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Southwestern North America

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Landscape and Climate

Dynamic change and great diversity have characterized the Holocene vegetation of the western and southwestern portions of the North American continent. This region encompasses the modern states of California, Nevada, Utah, Arizona, New Mexico, and adjacent regions of Oregon, Idaho, and Texas in the United States, and the states of Baja California, Baja California Sur, Sonora, Sinaloa, Chihuahua, Durango, and western Coahuila in northern Mexico.

Driven by the interaction of climate, topography, and distance from the Pacific Ocean, and the Gulf of Mexico, vegetation communities as diverse as desert shrub, semi-arid woodlands, montane forests, and tundra can be found within relatively short distances of each other in the region. Topographically the region varies from sea-level coastal plains to extensive interior plateaus sometimes lying at over 1,300 meters with flanking mountain ranges with peaks well over 3,000 m (Hunt, 1967). The north–south to northwest–southeast trending mountain ranges which dominate the region serve both to impede the flow of moisture-laden storms from the Pacific, and to channel monsoonal storms from the Gulf of California and the Gulf of Mexico.

For discussion purposes, the area can be divided into three large regions based upon the dominant climate influence upon it. These include: (1) most of California west of the crest of the Sierra Nevada Mountains, (2) the high-elevation interior plateau known as the Great Basin which lies east of the crest of the Sierra Nevada Mountains, and (3) the Desert Southwest which lies south and southeast of the Great Basin extending into northern Mexico.

Coastal vegetation ranges from rainforest in the north to chaparral in the south. The interior Central valley before Euro-American settlement was characterized by mixtures of shrubs, grasses, and other herbaceous plants in the north which graded southward into shrubby steppe. Oak-dominated deciduous woodlands flanked (and to a lesser degree still flank) the Central valley on all sides. Lying above the deciduous forests, the intermediate elevation slopes of the Sierra Nevada Mountains still support pine-dominated montane forests. These make a transition into pine-dominated sub-Alpine woodlands at higher elevations, and to sub-Alpine grasslands and tundra at even higher elevations in some areas.

East of the crest of the of the Sierra Nevada Mountains the lowest elevation basins in the Great Basin are characterized by shadscale- (saltbush) dominated desert shrub communities (Billings, 1951). On the surrounding slopes this transitions into sagebrush-dominated steppes. Piñon pine and juniper dominate semiarid woodlands that cover the intermediate mountain slopes of the region. In the case of the lower mountain ranges in this region this plant community comprises the highest elevation vegetation community as well. Limber pine-dominated sub-Alpine woodlands are found above the semi-arid woodland in a few of the higher ranges. Only the highest mountain ranges of the region support narrow zones of ponderosa pine and white fir-dominated montane forests between the semiarid and sub-Alpine woodlands. Sub-Alpine grasslands, and/or Alpine tundra occur rarely above the sub-Alpine woodland in only the highest mountain ranges.

Similar to the Great Basin, the Desert Southwest is a region of dramatic contrasts in topographically governed microclimate and vegetation. Most of southern Nevada, eastern California, and northwestern Arizona is covered with Mohave Desert vegetation. The most common valley floor vegetation community within the Mohave Desert is dominated by creosotebush and white bur-sage. Joshua tree is characteristic of many of the alluvial fans that surround the broad basins of this area. However, the vegetation of the region also includes a great diversity of other shrubs, and cacti. In fact, desert vegetation diversity increases southeastward from the Great Basin and into southern Arizona. In central Arizona the Mohave Desert vegetation transforms into the richly diverse Sonoran Desert. A great variety of cacti characterize the vegetation communities of the Sonoran Desert. Sahuaro cactus, paloverde, and brittlebush are common in these communities. In extreme southestern Arizona and southwestern New Mexico the Sonoran Desert gives way to the Chihuahuan Desert. Primarily a shrub desert lying above 1,100 m, most of the Chihauhuan Desert lies further south in the Mexican states of Chihuahua, Coahuila, and parts of Durango, Zacatecas, Neuvo Leon, and San Louis Potosi (Lowe, 1977). Much of the altiplano is dominated by Chihuahuan Desert shrub desert vegetation. Tarbush, creosotebush, and white thorn are among the most abundant species represented in the these communities, though grasses, yuccas, and cacti are also common (Lowe, 1977). Changes in soils often result in dramatic shifts in vegetation community composition over very short distances in the Chihuahuan Desert (Lowe, 1977: p. 21).

As in the Great Basin, the northern portion of the Desert Southwest, piñon pine and juniper codominate semiarid woodlands that cover many of the lower elevation mountain ranges, and the intermediate elevation slopes of the higher ranges (Lowe, 1977). Above this on the higher ranges, lying in the western portion of this region, limber pine and, occasionally, white fir are found. In the northeastern part of this region, montane woodlands dominated by ponderosa pine overlie the semiarid woodland. Above this, fir becomes more common; on the highest mountains, spruce may be found mixed with fir.

In southern Arizona, however, oak, and oak pine woodlands and chaparral replace piñon juniper semiarid woodlands on intermediate elevation slopes. Higher mountain ranges still support ponderosa pine at lower elevations in the montane forest, and fir and spruce fir forests at highest elevations.

Climatically the three regions can be generally characterized by the distribution of seasonal rainfall and temperature. California can be divided into a northern area which is characterized by cool wet winters and warm dry summers. The southern area is characterized by warm moist winters and hot dry to moist summers. The Great Basin is generally characterized by cold, moist winters and hot, dry summers. The Desert Southwest is characterized by warm dry winters and hot moist summers.

The climate of this region reflects the effects of both the heterogeneous topography and the varying impact of three major air mass systems that intersect over it (Houghton *et al.*, 1975). The predominance of these air masses varies both seasonally and annually to influence the weather of the region today. In the past, changes in their average position have resulted in significant changes in the distribution of vegetation communities within the region, and upon the animals and peoples that have depended upon them. These systems converge upon the central Great Basin from the west, southeast, and northeast and can be described as follows:

- *Pacific*: a regime dominated by maritime polar air masses. These moist cool air masses from the Pacific Ocean produce cool, wet winters, and their absence in summer makes the growing season hot and dry.
- *Gulf*: a regime dominated by maritime and continental tropical air masses. These warm, moist air masses entering the southwest from either the Gulf of Mexico or the Gulf of California produce hot, moist summers with mid-summer torrential rainfall (originating during convective storms) and warm dry winters.
- *Polar*: a regime dominated by continental polar and Arctic air masses. These cold dry continental air masses from the North American interior extend into the Great Basin from the northeast during the winter.

Movements of these air systems, and their impact on local and regional climate, are reflected in changes in hydrology, erosion/deposition processes, and vegetation. Displacement of winter and summer stormtracks, and variations in the penetration of the summer monsoon are all affected by the realignment of these pressure systems through time.

Pollen Records

Climate not only affects the ecology of the region but it has also determined where pollen records are found as well as their quality. The distribution of palynological evidence in the region is primarily constrained by moisture differences. The major sources of late Quaternary pollen records in the region include lacustrine and marsh deposits, dry cave deposits, alluvial and cienega deposits, and ancient woodrat middens (a unique source for the North American record).

In general, the number of well-preserved pollen records from aquatic environments at all elevations decreases southward, reflecting the greater rarity of lakes and marshes. Most lacustrine records span only a few thousand years, though some span the full Holocene and, in rare cases, extend well into the Pleistocene. Springs and associated ephemeral ponds are the primary source for well-preserved Holocene pollen records in the southern portion of this region. These often provide records spanning the Holocene; however, they often miss the middle Holocene. Also, they are often complex and difficult to interpret because of dramatic changes in deposition rates, and occasional hiatuses. However, high organic production in some of these records results in rapid rates of sediment accumulation which make them amenable to the examination of high-frequency vegetation records. These can be compared with tree-ring data to generate detailed records of regional climate and vegetation response.

Pollen records from ancient woodrat middens usually have excellent preservation. However, their interpretation must be constrained by the fact that they represent the collecting activities of woodrats, and often are found in sheltered localities where airfall pollen is much reduced. Woodrat midden pollen samples are obtained from the radiocarbon-dated layers of crystallized urine-encased nest materials that comprise an ancient nest (Betancourt *et al.*, 1990). Each pollen spectrum obtained from each a layer represents a single 'snapshot' of a particular point in time on the landscape.

Alluvial, cienega, and cave pollen samples from the North American west and southwest suffer from stratigraphic, that is, chronometric problems. Alluvial and cienega deposits can represent highly variable depositional environments that contain scant organic materials for radiocarbon dating. Cave deposits, from the dry caves of the interior, often contain abundant material for radiocarbon dating, but because rodents nest in the loose deposits, they are often heavily mixed. However, pollen preservation in cave deposits can be excellent in comparison to the heavily oxidized and/or mechanically abraded pollen found in alluvial and cienega deposits.

The Data

Pollen records from the west and southwest are not as abundant as those from the eastern or northwestern portions of North America. In addition, many of the analyzed records have either not been published or are only partially published. Many are only recorded in Doctoral dissertations, Masters' thesis, or in project reports or 'gray literature.' More recently, some have been published on the internet. The coverage in this article is restricted to those sites that have recently been published in peer-reviewed literature, and provide more detailed, regionally representative vegetation and climate histories. Older palynological research is covered in several review articles Mehringer (1985), Hall (1985), Adam (1985), Mehringer (1986), and Martin and Mehringer (1965), and more recent research in the Great Basin by Wigand and Rhode (2002).

The Holocene vegetation record from the west and southwest is as diverse as its landscape. However, it can be characterized by several general trends, as well as by crosscutting climatic events that are found in most of the region. These events can be tracked by tracing the response of climate indicator species which are characterized by wide spatial distribution, and relatively rapid response to changes in climatic input. Differences in the magnitude of these events from one area to the next reflect the varying predominance of the major climate influencing air masses discussed above. Below are summarized some of the salient trends and crosscutting events from a region-wide perspective. Select sites will be briefly discussed later.

Vegetation and Climate History of the North American West and Southwest

General Summary

The Pleistocene/Holocene transition has been variously placed at 12,000 or 10,000 rcyr BP based upon geologic, glacial, or other criteria. We will simply indicate that the major break in vegetation assemblages between the Pleistocene and Holocene in the west based upon dissimilarity analysis of pollen spectra usually occurs about 12,000 to 11,500 rcyr BP. The following period, which corresponds to the Younger Dryas in Europe, is usually characterized by initial drought followed between 11,200 and 10,200 rcyr BP by effectively moister conditions, probably driven by colder temperatures and reduced evaporation rates rather than by an increase in precipitation.

Warm, moist conditions seem to have predominated much of the interior of the region between 10,200 and 8,500 rcyr BP. These conditions may have resulted from increased late spring through mid-summer precipitation as evidenced by the pollen record, woodrat midden plant macrofossils (Wigand and Rhode, 2002), and spring discharge in the northern Mohave Desert (Quade *et al.*, 1998).

During the middle Holocene, much warmer and drier conditions seem to have characterized much of the interior west and southwest between 8,000 and 5,500 rcyr BP The southern part of the region, however, apparently enjoyed a significant increase in late spring or mid-summer rainfall. Between 5,600 and 5,500 rcyr BP a major episode of increased winter precipitation recorded from the Plateau of Eastern Washington well into the northern Mojave brought middle Holocene drought to a sudden halt. Although there was a brief return to slightly drier conditions after this event, they were never as severe as before 5,500 rcyr BP

Increasing winter precipitation after 5,000 rcyr BP climaxed in the interior between 4,000 and 2,600 rcyr BP during the Neopluvial. Renewed drought cycles characterized the period between 2,600 and 1,700 rcyr BP, but were interrupted by a dramatic winter wet event centered between about 2,100 and 1,900 rcyr BP Between about 1,700 and 1,000 rcyr BP increased grass abundance, piñon pine expansion, and increased marsh water depth confirm a period of highly variable, near-decadal variations in precipitation with a shift from winter to late spring to mid-summer dominance.

A return to winter-dominated precipitation in the northern portion of the region about 1,000 rcyr BP signaled the beginning of generally much drier conditions punctuated by a significant warm, moist event about 730 rcyr BP A return to drier conditions followed until about 250 rcyr BP when a return to cooler, moister conditions may signal the last phase of the Little Ice Age in the region. These conditions ended about 150 years ago. Vegetation since then probably reflects the impact of both the Euro-American settlement as well as climate. A few key pollen records whose locations can be found on Figure 1 are discussed below.

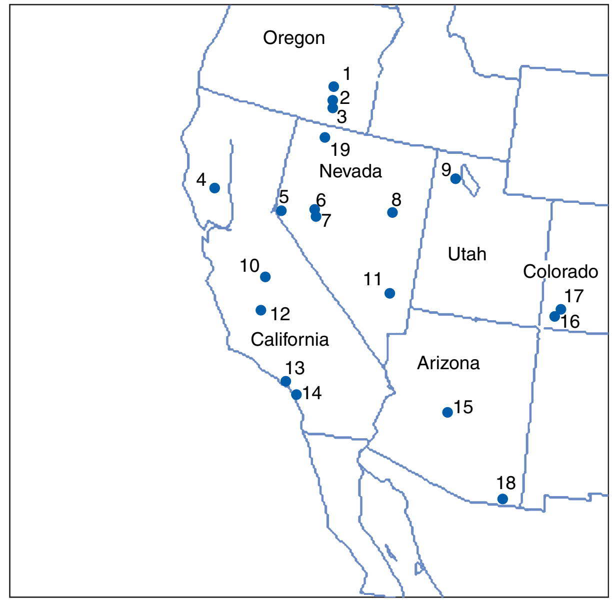

Figure 1 Location of published, radiocarbon-dated Holocene pollen records from the western and southwestem US mentioned in the text. Most of these are not in the NOAA National Climatic Data Center's North American Pollen Data Base. The sites are: 1, Diamond Pond; 2, Fish Lake; 3, Wildhorse Lake; 4, Clear Lake; 5, Little Valley; 6, Lead Lake; 7, Hidden Cave; 8, Ruby Marshes; 9, Crescent Spring; 10, Exchequer Meadow; 11, Lower Pahranagat Lake; 12, Tulare Lake; 13, Ballona Estuary; 14, San Joaquin Marsh; 15, Montezuma Well; 16, Twin Lakes; 17, Beef Pasture; 18, Double Adobe; 19, Summit Lake.

The Details

Coastal California The Clear Lake microfossil record from the north central coastal range of California reveals the dramatic shift from pine and Cuppressaceae – *Pinus*-dominated conifer forest to oak-dominated deciduous forest during the Pleistocene/Holocene transition (Adam, 1988; *see* Northwestern North America). With a sample roughly every 500 years this record reveals a maximum extent of oak forest about 7,500 rcyr BP. Thereafter, various shrubs and low-growing trees in the Rhamnaceae family (*Ceanothus* and *Rhamnus*) become more abundant, remaining so (except for the period between about 4,000 to 2,600 rcyr BP) until the present (Adam, 1988). *Chrysolepis* (chinquapin), *Alnus* (alder), *Salix* (willow), and less commonly *Artemisia* (sagebrush) and grasses comprise the major part of the Holocene plant community in the area.

In east central California the record from Exchequer Meadow located in the montane forest on the west slope of the Sierra Nevada Mountains indicates that the transition from an *Artemisia*-dominated alpine tundra and wet sedge meadow community to a a *Pinus* (pine)-*Abies* (fir) dominated montane forest had begun as early as 12,000 rcyr BP (Davis and Moratto, 1988). However, it was not fully established until about 8,500 rcyr BP. Lower elevational deciduous oak forest expansion is reflected in the rise of *Quercus* (oak) pollen about 11,500 rcyr BP, but it is not until about 9,000 rcyr BP that it is clearly well established at lower elevations in the region. Renewed abundance of Cyperaceae (sedge) pollen about 5,500 rcyr BP. after a middle-Holocene lull reflects increased regional moisture evidenced in pollen records elsewhere in the region (Davis *et al.*, 1985).

The Holocene portion of a pollen record from the Tulare Lake Basin near the southern end of the Central Valley records a history of lake and marsh fluctuation in its littoral vegetation, primarily Cyperaceae (sedge) and *Typha* (cat-tail) pollen, and pelagic algae (primarily *Pediastrum* sp. and *Botryococcus* sp.) (Davis, 1999) (**Fig. 2**). The absence of a pollen or algae record for the period about 11,500 BP may indicate that the basin was totally dry during the so-called Clovis drought (Davis, 1999, figure 3; Haynes, 1991). Pollen from the base of the Holocene section of the Tulare Lake core dating to about 10,000 rcyr BP suggests that by about 10,200 rcyr BP, marsh vegetation (as evidenced by the littoral vegetation pollen) was restricted, but the abundance of pelagic algae at about 8,900 and 7,900 rcyr BP indicate at least two episodes of deep (Davis, 1999, figure 3). The terrestrial pollen indicates the presence of an extensive, nearby juniper woodland with an *Artemisia* understory which disappeared by 8,000 rcyr BP to be replaced by a saltbush (Chenopodiaceae – *Amaranthus* pollen)-dominated desert shrub community. Copious *Aster*-type (sunflower) pollen from the Holocene record suggests abundance of both shrubs and forbs of the Asteraceae family around Tulare Lake (Davis 1999, figure 3). The greatest abundance of Aster-type pollen occurs between 7,000 and 5,500 rcyr BP, suggesting increased late-spring to middle- summer precipitation. Quercus pollen from the Tulare Lake record suggests that regionally oak was common in the hills surrounding the basin between 9,000 and 3,500 rcyr BP (Davis, 1999, figure 3).

After episodic middle Holocene drought, increasingly wetter conditions are marked by the expansion of littoral vegetation about 4,500 rcyr BP (Davis, 1999, figure 3). The Holocene climax of marsh expansion about 4,100 rcyr BP is followed by an abrupt decline of littoral vegetation and its replacement by

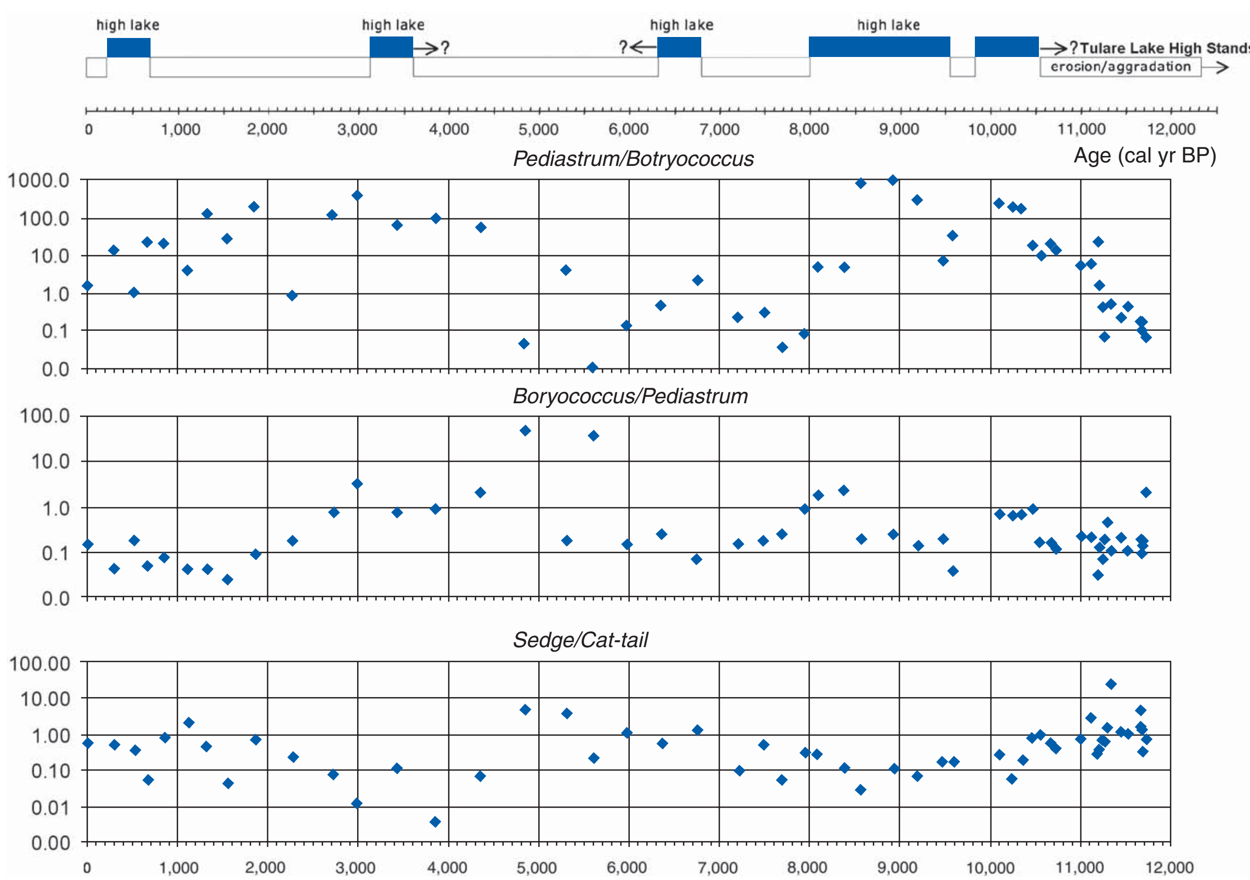

Figure 2 Comparison of reconstructed Holocene high lake stands of Tulare Lake with ratios of littoral marsh species and pelagic algae. High stands were mapped in shoreline trenches by Dr R. Negrini, and this author during the last three years. The ratio of *Pediastrum* to *Botryococcus* algae indicates slightly more oligotrophic (fresher) water conditions vs. more eutrophic (stagnant) water conditions. *Pediastrum* abundance suggests recent recharge of the lake. The sedge to cat-tail ratio reflects marsh extent and stability. Cat-tails appear when there is renewed influx of fresher water into the Tulare Lake Basin. Sedges predominate when there are extended periods of low water. Note that sedge is usually abundant between high lake stands, and lower during high lake stands. The algae and pollen used in these ratios have been standardized with respect to pollen abundance per sample so that they reflect actual increases and decreases in the pollen of these species in the record.

the pelagic algae indicating that water depth within the Tulare Lake Basin rose rapidly to drown the marsh and result in a dramatic expansion of the lake just after 4,000 rcyr BP (Davis, 1999, figure 3). The climax of *Pinus* (pine) pollen (a reflection of increased winter rainfall) in the Tulare Lake record at the same time as the pelagic algae about 2,700 to 2,800 rcyr BP suggests a regional increase in precipitation at that time (Davis, 1999, figure 3). Extremely low charcoal abundance during this period also suggests wetter conditions. Increasing saltbush pollen coupled with decreasing pine, oak, and littoral vegetation pollen, as well as declining pelagic algae abundance suggests significantly drier conditions during the last 2,000 rcyr BP (Davis, 1999, figure 3).

A 7 kyr- long pollen record from the San Joaquin Marsh provides additional evidence that during the middle Holocene coastal southern California had a moister climate (Davis, 1992). Prior to 3,000 rcyr BP pollen from Aster-type plants predominated the pollen record (Davis, 1992, figure 4). After that point in time pollen from plants from the Chenopodiaceae family predominates. In addition, greater abundance of pine, oak, ceanothus, and sagebrush provides further evidence of moister climate. Higher values of Liguliflorae-type pollen prior to 5,000 rcyr BP suggests that this may have been in the form of late-spring through mid-summer precipitation. Ongoing re-analysis by this author of pollen from 12 and 16 kyr long cores from the Ballona Estuary in the southwest corner of Los Angeles confirms this conclusion. There Lamiaceae, *Ceanothus*, and Rosaceae pollen value increases indicate a major chaparral expansion between 8 and 5 ka (**Figs. 2 and 3**).

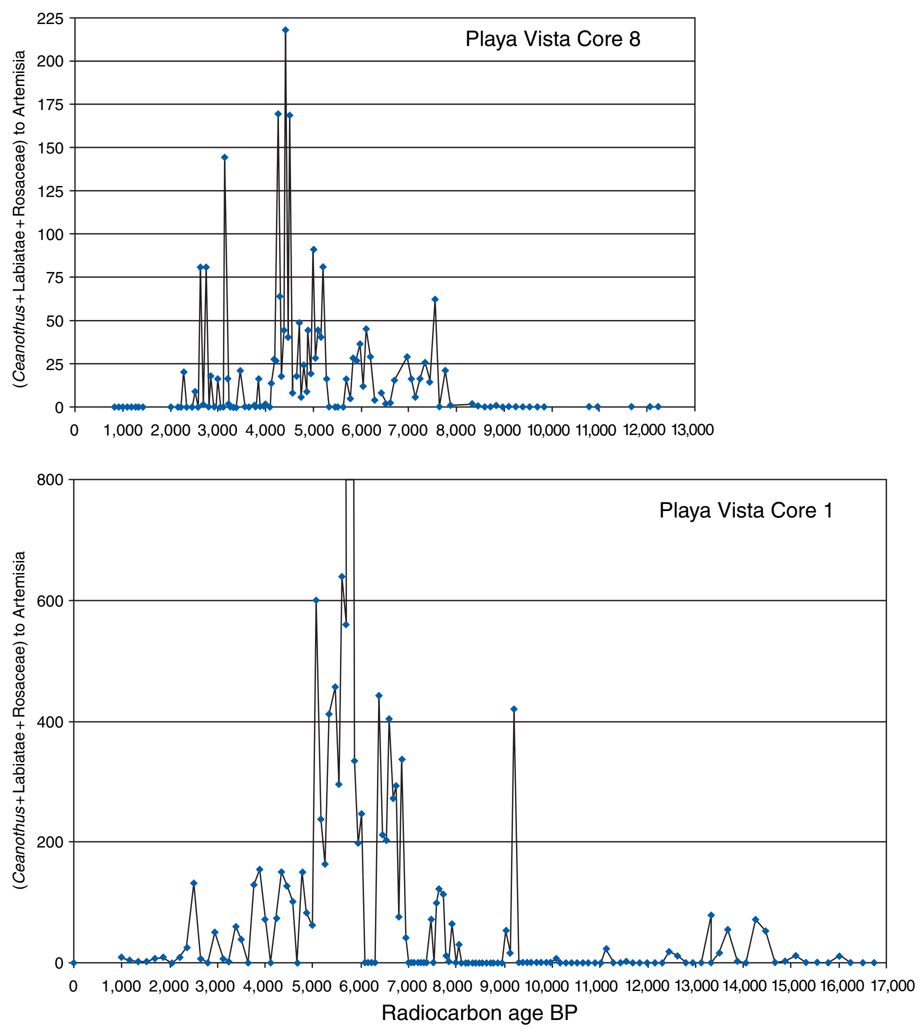

Figure 3 Comparison of the ratio of (*Ceanothus* + Labiatae + Rosaceae) to Artemisia pollen for both Playa Vista Cores 1 and 8. The primary source of *Ceanothus,* Labiatae, and Rosaceae pollen is the moister climate coastal chaparral. *Artemisia* (primarily California sagebrush) is characteristic of the drier coastal chaparral. The period of greatest chaparral expansion between 8,000 and 5,000 rcyr BP corresponds to events throughout the southwestern US.

Great Basin Three pollen records from an elevational transect up the west slope of Steens mountain in south central Oregon provide a record of Holocene vegetation change (Mehringer, 1985, 1986; Wigand, 1987; Johnson *et al.*, 1994). The longest record from Fish Lake (2250 m elevation) provides a 13 kyr record of high elevation sagebrush community dynamics. A ratio of sagebrush to grass pollen indicates that drier conditions predominated between 8,000 and 5,500 rcyr BP (Mehringer, 1985). During the same period sagebrush became more common than grass around Wildhorse Lake at 2,565 m elevation. The 9.4 kyr long record from Wildhorse Lake indicates that grasses did not regain their early Holocene predominance until after 4,000 rcyr BP (Mehringer, 1985). Diamond Pond at 1,265 m at the base of the northwest slope of Steens Mountain records the shifting boundary between the lower sagebrush and desert shrub communities during the last 6,000 radiocarbon years. A brief, but major wet episode about 5,500 rcyr BP resulted in a shift from Sarcobatus (greasewood) to sagebrush predominance in the shrub communities around Diamond Pond. Between 4,000 and 2,000 rcyr BP a further shift to wetter conditions resulted in the expansion of *Juniperus occidentalis* (western juniper) in the volcanic complex around and to the east of Diamond Pond (Mehringer and Wigand, 1990). Close correspondence between the pollen record from Diamond Pond and the macrofossil record from ancient woodrat middens in the same area document the actual arrival and subsequent departure of western juniper. Juniper macrofossils from the ancient woodrat middens also permitted direct identification of the juniper species in the pollen record from Diamond Pond (Mehringer and Wigand, 1990).

The charcoal record reconstructed from microscopic charcoal counted on the pollen slides reveals a dynamic relationship between fuel accumulation during wet climate episodes and fire during subsequent drought in the Diamond Craters complex (Wigand, 1987). It also indicates that when climates became dry enough after 2,000 rcyr BP catastrophic fires resulted in the ultimate demise of juniper woodland at lower elevation sites such as those around Diamond Craters. Such fires characterized other periods as well when forests that expanded during episodes of wetter climate were destroyed at their lower elevational distribution by fire. Increased grass pollen relative to juniper pollen between 1,600 and 1,000 rcyr BP shows a period when the precipitation pattern shifted from winter-dominated to a late-spring through mid-summer pattern (Wigand, 1987).

In the western Great Basin south of Reno, Nevada, a 5.5 kyr long record from Little Valley provides additional evidence of a period of wetter climate between 4,000 and 2,000 rcyr BP ago (Wigand and Rhode, 2002). Lying in the montane forest just east of Lake Tahoe, the pollen from the Little Valley core reveal increasing pine abundance relative to sagebrush after 5500 rcyr BP. Increased alder, Betula (birch), and willow pollen between 4,000 and 2,000 rcyr BP indicate cooler wetter conditions in the Little Valley meadows (Wigand and Rhode, 2002, figure 11).

Expansion of marshes in the Carson Sink west of the Stillwater Mountains as a result of increased precipitation during this period is confirmed by the appearance of abundant *Typha* (cat-tail) pollen in the deposits of Hidden Cave (Wigand and Mehringer, 1985, figure 36). Cat-tail pollen may have arrived naturally, but most reflects human activity in the cave. However, today the nearest marsh is kilometers distant from the cave, and its presence in the cave between 4 and 3 ka suggests that marshes were probably much closer to the site. Wetter conditions between 4,000 and 3,000 rcyr BP are confirmed by the relative increase in sagebrush pollen relative to Chenopodiaceae pollen at Crescent Spring, Utah in the northwestern Bonneville Basin (Mehringer, 1985, figure 11). Late Holocene precipitation increase stands in stark contrast to the severe middle Holocene drought recorded in pollen from the sediments of Hidden Cave (Wigand and Mehringer, 1985), and from lake and marsh sediments in the Ruby Valley of east central Nevada by Thompson (1992).

A 2.3 kyr long core from the Carson Sink east of Fallon, Nevada, provides additional evidence of the late-spring through mid-summer shift in annual precipitation documented in the Diamond Pond core. A significant increase in pine pollen relative to juniper pollen between 1,600 and 1,000 rcyr BP corresponds to an expansion of *Pinus monophylla* (single-leafed piñon pine) documented in the ancient woodrat nests of the region (Wigand and Rhode, 2002, figures 13 and 14).

A recent pollen record from Pyramid Lake (Mensing *et al.*, 2004) suggests that the early middle Holocene, 6,600 to 5,500 rcyr BP was extremely dry, although it included one short but intense wet phase. Evidence of a greatly reduced volume and depth of Pyramid Lake suggests that Lake Tahoe probably did not overflow its rim during this period. The climate became much more mesic after 5,400 rcyr BP with episodes of moister climate corresponding with the Neopluvial between 4,000 and 2,000 rcyr BP (Mensing, 2004, figure 5). The past 2.4 kyr appear to have had three cycles of wetter climate (Mensing, 2004, figure 5). One centered around 1,600 rcyr BP and corresponds with the period of late- spring to summer-shifted precipitation postulated elsewhere (Wigand and Rhode, 2002). Wetter climate between 1,100 and 800 rcyr BP corresponds with a return to increased winter precipitation in the northern Great Basin (Wigand, 1987), and between 350 and 150 rcyr BP with the Little Ice Age (Wigand and Rhode, 2002). The timing and magnitude of the Pyramid Lake wet/dry cycles compares favorably with those found in other pollen records (Wigand, 1987; Wigand and Rhode, 2002), in stable isotope data (Benson *et al*, 2002), in ancient woodrat midden records (Tausch *et al.*, 2004; Mehringer and Wigand, 1990), and with ages of submerged rooted stumps along the eastern Sierra Nevada (Stine, 1994; Lindström, 1990). These drought episodes appear to correspond with the timing of ice drift minima (solar maxima) identified from North Atlantic marine sediments (Mensing, 2004).

Desert West A high-resolution pollen record from Lower Pahranagat Lake about 90 km north northeast of Las Vegas, Nevada, records 3,700 radiocarbon years of low elevation vegetation dynamics in the northern Mohave Desert (Wigand and Rhode, 2002, figure 17). With a sample about every 14 yr for the span of the record, very high frequency climate cycles could be identified, and compared with long tree-ring records in the region (Wigand and Rhode, 2002, figure 17). Although the magnitude is not as great as in the northern Great Basin records, the three major wet phases of the Neopluvial between 4,000 and 2,000 rcyr BP first recorded at Diamond Pond are also evident (Wigand and Rhode, 2002, figure 18; **Figs. 3** and **4**). In addition, the period of late-spring to mid-summer-shifted precipitation recorded in northern and western Great Basin pollen records is also prominent in the pollen sequence from Lower Pahranagat Lake (Wigand and Rhode, 2002, figure 18).

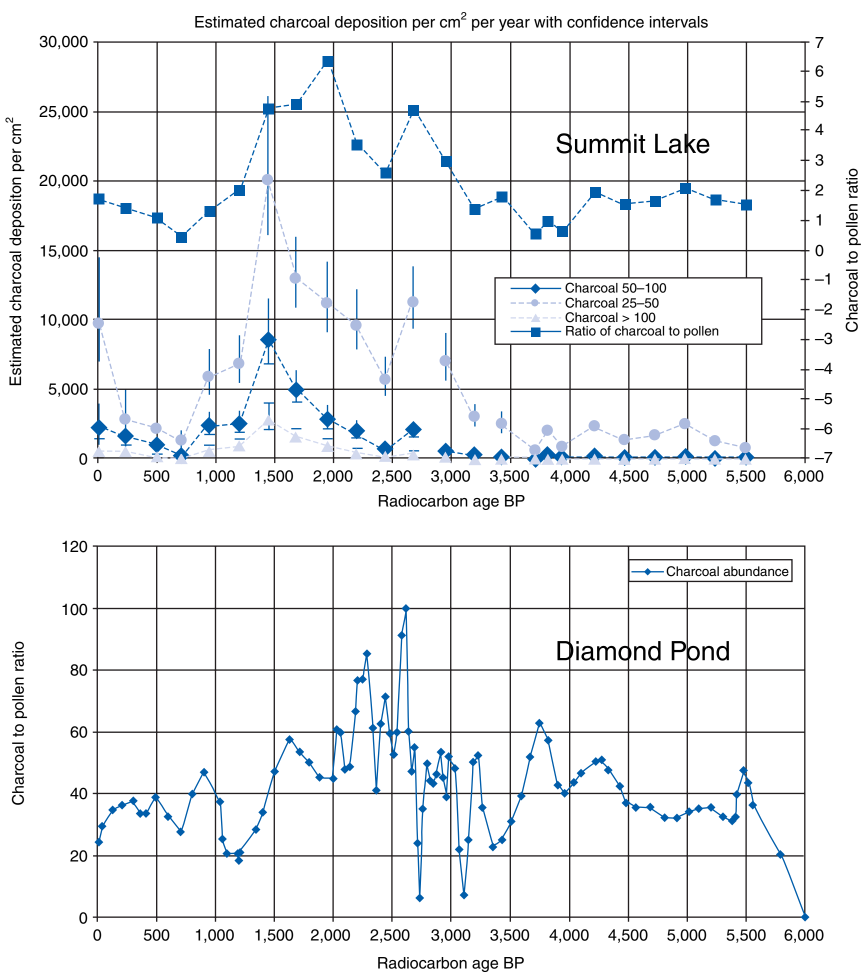

Figure 4 Comparison of the charcoal-to-pollen ratio from Diamond Pond and Summit Lake in the northern Great Basin. Diamond Pond is located on the ecotone between the desert shrub and lower sagebrush communities. Summit Lake lies within the upper sagebrush community in the Black Rock Range of northcentral Nevada. There are other charcoal records in the region that are similar in the timing of charcoal abundance suggesting periods of increased fire frequency due to climate.

Palynological investigations during the middle and late 1950s led Martin (1963) to propose a period of middle-Holocene-increased monsoonal precipitation for central and southern Arizona. Working with pollen records obtained from cienega deposits where pollen preservation is often poor and deposition rates are highly variable with some climatic episodes missing from the stratigraphic record, he proposed that the climate of the middle-Holocene of the Desert Southwest was characterized by heavy summer rains resulting in higher values of Chenopodiaceae pollen. Martin associated increased values of Aster-type pollen with higher water tables, flood plain alluviation, fewer and lighter summer storms, and perhaps increased winter precipitation. If this is the case the record from Double Adobe IV suggests a Neopluvial moist episode similar to those seen between 4,000 and 2,000 rcyr BP in the northern Mohave Desert and the Great Basin (Martin, 1963, figure 19). An extended period of increased Aster-type (Compositae) pollen is centered around 3,800 rcyr BP at Double Adobe. He also recorded that an early Holocene transition from Aster-type pollen dominance to Chenopodiaceae-dominated pollen spectra occurred about 7,900 rcyr BP (Martin, 1963, figure 20).

The Montezuma Well pollen sequence from central Arizona records over 10 kyr of vegetation dynamics (Davis and Shafer, 1992). Declining values of Cupressaceae (probably *Juniperus*), *Fraxinus* (ash), and pine occurred between about 10,000 and 7,500 rcyr BP (Davis and Shafer, 1992). Middle Holocene drought characterized by significantly increased values of Chenopodiaceae pollen after 7,000 rcyr BP occurred at the same time that Cyperaceae (sedge) pollen suffered a dramatic decline (Davis and Shafer, 1992). After 4,000 rcyr BP Chenopodiaceae pollen declined and Cupressaceae pollen values increased, suggesting an increase in regional precipitation contemporaneous with the Neopluvial event seen further north and west. Resurgence of sedge pollen values after 4,000 rcyr BP also substantiates the regional increase in precipitation (Davis and Shafer, 1992) (**Fig. 5**).

Two well-dated pollen records from extreme southwestern Colorado, Beef Pasture, and Twin Lakes reveal more detail of Holocene vegetation in the northeastern corner of the Desert Southwest. Beef Pasture lies near the base of the spruce zone in the La Plata Mountains, while Twin Lakes lies in the middle (Petersen, 1988). *Picea* (spruce) pollen from the Twin Lakes record suggests that prior to about 8,600 rcyr BP spruce was not as abundant around the site. Two episodes between 8,600 to 5,800 rcyr BP imply that spruce reached its greatest

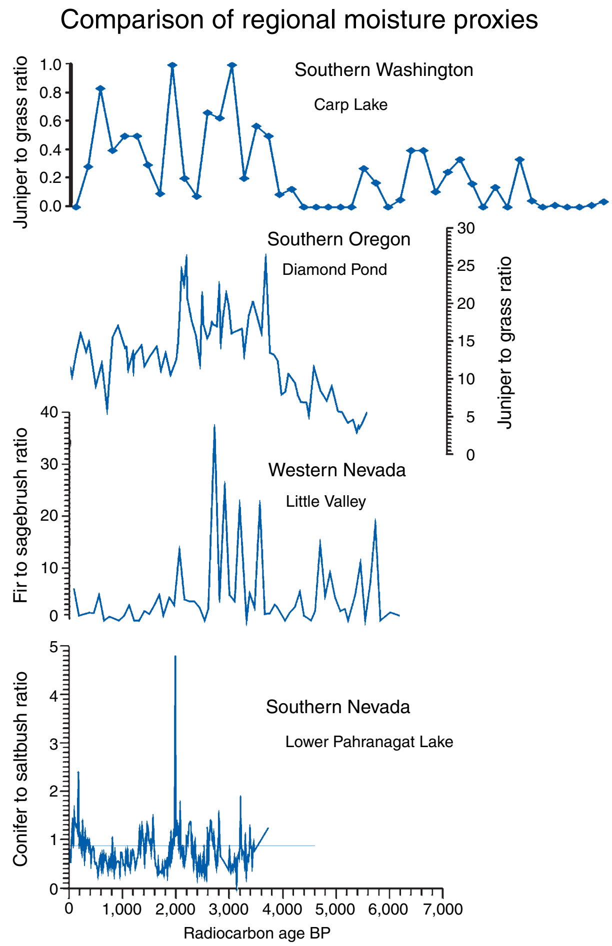

Figure 5 Comparison of drought indices generated from the pollen of climate indicator plant species at four western US pollen localities in the Intermountain West. They range from Carp Lake in the north to Lower Pahranagat Lake in the south. Allowing for slight differences in the position of the climatic events due to the vagaries of radiocarbon dating, there is significant similarity between the records. Differences usually reflect the origin point of the event. If the source of moisture driving a wet episode or period is the northern Pacific, that event is strongest in the northern portion of the West, and at higher elevations. If the event is derived from monsoonal rains, the event is stronger in the southern portion of the West. The plant species used in these ratios vary only in order to select the most representative wet vs. dry climate indicator plant species from each site.

Holocene density in the La Plata Mountains (Petersen, 1988, figure 26; Petersen and Mehringer, 1976). This may have been driven by warm, moist, perhaps monsoonal climates in the early middle-Holocene. Declining spruce pollen values from the Beef Pasture record indicate that climatic conditions became relatively drier after 2,800 rcyr BP (Petersen, 1988, figure 27). This may reflect the same climatic transition that occured near the end of the Neopluvial at Diamond Pond in the northern Great Basin and in other sites between the two areas.

Petersen (1988, 1994) attempted a reconstruction of the relative positions of the lower and upper spruce treelines of the La Plata Mountains (Petersen, 1988, figure 51). He believed that lower spruce tree-line reflected the relative proportion of summer to winter precipitation. Upper treeline was influenced by temperature. He suggested that except for a period between 1,300 and 800 calendar years ago upper treeline retreated to lower elevations for much of the last 2 kyr (Petersen, 1988). Several episodes of lower spruce treeline retreat to higher slopes occurred during that same period. The result was a dramatic shrinking of the spruce zone in the La Plata Mountains. Counts of piñon-type pollen coinciding with the upslope retreat of spruce indicate a relatively increased summer to winter precipitation (Petersen, 1988, figure 51). Petersen uses this information to explain the success of Anasazi farmers in the Four Corners area during that period.

In the desert regions of northern Mexico the potential for reconstructing ancient vegetation and climate histories has been explored using the combination of plant macrofossils and pollen from ancient woodrat middens (Anderson and Van Devender, 1991). This technique fills a crucial proxy data void in a region that lacks pollen records from aquatic, dry cave, or alluvial contexts. Currently, only cursory vegetation histories and their possible paleoclimates have been reconstructed for the coastal lowlands of Sonora, Mexico (Anderson and Van Devender, 1995). In particular, the spatial movement of indicator plant species (e.g., piñon and creosotebush) is being reconstructed for very localized areas. However, as the spatial and temporal distribution of woodrat midden strata increases, the possibility of reconstructing more detailed vegetation and climate histories for the region will increase.

Glossary

rcyr BP Radiocarbon years BP I left my dates in radiocarbon determinations because much of the older literature is still in radiocarbon ages, and also because conversion programs are still being changed so that calendar ages will differ depending upon the conversion program used. The radiocarbon date does not change.

See also: **Pollen Methods and Studies**: Databases and their Application. **Pollen Records, Postglacial**: Northeastern North America; Northwestern North America; Southeastern North America.

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Potassium-Argon Dating *see* **K/Ar and Ar/Ar Dating**