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LONG TREE-RING CHRONOLOGIES FOR THE EASTERN MEDITERRANEAN

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The goal of the Aegean Dendrochronology Project is a continuous time-line from the present to at least 7500 BC. Twenty consecutive years of field-work in Anatolia and neighboring lands have allowed us to fill in about two-thirds of the calendar between the present and 7200 BC, or about 6000 years. New dimensions have been the development of almost 700 years of Neolithic chronologies and a 577 year chronology for the EBA which ought to fit on the early end of the 1761 year MBA/LBA/IA master chronology extending from about 2259 to about 498 BC. The latter chronology is pinned in place, or wiggle matched, by 18 radiocarbon dates of specifically selected ring-groups so that the error margin is ±37 years. Our second longest chronology, 1068 years long and absolutely dated from AD 927-1994, incorporates wood from over 1357 medieval monuments.

KEYWORDS: AEGEAN, ANATOLIA, NEAR EAST, DENDROCHRONOLOGY, TREE RINGS, TIMBER, TRADE, CLIMATE

INTRODUCTION – TIME-SPAN

The quickest way for the reader to arrive at an estimate of the progress of the Aegean Dendrochronology Project since its inception in 1973 is to look at Figures 1 and 2 in succession. Figure 1 (bar graph) shows a schematic rendering of tree-ring chronologies from the present to the 8th millennium BC, a total of over 6000 years, or about two-thirds of the 9000 years between now and then. The graphs are divided according to species: oak, boxwood, cedar, pine, and juniper. Additional chronologies not shown include a 307 year chronology for yew and shorter sequences for chestnut, cypress, and beech.

GEOGRAPHY AND BREAK-DOWN BY PERIODS

Figure 2 (map) shows the spatial distribution as far east as the eastern border of Turkey, south to Lebanon and Cyprus, including all of Turkey and Greece, north to include at least Bulgaria and what used to be known as Yugoslavia, and west to the instep of the Italian boot. Crossdating farther afield may be possible some day for Romania, Ukraine, Georgia, Armenia, and Iran. The crossdating zone (or set of overlapping zones) shown on the map is about 2400km east-west and 900 to 1000km north-south. Since over 500 sites have been sampled and over 300 crossdated, a detailed listing is inappropriate for this paper. Breakdowns are tabulated by country. The term "Medieval" is a liberal term for everything from AD 500 to the 20th century, and "Ancient" includes everything from Neolithic to Late Antique (=end of the Romans/beginning of the Byzantines or about AD 500). The list of dated sites as of 1987 is given in Kuniholm and Striker (1987). Sites dated since 1987 are listed with their dendrochronological dates in an alphabetical table at the end of this paper (Fig. 5).

REGIONALISM

Clearly the most important development since the 1986 Archaeometry Symposium in Athens has been our recognition of a regional climatic stimulus (or set of stimuli) so that inter-species crossdating is possible. Figure 3 is a tabulation of crossdating among various species of trees, all with a minimum overlap of 600+ years. There seems to be some kind of forcing mechanism in the greater Aegean region which is making these trees respond in a relatively uniform manner. Naturally, there are enough regional variations so that, for the medieval period where we have the most widely-dispersed and replicated sets of samples, we are often able to identify the source of timber, at least to the general region.

TIMBER TRADE IN ANTIQUITY

Thus, a number of buildings in Thessaloniki, Greece, both secular and religious, are made with oak timbers imported from the Black Sea coast of Turkey some hundreds of kilometers to the East. Similarly, a Renaissance palace in Dubrovnik, Croatia, has fir planking which must have been imported from the Alps, most probably via Venetian merchants (Kuniholm and Srša in preparation). Even more specifically, oak beams in the Green Mosque of Sultan Yıldırım I in Bursa, cut in or very shortly after 1413, and oak beams from the Yıldırım Darüşşifası, a hospital endowed by the same Sultan in 1400, can be shown to have come most probably from the same forest, if not the very same stand of trees. The time may come, if enough data can be amassed, when we will be able to make the same kind of estimates for timber cut in remote antiquity.

CLIMATIC IMPLICATIONS

A study of the climatic implications of the above with M.K. Hughes, G. Garfin, and colleagues at the University of Arizona, Tucson, and the Center for Atmospheric Research, Boulder, in which data from 23 selected Aegean forests are being compared to a gridded set of Mediterranean meteorological data, is in an advanced state of preparation. Figure 4 is the result of a search for "pointer" years or "signature" years over the last century. We defined the term as a year in which mean ring-growth either increased or decreased in at least 75% of our forests. In 26 years out of the last 100 we found such pointer years. If the extreme east and west fringes of our zone of Erzurum in eastern Turkey and Italy in the west were to be left out of the calculation, even more years could be classified as "pointer" years. Indeed, in some years uniform increase or decrease would approach 100%. When the statistical analyses are complete, we should be able to make some informed comment on climate change in the period before 1880, in other words for the centuries preceding modern meteorological observations. For a preliminary discussion of some of the more simple-minded aspects of this see Kuniholm (1990).

ABSOLUTE CHRONOLOGIES–THE SECOND MILLENNIUM AD

Dating for the last thousand years is now a relatively straightforward process, simply because of the quantities of material available. Over 137 buildings or sites have been dated dendrochronologically as of May 1994. In some cases confirming evidence is available from inscriptions or other non-dendrochronological sources. Almost without exception in the Aegean and the Balkans wood was cut and used at once without delay. Wood cut in the winter when the leaves are off the trees will be found incorporated in a building with an inscription dated to the following year. For buildings without such confirming inscriptions our presumption has been that the same practice of wood use was observed (Kuniholm and Striker 1987).

RELATIVE CHRONOLOGIES–THE FIRST MILLENNIUM AD

This is the most difficult 1000 years of the past 8000, simply because of the shortage of available material. Most Roman construction is of stone, and timbers have either rotted or have been robbed out. The most noteworthy ring-sequences are 272 years of oak from the Kütahya Fortress (date unknown but estimated to be in the second half of the millennium) and 226 years of cedar from a burned tower at Amorium (thought by the excavator to be somewhere between the late 5th century on numismatic evidence and 838 when it was burned by the Arabs). Amorium is still being excavated, and we have reason to hope that more burned first millennium wood will be forthcoming in the near future. Even though many of the buildings we have sampled from this millennium are well known to art-historians and archaeologists, if not famous to the public at large, the tree-ring data sets are short: Istanbul/Hg. Sophia Primary-127 years, Istanbul/Hg. Sophia Secondary-154 years, Istanbul/Hg. Eirene-152 years, Zadar/Sv. Donat-161 years, Hosios Loukas Katholikon-100 years, Hosios Loukas Theotokos-241 years, Prespa/Hg. Achilleos-135 years, Thessaloniki/Hg. Sophia 117 years, and so forth. We may have overlaps between some of these chronologies, but the overlaps are not long enough to guarantee crossdating.

MODERN SISAK - ROMAN SISCIA - CELTIC SEGESTICA - HALLSTATT ? (NAME UNKNOWN)

Sisak is a category unto itself because it spans the first two centuries AD, the last two centuries BC, and now, perhaps the middle of the first millennium BC as well, with the arrival in Ithaca (New York, U.S.A.) this month of some 100 oak sections from Pogorelec (=Burned City), a settlement on the right bank of the River Kupa 200-300m upstream and around the bend from the Roman site where we collected over 300 pilings in earlier years. The wood was rescued for us by Professor Aleksandar Durman, University of Zagreb, under live grenade and rifle fire. Associated objects for the new Sisak pilings are from the late Hallstatt period, which is to say the 6th century BC Sisak may turn out to be the key link between the AD/BC periods. The ring-sequence at Sisak is already 434 years long.

FIRST MILLENNIUM BC – THE COMACCHIO SHIPWRECK

For years the first few centuries BC were almost as dismal a prospect as the first few centuries AD, but in 1989 thanks to the intervention of Dr. Fede Berti of the Ferrara Museum we were able to collect 23 samples of a cargo of boxwood, 17 of which crossdate splendidly, from a ship found in a canal near Comacchio south of Venice and east of Ferrara. The wood, all cut in the same year and with the bark preserved, forms a chronology 513 years long. On board the ship were two and a half tons of lead ingots stamped with the name AGRIPPA. If this is the famous Agrippa who died in 12 BC, the Comacchio ship probably sank within a decade or two or three before 12 BC. The Comacchio wood looks promising when compared to Sisak and six other Roman chronologies, and we have a tentative combined chronology for this period that is now 712 years long. We do not have any idea, for the moment, where the ship was coming from when it sank or where the wood may have been cut (Kuniholm *et al.* in press).

THE LONG BRONZE AGE/IRON AGE CHRONOLOGY – 498±37 BC TO 2259±37 BC

This 1761 year ring-sequence spanning the end of the Early Bronze Age, all of the Middle and Late Bronze Age, the Early Iron Age, and ending in Classical times was reported on in Athens but only in bits and snippets. Now the chronology is linked together and has been wiggle-matched and pinned down by 17 radiocarbon determinations of ten-year segments by Dr. Bernd Kromer at Heidelberg. The margin of error is ±37 years, and we hope to have this narrowed down further before long. Some 22 sites, many with multiple constituent parts, are included (Kuniholm and Newton 1990; Kuniholm 1993; Kuniholm, Tarter, Newton and Griggs 1993).

In addition to the information inherent in the realization of a more-or-less firm date BC for a given site, there is also an independent cross-check on other methods of dating such as vase-painting styles and king-lists. Here in reverse chronological order and in tabular format is a list of some of the more noteworthy sites:

SITE	DATE BC	EXTERIOR	OTHER DATING EVIDENCE
Pergamon, Elaia Tumulus	498±37 BC	No bark	Vase-painting styles
Zadar, Relja	524±37 BC	Bark	Liburnian & Greek pottery
Afyon, Dinar, Tatarlı Tumulus	531±37 BC	Bark	Painting styles
Samos, Heraion	634±37 BC	No bark	Sculptural styles
Gordion, Midas Mound Tumulus	757±37 BC	Bark	Assyrian King Lists
Tille Höyük	1140±37 BC	No bark	LBA/Iron Age Transition
Maşat Höyük	1392±37 BC	No bark	Imported Mycenaean Pottery
Porsuk Höyük	1590±37 BC	No bark	Hittite Architecture
Acemhöyük, Sarıkaya Palace	1791±37 BC	Bark	MBA Architecture and small finds,
Acemhöyük, Hatipler Tepesi	1791±37 BC	Bark	also Old Assyrian King List
Kültepe, Waršama Sarayı	1849±37 BC	Bark	Old Assyrian King List

POSSIBLE MODIFICATION TO THE ABOVE

We have known for some time that if we were to shift all of these dates 37 years down, that is to say, to the extreme recent end of the ±37 years allowed us by the wiggle-matching, we might have an explanation for several curiosities that have intrigued us for some years. The first is that the cutting date for the timbers of the Midas Tumulus at Gordion would then be 720 BC, a date very close to that originally estimated by its excavator, Rodney S. Young (1981). The second is that an enormous spike where ring-growth in 38 separate trees surges to 200% of normal would be dated to the year 1628 BC. Since the site of Porsuk/Ulukışla where these trees were found is directly east and downwind of Santorini/Thera, and since a volcanic explosion of that magnitude might be expected to produce cool, wet summers, the extraordinary growth surge would thereby be explained (Kuniholm 1991). The third is that a period of almost equally abnormal growth (alternately enormous and tiny rings) at Gordion would then be placed in the middle of the 12th century BC, lending partial supporting credence to the argument first advanced by Rhys Carpenter 26 years ago that climatic phenomena had something to do with the end of the civilizations of the Eastern Mediterranean Bronze Age (Carpenter 1968; Bryson, Lamb and Donley 1974; Baillie 1989).

ACEMHÖYÜK EARLY BRONZE AGE MASTER CHRONOLOGY (EB III)

A 503 year tree-ring chronology from service buildings (kitchens) in Acemhöyük's Northwest Trench–a Middle Bronze Age context (MBA pottery, MBA seals) similar to that of the adjacent buildings of Sarıkaya and Hatipler Tepesi, both dated to 1791±37 BC–but which did not fit anything else on the enormous mound of Acemhöyük, has now been placed by means of Dr. Kromer's wiggle-matching to approximately 2671-2169 BC ± not very much. Further determinations are in progress in Heidelberg, and we should have precise dates by July 1994. Some of the wood was clearly charred by fire and yet was found as stretchers inside unburned mud-brick walls. We guessed that the wood had been re-used even before the radiocarbon determinations came in, but this was an unexpected windfall in that it filled in most of a 500 year gap. The overlap with the 1761 year Bronze Age/Iron Age chronology is not long enough to allow us to claim on dendrochronological grounds alone that we have a continuous sequence, but the summer of 1994 may bring us what we need for a link. The 24 dated pieces from the Northwest Trench could easily have come from an EB III building which was replaced, but with valuable building materials prudently saved for the next construction activity on the mound.

TROY I–EARLY BRONZE AGE I

Clearing and cleaning in the great trench first excavated by Heinrich Schliemann at Troy has yielded a 226 year pine chronology which has been wiggle-matched to end at 2699±15 BC or about 28 years earlier than the Acemhöyük EBA chronology (Korfmann and Kromer 1993). It fits admirably around the big V-shaped radiocarbon anomaly in the middle of the 29th century BC. Another chronology of oak–285 years long–from Kiten, Bulgaria, also fits this V-anomaly. The oak from Kiten and the pine from Troy do not fit each other in any recognizable fashion and have therefore been left as separate entities. A 139 year oak sequence from Demircihüyük (Kuniholm 1987) should fit somewhere near or in this period.

THE CHALCOLITHIC

These millennia are almost as devoid of good dendrochronological news as the first millennium AD, but we do have a 212 year chronology from Can Hasan, a 159 year chronology from Hacilar (also shorter ones), and a 134 year chronology from Köşk Höyük, all juniper. We have a 224 year chronology of oak from neolithic Sozopol in Bulgaria. More material from this period is expected in future summers from the salvage excavation of Seyitömer Höyük north of Kütahya where excavation is proceeding at a rapid pace.

THE NEOLITHIC

Maryanne Newton has finished measuring, as part of her M.A. thesis work, some 40kg of charcoal left over from the MASCA radiocarbon laboratory's testing of Çatal Hüyük neolithic wood 30 years ago. She has over 600 years of sequences, 569 in one continuous chronology. One of her first observations was that a so-called

"problem" piece that has been plaguing the literature since it was first published (Mellaart, 1967) was apparently about 400 years too old because the determination was made on inner rings from a 25cm diameter juniper post which had at least 630 annual rings on it. Miss Newton reconstructed the full radius of the post from over 42 fragments. The rings are so tiny that normal visual inspection does not reveal which fragment is from the interior and which from the exterior. The "anomaly" is thus no longer an anomaly but rather an example of inadvertently unfortunate selection on the part of the physicists. New excavations at Çatal Hüyük and at Aşıklı Höyük should add more information to this most interesting period.

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NOTE: annual reports by the author appear in the *Proceedings of the Symposium on Excavation, Research and Archaeometry* sponsored by the General Directorate of Monuments and Museums, Ministry of Culture, every May (Ankara: Türk Tarih Kurumu Basımevi).

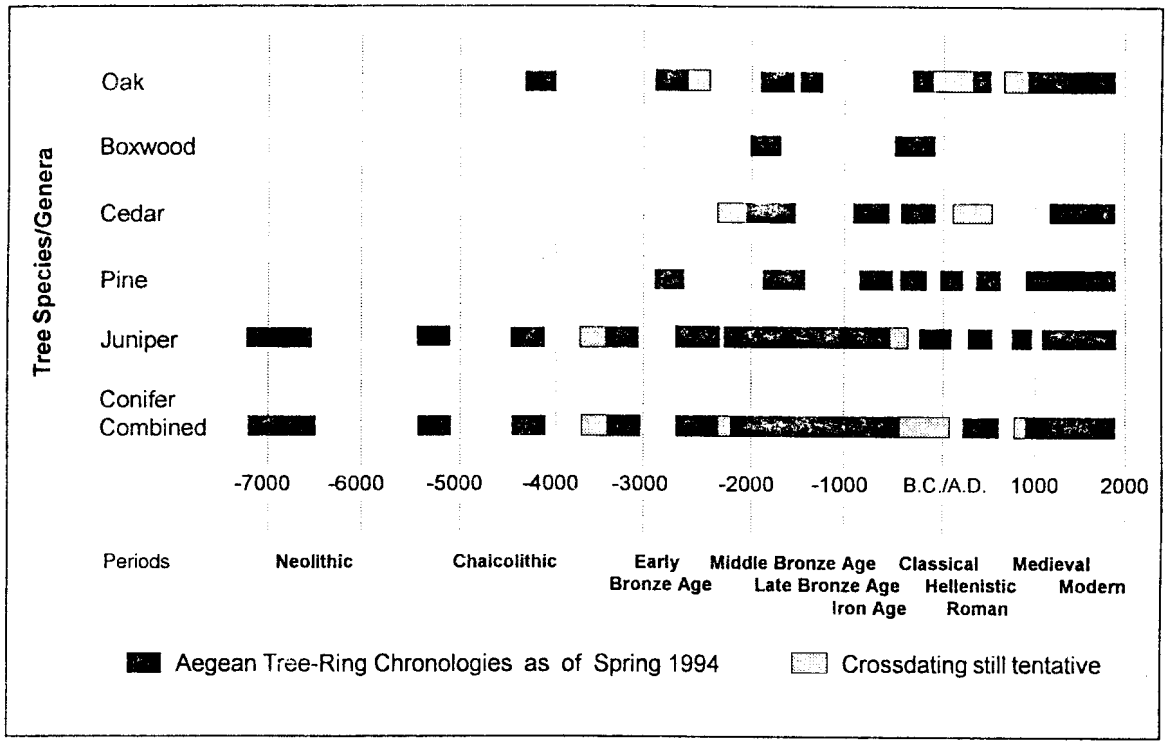

Fig. 1. *Schematic rendering of Aegean tree-ring chronologies as of Spring, 1994.*

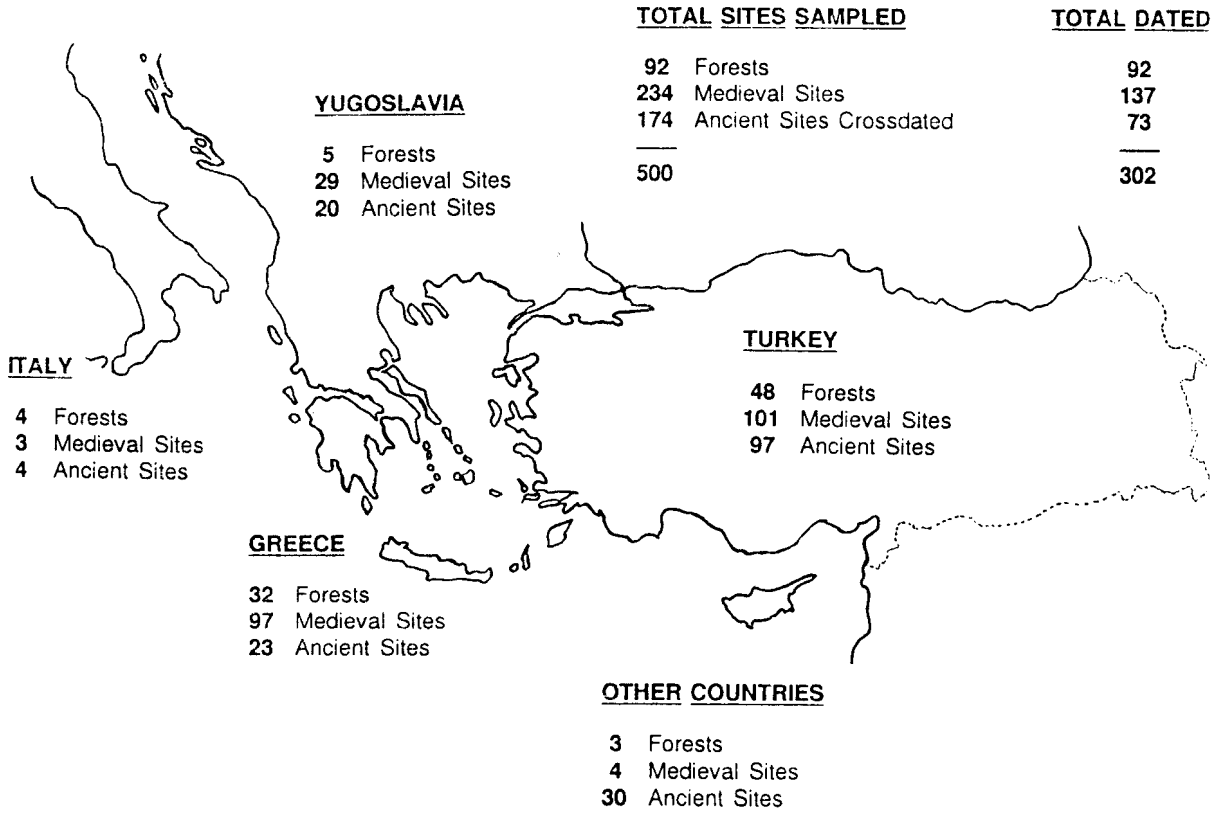

Fig. 2. *Spatial distribution of sampled and dated sites.*

Quality of Crossdating Among Aegean Trees

Species	t-score (Parametric)	Years of overlap (n=)	Trend Coefficient (Non-parametric)	D-score [t-score • (trend % -50%)]
Oak vs. Pine	11.62	841	64.4%	167.3
Pine vs. Juniper	10.31	841	59.9%	101.9
Oak vs. Juniper	9.87	886	59.2%	90.9
Juniper vs. Cedar	7.42	619	67.6%	130.8
Oak vs. Cedar	5.92	619	57.6%	45.0
Pine vs. Cedar	4.59	619	58.6%	39.4

Fig. 3. *Tabulation of crossdating quality among various species of trees.*

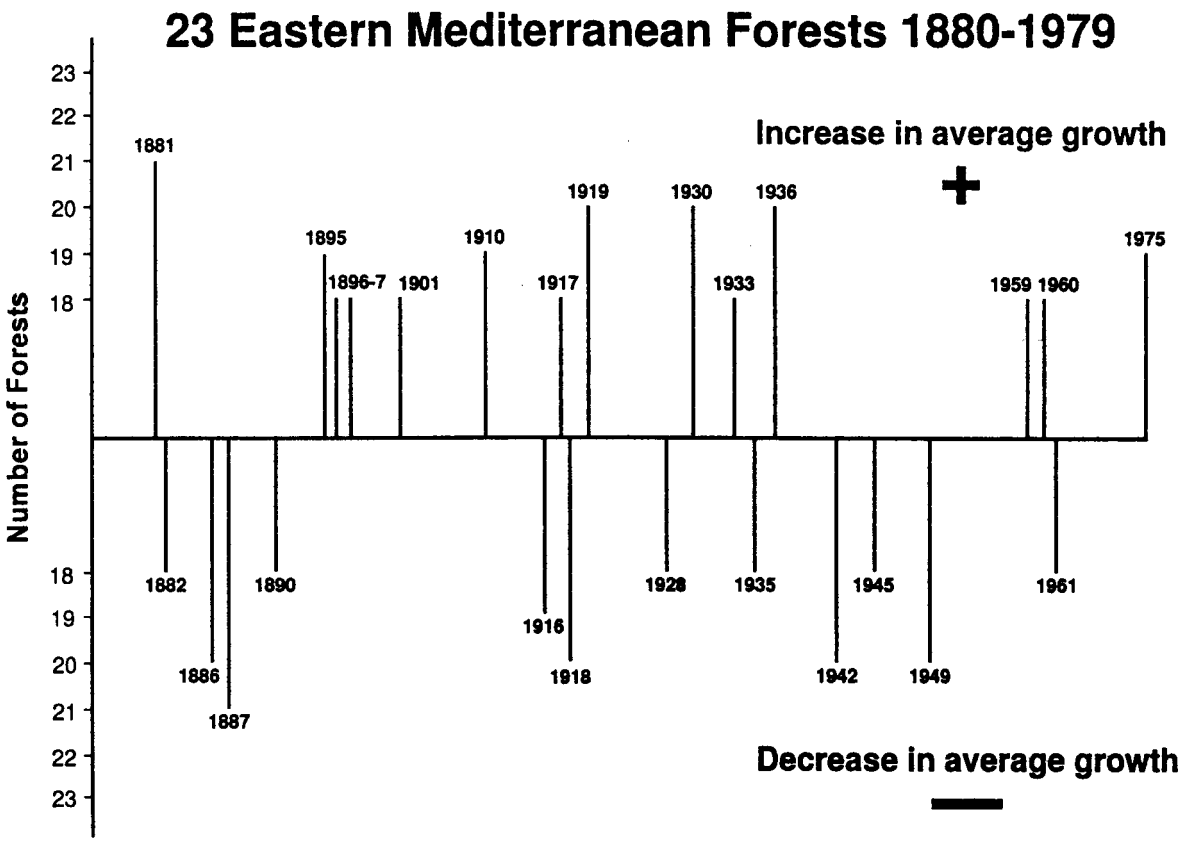

Fig. 4. *"Pointer" years over the last century attesting to a common climatic signal.*

COUNTRY - SITE NAME	DATE	EXTERIOR
BG- Bourgas, Kiten, EBA Settlement	approx. 2711BC	Bark
GR- Dodona, Kostaniane, Taxiarchs *	1334	vv
GR- Ioannina, Arslan Pasha Mosque *	1543	vv
GR- Ioannina, Nikolaos Dilios Monastery *	1690	vv
GR- Kastoria, Omorphoklissias, Hg. Georgios *	1296	vv
GR- Makri, Hg. Anastasia *	1831	Bark
GR- Meteora, Rossanou Monastery *	1555	vv
GR- Meteora, Barlaam Monastery *	1548	v
GR- Pherrai, Kosmosoteira (Turkish modifications) *	1493	vv
GR- Rendina Monastery (Karditsa) *	1568	vv
GR- Samian Heraion, Votive Objects (Archaic)	634BC±37	v
GR- Serres, Orestes Tower *	1167	vv
I - Comacchio (Ferrara) Shipwreck	shortly before 12BC	Bark
SY- Tell Brak, Mitannian Palace	1293BC±37	vv
TR- Afyon, Emirdağ, Amorium, Step Trench	1564	vv
TR- Afyon, Sincanlı, Boyaliköy Medrese	1206	Bark
TR- Afyon, Dinar, Tatarlı Tumulus (Archaic)	531BC±37	Bar
TR- Afyon, Çay, Yusuf Bin Yakub Medrese	1268	Bark
TR- Aksaray, Acemhöyük, Sarıkaya Palace (MBA)	1791BC±37	Bark
TR- Aksaray, Acemhöyük, Northwest Trench Buildings	approx. 2169BC	vv
TR- Aksaray, Acemhöyük, Hatipler Tepesi (MBA)	1791BC±37	Bark
TR- Akşehir, Taş Medrese	1197	vv
TR- Akşehir, Taş Medrese (Mosque)	1251	Bark
TR- Akşehir, Taş Medrese (Mosque Porch)	1251	v
TR- Beyşehir, Kubadabad Sarayı	1231	Bark
TR- Bilecik, Vezirhan	1657	Bark
TR- Burdur, Taş Oda	1566	Bark
TR- Burdur, Koca Oda	1712	vv
TR- Bursa, Yıldırım Darüşşifası	1400	Bark
TR- Bursa, Murat I. Hüdavendigâr Camii *	1385	v
TR- Çatal Höyük	various dates in the 7th millenniumBC	vv
TR- Çorum, Ortaköy (Hittite)	1304BC±37	vv
TR- Elaia, Sarcophagus (Classical)	498BC±37	vv
TR- Enez, Hg. Sophia	1162	Bark
TR- Gordion, Kızlarkaya Tumulus (Phrygian)	874BC	vv
TR- Gordion, Terrace Building IIA (Phrygian)	900BC±37	vv
TR- İnegöl, Höyük (EBA)	approx. 2299BC	v
TR- Kırşehir, Kaman, Kalehöyük (Phrygian)	448BC±37	vv
TR- Konya, Karahöyük, 1953 Excavs., Level 1, Room 8 (MBA)	1927BC±37	vv
TR- Konya, Karahöyük, 1974 Excavs., Level 1, Room 4	1839BC±37	vv
TR- Konya, Karahöyük, 1990 Excavs., Trench X, Room 1	1784BC±37	vv
TR- Konya, Karahöyük, 1992 Excavs., Trench X, Room 4	1782BC±37	vv
TR- Konya, Karahöyük, 1956?Excavs., Trench C, Level 4	1956BC±37	vv

Fig. 5. *Tabulation of dendrochronologically dated Aegean sites since 198?.*

COUNTRY - SITE NAME	DATE	EXTERIOR
TR- Konya, Karahöyük, Levels 6/7 (EBA)	approx. 2181BC	vv
TR- Kültepe, WarŠama Sarayı (MBA)	1849BC±37	Bark
TR- Malatya, Çavuşoğlu Kilise (Armenian)	1906	Bark
TR- Niğde, Çamardı, Göltepe (EBA)	1979BC±37	vv
TR- Porsuk Ulukışla, inner postern (Hittite)	1621BC±37	Bark
TR- Porsuk Ulukışla, outer postern (Hittite)	1590BC±37	Bark
TR- Samsun, Çarşamba, Yaycılar Camii	1211	vv
TR- Samsun, Çarşamba Mezarlık Camii	1206	Bark
TR- Sivas, Şifaiye Medrese	1215	v
TR- Sivas, Divriği, Hünkâr Mahfili 1240, 1665,	1766	Bark
TR- Tille Höyük, Burned Gateway, Phase I (LBA/IA Trans.)	1210BC±37	vv
TR- Tille Höyük, Burned Gateway, Phase II	1140BC±37	vv
TR- Troy I (middle) (EBA)	2699BC±15	vv
TR- Van, Ayanis/Ağartı (Uratian)	654BC±37	vv
YU- Dubrovnik, Palača Tudizić, Primary	1514	Bark
YU- Dubrovnik, Palača Tudizić, Repairs 1780,	1784	vv
YU- Ohrid, Sv. Sofija, Late (after 1669 earthquake) *	1673	Bark
YU- Ohrid, Gorny Saraj *	1237	Bark
YU- Ohrid, Sv. Sofija, modifications of Archbishop Gregory *	1314	v
YU- Relje/Zadar, Liburnian Well	524BC±37	Bark
YU- Sisak 434 year chronology from about the 3rd cent.BC to 2nd cent.AD		
YU- Zagreb, Klarissa Monastery, Substructure #1	1171	v
YU- Zagreb, Klarissa Monastery,Water Cistern	1292	v

NOTE 1: YU is used to denote the country which then existed when most of the samples were taken.

NOTE 2: 14 of the sites marked with an * above were investigated during a collaboration with Professor C.L. Striker of the University of Pennsylvania. He may or may not publish an architectural commentary thereon at some unspecified future time.

NOTE 3: Terminology for the right-hand column:

Bark indicates that the ring which was formed immediately before the tree was felled is still present.

v means that there is some subjective reason for thinking that the last preserved ring is near to the terminal ring.

vv means that we have no way of knowing how many rings are missing from the sample. The date is therefore a terminus post quem date.

± The sample is not pinned down to the precise year by dendrochronological curves which extend to living (and therefore absolutely-dated) trees. The limits of ± are imposed by radiocarbon wiggle-matching and other non-dendrochronological criteria until the tree-ring sequences are complete down to the present day.

Fig. 5. *Tabulation of dendrochronologically dated Aegean sites since 1987 (continued).*