Second International Workshop on Global Dendroclimatology

REPORT and RECOMMENDATIONS

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July 1980

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EXPLANATORY PREFACE

The Second International Workshop on Global Dendroclimatology was held at the University of East Anglia, Norwich, U.K. on 7-11 July 1980. This was not a conference but a working meeting of invited scientists selected on the basis of their proven willingness and ability to engage in collaborative research in dendroclimatology. The First International Workshop on Dendroclimatology took place at the University of Arizona, Tucson, U.S.A. in 1974. That workshop achieved such success in establishing international collaboration in the following six years that the present meeting contained scientists from twelve countries and all inhabited continents. At a planning meeting held in July 1979, a group from a number of these countries agreed that a second workshop should be held. It was agreed that in order to foster mutual understanding it was necessary to review the basic methodology of dendroclimatology, its concepts, techniques and applications. This would then serve as a common basis for discussion and facilitate the collaborative efforts needed for the reconstruction of climate over large parts of the globe using tree-ring and other proxy data.

The specific aims of the Workshop, as set out in the prospectus issued to participants, were as follows:-

a) To review basic concepts and techniques to provide a common basis for discussion.

b) To consider what kinds of information available from tree rings would be of value to climatologists, hydrologists, historians, economists and others working with palaeoclimatic proxy data; in doing so, the properties of the original data and their consequences for the types of information that may be derived must be reviewed.

c) To evaluate critically the past and potential contribution of tree-ring data to palaeoclimatic and related studies.

d) To exchange information on analytical techniques and results as well as on recent technical developments; particular emphasis should be placed on those techniques essential to the acquisition of data appropriate to dendroclimatology.

e) To review systematically the existing geographical and temporal extent of appropriate tree-ring collections, of data analysis and of applications.

f) To prepare a review of the current status of dendroclimatology and a set of recommendations for the development of dendroclimatic research on a global scale.

In order to achieve these ends, the Workshop was organised in three phases. In the first phase, invited contributors prepared their papers, which were then sent to discussants for written comment. These papers were circulated to all participants prior to the meeting. This greatly facilitated discussion during the Workshop sessions. The second phase was the meeting itself consisting of sessions and working group periods as detailed in the Programme which follows this Preface. The participants entered into the spirit of discussion and collaboration fully, making the meeting itself a very positive experience. The third phase, which is still in progress, is the communication of the results of the Workshop to the scientific community and to decision-makers and the preparation of the volume based on the Workshop proceedings by the Editorial Board. It is intended that this volume 'Climate from Tree Rings' will appear early in 1981.

This Workshop has been an expensive enterprise. It was generously supported by the World Meteorological Organization and the United Nations Environment Programme, the Scientific Affairs Division of the North Atlantic Treaty Organization, and the United States National Science Foundation. The support of these organisations covered the travel and living costs of almost all participants and most of the administrative costs of the Workshop. The Editorial Committee wishes to express its gratitude and that of the Workshop participants to these bodies. Thanks are also due to the U.S. Organizing Committee, Drs. H.C. Fritts and V.C. LaMarche Jr., and to Dr. T.M.L. Wigley, Director, Prof. H.H. Lamb, Professor Emeritus, and the staff of the Climatic Research Unit at the University of East Anglia, who hosted the Workshop. The organisation of this Workshop would not have been possible without the assistance of Bernadette Harris, Susan Boland, Sue Napleton, Arabella Andrup, Keith Briffa, Desnee Campbell, Brigid Cherry, Graham Farmer, Barbara Gray, Nigel Huckstep, Janice Lough and Pete Mayes.

<u>Malcolm Hughes</u>   <u>Mick Kelly</u>   <u>Jonathan Pilcher</u>

<u>Organising Committee</u>

PROGRAMME

Second International Workshop on Global Dendroclimatology
7-11 July 1980

Introductory Session

Welcoming address:	T.M.L. Wigley
Climatic overview:	H.H. Lamb
Introduction to Workshop:	J. Pilcher

Data acquisition and preparation

Sampling strategies:	V.C. LaMarche Jr.
Comment:	E.R. Cook
	M.G.L. Baillie
Measurement of densitometric properties:	F.H. Schweingruber
Comment:	D. Eckstein
Study of isotopic and other parameters:	A. Long
Comment:	T.M.L. Wigley
Chronology development and analysis:	D.A. Graybill
Comment:	R.W. Aniol
	B. Schmidt

Data analysis

The climate-growth response:	H.C. Fritts
Comment:	M.K. Hughes
	S.J. Milsom
Response functions:	J. Guiot, A.L. Berger and A.-V. Munaut
Comment:	D.W. Brett
	J.P. Cropper

Report and Recommendations

Transfer functions:	G.R. Lofgren and J.H. Hunt
Comment:	B.M. Gray, J. Guiot, A.L. Berger and A.-V. Munaut
Verification:	G.A. Gordon
Comment:	J. Pilcher
	B.M. Gray
Climatic reconstructions from tree-rings:	A.B. Pittock
Comments:	G.R. Lofgren
	J.P. Cropper
The design of palaeo-environmental data networks:	J.E. Kutzbach
	P.J. Guetter

The Southern Hemisphere

Climatic context:	M.J. Salinger
Southern Africa:	T.G.J. Dyer
Comment:	V.C. LaMarche Jr.
South America:	R.L. Holmes
Comment:	J.A. Boninsegna
Australasia:	J. Ogden
Comment:	P. Dunwiddie

The Northern Hemisphere

Climatic context:	P.M. Kelly
The Arctic:	G.C. Jacoby
Comment:	L.B. Brubaker, H. Garfinkel and M.P. Lawson
Western North America:	L.B. Brubaker
Comment:	L.G. Drew
Eastern North America:	E.R. Cook
Comment:	L.E. Conkey
	R.L. Phipps
Alpine Europe:	Z. Bednarz
Comment:	O.U. Bräker

The rest of Europe:	D. Eckstein
Comment:	T. Bitvinskas
	J. Pilcher
The Mediterranean Basin and the Near East:	A.-V. Munaut
Comment:	F. Serre-Bachet
Asia:	Zheng Sizhong, Wu Xiangding, and Lin Zhenyao
Comment:	M.K. Hughes

Final Session

The International Tree-Ring Data Bank:	L.G. Drew
	H.C. Fritts
Dendroclimatological overview:	H.C. Fritts

The Workshop concluded with reports from working groups and general discussion.

Sessions were chaired by:

M.G.L. Baillie, A.L. Berger, D. Eckstein, H.C. Fritts, B.M. Gray, V.C. LaMarche Jr., J. Pilcher, and A.B. Pittock.

Working groups were convened on:

Chronology and network building
Hughes (Chair) LaMarche Jr. (Secretary)

The properties of chronologies and their preparation for use
Bräker (C) Cook (S)

Statistical problems in response and transfer functions
Gray (C) Gordon (S)

Report and Recommendations

Very long chronologies and isotopic parameters
Pilcher (C) Conkey (S)

Applications and verification
Fritts (C) Pittock (S)

The Southern Hemisphere
LaMarche Jr. (C) Dunwiddie (S)

North America
Brubaker (C) Lofgren (S)

Europe
Berger (C) Pilcher (S)

The Mediterranean and Asia
Munaut (C) Hughes (S)

The Arctic
Jacoby (C) Cropper (S)

The Tropics
Jacoby (C) LaMarche Jr. (S)

1

INTRODUCTION

There is an urgent need for greater understanding of the nature and causes of the fluctuations in climate that have occurred since the most recent ice age. In a world faced with a growing population and accelerating use of energy, water and food resources the demand for estimates of climatic change over the next few decades is pressing. This demand cannot be met now because our knowledge of the course and causes of past climate is too limited. The instrumental records of meteorological variables such as temperature, pressure and rainfall are sparse over much of the globe before the beginning of the 20th century. A very few extend back two or three hundred years, but these are mainly restricted to the North Atlantic sector. In order to gain some understanding of climatic variations on timescales of up to a few decades, climatic records for much of the globe over several centuries are needed. Information on large-scale climatic change during the early- and pre-instrumental periods may only be established by the use of historical or proxy climate records. The term 'proxy climate records' describes dateable evidence of a biological or geological phenomenon whose condition is, at least in part, determined by climate at the time of its formation.

It is now clear that the geographical patterns and timing of climatic change are complex, rarely synchronous and rarely hemispheric in scale. Even a simple change in the atmospheric circulation is likely to produce a complicated response in climate, particularly in temperate latitudes as the changing position of the atmospheric long waves shifts the location of depression tracks and meridional air flow. Climatologists cannot rely on data for any single location to give a picture of climatic change on a global or even hemispheric scale.

Tree growth provides a variety of measurements which can be used as proxy climate records. As records which may be assigned accurately to a particular year and place, tree growth occupies a special position in the catalogue of proxy climate information alongside annually layered lake sediments, some ice cores, and certain historical data. Trees are found over a large part of the Earth's landmass and although not all trees form dateable annual layers from which climatic information may be decoded, many do. Among these there is a wide variety of responses of growth to climate, both on the basis of inherited capabilities and of their expression under a given set of site conditions. Consequently, tree rings record responses to a wider range of climatic variables over a larger part of the Earth than any other kind of annually-dated proxy record. Climatically responsive trees forming annual growth rings may be found in many regions of the world. A global network of several centuries length is conceivable, although not yet established.

There have been striking advances in the field of dendroclimatology during the last twenty years. Tree-ring data have been used to derive various climatic variables for certain localities and have been used in a handful of cases to provide estimates of spatial patterns of climatic anomalies for larger regions. Despite these successes, the full potential of tree rings as sources of proxy climate data is far from realised. Although the reconstruction of global climate must be an international exercise, the related sciences of dendrochronology and dendroclimatology have developed rather parochially. Dendrochronology was concerned with climate right at its conception in the early decades of the present century. In fact, much of the research reported at this Workshop was foreseen in essence by DOUGLASS as early as 1914. The spur to the development of dendrochronology came, however, not from climatology, but from archaeology. The science developed as an archaeological dating tool both in the southwestern United States and in Europe. Because, from an archaeological standpoint, these two areas were so far apart, the techniques developed along very different lines and with little contact between researchers. Moreover, in recent years the frontiers of the science have extended into new geographical areas and experience in these regions has led to the modification and refinement of many techniques, and to the healthy diversity of a maturing discipline. But climate does not respect political, cultural or methodological barriers.

This Workshop was organised in order to provide an international and interdisciplinary forum in which methodological differences could be aired constructively in order to provide the basis of understanding, if not agreement, that is necessary for collaborative effort. The current extent of the dendrochronological data base was extensively reviewed by leading workers from both hemispheres. Finally, an attempt was made to assess the prospects for each analytical field or geographical area and the needs that must be met if the full promise of dendroclimatology is to be realised.

Section 2 of this document deals with the acquisition and preparation of tree-ring samples as discussed at the Workshop and Section 3 covers the analysis of the resultant dated time series. Sections 4 and 5 offer a global coverage of current progress and also prospects for the future. In Section 6 the deliberations of the working groups at the Second International Workshop on Global Dendroclimatology are summarised, whilst their detailed recommendations are given in Section 7. Reports on the

International Tree-Ring Data Bank which were presented at th Workshop are summarised in Section 8.

The Editorial Board hope that this report will give an accurat and useful picture of the Second International Workshop on Globa Dendroclimatology. The members of the Editorial Board accept ful scientific responsibility for the contents of this document, an gratefully acknowledge the assistance of Workshop participants i the preparation of certain sections before or, under considerabl pressure, during the Workshop. Many readers not familiar wit this field will find it helpful to refer to what has been for many of the contributors to the Workshop the seminal work i dendroclimatology: H.C. Fritts' 'Tree Rings and Climate' (Academic Press, London, 1976). Indeed, it is our view that a reasonable background in this field cannot be gained without reference to that work, to the author of which we all owe a considerable debt of gratitude.

2

DATA ACQUISITION AND PREPARATION

Where trees form annual growth layers, there exists the likelihood that the characteristics of those layers reflect the conditions under which they were formed. Differences in annual growth layers, which are seen as tree rings, may be parallel in many trees within regions indicating that some common set of (external) factors is influencing growth. Such similarities in growth variation may be strong and spatially extensive. Where this is true, it is reasonable to assume that the external agents forcing the pattern of variability common to trees in a region relate to climate. There are no other environmental factors likely to act on the same range in the space, time and frequency domains. It should be possible therefore to extract a record of the climatic variables recorded in the rings of wood formed in the past. This is the basic assumption of dendroclimatology.

Many tree species in the temperate regions show patterns of common year-to-year variability in one or more measure describing the state of the tree ring. This phenomenon has been exploited by scientists in two main fields: dendrochronology (tree-ring dating of wood found in archaeological, geological, or other contexts) and dendroclimatology (the use of tree rings as proxy climate indicators). Both fields depend heavily on the identification and verification of patterns of common year-to-year variability in many wood samples from a site or region. A variety of methods for establishing basic calendrical control have been used, and *a priori* criteria have been developed for assessing whether material from a given tree ring, variable, species, site or region is likely to yield a strong enough common pattern of variability for either dating or dendroclimatic use. For dendroclimatology, a range of techniques has been used to treat the absolutely dated time series of tree-ring measurements in such a way that climatically-related information (signal) is retained with minimum distortion, whilst the non-climatic variation (noise) is removed as far as possible.

This section of the Report covers the session of the Workshop concerned with the acquisition and preparation of tree-ring data for the specific purpose of reconstructing past climate and related phenomena. Some indication is given of promising new approaches.

LAMARCHE outlined a general sampling strategy for extending the existing tree-ring data base into a new geographical area. He demonstrated that some generally applicable principles and concepts may be used to guide sample selection from the initial identification of a promising region through to the choice of individual trees and radii. LAMARCHE drew on his great experience in exploiting new regions for dendroclimatology in order to assess the generality of these concepts and emphasised the need for constant reassessment. COOK took up this theme, taking the particular case of the relative importance of site and species selection in securing good proxy records of climate. Whilst in many cases climate-growth responses are peculiar to a particular site-habitat-species complex, there are some species, such as *Tsuga* Carr. in eastern North America, which show a characteristic response. There was a tantalising hint in BAILLIE's discussion of correlations between chronologies in different parts of Ireland that Quercus may behave similarly.

Reference has been made to the influence of past conditions on the state of annual growth layers. A number of different measures have been used to describe this, most commonly the width of the annual ring (the annual radial increment). In recent years other physical and chemical variables have been studied in the context of dendroclimatology. Particular progress has been made in the use of X-ray densitometry to reveal intra- and interannual variations in wood density. Density measurements integrate changes in proportions of cell types and their relative dimensions. SCHWEINGRUBER described the methodological basis of this approach. The results of a remarkably successful reconstruction of past temperature from ring-width and density records of coniferous trees from Swiss sites have been reported elsewhere (SCHWEINGRUBER et al., Tree-ring Bull., 38, 61-91, 1978). These variables may also be recorded directly as described by ECKSTEIN for Quercus in Europe. ECKSTEIN reported indications of a significant climatic signal in early wood vessel size in Quercus.

Of all the possible chemical descriptions of the state of the annual growth layer, most attention has been paid to variations in the stable isotopes of H, C and O. LONG reviewed the basis of this approach. He showed that the climatic interpretation of stable isotope variations in tree rings is at the learning stage, and stressed the dangers of making naive assumptions of a simple relationship between isotopic parameters and particular climatic variables. Whilst it is possible that general trends may be inferred from stable isotope data from tree rings, more precise palaeoclimatic inferences will require a more thorough understanding of the systems involved, necessitating carefully designed growth experiments and suitably structured field measurements. This need for a fuller understanding of the physiological and biochemical mechanisms involved was emphasised by WIGLEY, who also drew attention to the problems associated with using changes in the Carbon-14 content of tree rings as a proxy record of climate.

Regardless of which tree-ring variables are measured, the measurement procedures are designed to yield a set of absolutel dated time series that are records of the environmental condition experienced by each tree in past years. GRAYBILL described th most widely used procedures for enhancing the climatic signal b methods intended to remove growth trends and biologically induce changes. Series for individual radii and trees are combined t give the maximum common signal. Descriptive sample statistics ar then calculated and should be used to evaluate samples, t characterise time series, and to assess the relationships betwee annual ring variables. These methods have been developed wit ring-width measurements in mind and may require furthe modification for use with other variables and sets o variables. Whilst standardising by division of the actual valu by the calculated growth curve value may be most appropriate fo ring-width, density data may only require the computation o differences since the variance of raw density data appears not t vary through time.

Dendroclimatologists are familiar with the phenomenon of <u>pointe</u> years described by ANIOL and SCHMIDT. In such years a very hig proportion of all trees at a site or in a region show a change o ring width or other variable in the same sense. Whilst th proportion of years showing such behaviour increases with sampl size, some years remain as a record of disparate tre response. Pointer years in the tree-ring record potentiall record climatic phenomena which are coherent over a larg area. This has not yet been fully exploited.

Many of the statistical techniques described in these papers have been developed for use on material from sites where trees are obviously limited by heat or moisture deficit at one or more times of the year. In general, these trees grow in open-canopy forests as distinct from the more closed canopies of mesic forests. In the regions into which dendroclimatology is presently expanding, such as Tasmania, eastern North America, and much of Europe, strong common patterns of year-to-year variability (good crossdating in dendrochronological terms) are being found in trees from closed-canopy forests. In these cases, factors related to stand and population dynamics and disturbance as well as age-trend may influence ring width and other variables. The variations in the tree-ring series that result from such factors are likely to be of medium to low frequency and thus may be confused with medium to low frequency climatic change. It is of considerable importance that methods of standardisation that are capable of removing as much of this non-climatic variation as possible be developed. It is likely that suitable algorithms will start from a consideration of the common and of the unshared variance in several frequency bands for the whole data set of cores and trees. An attempt can then be made to remove unshared variance in order to find the best available expression of the common variance in all frequency bands.

In addition to its value in preparing chronologies from living trees for dendroclimatic analysis, such a method of standardisation would be needed for the pretreatment of the many short series to be included in long composite chronologies. A further problem in the compilation of long composite chronologies concerns the kinds of adjustment to the time-series properties of the series to be merged that may be made safely without inadvertently distorting the low frequency climatic signal.

Methods of establishing precise calendrical control are shared by dendrochronology and dendroclimatology, but major differences exist in other areas. In particular, specific criteria are being developed in dendroclimatology for the selection of suitable regions, sites, species and trees to achieve the maximum climatic signal. Similarly, techniques of measurement and analysis have been and are still being developed which are designed specifically to describe, extract and strengthen that signal without distortion. The particular method chosen at each stage depends on both the tree-ring variable or variables being measured and the climatic information that the investigator hopes to extract. Consequently, whilst many of the methods described have very general application, it is not possible to prescribe a procedure that would be appropriate in every case. Indeed, it is important that new approaches be investigated in order that the considerable scientific resources presented to dendroclimatology by as yet unused material be tapped.

3

DATA ANALYSIS

In the previous section, various methods of enhancing the climatic signal in tree-ring chronologies have been mentioned. In order to reconstruct climate, it is necessary to extract this climatic signal - to separate climatic factors from the many other environmental variables limiting the plant processes which control growth. The climate-growth response is complex, and reliable theoretical models have yet to be developed. Semi-empirical techniques have therefore been developed in order to extract the climatic signal. Response functions are used to determine associations between climate data and annual ring measurements. Transfer functions are used to calibrate the ring measurements with climate data in order to provide regression equations for climate reconstruction. Both techniques employ multivariate statistical methods such as eigenvector or principal components analysis and canonical correlation and regression.

The response of the growth of trees to climate and other environmental factors was discussed by FRITTS. He highlighted the need for semi-empirical techniques to define and extract the macro-climatic signal from tree-ring chronologies. The response function provides an empirical method of describing the nature of the climatic factors that influence tree growth. As HUGHES and MILSOM pointed out, the response function does not measure the climate-growth response but rather the effectiveness of a particular statistical model at predicting the element of tree-ring variation forced by external factors.

The response function has proved to be a valuable tool for analysing the climate-growth relationship. GUIOT, BERGER and MUNAUT reviewed various methods of calculating response functions. All are based on the fundamental model described by FRITTS et al. (J. Appl. Meteorol., 10, 845-864, 1971) but differ in the way in which they handle statistical problems arising from the complex nature of the climate-growth response. For example, the growth of the tree in a particular year may depend not only on environmental conditions during the growing season but also on conditions in prior seasons. Climate data for prior seasons, and the growth of the trees in prior years, have therefore to be included as predictor variables in the response function. Statistical questions arise concerning the best way to include these variables in the response function, and the interpretation of the role of prior growth in the response function is problematic. This matter was further discussed by BRETT who gave specific examples from his work on English *Ulmus* and *Quercus*. Spectral techniques have been introduced in order to determine whether or not trees respond in a different manner to climatic fluctuations on different timescales. The possibility that the trees' response to climate changes as the trees age has also been considered. In view of these and other problems, CROPPER questioned the value of current methods of calculating response functions and of interpreting their results, but made the constructive suggestion that simulation techniques should be used to evaluate their strengths and limitations.

While the response function is a means of predicting tree performance from climate data, climate reconstruction requires that climate data be predicted from tree-ring data. The response function is used as a guide to the climatic factors which influence tree growth and to the direction and strength of the relationship; this information is used in the design of the transfer function model. LOFGREN and HUNT described the use of the transfer function. Transfer functions are calibrated over a period of time when both instrumental climate data and tree-ring data are available and the resulting regression estimates are then used to extend the climatic record back in time prior to the calibration interval. Again, because of the complexity of the climate-growth response, multivariate techniques are employed and various statistical problems arise. LOFGREN and HUNT noted particular concerns, such as the proper inclusion of the autoregressive and moving average nature of the climate-growth relationship, the need for statistical significance testing, and the use of eigenvector analysis to maximise the climatic signal. GRAY discussed the validity of the assumption that the climate-growth response is stable with time. The no-analogue problem was also considered. If a particular climatic pattern was prominent prior to the calibration interval, but not present during it, then that pattern cannot be included in the transfer function model and the resulting climatic reconstruction will not include it unless it is a linear combination of other patterns. Research described by GRAY suggested that for European temperature the no-analogue problem is unlikely to be critical for the period since 1780. Non-linearity in the climate-growth response can also cause no-analogue problems. GUIOT, BERGER and MUNAUT described a methodology for the transfer function which is more applicable in areas where tree-ring data are available from only a small number of sites. They illustrated their technique with a reconstruction of temperature data for Switzerland.

The critical assessment of the reliability of any dendroclimatic reconstruction is a crucial stage. GORDON described the various methods through which this can be achieved. Data not used in the development of the transfer function model are necessary. Instrumental climate data not included in the calibration of the model are most suitable but often limited in availability. This means that withholding data for verification results in a loss of data for calibration and therefore less reliable or less stable regression estimates. Some compromise h to be reached. GORDON suggested that subsample replication m provide a solution to this problem. Another approach is to u independent proxy climate data and historical (documentar information for verification. PILCHER noted the irony of the fa that in Europe where climate data are relatively plentiful a thorough verification is possible, the tree-ring data base is ve poorly developed. Both PILCHER and GRAY stressed the value o historical climate information in verification for the Europe region. GRAY also noted that the problem of the lack of climat data for calibration could be partly alleviated by the use o transfer function models containing fewer variables.

The need for critical evaluation of the methodology and results o dendroclimatic reconstruction was stressed by all the contributor in this section, whether they came from a dendrochronological o climatological background. PITTOCK described what th climatologist requires of dendroclimatic reconstruction an questioned the extent to which dendroclimatology can meet these requirements. He emphasised the need for better understanding of the biological processes underlying the reconstruction technique, and for continuous refinement of the techniques employed. He also noted that attempts should be made to extract information concerning more and different climate parameters and that longer records, of great value to climatologists, could be made available if dating standards were relaxed. LOFGREN and CROPPER pointed out that, when evaluating dendroclimatology's potential, the method by which the magnitude of the climatic signal in tree rings is determined needs to be considered carefully.

Finally, to set the stage for the review of the global dendrochronological data base, a paper by KUTZBACH and GUETTER was presented, in their absence, reporting experimental results aimed at defining the density of the sampling network necessary to reconstruct mean sea level pressure from temperature and precipitation data. The methods employed were identical to those of dendroclimatic reconstruction; the results are therefore relevant to the design of dendroclimatological sampling networks.

It is unlikely that all the problems inherent in the statistical modelling of the climate-growth relationship will ever be solved, but reproducible results are a strong indication of reliability. Reproducibility can be assessed by analysing subsets of the data in the case of a single site, and by comparing the results of response functions for a large number of sites in a particular region. Likewise for the transfer function, subsample replication, in space as well as time, is important. The number of variables to be predicted needs to be balanced carefully with considerations of reproducibility and stability. The response function, or preferably the pooled results of a large sample of response functions, should be used as a guide to the design of the transfer function model: for example, how many and which climate variables to include, which seasons to select, and so on.

Because of the sophistication of the statistical techniques employed, critical evaluation of the results, in terms of statistical, biological and physical significance, is of paramount importance. Verification of climatic reconstructions is needed not only to place dendroclimatology on a firm scientific basis but also to assure potential users, mainly in the climatological community, of the validity and reliability of the reconstructions. The requirement for thorough verification must influence the entire reconstruction process from the design of the sampling network through to the design of the transfer function model. A well-verified but small set of proxy climate data is preferable to a large set of data of questionable quality. The documentation of verification results alongside the publication or dissemination of reconstructions is essential.

Most of the techniques discussed in this section were designed for ring-width data rather than density or isotope measurements. This reflects the relative progress in the use of these three types of tree-ring data to produce climate reconstructions. Although standard ring-width techniques have been applied to density measurements, it may be necessary to develop alternative techniques for parameters other than ring width. Techniques should also be developed which can handle more than one type of tree-ring measurement and possibly other proxy or historical climate data as additional predictors.

There has been a lively debate concerning the use and interpretation of the response function in recent years. While this is due in part to the statistical complexity of the techniques employed, it is largely a result of the expansion of dendroclimatology into many new areas with species, site types and climate different from those for which the original techniques were developed. The extension of the basic dendroclimatological techniques to new regions has led to a necessary reassessment of the validity of the methodology and to many modificaions and improvements. As dendroclimatology progresses in these new regions, it is likely that the debate, which is characteristic of the healthy diversity of a maturing discipline, will continue.

4

THE SOUTHERN HEMISPHERE

One of the main aims of the Workshop was to review the current extent of the dendroclimatological data base and to assess the potential for its expansion both in space and time. Review papers were presented for various regions during the general sessions and working groups formulated recommendations concerning research priorities which were then discussed by all the participants in plenary session. The geographical areas referred to in these two sections reflect areas of research activity rather than climatically or dendrochronologically distinct regions. The climatologists present at the Workshop played an active part in the discussions and research priorities were assessed on both climatological and dendrochronological grounds. This was the first time that the potential users of dendroclimatic data had been directly involved at this early stage of the reconstruction process and it proved of great value. Knowledge of the characteristics of the spatial patterns of climatic variation evident in instrumental records was used to guide sampling strategies, alongside the more commonly used principles of dendrochronology. Brief descriptions of the climatology of the hemispheres provided a context for the discussions of the global data base.

SALINGER described the climatology of the Southern Hemisphere. The small land area in the temperate zone and its generally low relief, as well as the presence of the ice-covered continent of Antarctica, promote a vigorous year-round circulation. The strong but eccentric circumpolar vortex of low surface pressure is one manifestation of this. The associated extratropical depressions provide the seasonal or year-round rainfall that supports the forest and woodland vegetation of the southern parts of the continents and New Zealand. This rainfall is modified by rain-shadow effects in eastern New Zealand and Argentina and in interior South Africa and Australia. The strong and persistent subtropical high pressure belt may influence the tracks of these depressions, and also plays an important role in the seasonal climate regimes in lower latitudes. The Southern Oscillation is a most important feature in low latitudes of the Southern Hemisphere, and it influences climatic variability at higher latitudes in both hemispheres as well.

The paucity of land in the Southern Hemisphere obviously limits both the development of a tree-ring data base and the extent of comparative climatological data. As a consequence, the approach to reconstruction of climate parameters beyond the local and regional scales will probably depart somewhat from the schemes developed and successfully applied in parts of the Northern Hemisphere. Even if tree-ring records could be developed covering all of the land areas, the network size would still be small in comparison with the total area of the hemisphere. Therefore, the most effective approach may be one specifically directed towards reconstructing the behaviour of some of the more important features of the general circulation, such as the circumpolar vortex, the subtropical high pressure belts, and the Southern Oscillation.

Tree-ring work in the Southern Hemisphere has lagged greatly behind that in the Northern. Until very recently few dendrochronological studies had been attempted, and rarely were accurately dated and well-replicated chronologies produced. The reasons for this lag include the scarcity of experienced people, the apparent lack of suitable species or habitats in some regions, a low level of interest in climate variability within the broader scientific community in some countries, and the lack of suitable wood in archaeological or historical contexts that might have led to development of an archaeological dendrochronology. The situation changed dramatically about six years ago, when local workers in South Africa, Australia, and Argentina, as well as outside investigators, began comprehensive programmes of tree-ring research.

The relatively small size of the tree-ring data base in the Southern Hemisphere reflects the recent initiation of sampling and analysis programmes. The chronologies are, however, of high quality because modern sample size and replication requirements generally have been met, site characteristics are well described, the dating is reliable, and modern techniques have been used in the processing and analysis of the data. The total of less than 100 up-to-date chronologies does provide a firm starting point for future work. This data base and future prospects for its expansion were discussed in papers presented by OGDEN and DUNWIDDIE (Australasia), DYER and LAMARCHE (Southern Africa) and HOLMES and BONINSEGNA (South America).

The needs and prospects for further collection differ from region to region. In the temperate zone, New Zealand, Tasmania and parts of Argentina and Chile have fairly dense coverage, although gaps do exist. Future sampling should include a greater variety of species and climate response characteristics as well as sampling for densitometric and other analyses. Temperate areas that are poorly covered include southern areas of South America, mainland Australia, and South Africa. Recent collections are available for parts of these areas, but dating problems remain to be solved for some species.

Areas with virtually no coverage include the subtropical and tropical parts of Africa, Australia, South America and the islands of Madagascar, Indonesia, New Guinea, New Caledonia, and the smaller islands of the tropical South Pacific. One of the reasons for the lack of progress in dendrochronology in this vast region is the general lack of interest in the past, although several groups have recently been working on problems of warm temperate, subtropical and tropical dendrochronology in South Africa, South America, and Australasia. A major obstacle has been the lack of clearly defined rings in most species and the presence of obvious intra-annual growth bands in others; these problems lead to major difficulties in dating. Several promising species have been identified, however, and future work could emphasise the study of trees in taxa that have proven their worth in extratropical regions of the Southern Hemisphere.

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THE NORTHERN HEMISPHERE

The distribution of land and its relief differs markedly between the two hemispheres, and this influences both the potential extent of the tree-ring data base and the nature of the climatic and atmospheric circulation features that are to be reconstructed. The atmospheric circulation does not have the year-round vigour of the Southern Hemisphere. Pronounced seasonal changes in climate and the strength and position of the major circulation features occur, particularly in the continental interiors. The greatest variations in temperature on longer timescales tend to occur in high latitudes and in winter.

The major modes of spatial variation in the hemispheric surface pressure field affect the strength of the Arctic High and of the Icelandic Low. KELLY, in describing the climatology of the Northern Hemisphere, noted that principal component analyses of instrumental climatic data could be of value in guiding the design of dendroclimatological sampling programmes.

The Arctic area, reported on by JACOBY, BRUBAKER and GARFINKEL, and LAWSON and KUIVINEN, is of special interest as climatic variations in high latitudes are particularly marked and may indicate changes over a much wider region. Temperature-responsive trees may be expected. As the papers showed, there has been a considerable amount of work undertaken in high latitudes, particularly in Alaska where a clear climate signal in tree-rings has been demonstrated. The area has its special problems related to access to sites and the properties of the tree-ring series themselves. It is an area with great potential and one especially requiring international cooperation.

Western North America, reported on by BRUBAKER, is one of the most heavily worked areas of the globe. It is the source of most climate reconstructions to date. The range of species, the altitudinal gradients and the latitudinal range have all contributed to this success, although there is much to be done. Many gaps still exist in the tree-ring network and many species have yet to be investigated. Its position at the eastern edge of the largest ocean of the hemisphere makes it sensitive to climatic variation.

In contrast to the west, eastern North America, reported on by COOK, CONKEY, and PHIPPS, was neglected in the early days of the science. Much of the native forest has been destroyed and what remains is dominated by angiosperm genera. Techniques for handling these genera have been more extensively developed in Europe than the U.S.A. In spite of these difficulties, the recent progress, including the development of 48 long modern chronologies, shows the great potential of this area. Eastern North America will be vital to any attempt to determine the past climate of the North Atlantic sector; data from the eastern United States and Europe could be combined in a grid surrounding the North Atlantic Ocean. Such a reconstruction is rapidly becoming feasible as chronologies up to 250 to 300 years long with a strong climate signal are becoming available from both areas. The value of density measurement in eastern North America, as well as in the Arctic and Alpine regions, was well illustrated.

In Europe, which was reported on by ECKSTEIN, BITVINSKAS and

PILCHER, many of the existing chronologies are not in a form suitable for dendroclimatology without reworking. The high quality of crossdating and limited dendroclimatological study have shown that trees from the mesic hardwood forests have a strong common climate signal. The Alpine areas, reported on by BEDNARZ and BRÄKER, although dealt with separately at the Workshop because of different methodologies, will form part of a single unit with lowland Europe for a climate reconstruction grid. As pointed out by several contributors, human influence on the forests is strong in the Northern Hemisphere but nowhere more so than in Europe and the Mediterranean region. Grazing by domestic animals is a particularly severe factor in the Mediterranean region. Nevertheless as MUNAUT and SERRE-BACHET demonstrated, a clear climate signal is present in tree-ring chronologies in this area. Density measurements on coniferous timber from a variety of areas in Europe are valuable additions to the tree-ring data base. Europe has the potential for reconstructions extending back beyond 1,000 AD using composite chronologies from archaeological and other non-living timber. Dendroclimatology is apparently advancing in eastern Europe, although little firm information has been published in the West. As the U.S.S.R. forms a major part of the European landmass, its contribution to the hemispheric data base cannot be ignored.

The Asian continent, reported on by ZHENG, WU and LIN, is the largest landmass of the hemisphere and perhaps the least studied. The impressive list of long-lived tree species in China highlights the potential of the region. It is in an area such as this that instrumental, historical, and tree-ring records may be fruitfully combined. International cooperation is again essential if this region is to be included in a hemispheric data base.

6

WORKING GROUPS

A summary of the work and findings of the eleven working groups which met during the Second International Workshop on Global Dendroclimatology is given here. Each group consisted of between six and ten scientists active in the field under review. They were asked to pay particular attention to the prospects for development of their field in the near future and to the needs that must be met if these prospects are to be realised. Their reports were subsequently discussed in plenary sessions.

Each participant at the Workshop contributed to two working groups: one was methodological, and the other concerned the global data base. The methods working groups briefly reviewed the current status of their particular topic before going on to assess future prospects and make specific recommendations about research priorities. The global data base working groups, each assigned to a specific geographical area, determined the extent of the existing data base and then looked towards prospects and needs for the future. In this Section, the reports of the working groups are summarised by the Editorial Board. Explicit recommendations from the working groups concerning research priorities are given in Section 7.

Working Group 1: Chronology and network building

This group focussed on the problems of establishing chronologies and networks of chronologies suitable for use as proxy climate records. It took as its starting point LAMARCHE's paper on sampling strategies in dendroclimatology. The following paragraphs summarise the discussions that arose from considering the situation of a dendroclimatologist arriving at the shores of a hitherto unsampled continent.

A tree-ring sampling programme is normally carried on in the context of some broader climatological problem which will determine, at least in part, which regions should be sampled. All pertinent information, such as topographical, geological, soils and vegetation maps and floras, should be used in planning network initiation. Preliminary sampling should aim to characterise the range of tree-ring responses found in the region in their species, site and regional contexts. Not all tree species are suitable for dendroclimatology; only trees with clearly identifiable and definitely annual growth layers are usable. Absolute dating of all materials using rigorous, repeatable methods is neccessary. A number of approaches exist for this but all need the skill and experience of the scientist and all consist of the cross matching of a large body of comparable ring sequences. The resultant absolutely dated time series are standardised to remove non-climatic variation. The standardised series for many trees at a site are then combined to maximise the common signal.

Descriptive statistics should be calculated to quantify sample distribution and time series properties at both the tree and site chronology levels. The next step is to characterise the climatic signal recorded in each chronology by comparison with nearby meteorological records. All these procedures apply equally to ring width and density series. It is essential that the researcher stay in close contact with the data at all stages, being aware of site and tree characteristics that may affect the process. The statistics cannot fully describe the data base and the experienced worker must, at times, rely on intuitive judgements which may influence decision-making in analysis.

Reviewing recent extensions of the data base to new regions, the working group concluded that care must be taken in establishing criteria for selecting new sites. Whilst sampling at ecotones may be most appropriate in cold and arid regions, this is often not the case in mesic forests in the temperate zone and may well not apply in the tropics. Disturbed sites should be avoided, but when this is impossible all available information on disturbances should be documented. Networks should be designed to yield maximum climatic information. Information on the properties of species, sites and variables is necessary for this. Improved understanding of the effects of choice of network structure (spacing, geographic distribution, and so on) is desirable. Analysis of existing networks, for example by studying correlations between records as a function of distance and climatic zonation, should help in this. At the site level, analysis of variance and other techniques give a quantitative basis for estimating the sample size needed to give an acceptable climatic signal. At both the site and network level such statistical analyses should be based on a sound understanding of the underlying biological system.

Working Group 2: The properties of chronologies and their preparation for use

This group discussed in detail some of the statistical analyses briefly referred to in the account of the work of Working Group 1. It should be emphasised that the methods discussed here are specific to the preparation of tree-ring chronologies for use as proxy climate records.

The group dealt first with the standardisation of tree-ring series; that is, the removal of growth trends and non-climatic perturbations. Most approaches involve the use of a curve-fitting computer program to model and remove the growth trend and averaging to remove the unwanted variance (noise). Two of the most common curve-fitting techniques used, namely the modified negative exponential curve and the simple linear regression line, do little more than remove a monotonic trend from the series. Other more flexible techniques, such as the use of orthogonal polynomials, cubic splines and low pass digital filters, must be used with great care. They remove more medium frequency variance and in doing so may remove some climatic signal. However the model of the growth trend and non-climatic perturbation is derived, it is then used to stabilise the variance of the time series. In the case of ring-width data, this has usually been done by deriving for each year an index, such as the ratio of the actual ring width to the curve estimate. Densities may be more homoscedastic and so it may be appropriate merely to subtract from the actual value the calculated value from the curve. Once the series of measurements from each measured radius has been standardised, the arithmetic mean of all series is taken. This produces a site chronology in which the signal-to-noise ratio is increased because the common signal is retained and random errors average out. The original series, the standardised series, and the site chronology may then be analysed to characterise the data statistically.

Once a chronology has been established and analysed in the manner described above, it is important that it be presented with the appropriate documentation. The working group took the view that the format used by LAMARCHE et al. (Chronology Series V , Laboratory of Tree-Ring Research, University of Arizona, 1979) is appropriate. The chronology is presented along with site information and all the statistics described by GRAYBILL at the Workshop. In addition, details of the standardisation methods used should be given. The raw data and the indexed chronology should be archived in the International Tree-Ring Data Bank, assuming the material is of the necessary standard.

Working Group 3: Statistical problems in response and transfer functions

The group defined the role of the response function as an aid in the evaluation of the nature of climatic signals in chronologies and in the definition of seasonality. The evaluation is made most effectively by examining many response functions for each species from a range of internally homogeneous sites. It is necessary to check for both within-site reproducibility and for temporal stability of response functions. In particular, the possibility that response functions may vary with tree age or canopy status should be borne in mind. The need to make these checks generates a requirement for statistical tests of significance of differences between response functions. The general question of the statistical significance of response function results requires further examination.

Problems arise with the inclusion of climate or ring data, or both, from years prior to the growth year as predictors in response functions. One promising approach is the use of selective filtering techniques. Since autocorrelation is more apparent in tree-ring data, the prior growth data may be orthogonalised along with the climatic variables, or alternatively the tree-ring data may be prewhitened. Whenever new response function methods are developed, the method developed by FRITTS et al. (J. Appl. Meteorol ., 10 , 845-864, 1971) offers a widely available benchmark against which they may be tested. Simulation techniques can also be used to test their value.

Both response and transfer functions are complex applications of simple linear regression models. The results are subject to all the limitations of this method. Where it is found necessary to introduce non-linearity this may be done by combining climatic variables into parameters relevant to physiological processes. In the case of transfer functions using only linear relationships, a variety of model structures may be used. In any calibration, sufficient predictand data must be withheld to allow statistical verification of the model. Further study of the econometric and biometric literature may yield new approaches to the problems of using transfer functions.

It is a basic assumption of the transfer function approach that the modes of climatic fluctuation have not varied between the periods of calibration and extrapolation. Climate and tree-ring data should be tested for this, as, for example, has been done in Europe (HUGHES et al., Nature, 278, 283, 1979). Of course, the climate data themselves should be critically reviewed.

Working Group 4: Very long chronologies and isotopic parameters

Although living-tree chronologies of one or more millenia do exist at a few sites, most chronologies longer than a few hundred years are based on overlapped series from living and dead trees. Specific problems arise in the dendroclimatic use of such chronologies. These include the statistical problems of merging many small overlapping temporal segments, the degree of replication required, the nature of the climatic signal when series from a wide region are merged, and the stability of the climate-growth relationship. In addition there is the potential for extracting climatic information from stable and radioactive isotope records from wood dated using composite chronologies.

There are a number of long composite chronologies of 1,000 to 2,000 years length in the Northern Hemisphere which have potential for dendroclimatic use. These may form a network which, although sparse, may be dense enough for climatic reconstruction on a hemispheric scale. Of the chronologies needed, 30 exist only as dating chronologies. These will need to be rebuilt from the raw data. Localised reconstructions may be possible using chronologies of 2,000 to 10,000 years length. The value of these chronologies may be enhanced by the use of stable and radioactive isotope measurements. It is particularly important that modern observational and experimental work on isotope-climate relationships be carried out to provide a basis for interpreting long isotope chronologies. While the material for composite chronologies may be largely archaeological in the Northern Hemisphere, subfossil material (for example, *Agathis* in New Zealand) may be of great value in the Southern Hemisphere.

The group expressed great concern at the extensive loss of valuable subfossil and archaeological timber and made recommendations designed to lessen this loss (see Section 7).

Working Group 5: Applications and verification

The group discussed the special attributes of dendroclimatology. It noted that dendroclimatology can provide quantitative information on past space and time variations in climate during the Holocene, and that considerable potential for long records within that period exists (see Working Group 4). Dendroclimatology produces continuous data sets with high time and space resolution. These data sets do, however, share with all other proxy data the limitation that only part of the climatic variance may be reconstructed. The group took the view that dendroclimatic reconstructions have considerable value in the following applications:-

a) The extension of the climatic data base to make possible more rigorous testing of climatic models and the adjustment of climatic statistics to a longer and more representative data base. The latter applies, for example, to the estimation of flood and drought recurrence intervals.

b) The provision of detailed descriptions of climate in relatively distant periods to act as analogues of possible future climatic changes (for example, towards a carbon dioxide-warmed Earth).

c) The verification of other proxy climatic records, including historical data, in both time and frequency domains.

In addition to these direct uses of dendroclimatic reconstructions, methods developed for tree-ring analysis may be of use with other types of data. For example, response functions may be calculated for other proxy data, such as isotopic data from ice cores, or be used to calculate climatic impacts on crop or forest yields. The group emphasised that a wide range of climate-related variables, from seasonal temperatures and pressure anomaly fields to streamflow, lake levels, drought severity indices, sea surface temperature and others, has been reconstructed from tree rings.

Having discussed applications, the group turned its attention to the verification of dendroclimatic reconstructions. It echoed GORDON's paper in asserting that verification against independent data is absolutely essential. This verification should be based on well understood statistical methods. Verification over long timescales using independent proxy or historical information is particularly desirable for reconstructions based on long composite chronologies. The group felt that standardisation of statistical techniques for calibration and verification should be sought.

Working Group 6: The Southern Hemisphere

Current status

The tree-ring data base in the Southern Hemisphere is relatively small and is concentrated in only a few regions. However, it has the advantage of having been recently collected specifically for dendroclimatology, so that modern sample size and replication requirements have largely been met. The dating is reliable and the chronologies and sites properly documented. Thus, although there are fewer than 100 such records, they constitute a good basis for future progress. In South America, existing chronologies are primarily from central and south-central Chile and Patagonian Argentina. Fairly good coverage exists for New Zealand, but Australian chronologies are virtually restricted to Tasmania. Only one accurately dated and well-replicated tree-ring record exists for South Africa. One important qualification of the existing data base for dendroclimatic applications is that a majority of the chronologies are derived from trees that show a strong temperature response component rather than a drought response, except for some of the South American records.

Prospects

Dendroclimatology is particularly important in the Southern Hemisphere because of the lack of an extensive instrumental or historical data base. Although the ultimate extent of a dendroclimatic network is constrained by the geography of the hemisphere - little land, of which only a fraction is covered by temperate or sub-tropical forests - there is a good prospect for further development. This could include expansion into new areas, an increase in the density of coverage, and diversification of the types of climatic response represented in areas already covered. It may require the sampling of a wide range of species (with special emphasis on angiosperms) and the measurement of other variables, such as density. Also, in some areas where native species are unsuitable for dendrochronological study, an opportunity exists for taking advantage of exotic plantings by

European settlers. For example, Quercus sp. was widely planted in the Cape area of South Africa over 200 years ago.

South America presents several opportunities for data base inprovement. These include network extension to the warm-temperate/subtropical forests of northern Argentina, Bolivia, Peru and southern Brazil. The corresponding southward extension from south central Chile to Tierra del Fuego might be approached through utilization of the southern beeches (Nothofagus sp.) as well as the conifer Pilgerodendron. Coverage in central Chile, although of high quality, is sparse, and additional collections could be made of Austrocedrus to strengthen this sector. In New Zealand, the existing coverage could be greatly improved by extension to include new species and areas. Northern North Island and southern and western South Island are climatically sensitive areas that are under-represented. A number of coniferous species have not been sufficiently well-explored - especially Kauri (Agathis sp.), with potential for development of very long chronologies. Nothofagus sp. look very promising, and could be much more extensively sampled, especially at the upper treeline, where they would be expected to show a pronounced positive temperature response. Opportunities may also exist for development of tree-ring records from drought-responsive trees in the drier areas of the South Island. In Australia, the Tasmanian network can be greatly strengthened by geographic expansion and by obtaining increased time depth through additional sampling of the species currently in use. Increased diversity and potentially very long records may result from intensive study of the little-known Huon pine (Dacrydium franklinii). On the mainland, a major opportunity exists for utilization of the dendrochronologically difficult Callitris sp., distributed throughout much of the arid and semi-arid interior. It could yield a network of fairly short, but strongly drought-responsive records. Great potential for dendroclimatology is also presented by both gymnosperm and angiosperm species in the warm-temperate to subtropical forests of northeastern and northern Australia. Southern Africa is a very difficult area, but existing results could be built upon through additional chronology development in the southwestern and possibly southern Cape region, based on Widdringtonia . Further exploration of long-lived Podocarpus species in southern and eastern Africa is clearly warranted, although densitometric techniques seem more appropriate than conventional ring-width measurements. Because of the importance of angiosperms in the forest, woodland and savannah vegetation, these offer the only opportunities for chronology development over most of this vast region.

Problems

The greatest scientific problems are connected with the extension of the data base into new areas where there is an apparent scarcity or even complete lack of suitable species. In both temperate and subtropical areas, only angiosperms are available and these may present serious dating difficulties requiring special attention. The lack of instrumental climate data for calibration and verification poses problems in many regions. An important problem is the scarcity of facilities and trained personnel, as well as inadequacy of local funding, especially in South Africa, New Zealand, and Chile. Severe logistical problems also exist in several areas, notably interior Australia, Southern Chile, and in parts of the South American and Southern African subtropics.

Working Group 7: North America

Current status

Temperate or boreal forests are widespread over much of the North American continent. Dendroclimatic collections are extensive from arid sites and mountainous western North America and new chronologies are available from mesic forests in the Pacific Northwest and the northeastern United States. Dendroclimatic reconstructions have been possible in all parts of North America where they have been attempted seriously.

Prospects

The need for dendroclimatic analysis is especially great in North America because the meteorological records are quite short. Prospects exist for networks of chronologies on four timescales. A dense network of 200-year chronologies covering forested areas in North America should be possible. A less dense, but adequate, network can be obtained across the same area for a 300- to 400-year period. In western North America it will probably be possible to establish a network of 500- to 1,000-year chronologies. Several species in the West provide potential for a number of chronologies over 1,000 years long. This includes some species not yet fully exploited for this purpose. The prospects for increasing the climatic information from chronologies in general by using density as well as ring width are great. The very long chronologies may be of value as isotopic records.

Problems

The first problem discussed was the extension of the data base into the subtropics and tropics (see Working Group 11). The second problem was the collection and analysis of historical data for verification of dendroclimatic reconstructions. Practical problems of access arise for reasons of geography in remote areas and from the need to gain landowners' permission to core old trees in protected natural areas in eastern North America.

Working Group 8: Europe

Current status

Almost all existing tree-ring chronologies in Europe have been collected for the purpose of dating timbers from archaeological or art-historical contexts. Only recently has any serious attempt been made to evaluate the climate signal in European tree rings. The group concluded that only a minority of the existing chronologies will be of use in dendroclimatology. Those that come from defined sites and are properly replicated do however have similar properties to chronologies that have been used in successful climate reconstructions in the Arctic, South America and Australasia. The material that is already available in a suitable form covers, albeit sparsely, some of the most important areas of the continent, notably the Alps, parts of Scandinavia, Germany and the British Isles. Where they have been studied, lowland mesic forest hardwoods such as *Quercus*, *Ulmus* and *Fagus* all contain a strong climatic signal, whilst montane conifers are particularly useful in densitometric studies.

Prospects

The group concluded that a real potential for dendroclimatology exists in Europe. Tree growth measurements are useful both as a source of proxy climate data on their own merits and in conjunction with the rich resources of historical and other indirect climatic information. The immediate goal is to bring the existing network to the necessary standard back to 1750 AD from the present. This will involve new sampling in the key regions of Scandinavia, Poland, western and central France, the Iberian Peninsula, the Balkans and Yugoslavia. It will be necessary to establish closer links with workers in the U.S.S.R. In addition to new sampling, some existing chronologies will need resampling to improve replication and to bring those sampled some decades ago up to date. Throughout the period 1750 AD to present, density as well as ring-width measurements should be made in maritime as well as montane sites. The group judged that an enhanced network for the period from 1750 AD could be developed in two to three years given adequate resources. Climate reconstructions based on this data set could be used to test the general methodology of dendroclimatology, as Europe has a greater quantity of independent data available for verification than most other regions.

The prospect also exists of using a less dense grid of tree-ring data extending back to 1350 AD or beyond. This would be based largely on composite chronologies (see Working Group 4), although living tree chronologies 500 years in length exist in Scandinavia, the Alps, southern Germany, Scotland and France. At least seven composite chronologies already extend to 1350 AD. The group considered that this long data set could be used as a basis for climatic reconstruction, particularly if gaps in Spain, France, parts of Scandinavia and eastern Europe were filled. Furthermore, it should be possible to extend the grid to 1,000 years at a reduced density.

Problems

Problems associated with long composite chronologies were dealt with by Working Group 4. The proposed intensive sampling for the period back to 1750 AD should provide basic data to be used in improving our understanding of the range and consistency of climatic response in European trees. Particular care must be taken to ensure replication appropriate to dendroclimatology in all European collections. The effects of human interference must be taken into account. There are three main practical problems. First, the establishment of tree-ring networks for dendroclimatology has received no funding in Europe, other than for some density studies. Second, it is clear that densitometry will be of great value to European dendroclimatology but there is a shortage of laboratory capacity. Third, the lack of effective communication at a detailed level with workers in the U.S.S.R. seriously limits progress.

Working Group 9: The Mediterranean Basin and Asia

The Working Group considered the regions of the Mediterranean Basin and Asia separately.

MEDITERRANEAN BASIN

Current status

This area is climatically distinct from the surrounding regions and it is convenient to deal with it as two units: first, the areas where the dendroclimatic potential is already proven, that is, the northern side of the basin and parts of Morocco and Algeria, and second, the more difficult areas of eastern North Africa, Israel, Lebanon and Syria where established techniques have met with major difficulties. The great majority of existing chronologies of the necessary standards of crossdating and replication are in Morocco and in a small region of southeast France and northwest Italy. A few other chronologies exist, scattered through Italy, the Balkan Peninsula, and Turkey. In eastern North Africa and the Levant, there are no suitable chronologies.

Prospects

Whilst it is unlikely that a uniform grid of suitable chronologies will ever be established around the Mediterranean, the first region referred to contains many potentially high quality chronologies of useful length. The second and more difficult region offers no immediate prospect of an extensive tree-ring network established by conventional means. This is a result of a lack of trees in large areas, a long history of human action, and a complex biogeographical situation.

Problems

In the first potentially productive area, there is a lack of scientific knowledge of climate-growth relationships that must be corrected as far as possible. It seems appropriate to approach this by means of a more systematic sampling effort, the calculation of several response functions for each species, and the investigation of more than one species per site. In the second region, the problems are fundamental and must be approached at a basic level, through investigations of the biology and ecology of potentially useful species.

ASIA

Current status

In many areas, particularly Soviet Central Asia, Siberia, and the Soviet Far East, difficulties of communication mean that we do not know how good the existing cover of tree-ring data is. Even where chronologies do exist, it is unlikely that they were produced specifically for climate reconstruction and thus they will, like many of the European chronologies, need reprocessing. Even assuming that there is a reasonable grid in the U.S.S.R., there are still vast areas of Asia with no dendrochronology at all.

Prospects

The area is vast and much of it is thought to contain suitable species and habitats. Some selectivity is needed to make best use of the resources available. The group proposed that attention be focussed on a region comprising the Himalaya and the areas to the immediate north (Tibet, Tien-shan). These are important as it is here that the Mediterranean, Tropical and Temperate climate influences interact.

Problems

Communication is at present the major problem. As with the Arctic and Europe, the Soviet contribution is important and data exchange will be vital to progress on a hemispheric scale. Lack of information on the tree flora and difficulty of access to the more remote mountainous areas will increase the costs of operations in

Asia. The links already established with colleagues at the Academia Sinica will be of great value in establishing a data base for China and surrounding regions.

Working Group 10: The Arctic

Current status

The Arctic was defined, for dendroclimatic purposes, as the forest-tundra ecotone and the northern portion of the boreal forest throughout the Northern Hemisphere. Existing climate data indicate that it is an area of great climatic variability and may be a good indicator of the climate of the whole hemisphere. The existing tree-ring data are uneven in distribution, length and replication and were mostly not conceived as part of a global tree-ring network.

Prospects

There are large areas of the forest-tundra and boreal forest that have not been sampled, but that are known to contain suitable trees. The climatically sensitive areas of the west coast of North America, Scandinavia, the Hudson Bay region and central Siberia are particularly important for additional sampling. These are mostly areas of scant human population where undisturbed, long-lived trees are likely to be found. Chronologies of 300 to 500 years in length are possible in most areas. In addition, there is the possibility in a few areas of constructing much longer chronologies using subfossil timber which is well preserved in the Arctic. In a number of areas, resampling is needed both to increase replication and to update early collections to the present day. As the instrumental climate record is so short for most of the Arctic, the tree-ring records will need to be extended to the present day to make the best use of it for calibration. Unfortunately, the labour involved in updating a chronology is little short of that involved in collecting and processing a new chronology.

The number of potential species for dendroclimatology in the Arctic is small and most success has so far been with spruce (Picea sp.), but several other conifers and birch (Betula sp.) will also be of value. As in other areas, the use of more than one species in the climate reconstruction grid may enhance the climate information. So far Arctic reconstructions have concentrated on temperature as the most obvious limiting factor to tree growth, but the potential exists for demonstrating good linkages with other climate variables such as pressure, precipitation and sea ice. Limited investigations in demonstrating and calibrating such linkages are already in progress.

Problems

The problems of autocorrelation seem more severe in Arctic trees than in arid and mesic forest trees and it is suggested that densitometric measurement may be particularly valuable in this region. There is a general need for greater understanding of Arctic tree biology; there has been less work on growth influences on Arctic trees than in temperate latitudes. Because of the short growing season, monthly meteorological variables may not be the most appropriate. It is suggested therefore that Arctic dendroclimatologists should examine different timeframes in studying the climate growth relationships. The short length of most climatic records in high latitudes is a major problem. As in the case of lower latitudes, greater cooperation with the U.S.S.R., which includes a large area of the Arctic, will be necessary.

Sampling problems in the Arctic are mostly more severe than in other areas of the globe. The physically large area, together with the low population, means that access is difficult and expensive, often involving extensive use of aeroplanes, helicopters and boats. This high cost of sampling would suggest that cooperation between different research agencies would make best use of the available resources.

Working Group 11: The Tropics

The problems of dating tropical trees have frustrated attempts at tropical dendroclimatology. Intensified wood anatomical analysis as well as new methods including X-ray densitometry and isotopic analysis should be coupled with renewed efforts in dendrochronological studies to try to move the science into the tropics. It is a large region with a great agrarian population strongly influenced by climate. There have been a few successful efforts in tropical dendrochronology and some tropical foresters feel they can discern annual growth increments in tropical trees. There is a tremendous species diversity and, by communication with tropical foresters and other biological researchers in this region, dendroclimatologists may find promising species or locations to study. It is premature to estimate a level of desired coverage until the viability of tropical dendroclimatology is established. From a climatological point of view, data from tropical latitudes are vital for global palaeoclimatic reconstruction. Both the strength and extent of the Monsoons, the Inter-Tropical Convergence Zone and Southern Oscillation are very important in the global context.

In initiating pilot studies in tropical dendroclimatology, a good strategy might be to concentrate initially on tropical and subtropical taxa that have proven useful in temperate latitudes; for example, *Alnus* , *Juglans* , and *Podocarpus* in Argentina, Bolivia and Peru; *Araucaria* in Brazil and northern Australia; *Podocarpus* in Australia; *Phyllocladus* in New Caledonia; *Pinus* in Central America; and so forth. For further information, see ' *Proceedings on the Workshop on Age and Growth Data Determination for Tropical Trees*', (New Research Directions, Harvard University, April 1980, in press).

Towards global dendroclimatology

Several general points emerged from the working groups. Even in the most intensively worked areas there are still gaps and deficiencies in the tree-ring records that need to be filled. A greater diversity of species and of sites would be of value in all areas. The natural climatic regions of the globe cut across political and cultural regions, demanding a greater degree of international cooperation than is usual in most branches of science. The International Tree-Ring Data Bank should form a starting point and nucleus for a positive approach to cooperation. In Europe especially, the political units are too small for climatic reconstructions on a national scale. The newly-initiated climate programme of the European Economic Community provides an obvious framework for dendroclimatic cooperation throughout a large part of Europe.

It is clear that in most areas the major obstacle to progress lies in the shortage of workers and finance, which in many cases has made it difficult to reach the goal of producing well-verified reconstructions, rather than in material to work on. In all areas where crossdatable trees have been found, a distinct climate signal can be demonstrated. In most areas, a close grid suitable for at least regional temperature and pressure reconstructions is clearly possible. Progress in the tropics is hampered at present by the lack of suitable techniques for treating the materials that are available. Further research is urgently needed in this area. In the higher latitudes of the Southern Hemisphere, the relatively small land area means that the potential dendroclimatological cover is less than in the Northern Hemisphere. It is likely that dendroclimatology in the Southern Hemisphere will be directed more towards the reconstruction of key climatic indices rather than towards the reconstruction of dense grids of climate variables. The latter may however be feasible in the Northern Hemisphere. With close cooperation between scientists of all nations, it should be possible to produce climate reconstructions for the whole Northern Hemisphere for about the last 200 years.

7

RECOMMENDATIONS

The narrative account of the working group discussions in Section 6 contains many indicative statements of relevance at both the scientific, organisational and funding levels. In this Section, the specific recommendations of the workshop most likely to be of interest to bodies charged with the organisation and funding of palaeoclimatic research are collated. The recommendations are intended to give an indication of the priorities in dendroclimatic research as perceived by its practitioners. Where a recommendation has particularly large or urgent new financial or organisational implications, this has been indicated by an asterisk. This does not, however, indicate a higher scientific priority than for unmarked recommendations.

In plenary session, the Workshop participants accepted responsibility for implementing these recommendations as far as was within their power. They agreed that a further workshop to review progress and plan further cooperation be held approximately five years after the Second Workshop, that is, around 1985.

Chronology and network building and data preparation

* 1. Wider use should be made of the techniques of X-ray densitometry. Material both from regions already collected and from new areas should be analysed in this way.

* 2. Newer techniques of tree-ring measurement, such as snalysis of wood structure and isotopic analysis, should be developed further.

3. There should be increased use of modern, computer-based, data acquisition systems. Preferably, such systems will be user-dedicated, interactive and have good editing facilities.

4. Background studies in fields such as wood microanatomy, phenology and physiological ecology should be carried out in order to improve understanding of the underlying mechanisms producing the proxy climate record. These will provide tests for empirically derived climate-growth relationships.

5. The current curve-fitting techniques used in standardisation do not always differentiate between synchronous and non-synchronous low frequency variance. It is recommended that numerical techniques be developed that use all the information from a site collection when standardising each series.

6. It is recommended that all site chronologies be presented in the format used by LAMARCHE et al. (Chronology Series V, Laboratory of Tree-Ring Research, University of Arizona). This includes site details (an extensive abstract of the collectors full site notes), the chronology in indexed form, details of the method of standardisation used and full chronology statistics. This record of the details should be referenced whenever the data are published.

7. The raw data and indexed chronology should be archived in the International Tree-Ring Data Bank whenever they meet the acceptance criteria.

Response and transfer function analyses

8. It is recommended that the FRITTS response function (FRITTS et al., J. Appl. Meteorol., 10, 845-864, 1971) be used as a benchmark against which new methods may be tested.

9. The statistical significances of response functions should be investigated fully using simulation techniques or other appropriate tests.

10. It is important that site reproducibility and temporal stability of response functions be investigated for each major species/site combination.

11. It is recommended that groups of response functions covering a wide ecological and geographical range for each species be used to evaluate the nature of climatic signals in chronologies, to define seasonality, and design transfer function models. Single response functions should not be used for this purpose.

* 12. The calculation of both response and transfer functions and their verification depends on the availability of sufficient and suitable meteorological data. A continuing effort to critically review, digitise and make available climatic data is essential.

13. The assumption that modes of climatic and of tree-ring fluctuation have not varied between the period of calibration and the period of extrapolation should be tested in those parts of the world where this has not been done.

14. Care should be taken to ensure stability in response and transfer functions by using an adequate number of observations in relation to the number of variables.

15. The effects of dendroclimatic techniques on the frequency characteristics of derived reconstructions should be investigated.

Verification

16. Verification of dendroclimatic reconstructions against independent data is absolutely essential. Particular care should be taken to ensure that such data will be available in dendroclimatic projects; if necessary, by holding back instrumental data from the calibration.

17. Where qualitative data are used in verification, they should conform to criteria of historical reliability.

18. The possibility of standardising the statistical techniques used in calibration and verification should be investigated.

Applications

* 19. The details of the particular climatological problem to be studied with the proxy climate data set should be considered at all stages of the reconstruction process.

* 20. The reconstruction of a wider range of climatic parameters should be attempted and the combination of tree ring data and reconstructions with other proxy climate information should be investigated.

* 21. Existing climatological data banks and relevant international organisations should consider the inclusion of data from dendroclimatic reconstructions. Acceptance criteria would need to be formulated. Any climate data collected and homogenised in the course of a dendroclimatic project should be entered into the appropriate data bank.

Long and composite chronologies

* 22. High priority should be given to the collection and preservation of subfossil and archaeological timber that is being destroyed or discarded, and to the archiving and cataloguing of dated timbers.

23. When primary measurements are stored in the International Tree-Ring Data Bank the location of the wood samples should be recorded there.

24. Better understanding of detailed observations on modern trees should be used to provide an objective basis for the interpretation of composite chronologies and the relationships between measurements such as ring width, density, wood anatomy and isotopic ratios and modern climate should be investigated.

25. New long chronologies should be established as indicated by Working Group 4.

26. Once sufficient new long chronologies are available, hemispheric climate reconstructions for the last 1,000 to 2,000 years should be attempted.

The global data base

27. Even in well-collected regions, it is important that time and space coverage and replication be improved; that tree-ring measurements other than ring width, particularly density, be used; and that the range of reconstructed climatic parameters be increased by more diverse site and species sampling.

* 28. A number of important, temperate regions have not been investigated intensively and should be accorded high priority. This applies in particular to most of the Eurasian landmass.

29. It is extremely important that all chronologies be based on properly replicated, crossdated material and that the data be recorded in a standard form. These data should be archived and made available through the International Tree-Ring Data Bank.

* 30. It is vital that resources be made available to support the continuation and development of the International

Tree-Ring Data Bank.

* 31. Every effort should be made to involve scientists in the U.S.S.R. in the international exchange of data made possible by the existence of the International Tree-Ring Data Bank. Further than this, efforts should be made to involve these scientists in collaborative work in the Arctic, Europe and Asia.

32. As dendroclimatic investigations spread to new regions, the work should be done by local groups wherever possible with support from established workers especially in specialised techniques such as densitometry.

Southern Hemisphere

33. Priority should be given to: increased density and response diversity in areas already covered; extension into cool temperate and warm temperate areas not yet covered; and development of appropriate techniques and then chronology networks in the Southern Hemisphere tropics and subtropics.

34. Extension into southern South America and into the tropics would be helped by the development of techniques of dating and analysis more appropriate to angiosperms.

35. The possibility of using non-coniferous species and exotic plantings should not be ignored especially when dendrochronologically proven (mostly coniferous) native species are unavailable.

36. Conventional sample preparation and ring-width analysis techniques may need modification for some Southern Hemisphere species, particularly those from subtropical areas.

37. Climatic information in some species in tropical areas may be present in intra-annual characteristics of material with little intra-annual ring-width variability. Techniques to identify and measure these characteristics may be more

appropriate than or supplementary to conventional ring-width measurements.

The Arctic

* 38. In order to produce a more consistent network, further sampling at minimum intervals of 30 degrees longitude should be carried out. These intervals should be smaller in the climatically important regions of the west coasts of North America and Scandinavia, the Hudson Bay region and central Siberia.

* 39. Since many existing chronologies were sampled 30 to 40 years ago, extensive resampling to update chronologies should be carried out.

40. Extensive use of densitometric analysis is likely to prove productive.

41. Workers in the Arctic should examine different climatic parameters and timeframes (monthly meteorological records may not be appropriate in the short Arctic summer).

North America

42. Palaeoclimatic reconstructions for all parts of North America are important and should be pursued on an equal basis in all areas.

43. Future collections should include a greater diversity of species and habitats than in the past.

* 44. Analyses of wood density should be given equal status with the analyses of ring widths and, whenever possible, samples should be collected and treated to allow both ring-width and density measurements.

45. The aim of future collections should be to establish networks of chronologies suitable for reconstructing spatial

patterns of climate over the differing time periods referred to by Working Group 7.

* 46. Attention should be given to the collection, analysis and presentation of historical data, both instrumental and documentary, in a form suitable for the verification of dendroclimatic reconstructions.

Europe

* 47. Priority should be given to completing a properly replicated grid of ring-width and density chronologies back to 1750 AD. Areas requiring particular attention are the Iberian Peninsula, parts of France, parts of Scandinavia, Poland, Eastern Europe and the Balkan Peninsula.

48. The completion of this grid would allow all-Europe reconstructions back to 1750 AD. This should be used as a test of dendroclimatology, since there are more long instrumental and detailed documentary records available for use in verification in this region than in any other.

49. A sparser grid of composite chronologies back to 1350 AD or further should be developed both from newly collected material and from reworked existing data.

* 50. In order to build these networks adequate resources should be made available. In particular the shortage of densitometric laboratory capacity should be rectified and mechanisms for effective all-Europe collaboration established.

The Mediterranean Basin

51. A systematic approach to sampling in the north and west of this region is recommended with the aim of exploring its considerable possibilities.

52. In the south and east of the region the search for suitable material should be continued at a basic level.

* 53. In the light of the complex political and geographical nature of the region and of its climatological interest and importance, support is recommended for the recently-founded Multidisciplinary International Working Group on the Mediterranean (contact: Dr. A-V. Munaut). This will provide a forum for the detailed planning of collaborative dendroclimatic research in the Mediterranean region.

Asia

54. Given the enormous size of this region, it is recommended that, in the first place, attention should be focussed on a region comprising the Himalayas and the areas to their immediate north (Tibet, Tien-shen).

* 55. It is recommended that resources be directed to the work based in China in order to realise the potential that exists there.

* 56. It is proposed that an international working group be set up to coordinate dendroclimatological work in Asia.

The Tropics

* 57. Initiation and support of pilot studies in tropical dendroclimatology are recommended.

8

THE INTERNATIONAL TREE-RING DATA BANK

Two previous managers of the International Tree-Ring Data Bank (ITRDB), L.G. DREW and J.A. SHERWOOD, reported to the Workshop on the origins and current status of the data bank.

Introduction

The International Tree-Ring Data Bank is a professional organisation which was formed to encourage international cooperation among the various branches of dendrochronology. The primary purpose of the ITRDB is to serve as a central storehouse of tree-ring data from around the world so that (1) data are protected from loss when laboratories move or dissolve or when scientists move to other projects or retire, and (2) research data are more easily available to others working in dendrochronology.

The ITRDB is now recognised around the world and is referenced in two data directories: ENDEX, the Environmental Data Index sponsored by the Environmental Data Service of the U.S.A., and the Encyclopedia of Information Systems and Services.

History

The ITRDB was established in April 1974 as a result of discussions among the 27 scientists attending the International Workshop on Dendroclimatology held in Tucson, Arizona, U.S.A. The first Newsletter was published, and contributions were actively sought in July 1975.

An early objective of the Data Bank was the establishment of standard site information forms to record necessary information about entries in the ITRDB. These forms are now available in four languages (English, French, Russian, and German.)

A second objective was to develop computer programs to facilitate the storage and retrieval of all entries. Flexible search routines now allow retrieval of information about individual entries.

A third objective was to enhance communication among dendrochronologists. The ITRDB Newsletter which is available at no charge to all interested scientists, serves as a communication medium among researchers in 20 countries.

Objective

The ITRDB is an independent organisation presently housed at the Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona, U.S.A. It has until now been administered by a committee consisting of the Chairman, H.C. Fritts (U.S.A.), and B. Becker (Federal Republic of Germany), Z. Bednarz (Poland),

J. Pilcher (U.K.), and C. Stockton (U.S.A.). A manager handles the daily business and computer files of the ITRDB, and an editor is responsible for the ITRDB Newsletter and other communications among members.

The membership of the ITRDB consists of those individuals and organisations which have submitted dendrochronological materials to the ITRDB. Acceptable materials must meet the following requirements:

A. Original ring-width or other measurements (not averaged in any fashion) must be included with each contribution.
B. All materials must be crossdated.
C. A completed Site Information Sheet, including the signature of the contributor, must accompany each site.
D. The measurements must be assigned to a specific calendar year (i.e., absolutely dated, not floating chronologies).
E. It is also hoped that materials will:
   (1) represent a single geographical location
   (2) represent a single species
   (3) represent at least three trees
   (4) contain measurements of at least two radii per tree.
   (5) cover a period of at least 100 years.
F. It is strongly recommended that the average or final chronology (indices or other measurements) of each site be included with the original contribution.
G. Members are also encouraged to submit any supplementary information such as maps, photographs, statistical analyses, and so on.

The present holdings have focussed largely on materials useful to climatological interpretations, but other materials are also acceptable.

Present status

The ITRDB now contains 405 entries from 21 countries representing 37 individual and 2 institutional contributors. In addition, approximately 80% of the ITRDB entries are supported by final chronologies. These final chronologies are especially valuable because they are readily usable by other researchers in the solution of specific problems.

The future

A great deal has been accomplished in the six years since the ITRDB was established, but a great deal still remains to be done. A critical issue is that of funding for the ITRDB. Funds for the establishment and organisation work were supplied by the National Science Foundation through the efforts of H.C. Fritts. Alternate sources of funding must be found to continue the ITRDB at its present level as an information gathering agency. If more retrieval capabilities are desired (as was originally intended) additional sources of funding must be found. A fee schedule and subscription rates or dues will help to meet these costs but will not be adequate in themselves. Computer funds are needed to enter each contribution onto files.

A second and perhaps more subtle problem is that of participation by scientists. Initial response has been good, but continued contributions and active involvement are essential for the ultimate success of the ITRDB. The ITRDB is a valuable tool for safeguarding scientific endeavour on an international scale. However, it will serve that function and remain viable only if it is used.

The Chairman of the ITRDB, H.C. Fritts, reported to the Workshop on the present problems of the data bank and suggested lines for its development. Previous funding for the establishment of the data bank has now ended and the ITRDB is temporarily closed. The Laboratory of Tree-Ring Research at the University of Arizona continues to give full support to the ITRDB but is not in a position to accept the full financial burden. It has agreed to maintain the data bank in its present condition until further funding for the proper operation of the ITRDB is available.

H.C. Fritts proposed a new structure for the data bank administration consisting of an Advisory Committee with a Chairman, a Director and a Manager. The role of the Advisory Committee would be to seek financial and scientific support and to advise the Director. The Director would oversee the operation of the data bank, hire personnel, and so on, and the Manager would be in charge of the daily working of the data bank.

Participants at the Workshop strongly endorsed the activities of the International Tree-Ring Data Bank and approved the new structure. H.C. Fritts takes on the role of Director, with J. Pilcher as Chairman of the Advisory Committee. As is clear in the recommendations of the Workshop, there is strong support in the scientific community for the data bank and efforts are now being made by the Advisory Committee to put it on a sound financial footing. The Advisory Committee is also to consider various aspects of security, access and entry requirements for materials, which were discussed at the Workshop.

An asterisk indicates that the contributor did not attend the Workshop

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