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THREE CONFLATED DEFINITIONS OF MEDITERRANEAN CLIMATES

Mark A. Blumler
Department of Geography
SUNY Binghamton
Binghamton, NY 13902-6000

ABSTRACT: *"Mediterranean climate" has in effect three different definitions: 1) climate of the Mediterranean Sea and bordering land areas; 2) climate that favors broad-leaved, evergreen, sclerophyllous shrubs and trees; 3) winter-wet, summer-dry climate. These three definitions frequently are conflated, giving rise to considerable confusion and misstatement in the literature on biomes, vegetation-environment relationships, and climate change. Portions of the Mediterranean region do not have winter-wet, summer-dry climate, while parts that do, may not have evergreen sclerophylls. Places away from the Mediterranean Sea, such as the Zagros foothills, have more mediterranean climate than anywhere around the Sea under the third definition. Broad-leaved evergreen sclerophylls dominate some regions with non-mediterranean climates, typically with summer precipitation maximum as well as winter rain, and short droughts in spring and fall. Thus, such plants may be said to characteristize subtropical semi-arid regions. On the other hand, where summer drought is most severe, i.e., the most mediterranean climate under definition 3, broad-leaved evergreen sclerophylls are rare to absent. Rather than correlating with sclerophyll dominance, regions of extreme winter-wet, summer-dry climate characteristically support a predominance of annuals, the life form best adapted to seasonal rainfall regimes. Given the importance of useful forecasting of vegetation and climate change under greenhouse warming, it is imperative that biome maps begin to reflect the complexities of vegetation-climate relationships.*

INTRODUCTION

Mediterranean-type climates have been defined: (1) Geographically, as climates similar to those found around the Mediterranean Sea; (2) Vegetationally, as climates where broad-leaved evergreen sclerophyllous shrublands (maquis, chaparral, matorral, macchia, fynbos, kwongam) are common or dominant; and (3) Climatically, as regions of summer drought and winter rainfall.

Ecologists, geographers, and others concerned with vegetation-climate relationships frequently conflate these definitions (Fig. 1). Most maps delineate mediterranean-type regions neither according to climate nor according to vegetation, but rather as an approximate intersection of the two. This is true of most Köppen maps, for instance. Köppen's (1918) system was intended to delineate biomes solely on climatic differences, at a time when climate data were limited. Today, a cartographer may employ the complicated algorithms that introductory geography students encounter in section assignments, but in the end typically will alter the map to exclude from the Cs designation those summer-dry regions that do not support sclerophylls. (An exception is the map in James [1966:566-567], which gives a reasonably good representation of the total extent of Cs climate.) Not only are vegetation and climate maps seriously inaccurate, the ecological literature also is replete with inaccurate statements about mediterranean regions. Regions that have evergreen sclerophylls or that border the Mediterranean Sea are said to be summer dry when they are not; other regions that do not have sclerophylls and are far from the Sea are said to be summer moist or winter dry when they are not; or alternatively, such regions are said to have sclerophyll vegetation even though they do not. While climatologists are well-aware of the complexity of climate in the lands bordering the Mediterranean Sea (e.g., Trewartha, 1961), ecologists, biogeographers, and some global climate modelers have reduced matters to a simple equation:

> "The mediterranean ecosystems are dominated by evergreen shrubs and sclerophyll trees that have adapted to the distinctive climatic regime of summer drought and cool moist winters." — Archibold, 1995:131

As will be discussed in this paper, there is much less correspondence between the three definitions of mediterranean climate than is generally realized. Given the great interest today in predicting how ecosystems will respond to global change, it is essential that current patterns of vegetation be understood, and mapped correctly in relation to climate.

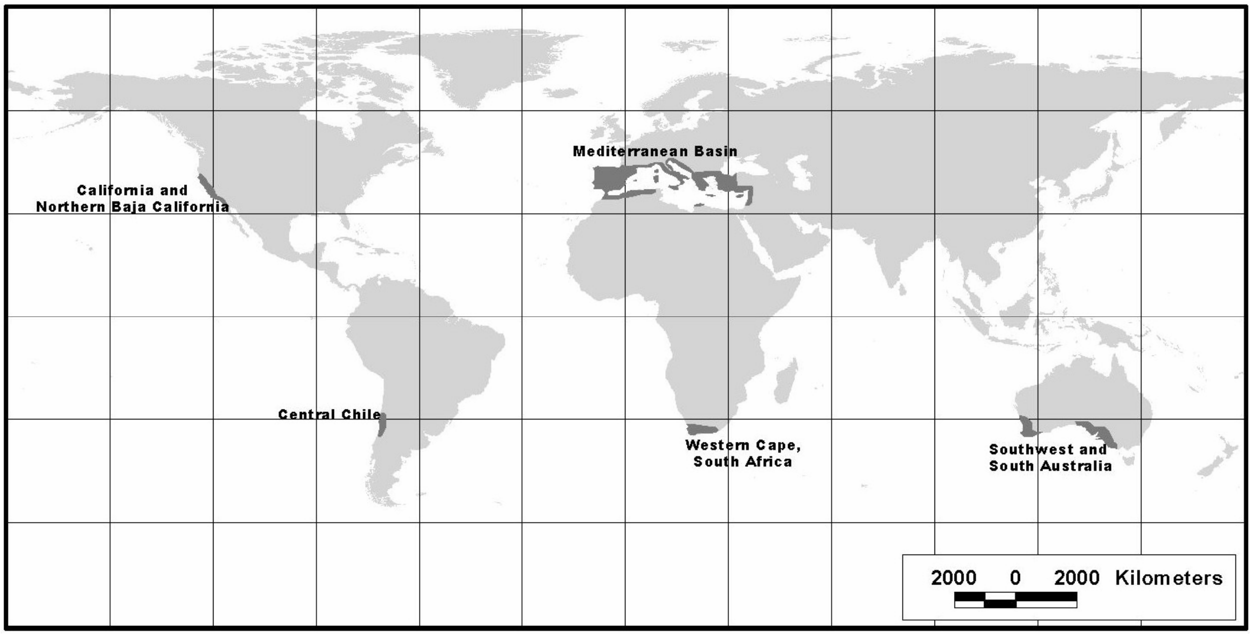

Figure 1. A typical map of the world's mediterranean-climate regions. Note that the climate is mapped as extending only a short distance east of the Mediterranean Sea, because sclerophyll vegetation only extends that far. In actuality, the climate (winter-rain, summer-dry) continues far to the east of the Sea.

Viewed from northern Europe, the Mediterranean was distinctive not only because the Sea lent the region a certain geographical continuity, but also because crops such as the olive could be grown only there. The limits of olive cultivation are often taken to delineate the Mediterranean climate zone (Grisebach, 1872; Grove and Rackham, 2001). The obvious parameters differentiating the climates of Mediterranean and non-Mediterranean Europe are the presence or absence of summer drought, and the harshness of the winter. The prevalence of maquis vegetation in the Mediterranean countries, including among its constituents wild olive, led very early to the notion that broad-leaved, evergreen sclerophylls – a term coined by Schimper (1898) to apply to plants with leathery, rigid, heavily cutinized leaves - are especially suited to and typify mediterranean climates. Later, it was realized that winter-wet, summer-dry climates have a very restricted but characteristic distribution, being found on the west side of continents at approximately 30°-40° latitude. When maquis-like vegetation was discovered in several other summer-dry regions, the notion that evergreen shrubland was particularly well-adapted to mediterranean climates was reinforced, and the concept of "convergent evolution" developed (Schimper, 1898; Specht, 1969; Mooney and Dunn, 1970; di Castri and Mooney, 1973; di Castri *et al*., 1981; Cody and Mooney, 1978; Shmida, 1981; Shmida and Whittaker, 1984). Subsequently, individual biogeographers and ecologists have noticed and pointed out a lack of correspondence between evergreen sclerophyll shrublands and summer drought for individual regions (Freitag, 1971b; Kruger, 1985; Minnich, 1985; Barbour and Minnich, 1990), but awareness that this is a global pattern has remained elusive. In part this reflects the narrow regional focus of most ecological research, and in part the continuing influence in Europe and on vegetation mappers of traditional succession theory (Clements, 1916), with its notion of climatic climax, or one, predictable vegetation, in the absence of disturbance, for each distinct climate.

CLIMATIC PATTERNS

> "Although the Mediterranean Basin has given its name to one of the earth's most distinctive climatic types, the region as a whole is not a good model of subtropical summer-dry climate (Cs) in its simple or pure form. Only the southern and eastern parts can so qualify." — Trewartha, 1961:11

Seasonal rainfall patterns in the Mediterranean Basin vary remarkably over short distances, and some areas bordering the Mediterranean Sea (especially in the north) experience only mild summer drought or even a summer precipitation maximum. Evergreen sclerophylls vegetate some of these areas (Blumler, 1991; 1993). To the east, a huge winter-rain region extends from the Levant to the Hindu Kush, Pamirs, and Tien Shan, with no maquis despite summer drought as severe as in any part of the Mediterranean Basin (Perrin de Brichambaud and Wallén, 1963; Walter and Lieth, 1967; Walter *et al*., 1975; Blumler, 1991; 1993). As in the Mediterranean, summer drought decreases to the north; in contrast to the Mediterranean, summer monsoon rains come into play towards the southeast. For want of a better term, I shall call this region the Near East, though most would not define it so broadly. Much of the Near East is too dry, and some of it may be too cold, to support maquis type vegetation, but this still leaves extensive regions of true, i.e., winter-wet, summer-dry, mediterranean climate, as discussed below. In any case, a purely climatic definition, without reference to vegetation, probably would ignore winter temperature. For one thing, high mountain ranges within the Mediterranean and other summer-dry regions can experience very cold temperatures. And summer drought is distinctive on our mostly summer wet planet.

Because of the complexity of precipitation patterns in the Mediterranean and Near East, there has been considerable confusion concerning climatic similarities and differences between mediterranean regions. For instance, it sometimes is stated that nowhere in the Mediterranean and Near East is there a large area of Csb (cool summer) climate, and that Mediterranean summers are not as dry as in California and Chile (Aschmann, 1973; Cody and Mooney, 1978). In fact, the Iberian and Moroccan Atlantic coasts are Csb. Western Morocco's climate is also similar to California's with respect to seasonal distribution of precipitation, while much of the eastern Mediterranean experiences a drier summer than any part of the New World (Blumler, 1984). The most severe summer drought in a winter-wet region is found in the Fertile Crescent, especially along its southern margins in Palestine and southwestern Iran (Perrin de Brichambaud and Wallén, 1963; Walter and Lieth, 1967; Blumler, 1984). Not only are summers here bone-dry, they also are hotter than in other mediterranean regions. In a sense, then, the Fertile Crescent has the purest mediterranean climate in the world. But only its western arm is along the Mediterranean Sea, and only that western arm supports broadleaved, evergreen, sclerophyll shrubland or woodland. In contrast, the smallest degree of summer drought, among the so-called mediterranean regions, occurs in South Africa (Cape Province) and the northern portion of the Mediterranean Basin.

Climatic Requirements of Sclerophylls

Estimates of the amount of precipitation required to support sclerophyll shrubland vary, but most would agree on a minimum in the range of 250-400 mm annually. In any case, much less than this and the contrast between summer drought and winter rain becomes blurred. There is less agreement concerning winter cold. Broadleaved evergreen sclerophylls are susceptible to winter cold, though there may be exceptions (Barbour and Minnich, 1990). Woodward (1987) suggested that broadleaved evergreen sclerophylls are eliminated by annual minimum temperatures of about -15° C. Aschmann (1973) hypothesized that places experiencing temperatures below freezing during more than 3 % of the hours of the year might be too cold for chaparral. Unfortunately, however, climate records from many countries do not include appropriate data. Therefore, monthly mean temperatures are typically used in determining what regions may be too cold to qualify as mediterranean. For instance, the International Geographical Union's Study Group on Mediterranean Erosion and Desertification decided, after much discussion, to exclude places with mean temperature in any month < 0°C.

Table 1 (see also Fig. 2) presents climatic data for selected stations (it should be noted that some have short climate records, unfortunately). Marseille and Madrid, both surrounded by evergreen sclerophyll vegetation, receive considerable summer rain and appear to be as cold in winter as stations in the northern and eastern Fertile Crescent (Urfa to Kermanshah) as well as those in low-elevation interior California (Colusa, Auberry). The latter are located below, i.e., are warmer than, the chaparral belt. California's Central Valley, where Colusa is located, was a grassland when Europeans first arrived, while Auberry in the lower foothills of the Sierra Nevada is surrounded by deciduous oak (*Quercus douglasii*) park forest. Yosemite Valley is just above the main chaparral belt, though chaparral shrubs do occur there. Maimana is representative of a strip of winter-wet, summer-dry climate running across northern Afghanistan. No sclerophylls occur there. In contrast, the Afghanistan-Pakistan border region represented by Peshawar, supports maquis and receives rain in winter and summer, with short spring and fall droughts. Payson, Arizona, also receives both winter and summer rain, though its winter temperatures are more similar to northern Afghanistan. Chaparral occurs in near Payson, on sites that presumably are at least as cold.

Table 1. Winter cold, summer drought, mean annual precipitation, and evergreen sclerophyll vegetation in selected locations (Walter *et al*. 1975; Blumler, 1984; 1992).

Location	Annual Precip.	Jan Temp.	Jun-Aug Precip.	Broadleaved Evergreen Sclerophylls	
				Locally?	Regionally?
Marseille	572	7	69	yes	yes
Madrid	412	5	43	yes	yes
Urfa, Turkey	465	5	0	no	no
Siirt, Turkey	710	2	8	no	no
Mosul	382	8	0	no	no
Kirkuk	379	9	0	no	no
Khanaquin, Iran	327	9.5	0	no	no
Kermanshah, Iran	489	3	0	no	no
Maimana, Afgh.	400	2	1	no	no
Peshawar, Pak.	344	10.5	80	no	yes
Colusa, CA	379	8	8	no	yes
Auberry, CA	591	7	4	no	yes
Yosemite NP, CA	895	2	30	no	yes
Payson, AZ	561	2	128	?	yes

Mean precipitation in mm, mean monthly temperature in °C

Examination of this table suggests that the IGU's rule of thumb of a 0°C mean monthly lower bound for broadleaved evergreen sclerophyll vegetation may be valid. But Conacher and Sala's (1998) map, supposedly based on this criterion, mistakenly excludes the eastern Fertile Crescent and northern Afghanistan even though they are warm enough. The excluded regions have in common that they receive plentiful rain in winter, but experience extreme summer drought. Aschmann (1973) also excluded those regions, after estimating the number of hours below freezing with Bailey's (1966) nomogram. But Bailey himself acknowledged that his nomogram is not a good predictor of number of hours below freezing. Subsequently, Aschmann (1985) recognized that the southern Zagros, a region vegetated with scattered winter deciduous trees, meets his criteria for mediterranean climate. In contrast, his criteria also exclude parts of the Mediterranean, such as the Spanish Meseta Central, that are vegetated with evergreen sclerophylls.

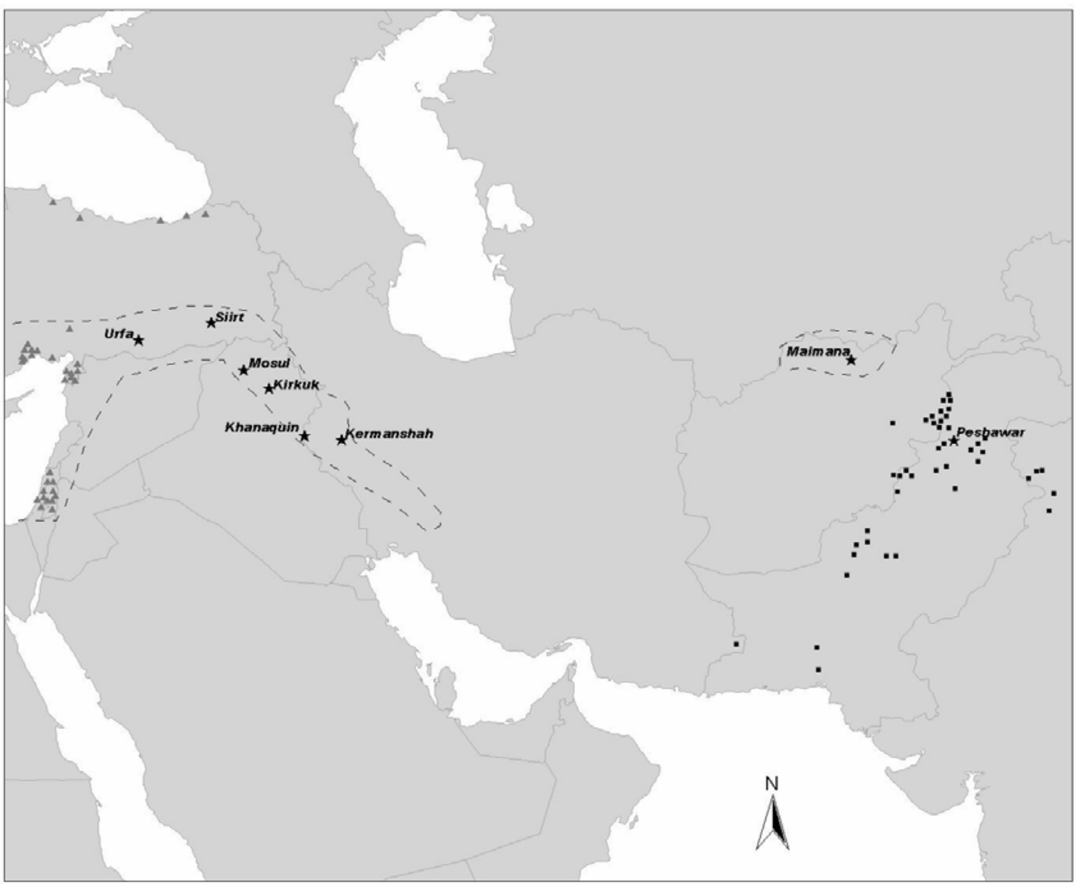

Figure 2. Near East location map, showing cities listed in Table 2, and distribution of wild olive, a sclerophyll. *Olea europaea* is delineated as triangles on the west; *O. ferruginea* (which is included in *O. europaea s. l.*) as squares, on the east. Approximate limits of winter-wet, summer-dry climate are also outlined. There may be additional patches of this climate, for instance in northeastern Iran, but climatic data are limited.

EVERGREEN SCLEROPHYLL DISTRIBUTION

Broad-leaved, evergreen, sclerophyllous shrublands are important components of the vegetation in several regions with non-mediterranean climates, such as Arizona, Mexico, the Indus watershed in northern Pakistan and adjacent Afghanistan, many parts of Australia, and east of the Cape of Good Hope (Freitag, 1971a; 1971b; Axelrod, 1973; Seddon, 1974; Raven and Axelrod, 1978; Kruger, 1985; Barbour and Minnich, 1990). Awareness of such "exceptions" has given rise to attempts to somehow subsume the climates of these regions under the rubric of "mediterranean" (Kruger, 1985; Quézel and Taylor, 1985; Keeley and Keeley, 1988; Specht, 1988). But since these regions receive their precipitation maximum in summer, it would be preferable to use some other term. I would suggest "subtropical semi-arid", since all the above regions, as well as those true mediterranean climate regions with sclerophylls, are subtropical with drought periods though not necessarily in summer.

In contrast, there are large regions with mild, rainy winters and severe summer drought, such as the Zagros foothills of Iraq and Iran, that do <u>not</u> support evergreen shrub vegetation (Fig. 2) (Blumler, 1984; 1991). Moreover, even in summer dry regions that do have sclerophylls, they often are absent from the most summer-dry microsites.

It is widely believed that winter cold is a major limitation on the distribution of sclerophylls, and hence on maquis (Mitrakos, 1980; Larcher, 1981; Quézel, 1981; Woodward and Williams, 1987). The prevailing assumption seems to be that areas such as the Zagros Mountains lack maquis for this reason. However, existing temperature records indicate that the Zagros and several other non-sclerophyllous regions do not experience winter temperature extremes beyond those of the Spanish Meseta Central, which receives some summer rain, and is vegetated with evergreen oaks (Table 1). In any case, evergreen dicotyledonous shrubs can be found in very cold environments, such as the arctic tundra and at high altitudes in the Sierra Nevada of California. *Quercus vaccinifolia* ranges up to 3000 m in the Sierra Nevada (Munz and Keck, 1959), though presumably, it grows where there is reliable snow cover. Though not broad-leaved, conifers also are sclerophylls and most are evergreen — and often are remarkably cold tolerant (Woodward, 1987).

Mediterranean climates are thought to be recent. Dating their onset depends on one's definition of the degree of summer drought necessary before a climate can be called mediterranean, and also on one's interpretation of plant adaptations to climate. Axelrod (1973) concluded from an analysis of fossil floras that California had plentiful summer rain through the Miocene, and that summer drought developed progressively during the Pliocene. True mediterranean climate did not appear until the early Pleistocene, and then only during interglacials, being eliminated again during glacial pluvials. Axelrod recognized that evergreen sclerophyllous shrubland is found under summer rain conditions in many regions today; accordingly, he did not regard the presence of chaparral taxa as evidence for the existence of summer drought. Axelrod's interpretation is supported by geophysical evidence and consideration of the potential climatic effects of plate movements, which suggest that summer drought began to develop after the mid-Miocene (Minnich, 1985).

Axelrod (1973) also suggested, based on a review of more limited evidence, that climate in the Mediterranean underwent a similar and essentially synchronous pattern of development. Suc (1984) concluded from a study of pollen cores taken off the coasts of southern France and northeastern Spain that summer-dry conditions commenced around 3.2 million years ago. True mediterranean vegetation, however, did not appear until 2.3 million years B.P. Like Axelrod, Suc was aware that evergreen sclerophylls grow in summer-moist conditions today, and thus his interpretation of the pollen record was similar. In short, it appears that many sclerophylls pre-date the development of true mediterranean climate. Sclerophylls are well-adapted to the shorter periods of moisture stress characteristic of the less seasonal climates of the early- and mid-Tertiary. The distributional and climatic evidence presented here, however, suggest that they are not well-adapted to true mediterranean climates, i.e., featuring winter rain and severe summer drought.

Schimper (1898) thought sclerophylly an adaptation to drought. Later, it was observed that sclerophylls are common on infertile soils even under humid conditions (Beadle, 1966; Small, 1973; Janzen, 1974; Seddon, 1974; Chapin, 1980). Grime (1979) noted that sclerophylls have the characteristics of "stress-tolerators" in his tripartite system, being adapted to slow but steady growth under conditions in which rapid growth is either impossible or detrimental. Beadle (1966) showed that the level of soil phosphorus affects the degree of sclerophylly, with low soil P conferring increased leaf hardness; in Australia, sclerophylls are strongly correlated with soil infertility. Much of the Mediterranean is covered by skeletal or poor soils, and this is one reason that maquis vegetation is widespread there (Specht, 1969; Cody and Mooney, 1978; Blumler, 1984) — although it is not so ubiquitous as is generally believed. Evergreen species are rare or absent on fertile, deep, or heavy soils in parts of the Mediterranean and Near East where summer drought is severe, and woody plants in general are widely scattered in such areas (Blumler, 1984, 1991, 1992, 1993, 1998). The same is true in California (Hanes, 1981; Blumler, 1991).

The distribution of Mediterranean sclerophylls provides strong evidence that they are <u>not</u> primarily adapted to winter-wet, summer-dry conditions. *Olea europaea s. l.* (wild olive) is widely spread from Africa to southeastern Afghanistan in non-mediterranean climates (Freitag, 1971b; Wickens, 1976), and even *O. europaea s. s.* can be found along the Black Sea where there is little summer drought (Fig. 2). The mastic (*Pistacia lentiscus*) grows in East Africa, where precipitation occurs primarily in summer (Zohary, 1973). The carob (*Ceratonia siliqua*) grows in summer rainfall areas in the southern Arabian peninsula (Zohary, 1973). And although the holly oak (*Quercus ilex*) has a largely mediterranean distribution, the sibling species *Q. baloot* grows in southeastern Afghanistan under monsoon influence (Freitag, 1971b; 1982). Thus, of the five most characteristic evergreen sclerophylls of the Mediterranean region, only the kermes oak (*Q. coccifera*/*Q. calliprinos*) has a mediterranean-climate distribution — and even it can be found in areas that receive significant quantities of summer precipitation.

The difficulty evergreen sclerophylls experience where summers are extremely hot and dry is also illustrated by what I call the "Zagros gap" in sclerophyll distribution. Taxon after sclerophyll taxon ranges east in the Mediterranean Basin to the Levant or western Turkey (Browicz, 1978; 1982-88), but the Zagros and other ranges of southeastern Turkey, Iraq, Iran, and Afghanistan are dominated almost exclusively by winter-deciduous species (Freitag, 1971ab; 1982; Zohary, 1973; Browicz, 1978; 1982-88). Evergreen species reappear on the southeastern slopes of the Hindu Kush (Freitag, 1971ab; 1982; Meusel, 1971; Browicz, 1978; 1982-88), where a strong monsoon influence reduces summer drought considerably. This pattern, which is seen most clearly in Browicz' (1978; 1982-88) numerous excellent distribution maps, applies even to conifers. Only junipers, the most xeric of conifers, are widely distributed in Near Eastern ranges, and even they occur primarily in the north, where there is less summer drought. Pines do not range southeast of an area along the Turkish/Iraqi border that receives high precipitation amounts during a relatively long rainy season; they appear again, along with cedar, spruce, and fir, in southeastern Afghanistan/northern Pakistan. Freitag (1971ab) noted this pattern within Afghanistan; he stated that winter precipitation seems to be very high in some parts of northern and central Afghanistan, and suggested that summer drought must be the factor excluding evergreen conifers there. Freitag (1982) also pointed out that some of the cedar populations must withstand extremely cold winters.

The Near East may have been subject to severe depression in winter temperatures during the Pleistocene (Blumler, 2002), which could have eliminated many sclerophylls. However, relict populations of several taxa do exist, and one would expect that these would have expanded during the early Holocene, at least before human impacts became pervasive. Deciduous oaks expanded in the Zagros until about 5500 BP. (van Zeist, 1969). Remnant populations of wild olive and cypress in the southern Zagros, however, have remained remnant. The southern Zagros is on the northern edge of the region of monsoon influence today (Bauer, 1935); in the early and mid-Holocene, this region probably received significant summer rainfall (Kutzbach and Otto-Bliesner, 1982). That is, sclerophylls may have survived, barely, in the southern Zagros not so much because of mild winter temperatures, but because seasonality of precipitation was, and perhaps is, not as extreme as further north. Since woody evergreen dicotyledons are generally more tolerant of cutting, browsing, fire, and plowing than are deciduous taxa (Blumler, 1991), it is difficult to see how people could have been responsible for the greater success of deciduous trees (*Quercus*, *Pistacia*, *Amygdalus*, and many, many others) in the Zagros and other Irano-Aghanistani mountain ranges during the Holocene.

CONCLUSIONS

For historical reasons, and because of the continuing influence of climatic climax theory, many ecologists, biogeographers, and global climate modelers, and all vegetation maps, assume the relationship:

mediterranean climate = wet winters with severe summer drought= natural dominance by evergreen sclerophyllous shrubs, because the hybrid nature of definitions of mediterranean regions has been overlooked. In fact, however, there are really <u>two</u> "mediterranean-type" climates:

(1) that which favors annuals (wet winters with severe summer drought [Blumler, 1984]); and

(2) that which favors evergreen sclerophylls (semi-arid, with relatively short, hot and dry spells).

The latter might better be termed "subtropical semi-arid" or "submediterranean", despite the fact that it is characteristic of a considerable part of the Mediterranean Basin. It clearly has been around a long time, as have sclerophylls. The climate that favors annuals, on the other hand, is recent. Sclerophyllous shrubs are adapted to relatively short dry periods because they do not need to waste time growing new leaves when wet conditions return. But as drought lengthens, the likelihood increases of loss of leaves or shutdown of photosynthesis to conserve water. Consequently, in the more summer-dry portions of mediterranean climate regions evergreen sclerophylls become restricted to soil types that conserve moisture, or as in the Zagros, are absent altogether. In contrast, annuals become progressively more dominant as summer drought increases, since they avoid the drought as dormant seeds, but can grow rapidly during the wet season (Blumler, 1984).

Vegetation mapping of winter-wet, summer-dry (and other subhumid) climate regions is problematic for the simple reason that several different vegetation types typically co-occur. In the case of the low elevation portions of the Mediterranean Basin, for instance, there are in addition to maquis, evergreen oak forest, deciduous oak park forest, evergreen oak park forest, annual grassland, perennial grassland, phrygana (low malacophyllous shruband), to name just a few. Given the spread of GIS technology, it should be possible now to map the various co-occurring vegetation types as separate layers, rather than oversimplifying by pretending that only a single type grows within the climate region. This would lead to greater appreciation of the vegetation complexity and should lead also to research into the specific adaptations of plant growth forms such as evergreen sclerophylls. Hopefully, too, it would lead to a much needed improvement in the complexity of vegetation map output from GCM predictions of future climate change.

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