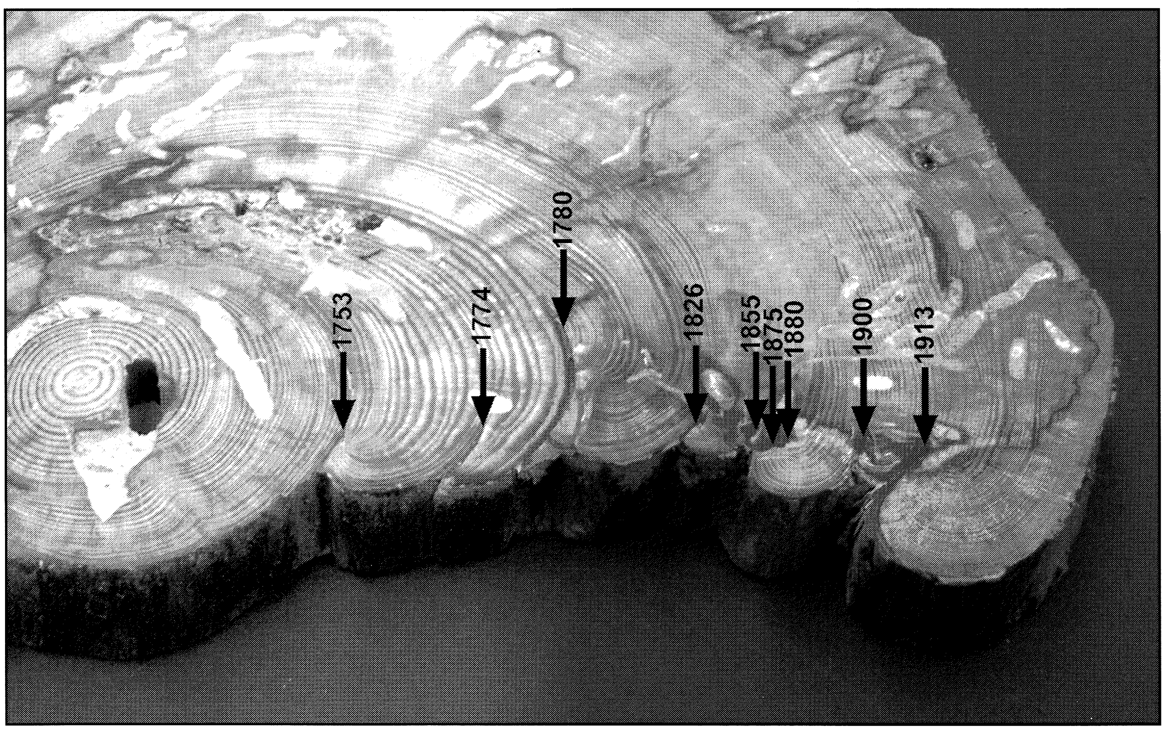

B

Figure 2. (a) Fire scars on a dead pine tree in Rockingham County, Virginia. The vertical ridges in the "catface" result from the curling of wood over the scar from the sides. The scars are all on one side of the tree – once the tree is scarred, it lacks protection from subsequent fire and is scarred easily in the same location. (b) Cross-section with nine scars (indicated by arrows with dates), cut from a fire-scarred pine.

THE EXERCISE

(Answers are shown in brackets.)

Introduction

The attached diagram (Fig. 3) represents cross-sections cut from the trunks of two pine trees in a forest stand in North America. The cross-sections have been sanded so that the annual rings are visible. Each line represents the boundary separating two adjacent rings (Fig. 4, label A). The cross-section in Figure 3a is from a tree that was cut recently. The gray zone around the outside of the cross-section represents the bark. In the other cross-section (Fig. 3b), the bark has fallen off, indicating that the tree died some years ago.

In each of the cross-sections, the first year's growth is in the center of the tree and is represented by a circle (Fig. 4, label B). Rings toward the outside grew more recently. For the recently cut tree, the last ring (the one on the outside edge next to the bark) was added to the tree during the most recent growing season. For this exercise, assume that this last ring was grown in the year 2000. You do not know when the dead tree died, but you can use the dendrochronological technique of crossdating to determine its death date.

Note that ring-width varies—that is, the trees grew more rapidly during some years than others. The narrow rings formed during years in which growing conditions were less favorable than in other years. For this exercise, assume that drought was the cause of unfavorable growing conditions. In some cases reduced growth reflects other factors (for example, below-normal temperatures for arctic or alpine treeline environments), but is typically associated with drought in temperate forests. Some tree species display stronger responses to drought than others; this exercise assumes that all samples were obtained from the same species.

Drought should influence the growth of all trees in a region. Therefore, all trees in this exercise should exhibit slow growth during the same years, making it possible for you to match the narrow rings in one tree to those in another tree. Once you match the narrow rings between the freshly cut and dead trees, you can assign dates to the rings in the dead tree, and determine its establishment and death dates. In matching ring-width patterns between trees, you are applying the fundamental dendrochronological principle of crossdating.

Crossdating is necessary not only for dating specimens from dead trees but also for ensuring the accuracy of dating in live trees. One situation that can undermine dating accuracy is the occurrence of missing rings. During a year with highly unfavorable growing conditions, the tree ring may be absent in part of the tree. For example, note that in the live tree (Fig. 3a), the narrow ring that formed in 1996 is missing over part of the cross-section. For many studies, dendrochronologists do not cut cross-sections from trees but instead use increment borers to obtain a core from the radius of the tree. If you by chance cored the live tree through the segment with a missing ring, you would not be able to date it accurately. However, by crossdating the specimen with other trees, some of which would not be missing the 1996 ring, you could determine the existence of the missing ring and account for it when you assigned dates.

Another condition to note is that each cross-section has fire scars on one side. In these drawings, the heavy black lines represent the scarred portion of the tree trunk (Fig. 4, labels C, D). New wood cannot grow in these scarred sections. Instead, the tree begins to cover the wound by growing new wood over the damaged area (Fig. 4, label E). Subsequent fires cause new damage, and the process is repeated, leaving a record of the occurrence of fires. These fire-scars permit precise dating of the years when fires occurred. In this exercise, you will use fire scars to reconstruct the fire history of the forest from which these specimens were collected.

This exercise also includes cores obtained from several pine trees in the forest (Fig. 5). As in many biogeographical and ecological studies, you will use these tree cores to determine establishment dates for trees in the forest. Tree establishment dates show whether disturbances (fires, in this case) provided conditions favorable for the establishment of new cohorts of trees. The cores in your exercise are from live trees, and the last ring formed in 2000. The gray patch at the right end of each core represents bark. Only one core (J), the one without bark, is from a dead tree. It will be necessary to crossdate all the cores to determine correct dates for each ring.

Step A. Dating the freshly cut tree.

1. Assume that the freshly cut tree has no missing rings, other than the missing portion of the 1996 ring. This assumption would be valid in an actual study only if the specimen had been crossdated against tree-ring chronologies from a number of other trees, and found to have no rings missing. The assumption is permitted for this assignment because the tree in the exercise was designed without missing rings to expedite your completion of the project. Assign dates to the rings, placing a dot (with pencil) on every tenth ring in Figure 3a. The dots should be placed only on even decades (e.g., 1980, 1990, 2000). See Figure 4, label F for an example. (In an actual tree-ring study, you would mark dots on the wood).

   NOTE: Be careful in your counting, and check your counting to make sure it is correct.

2. In what year was the tree established (i.e., what is the date of the innermost ring)? [1979]
3. Mark the establishment date on graph A (Fig. 6) by drawing a downward-pointing arrow about one inch long on that year (for an example of a 1988 establishment date see Fig. 7a). Each tic mark on the graph represents one year. Also draw an arrow on year 2000 to indicate the last year (see Fig. 7a).
4. Based on tree-ring widths, four years were characterized by drought conditions. (Look for rings that are substantially narrower than surrounding rings). List the four drought years. [1982, 1983, 1989, 1996]
5. Mark the four drought years on graph A (Fig. 6) by drawing a vertical line about one inch long for each drought year (For an example, see 1993 and 1995 in Fig. 7a). Your completed graph provides a visual depiction of the temporal pattern, or chronology, of ring-width variation in the tree. A graphic representation aids in crossdating. Dendrochronologists often create similar representations for actual tree rings; these are called "skeleton plots."

Step B. Dating the dead tree.

6. Because you do not know the death date for the dead tree, you cannot yet assign actual dates to the rings. Begin by placing a dot on the innermost ring (Fig. 3b) and assigning that ring a date of zero. Then count outward and place a dot on every tenth ring (0, 10, 20, etc.).
7. On graph B (Fig. 6) draw a downward-pointing arrow as before on year 0 to indicate establishment year.
8. Also, draw an arrow to indicate the last year of the tree's life (the death year). For example, if the tree died at age 10, you would draw an arrow at year 10. [Draw the arrow at year 25.]
9. Note that four rings are exceptionally narrow and probably indicate drought years. These are rings number ___, ___, ___, and ___. [5, 15, 16, and 22].
10. On graph B, draw vertical lines as before to indicate these drought years.
11. Compare the pattern of drought years between the freshly cut and dead trees (Fig. 6a,b). Both trees were in the same forest and would have responded to the same droughts, making it possible to crossdate them. Based on this pattern, you should be able to assign actual dates to the rings in the dead tree. The occurrence of two consecutive narrow rings in each tree should be especially helpful. You may write or draw on your graphs if it helps. For example, you may want to label the establishment year, death year, and drought years above each vertical line in graph B. You may also find it helpful to cross out the labels for years 0, 10, 20, and 30 and instead label the graph with actual years (e.g., 1970).
12. In what year was the tree established? [1967]
13. In what year did the tree die? [1992]
14. Erase the dots on Figure 3b and place new dots on actual years, as before (e.g., 1970, 1980).
15. The dead tree preserves a record of growth that extends further back in time than that provided by the freshly cut tree. Name one earlier year of severe drought that occurred before the freshly cut tree was established. [1972]

Step C. Developing a master chronology.

You will develop a "master chronology" to aid in crossdating additional specimens collected from the forest. The master chronology combines the record of narrow rings recorded in both the freshly cut and live trees. (In an actual study, the dendrochronologist would develop the master chronology from a larger number of trees to ensure that missing rings or other dating problems were identified. For your project, assume that no dating problems exist).

16. List all five years in which severe drought occurred, based on the record of both trees combined. [1972, 1982, 1983, 1989, 1996]
17. On graph C (Fig. 6), record these drought years as vertical lines, as before.
18. Also draw arrows on the graph, as before, to indicate the time span covered by the chronology. Draw the first arrow on the year in which the dead tree was established [1967], and the last arrow on year 2000, the last date of growth for the freshly cut tree. This graph represents your master chronology.

Step D. Reconstructing fire history.

19. List the three years in which the freshly cut tree was scarred by fire. Take your time and be careful in counting rings. [1987, 1992, 1998]
20. List the four years in which the dead tree was scarred by fire. [1974, 1978, 1987, 1992]
21. Now list all five years in which fire occurred in this forest, based on the combined fire-scar record of both trees. [1974, 1978, 1987, 1992, 1998]
22. On graph D (Fig. 6), draw arrows below the x-axis to indicate the years in which fire occurred. For an example, see Figure 7b.

Step E. Calculating Mean Fire Interval (MFI).

MFI is the average number of years between consecutive fires. To calculate MFI, you will first determine the number of years between each consecutive fire. For example, if you had records of three fires that occurred in 1881, 1886, and 1895, you would calculate two fire intervals (1886 – 1881 = 5 years; 1895 – 1886 = 9 years). MFI is the mean of these two intervals (i.e., 7 years).

23. Because your data record five fires, you must calculate four fire intervals. List these four intervals. [1978 – 1974 = 4 years; 1987 – 1978 = 9 years; 1992 – 1987 = 5 years; 1998 – 1992 = 6 years]
24. What is the MFI for the forest in this exercise? [(4 + 9 + 5 + 6)/4 = 6 years]

Step F. Determining tree establishment dates.

25. Date each of the ten cores (Fig. 5), placing a dot every 10 years, as before. You will need to indicate actual dates. Now that you have a list of the drought years, you will probably find that the easiest way to date the cores is to start counting at year 2000 and count backward, placing dots on *1990, 1980, etc.*
    NOTE: Remember that the gray area represents bark, not the 2000 ring. Also, watch out for missing rings! In some cores, a drought-year ring is missing, while in most cores the drought years show up as narrow rings. Make sure to account for missing rings when placing your dots! Indicate the missing rings on the core by placing dots diagonally across from each other on each side of the ring boundary (see Fig. 4, label G for an example).
26. Record the establishment date (the date of the inner ring) for each tree in the space to the right of each core. [A) 1993; B) 1968; C) 1993; D) 1981; E) 1993; F) 1994; G) 1980; H) 1980; I) 1979; J) 1967]
27. What was the last year of growth for the dead tree represented by core J? [1992]
28. On graph D (Fig. 6), draw a vertical line one unit tall to represent each tree established during a given year. For example, if two trees were established in 1988, you would draw a vertical line 2 units high for the year 1988. See Figure 7b for an example.
29. Add to graph D the establishment dates for the trees from Figure 3.

Step G. Assessing the influence of disturbance on tree establishment, growth, and mortality.

30. What event would you hypothesize killed the dead tree in Figure 3 and the tree represented by core J (Fig. 5)? [The fire of 1992]
31. The freshly cut tree in Figure 3a exhibits a pronounced increase in ring width beginning in 1993. Cores D and I in Figure 5 show a similar pattern. What would you hypothesize to be the cause of this increase? [Increased resource availability as a consequence of tree mortality following the fire of 1992.]
32. Of the five fires you dated for this exercise (Fig. 6d), two of them appear to have been more intense than the others, killing a number of canopy trees and hence making more resources available for other trees. The remaining three fires probably were milder burns that consumed leaf litter and killed seedlings, but caused little damage to the larger trees. Which two burns were most severe? [1978, 1992]
33. On what evidence do you base the conclusion in the previous question? [The 1992 burn was followed by increased growth in some of the surviving trees, and new trees became established within a few years after these two fires].
34. Do the specimens in this exercise provide any evidence for an earlier disturbance of high severity? Explain. [Yes – the establishment of three trees in the late 1960s suggests a fire or other disturbance occurred.]
35. Do the pines in this forest appear to depend on periodic fire for reproduction? Why or why not? [Yes – they establish after fires.]
36. Resource managers often ask researchers to use the results of their studies to speculate about possible consequences of management decisions. Predict whether pines would continue to reproduce if fire were excluded from this forest for several decades. [Probably not, at least during the period of fire exclusion.]

Step H. Interpreting an actual fire-history study.

Following completion of the exercise, students in my field geography course read a paper on fire-history and tree-establishment in Table Mountain pine (Pinus pungens Lamb.) forests (Sutherland et al. 1995). The students applied the concepts learned in their exercise to interpret the methods and results of Sutherland et al. The Sutherland et al. study included both a fire-history reconstruction and an age-structure analysis for a species whose populations apparently were maintained historically by a mixed regime of frequent surface fires (MFI = approximately 10 years) punctuated occasionally by more severe fires that stimulated the establishment of new pine cohorts. The paper was appropriate for the students because of my own research in these same forests. Fire-scarred specimens from Table Mountain pine trees were brought to class to illustrate some of the concepts addressed in the exercise. The paper by Sutherland et al. is short and straightforward, and can be obtained from the web site of the North American Dendroecological Fieldweek (http://web.utk.edu/~grissino/nadef/reports/1993elaine.htm). Different papers may be more appropriate for other universities or colleges.

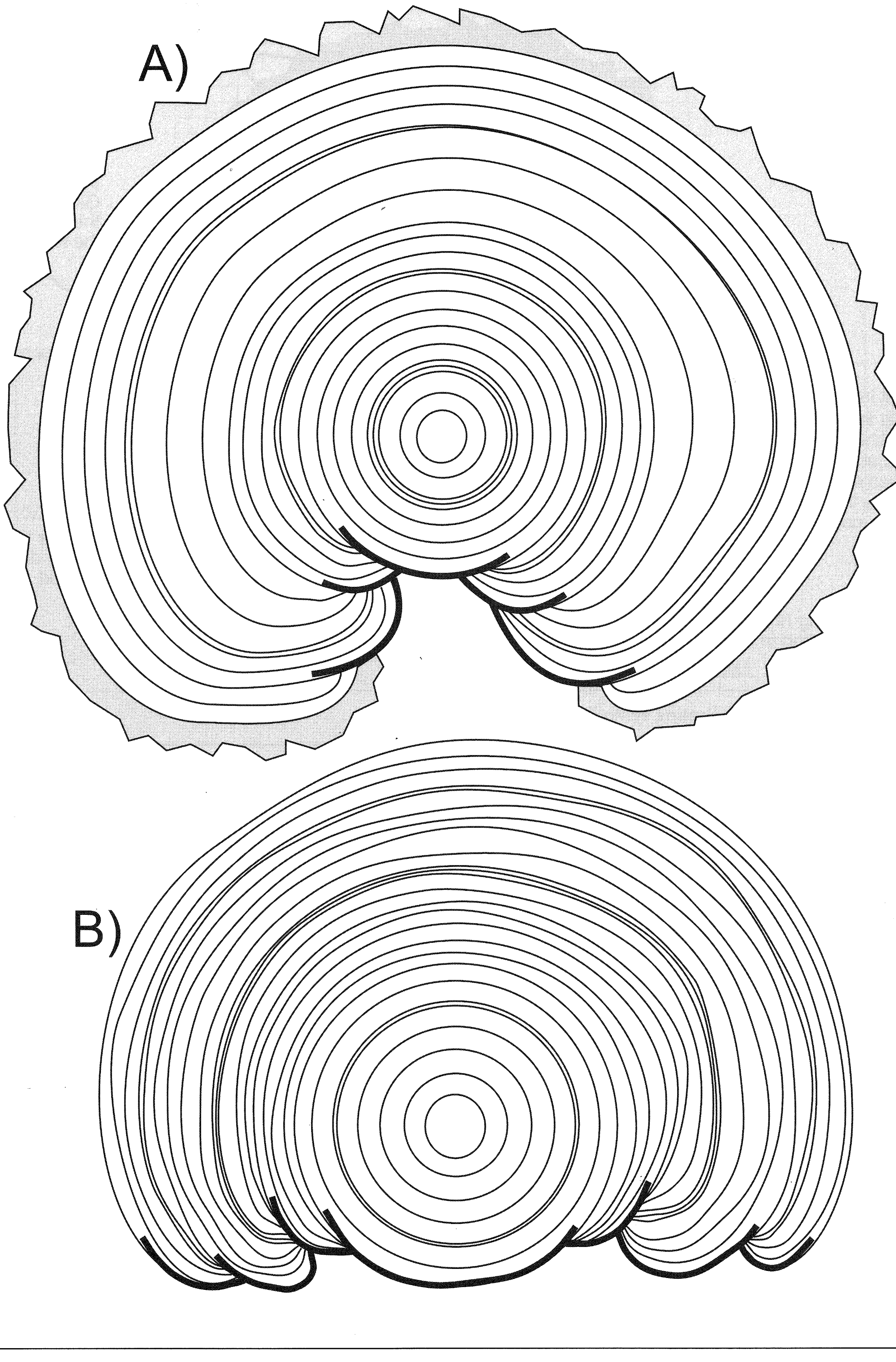

Figure 3. Cross-sections showing annual rings and fire scars: (a) freshly cut tree, (b) dead tree.

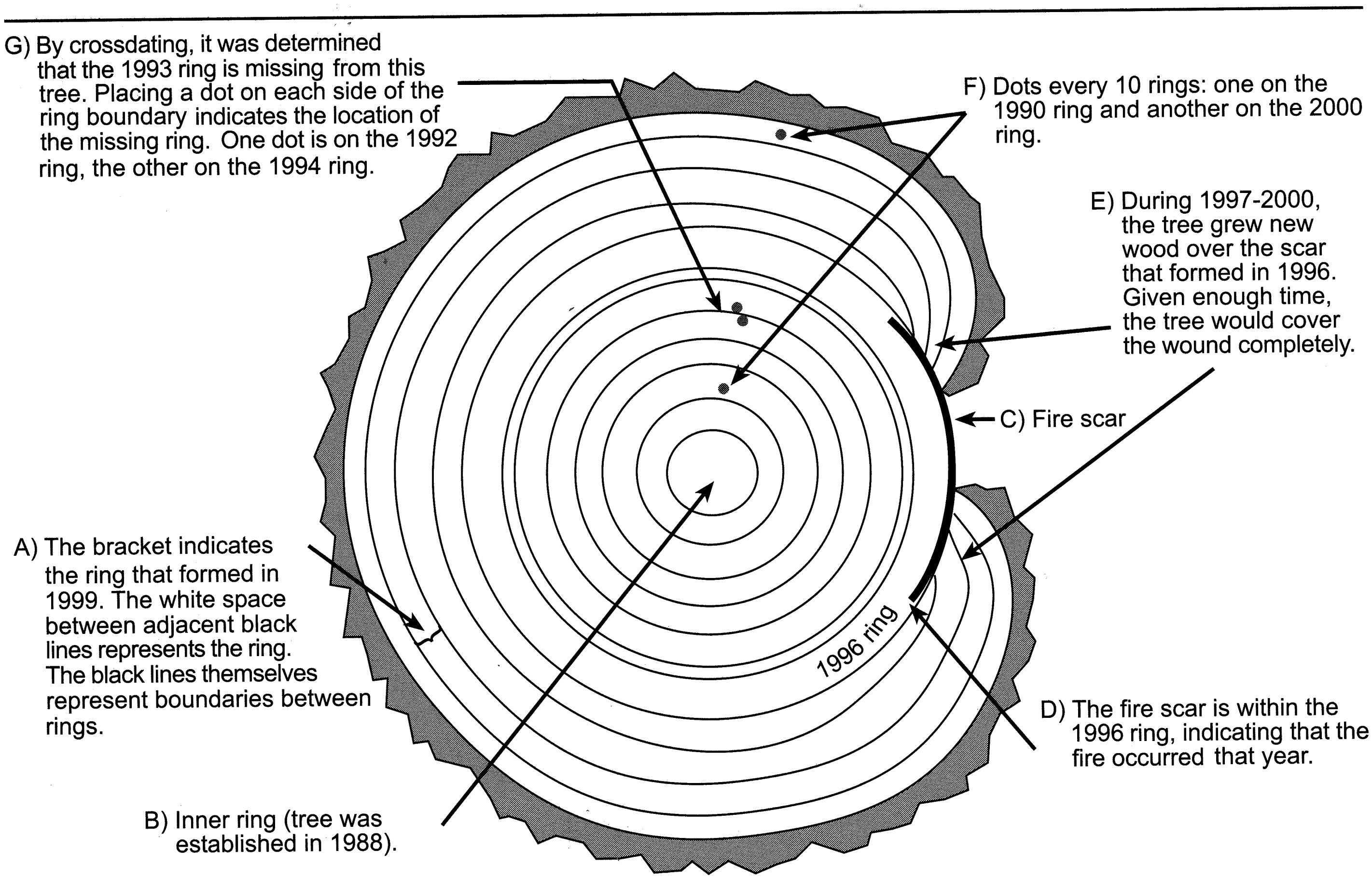

Figure 4. A sample cross-section indicating symbols used in this exercise.

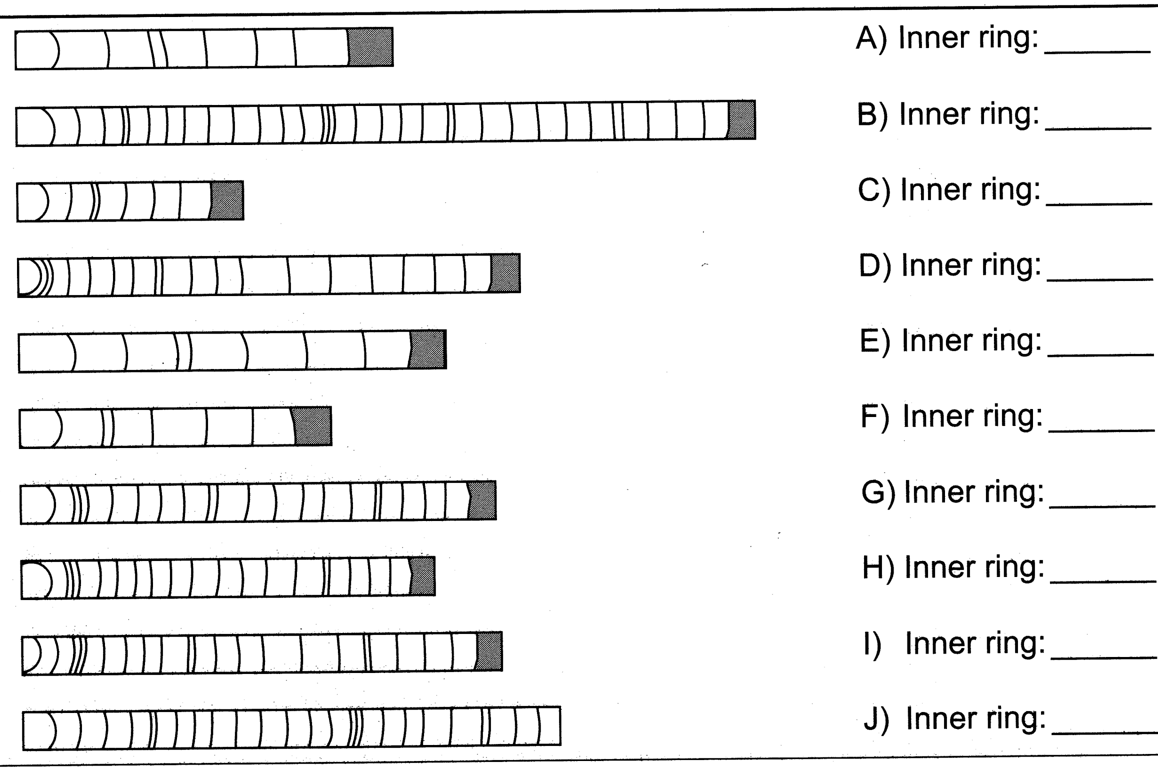

Figure 5. Tree cores. In each core, the inner ring on the left, and the bark is on the right side.

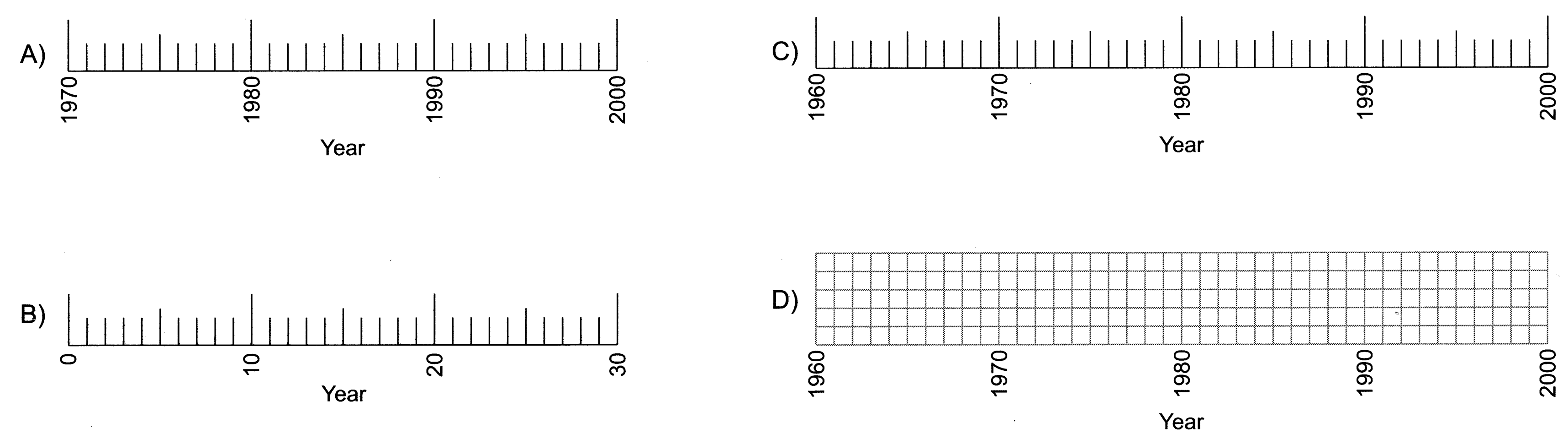

Figure 6. Graphs for your chronologies.

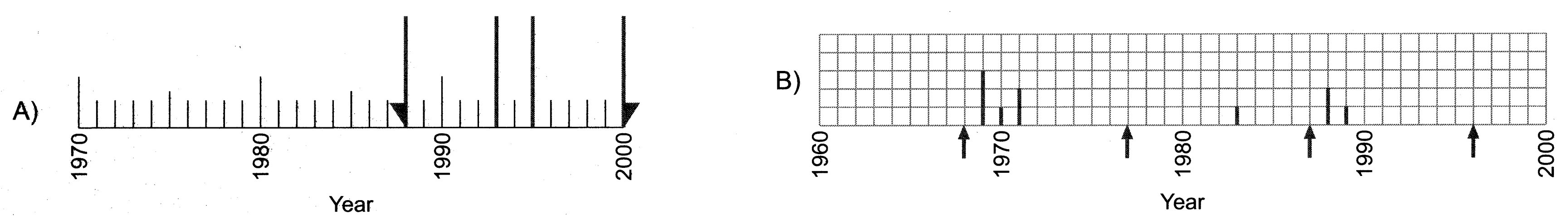

***Figure** 7.* (a) A sample graph for the tree in Figure 4. The arrow on the left points to 1988, indicating the tree was established in 1988. The arrow on the right indicates the last year recorded was 2000. The two long vertical lines for 1993 and 1995 indicate the presence of narrow rings in those years. This graph is similar to the "skeleton plots" used by dendrochronologists. (b) A sample chronology of fire and tree establishment. Arrows below the x-axis indicate that fires occurred in 1968, 1977, 1987, and 1996. Vertical lines above the x-axis indicate the number of trees that were established in each year: three trees in 1969, one in 1970, two in 1971, etc. This graph makes it clear that the fires of 1968 and 1987 were followed by tree establishment, and that little tree establishment occurred except after fire.

Evaluating the Exercise

An earlier version of the exercise was used over two years in laboratory sessions of the introductory physical geography course at Texas A&M University. During the same period, the exercise was assigned to students in a senior-level biogeography course at the University of Tennessee. No formal evaluations of the exercise were conducted during this time; however, feedback from students and graduate teaching assistants indicated that the exercise was clearly written, enjoyable, and effective for helping students learn about tree-ring dating and fire history. According to Professor Sally Horn, "answers on short essay questions in my class revealed that they remembered more about fire scars as a means of reconstructing past disturbances as a result of doing the lab than I think they would have otherwise."

During Fall 2003, several graduate students in the senior-level biogeography course at the University of Tennessee assessed the exercise and suggested several improvements. Guided by these suggestions, I revised the exercise.

I assigned the revised exercise to students in my senior-level field geography course as part of a dendrochronology assignment that also involved coring and dating actual trees. Student performance on the exercise was good. Question 33 was the only one missed consistently. Nearly all nineteen students recognized that the establishment of new trees following the fires of 1978 and 1992 was a good indication that those two fires were more severe than the others. However, only one student noted that the post-1992 increase in ring width of some trees demonstrated the occurrence of a severe fire that killed competing individuals. I intended questions 30 and 31 to lead students to recognize this evidence. It may be necessary to emphasize this concept strongly in lecture before assigning the exercise, or to rephrase one or more questions to make the connections among questions 30-33 more obvious.

I provided the field geography students with a short questionnaire about the exercise. Student responses to the questionnaire indicate a high level of satisfaction with the exercise and suggest that it promoted learning (Table 1).

Conclusion

Dendrochronology is one of the tools most widely used to investigate disturbance regimes. The exercise presented in this paper introduces fundamental dendrochronological topics, such as crossdating, and demonstrates some ways in which tree rings can be used to infer historical patterns of disturbance. In particular, the exercise allows students to integrate information on fire scars, tree establishment dates, tree mortality, and ring width to reconstruct fire history. Feedback from students at two universities led to revisions that I incorporated into the current version of the exercise. Given good student performance and strong evaluations of the revised exercise, I conclude that it is an effective teaching tool that can be adapted for a range of courses and levels.

The exercise is effective because it permits students to grapple with disturbance and dendrochronology via a concrete experience. Students are able to construct a deeper understanding of these topics than they likely would gain through a single, more passive exposure (e.g., lecture). Knowledge obtained in this way also persists, as suggested by the observation of Dr. Horn, who found that the exercise seemed to help students retain knowledge about fire history reconstruction.

The exercise fits readily within the experiential learning cycle (Healey and Jenkins 2000), which currently is being emphasized in geographic education. Doing the exercise provides a concrete experience, a key part of experiential learning. However, the experiential learning cycle also entails linking the experience to other learning processes, or stages. The fire history exercise presented here ideally would be followed by an assignment that encourages reflection on the experience. For example, as described above, I require students to read and interpret a paper concerning an actual fire history study. This reading assignment encourages reflection about fire history reconstruction and the role of fire in maintaining the populations of fire-dependent species. Additionally, it leads toward the next

Table 1. Responses of students in Field Geography course to questions about the exercise. Each score is the mean on a scale of 1 (strongly disagree) to 10 (strongly agree).

Question	Mean score (n = 16)
1. The exercise was clearly written and conveyed the concepts effectively.	9.4
2. The exercise helped me understand the crossdating concept.	9.4
3. The exercise helped me understand how dendrochronology can be used to reconstruct the history of fire (and other disturbances) in a forest.	9.4
4. The exercise helped me understand how dendrochronology can be used to assess the dates of tree establishment in a forest.	9.3
5. The exercise helped me understand how disturbances like fire can influence tree establishment.	9.4
6. It was beneficial to complete the exercise before attempting to date actual tree cores or construct skeleton plots.	9.1
7. Completing the exercise helped me understand the material presented in the paper I read on an actual fire-history study.	8.9

stage (abstract conceptualization) in the learning cycle. Other stages of the cycle also could be addressed through lectures, fieldwork, and the dating of actual tree cores or cross-sections.

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