Methods of Dendrochronology

Applications in the Environmental Sciences

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lived. The forests have been influenced by man since prehistoric times. Moreover, many of the current chronologies that were constructed for dating purposes are unsuitable for climatic studies as they are based on timbers from too wide a geographical area. Only their youngest parts are based on trees from known sites. The trees that form the older parts of the chronology are nonliving trees from a large area and in many cases from habitats that today do not support trees. This is particularly true of the long oak chronologies that are formed from subfossil oaks grown on developing fens for which there are no modern analogs.

1.4. Dendrochronology in the USSR

L. Kairiukstis and S. Shiyatov

In contrast to West European approaches, dendrochronology in East Europe started from dendroclimatology. The first notable dendroclimatological work was carried out by F. Shvedov in 1882 on two black locust trees (*Robinia pseudoacacia*) growing in Odessa in the Ukraine (Shvedov, 1892). He showed that, in this region, the width of annual wood layers depends to a large extent on annual precipitation, and the narrowest layers form in very dry years. The narrow layers are regularly repeated at three-to-nine-year intervals. On the basis of the periodicity revealed in these tree-ring variations, he gave a prognosis of droughts (in 1882 and 1891) that was proved correct. In this work Shvedov demonstrated very well the possibility of the *dendrometric* method for reconstructing climatic conditions of the past. He should be rightfully considered as one of the founders of dendroclimatology.

From the first half of the 20th century, the work of Zaozersky (1934) should be noted. In a paper entitled "Towards the Methods of Retrospective Revealing of Climatic Conditions by the Tree Growth Study," he reported the significance of tree-ring information for the solution of a wide range of problems, especially hydrological ones, and gave valuable methodological advice for collecting field samples. He also provided quantitative and qualitative reconstructions of some environmental factors influencing annual tree-ring variability. Tolsky (1936) gave a survey of works devoted to the influence of climate on tree growth, reconstruction of climatic conditions of the past, and practical recommendations about the choice of the most valuable regions, sites, and species for dendroclimatological investigations. Analysis of drought periodicity in the Voronezh region in terms of annual growth of European ash (*Fraxinus exelsior*) was given by Kostin (1940). At this time the abstracts about the works of American dendrochronologists were first published in the USSR. In abstracts by Jashnov (1925), Krishtofovitsh (1934), and Chrgian (1938), the works of Douglass and his students on the relationships between growth and heliogeophysical and climatic factors, the reconstruction of climatic conditions, and the study of the cyclicity in tree growth were reviewed.

Intensive development of dendrochronological investigations in the USSR began only in 1950–1960. Rudakov (1951, 1958, 1961) is credited with popularizing of the dendroclimatological method. In particular, he advocated the moving average method for estimating the time trend in ring-width series. Important work on the reconstruction of humidity in Central Asia during the last millenium on the basis of a study of ring width in Turkestan juniper (*Juniperus turkestanica*) was carried out by Gursky *et al.* (1953). Tree rings were extensively used by Galazy for reconstruction of climatic conditions and the upper-timberline dynamics in Transbaikal (Galazy, 1954) and reconstruction of the dates of high water levels in Lake Baikal (Galazy, 1955, 1967). Periodic recurrence of dry and moist periods have also been studied from tree rings in the Karelian Neck (Dmitrieva, 1959) and in the central Chernozem region (Kostin, 1960, 1963). And, significant dendroclimatological investigations, particularly on tree response to solar activity, were carried out in the Latvian SSR by Zviedris and Sacinieks (1958) and Zviedris and Matuzanis (1962).

At the same time, dendrochronological methods were first used for dating historical and architectural monuments and relics. Zamotorin (1959, 1963) and Zacharieva (1974) carried out a relative dating of Sajan–Altai barrows. In 1959 the first Dendrochronological Laboratory in the USSR was established at the Institute of Archaeology of the USSR Academy of Sciences. The researchers at the Institute studied absolute dating of medieval wood buildings in the northwest of the Soviet Union. Today the laboratory contains more than 800 wood samples collected from 18 old Russian towns, from 12 ancient monuments, and from living trees. On the basis of this collection, a tree-ring chronology 1,200 years long was obtained (Kolchin and Chernych, 1977). Dating of historic and architectural monuments and relics by dendrochronological methods has been accomplished by Shiyatov (1980) and Komin (1980) in the north of western Siberia, by Kolishchuk *et al.* (1984) in the Ukraine, and by Brukstus (1986) in the Lithuanian SSR.

During the last two decades, dendrochronological methods have been used extensively in different regions of the country to study cyclical forest ecosystem dynamics and different natural processes, the reconstruction of climatic conditions and catastrophic phenomena, and the evaluation of forest management measures.

Quite a number of dendrochronological investigations were also carried out in the Urals and the adjacent plains. Adamenko (1963a, 1963b) engaged in the reconstruction of climate and glacierization in the polar Urals. Dendrochronological information has been used by Shiyatov (1965, 1975, 1979, 1986) for climatic reconstruction and for investigations of the upper and polar timberline dynamics. Komin (1963, 1969, 1970a) carried out his studies in the taiga and forest-steppe zones on the eastern slope of the Urals and in the west Siberian plain. Olenin (1976, 1977) used tree-ring analysis for the investigation of forest cyclic dynamics on the western slope of the Urals and the eastern part of the Russian plain. Pugachev (1975) worked in the steppe zone of the northern Kazakhstan. Ural dendrochronologists are paying close attention to establishing methods to obtain more reliable dendroclimatic series, to reveal cyclic components in tree-ring chronologies, and to work out long-term prognoses of tree-ring indices and forest-growth conditions (Komin, 1963, 1970b; Shiyatov, 1972, 1986; Olenin, 1974; Mazepa, 1982, 1986).

Since 1953, research on dendrochronology has been carried out in the Lithuanian SSR. The Dendroclimatochronological Laboratory at the Institute of

Botany of the Academy of Sciences at present is the biggest specialized scientific subdivision in the Soviet Union operating in the field of dendrochronology (Bitvinskas, 1978a,b,c). Scientists at this laboratory are investigating dendrochronology in the European part of the USSR, Siberia, and the Far East. They are giving much prominence to revealing the relationships between tree growth and some astrophysical–geophysical phenomena and hydroclimatic factors, establishing a chronology several thousand years long, studying cyclicity in tree growth, reconstructing the radiocarbon content of the Earth's atmosphere, and estimating forest management effectivity (Bitvinskas, 1964, 1965, 1974, 1978, 1984, 1987; Pakalnis, 1972; Bitvinskas and Kairaitis, 1975; Stupneva and Bitvinskas, 1978; Karpavichus, 1981; Dergachev and Kocharov, 1981). Along with the research problems mentioned above, various fields of application, including dendrochronological investigations near the Baltic Sea, are also dealt with at the Lithuanian Research Institute of Forestry (Kairiukstis, 1968; Kairiukstis and Juodvalkis, 1972; Stravinskene, 1981; Kairiukstis and Dubinskaite, 1986; Kairiukstis *et al.*, 1987a), the Latvian Research Institute of Forest Management Problems (Zviedris and Sacinieks, 1958; Zviedris and Matuzanis, 1962; Shpalte, 1971), as well as the Tartu State University (Läänelaid, 1981).

In the western Ukraine, Kolishchuk (1966, 1979) is studying the process of the recognition of factors influencing tree-growth variability. On the basis of the study of radial growth regularities in prostrate trees, he has worked out a method of obtaining standardized tree-ring chronologies (Chapter 2).

In the area of the European part of the USSR, dendroclimatic investigations have been carried out also by Liseev (1962), Gortinsky (1968), Lovelius (1979), Feklistov (1978), Evdokimov (1979), Barsut (1984), and Molchanov (1970). Dendrochronological methods have been used for dating such catastrophic phenomena as snow avalanches, mud flows, and landslides (Turmanina, 1972, 1979). Kovalev *et al.* (1984) have carried out dendroclimatic investigations in the Caucasus Mountains.

In Siberia, dendrochronological investigations are carried out at the V.N. Sukachev Institute of Forest and Wood of the Siberian Division of the USSR Academy of Sciences (Glebov and Pogodina, 1972; Glebov and Litvinenko, 1976; Buzikin, Dashkowskaya, and Chlebopros, 1986). They are focusing attention on a study of dendroclimatic relationships in forest-bog ecosystems and on the regularities of radial growth in forest stands. Their colleagues at the Institute of Biophysics have made a significant contribution to recognizing the mechanisms of annual tree-layer formation (Spirov and Terskov, 1973; Vaganov, Smirnov, and Terskov, 1975; Vaganov and Terskov, 1977; Vaganov *et al.*, 1985). In 1970, a microphotometric analyzer of wood was constructed, which allows the examination of annual ring structure automatically on the basis of diffused–reflected light recording. In 1977, a measuring instrument of ring structure (MSR-2M) was constructed for use with a minicomputer, which allows the semiautomatic recording of the number and dimensions of cells within the growth ring and allows the obtained information to be processed quickly. By these devices, the procedures of investigation of microanatomical heterogeneity of annual wood rings were worked out. This established the importance of regularities of seasonal tree growth and projected ways and means of using photometric curves and tracheidograms for dendrochronological needs. Cyclic oscillations in tree growth in connection with climatic changes and solar activity have been investigated by Polushkin (1979) and Polushkin *et al.* (1977). Adamenko (1978, 1986) is using dendrochronological methods for reconstructing the thermal regime of summer months and glacierization in the Altai Mountains.

A comparatively small number of dendrochronological investigations have been carried out in the Soviet Far East. In this region, works on cyclic oscillations in tree growth and the influence of hydroclimatic and phytocoenotic factors in tree-ring variability have been produced (Tarankov, 1973; Malokvasov, 1974, 1986; Sabirov, 1986).

In Central Asia, annual growth variability of Turkestan juniper (*Juniperus turkestanica*) was studied by Muchamedshin (1974). This species is the most long-lived in the USSR (up to 1,500–2,000 years) and is very sensitive to climatic changes. Interesting dendroclimatological investigations on Schrenka spruce (*Picea schrenkiana*) were carried out in the Tien Shan Mountains (Borshova, 1981, 1986).

Coordination of dendrochronological investigations in the USSR is conducted by the Commission for Dendroclimatology of the USSR Academy of Sciences. Every five years the Commission organizes an All-Union Meeting on problems of dendrochronology and dendroclimatology (Vilnius, 1968; Kaunas, 1972; Archangelsk, 1978; Irkutsk, 1983, 1987). With the assistance of the Commission, the Dendrochronological Bank of the Soviet Union (DBSU) was organized in 1980 at the Dendroclimatochronological Laboratory and the Lithuanian Research Institute of Forestry (Kaunas). Also the proceedings, *Dendroclimatological Scales of the Soviet Union* (1978, 1981, 1984, 1987), and the bibliographical pointer, *Dendroclimatochronology, 1900–1970* (Vilnius, 1978), have been published.

Four basic points should be mentioned that are essential for evaluating dendroclimatology in the USSR.

- Having access to a large territory covering several vegetation zones for sampling in natural forests, Soviet scientists have arrived at the general conclusion that dendroclimatological investigations are best based on a precisely understood ecological background and carried out on a large spatial scale by means of the dendrochronological profile method: north–south and east–west. Comparisons of similar data both by site conditions and by species composition allow them to reveal, under such conditions, zonal differences in tree-ring-climate relationships.
- Dendroclimatological investigations involve problems of high complexity and are analyzed with the participation of different specialists, particularly climatologists and traditionally also those dealing with astrophysical and geophysical phenomena. Studies are based on carbon isotope measurements of exactly dated tree rings; carbon content variations in tree rings are observed to be extremely valuable indices of Earth biosphere changeability under the influence of cosmic and geophysical factors. Variation of solar activity and its strong influence on atmospheric circulation has been used for indication of extreme behavior of trees in separate regions.

- Variation in rhythms of tree-ring increment and their significance for indication of background climatic changeability (complex hydrothermic indices, cosmic and geophysical factors) in a given territory have been considered important subjects of investigation. Cyclicity in dendrochronologies provided a basis for the subdivision of regions on a dendroclimatic basis. In this field there remains a need for a high degree of rigorous testing and verification.
- Finally, dendroclimatology in the Soviet Union, particularly owing to prognostic activities, has become an important tool in forestry and regional planning (timing of soil reclamation, application of fertilizers, stand thinning).

1.5. Dendrochronology in the Southern Hemisphere

D.A. Norton

1.5.1. Introduction

Dendrochronological research started relatively late in the Southern Hemisphere, and it has only been in the last 10–15 years that large numbers of chronologies have been developed. This late start undoubtedly reflects, at least in part, the small land area and population compared with the Northern Hemisphere and the often limited knowledge about the ecology and botany of the southern forests. Much of the impetus for Southern Hemisphere dendrochronology has come from visiting northern scientists: in the 1950s Schulman in South America and Bell in New Zealand and in the 1970s LaMarche, Holmes, and others. Today active groups of dendrochronologists work in Argentina, Australia, New Zealand, and South Africa.

The historical development of Southern Hemisphere dendrochronology is briefly discussed here. Earlier reviews have been provided by Dyer (1982), Holmes (1982), and Ogden (1982).

South America

The first published chronologies for South America were presented by Schulman (1956) for Chilean incense cedar (*Austrocedrus chilensis*) and Chile pine (*Araucaria araucana*) from Argentina. *A. chilensis* was found to be the easier species to work with, although relationships between growth and climate were ambiguous for both species. Further sampling of *A. chilensis* in Chile in the early 1970s lead to the development of a well-replicated chronology that was used to develop a preliminary reconstruction of Santiago precipitation back to A.D. 1010 (LaMarche, 1975). This reconstruction is still the longest developed for the Southern Hemisphere, although the calibration regression was not verified. The study was followed by an extensive sampling program that resulted in the development of 32 chronologies from three species (*Austrocedrus chilensis*, *Araucaria araucana*, and *Pilgerodendron uviferum*) in Chile and Argentina (LaMarche *et al.*, 1979a, 1979b). Climatic analyses of these chronologies have, however,