PREFACE

Society faces many challenges, few of them more complex than the need to conserve natural resources at the same time as providing the benefits of economic development to all sectors of the population. This challenge is particularly severe in dry lands, where the resource limitations come not merely from a shortage of water, but from the high variability of precipitation in space and time in such regions, and hence chronic uncertainty for those using climate-related resources. In this technical training course we offer a possible response to this challenge, in which we combine integrated resource management, including reclaimed water re-use, with scientific means of describing, and eventually understanding, natural variability in climate and ecological systems. The scientific tool we use is the technique of dendrochronology, and several of its applications.

Although there will be three instructors for the course, each bringing a special expertise, the course participants will also have a responsibility to learn not only from the instructors, but from one another. Participants are drawn from several governmental and other organizations, each bringing a different technical background and professional experience. It is our hope that this powerful mixture of expertise and experience will allow the refinement of the techniques and concepts we will present, and will promote the development of new or improved ways of answering the challenge of conservation and sustainable development of natural resources in dry lands, especially regarding wise water use. In order to do this we have arranged to combine lectures and discussions with laboratory work and field visits. In this volume you will find a summary of the course materials, and in a separate package, a collection of readings that illustrate points made in the summary.

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I. INTRODUCTION TO DENDROCHRONOLOGY AND HISTORICAL BACKGROUND

A. Introduction to Dendrochronology: The Near East and Dendrochronology

Water resources are a critical factor in arid and semi-arid regions. Water is always in critical balance with arid ecosystems. This balance is upset by dense populations of people and their livestock in many countries. Brook et al. (1986), state that one-third of the land surface of the earth is dry. Over half of the dry area is inhabited by 630 million people. The remainder is climatically so arid and unproductive that it cannot support human life. The increasing pressure of human activities in dry regions in Asia, Africa, and America may cause the degradation of land and water resources.

In the Near East the population is growing rapidly, now surpassing 200 million, and competes for shrinking water resources for agricultural development. Nations like Jordan and Israel are swiftly approaching the point where they will exhaust all the water resources available to them. The Bureau for the Near East (1993) projected the demand for water in Jordan in the year 2030 will be sixfold that of 1985. In the year 2000, Israel will face a shortage of 800 million cubic meters per year, which is half its present consumption (Sexton 1990 in the Bureau for the Near East 1993). In Syria, the demand for water in 1985 was 6,883 billion cubic meters (bcm). In the years 2000 and 2030 the projected demand for water will be 8,498 and 14,915 bcm consecutively. The effect of this growth in demand for water is to increase the sensitivity of society to drought.

Long term drought in the Near East will greatly affect human beings, animals and soils. Persistent drought can cause human suffering where agricultural production and food supplies are marginal, and diminished forage will reduce animal production. Drought can also exacerbate the deterioration of marginal lands such as Jordan's Badia region, where shortages of water force the nomad people along with their animals to migrate, looking for water resources and grasses among four adjacent countries: Syria, Iraq, Jordan, and Saudi Arabia. Such human movement causes those areas with limited forage production to be overgrazed and causes deterioration.

The effects of severe drought in the Near East are difficult to manage without careful planning. This requires the ability to anticipate climatic variability, especially drought. Skilled management of water and other natural resources requires sufficient information about the probable duration, distribution and intensity of future drought. To understand drought we need to characterize the variability of climate in the area on time scales of decades to centuries. Most of the high-quality instrumental climate records start in the 1940s or 1950s, and so contain little information on variability over decades and longer periods. Indirect evidence of climatic variability such as long time series of tree-ring growth measurements spanning several centuries may serve as proxy records of past conditions.

They provide us with knowledge of the past frequency and severity of climatic anomalies such as drought and wet periods which may be used to help anticipate the probability of such events in future time periods.

Generally, tree-ring series can be used to reconstruct over several centuries, and occasionally millennia, past variations in precipitation, temperature, soil moisture, river flow, the frequency of extreme droughts, forest fires, major forest pest outbreaks, and several other variables. What can be reconstructed depends on those factors that limit tree growth. Many of these are relevant to the concerns of Near Eastern countries such as Jordan. Such data provide a standard against which to check the applicability of ideas and models concerning the natural conditions found in this region and, like all observations, constitute a source of information for better understanding current and future environmental variability. It would be useful for most Near Eastern countries to develop their own capability in this field of knowledge since the creation of these records requires a combination of good scientific skills and extensive local knowledge, and since information on the local environment can best be developed locally, and used both locally and as part of the global effort to understand our environment.

B. Practical Importance of Dendrochronology

In the past it has been unusual for studies and management plans of water and other natural resources to make use of tree rings as a tool for reconstructing long-term means and variability in precipitation and streamflow. One of the most outstanding examples of a problem where the lack of historical information caused severe water resource over-allocation is the case of the Colorado River Water Compact in the southwestern United States. Around 1922, when tree-ring studies were very limited, planners for the Colorado River Basin met to agree on the distribution of rights to the water coming down the Colorado River. The 2,667-kilometer river flows through some of the most arid lands in North America, including parts of seven states in the US. and a small portion of two states in Mexico. From existing instrumental records, planners estimated that the Colorado River had an average annual flow of 19,985 billion cubic meters. This estimate was based on the 17 years of precipitation and streamflow data that was available (1906 to 1922). In 1976 at the Laboratory of Tree-Ring Research of the University of Arizona, Stockton and Jacoby (1976) reconstructed the flow of the Colorado River back to A.D. 1564 (450 years) using time series derived from tree-ring studies. Their reconstruction indicated that the period from 1906 to 1930 was the longest period of sustained high streamflow during the past 450 years. The short period of the instrumental record was simply not representative of the long-term flow of the river. Therefore, the allocation of water among the US. states and Mexico was based on an anomalously high value which resulted in shortages when all of the entities involved demanded their share of the available water.

C. What is Dendrochronology?

The term *dendro* is from *dendron*, the Greek word for tree, and *chronology* means the assignment of dates to particular events in a time series (Fritts 1987). Dendrochronology is a set of techniques by which (1) the annual growth layers of trees may be assigned to the specific year of their formation; and (2) the history of changes in the tree's environment may be reconstructed using various properties of annual tree rings, (e.g. their width, cell sizes, wood density, trace element composition, and radioactive and stable isotope ratios).

In their textbook on tree-ring dating methods, Stokes and Smiley (1968) established four principles for crossdating. This is a term used to describe the process of assigning year dates to annual tree rings by cross-comparison of rings from several trees growing in the same area (Figure 1).

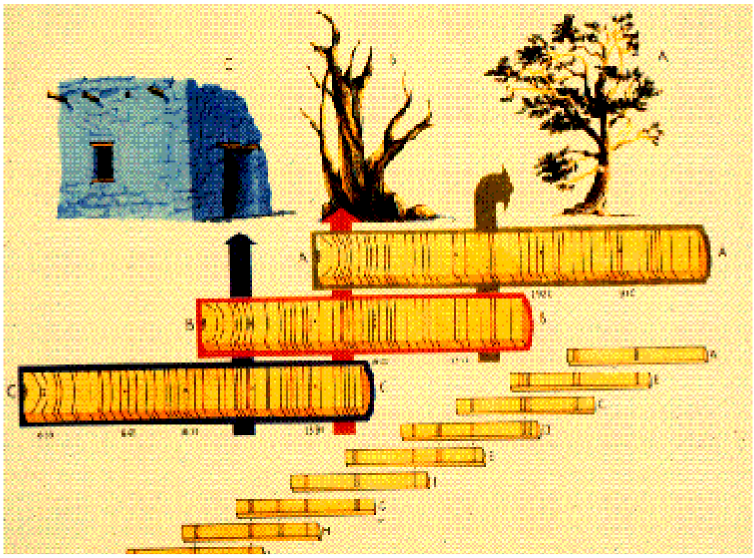

Figure 1. Extending chronologies by crossdating using living and dead wood.

1. The trees that will be used for crossdating should produce one ring for each year.
2. One environmental factor must dominate in limiting the annual growth such as precipitation or temperature.
3. The intensity of growth-limiting environmental factor must vary from year to year and the resulting annual rings faithfully reflect such variation in their growth.
4. The growth-limiting factor must be effective over a large geographical area.

D. Historical Background

Andrew E. Douglass established the scientific basis of dendrochronology in the early years of this century (Figure 2). He graduated from Harvard University and became affiliated with the Harvard Astronomical Observatory. In 1894, he traveled to Flagstaff, Arizona, where he became assistant to the director of the Lowell Astronomical Observatory.

Douglass was interested in sunspot events. He was trying to understand the relationship between cyclic activity of sunspots and climate on earth, particularly precipitation, because he believed that sunspot activity might influence the weather on earth. He was not able to establish a clear relationship between the two.

Figure 2. A.E. Douglass examines a Ponderosa pine core.

Douglass first attempted to use tree ring growth to test the relationship between climate and sunspot activity in 1901 when he was on a trip to the forests of northern Arizona. On the sawed end of a log he noticed how the ring widths varied. He began to examine more specimens from the area surrounding Flagstaff. In examining six cross-sections of logs from a lumberyard, he noticed that a similar pattern of small rings twenty-one years inward from the bark occurred in all the logs. He then realized that the determination of the age of the trees does not depend on the existence of the outside bark. To prove his findings he examined a stump that had been cut some years earlier. He noticed the same pattern of small rings, but they were only eleven years from the outside. By matching the earlier samples with the rings on the stump, he concluded that the tree had been cut ten years earlier than his first group of samples. He had, in effect, established the technique of crossdating.

In 1906, Douglass and was appointed Assistant Professor of Physics and Geography at the University of Arizona in Tucson. In 1909, he published an article on his tree-ring research in the *Monthly Weather Review* .

In 1911, Douglass recognized the significance of his observation when he examined trees from Prescott, 81 km southwest of Flagstaff. He noticed a similar pattern of wide and narrow rings to those that he had seen in the Flagstaff trees. He recognized that crossdating can be used over wide areas where the tree growth is limited by the same climatic factor.

Douglass noted that his discovery had two major implications (Fritts 1976):

1. Crossdating can be used as a tool to identify the exact calendar years of growth rings in a tree by studying the pattern of wide and narrow rings;
2. The pattern of ring-widths represents a record of changes in past environmental conditions for a region.

He continued to derive the record of past climate by comparing and combining the tree ring records of many different trees. This procedure is called chronology building. In 1914, he was able to build a 500-year long tree-ring chronology from ponderosa pine (*Pinus ponderosa*). He was also able to demonstrate a direct relationship between the annual ring width and total precipitation in the winter preceding growth of the ring.

Figure 3. Large ruins at Tonto National Monument in southern Arizona where A.E. Douglass dated the construction periods for Puebloan ruins.

In 1914, Douglass met Clark Wissler, an anthropologist at the American Museum of Natural History, New York, and presented a talk at the Carnegie Institute about his research. Clark Wissler was trying to date prehistoric Indian village sites in the southwestern United States. This meeting encouraged both to use the technique of crossdating to date logs from the Indian settlements. Over a twenty year period Douglass studied the history of the villages by crossdating prehistoric wood found in the houses (Figure 3). He developed these chronologies by crossdating specimens from the ruins, and collecting samples from living trees surrounding those ruins to bring the chronologies to the present time. Douglass was thus able to document the history of many Indian sites in the Southwest for periods where no written documents exist.

In 1937, he established the Laboratory of Tree-Ring Research (LTRR) which became the first institution devoted exclusively to tree-ring studies. Two students (Waldo S. Glock and Edmund Schulman) helped Douglass to develop chronologies for different purposes, using several species. Glock left the LTRR and later wrote extensive reviews of tree growth and climatic relationships, while Schulman continued his work in the Southwest. His two best known contributions were a monographic study on dendroclimatology and his discovery of 4500-year-old bristlecone pine (*Pinus longaeva*) (Fritts 1978).

E. Tree-Ring Studies Elsewhere

Douglass' pioneering work was far from unique in attempting to relate environmental factors to the size of annual rings. This had been done in Europe and elsewhere in the 19th century. His contribution was to establish systematic crossdating as the basis for rigorous work in this field, a development which has since been adopted in many countries. This made possible the growth of dendrochronology seen in recent decades.

In the Near East, relatively few dendrochronological studies have been performed. A.E. Douglass, after his success in dating prehistoric timbers in the American Southwest, thought of applying the same techniques to timbers found in structures of ancient Near East civilizations, but he never fulfilled his dream. However, his former student Bryant Bannister was the first dendrochronologist to attempt systematic tree-ring dating of Near East archaeological sites (Bannister 1970). He collected and analyzed tree-ring specimens from an eighth century B.C. tomb in Turkey and carried out preliminary examination of wood samples from Egyptian coffins. He also collected and cross-dated samples of Cedar of Lebanon (*Cedrus libani*) in Lebanon. Since Bannister's early investigations, various dendrochronological studies in the Near East have been performed. Some studies concentrated on using tree ring data to develop paleoclimate records (Liphschitz and Waisel, 1967; Shanan et al., 1967; Chalabi and Serre-Bachet, 1981; Chalabi and Martini, 1989; Munaut, 1982; Parsapajouh et al., 1986). Other studies used tree-ring series to date archeological sites (Kuniholm and Striker, 1987; Lev-Yadun, 1992). There have been other studies of the cycle of cambial activity in a given species of tree to determine if a ring represents one year of growth (Liphschitz et al. 1981, 1984, and 1985; Liphschitz and Lev-Yadun, 1986; Fahn et al., 1986) .

Touchan et al. (1999) developed the first dendroclimatic reconstruction in the Near East for southern Jordan, a 396-year-long reconstruction of October-May precipitation based on two chronologies of *Juniperus phoenicia* . They showed that the longest reconstructed drought, as defined by consecutive years below a threshold of 80% of the 1946-1995 mean observed October-May precipitation, lasted four years. The longest drought recorded in the 1946-95 instrumental data lasted three years. Based on the results of the reconstruction, 7 droughts of 3 or more years have occurred during the past 400 years. The chronology from southern Jordan covers 527 years (1469-1995). To ensure the reliability of the reconstruction, they restricted their analysis to the period (1600-1995) when the chronology is well replicated. Touchan and Hughes (1999) were able to build the first tree-ring chronologies in northern Jordan from *Pinus halepensis* and *Quercus aegilops*. They also built one chronology of *Pinus halepensis* from Carmel Mountain in Israel. The results of their study show significant correlation between the northern site chronologies (northern Jordan and northwestern Israel), but no correlation between the northern and the southern sites.

F. What is the Role of the Laboratory of Tree-Ring Research Now?

The application of Douglass' crossdating has been remarkably successful. Major contributions have been made to archaeology, quaternary geology, geophysics, solar physics, ecology, hydrology, and climatology. Using precise chronologies based on tree-ring dating, LTRR faculty and staff have been able to improve our understanding of processes in natural and human systems, and have made important estimates of the rates of these processes. They were also able to establish new tree-ring chronologies in many parts of the world.

Several hundred scientists around the world use dendrochronological techniques in many fields of science. The LTRR is the place to which they most commonly turn for advice and training. For example, more than twenty foreign visitors spend one week or more in the Laboratory in single year, and 250 attended a conference organized by the LTRR in May 1994. Recent students and visitors have come from countries as diverse as Russia, Lithuania, Finland, Italy, Austria, Spain, Morocco, Syria, Oman, Saudi Arabia, Canada, Mexico, Chile, Argentina, South Africa, China, Japan and India.

G. International Tree-Ring Data Bank (ITRDB)

The ITRDB is a professional organization that stores dendrochronological data from around the world. The ITRDB was formed in 1974 at a workshop of dendrochronologists. The NOAA Paleoclimatology Program (World Data Center A for Paleoclimatology) is the home of the ITRDB. Its status as a component of the International Council of Scientific Unions (ICSU) World Data Center System means that its holdings are freely available for no more than the cost of reproduction. Over 1500 sites on five continents are included (Figure 4). The Data Bank includes raw ring width or wood density measurements, and site chronologies. Reconstructed climate parameters are also available for some areas.

Figure 4. Location of tree-ring series stored in the ITRDB.

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