A Late-Holocene Pollen Record from Lower Pahranagat Lake, Southern Nevada, USA: High Resolution Paleoclimatic Records and Analysis of Environmental Responses to Climate Change

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ABSTRACT: High resolution paleobotanical records provide sufficient detail to correlate events regionally. Once correlated events can be examined in tandem to determine the underlying inputs that fashioned them. Several localities in the Great Basin have paleobotanical records of sufficient detail to generate regional reconstructions of vegetation changes for the last 2 ka and provide conclusions as to the climates that caused them. In southern Nevada, analysis of 266 pollen samples from the upper two-thirds of a 15-meter-long, 10-cm-diameter set of overlapping cores retrieved from Lower Pahranagat Lake (elevation 975 meters), Lincoln County, Nevada, is providing a detailed record of vegetation change at an interval of every 14 years over the last 3.8 ka. Samples, averaging about 3.8 years of pollen deposition with about 10.4 year gaps between each, outline a record of dry and wet periods with rapid onsets and terminations. Periodic increases in the values of sagebrush (*Artemisia*) pollen, sometimes coincident with increases in juniper pollen reflect intervals of cooler and/or wetter climate. Occasional, sometimes severe, drought is marked by increased bur sage (*Ambrosia*-type) and saltbush (Chenopodiineae) pollen and decreased regional conifer pollen. Drier climates between 3.0 and 2.5 ka, 2.4 and 2.0 ka are eclipsed in magnitude by the severe droughts of the last 1.9 ka. In particular, the droughts between 1.9 and 1.6 ka and at 0.9 and 0.3 ka have little parallel during the late Holocene (last 4.0 ka) in southern Nevada. The ratio of aquatic to littoral pollen types indicates generally deeper water conditions about 1.6 to 1.3 ka (also characteristic of most of the early part of the record from 3.7 to 2.0 ka) and more variable, but predominantly more marshy, conditions during most of the last 1.3 ka. Ongoing geomorphic investigations in the Lower Pahranagat Lake area suggest that the sudden shift from lake to marsh conditions around 1.2 to 1.4 ka may be linked to the impact of extreme rainfall events. These may have eroded a spillway through the alluvial fans that impounded the lake during the early portion of the Late Holocene (3.7-1.4 ka), thereby reducing the effective lake level after 1.4 ka. Increasing *Pinus* (pine) pollen values with respect to *Juniperus* (juniper) pollen values indicate that piñon pine is now more abundant in the southern Great Basin than at any time since the beginning of the "Neoglacial", about 4.0 ka. This is due not only to a shift from harsher winters about 2.0 ka (in part evidenced by the decline of juniper dominance in the woodland), but also to periods of summer-shifted rainfall (increased summer rainfall often with decreased winter rainfall), which favored seedling survival during the summer. In southern Nevada, evidence of summer-shifted precipitation during the first millennium of the Christian Era is seen in the expansion of grasses (reflected in Poaceae pollen) preceding expansions of piñon pine without coincident expansions of winter precipitation-loving species such as sagebrush and juniper. To the north, pollen and woodrat midden records from the Carson Sink of the central Great Basin (Lead Lake, Nevada) evidence summer-shifted rainfall in contemporaneous expansion of piñon pine into semi-arid woodlands. Pollen records from the northern Great Basin (in particular, the high-resolution pollen record from Diamond Pond, south-central Oregon) indicate grass expansion at the expense of juniper at the same time, providing further evidence of a major period of summer-shifted precipitation that characterized much of the Intermountain West.

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Introduction

Most paleoenvironmental proxy data have inherent time lags that limit their utility in reconstruction of paleoclimatic records of sufficient detail and synchroneity for deriving understandings of environmental processes. With the exception of dendroclimatology, and perhaps studies of varved lake sediments containing invertebrates, algae, and pollen, significant periods ranging from several years to millennia may intervene between climatic change and its first manifestation in most paleoclimatic proxy records as traditionally analyzed.

Efforts to recover high-resolution paleoenvironmental records from the Great Basin have been dominated by high-elevation bristlecone pine dendroclimatological research (Graybill *et al* 1994). Through measurements of the tree-rings (an indirect assessment of the climate-driven productivity of the sampled trees) otherwise unattainable reconstructions of the exact timing and magnitude of past precipitation and, to a lesser extent, of past temperature extremes can be achieved. Although these records indicate the physiological response of bristlecone pine trees to changing climates, they give no indication of the response of the rest of the botanical community to these changes. This role is filled by both pollen and woodrat midden records.

Both fossil pollen and woodrat midden records traditionally have been used to reveal past plant/climate interactions through reconstruction of past **terrestrial** plant community composition (Wigand 1987; Spaulding 1985). Although this may reveal an ultimate response to climate, the composition and structure of a plant community at a particular time in the past might not actually reflect an immediate link to the climate of that period. Instead, a community reconstruction might mirror the conditions of a previous climate state.

The response rate of plant communities to climate change is constrained by many factors including:

- Distance to the plant source area.
- Intervening geographical barriers along the path to the plant source area.
- Seed dispersal mechanisms of the plant species.
- Availability of niches opened through disturbance phenomena (insect infestations, disease, fire).

In addition, an apparent lag may occur in the paleobotanical record because evidence of a plant might not appear until well after its arrival. For example, it might be many years before a plant is mature enough to become a significant contributor to the regional pollen rain. On the other hand, its abundance might be low and, therefore, it might not be located near areas (paleobotanical repositories) where its macrofossils (leaves, twigs, *etc*) can be preserved. As a result, even if plants have already become established in an area they might be absent from the fossil woodrat midden, bog, dry cave, or other paleobotanical record.

Changes in **aquatic** plant community composition, however, can reflect the contemporaneous climate state because these communities spread and proliferate rapidly and their remains are almost immediately deposited in localities where they are preserved. Only rarely will aquatic plant communities lag climate change by some interval because their response might mirror longer-term changes in lake or marsh water levels and/or chemistry. Occasionally lagged response in the water chemistry of spring-fed aquatic plant communities reflects the long travel times of regional deep ground water, which evidences the climates of past periods (Smiley and Mehringer no date; Mehringer and Warren 1976; Mehringer and Sheppard 1978).

Finally, no model exists for integrating the various paleobotanical data available to reveal the processes linking climate, biotic response, and its appearance in the paleoenvironmental record. If our understanding of processes of change in the biotic sphere were more complete, we could apply it more rigorously to prediction of potential impacts of future climate changes. Keys to such understanding lie in the promise of combining dendroclimatological data with other high-resolution paleobotanical dataset(s) and in validation of models with both modern and past analogue data.

The Great Basin as a Sensitive Indicator of Past Western Climates

Today, the Great Basin is characterized by semi-arid to arid climates (Houghton 1969; Houghton, Sakamoto, and Gifford 1975). Except for a few mountain summits and the more northerly quarter of the region where ~20 inches is the norm, mean annual precipitation averages less than 10 inches. Due to the effects of latitude and elevation, the cold (10-40°F) winters and hot (50-80°F) summers of the northern Great Basin contrast with the mild winters (40-50°F) and very hot summers (80-90°F) of the southern Great Basin.

Today, as in the past, the Great Basin lies at the intersection of the Pacific, Arctic and Gulf of Mexico pressure systems. Displacement of winter and summer storm-tracks, and penetration of the summer monsoon are all affected by the realignment of these pressure systems through time. Past movements of these systems and their impact on local and regional climate are reflected in the paleoenvironmental record as changes in hydrology, erosional and depositional processes, and vegetation. Evidence that these movements and responses are a reflection of changes occurring on the global level is clear (Thompson *et al* 1993). In addition, the effect of topographic diversity in the Great Basin on the distribution of precipitation has complicated the effects of the major pressure systems through formation of a multiplicity of habitats within close proximity of each other.

The dramatic year-to-year vegetative response of individual plants within the Great Basin to changing weather arises as the result of millions of years (since late Miocene and early Pliocene times over 5 million years ago) of adaptation to arid and semi-arid conditions (Axelrod 1976). Plants that grow in the Great Basin are often opportunistic, having evolved to quickly take advantage of increased precipitation. Numerous species respond to wetter conditions through rapid vegetative growth and increased pollen and seed production. For example, annual production of biomass in arid and semiarid environments is linearly related to effective precipitation up to 600 cm (Walter 1954), so even moderate increases in rainfall can result in dramatic spurts in biomass production.

In the Great Basin, changes in the areal extent and elevational distribution of plant species through time are accentuated by topographic relief. Climate changes are emphasized by the rainfall forcing effect of north-south trending mountain chains that lie across the paths of Pacific storms. Rapid changes in plant distributions in the Great Basin occur because many plants disperse their seeds with the wind or by animals that feed on them and carry them within their digestive tracts great distances to favorable locations. In addition, long-term seed and plant dormancy, characteristic of many of the plants found in the Great Basin, provides a supply of seeds in most plant communities that can span the periods between favorable conditions and respond rapidly to them. Vegetation response to even single precipitation events can be dramatic, and changed patterns of plant distribution can be noted within one or two years. Reflection of these changes in the paleobotanical record is equally striking and is evidenced in high-frequency pollen records (Wigand 1987; Mehringer and Wigand 1990).

Finally, low effective precipitation has favored the preservation of plant macro- and microfossils in dry cave deposits and woodrat middens. These can provide records of local vegetation spanning tens of thousands of years. Wood from long-dead trees, preserved by dry conditions that characterize upper and lower tree-lines in the Great Basin, provide continuous long-term evidence of climatic variation that has the potential to extend the record obtained from living trees into the early Holocene. Although lakes with lifetimes spanning the Holocene are rare in the Great Basin, especially in the southern portion, desert springs and marshes with long but complex records are available to provide continuous records of local and regional vegetation change for much of the last 11 ka. Often these highly organic sediments have rapid deposition rates from which high-frequency terrestrial and aquatic pollen and local aquatic plant macrofossil records can be obtained and compared with tree-ring data for the generation of long, detailed records of regional climate and vegetation response.

High Resolution Pollen Records from the Great Basin

Typically in the arid West, reconstructed vegetation history reflecting general trends in changing precipitation and temperature has been based on low-resolution analyses of pollen from stratified deposits in lakes, marshes, and alluvium and on plant remains preserved in ancient woodrat dens (middens) (Mehringer 1985; Mehringer 1986; Betancourt *et al* 1990). Whereas woodrat midden studies result in intermittent records of the appearance and disappearance of specific indicator species that characterized changing plant communities, analyses of pollen records result in the reconstruction of more continuous, long-term shifts in the gross composition of plant communities. In part, this focus has been dictated by techniques available to investigators and by limitations of time and money.

During the last two decades, techniques more amenable to the investigation of past plant response to climate change at the organismal level have been inaugurated in Great Basin paleobotanical analyses to extend our knowledge of plant community history and to reveal differences and/or similarities in the physiological response of plants during the Holocene and the Pleistocene (Long *et al* 1990; Van de Water 1993, Mehringer and Wigand 1990, Wigand and Rose 1990). Thus far, integration of past and ongoing late Holocene paleobotanical research in the Great Basin reveal widespread, contemporaneous, short-term temperature and precipitation changes (Wigand 1987; Wigand *et al* 1995).

Southern Nevada pollen records investigated to date include:

- Those of P.J. Mehringer (1967) from Tule Springs in the Las Vegas Valley and from Saratoga Springs (Smiley and Mehringer no date) in the Panamint Valley.
- Our own from the Oasis Valley northeast of Beatty, Nevada, and Lower Pahranagat Lake south of Alamo, Nevada (Wigand and Rose 1990; Wigand *et al* 1995; and this report).

These form the basis of relatively continuous late Holocene and intermittent early Holocene and late Pleistocene reconstructions of vegetation history for the northern Mojave Desert. Of these, the pollen sequence from Lower Pahranagat Lake is providing one of the most important records of vegetation response to past climate currently available in the Great Basin. It has the potential to provide a record of vegetation response to climate change of comparable resolution and time span as the pollen record from Diamond Pond in the Harney Basin of southern Oregon. As such, it will serve in comparisons of climate change and vegetation response for the northern and southern Great Basin.

Comparison of two such high-resolution records with the dendroclimatological records from the Intermountain West makes it possible to examine vegetation responses to decadal or near-decadal climate shifts, *eg*, El Niño cycles. In addition, the charcoal from these records can provide a means of extending current records of fire history (Swetnam and Betancourt 1990) into previous millennia.

Lower Pahranagat Lake Record

Lower Pahranagat Lake lies in one of the many low areas in the fill currently accumulating between the truncated alluvial fans lining the White River Valley in southeastern Nevada (Figure 1). Located about 152 km (92 miles) northeast of Las Vegas, the shallow (~2m deep) lake is lined with tamarisk thickets, sedge marsh, and heliotrope and lizard-tail meadows. In most areas the "green belt" surrounding the lake is no wider

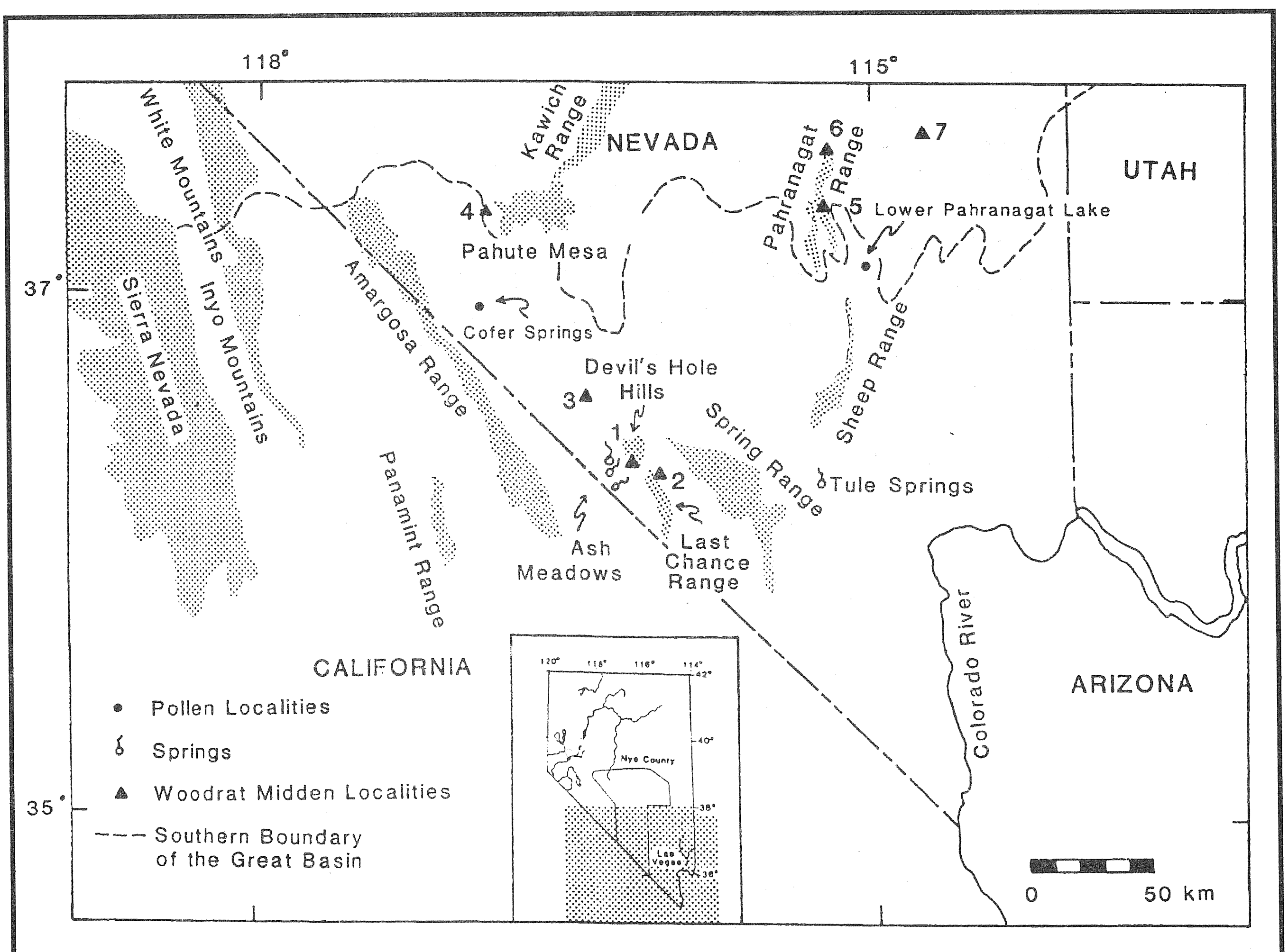

Figure 1 Southern Nevada with pollen localities mentioned in the text and woodrat middens sites studied in the area: (1) Owl Canyon; (2) Last Chance Range; (3) Little Skull Mountain; (4) Ribbon Cliffs; (5) and (6) Pahranagat Range, and (7) Pahroc Springs.

than 10 to 30 meters. Areas subjected to annual water fluctuation are characterized by saltgrass. Today the broad alluvial fans surrounding Lower Pahranagat Lake are covered by creosote bush dominated scrub. Other common components include white bur sage, Mojave yucca, Joshua-tree, purple sage (alluvial channels), Fremont dalea (sandy areas), and many species of cactus.

Sediments from two sets of overlapping cores retrieved in 1988 and 1993 span 5 and 15 meters respectively and contain a radiocarbon-dated environmental record of the last 5.6 ka. Although some of the radiocarbon dates in the upper portion of the cores are contaminated by old carbon, when taken together with the remaining uncontaminated dates taken from sedge peats in the lower portion of the cores, the two dozen radiocarbon dates distributed through the cores indicate an almost continuous rate of sediment accumulation. Based on this chronology, each centimeter-high sample incorporates about 3.8 years of sediment spaced about 14 years apart. The intervening unsampled sediment represents about 10.4 years. Ongoing analyses address the ostracode, diatom, and mollusk records in addition to the pollen and plant macrofossil contents. Variations in charcoal abundance and size in the core are revealing changes in local and regional fire history.

Pollen of terrestrial, littoral and aquatic plants record both local and regional vegetation dynamics and local water table fluctuation in response to climate change during the last 2 ka (eventually to 6 ka) (Figure 2). Increases in juniper (*Juniperus*), and to some extent pine (*Pinus*), pollen values reflect increased winter precipitation and its impact

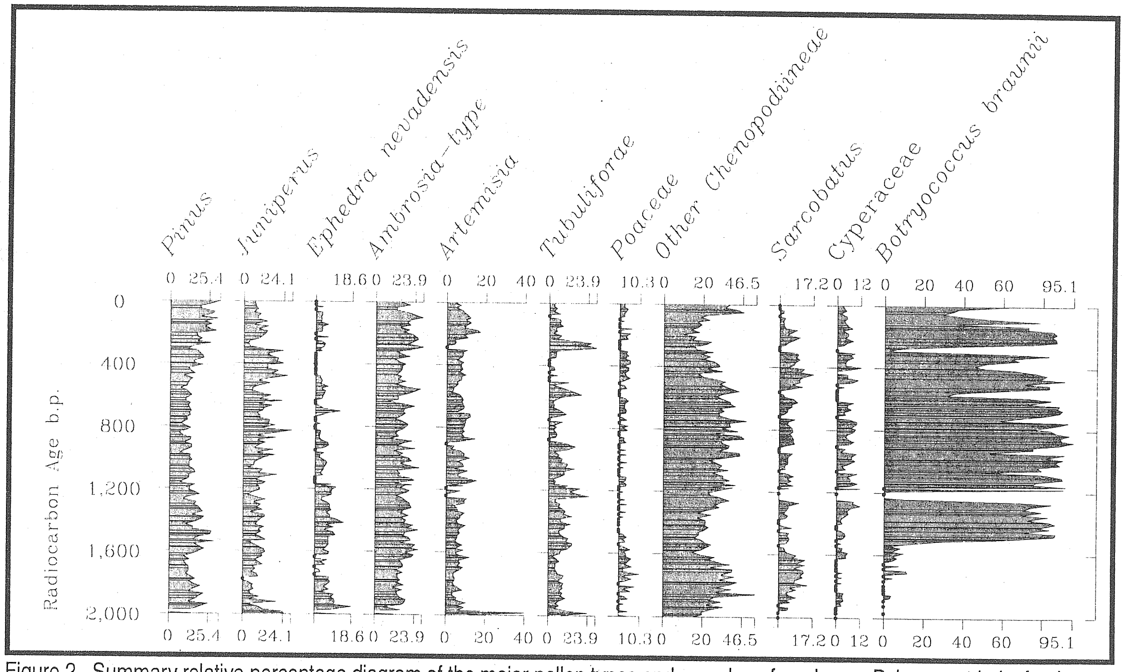

Figure 2 Summary relative percentage diagram of the major pollen types and one algae from Lower Pahranagat Lake for the upper 2 ka of the record. Percentages are based on the sum of all terrestrial pollen types. Both long- and short-term shifts in vegetation are clear. Sample spacing is about one per 14 years. A dot indicates relative percentages of less than 2%.

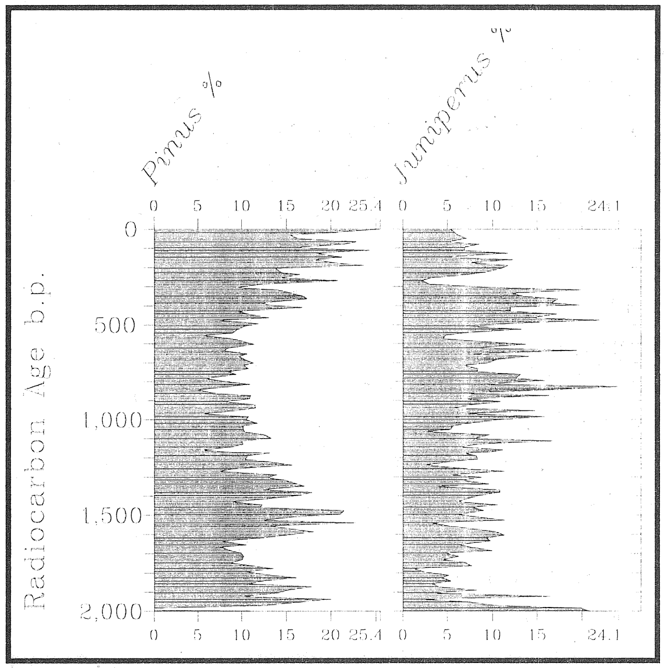

Figure 3 The pine (primarily piñon) and juniper pollen records reflect the history of the semi-arid woodlands in the mountains surrounding Lower Pahranagat Lake. Pine seems to have been greatly affected during the drought following the "Neoglacial" (~1.6 to 1.8 ka) and during the "Medieval Warm Period" and the severe droughts recorded in the tree-ring records of the Sierras (~1.0 to .4 ka). Juniper seems to have fared much better.

on the health and composition of intermediate elevation semi-arid woodlands. Juniper pollen values during the last 2 ka vary between 5 and 22 percent (Figure 3). High pollen values reflect major increases in the productivity, density, and distribution of juniper on the landscape.

High frequency variations of juniper (and other) pollen values throughout the Lower Pahranagat Lake record on the order of 10 to 14 years apparently mirror differences in pollen production, not increased numbers of trees. These variations can serve as a proxy for past interdecadal climate variations. Long-term, low frequency increases in mean juniper (and other) pollen values reflect initial response to such events through increased biomass and, in the later stages, increased local density and/or expansions of juniper (or these other species) into adjacent vegetation communities.

Such an increase in the Lower Pahranagat Lake record of juniper pollen suggests that this species may briefly have grown at slightly lower elevations about 2 ka than they currently do (Wigand and Rose 1990). This would evidence a drop in lower tree-line of from tens to a few hundred meters. Woodrat midden data from the Sheep Range south of Lower Pahranagat Lake suggest there may have been as much as a 200m depression in lower tree-line prior to 2 ka (Spaulding 1981, 1985).

Reconstructed deposition rates of the Lower Pahranagat Lake record together with dramatic changes in relative pollen values indicate that at times the transition to wetter, or conversely drier, conditions took less than a decade or two. The local increase in effective precipitation necessary to accomplish this change, based on the difference in the minimal annual rainfall requirements between sagebrush (Mozingo 1987) and Utah juniper (Leonard *et al* 1987), must have been at least 10-20 mm per year and could have been as much as 70 mm per year at elevations around 1500 meters. Reduced evaporation rates due to reduced mean annual temperature may also have played a significant role in increasing effective precipitation.

At Lower Pahranagat Lake, additional increases in juniper pollen, indicating greater effective precipitation resulting from increased winter precipitation and/or reduced evaporation rates, occur about 1.5, 0.9, 0.7, and after 0.5 ka (Figure 3). Increased juniper values climaxing at about 0.8 and between 0.4 and 0.3 ka approach relative values that occurred about 2 ka. The times when these pollen values begin to increase roughly coincide to times when Stine (1990) indicates the drowning of trees in the basins and valleys surrounding Mono Lake. These periods are mirrored in the marsh pollen records from Cofer Spring north of Beatty, Nevada (Wigand and Rose 1990), at Warm Sulfur Springs in the Panamint Valley (Smiley and Mehringer no date), and in the timings of the latest dune and peat layers from Ash Meadows (Mehringer and Warren 1976). The regional nature of some of these events is confirmed by comparison with pollen and woodrat midden records farther north.

In contrast to the general increase in juniper pollen values, which climaxed about 0.3 ka and has plunged since, there have been at least three significant increases in pine pollen values over the last 2 ka. Of these, a period of increased pine pollen values between about 1.6 and 1.2 ka (Figure 3) is characterized by minimal corresponding increases in juniper pollen values and a distinct period of increased grass pollen values immediately preceding (Figure 4). Based upon ongoing analysis of woodrat midden data from the Pahranagat Range and the pollen data from Lower Pahranagat Lake, this regional expansion of piñon may evidence a period of summer-shifted rainfall (increased summer rainfall with reduced winter rainfall). Juniper, which favors winter precipitation, responds little during this period. Sagebush (*Artemisia*), another plant favored by winter precipitation, did not respond during this period (Figure 4). The grass expansion evident just prior to the beginning of this period, at a time when according to saltbush (Chenopodiineae) and greasewood (*Sarcobatus*) pollen (Figure 5) drier climate was prevalent, suggests summer-shifted rainfall. This would have favored the establishment of piñon seedlings through more reliable supply of moisture during the hot summer months.

The relatively greater abundance of pondweed (*Potomogeton*) pollen in relationship to sedge (Cyperaceae) pollen (Figure 6) from 1.6 to 1.4 ka indicates the development of a shallow, fluctuating lake system. Maintenance of a shallow perennial lake at a time contemporaneous with the expansion of piñon pine despite the apparent reduction of winter precipitation provides additional evidence of summer-shifted precipitation. Increased dominance of sedge pollen after 1.4 ka indicates the expansion of littoral plant communities at the expense of shallow lake plant communities. This might have occurred either as the result of in-filling of the basin, breaching of the alluvial fans that dammed the lake, or through reduced hydrologic input.

Expansion of piñon pine in the Great Basin was further favored by reduction in harshness of winter conditions following the end of the "Neoglacial" about 2 ka. Piñon pine is readily subject to winter-kill during times of extreme cold. Even today its distribution in the northern Great Basin is characterized by distributions on lower mountain ranges sheltered behind larger chains that effectively block the direct impact of winter storms.

An index generated by placing conifer pollen against saltbush pollen recovered from Lower Pahranagat appears to be an excellent measure of regional drought when compared with a bristlecone pine tree-ring record from Methuselah Walk in the White Mountains of southern California (Graybill *et al* 1994) (Figure 7). Except for the extreme drought centered around 1.9 ka, the correspondence for the last 2 ka is very close. The discrepancy around 1.9 might reflect the variable effect of summer-shifted precipitation at high and low elevations. At lower elevations, summer rainfall had limited impact on the conifer pollen record from Lower Pahranagat Lake because the semi-arid woodlands had already

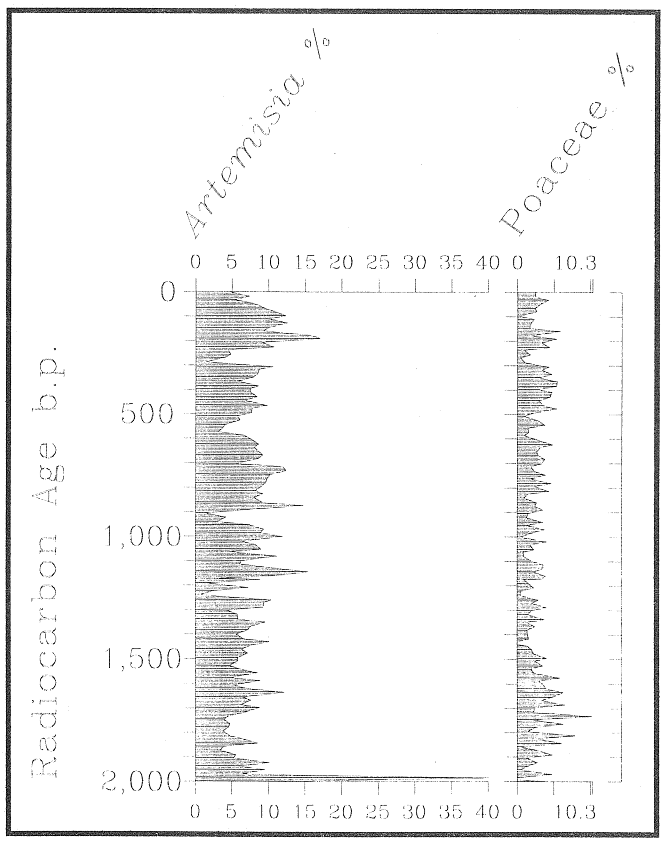

Figure 4 Comparison of the sagebrush (*Artemisia*) and grass (Poaceae) pollen records from Lower Pahranagat Lake.
In general, sagebrush (which generally grows above 1,700 m in the surrounding mountains) and grasses respond similarly. They seem to have been less impacted (except during the most extreme events) by the droughts that have characterized the last 2 ka. However, one period centered around 1.8 ka is characterized by dramatic grass expansion. Pine and juniper both suffer during this period. We suggest that this is a time of summer-shifted precipitation when grasses could benefit from summer rainfall, but the semi-arid woodland species (already having stopped growing for the year) could not respond to the input of additional precipitation.

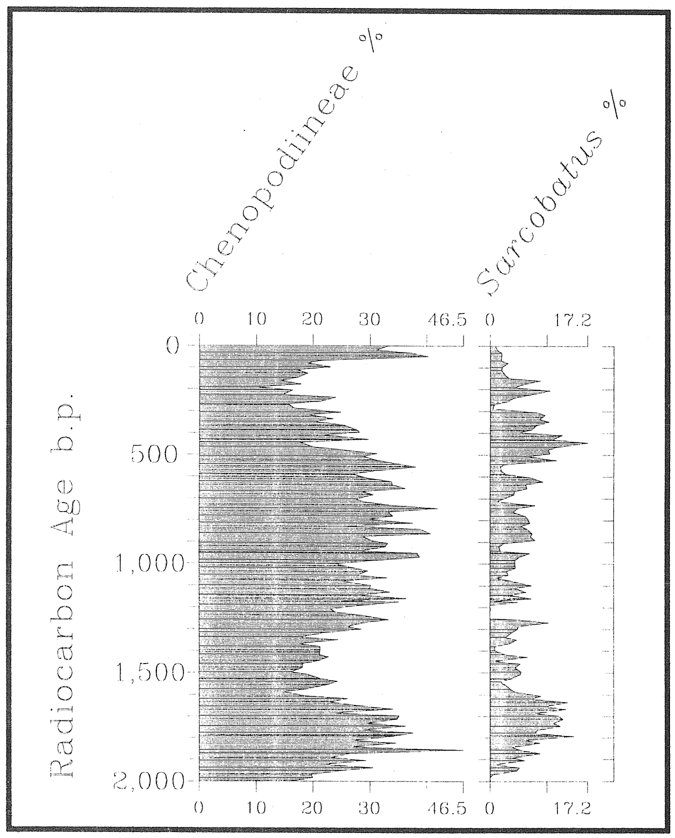

Figure 5 Increases of saltbush (Chenopodiineae) and greasewood (*Sarcobatus*) pollen at Lower Pahranagat Lake highlight the major droughts of the last 2 ka. Saltbushes (*Atriplex* spp.) demonstrate vigorous response to drought shifted climate. It is clear that both the onsets and the termination of these droughts are very rapid. Again the terminal "Neoglacial" and "Medieval Warm Period" droughts are clear. In particular the droughts of about 0.5 to 0.6 ka documented in the Sierran tree-ring record (Graumlich 1993) are among the worst of the last 2 ka.

completed their annual growth and pollen production. However, the high-elevation bristlecone pine forest was still in the growing season and could easily respond to summer rainfall inputs, which would be reflected in wider tree-ring growth.

The Lower Pahranagat Lake pollen record provides an additional dimension to the climatic index that is generated from the tree-ring record, *ie*, the response of various plant species to climate can be assessed. The tree-ring record only provides a measure of the climate and the response of one plant species (bristlecone pine, *Pinus longaeva*). It is apparent from this comparison that the response of semi-arid woodlands and desert scrub communities are potentially just as sensitive and immediate as the tree-ring record even in comparisons of the relative magnitudes of the variations. Thus, the regional nature of the climate changes reflected in the Lower Pahranagat Lake record is clear.

In north-central Nevada, a pollen record from Lead Lake in the Carson Sink records the same dramatic expansion of piñon pine seen in the Lower Pahranagat Lake record between 1.6 and 1.2 ka just prior to the

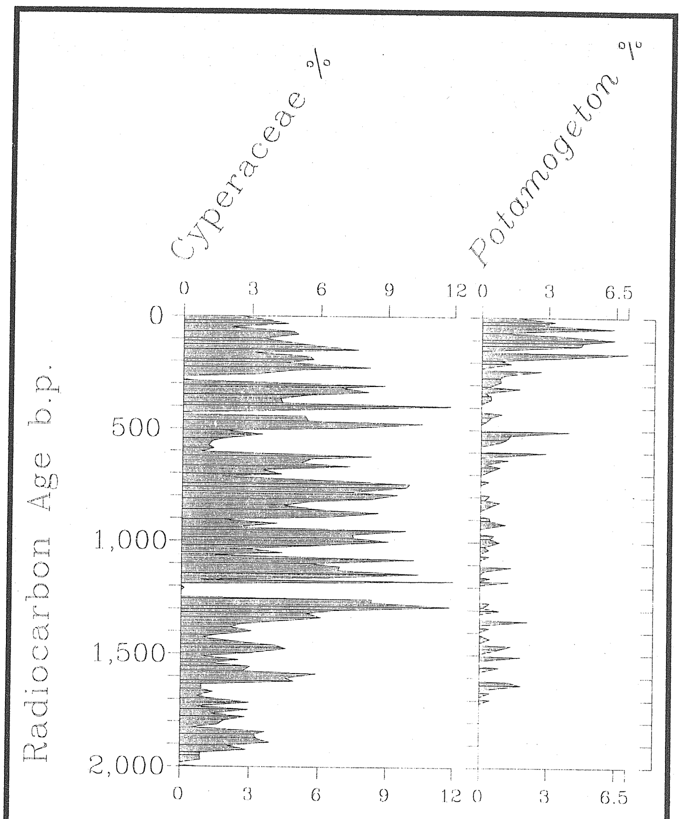

Figure 6 Sedge (Cyperaceae) and pondweed (*Potomogeton*) pollen reflects Lower Pahranagat Lake/Marsh history. Rapid shifts in this vegetation result from the shallowness of the lake (a 1- or 2-meter change in water depth can expose or drown huge areas). In general, the "Medieval Warm Period" and the early part of the millennium were characterized by marsh. However, the "Little Ice Age" and a period between 0.6 and 0.7 ka seems indicative of two brief deeper lake episodes.

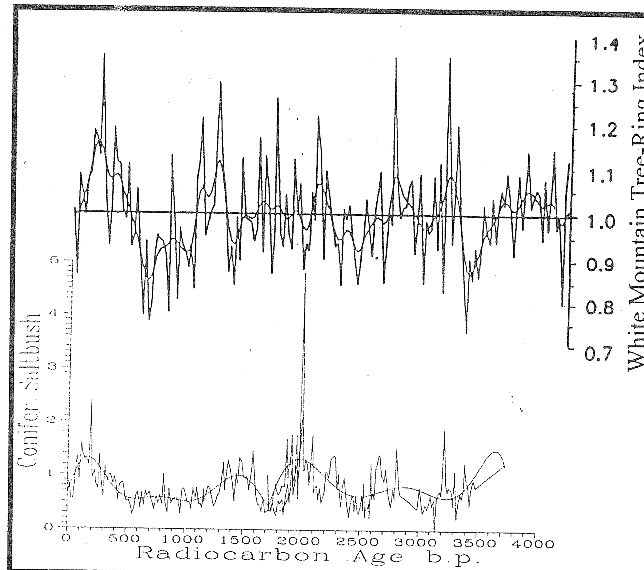

Figure 7 Comparison of an effective precipitation index derived from the Lower Pahranagat Lake pollen record (lower line plotted against the age scale as radiocarbon age b.p.) and the White Mountain bristlecone pine tree-ring record (upper line plotted against the age scale as calendar years b.p.)(Graybill *et al* 1994). The (Juniper + Pine)/All Chenopodiineae ratio reflects regional precipitation. Increases in this ratio indicate wetter periods (primarily winter precipitation). Decreases indicate reduced winter precipitation. The tree-ring index from the White Mountains also reflects regional precipitation, though temperature may also play a role. Wider ring width (up) corresponds with greater precipitation, while narrower ring width (down) corresponds with reduced precipitation.

"Medieval Optimum" (Wigand *et al* 1995) (Figures 8 and 9). The earliest record of piñon pine in the woodrat midden record from northwestern Nevada west of the Lahontan Basin, thus far, is 2.1 ka (Wigand and Nowak 1992). However, around 1.4 ka, based upon both the pollen and woodrat midden records, it expands both northward (Figure 8) and downward in elevation (Figure 9). Reduced numbers of dated piñon pine-containing middens and decreased pine pollen abundance after 1.0 ka reflect the same conifer retrenchment pattern seen at Lower Pahranagat Lake during the early and mid-millennial droughts. Increased occurrence of pine in the pollen record of Lead Lake during the last 0.15 ka corresponds to the unprecedented, post "Little Ice Age" expansion of piñon pine recorded in stand establishment records (Tausch *et al* 1981).

Finally, at Diamond Pond in the Harney Basin of south-central Oregon, an early post "Neoglacial" expansion of grass between 1.9 and 1.0 ka overlaps with both grass and piñon pine expansions seen at Lower Pahranagat Lake and the piñon pine expansion at Lead Lake (Wigand 1987) (Figure 10). Because juniper is not increasing in abundance, grass expansion at Diamond Pond also seems to indicate summer-shifted rainfall. Radiocarbon dates plotted with standard deviations on bison remains from archaeological sites in the northern Great Basin (Marwitt 1973) and the plateau of eastern Washington (Schroedl 1973) show remarkable coincidence with this period of grass expansion (Figure 10).

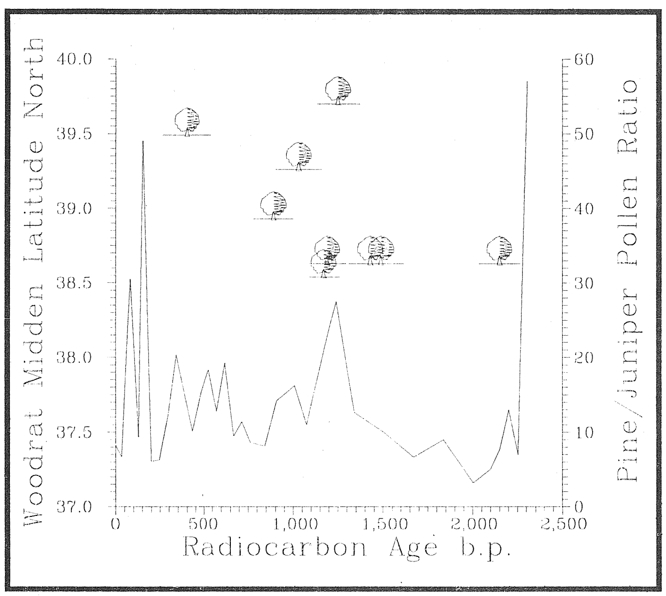

Figure 8 In north-central Nevada, the pollen record from Lead Lake in the Carson Sink records the dramatic expansion of piñon pine with respect to juniper prior to the "Medieval Warm Period". The pine-to-juniper pollen ratio from Lead Lake indicates that around 1.4 ka, increased pine pollen abundance records a dramatic, regional expansion of pine. Elevational distribution of directly dated piñon pine from woodrat middens around the Lahontan Basin indicates that it is single-needle piñon pine (*Pinus monophylla*) that is making significant headway northward at this time. Retrenchment of piñon pine after about 1.1 ka and subsequent re-expansion around 0.15 ka is also documented in the pine to juniper pollen ratio from Lead Lake.

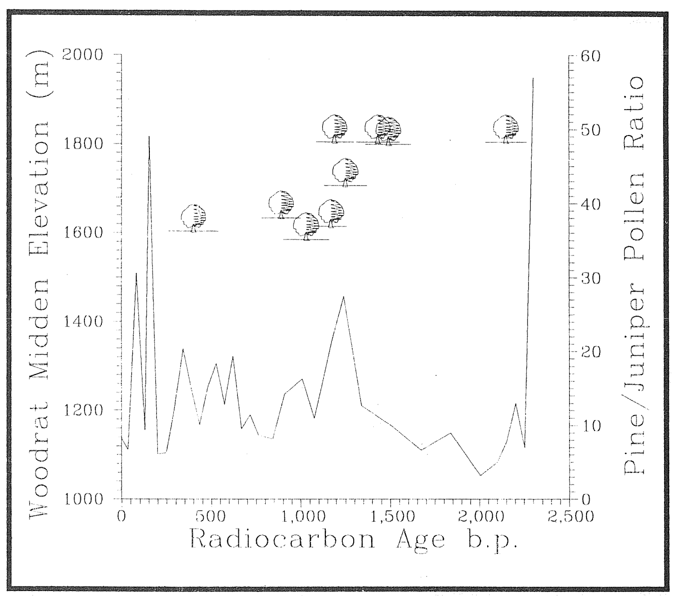

Figure 9 At the same time that the pollen record from Lead Lake indicates a dramatic, regional expansion of pine, directly dated piñon pine from woodrat middens around the Lahontan Basin indicates that single-needle piñon pine is also lowering its lower elevational distribution by as much as 200 meters.

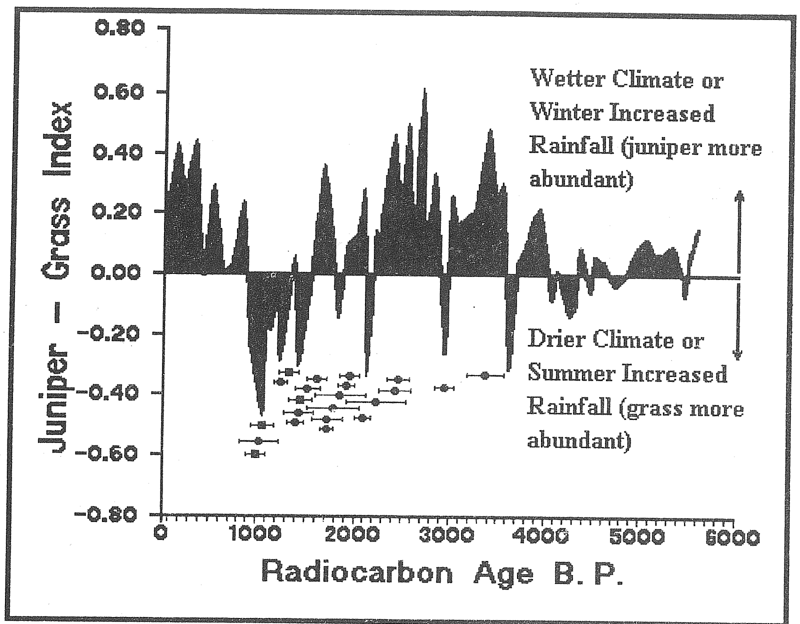

Figure 10. At Diamond Pond, the juniper-to-grass index records an early post "Neoglacial" expansion of grass. This expansion mirrors both the regional increase of grass and pine at Lower Pahranagat Lake and the piñon pine movements recorded in pollen at Lead Lake and Lahontan Basin woodrat middens. Grass expansion at Diamond Pond, indicating summer-shifted rainfall, coincides with radiocarbon-dated bison remains from archaeological sites in the northern Great Basin and the plateau of eastern Washington. The dates are plotted with one standard deviation dashes.

Containing the greatest concentration of dated middle to late Holocene bison from archaeological contexts in the Intermountain West, this period also corresponds with the expansion of Fremont corn horticulturists in the eastern Great Basin (Marwitt 1973). Corn, in a horticultural society, requires summer rainfall to grow. Expansion of the practice of growing corn as far north as the Snake River plain, Idaho, and apparently as far northwest as the Ruby Valley, central Nevada, between 1.6 and 0.9 ka is more than coincidental.

Conclusions

Integration of high-resolution pollen sequences and woodrat midden macrofossil records from the Great Basin offer an opportunity to examine climate change and subsequent plant community response not offered by the tree-ring record alone. Although the resolution and precision of the pollen record is not as great as that of the tree-ring record, at near decadal resolution, it provides unique information on plant response to climate both at the community and the organismal level.

Great Basin paleobotanical records discussed above indicate that considerably wetter, as well as drier, conditions have occurred during the last few millennia, resulting in dramatic responses in vegetation communities. Highly variable responses in woodland and shrub species and in the grasses that grew among them provide evidence of significantly wetter periods of climate sometimes with strong seasonal shifts in precipitation that in most cases were regional in extent.

Variations in the duration (ranging from a few dozen to a few hundred years) and the rapidity of the onset and demise of these shifts (some on the order of a decade or less) are clear in the pollen record. Hydrologic impacts from rapid shifts to wetter climates are obvious. Initial inability of local vegetation to accommodate such increases in precipitation would result in abundant surface water that would yield considerable runoff and recharge.

Finally, although the Holocene as a whole has been drier than the late Pleistocene (last 12 ka), higher resolution sampling of paleoclimatic proxy records (12-24 ka) indicate that there have been events of short duration that have approached the extremes recorded during the Pleistocene. However, the shorter duration of Holocene events has averted the responses in regional vegetation that were seen during the Pleistocene.

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