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ORIGINAL ARTICLE

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Long-term increase in climatic dryness in the East-Mediterranean as evidenced for the island of Samos

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Abstract The Eastern Mediterranean region is among the regions which were predicted to become drier under IPCC climate scenarios. Here, we document a gradual reduction of rainfall and tree growth and the loss of rural springs during the last decades of the twentieth century. Years with severe drought are associated with very low tree growth (dendrochronology) and dry falling of springs as evidenced by interviews with local stakeholders. The paper discusses the consequences of accelerating drought on natural vegetation and agriculture and points at the interaction with fire dynamics and economy, both likely to enhance the drought effect.

Keywords Drought · Ecosystem · Vulnerability · Forest · Tree-rings · Agriculture · Water · Greece

Introduction

Anthropogenic global changes such as atmospheric change (including the change of atmospheric chemistry and its consequences on the climate), land use change (transformation of the land surface) and the associated socio-economic changes will have particularly strong effects in areas which are traditionally operating under strong environmental limitation. Seasonal shortage of water in the Mediterranean exerts such major limitations. Hughes et al. (2001) identified a number of drought periods during last 7,000 years till present, in the Aegean based on archaeological tree-ring data. Similar to what modern climate models predict, they interpreted the associated weather phenomena as a consequence of a northward shift of the circumpolar jet stream with the predominant transfer of moisture from the Atlantic getting directed to northern Europe, leaving descending dry air in the eastern Mediterranean. Kuniholm (1990) describes drought in Attica in the eighth, fourth and second centuries BC and a nineteenth century drought in Turkey, with the drought signals clearly captured by tree-ring data.

Under IPCC climate change scenarios, global circulation models predict more precipitation in the Atlantic-influenced western part of the Mediterranean and less in the more continental East of the Mediterranean (a northward expansion of the Saharan climate; IPCC 2002; JISO 2003). Although Spain and the Balearic Islands underwent drought in recent years as well, long-term meteorological data and satellite images of land surface greenness to date, do not suggest a systematic long-term trend in moisture conditions in the western Mediterranean (Bolle 2003). However, for the eastern Mediterranean, meteorological records and climatic proxy-data for the past 500 years do indicate a clear trend towards a drier climate in recent decades (Xoplaki et al. 2001; Luterbacher and Xoplaki 2003). Such a trend has also been postulated from meteorological data for Greece (Maheras and Anagnostopoulou 2003). Circumstantial evidence suggests that this holds for the Aegean islands as well, but hard facts are not yet explored, which is the aim of this study. Here, we explore the actual moisture history and its consequences during the last century in this region, exemplified by the island of Samos.

The island of Samos is situated in the central east part of the Aegean sea, close to Asia minor, is 20-km wide and 45-km long, has the highest mountain of the central east Aegean in its calcareous Kerkis massive (Vigla, 1,433 m) and is inhabited by a local population of 34,000 people, plus periodically around 300,000 tourist, who visit the island every year for its scenic landscape and beaches. The natural vegetation of Samos would be evergreen oak forest (*Quercus ilex* and *Quercus coccifera*) at low and conifer forest (*Pinus halepensis* ssp.

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brutia, *P. nigra* ssp. *nigra*, *Cupressus sempervirens*) at high elevations (Christodoulakis and Georgiadis 1990). However, land use and fires have eliminated the oak forest. Recurrent fires are in favour of pine forests (Thanos et al. 1989). *Pinus halepensis* ssp. *brutia* is the most important and dominant conifer in this region (Ne'eman and Trabaud 2000).

Today, 21% of the island is covered by coniferous forest, 41% is rangeland and 'bushland', including everything from open pastures, the typical low stature shrubland called 'phrygana', to tall macchia-type sclerophyllous woodland. The dominant woody genera there are *Juniperus, Pistacia, Arbutus, Phillyrea*, wild *Olea* and *Quercus*. 34% of the land falls into agricultural cropland, vineyards and olive gardens, and 4% is settlements, roads etc. The climate is typically Mediterranean with a wet season (late October to early April) and a dry season. Most of the 700–900 mm total annual precipitation falls between December and February. Generally, there is hardly any precipitation between May and September and midday temperatures may reach 40°C during July and August. Plant survival during summer depends on moisture stored deep in the ground, with root depth exceeding 10 m. During winter, temperatures regularly fall below freezing point at elevations above 300 m and temperatures reach as low as −12°C at the top of Vigla (Ch. Körner, unpublished data) . For more details on geology, climate and vegetation see Rechinger (1950) and Christodoulakis and Georgiadis (1990).

In this contribution, we will report recent findings from several disciplines: meteorology, dendrology, ecophysiology and hydrology (the latter through trends in local spring water supplies). We will complement these findings by considering their socio-economic consequences through information obtained from local people.

Methods

Precipitation data

We used annual sums of rainfall collected in Samos for the last ca. 70 years. Data were first recorded in Samos city (1931–1941, 1947–1977) and then, 15 km south, at Samos airport (1978–2000). Since the transfer of the station could have caused a change in records, we compared data of 5 years before (1973–1977) and 5 years after the relocation (1978–1982) with records from the other nearest weather stations in the eastern Aegean. For Lesbos precipitation was 688 mm before and 732 mm (+7%) after the change, for Skiros 487 mm and 573 mm (+18%). For the same periods the numbers for Samos are 760 and 841 mm (+11%), which is in line with the other stations. In any case, the relocation of the weather station was not associated with a reduction in rainfall records. If there were a re-location effect, it should be immediate rather than progressing to lower values over several decades, as the results will show.

We have extended the Samos rainfall data for the missing first 30 years of the twentieth century, by regressing the available Samos data with those of closest climate stations which have longer records (Naxos, Lesvos and Larissa). We do not use these regressed data in any analysis, but they should at least provide a rough trend for those earlier periods in Samos for which tree-ring data is available. Precipitation data before 1931 were provided by the National Observatory of Athens (NOA) and after 1931 by the Greek National Weather Service (EMY).

Dendrological data

We cored trees of the local pine species *Pinus halepensis* ssp. *brutia* at three locations, namely near Limnionas (SW-Samos; 37°41′N, 26°38′E), near Vourliotes (N-Samos; 37°47′N, 26°51′E) and near the monastery Zoodocho Pigi (E-Samos; 37°45′N, 27°01′E). *P. brutia* is the most drought tolerant among the Mediterranean pines (Schiller 2000) and is the East-Mediterranean subspecies of *P. halepensis* which dominates over much of the rest of the Mediterranean (Quézel 2000). Drought and fire are known to be the main drivers of the abundance of this species (Zavala 2000).

Trees were cored at breast height with a 5 mm increment corer (Suunto Inc., Vantaa, Finnland). Here, we show pooled data for all three coring locations with nine trees for each of two age classes (three from each location, 18 trees in total). The data reported here are from old (>85 years, mostly around 100 years chronologies) and currently young (15–45 years) trees, sampled from places on ridges or hilltops (avoiding locations with ground water access), all situated less than 300 m above sea level. A detailed dendro-ecological analysis, also including wetter sites and a middle age class of trees will be presented elsewhere (D. Sarris, ongoing project). Annual increments to the nearest 0.01 mm, from bark to pith were measured on a computer-linked mechanical platform using a stereomicroscope and a software package (LINTAB3 with Time Series Analysis and Presentation, TSAP 3.1, Rinntech.com, Heidelberg, Germany). We show original data for the annual radial increment. The common de-trending procedure (removal of age trends in tree-ring width) would largely remove the parallel climate-signal we search for. Instead, data of young and old trees permit a comparison of radial tree growth at equal tree age but from different periods. The three oldest trees we could find were 149, 139 and 123 years old. Note that age refers to breast height, hence another ca. 10–20 years would have to be added to arrive at true age from germination. We also measured needle length for the past 6 years and annual lateral shoot length growth for the past 12–15 years in autumn 2003 (counting the branching nodes), thus also including the recovery period after the year 2000 drought.

Ecophysiological data

We used the pool of mobile carbohydrate compounds in leaf and stem tissue to differentiate between drought-imposed limitation on photosynthesis and meristem activity during 3 years, including the driest on record (2000). The greater the mobile carbon pool, the less likely is photosynthesis limiting growth and the more likely growth itself is limited by the given environmental conditions (see Körner 2003 for details). This explains the primary mode of action of water shortage on plants. We also show stable carbon isotope data for needles produced during the peak of the recent drought and for needles produced during moister periods. Plants discriminate the heavier ^{13}C isotope (ca. 1% of all CO_2) against the common ^{12}C isotope (ca. 99% of all CO_2), which involves a diffusion (stomata) and a biochemical (CO_2 fixation) component. Under water stress, when stomatal opening is restricted, $^{13}CO_2$ is less discriminated, i.e. a relatively greater fraction of ^{13}C is incorporated into biomass. This permits a post hoc assessment of water limitation by mass-spectrometric analysis of biomass samples for the $^{13}C/^{12}C$ ratio compared to the ratio in a ^{13}C-rich international limestone standard ($\delta^{13}C$ values', which become less negative as ^{13}C becomes more abundant in tissues; Warren et al. 2001). We also report spot measurements of actual leaf-water content for the peak of the drought period expressed in the percentage of turgid water content (=100%) after 24 h of dark and cool resaturation of branchlets, which were collected early in the morning (predawn water content). Finally, visual assessments of drought damage such as loss of foliage or complete desiccation are reported and illustrated by photographs.

Hydrological indicators

The municipal areas of the island are well supplied with drinking water, thanks to the large mountains Kerkis and Ambelos, and thanks to high yielding deep wells. If there are periodic shortages in household supplies, these are commonly because of faulty pumps, broken pipes or power breakdown rather than water availability as such. However, many of the thousands of little dwellings and gardens in the hills over millennia depended on some local spring water, and also rural communities depend on more local supplies. If there are ruins of a dwelling, one can be almost certain that there was water available within about 300 m at the time when the house was built. Most of the surroundings of ruins are bare of any water today and drilling wells is unsuccessful in most cases, at least in the west and south. Springs in calcareous ('karst') mountains are good indicators of a region's water regime because they do not strongly respond to year-to-year changes in weather, but reflect accumulative effects of precipitation over several years. While surface runoff ceases in most cases during May, such springs often provide year-round access to fresh water.

Here, we assessed the years of disappearance of local springs through interviews (made between December 2002 and March 2003) with local people, 2–3 years after the severe 1999–2000 drought. We do not refer to the major municipial water supplies (which also have declined according to the local experts). For a total of 28 rural springs (all the springs which existed in the respective regions), locals were able to reconstruct the years of drying. In the western part of the study region (18 springs), there are no reliable surface springs left at low elevation, hence the reports for this region commonly refer to some of the last springs which existed. Interviews also included questions about land use and practical consequences. Whenever possible, we tried to obtain information for a spring from two independent witnesses, to check for the accuracy of the year of disappearance, which usually was better than 2 years.

Results and discussion

Precipitation records

Annual sums of precipitation (Fig. 1) declined significantly over the 70 years of record, irrespective of the statistical test employed. A linear regression for the full data set arrives at a mean 5.1 (±1.3) mm a^{-1} reduction of rainfall ($p=0.0002$). A smoothing function (Cleveland 1981) yields a break point around 1972–1978 after which the trend accelerated. The rate of decline for the last 25 years was ca. 10 mm a^{-1} (ca. -12 mm a^{-1} for the Islands of Kos and Skyros, D. Sarris, in preparation). If we separate records for the period before and after this transition (after accounting for a linear trend), the slopes before and after 1979, however, do not differ significantly ($p=0.6$). A quadratic model revealed no significant deviation from linearity ($p=0.45$). We then compared by a *t*-test the periods before 1972 and after (including) 1972,

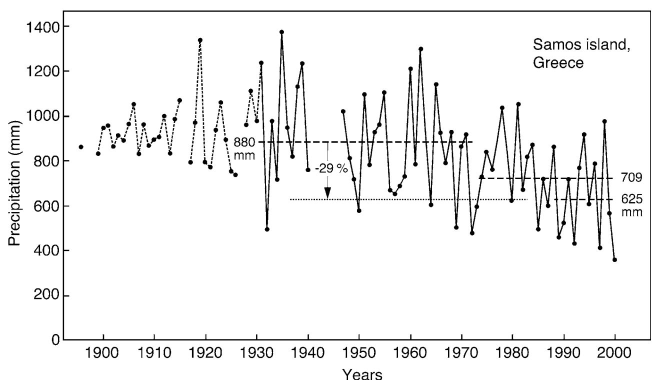

Fig. 1 Precipitation records for Samos from 1931 to 2000, extended back to 1899 by data regressed from other stations with longer records (*dotted line*). Since most stations, including Samos, had no records during and after world war II, there remains a 6 year gap of data. For 1917–1926 we had data from three stations, namely Naxos, Larissa and Lesbos (r^2 0.24); for 1899–1915 and 1928–1930 the extrapolated data are from Naxos and Larissa only (r^2 0.12). These regressed data are not used for any statistics

which yielded a highly significant ($p = 0.0005$) reduction in rainfall. The period 1931–1972 averaged at 880 mm compared to only 709 mm for the 1972–2000 period (625 mm for 1989 to 2000 period, i.e. a 29% reduction; $p = 0.0015$). The 400 mm record for 2000 is only about two-third of the lowest annual precipitation recorded between 1931 and 1999. Although we do not have direct readings for the time before 1931, this is most likely the lowest annual rainfall during the last 100 years (Fig. 1) and according to tree-rings (see later), possibly longer.

This local trend matches the long-term trend for the whole Aegaean as compiled by Xoplaki et al. (2001) and Luterbacher and Xoplaki (2003). Their data document a lot of variability and periodic severe drought episodes during the past 500 years, but their data also suggest a reduction in preciptation during the last century in this wider region.

Tree-ring and shoot growth in response to drought in Pine

The mean radial growth of *Pinus brutia* varies between 0.4 mm and 3.5 mm i.e. ninefold over the years. Some years with very little growth may be related to mass fruiting episodes, some may reflect 'out-breaks' of pine processionary moth populations. However, most of the variation (Fig. 2) is in phase over the whole island and is related to precipitation (Fig. 3). By comparing tree growth along dry river beds (presumably with ground water) with tree growth on adjacent ridges (no ground water access; data not shown) a clear moisture relation of radial increment could be established (twofold growth rates in depressions). As expected, tree-rings also revealed much more pronounced year-to-year variation on the dry ridge top sites, compared to the sites with ground water access, hence, we use only the more sensitive ridge top data for the current purpose (Fig. 2).

For geometric reasons, young, small diameter trees show wider growth rings per unit of areal increment than

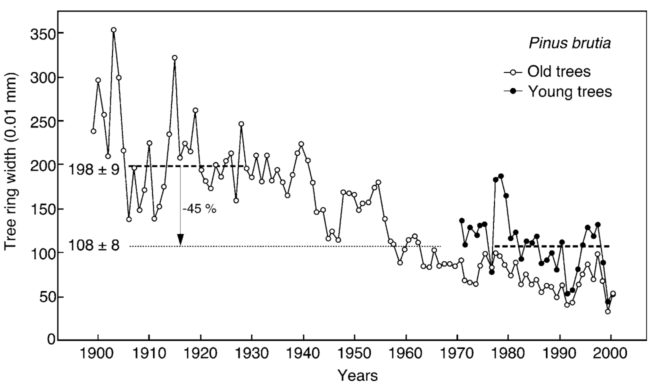

Fig. 2 Tree-ring data for *Pinus brutia* from dry habitats in Samos for the twentieth century for old and young trees. The *curves* represent means for three sites (nine trees per age class). The *dashed lines* illustrate the means of growth rates when trees had a similar cambial age of about 20–40 years at breast height, thus illustrating an age-independent decline in radial tree growth

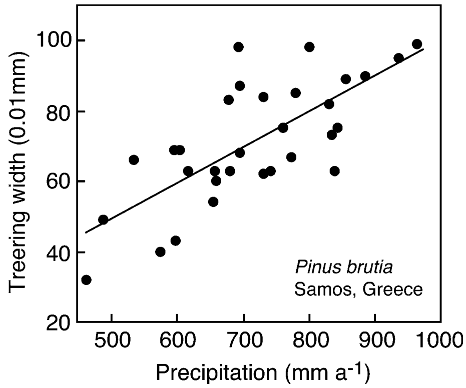

Fig. 3 Correlation between tree-ring width and precipitation (2-year running mean) for trees older than 85 years during the period 1970–2000 ($r^2 = 0.54$, $p < 0.01$). During the wetter, earlier part of the twentieth century (cf. Fig. 1) there was no such correlation

older, larger diameter trees. So, part of the decline in radial growth shown in Fig. 2 relates to tree age. Such trends must never be removed by so-called 'de-trending', when con-current climatic trends are to be explored. By comparing similar age periods in trees grown at different times, we can remove the age trend without affecting the environmental signal. When the same age class of trees (20–40 years of cambial age at breast height) is compared between 1906–1928 and 1978–2000, a dramatic, age independent drop in average growth rate from 2 mm a^{-1} to 1.1 mm a^{-1} can be seen in Fig. 2. The minimum growth rates in these young trees dropped even more, namely from 1.4 mm a^{-1} around 1911 to 0.4 mm a^{-1} in 2000, a more than threefold reduction for trees of similar (young) age in the last ca. 80 years. There are no records of situations in which tree growth had been slower than during the last 10 years of the twentieth century.

Thus, the average decline over the years is much more rapid than what could be explained by any age effect. From 1900–1940 trees grew on average 2 mm a^{-1} with a steady decline thereafter down to 0.5 mm a^{-1} in 1992–1993. There was a small recovery in the late 1990s, followed by the >100 year minimum of growth in the year 2000. Note that during the drought period in the last 10 years, the difference between young and old trees had almost disappeared, indicating that young trees were relatively more affected than the older trees.

Dry periods are clearly evident for 1906–1911, 1945–1947, 1959, 1964–1965, 1972–1974, 1983, 1987–1992, 2000. Note that tree-rings (Fig. 2), in accordance with precipitation data (Fig. 1), mostly indicate sequences of several unfavourable years, interrupted by a series of better years. These 'better' years have recently been far worse than the good years in the first half of the twentieth century. Until the 1964 decline, the interval between low growth (dry) and high growth (moist) periods was about 5–8 years, mostly 7 years. After the mid-1960s that cyclicity faded into a nearly linear, 30 years decline, interrupted between 1994 and 1998 by a short recovery, and then falling to the absolute minimum of year 2000.

Tests showed that the best correlation ($r^2 = 0.54$) between tree-ring and precipitation data is obtained for a 2-year running mean of rainfall, most likely reflecting the carry-over effect of deep soil water storage for annual growth. The regression line shown in Fig. 3 yields a slope which rounds to a 0.5 mm a^{-1} radial growth for a 2 year mean of 500 mm a^{-1} precipitation, and a growth of 1 mm a^{-1} at a 1,000 mm a^{-1} rain fall regime. So every additional 100 mm a^{-1} of rainfall corresponds to 0.1 mm of additional ring width. A similar correlation holds for young trees (not shown, $r^2 = 0.34$) with 0.15 mm of ring width increment for every 100 mm a^{-1} of additional rainfall. This correlation underpins, that rainfall is the main driver of growth of *Pinus brutia* in this region. (Fig. 3). No correlation between radial tree growth and precipitation was found for the period before 1970, when precipitation varied around 900 mm a^{-1}. These tree-ring responses are in line with earlier observations in Anatolia (Gassner and Christiansen-Weniger 1942; Touchan et al. 2003) and with stable isotope studies, which have also revealed a certain threshold for conifer sensitivity to water availability in Mediterranean climates (Warren et al. 2001). Cambial activity in *Pinus brutia* has also been shown to be clearly moisture driven in Israel (Messeri 1948; Lev-Yadun 2000).

Length growth of lateral shoots was similarly affected by the 2000 drought, reaching only a third of that of years with high precipitation and half of average years, despite the fact that shoot expansion is a short event in April, when top soils still store some moisture even in a dry year (Fig. 4). The data show a decline over the 10 years preceding the year 2000 drought, with a recovery in 2002–2003 to the mid-1990s mean. Needle-length values before and after the year 2000 drought, yield a sharp reduction in the year 2000 cohort (inset in Fig. 4).

In summary, the tree-ring data leave no doubt that growth conditions for the dominant conifer of this region declined dramatically during the second half of the twentieth century. This trend also finds expression in more recent growth responses in shoot-length and needle-length, which can be assessed for shorter time periods only.

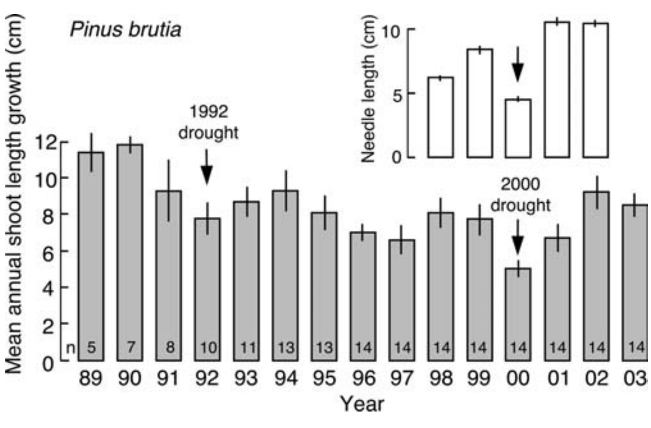

Fig. 4 Length growth of leading lateral shoots of tall *Pinus brutia* in W-Samos (Limnionas) from 1989 to 2003 (*n* number of trees sampled). The *inset* shows mean needle-length in lateral branches of ten saplings before until after the year 2000 drought (*x*-axis as for shoot length)

Stress and stress responses in evergreen vegetation

In the previous section, tree-ring and shoot-growth data were shown to clearly characterize the year 2000 as the worst on record for tree growth in Samos. Here, we explore some shorter-term physiological responses of pines and some evergreen shrubs during this period.

In the test region, the year 2000 cohort of needles could not complete its expansion growth in most places of lower elevation. In 'normal' years *Pinus brutia* produces needles of 10–15 cm length, in the year 2000 needles measured 4–6 cm in length, hence reached about 30% of normal final length (Fig. 5a). Needles sampled at the end of the summer 2000 had a significantly higher $\delta^{13}C$ value (less ^{13}C discrimination) than needles formed in the previous year (Fig. 5a). The ca. 2‰ difference is massive, given the common small variation of such signals within a species and reflects the fact that needles are constructed from recently fixed carbon. In tree-rings wet-dry year $\delta^{13}C$ differences strongly depend on habitat type. Taking 1978—a moist year, as a reference, $\delta^{13}C$ for 1992—a dry year, differs by 0.72‰, and $\delta^{13}C$ for 2000 differs by 0.93‰ (−25.68 ± 1.53‰ vs. −24.96 ± 0.48‰ vs. −24.75 ± 0.28‰, corrected for atmospheric $\delta^{13}C$ in 2000, $n = 4$) in dry habitats. The corresponding means for the wet habitat pines are: −26.39‰, −24.88‰ and −23.09‰ for 1978, 1992 and 2000, respectively, illustrating a much greater impact on these trees (the year 2000 value is among the lowest ever reported in the literature for conifers). These numbers suggest that trees at dry sites and/or shallow soils (the sites considered predominantly in this paper) stop assimilating and investing carbon rather abruptly when it gets dry (hence no isotope signal of drought is stored in tissues), whereas trees from deeper and wetter substrates presumably run into a longer transition period during which significant amounts of carbon are fixed under stress, hence the stronger isotope signal captured in tree-ring tissue. In essence, these numbers suggest that drought affects growth at dry sites predominantly through a shortening of the productive period and to a lesser extent through production under stress.

Pine and sclerophyllous broad-leaved trees–shrubs were monitored from 1998 to 2002 for their seasonal variation in mobile carbohydrates (largely starch, Fig. 6; Körner 2003). The highest concentrations during this period were found in late winter and in October 2000 (i.e. after the driest of the four summers). The October data indicate that these plants assimilated carbon, but could not invest photoassimilates into structural growth because of the drought (it needs turgor to expand cells), and as a result mobile photosynthates accumulated (largely in osmotically inactive form). These findings are in support of a direct drought induced growth limita-

Fig. 5 **a** Shoots and needles remained short (see also Fig. 4) and the stable carbon isotope discrimination in needle dry matter in 2000 was close to the minimum known for C3 species, A year 2000, B year 1999. **b**–**d** On many ridges and S-exposed slopes sclerophyllous shrubs died from drought in the year 2000 in the SW of Samos (Limnionas-Kalithea). **e**, **f** In former days, olive gardens had three functions: olive production, spring cereal growth and finally, grazing. Only a limited market value of olive is left today and the other two functions became abandoned. The cleaning of the undergrowth became human handwork. Loss of labour force (emigration), low market value of this extensive way of olive production, and increasing drought (reduced yield) lead to wide spread abandonment of olive groves, with rapid shrub encroachment and standing dry grass following and facilitating the spread of fire. **e** Abandoned olive garden; **f** still (mechanically) managed, 'clean' olive garden, both in late summer

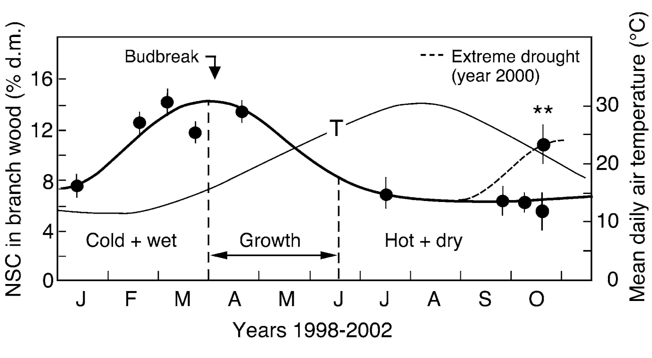

Fig. 6 The seasonal course of non-structural carbohydrates (NSC) in stems of Mediterranean sclerophylls in SW-Samos. Each mean (±SE) stands for four species (wild *Olea europea*, *Arbutus andrachne*, *Quercus coccifera* and *Pistacia lentiscus*) with three stems per species (12 samples per data point). Data were collected between 1998 and 2002, with the samples taken at the end of the extremely dry year 2000 representing an all time high for NSC in autumn ($p < 0.01$). NSC includes various sugars, but seasonal variation is dominated by starch (from data in Körner 2003). 'Growth' stands for the 2.5 month period of tissue growth in spring

tion, with photosynthesis itself being less affected than growth. This growth cessation can be easily understood, considering that early morning leaf relative water content dropped to 40–50% of turgid water content, close to the drought damage limit known for such species (Larcher 1972). Most leaves were curled and many had a slightly brownish colour as had the overall shrub-covered landscape compared to the other years.

Visible damage: close to our tree coring site near Limnionas, but also in many other topographically exposed places throughout the western slopes of the Kerkis massive, hundreds of tall trees became brown and had become fully desiccated by the end of summer. These mostly >80 year-old trees did not resprout in the following spring and were definitely killed. On these south- and west-exposed slopes where the pines died, hectare size areas of shrubland turned completely brown and died as well (Fig. 5b–d). In contrast to fire, after which most individuals resprout, desiccation affects the whole plant and those areas were definitely devastated by the drought, and can still be seen dead in 2004. *Juniperus phoenicea* and *Phillyrea latifolia* were affected most, *Quercus coccifera* and wild *Olea* second and *Pistacia lentiscus* least.

The surprising fact that *Juniperus* was affected most, seems to be related to its leaf-type. The narrowly attached scale leaves help reducing transpiration as long as drought does not get too severe (perhaps an advantage over the broader leaved sclerophylls on dry places during normal Mediterranean summers). However, when drought conditions get extreme, those other species can shed their complete foliage and thus prevent further water loss, not an option for *Juniperus*, which died with its full envelope of scale-leaves. Most of the affected oaks and olive trees resprouted in the following spring but not *Juniperus*.

These data and the observations of visual drought damage underline that the year 2000 drought was truly exceptional, exceeding the stress tolerance of natural, adapted vegetation on exposed sites. Given the age of the pines and the sclerophyllous bushes, the centennial nature of the drought is obvious. Note, these shrubs are markedly older than the period since their last resprouting after a fire in 1986 (i.e. 14 years earlier), because—as mentioned above—their root stock is normally not affected by fire, so the genetic individual can survive and regenerate from many fire cycles and reach hundreds of years of age, in most cases exceeding the age of the pines. Some of these shrubs exhibit clonal growth and are theoretically immortal. Hence, desiccation to

Fig. 7 **a** Example of one of the small springs which dried in rural areas around the lower slopes of the Kerkis massive. **b** At Pano Kiourka, a spring near the base of the calcareous outcrop in the top center supplied a little dwelling until 1993 and attracted wildlife (and the hunters). **c** A natural harbour called Makria Pounta in the SW of Samos is surrounded with terrassed hills which supplied the livelihood for eight families and ca. 40 people into the early second half of the twentieth century. Between the olives, cereals were grown on the terrasses and goats grazed the winter grass and any emergent shrub. The major spring which supported these families became unreliable in the early 1970s and dried during the 1999–2000 drought. Most of the former homes are abandoned, the few left and vacation chalets are now supplied by a public water line. **d** A typical interview situation (here in a local taverna in Drakei) during which the history of rural springs was explored. **e** An example of the type of gardes, which depend on irrigation from small springs from another area (below Spartarei). **f** The famous boat ramp of Ag. Isidoros. A local spring supplied the workers and their families until it dried out in 1972. Today water comes through a pipe from the 3 km uphill reservoir of the community of Drakei. Also the spring (encircled) at the far end of the bay dried

death in such long-lived species underlines the exceptional nature of the drought.

The recent history of springs

From interviews on 28 springs in the Kerkis-Ambelos (W-Samos) region we report, as examples, the fate of springs at five locations from the southwest and far west of Samos (some examples shown in Fig. 7). The trends for the complete sample are illustrated in Fig. 8. We recall that these springs represent the complete set of known springs in the respective areas.

Limnionas—Makria Pounta—Ag. Kyriaki area

Pano Kiourka (under Evangelistria)

Mr. Ioannis Salamalekis (79) of Limnionas/Marathokampos said, that the southwestern lower slopes of Kerkis were always short of water, but there were remarkable exceptions. One of these was a place called Pano Kiourka with a spring named after the former land owner 'Vasilis Kikibasos'. This spring was near the end of a small dirt road branching left from the terminal part of the road to the parking area for the Evangelistria monastery trail, with this branch circumventing a hump-shaped calcareous outcrop to the west (Fig. 7b). The spring at ca. 350 m altitude supplied a little house, the remains of which are on a little saddle at the end of the road. Ioannis remembers that there was a fig tree among the macchia-shrub—quite an unusual plant for these dry slopes, and there were always lots of birds, the hunters were after, hence the tree was hit hard from the shooting. The water disappeared around 1993 and so did the birds. The locality and the drying of this spring was confirmed independently by two other witnesses, one of them Nikolaos Tsoulas.

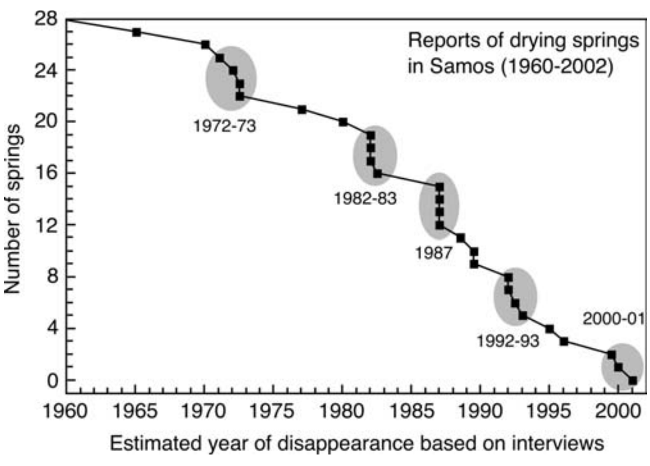

Fig. 8 The complete set of years of disappearance for 28 rural springs in western Samos. The diagram starts with all springs active (*top left*; these were all the existing springs in the test areas by that time) and then denotes the years when springs have been dried. Note the accumulation of dry falling around certain years. The *right end* denotes the last springs which dried. At this point, the driest year on record, all 28 springs were dry

Makria Pounta

Mr. Xenokratis Psomas (67), today in Marathokampos, remembers his childhood in Patniotes 0.5 km west of Makria Pounta/Limnionas. When he went to primary school in Ag. Kyriaki, there were eight families living permanently in the Makria Pounta bay (Fig. 7c), and two in Patniotes (just behind the ridge), alltogether ten families or ca. 50 people. There was enough water, with the three springs of the area all associated with the commonly dry beds of little streams. The most important and the most reliable spring was in a place called Manola (above the house of A. Moukazis); it finally disappeared in 2000. The other, minor one (above the late E. Opsimos' property) disappeared around 1992. The third one in Patniotes, a small water hole only, still yields a little water pumped to the rural Taverna by Andreas Kotsos. Sporadic reeds of *Arundo donax* and shrubs of *Myrtus communis* indicate shallow ground water in these ravines. Mr. Psomas remembers that water became scarce in the early 1970s in late autumn, which had not been observed before. The drinking quality water for the Psomas family had to be carried from Manola in clay jars for a walking distance of ca. 15 min. No permanent settlers are left in this area, most of the houses burned in the 1986 fire, which spread rapidly across the abandoned cultures, and the Manola spring, which once supplied 50 people, is dry, except for some irregular (early season) supplies after heavy rainfall.

Mourteri

Mr. Manolis Kalvinos from Marathokampos commented on his own family's water supply in Mourteri along the Drakei road, ca. 350 m above sea level, west of Ag. Kyriaki. There is an old concrete trough with a tap-outlet on the upper road side (with the supplied houses and gardens below the road). This spring ceased between 1992 and 1993. The owner recalls his grandfather reporting that the spring dried out first in 1927 or 1928, which was close to a catastrophe, because the family totally depended on this water (there was no road in those days) and one can vividly imagine that these people must have seriously considered giving up the place. Fortunately the spring resumed in 1929. But for 1 year they had to bring the water with a donkey, presumably from Ag. Kyriaki. Now they operate a deep borehole in the gulley, which is still, in 2003, yielding water.

Drakei—Ag. Isidoros area

The following three examples (out of 14 others) were jointly reported by three witnesses from Drakei (Fig. 7d), namely Mr. Panagiotis Karamaroudis (83), Konstantinos Angelinas (71) and Nikolaos Kapantais (73). Later Mr. Ioannis Angelinas (50) confirmed the cases. We asked the witnesses to concentrate on what they would consider important springs. Several of the springs they mentioned (one case given below) referred to gardens at a substantial distance from the village (similar to the one in Fig. 7e). This may sound surprising, but has to do with the shortage of flat, arable land in and around the village of Drakei. In some cases, people had to walk almost an hour to reach their garden, with the locally available water permitting good crops.

Karastamati

About 70 m below Drakei, at ca. 200 m, was a rich spring, which supplied ca 200–300 m^2 of garden land in five terraces. Main crops were tomato, cucumber, egg-fruit, peppers etc. The spring's overflow fed a 5 m diameter natural basin, a 1 m deep pond of fresh water in the middle of the hot Mediterranean summer. The pond was well known among children (now in their fifties), because, on the way home, it permitted them to wash the traces of salt from forbidden swimming in the sea near Ag. Isidoros. The sea is particularly rough on this coastline and mothers (including that of DC) did not like kids to swim there. By licking the skin it became obvious whether their order was respected. Hence, this pond is well remembered. It fell dry between 1972 and 1973, the pool never saw water again and the gardens had to be given up.

Sebastou Rema and Glyfada

Very close to Ag. Isidoros, there was the Sebastou Rema spring that had been used by people for drinking. There is a famous wharf at the harbour, one of the last three classical ones for timber boats in Greece (Fig. 7f). This work place is supplied with water from Drakei today by a several kilometer long pipeline, because the spring they had before fell dry in 1972. If one rowed across the natural harbor of Ag. Isidoros coming from the boat ramp, there was another spring called Glyfada under the rocks very near to the sea some 40 years ago (Fig. 7f). The spring is dry today as well, but it is not known when it ceased.

The results of the 28 interviews as summarised in Fig. 8 made it clear that the climate history, as documented by meteorologists using climate data, and as reconstructed from the width of annual growth rings in trees, finds its parallel in real life. We documented 28 cases where important springs had disappeared in the west of Samos over the past 30 years, with most of the losses reported in the last 20 years. The years mentioned by our witnesses yield a series of critical periods (see Fig. 8): 1972–1993, 1982, 1987, 1992–1993, and 2000 all coinciding with periods of significant growth reductions in trees, according to tree-ring data, as can be seen in Fig. 2.

Human responses to drought

The drying of spings had immediate consequences on the local people. We asked specifically how they responded: People gave up gardens, built high elevation reservoirs, drilled deeper wells or installed water supply lines, they lost hunting grounds and watering places for herds.To be fair, one needs to say that in many cases the abandonment of the gardens would have taken place irrespective of the activity of springs. There is no need for the local population to be self-sufficient in vegetables these days. Modern roads have been built and there are daily bus-services to town. School and work is in larger towns. The economic significance of local agriculture has become very much reduced and the population of remote villages such as Drakei had been drastically reduced through emigration to larger towns or abroad. The increasing scarcity of water and crop failure may have accelerated this trend.

Implications and conclusions

In line with the modelled climate scenarios, the meteorological records for the past 70 years, tree-ring data for the past 100 years, eco-physiological information for the so far worst part of the drying trend and the hydrological indicators observed by local people (springs), all together point in the same direction: the climate became drier in Samos in recent decades. The data also underpins that the last 10 years were exceptional for the twentieth century, by showing the lowest mean rainfall, the lowest recorded growth rate of trees, death of old growth natural vegetation and the disappearance of small surface springs in the explored region.

What these cases document is a loss of options. A clear reduction of the carrying capacity of the land and its value as a primary resource for humans. We have no evidence on how wild animals have been affected, but in some way there must have been declines associated with the decline in moisture. Hunters may have a word on this. Vegetation has paid visible tribute in some areas. The major industry of Samos, tourism, will be hardly affected by water shortage itself, given the plentiful supplies so far guaranteed by one of the highest mountains of the Aegean. Less mountainous islands such as Ikaria will be under greater risk.

A comparison of data from stations across the whole Aegean (Maheras and Anagnostopoulou 2003, D. Sarris, unpublished) shows that the drying trend holds for most of the places, but the central eastern part, as represented here by Samos, is among the most affected. Although such a long-term trend of reduced moisture availability was predicted for this region by global climatic change models (see Introduction), it is still difficult to separate global change associated phenomena from the natural climatic variability. The nearly half-century duration of the drying trend and its recent dramatic consequences certainly place it in a special 'historic' category that deserves attention.

Indirect consequences of reduced precipitation such as increased fire frequency may become problematic for tourism. The reasons for increased fire frequency in Greece in general (Georgiadis 2003) and in Samos in particular are not necessarily drier summers, but also less rain during the cool season as in 1999 and 2000. It is the cool season which is responsible for the decomposition of plant debris. The slower this process, the greater the fuel load on the landscape and more severe and difficult it becomes to stop fires. It is not a single year's moisture regime, but the long-term trend, which matters. Dead wood debris has a 'long memory' with respect to climate history.

There is a second reason for the more frequent occurrance and faster spreading of fires in recent years, indirectly linked to moisture shortage: landuse itself (Fig. 5e, f). Olive gardens had been 'cleaned' from shrub encroachment and dried winter annuals in earlier days, had they not been grazed by goats and sheep in the first place. Herds largely disappeared, and the manual cleaning did not pay off with the meager olive crops in recent years because of the dry weather. As drought increases, the income from olives dropped, land care declined and plant debris accumulated. Drought is thus, indirectly contributing to the risk of devastating fires via its impact on the economy and on land care. One of these fires burnt nearly a fifth of the island (a triangle between Pythagorion airport and the villages Spatarei and Kokari) in July 2000.

What this study reveals, is a longer trend. Although rainfall continues to vary from year-to-year, it does at significantly lower multi-year sums, compared to 50 years ago. If this trend will find a continuation, the most dangerous outcome would be an increased rate of abandonment of farmland, olive gardens in particular, which will dramatically increase the impact of fires. Unfortunately, fires are lit intentionally and unintentionally more frequently in recent years (Georgiadis 2003). The combination of human misbehaviour, drought incidence and declining agricultural profit and thus land care, make enhanced fire impact the single largest risk factor in response to drought, severely affecting the most significant sources of income in this region, which is tourism. While large herds of animals have often been accused for devastating the Mediterranean landscape, one would like to see them return in certain regions for land care reasons in these man made ecosystems.

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