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PALYNOLOGICAL EVIDENCE FOR THE HISTORIC EXPANSION OF JUNIPER AND DESERT SHRUBS IN ARIZONA, U.S.A.

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Abstract

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Analysis of the sediment of Pecks Lake, Yavapai County, Arizona, has permitted the first reported palynological evidence for the historic expansion of juniper and desert shrubs in the American Southwest. The palynological evidence is supported by the comparison of modern and historical photographs, which shows the regional expansion of pinyon–juniper woodland, and the local increase of mesquite and creosote bush. A gradual increase in juniper pollen percentages began over 2000 years ago, but the rate of increase abruptly accelerated after the historic introduction of grazing animals. In contrast, juniper percentages did not increase during a prehistoric interval of intense disturbance by humans, about A.D. 1200, and a different weed flora was present. Prehistorically, water depth was greatest at ca. 600 B.C. and was lowest just prior to the arrival of Europeans. Regional climate has gradually cooled since the beginning of the record at 2630 B.P.

Introduction

The historic expansion of juniper and other shrubs is well documented in the western United States. It has been demonstrated repeatedly in comparisons of modern and historical photographs (Phillips, 1963; Hastings and Turner, 1965; Johnsen and Elson, 1979; Rogers, 1982). The causes of this invasion have been the subject of ecological debate for decades. Several alternatives have been proposed including climatic change, overgrazing by cattle or rodents, and fire suppression (Hastings and Turner, 1965; Blackburn and Tueller, 1970; Burkhardt and Tisdale, 1976). These alternatives are not mutually exclusive and the relative importance of the different agencies probably varies among areas.

Although clearly shown in matched-photograph comparisons, the juniper expansion has not been demonstrated in pollen diagrams from the western U.S., where palynological studies of historical vegetation change are rare. Pollen analysis can provide valuable information for the juniper-invasion controversy because it gives a more continuous and more ancient chronology than do photographic comparisons. Vegetation disturbance is reflected by the percentages of weed pollen, and the percentages of coprophilous fungal spores in lake sediments can be used to indicate the intensity of disturbance by livestock (Davis et al., 1977).

The Arizona flora contains many exotic species, but nearly two thirds of Arizona's weeds are native (Parker, 1972). This relatively large proportion (large for the U.S.) probably results from the area's long history of cultivation. The earliest evidence of agriculture in the

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Southwest is corn pollen from a *Neotoma* midden dated to 1120 B.C. from Canyon de Chelly in northeastern Arizona (Betancourt and Davis, 1984). The corn pollen is accompanied by the pollen of *Cleome*, a semicultivated weed that inhabits Indian fields today and is used as a pot herb (Martin and Byers, 1965). By A.D. 1150 extensive irrigation was underway in central Arizona. Diversion of the Salt and Gila rivers as well as many minor streams supplied water to approximately 1100 km of irrigation canals with local systems as large as 100 km^2 (Masse, 1981). Only remnants of this system remained when more extensive human impact began as Spanish missionaries introduced European weeds and livestock in the late 1600's (Lockwood, 1934).

Environmental setting

Pecks Lake is an oxbow lake in the Verde River Valley of central Arizona (Fig.1). It is at unusually low elevation (1016 m) for a Southwestern lake. Mean annual precipitation at Tuzigoot National Monument, 1 km south of the lake, is 388 mm and mean annual temperature is 16.9°C (NOAA, 1978–82). The only nearby lake at comparable elevation that has been studied palynologically is Montezuma Well 28 km to the southeast (Hevly, 1974). No pollen diagram has been published for Montezuma Well and severe dating problems at that site (Hevly, 1974) make comparison with Pecks Lake difficult.

The exact age and mechanism of lake

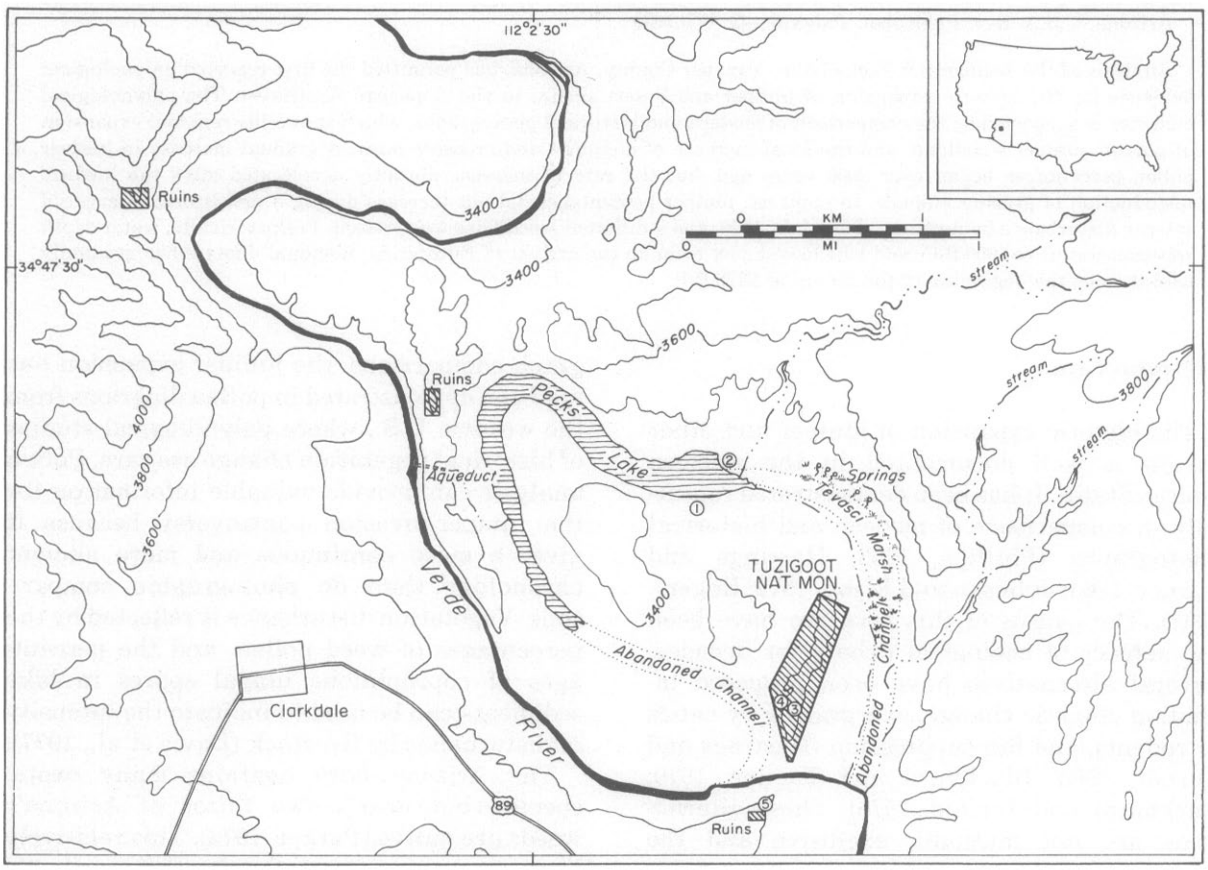

Fig.1. Location of Pecks Lake and Tuzigoot National Monument. Locations of photograph-matching stations are numbered *1–5*.

formation are not known, but the neck of the river meander probably was breached about 2600 yrs ago when the Verde was dammed by sediments from a small tributary (see page 179). The lake occupies secs. 16 and 21, T 16 N, R 3 E, 1 km northeast of the town of Clarkdale, Yavapai County, Arizona. The lake is about 3 km long, is 280 m wide near its eastern end, and has a total area of over 538,000 m^2. The mean depth is about 2 m with a maximum depth of over 3 m at its eastern end (Arizona Game and Fish, 1982). The present lake depth is maintained by an aqueduct (Fig.1) constructed shortly before 1913 (H. Young, Clarkdale, Arizona, personal communication).

The regional vegetation surrounding Pecks Lake is mapped as semidesert grassland (Brown, 1973; Brown and Lowe, 1980). Typical dominants of this community are grasses such as *Bouteloua*, *Muhlenbergia*, and *Aristida* species and a variety of shrubs (particularly *Prosopis* and *Acacia*), yuccas, and cactuses (Brown, 1982). Chaparral and juniper–pinyon woodland occupy higher elevations above the Verde Valley, and montane conifer forest covers the Mogollon Rim to the north and Mingus Mountain to the west of Pecks Lake.

Riparian trees along the southern margin of Pecks Lake include natives such as box-elder (*Acer negundo*), net leaf hackberry (*Celtis reticulata*), Arizona sycamore (*Platanus wrightii*), Arizona walnut (*Juglans major*), and the introduced tree-of-heaven (*Ailanthus altissima*) and tamarisk (*Tamarix pentandra*). Several species of sedge (*Carex*), bulrush (*Scirpus*), and rush (*Juncus*) are common in littoral areas; and the lake is the original collection site in Arizona (Lehr, 1983) for water milfoil (*Myriophyllum verticillatum*), which is very abundant where the water is over 50 cm deep in Pecks Lake.

Mesquite (*Prosopis velutina*) and catclaw (*Acacia greggii*) form dense groves east of the lake; and creosote bush (*Larrea divaricata*) and crucifixion thorn (*Canotia holacantha*) are the most prominent plants on the hillsides above the lake.

Tuzigoot National Monument is about 1 km south of the lake. The monument is the site of a pueblo-style archeological ruin excavated and restored in 1933–1934 (Caywood and Spicer, 1935). Four hundred and eleven burials were discovered and 86 rooms excavated (Hartman, 1976). Evidence for cultivation includes corn, beans, and squash (Caywood and Spicer, 1935), and prehistoric irrigation canals (Schroeder, 1951). Tree-ring analysis dates the construction of Tuzigoot pueblo to A.D. 1137 through A.D. 1386 (Hartman, 1976), but archeological evidence (Hartman, 1976) shows earlier occupation.

Methods

Photograph pairs

Photographs of Pecks Lake and the area east of the lake were taken on January 24, 1887, during the Mearns zoological expedition and were matched in 1984. Photographs of Tuzigoot National Monument, taken in 1945, were also matched in 1984. A photograph showing the expansion of juniper and pinyon pine onto grassland was matched in August, 1978. The original, taken in August 11, 1929, shows a U.S. Biological Survey experimental exclosure at 1950 m elevation near the town of Williams, Arizona.

Pollen analysis

Two 10 cm diameter, overlapping cores were taken near the center of eastern basin of Pecks Lake on May 8, 1982. The sediments consisted of 367 cm of gyttja (lake mud), clay, and peat, above basal sand. A surface core was taken in plastic (PVC) pipe and kept vertical; the other cores were taken with steel pipe, extruded in the field, and wrapped in plastic and in aluminum foil.

One cm^3 pollen samples were disaggregated in 10% HCl and *Lycopodium* tracers were added to permit calculation of pollen concentration. After screening, the samples were treated with 48% HF, acetolysis solution (Faegri and Iversen, 1975), and 10% KOH. The pollen-rich residue was transferred to silicone oil after two TBA washes, mounted on microscope slides, and the pollen counted at 400 × and 1000 × .

The percentages of each pollen type were calculated using a pollen sum (divisor) based on the sum of upland (non aquatic) plants. A minimum of 500 grains per sample were counted above 230 cm, and a minimum of 300 grains (and 500 tracers) were counted below this depth because the number of grains per slide was extremely low. Counting became so time-consuming that relatively few samples were counted in the lower portion of the core.

Several pollen types require special mention: cf. *Cowania* includes the *Cowania*, *Cercocarpus*, and *Purshia* genera; *Ephedra* pollen was divided among those with straight plicae (*Ephedra* cf. *trifurca*) and those with wavy plicae (*E.* cf. *nevadensis*); the "other Compositae" category excludes types with distinctive morphology (e.g., *Artemisia*, *Cirsium*, and *Ambrosia*); *Typha latifolia* refers to tetrads, whereas *Typha–Sparganium* refers to monads. *Pediastrum* includes two species of algae, *P. boryanum* and *P. simplex*.

Erodium refers only to *E. cicutarium*. Three species of *Erodium* are present in Arizona: *E. texanum* is a native species, *E. cicutarium* is thought to have been introduced in the late early 1700's, and *E. moschatum* is a recent introduction that was first collected in Arizona in 1973 (Lehr, 1974). *E. moschatum* is not included in the pollen type due to its limited distribution and recent introduction, and the pollen morphologies of *E. cicutarium* and *E. texanum* are quite different. The surface of *E. cicutarium* is striate, whereas that of *E. texanum* is more typical of the Geraniaceae and is reticulate with long baculae.

Charcoal was not counted in the pollen preparations because we were not confident that it could be distinguished from other opaque particles, and because we believe the screening and vigorous mixing of pollen preparation breaks it into smaller pieces. However, qualitative differences were evident and for each sample charcoal was ranked as abundant or not abundant.

Results

Radiocarbon dates

Five bulk-sediment samples were radiocarbon dated at The University of Arizona Radiocarbon Laboratory (A-2892, A-3220, A-3221, and A-3694) and Geochron Laboratory, Cambridge, Mass. (GX-10089). Four of these appear to be too old or are out of superposition and are plotted as filled circles in Fig.2. To resolve these problems with bulk-sediment dates, three samples of macrofossils were picked from the sediment and submitted to the University of Arizona TAMS Laboratory (Zabel et al., 1983).

The TAMS date (AA582) on juniper twigs (65–75 cm in core A) is < 140 B.P., which matches the "historic" age inferred from the earliest pollen of exotic plants. This date is much more reasonable than the bulk sediment date of 2540 ± 120 B.P. (A-3221) for this sedimentary interval. TAMS dates on charcoal (AA581) and *Scirpus* achenes (AA580) date a period of prehistoric human disturbance. These dates are equivalent to A.D. 1255–1950 (AA580) and A.D. 1040–1515 (AA581), which overlap the tree-ring dates for the construction Tuzigoot pueblo (Hartman, 1976).

We accept the TAMS dates as the actual age of the Pecks Lake sediment, and reject the four bulk-sediment dates as contaminated. We believe that finely-divided organic matter (ac-

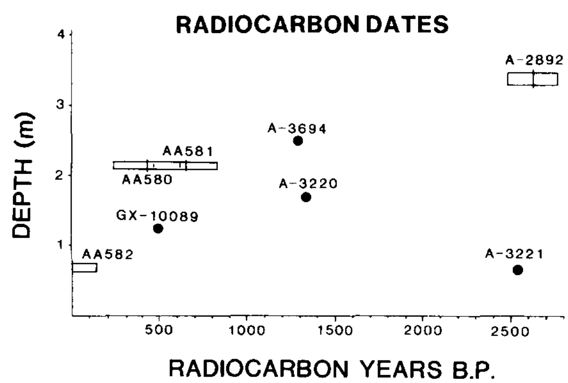

Fig.2. Plot of radiocarbon dates vs. depth for Pecks Lake sediment. Midpoint and one standard deviation plotted; rejected dates indicated with filled circle.

companied by deteriorated pollen) was washed into the lake from the surrounding watershed during historic and prehistoric periods of human disturbance. Historic erosion from the surrounding hills is evident in the matched photographs (see page 187). We do not believe that vertical mixing is responsible for the erroneous bulk-sediment dates because stratigraphic boundaries in the sediment are sharp, and mixing should have included plant macrofossils thereby producing concordant macrofossil and bulk-sediment dates.

The basal bulk-sediment date (A-2892) may also be viewed with suspicion, but deteriorated pollen percentages are low at this depth (329–337 cm) indicating a lesser contamination by in-washed carbon, so 2630 ± 140 B.P. is probably close to the actual age of the lake.

Pollen diagrams

The diagrams (Figs.3, 4) are divided into two zones characterized by maxima for *Juniperus* and Chenopodiaceae-*Amaranthus* percentages. The *Juniperus* zone above 100 cm is demarcated by the first appearance of the exotic *Erodium cicutarium*. The pollen of several other exotic plants is present including low percentages of *Cannabis*, *Eucalyptus*, and *Salsola*. *Cirsium* and *Morus* may also represent introduced species, but these genera also include native species. Samples from this zone generally contain >30% *Juniperus* pollen. *Prosopis* reaches a maximum of 2.4% at 40 cm, *Acacia* pollen is present only from 40–60 cm, and except for one grain at 300 cm, *Larrea* pollen is found only above 40 cm (Fig.4). Above 50 cm the percentages of several riparian trees increase, and *Myriophyllum* percentages reach 380% of terrestrial pollen (Fig.4).

The Chenopodiaceae-*Amaranthus* zone is the interval below the lowest occurrence of the pollen of exotic plants. It is characterized by generally high percentages (>50% at 200 and below 360 cm) of Chenopodiaceae-*Amaran-*

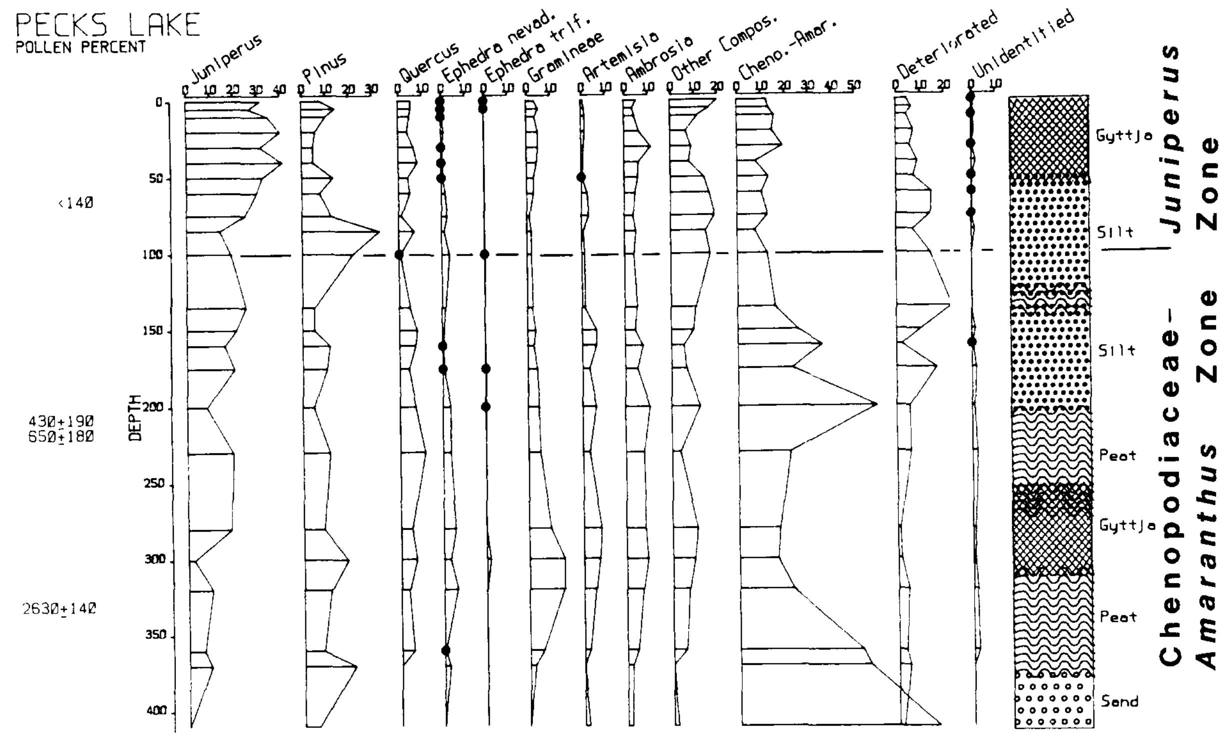

Fig.3. Pollen diagram of selected upland types. Radiocarbon dates shown on left margin, sediment stratigraphy on right. Filled circles indicate <2%.

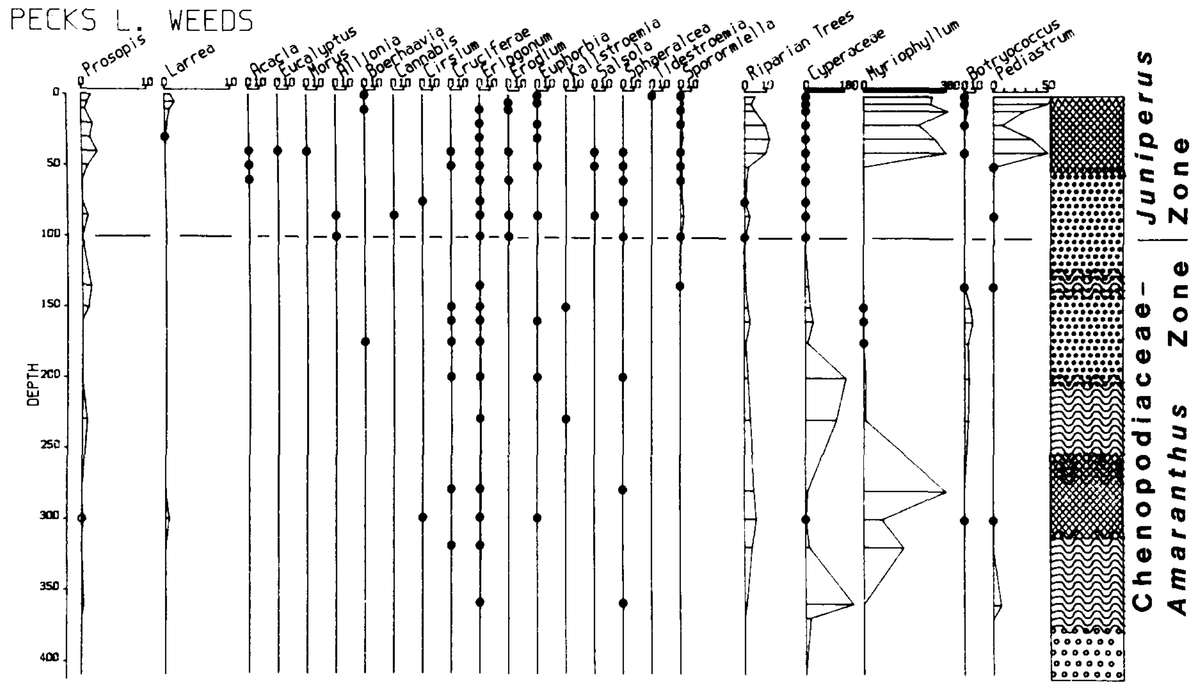

Fig.4. Pollen diagram of selected aquatic and ruderal taxa. Sediment stratigraphy shown on right. Filled circles indicate < 2%. Note scale change.

thus pollen. *Artemisia* and Gramineae percentages are greatest near the base of this zone, and the pollen of riparian trees increases near the base of the zone as *Myriophyllum* percentages reach 383% of terrestrial pollen. From 230–200 cm, Cyperaceae percentages reach 187% of terrestrial pollen, and at 360 cm Cyperaceae percentages reach 222%.

Historical photographs

The photographic comparisons demonstrate the major expansion of juniper at high elevation and several lesser but significant vegetation changes near the lake. Figure 10 shows the expansion of *Juniper* onto desert grassland at 1950 m. The 1929 photograph shows an open stand of young pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteosperma*) on the background hill and two small conifers in the exclosure. In the 1978 photograph juniper and pinyon cover the hill densely and fill the plot, obscuring much of the background visible in the 1929 photograph.

Other photographs show restricted increases of shrubs near the lake. Figures 5 and 6 demonstrate the local expansion of *Prosopis* and *Acacia* on the east shore of the lake, and the expansion of *Larrea* in the surrounding hills. Two plants of *Larrea* in the background of the modern photo of Fig.7 are not present in the 1945 photograph, and *Atriplex canescens* is much more common in the modern photograph. Figure 9 shows expansion of *Prosopis* east of Tuzigoot monument. Historic change of the upland vegetation near the lake is small. In Fig.8 *Canotia* is more common on the south-facing slope of a small hill.

Lake level was much lower in the 1887 photograph than when the modern photograph was taken. In Fig.5, emergent aquatics are present where today the water is too deep for such plants, and Fig.6 could not be exactly matched because the original position of the camera is now under water. Soil erosion is evident in Fig.6, which shows bedrock exposed in the 1984 photograph but not in the 1887 one.

Discussion

Juniper invasion

The pollen percentages in the *Juniperus* zone reflect historical vegetation change. The major feature of this zone results from the juniper invasion shown in Fig.10 and documented by several other matched-photograph studies in the western United States (Phillips, 1963; Hastings and Turner, 1965; Johnsen and Elson, 1979; Rogers, 1982).

The Pecks Lake study provides two new aspects to the juniper expansion debate: first, the historical increase in *Juniperus* pollen is just the final stage in the general trend of increasing *Juniperus* percentages that begins at the base of the diagram. Below 300 cm *Juniperus* percentages are less than 10%, near 150 cm they reach 20%, and in the juniper zone they exceed 30%. Juniper expansion in this area had been underway 2000 yrs before it was accelerated by human land use.

Secondly, the major increase in *Juniperus* percentages within the juniper zone occurs after the first occurrence of pollen of exotic plants (*Erodium cicutarium* pollen) and after earliest indications of increased grazing pressure. Except for one spore at 135 cm, spores of *Sporormiella*, a dung fungus, are present only in sediments of this zone. Members of this genus inhabit the dung of herbivores, particularly large herbivores (Munk, 1957). In southeastern Washington, percentages of this spore increase dramatically in lake sediments deposited after the introduction of European grazing animals (Davis et al., 1977). This phenomenon has been observed in other sites in the northern Great Basin (Davis, 1981; unpubl.), and *Sporormiella* is also present in the dung of extinct mammoths in Bechan Cave, Glen Canyon National Monument (Davis et al., 1984).

The brief *Pinus* peak at 85 cm (Fig.3) could have been produced by a cultivated plant that is no longer present, or from unusual sedimentation events when the lake was artificially filled.

Other historical vegetation changes

The expansion of *Prosopis*, *Acacia*, and *Larrea* vegetation shown in Figs.5, 6, and 9 is reflected by increased pollen percentages for these taxa above 50 cm. *Larrea divaricata* has spread onto southwestern rangeland in the last 100 years (Gardner, 1951; Humphrey and Mehrhoff, 1958), and its establishment is enhanced on open and unstable soil (Valentine and Gerard, 1968). The expansion shown in the photographs is probably a local phenomenon resulting from intensive grazing and erosion of soils surrounding Pecks Lake. The beginning of this expansion can be dated by its coincidence with increased *Myriophyllum* percentages above 50 cm, which reflect flooding of the lake basin shortly before 1913.

The maximum abundance of "other Compositae" pollen at the base of the juniper zone may coincide with maximum disturbance of the vegetation near Pecks Lake in ca. A.D. 1880 (Johnsen and Elson, 1979). The "other Compositae" type is produced by many native and introduced weed species (Parker, 1972). If weeds are responsible for this pollen maximum, then exotic weeds in the Compositae family may have replaced those in the Chenopodiaceae family and *Amaranthus* genus, which are prominent during the prehistoric interval (see page 196). This replacement may result from the introduction of new species of weeds or from different kinds of disturbance during the two intervals.

The pollen of exotic weeds present in the *Juniperus* zone includes *Cannabis*, *Erodium*, and *Salsola*. *Cannabis* was in southern Arizona by 1908 (Brown, 1908); *Salsola*, a very abundant weed in southern Arizona, was present by 1895 (Karpiscak, 1980); and *Erodium cicutarium* is thought to have been introduced by Spanish explorers in the 1600's (Parish, 1890; Thornber, 1906), and fruits of this plant are present in

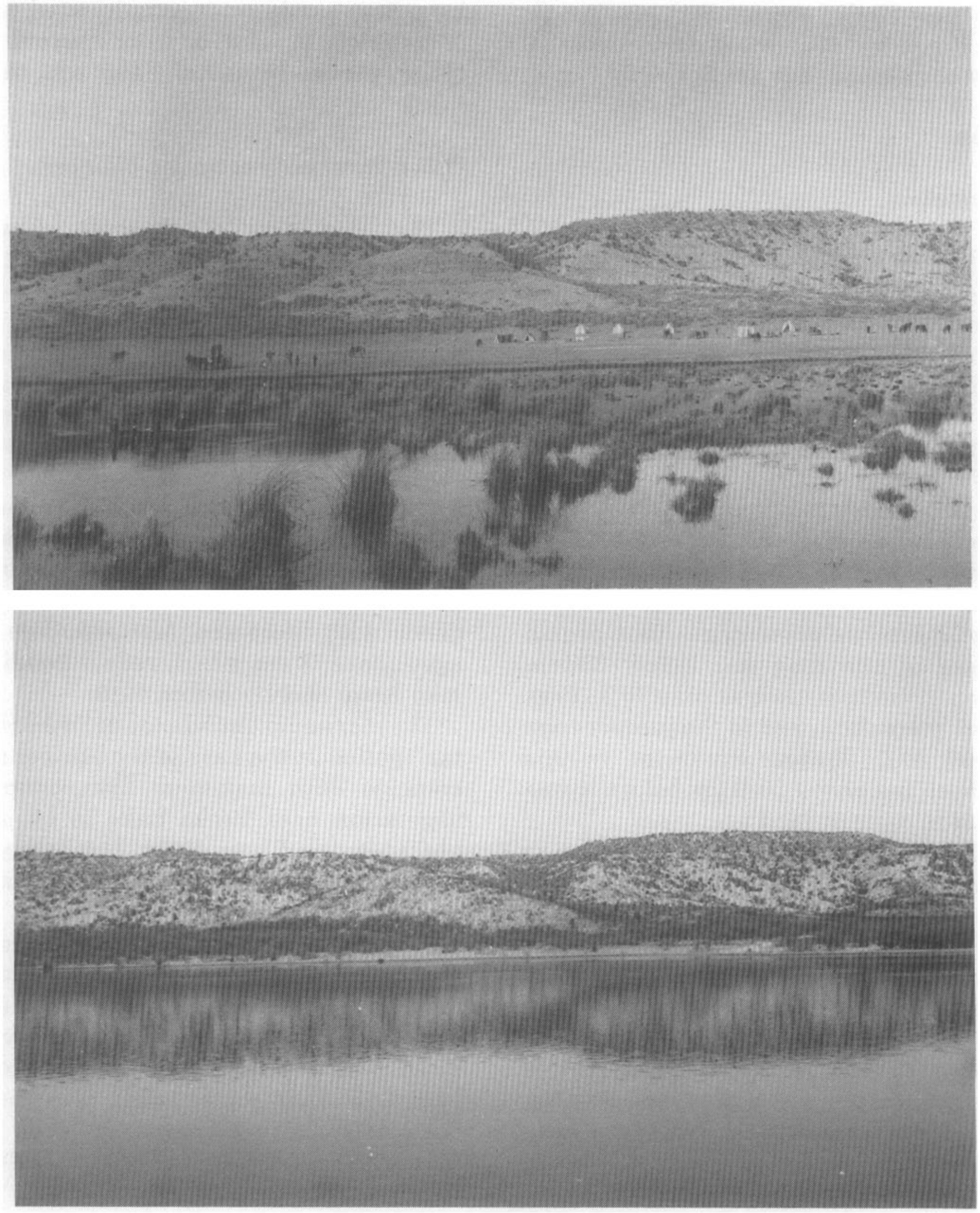

Fig.5. View toward north of Pecks Lake. Station 1 in Fig.1, upper photograph February, 1887, lower January, 1984. Note lower lake depth in 1887 (upper photograph courtesy of Arizona Historical Society). Increased abundance of shrubs apparent in woodland parallel to lake shore and in lower hills.

adobe bricks from Spanish missions built in California in the early 1700's (Hendry, 1931).

Erodium requires special mention because *E. texanum* is abundant in prehistoric archeological samples (S. Fish, 1984; personal communication); whereas *E. cicutarium* pollen has been found only in historic sediments (Davis et al., 1977). Only *E. cicutarium* is present in Pecks

Fig.6. View northeasterly across north shore of Pecks Lake. Station 2 in Fig.1, showing increased abundance of shrubs (mainly *Prosopis* and *Acacia*) between 1887 (upper photograph, courtesy of Arizona Historical Society) and 1984 (lower photograph). Note exposure of bedrock (at arrow) visible in lower photograph but not in upper.

Fig.7. Tuzigoot National Monument 1945 (upper) and 1984 (lower). Station 3 in Fig.1, note increased abundance of *Atriplex canescens* in foreground, two *Larrea* plants (arrows) are visible on ridge in midground in 1984, but not in 1945 (upper photograph courtesy of Western Archaeology and Conservation Center).

Fig.8. View from Tuzigoot National Monument toward northwest. Station 4 in Fig.1, note increased coverage of *Canotia* evident on hills in midground (arrow) in 1984 photograph (lower) compared to 1945 (upper photograph). Bare ground in foreground is a tailings pond for a nearby smelter. Upper photograph courtesy of Western Archaeology and Conservation Center.

Fig.9. Tuzigoot National Monument as seen from ridge above west bank of Verde River. Station 5 in Fig.1, *Prosopis* (arrow) is more evident at lower right of photograph in 1984 (lower) photograph than in 1945 (upper) photograph. Upper photograph courtesy of Western Archaeology and Conservation Center.

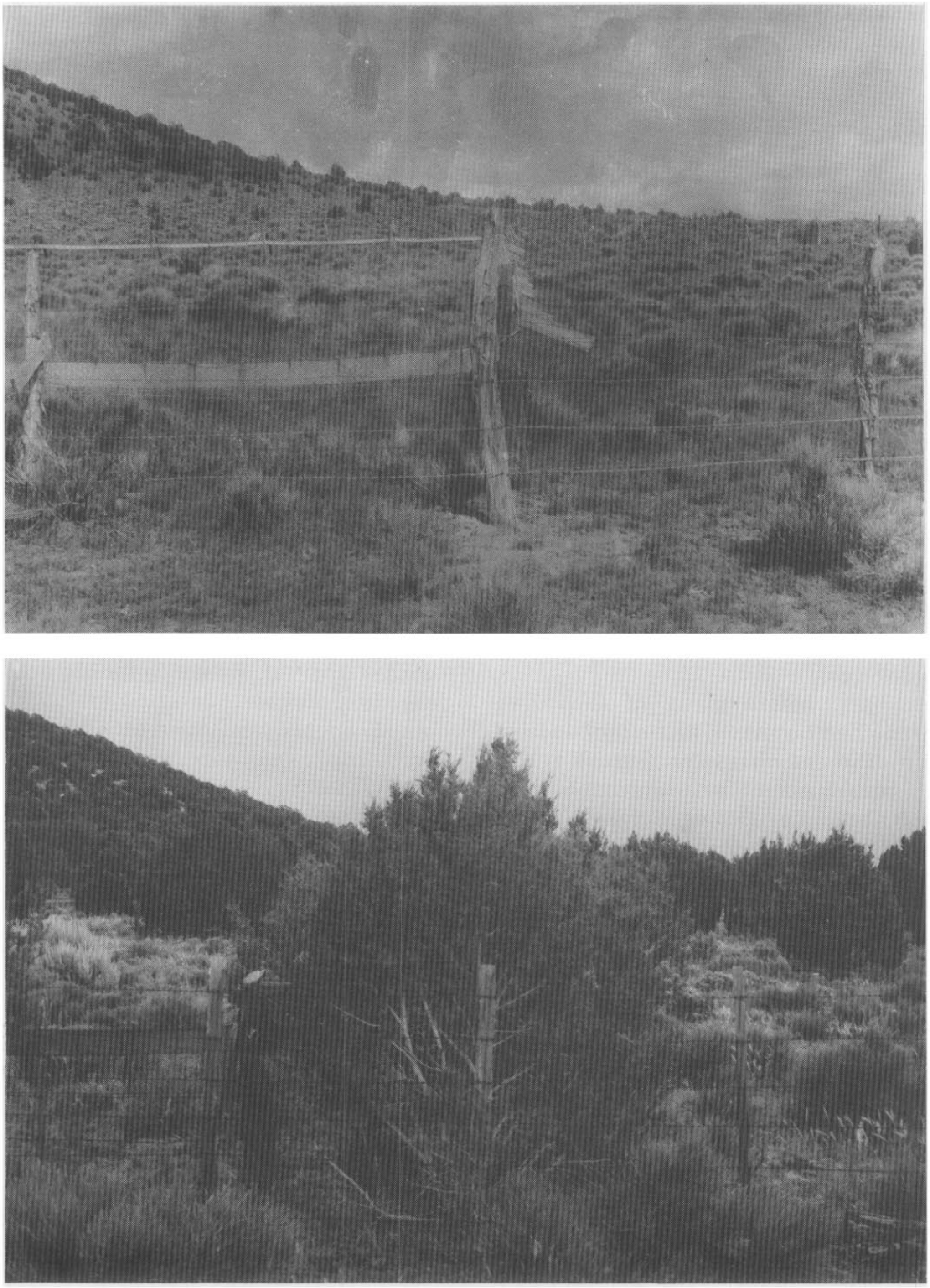

Fig.10. Old Biological Survey plot (elev. 1950 m, NW1/4, sec. 3, T 22 N, R 2 E) north of Williams, Arizona, 57 km north of Pecks Lake. The hill in the background of the 1929 (upper) photograph supports an expanding population of *Pinus edulis* and *Juniperus osteosperma*. By 1978 (lower photograph) these trees had increased greatly in size and number. Upper photograph, by W.P. Taylor courtesy of L.K. Sowls.

Lake sediments. Within Arizona *Erodium texanum* is not presently as widespread as *E. cicutarium* (Kearney and Peebles, 1960) and where the two occur together, *E. cicutarium* is usually more abundant (Inouye et al., 1980). *E. cicutarium* may have replaced its congener in disturbed areas.

The displacement of native weeds by historic weeds is suggested by the predominance of "other Compositae" pollen in the historic interval vs. Chenopodiaceae–*Amaranthus* pollen in the prehistoric interval, and may explain the predominance of *Erodium texanum* pollen in prehistoric pollen samples vs. *E. cicutarium* pollen in historic sediment. The displacement of native weeds is apparent in Karpiscak's (1980) study of abandoned fields in south central Arizona. Today, the successional sequence is dominated by Eurasian weeds beginning with *Salsola kali* and including several introduced species of the Cruciferae, Gramineae, and Compositae families. Only after many years do native species replace the introduced weeds.

In the 1920's, before many of the alien introductions had occurred, secondary succession had a different character. Shreve (1929) wrote, "... in agreement with much observational evidence ... the species and individuals which are the pioneers in the revegetation of cleared areas remain as the final components of the vegetation".

Comparison of pollen percentages and photographs

In this study historical photographs and pollen analysis have provided complementary evidence of historic vegetation. The comparison also permits a type of calibration of the palynology technique. The expansion of *Prosopis* and *Larrea* apparent in the photographs corresponds to an increase in coverage near Pecks Lake by roughly 1 km^2. The concomitant pollen increase is from $<1\%$ to $>2\%$ for *Prosopis* and from 0% to $>1\%$ for *Larrea*. Clearly, a substantial increase in local plant abundance produces only slight changes in the pollen rain for these insect-pollinated species.

The increase in *Juniperus* percentages is much greater, from about 20% below 100 cm, to $>40\%$ at 40 cm. Even though the closest juniper woodland is several kilometers from Pecks Lake, the historic expansion is a widespread event effecting thousands of square kilometers. In contrast to the local increases in *Prosopis* and *Larrea* pollen, the juniper expansion has effected the regional pollen rain. Stream transport of juniper pollen from the adjacent highlands also may have played a role in the juniper pollen increase because juniper macrofossils are present in the sediments from 65 to 75 cm.

Prehistoric land use

A prehistoric interval of vegetation disturbance from 150 to 250 cm provides an informative comparison to the historic disturbance, because juniper did not expand during the earlier interval. Evidence for disturbance during the prehistoric interval includes the combined occurrence of several native weeds including *Eriogonum*, *Boerhaavia*, *Kallstroemia*, *Tidestromia* and *Sphaeralcea* as well as high percentages of Chenopodiaceae–*Amaranthus* pollen.

These genera include several species that are important weeds today: *Eriogonum deflexum* is common on waste areas; *Boerhaavia coulteri*, *B. coccinea*, and six species of *Sphaeralcea* are found in waste areas and cultivated fields; and *Kallstroemia grandiflora* is abundant on irrigated fields (Parker, 1972). Pollen of these taxa has been recovered in higher percentages from archeological sites where prehistoric agriculture was practiced (Bohrer, 1978; Fish, 1984).

The Chenopodiaceae–*Amaranthus* pollen type, which is frequently abundant in Southwestern archeological sites (Schoenwetter, 1962; Hevly, 1981; Fish, 1984), reaches 60% at 200 cm. The potential sources of the Chenopodiaceae–*Amaranthus* pollen in this sediment include both cultivated plants and weeds. Van

Asdall et al. (1982) and Miksicek (1983) have found archeological evidence for prehistoric domestication of *Chenopodium berlandieri nuttalliae* in Arizona, and three of the nine members of the Chenopodiaceae–*Amaranthus* taxon considered to be native weeds in Arizona are used by Indians as pot herbs (Parker, 1972).

Atriplex canescens may be another source of Chenopodiaceae–*Amaranthus* pollen during the prehistoric period of human disturbance. In south central Arizona, *Atriplex* species become established after abandonment of fields and increase in abundance several years thereafter (Karpiscak, 1980). However, although it has increased dramatically at Tuzigoot since 1945 (Fig.7), Chenopodiaceae–*Amaranthus* pollen percentages do not reflect the increase in surface sediments (Fig.3).

High Chenopodiaceae–*Amaranthus* values (85%) in sand at 410 cm probably result from sedimentological processes rather than from environmental change. Lesser values at 360 and 370 cm may result from slight mixing, by less than 10 cm, associated with the development of peat on the abandoned channel.

Aquatic vegetation

The effects of climatic change and human disturbance may be seen in the pollen of aquatic plants. The dramatic increase in *Myriophyllum* pollen at 50 cm results from artificial filling of the lake in about 1913. The historic photograph (Fig.5) shows the lake at low level in 1887. After the lake level rose, *Myriophyllum* became very abundant (Arizona Game and Fish, 1982). Remains of *Pediastrum*, a planktonic alga, also became abundant after the lake filled (Fig.4) and the pollen of several trees now growing along the southern shore of the lake increased synchronously with *Myriophyllum*.

A prehistoric interval of increased lake level is apparent from 270 to 360 cm where percentages of *Myriophyllum* and riparian trees are high. Above and below this sediment interval Cyperaceae pollen exceeds 180% of terrestrial pollen. This sequence of aquatic types may have resulted from a single rise in lake level following abandonment of the Pecks Lake meander by the Verde River: (1) at first water depth was shallow and sedges predominated; (2) later water depth increased to near present depths and *Myriophyllum* predominated; (3) finally, lake level dropped as sedges once again occupied the site. By 1887 the lake was quite shallow (Fig.5).

This prehistoric interval of high lake level may be given two different interpretations. First, increased precipitation may have increased discharge of several springs that surround the lake and thereby increased lake level. Presently the springs southeast of the lake (Fig.1) supply enough water for irrigation and a large marsh. However, most of the springs drain southward away from the lake. Secondly, the Verde River may have occasionally flooded the meander after initial breaching of the meander neck. As the fan that now dams Pecks Lake grew, the lake level would have increased. Later, the frequency of flooding could have decreased when (1) the river level at the head of the meander was lowered by alluvial down-cutting, or (2) the channel between the river and the lake became blocked by sediments and vegetation.

Climatic change

Much of the vegetation change seen in the Pecks Lake pollen diagrams can be attributed to two intervals of human disturbance. During the historic interval juniper percentages suddenly increase. But during the prehistoric period of human disturbance juniper percentages reflect only the long-term increase, which is accompanied by decreased percentages of *Ephedra nevadensis*, Gramineae, *Artemisia*, and *Ambrosia*.

The last four pollen types are today most abundant in modern pollen samples from the low-elevation desert grassland whereas *Juniperus* is more abundant at higher elevation (Hevly, 1968). The simplest interpretation of the long-term trend is a gradual lowering of vegetation zones during the last two millennia, which probably resulted from climatic cooling.

Precipitation also may have changed. The most direct indication of precipitation change is lake depth, which has decreased over this period of time, implying increased aridity. However, as discussed above, the trend in lake level may reflect geomorphological evolution of the lake basin rather than climatic change.

Similar increases in *Juniperus* percentages are reported for surface sediments at Montezuma Well (Hevly, 1974) and during the Late Holocene at Bechan Cave in southern Utah (Davis, unpublished). The gradual expansion of juniper woodland during the late Holocene may be a widespread phenomenon in the American Southwest that was accelerated by historic vegetation disturbance.

Hastings and Turner (1965) concluded that climate and cattle both effected the historic increase of juniper in the southwest. The Pecks Lake study supports that conclusion and provides a longer chronology: the expansion of *Juniperus* began at least 2000 yrs before the introduction of grazing.

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