Quantitative and Historical Evidence of Vegetation Changes Along the Upper Gila River, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 655-H

QUANTITATIVE AND HISTORICAL EVIDENCE OF VEGETATION CHANGES ALONG THE UPPER GILA RIVER, ARIZONA

Photographs near Calva, showing encroachment of the Gila River flood plain by saltcedar between 1932 (above) and 1964 (below).

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By RAYMOND M. TURNER

GILA RIVER PHREATOPHYTE PROJECT

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Four vegetation maps of the upper Gila River valley show changes in channel width and vegetation for the past 50 years

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LIST OF PLANTS

[Scientific names after Kearney and Peebles (1960). Since usage of common names is not standardized, more than one common name may apply to a species]

Common name	*Scientific name*
Alkaliweed	*Suaeda torreyana* Wats.
Arrowweed	*Pluchea sericea* (Nutt.) Coville
Batamote	*Baccharis glutinosa* Pers.
Bermuda grass	*Cynodon dactylon* (L.) Pers.
Chamizo	*Atriplex canescens* (Pursh) Nutt.
Cottonwood	*Populus fremontii* Wats.
Creosotebush	*Larrea tridentata* (DC.) Coville
Grama grass	*Bouteloua* sp.
Iodinebush	*Allenrolfea occidentalis* (Wats.) Kuntze
Jimmyweed	*Aplopappus heterophyllus* (Gray) Blake
Mesquite	*Prosopis juliflora* (Swartz) DC.
Sacaton grass	*Sporobolus wrightii* Munro.
Saltbush	*Atriplex canescens* (Pursh) Nutt.
Saltcedar	*Tamarix pentandra* Pall.
Seepweed	*Suaeda torreyana* Wats.
Seepwillow	*Baccharis gultinosa* Pers.
Willow	*Salix* sp.

QUANTITATIVE AND HISTORICAL EVIDENCE OF VEGETATION CHANGES ALONG THE UPPER GILA RIVER, ARIZONA

By Raymond M. Turner

ABSTRACT

Vegetation maps showing past conditions along a 24-kilometer (about 15-mile) reach of the upper Gila River valley were compared with a recent vegetation map and changes in vegetation were determined. The maps, which were made during 1914, 1937, 1944, and 1964, provide a quantitative record of changes through half a century. Historical records and recent surveys show that the width of the Gila River channel has changed from narrow (pre-1900) to broad (early 1900's), to narrow (1960). The vegetation has not changed in a similar cyclic manner—the vegetation adjacent to the narrow channel of a century ago was vastly different from that adjacent to the narrow channel of the 1960's. During the last period (1944–64), saltcedar, an introduced species, has dominated the low areas bordering the channel, having replaced such native species as seepwillow and cottonwood.

Possible causes for the altered conditions are channel changes, dam construction, changes in frequency of fires, altered streamflow pattern, and the effect of saltcedar introduction. In the part of the study area that has been inundated periodically by a reservoir, saltcedar establishment was directly influenced by the dam. In areas along the valley outside the reservoir, the plant's establishment cannot be directly linked with dam construction. Moreover, the time of the plant's most rapid expansion outside the limits of the reservoir did not coincide with any major disruption of the flood-plain environment. Evidence is presented which indicates that saltcedar can eliminate native riparian species, such as cottonwood and seepwillow, from areas where the indigenes dominate.

INTRODUCTION

The vegetation of river valleys is characteristically complex. Rivers constantly shift position, often slowly, sometimes with devastating rapidity. As a result, the vegetation along stream channels [1] is in a constant state of flux or "perpetual succession" (Campbell and Green, 1968). Fluvial processes control the vegetation, which migrates in response to the constant changes in the river bed. The vegetation pattern is altered each time a new area is left open to occupancy by plants. The sequence of plant invaders varies with the habitat, but, given similar conditions, roughly the same group of plants comes to occupy similar habitat types in the shifting riparian setting.

[1] Channel as used in this report is defined as the continuous, open, unvegetated part of a valley, adjacent to and including the streambed, that is maintained free of terrestrial plants as the results of mechanical action of running water.

The segment of the Gila River flowing through Safford Valley in southeastern Arizona has undergone changes typical of streams in semiarid regions (Burkham, 1971). Within the past century, the channel has undergone a 10-fold variation in width. In 1875 the average width was about 46 meters (about 150 ft). This narrow channel was widened, perhaps almost overnight, to an average width of 610 meters (about 2,000 ft) during a record flood in 1905. By the mid-20th century, the channel width had returned to what it had been before the turn of the century (Burkham, 1971).

These channel fluctuations, well within the expected range for a stream draining a semiarid region the size of the Gila River watershed, have been accompanied by vegetation changes which do not reflect a similar return to some preexisting condition. The complex and variable assemblage of plant communities that apparently existed before the 1905 flood is no longer present. The kinds of plants formerly present are still there, but saltcedar, an introduced plant that clearly was not part of the old environment, is now the dominant plant of the flood plain.

The introduction of saltcedar to southern Arizona and its spread along the Gila River coincided with a period when lands bordering the Gila were increasingly used by man. Three vegetation maps of the middle Gila valley were drawn during this period—the first in 1914 and the others in 1937 and 1944. In 1964 a fourth map was made. Using these four maps as foundations, this report attempts to describe vegetation changes that have occurred in one short segment of the Gila River valley and to suggest possible causes for the changes.

GENERAL DESCRIPTION OF STUDY AREA

The study area lies within southeastern Arizona along a 24-kilometer (about 15-mile) reach of the Gila River valley east of its confluence with the San Carlos River (fig. 1). It lies within the San Carlos Apache Indian Reservation and is the location of the U.S. Geological Survey's Gila River Phreatophyte Project (Culler and others, 1970). The project area includes about 2,400 hectares (about 6,000 acres) of the Gila River flood plain which today is occupied principally by the phreatophytes, saltcedar and mesquite.

The project area lies between the Santa Teresa Mountains, about 15 kilometers (about 10 miles) to the south, and the Gila Mountains, about the same distance to the north. Most of the sediment in the valley is basin fill, extending to depths of 300 meters (about 1,000 ft) or more. This basin fill, the surface of which slopes uniformly from the mountains flanking the valley, has been dissected into mesas and benches (Davidson and Weist, 1970). The main valley and its tributaries are filled with alluvium, the substratum upon which most of the phreatophytes now grow.

San Carlos Reservoir, the body of water impounded behind Coolidge Dam, lies downstream from the study area and when full covers the lower two-thirds of the area. After the completion of the dam in 1928, the water level has been low, and the upper end of the impounded water body has remained downstream from the study area since then. During 1941–42, however, the reservoir was almost full, and water covered large parts of the lower two-thirds of the area. At other times water has covered lesser parts. The upper one-third lies above the level of the reservoir and has, therefore, never been subjected to inundation.

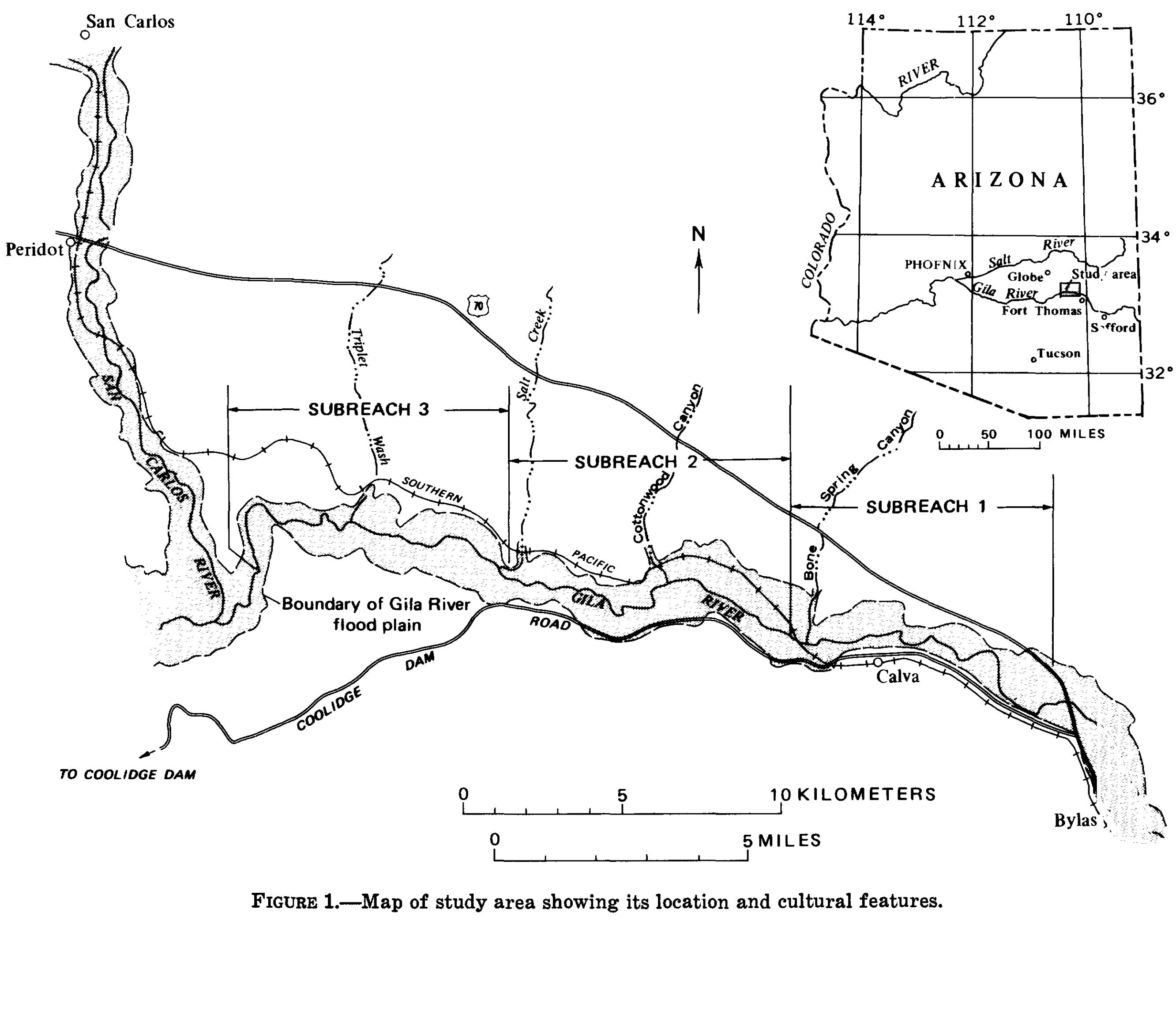

FIGURE 1.—Map of study area showing its location and cultural features.

The area of the basin draining into this reach of the Gila River is about 29,800 square kilometers (about 11,500 sq mi) (Burkham, 1970). The elevation at the study area is roughly 760 meters (about 2,500 ft), and the elevation of mountainous areas draining into the basin extend up to 3,350 meters (about 11,000 ft).

Surface-flow characteristics of the river have recently been described (Burkham, 1970). Streamflow is largely influenced by the biseasonal precipitation regime characteristic of this part of the Southwestern United States. Flow from summer precipitation extends from July through October; flow from winter storms, from December through June. Periods of no flow are common and may last, as in 1956, for as long as 4 months (U.S. Geological Survey, issued annually). Flow is also influenced by diversions associated with the irrigation of about 27,900 hectares (about 69,000 acres) of cultivated land upstream from the study area.

MAPS OF VEGETATION

Vegetation within the study area has been mapped on four different dates; these maps provide an unusual opportunity to follow changes in plant life over a relatively large area through approximately half a century. The first map (Schwennesen, 1921, pl. III) was the outgrowth of a survey in 1914 aimed at examining the geology and water resources of the Gila and San Carlos valleys within the San Carlos Apache Indian Reservation. The second, based on a range survey during 1937, was drawn by the U.S. Soil Conservation Service in a program designed to evaluate the grazing capacities of the entire reservation. In the early 1940's the Geological Survey, working through the Defense Plant Corp., was joined by the Phelps Dodge Corp. in a program to measure the water consumed by vegetation along a 74-kilometer (about 46-mile) reach of the Gila valley from Safford to Calva, Ariz. (Gatewood and others, 1950); this study resulted in a third vegetation map (1944). The most recent map (1964) was constructed as part of the Survey's current program to evaluate evapotranspirational losses from the Gila River valley.

VEGETATION MAP OF 1914

The Gila valley was mapped by planetable during the fall of 1914. The land was classified as arable or nonarable depending on its topography and the quality of its soil. In addition, the dominant plants were shown for most of the area bordering the river channel (Schwennesen, 1921, pl. III). To Schwennesen, the recognition of plant communities was of secondary importance, and his references to the vegetation were incomplete and brief. He recognized five vegetation types: cottonwood, alkaliweed, mesquite, creosotebush, and brush (pl. 1). The term "alkaliweed" probably referred to the plant which is usually called seepweed. Names of two vegetation types, cottonwood and mesquite, are in common use, and there is little doubt about what plants Schwennesen assigned to these patches of the vegetation mosaic. Areas dominated by creosotebush were on the surrounding uplands and are not part of the riparian habitat considered here. Of the five categories, the meaning of one—brush—is unclear. The patches of brush consistently bordered the river channel, and from a knowledge of the native plants of the region, one can assume that the term referred to areas dominated by seepwillow. Saltcedar later appeared in this same channel-border situation. Although saltcedar may have been a component of the brush vegetation, this phreatophyte was not prominent enough in 1914 to be singled out by Schwennesen. Furthermore, according to residents of the Gila River valley near Safford, saltcedar did not occur in the upper Gila valley until after the flood of 1916 when the plant was found growing in broad, flooded, and denuded land along the valley bottom (Robinson, 1965, p. 6). Thus, Schwennesen's survey of the valley may have come scarcely 2 years before saltcedar encroachment began.

VEGETATION MAP OF 1937

The Soil Conservation Service conducted a range-resources survey of the entire San Carlos Apache Indian Reservation from 1935 through 1937. An outgrowth of the survey was a vegetation-type map (unpublished Soil Conservation Service maps on file at Land Operations Department, U.S. Bureau of Indian Affairs, San Carlos, Ariz.) on which were shown the dominant plant species on all the rangelands of the reservation, including the land along the Gila River valley. (Most of the valley vegetation was mapped in 1937. This date has been used as the mapping date.) Because the survey was conducted by personnel familiar with the flora of the region and because each vegetation type was characterized by ranking the species according to the percentage of crown coverage [2] of each, these data provide a sensitive measure of the vegetation of the mid-1930's.

The original maps and field notes have far more detail than is necessary for the purposes of this

[2] Crown coverage is the percentage of the soil surface covered by a vertical projection of the living part of the plant crowns.

study. Accordingly, the detailed plant coverage data have been pooled into broad coverage classes. Furthermore, where the range surveyors tallied all major species in a vegetation type, only the most abundant species in that type (dominant species) were used in the present analysis. The vegetation types recognized on this basis are: saltcedar, mesquite, seepwillow, seepweed, arrowweed, and cottonwood (pl. 1). Each type has been further divided into three categories depending on the percentage of the soil covered by vertical projections of the crowns of the dominant species. The three coverage classes are: light, 0–39 percent; medium, 40–74 percent; dense, 75–100 percent. The choice of these coverage intervals was dictated by the form of the basic data for the 1944 vegetation map, to be discussed next.

VEGETATION MAP OF 1944

In April 1943 the Geological Survey, working through the Defense Plant Corp., joined the Phelps Dodge Corp. in an investigation of water use by natural vegetation along a portion of the Gila River valley. In response to wartime copper needs, the Morenci, Ariz., mines of the Phelps Dodge Corp. planned an expansion that would require additional water. The closest source of supplementary water was the San Francisco River, a tributary of the Gila. Use of water from this source was not possible because all the surface water in the Gila River basin above Coolidge Dam had been appropriated. A plan was proposed whereby water, removed from the San Francisco by the mine, would be replaced by clearing the natural vegetation from the Gila River below the San Francisco. This vegetation, it was reasoned, consumed a considerable amount of water; for man's purposes this was wasted water since the plants were of little or no economic value. The unknown quantity of water that was wasted was to be determined from the Safford Valley Study. The results of this investigation were later published (Gatewood and others, 1950). Included was a vegetation map of the Gila valley down to the railroad bridge near Calva. The upper one-third of the present study area was thereby shown.

The actual vegetation mapping of the upper subreach was done during the summer of 1944 by the Geological Survey (Gatewood and others, 1950). The original field notes and aerial photographs (on file at the Morenci Branch, Phelps Dodge Corp.) were consulted and serve as the basis for the 1944 vegetation map. At the time of the fieldwork, canopy coverage for each phreatophyte species was estimated in parcels of relatively homogeneous vegetation, and the acreage occupied by the species within the parcel was determined. In the present study, parcels were assigned to a particular vegetation type on the basis of the species whose coverage is densest within the parcel. In the case of a tie, the parcel was named for the species shown in the field notes to have the greater height. Only three coverage classes, light, medium, and dense, were used. These correspond to 0–39 percent, 40–74 percent, and 75–100 percent, respectively. These class limits, set during the Safford Valley Study, have been used as a basis for comparing the vegetation of 1937, 1944, and 1964.

Only five plant communities were recognized during the 1944 reconnaissance: saltcedar, seepwillow, mesquite, cottonwood and willow, and brush. The last category included arrowweed, several species of saltbush, seepweed, and iodinebush. By examining the aerial photographs, it has been possible to recognize areas of arrowweed and areas occupied singly or jointly by seepweed and idodinebush. The refinement made possible by consulting the original field notes and aerial photographs has resulted in a vegetation map differing in many respects from the more generalized map published by Gatewood, Robinson, Colby, Hem, and Halpenny (1950, pl. 3).

VEGETATION MAP OF 1964

Detailed vegetation maps of the study area were made as part of the Gila River Phreatophyte Project (Culler and others, 1970). As with the 1937 and 1944 maps, aerial photographs were used as a base for the fieldwork. The bottomland vegetation shown on the photographs was divided into irregular parcels of relatively homogeneous vegetation. Each parcel was later visited, and the dominant and subordinant species were noted. Estimates of crown coverage were not made in the field as had been done by previous workers; instead, coverage was measured from the photographs. (This technique is described fully in Culler and others, 1970). Briefly, measurement was made by viewing the black-and-white aerial photographs (approx scale 1:14,000) through a dissecting binocular microscope. One ocular of the microscope was fitted with a reticle divided into 100 squares, each 1 square millimeter in area. When superimposed on the photographic image (magnified 10 times), the square outlined areas were equivalent to 2 hectares (5 acres) on the ground. Coverage within each "plot" was then estimated, the estimates for the large dominants and the smaller subordinates being kept separate. The estimates from the many plots within a parcel were averaged and provided a coverage estimate for the entire parcel.

To test this technique, values obtained from the photographs were compared with coverage values obtained in the field. The field procedure used was the "line-intercept" method [3] described by Canfield (1941). Field estimates were not obtained from areas of saltcedar dominance because the dense growth typical of this vegetation in the study area is almost impossible to move through. Instead, patches of mesquite vegetation with trees of varying size and coverage were used. With both the photogrammetric and line-intercept methods, separate estimates were made of the dominant mesquite and of the small subordinate species. The latter category included, among others, Jimmyweed, arrowweed, and chamizo.

Where the large mesquites extended above smaller bushes, care was taken to consider only the coverage of the larger. The fraction of the plant community sampled by the ground survey should, therefore, coincide more closely with the aerial survey than would have been the case had total coverage of both layers of overlapping crowns been measured.

Results of this comparative study are given in table 1. In view of the wide range of values included in the three coverage classes used on the vegetation maps, agreement between the two methods is, for purposes of the present analysis, close. Some of the disparity between values of the two methods can be attributed to differences in areas actually sampled within the parcels—for the photogrammetric method, large 2-hectare (5-acre) "plots" were the basic units viewed, and for the line-intercept method, 100-foot lines spaced 10 feet apart were used as the basic measurement units.

VEGETATION BEFORE 1914

On November 1, 1846, Capt. A. R. Johnston, aide-de-camp to General Kearny, described the vegetation along the Gila River from the mouth of the San Carlos to the site of present-day Coolidge Dam as follows: "the grass along the edge of the water on the river grows in a thin stripe very luxuriantly; there is usually a thicket of willows, about 10 yards deep, along the borders of the stream; then in the bottom, which is subject to overflow, cotton-woods grow of two and three feet in diameter; this strip is usually 200 or 300 yards wide" (Johnston, in Emory, 1848, p. 588). On the same date, Lieutenant

[3] Mr. S. B. Bingham conducted the field work for this comparative study during the summer of 1965.

TABLE 1.—*Comparison of plant-coverage estimates, in percent, obtained by two methods for mesquite community*

Parcel No.	Parcel area (ha)	Line-intercept method: Mesquite	Line-intercept method: Subordinate species	Line-intercept method: Total	Photogrammetric method: Mesquite	Photogrammetric method: Subordinate species	Photogrammetric method: Total
20–2a	17.3	21.2	5.8	27.0	23.3	2.6	25.9
2b	11.5	19.8	2.5	22.3	24.7	4.8	29.5
2c	9.9	14.2	.8	15.0	17.6	.0	17.6
24–1	11.2	28.4	22.0	50.4	23.4	22.6	46.0
4	16.6	19.7	3.0	22.7	18.0	3.4	21.4
5	16.3	29.8	10.8	40.6	35.1	14.1	49.2
9	5.9	40.6	15.4	56.0	34.2	16.9	51.1
10	6.6	20.7	2.2	22.9	20.8	.0	20.8
24a	7.6	8.8	.8	9.6	16.1	.0	16.1
24b	6.8	7.4	.2	7.6	14.9	.9	15.8
26	1.8	23.9	.8	24.7	24.5	.0	24.5
27	.8	12.3	.0	12.3	12.7	.0	12.7
28	1.3	47.7	36.3	84.0	61.9	31.9	93.8

Colonel Emory also observed the "luxurious grama [grass] on the river banks" at the present site of Coolidge Dam (Emory, 1848, p. 71). The day before, in camp at the mouth of the San Carlos, Captain Turner noted that they were "at an excellent camp for grass" (Clarke, 1966, p. 98). A few days earlier and roughly 50 miles upstream from the San Carlos, Lieutenant Colonel Emory had noted "***close to the river, cotton wood and willows" (Clarke, 1966, p. 68). On this same day (Oct. 28, 1846), Dr. Griffin, surgeon with Kearny's dragoons, found the banks of the Gila "tolerably well wooded with cotton wood" (Griffin, 1942, p. 205).

By 1849 the route followed by Kearny's troops 3 years earlier was frequently used as a "road" by groups enroute to California's gold fields. William Chamberlin, keeping a daily account of the journey of one such party, noted that the Gila was fringed by cottonwood (Chamberlin, 1945, p. 160). Although he made no specific references to the vegetation within the part of the valley we are examining, he noted at a point upstream from present-day Safford, "the river is so beset with underbrush and drift that we cannot get a supply of water without extreme difficulty" (p. 164).

In the 1870's, two decades after the Gadsden Purchase brought the land on both banks of the Gila River under one flag and coincident with the defeat of the Apaches and the establishment of the San Carlos Apache Indian Reservation, the new settlers and Indian occupants of the Gila valley began tilling soil which had lain fallow for centuries. Because this intensive development created the need for permanent ownership records, accurate surveys were made of the valley upstream from the reservation. (No early surveys were made on the reservation although irrigation had begun at Old San Carlos by

1873, according to Commissioner of Indian Affairs (1873, p. 289).) For the area east of the reservation boundary, surveyors' field notes provide additional brief references to the plant life along the river. Although these notes include many imprecise references to "brush," enough specific references were made to the widely recognized willow, cottonwood, and mesquite that one can conclude that these plants were an important component of the vegetation of the period. Included under brush were probably seepwillow and seepweed, both of which were collected along the Gila by Lieutenant Colonel Emory in 1846 (Emory, 1848).

In part because of their large size, cottonwoods were frequently noted by travelers along the Gila road in the mid-19th century (Emory, 1848; Johnston, in Emory, 1848; Clarke, 1966; Griffin, 1942; and Chamberlin, 1945). A generation later in 1881, one photographer recorded a dense stand of old trees near Fort Thomas that are undoubtedly cottonwoods (fig. 2). In 1885 another photographer recorded what appears to be a mixed stand of willow and cottonwood (fig. 3) upstream from Fort Thomas and bordering the Gila. On that date the river was confined to a narrow channel. In 1909 photographs (not shown) show dense immature stands of this tree becoming established along the broad channel produced by the large flood of 1905. These same stands were present when the valley was mapped by Schwennesen 5 years later (pl. 1).

Today, only a century later, no traveler passing through uncultivated parts of this same section of the Gila River valley would find patterns of vegetation similar to those found during the half century before 1900. Cottonwood is still present but in widely scattered stands; willow is seldom found and then only as isolated clumps; the luxuriant strip of grass at the water's edge, if there at all, is composed not of "grama" but of Bermuda grass, a plant that is probably new since 1846. Seepwillow is locally abundant, but along much of the valley it can be found only as widely scattered plants or as a narrow fringe along the open channel. Seepweed is still common in open stands of vegetation where the water table is shallow. At present, all along the valley, the lowest levels bordering the river are heavily beset with underbrush comprising a single species, saltcedar, not once referred to in the early accounts.

VEGETATION FROM 1914 TO 1964

In the following sections, vegetation changes from 1914 to 1964 will be reviewed and causes for the changes discussed. Vegetation of subreach 1 will be emphasized for two reasons: (1) this area is above the maximum stage of the reservoir and has not been directly affected by impounded waters and (2) the vegetation map for 1944 covers only this part of the study area. In addition, the 1914 vegetation has not been stressed because the description

FIGURE 2.—Cavalry camp on a terrace of the Gila River near Fort Thomas, 1881. Cottonwood forest occupies a broad strip on the flood plain below the terrace. (Photograph from the Arizona Historical Society Library.)

FIGURE 3.—Gila River east of Fort Thomas, October 7, 1885. Forested strip of cottonwoods and willows is separated from the channel by a band of low shrubs (probably seepwillow). (Photograph from the Arizona Historical Society Library.)

of vegetation for that year was very general and not comparable in detail to that for the three subsequent mappings. Furthermore, over the 24-kilometer (about 15-mile) length of the study reach, the area included in the earliest map was narrower than that for subsequent ones.

As a means of judging changes from one map to the next, the area common to the detailed maps for the years 1937, 1944, and 1964 was used. In the following sections, estimates of areas occupied by vegetation types are based on planimetric measurements within the common area. These values are therefore somewhat below the actual totals.

SALTCEDAR

During 1937–64 the subreach 1 area dominated by saltcedar increased from 59 hectares (about 147 acres) to 407 hectares (1,006 acres) (fig. 4; table 2). This increase is even more dramatic when one notes that in 1914 saltcedar dominated no areas along the 8-kilometer (5-mile) segment of the Gila valley. The increase of saltcedar along the Gila during the first half of this century has close parallels elsewhere. In Utah, Christensen (1962) found that prior to 1925 the plant was virtually unknown and that the period of its most rapid gain along rivers and on reservoirs was from 1935 to 1955. According to Hefley (1937, p. 369), saltcedar increased rapidly along the Canadian River flood plain in Oklahoma from 1920 to 1935. In Colorado, along the lower Arkansas River, saltcedar advanced progressively during 1936–57 (Bittinger and Stringham, 1963). Robinson (1965, p. 6) showed for one 322-kilometer (about 200-mile) reach of the Pecos River in New Mexico that this plant was unknown prior to 1912; encroachment began that year and continued until 1960 when an estimated 23,000 hectares (about 57,000 acres) were occupied by the plant. Along the same river in Texas, Hefley (1937) noted: "during the past thirty-five years [saltcedar] has completely

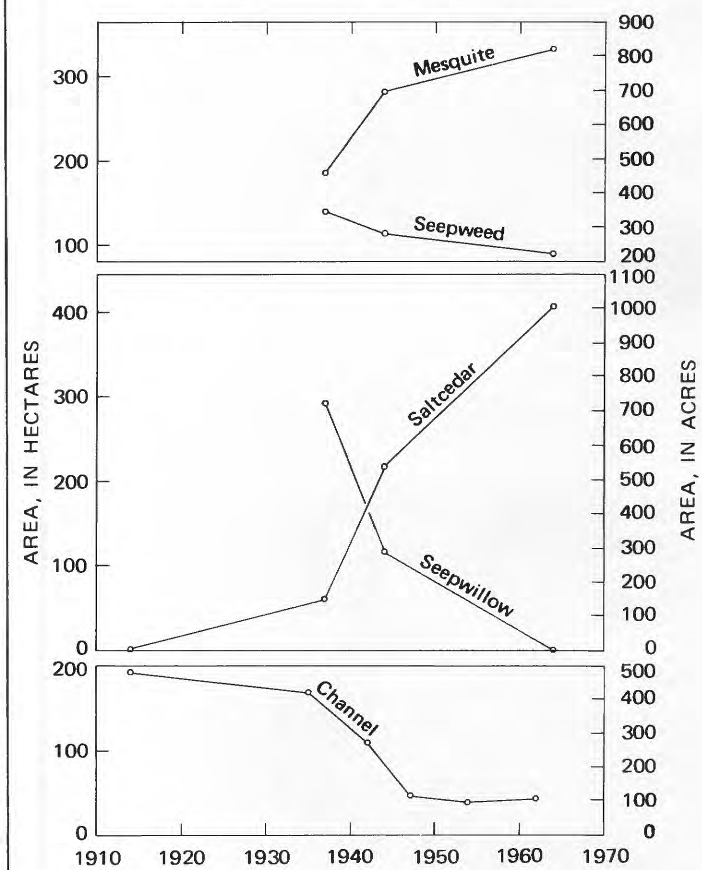

FIGURE 4.—Change in areas dominated by selected phreatophytes and in area occupied by channel, subreach 1.

replaced the endemic vegetation in many localities."

The foregoing reveals that saltcedar, an aggressive invader of riparian habitats, has often advanced into new areas that formerly supported native plants. Along the Canadian River, saltcedar has replaced the elm-oak forest (Hefley, 1937); along the Gila River, the native seepwillow and cottonwood are being replaced.

TABLE 2.—*Areal extent of vegetation, by class, and of barren or cultivated land and channel shown on maps of 1937, 1944, 1964, subreach 1, Gila River Phreatophyte Project*

[The three coverage classes are: light, 0–39 percent; medium, 40–74 percent; dense, 75–100 percent]

Plant community (and coverage class) and other areas	Area, in hectares		
	1937	1944	1964
Saltcedar:			
Light	59	55	102
Medium	0	106	195
Dense	0	56	110
Total	59	217	407
Seepwillow:			
Light	291	75	0
Medium	0	39	0
Dense	0	2	0
Total	291	116	0
Cottonwood:			
Light	0	65	0
Medium	0	0	0
Dense	0	0	0
Total	0	65	0
Seepweed:			
Light	138	0	44
Medium	0	25	42
Dense	0	89	3
Total	138	114	89
Arrowweed:			
Light	95	15	20
Medium	0	24	27
Dense	0	0	0
Total	95	39	47
Mesquite:			
Light	184	232	264
Medium	0	51	68
Dense	0	0	0
Total	184	283	332
Barren or cultivated land and channel	188	121	80
Grand total	955	955	955

SEEPWILLOW

Seepwillow, or batamote, is a native plant that superficially resembles willow. This plant grew abundantly within the study area until recently. In 1937, 291 hectares (718 acres) supported this species; in 1944, 116 hectares (286 acres); but in 1964, only minor areas too small to be mapped at the scale used here were occupied by seepwillow (fig. 4; table 2).

The reduction in seepwillow area follows a trend that is almost exactly opposite that for saltcedar. For example, there was a particularly sharp decrease in seepwillow acreage between 1937 and 1944; during the same period there was a rapid increase in saltcedar (fig. 4; table 2). The increase in saltcedar has been almost wholly at the expense of seepwillow (pl. 1). As seedlings of both find ideal conditions in sunny, moist situations, the two plants could occupy essentially the same habitat—recent flood deposits bordering rivers. Why one species has come to dominate is a central question of this study.

COTTONWOOD

Of the 641 hectares (about 1,584 acres) supporting vegetation on the upper subreach at the time of Schwennesen's survey, 33 percent were occupied by cottonwoods. Thus, this tree comprised the most widespread single community along this part of the flood plain in 1914. By 1944 the situation had changed—only 65 hectares (160 acres)[4] were occupied by cottonwoods growing densely enough to be considered a distinct vegetation type. By 1964 the cottonwood as a community was gone although a few scattered plants remained.

Individual cottonwood trees were identified from aerial photographs taken in 1935, 1942, and 1964. The location of the trees has been shown on the vegetation maps for 1937, 1944, and 1964 (pl. 1). Although many small trees were probably missed and individual large trees, where closely crowded, were often not discernible, the use of aerial photographs served to locate cottonwood stands and to illustrate relative density of the trees.

The dense cottonwood forest near the western limit of the project area shown on the vegetation map for 1937 (pl. 1) was composed of dead trees at the time (unpublished Soil Conservation Service field notes) and, judging from their appearance on the 1935 aerial photographs, they were perhaps dead even 2 years earlier. The simultaneous death of the entire stand probably resulted from inundation in 1932 and again in 1933 when the San Carlos Reservoir reached levels roughly 10 meters (32 ft) and 6 meters (19 ft), respectively, above the floor of the cottonwood forest (reservoir levels from U.S. Geological Survey, issued annually; ground elevations from U.S. Army Corps of Engineers unpub. 1947 planetable map).

[4] In 1937 approximately the same area was dominated by this tree. Because the range-survey techniques used at that time did not require a coverage estimate for those plants exceeding the reach of cattle, cottonwood, where present, was listed on the field sheets, but no coverage for it was given.

Additional cottonwood destruction probably occurred in the lower two-thirds of the study area in 1941–42 when the reservoir reached the record level of 762 meters (about 2,500 ft) and the impounded water extended upvalley to within 2.4 kilometers (about 1.5 miles) of the railroad bridge at Calva. Perhaps partly because of this flooding, the cottonwood was completely eliminated from the lower two-thirds of the project area west of the bridge by 1964. Upstream from the bridge the maps or field notes show cottonwood forests in 1914, 1937, and 1944. By 1964 cottonwoods occurred above the bridge in greatly diminished numbers, and the few remaining trees were all relatively old. As no young trees were present, establishment must have failed in recent years.

In an attempt to determine when cottonwood reproduction had failed, the existing population of 52 trees was examined. (More than 400 trees were in the same area in 1935 and 1942). Cores were taken from each tree at a height of 1 meter (about 3 ft) above the ground, and the number of xylem rings were counted. The stems of two were so badly decomposed that no ring count was possible. Stems of 14 others were partly decomposed; for these the number of obliterated rings was estimated.

Ring counts from 36 sound trees and estimated counts of the 14 slightly decomposed trees are sumarized in figure 5. Assuming each ring is a year's growth increment, the resulting histogram represents a survivorship curve for the entire cottonwood population of the project area in 1964. The youngest tree found was 32 years old; the oldest, 67. Accordingly, no tree living in 1964 became established after about 1932 or before about 1897.

The configuration of the survivorship histogram is a function of the number of establishments in any year and the number of subsequent losses. Where no mortality data is available, the survivorship histogram can be interpreted only in general terms. Apparently cottonwoods became established during the period prior to the large flood of 1905. Following the flood, the data suggest that establishment continued at the same or perhaps an accelerated rate during the period up to about 1914. Following that, establishment declined. There have been no establishments since 1934–39. It is noteworthy that during 1939–44 saltcedar invasion was particularly conspicuous.

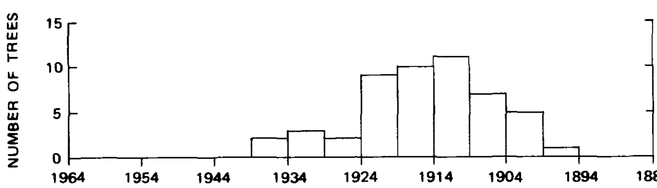

FIGURE 5.—Age distribution in cottonwood population (1964). Height of bars represents the number of trees within 5-year age classes.

SEEPWEED

The area occupied by seepweed has not varied greatly since 1937. Of the 955 hectares (2,360 acres) common to the vegetation maps of 1937, 1944, and 1964, seepweed occurred in 138, 114, and 89 hectares (340, 281, and 219 acres), respectively (table 2). Much of the reduction in seepweed areas by 1964 appears to have resulted from conversion of seepweed stands to mesquite bosques (fig. 4). The two plants often occur together, and many areas that start out with a mixture of the two are ultimately dominated by mesquite which, by virtue of its slow growth relative to seepweed, does not dominate earlier in the history of the stand.

According to Shantz and Piemeisel (1924, p. 774), seepweed is a good indicator of saline land except where it may occur briefly, as a weed, on abandoned farmland. It thrives best where moisture is available year round, at least at the 1.0- and 1.2-meter (3- and 4-ft) depths (Shantz and Piemeisel, 1924). In the Sulphur Springs Valley, Ariz., Meinzer (1927) found the plant as a dominant on areas where the ground water at low stage was 1.2 to 2.1 meters (4–7 ft) deep. Because of its apparent need for shallow water, aggradation within the project area has probably eliminated the plant from many areas.

ARROWWEED

In the 1914 vegetation survey, a distinct arrowweed community was not recognized, and there is no way to determine the extent of this species at the time. On subreach 1 the area occupied in 1937 was 95 hectares (235 acres); this value fell to 39 and 47 hectares (96 and 116 acres) in 1944 and 1964, respectively. Although some of the parcels of vegetation dominated by arrowweed appear relatively stable from 1937 to 1964, the land from which the plant disappeared was occupied mainly by seepweed or mesquite in 1964. Meinzer (1927) noted that arrowweed is an indicator of shallow ground water, and Gary (1963) described the configuration of the root system of plants growing in an area where ground water is at a depth of 1.2 meters (4 ft). The plant apparently reproduces by the abundant production of new shoots from widespread roots. Aggradation could account for conversion of arrowweed stands to mesquite areas.

MESQUITE

The area dominated by mesquite almost doubled in size during the 27 years following 1937; by 1964, 332 hectares (820 acres) supported light to moderately dense forests of this tree, compared with only 184 hectares (455 acres) in 1937. The greatest rate of change in coverage apparently occurred during the early part of that period of years. Schwennesen's 1914 map showed mesquite as occupying less than 10 percent of the upper subreach. Although not strictly comparable, the 1914 value may be compared with coverages of 19 percent, 30 percent, and 35 percent for the years 1937, 1944, and 1964, respectively.

Mesquite is probably adapted to a wider range of habitat conditions than the other phreatophytes in the project area. It is not an obligate phreatophyte because it can become established and complete its life cycle even in habitats where its roots do not contact the water table. Where it has become established on sites having a shallow water table, the plant assumes a tree form, and its branches produce a nearly continuous canopy.

The increase since 1914 in area occupied by mesquite is partly due to the aggradation prevalent on some parts of the early flood plain (Burkham, 1971). Mesquite is well adapted to such habitats. The tree produces sprouts when buried by sediment and is thus capable of remaining in areas in which aggradation is occurring. Furthermore, its roots are capable of growing to great depth, perhaps as deep as 53 meters (175 ft) (Phillips, 1963). Areas where deposition has taken place are relatively immune to the scouring action of heavy floods, and the slow-growing trees are able to reach maturity and dominate even where they formerly ranked only as subordinants.

INTERPRETATION OF VEGETATION CHANGES

INFLUENCES OF CHANNEL CHANGES

The Indian Agent at San Carlos wrote in his report for 1881 that there had been "very heavy floods along * * * particularly the Gila" producing "the highest water known by white men who have been in the country for seventeen years" (Commissioner of Indian Affairs, 1881, p. 8). In August and early September of 1890, at least three separate floods on the Gila at San Carlos caused inconvenience to travelers or damage to the irrigation system (Arizona Silver Belt, Aug. 9, 16, 30, Sept. 13, 1890). Other rivers in southern Arizona's desert country were also experiencing remarkably heavy flows at the same time. (For a short summary, see Hastings and Turner, 1965, p. 41–43). Six months later, in February 1891, even more serious floods occurred that swept a large part of the land cultivated by the Indians at San Carlos (Commissioner of Indian Affairs, 1892, p. 219). Floods became almost commonplace along the Gila and occurred again in 1895, 1896, 1905, 1906, 1914, and 1916 (Burkham, 1970).

The effects on riparian vegetation of these late 19th century and early 20th century floods is not clear. However, D. E. Burkham (oral commun., 1971) found evidence to indicate that the wide channel of 1914–16 (Schwennesen, 1921; Olmstead, 1919) was formed only after 1903, almost certainly as the result of the large floods of 1905–06. Furthermore, the small preflood channel of 1903 was approximately the same size as that in 1875 and again in the 1960's.

Olmstead's (1919) description of channel changes along the Gila above the Indian reservation agrees closely with the findings of Burkham. Olmstead reported a tenfold increase in channel width from the time of settlement in the last half of the 19th century to 1917. Channel area in one township east of Safford, Ariz., for example, increased from 42 hectares (104 acres) in 1875 to an area of 608 hectares (1,503 acres) in 1917. It seems clear that a full round of events, from narrow channel, to wide, to narrow, has occurred during roughly one century. Vegetation changes along the valley must be interpreted within this setting.

In a study of recent hydrologic changes along the Gila River above Coolidge Dam, Burkham (1970) noted a gradual decrease in surface flow (in rates and amounts), gradually decreased channel width, increased meandering coupled with increased channel length, and gradual aggradation. These slow changes occurring over roughly 60 years have been accompanied by an increase in the density of flood-plain vegetation and a decrease in precipitation. The complex nature of the interrelationships among these parameters makes the assignment of definite cause-and-effect relationships difficult.

Channel changes within subreach 1 have been determined by making measurements from available maps and aerial photographs for six different dates between 1914 and 1962. Channel configuration on these dates is shown in figure 6. The tendency toward a narrower, more sinuous channel is clear. The most rapid reduction in channel area occurred from 1935 to 1947 (fig. 4). The large channel produced by the floods of 1905 (Burkham, 1970; 1971), diminished in size only slightly from 1914 to 1935. This slight apparent change is probably related in

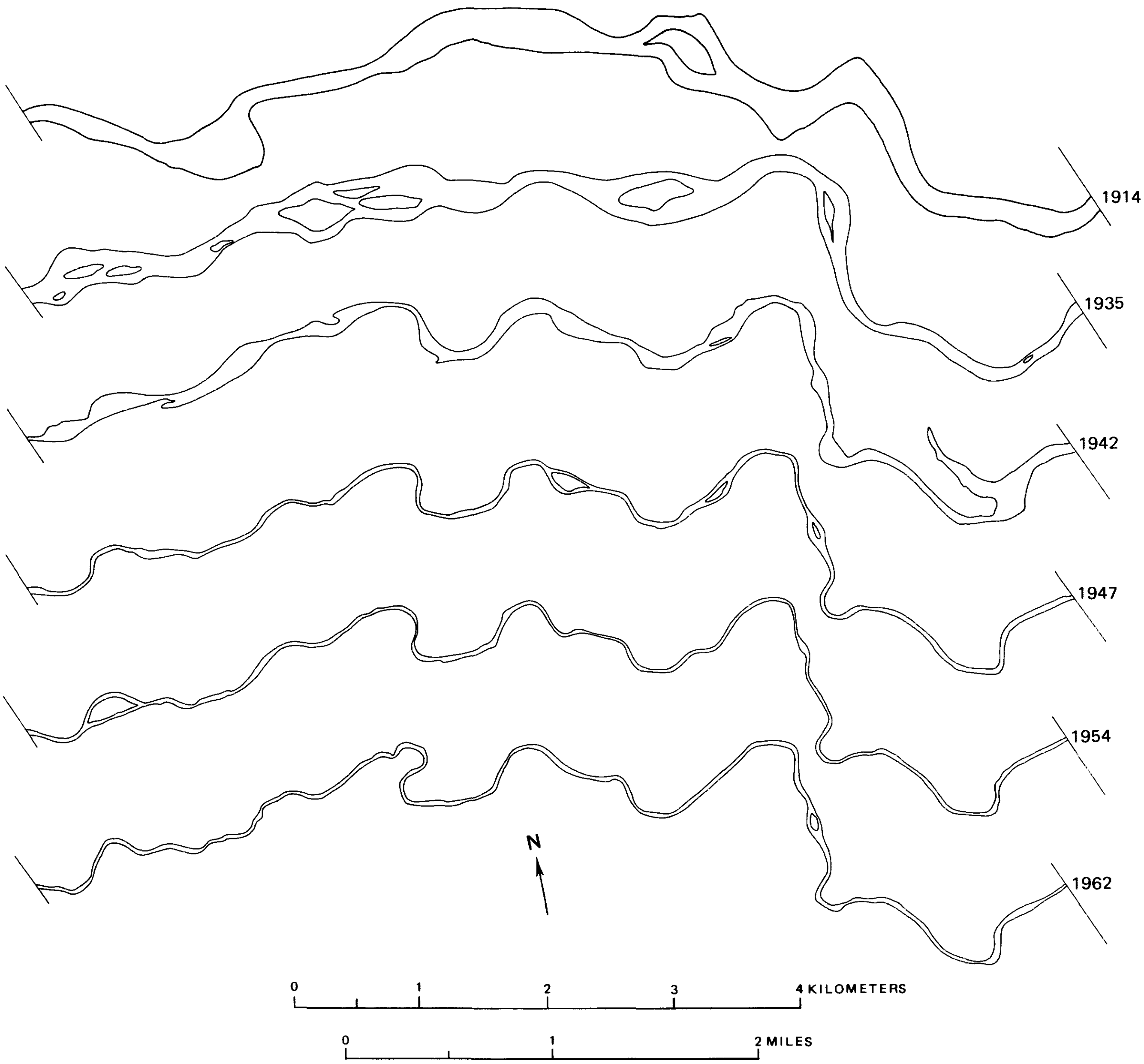

FIGURE 6.—Changes in channel configuration, subreach 1, 1914–62.

part to the floods of 1915–16 which scoured large areas of the 1905 channel that may have started to stabilize by 1914. (Olmstead (1919) showed that large areas of the 1914 flood plain on the upper subreach were eroded by the floods of 1915–16.)

During 1935–47, changes along the channel were abrupt. Of particular interest is the continued decrease in acreage from 1935 to 1942. On October 1, 1942, a flood having a peak discharge of approximately 28,000 cubic feet per second passed Calva at the lower end of subreach 1. (This flow was probably the highest since the much larger flow of 100,000 cubic feet per second in January 1916 (U.S. Geological Survey, issued annually).) Aerial photographs taken on December 10, 1942, only 2 months after the flood, show that scouring had not increased the channel area to that shown in the 1935 aerial photographs. By 1947 the channel had attained an area that remained relatively constant until 1962 (fig. 4), although, as can be seen in figure 6, the length of the channel increased and the width decreased during this final 16-year period.

Coincident with reduction in channel area has been a sharp increase in acreage occupied by saltcedar, an introduced species, and an abrupt decrease in the area occupied by the native seepwillow and cottonwood (fig. 4). These changes raise such questions as what role, if any, has the altered flora played in determining the new channel configuration, and, conversely, what role have the channel changes had in determining vegetation patterns? Also, why would one species come to dominate at the expense of another? Forces other than fluvial processes or floristic changes may also be involved in the shifts in vegetation cover. These will be considered in the final sections.

INFLUENCE OF FIRE

Because fire, or its absence, is often considered as a possible cause of vegetation change in the Southwestern United States (Humphrey, 1958), an examination of the possible effects of fire on the vegetation along the Gila River valley is needed. Two questions, in particular, should be reviewed: Are the riparian species adversely affected by fire? Has the frequency of fires along the valley bottom changed enough to explain the documented change in vegetation?

There seems to be little doubt that fires occurred in valleys of the region even before the era of settlement by non-Indians began. Plant growth in valleys is characteristically rank and provides adequate fuel to promote intense conflagrations. Several references to valley fires in the region support this view. Pfeffercorn (1949 translation, p. 198), an 18th-century missionary, recorded the use of fires by Pima Indians to flush rats and mice from dense stands of sacaton grass growing in bottomlands. In a later but specific reference to the Gila valley, Lieutenant Colonel Emory (1848, p. 65) described an extensive fire there in 1846, although it is not possible to determine from his account whether the fire burned on the flood plain or only on low terraces nearby. A description of an 1858 fire along the San Pedro River is particularly graphic: members of the Leach Wagon Road party set fire to a sacaton grass swale, and "the entire length of the Valley of the San Pedro was traversed by the flames consuming every vestige of this once luxurient growth" (National Archives and Records Center, 1858, p. 31–32).

There is little doubt that the dense, seasonally dry vegetation along the Gila and other streams of the region periodically caught fire, but with what frequency cannot be determined. In recent times, particularly since the advent of saltcedar, fires on the project area have become commonplace and are purposely set to open up the dense thickets for use by cattle. Although records of the frequency of burning were not carefully kept, tribal cowboys probably annually set fire to areas of rank saltcedar growth within the San Carlos Indian Reservation. Although some plants are killed, the remainder sprout from the burned stumps, and a stand of saltcedar soon grows back.

Because of the need for maintaining a stable vegetative cover during the calibration period, the custom of burning was stopped at the initiation of the Gila River Phreatophyte Project (Culler and others, 1970). The original vegetation-mapping field notes (1964) for the project contain several references to recently burned areas, however, and many other sections showed signs of having been burned earlier.

In summary, how frequently fires burned through the valley vegetation cannot be definitely determined, but it seems likely that fire frequency has increased recently, largely as a cultural practice in response to increased saltcedar growth. Fires, then, are perhaps a result, not the cause, of the most significant vegetation change—increased saltcedar growth.

Changes among the other species may be fire related, especially the loss of cottonwoods. This tree is easily killed by ground fires. Destruction of the cambium can result even though there is no deep burning of the thick outer bark. Loss of many mature cottonwoods from the study area through fires is suggested by the presence, at the time of the 1964 vegetative mapping, of numerous charred cottonwood bases. Which, if any, were burned following death from other causes is not known, however.

INFLUENCE OF CHANGED STREAMFLOW PATTERN

Shifts in the pattern of streamflow might influence the bottomland vegetation through two avenues. First, frequent large floods might maintain a broad, sparsely vegetated flood plain in contrast to a flood plain which is exposed only rarely to the same size flood. A change in flood frequency could conceivably cause a change in vegetative cover. A second influence of streamflow is through direct control of seed germination and seedling establishment. For example, if, through the years, the season of continuous flow in ephemeral rivers should end progressively earlier (or later) in the spring, seed germination and seedling establishment might be altered in species dependent on the coincidence of (1) prolonged moisture availability and (2) seed production over a short, well-defined spring period.

In terms of physiologic requirements for water, the establishment of riparian species is not directly related to amount of stream discharge. Whether a peak discharge of 50 cfs or 5,000 cfs passes a given point along a stream is unimportant; the alluvium may be fully saturated for its entire depth in either case. What is important to the plants is duration of flow (Zimmerman, 1969), particularly during the early stages of establishment when growth of shallow roots may not keep pace with the desiccating influence of surface evaporation. During this critical time, prolongation of periods of saturation by streamflow may be the main force promoting establishment of new seedlings. Although the Gila River flows continuously some years, interrupted flow on the project is common. These periods of no flow characteristically fall in June and July.

In figure 7 the duration of spring and summer no-flow periods each year at Calva is shown for the 35-year period from 1930 to 1964, inclusive. Although a slight tendency toward longer, earlier, and more frequent no-flow periods is evident, the effect of this changed streamflow regime on phreatophyte establishment has probably been slight. Willow and cottonwood, two species having brief, strictly vernal seed seasons, produce seeds a month or two in advance of the onset of most no-flow periods. Roots of seedlings probably would have penetrated deeply enough most years to survive surficial desiccation of the soil resulting from flowless periods. For other phreatophytes, such as saltcedar and seepwillow, a dry spring resulting in no seed germination would probably be followed most years by generous establishment during the period of summer floods because these species produce seeds through the summer months.

Although duration of flow may be of prime importance to seedling establishment, floods may quickly eliminate the new plants. Recurrent floods of even small size could result in the elimination of shallowly rooted seedlings. Once mature, the same plants could be dislodged only by much heavier flows. The pattern of flooding on the project has been studied by Burkham (1970), who noted that major floods occurred during nine winters from 1891 to 1916 compared to only one major winter flood during the much longer period 1917–65. The reduction in floods is related to the almost continual decrease in winter precipitation in the Gila River basin since 1920 (Burkham, 1970; see also Sellers, 1960, and Hastings and Turner, 1965). Decreased winter-flood frequency may have contributed to the increase in acreage dominated by phreatophytes and to the reduction in channel area because seedlings would not have been flushed from newly invaded habitats.

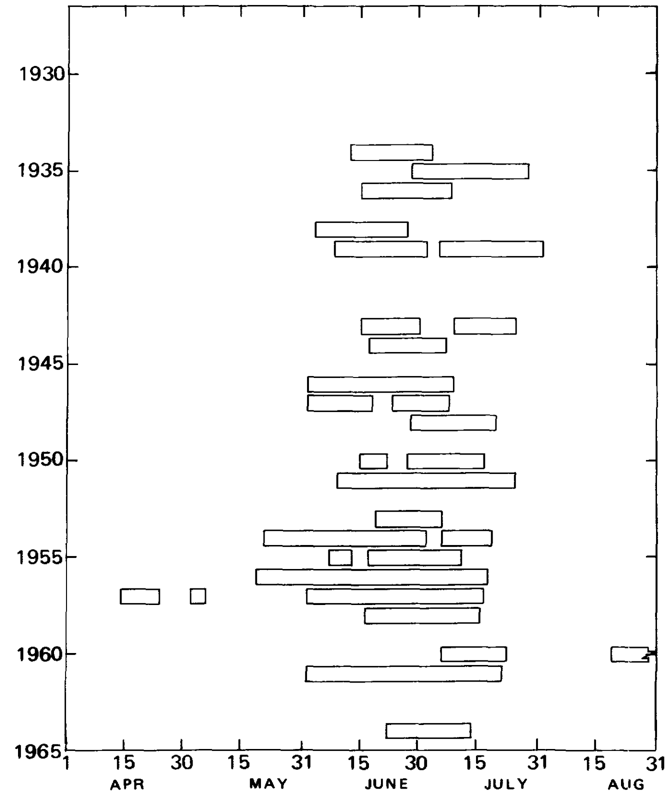

FIGURE 7.—Periods of no flow, April 1 through August 31, 1930–64, Gila River at Calva.

Summer flow, which constitutes only 32 percent of the average annual total, has shown no tendency toward long-term reduction (Burkham, 1970). Summer flow is also a relatively stable moisture source (interannual coefficient of variability = 0.71 versus 1.04 for winter flow) which might provide a dependable moisture supply for summer germinating species.

If a relationship exists between changed streamflow and the shifts in vegetation dominance, the mostly likely force is reduced winter-flood frequency which, in combination with the dependable summer flow, would enhance the establishment of summer germinators such as saltcedar and seepwillow. The reduction in spring germinators, such as cottonwood, does not seem directly related to observed trends in streamflow characteristics.

INFLUENCE OF SALTCEDAR INTRODUCTION

Fires, floods, flow duration, and, indirectly, climate have been considered as possible factors in promoting vegetation changes along the Gila. To these physical forces must be added one that is biotic—the introduction of saltcedar and the resulting interplay between the old and new riparian species.

Riparian plant communities vary with time at a comparatively rapid rate as a result of the dynamic nature of river channels. The river is the dominant force in the valley landscape. Because of the diversity of habitats open to a varied flora, river valleys normally support a complex pattern of plant communities. Today along the Gila and elsewhere this complexity is gone, and one suspects that the simplicity of the current phreatophyte forest results from some trait of the exotic plant which presently dominates that forest.

Saltcedar was introduced to this continent from Eurasia in the mid-19th century. It first appeared as a horticultural plant, but now occupies roughly 400,000 hectares (about 1 million acres) along watercourses in western North America (Robinson, 1965). As shown in an earlier section, saltcedar became increasingly important along the middle Gila River beginning sometime prior to the mid-1930's. The increase observed here has close parallels along rivers and around lakes and reservoirs in New Mexico (Robinson, 1965), Texas (Hefley, 1937), Utah (Christensen, 1962), Oklahoma (Hefley, 1937), and Colorado (Bittinger and Stringham, 1963).

Since bare, moist soil in well-lit openings is the ideal seedbed for saltcedar and the other phreatophytes, interspecies competition for this space is probably great. When saltcedar first invades an area, the pattern of encroachment is probably nearly the same everywhere: a few scattered saltcedars first gain a foothold; the population then increases and spreads into other adjacent favorable areas; and, most importantly, once the exotic is established in large numbers, the native plants are almost completely excluded. This change in vegetative composition is probably largely irreversible. Although many introduced plants grow along waterways in the Southwest, it is mainly saltcedar that has come to dominate extensive areas in this manner. Its rapid spread on the flood plain of the Gila River and elsewhere is largely the result of prolific seed production, effective seed dissemination, rapid growth, and early maturation. These and other features of the plant's life cycle will be considered next and will be compared with pertinent aspects of native phreatophyte life histories.

SEED VIABILITY

As with many riparian plants, seeds of saltcedar are short-lived, remaining viable for only a few weeks (Horton and others, 1960). Viability of willow (U.S. Department of Agriculture, 1948) and cottonwood seeds (Horton and others, 1960; Engstrom, 1948; Moss, 1938) is equally transient. In contrast, seeds of seepwillow and arrowweed, when stored under laboratory conditions, germinated even a year after collection (Horton and others, 1960).

Where germinability is rapidly lost, establishment can only occur at the time of seed production, or shortly after, and then, of course, only when proper environmental conditions for germination exist. The disadvantage to a species of temporary seed viability might be offset by a lengthy season of seed production. The probability for simultaneous occurrence of viable seeds and favorable germinating conditions would then be greatly increased. These requirements are met for saltcedar—the fruiting period is protracted, lasting from early May into September (D. K. Warren, oral commun., 1970), and the period of potential establishment is equally long.

In contrast, seed production in willow and cottonwood is brief and comes in March and April. Because both have short-lived seeds, spring flow is probably essential for their establishment (Zimmerman, 1969).

Seepwillow seed viability is long lasting, persisting for a year or more (Horton and others, 1960); in addition, seed production lasts from April to October. The combination of prolonged viability and protracted seed production should mean seeds are viable the year round for this species. Seedlings should appear any time that temperature and moisture conditions are favorable. Actually, germination has been observed from March through the summer (Horton and others, 1960; Zimmerman, 1969).

The pattern of seedling establishment around reservoirs or on flood plains can often be explained when the above life-history details are considered. In one study (Horton and others, 1960), new seepwillow seedlings were found in March along the shores of Granite Reef Dam, Ariz. In April saltcedar seed production commenced, and at the same time, the first seedlings of this species were observed. Subsequently, a band of dense saltcedar seedlings became established between the seepwillow area above and the receding waterline below. Similar bands of vegetation have been observed around reservoirs elsewhere in Arizona (D. K. Warren, oral commun., 1970) and in Kansas (Tomanek and Ziegler, no date).

The appearance by 1937 of light stands of saltcedar along the lower two-thirds of the study area (fig. 8) is probably directly related to the high water level in the San Carlos Reservoir in 1932. During 1932 the level of the reservoir reached about 753.3 meters (2,471.56 ft) above mean sea level,

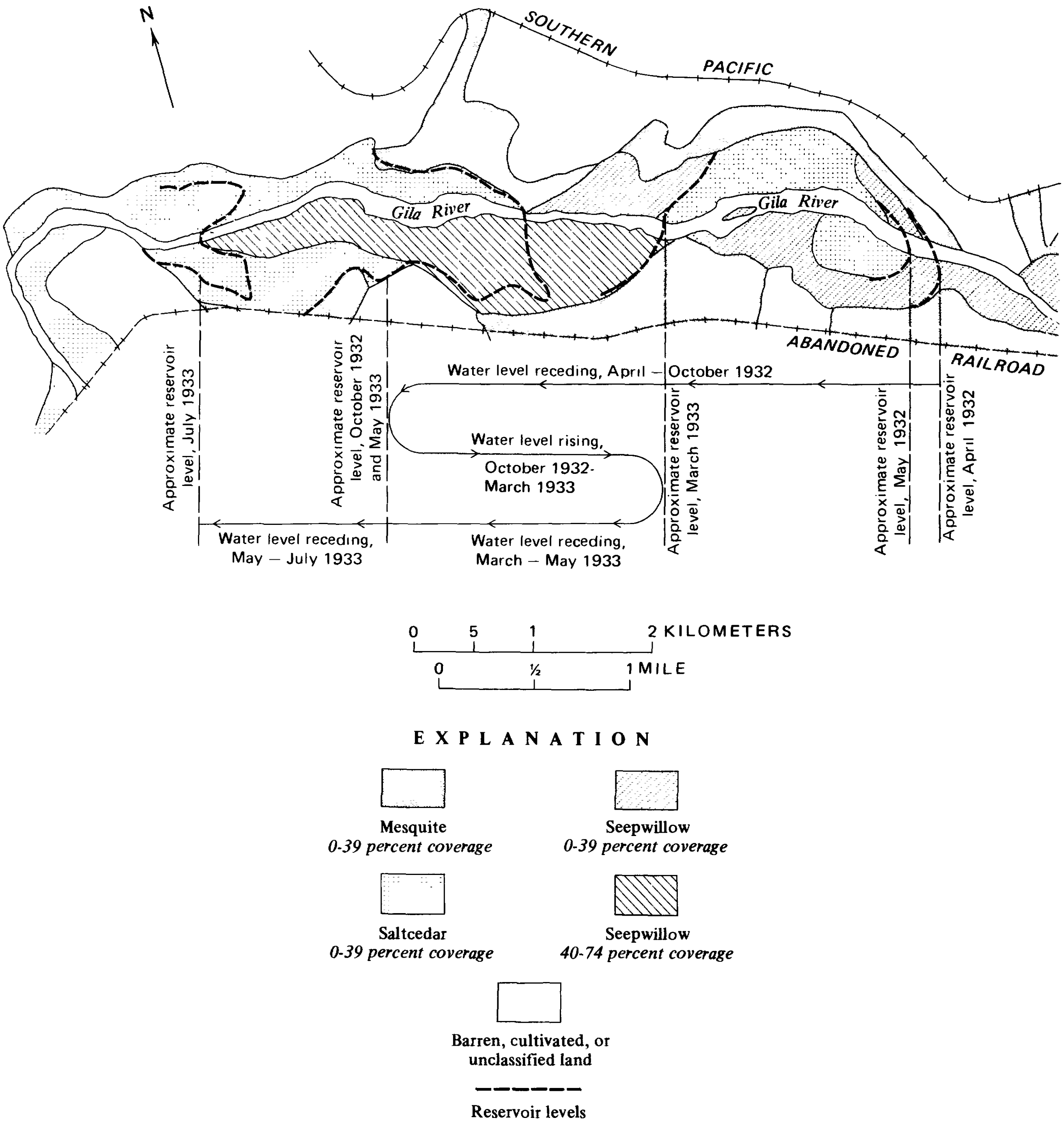

FIGURE 8.—Vegetation of the lower part of the project area in 1937 showing the influence of 1932–33 reservoir levels on vegetation pattern. As the reservoir receded from its maximum stage in April 1932, the sequence of plant invaders can be related to features of the annual life cycles of the dominant flood plain species, saltcedar and seepwillow (see text). Topographic data compiled by photogrammetric methods from aerial photographs taken in 1946.

the highest level yet attained following completion of the dam in 1928 (fig. 9). As the water receded, alluvium recently deposited at the head of the reservoir would have been invaded by the native seepwillow and by saltcedar in a pattern determined by the coincidence of ample seed supply, adequate moisture, and proper temperature.

As the water level began receding in 1932 from the high level of early April, no viable saltcedar seeds from the previous year's crop would have been

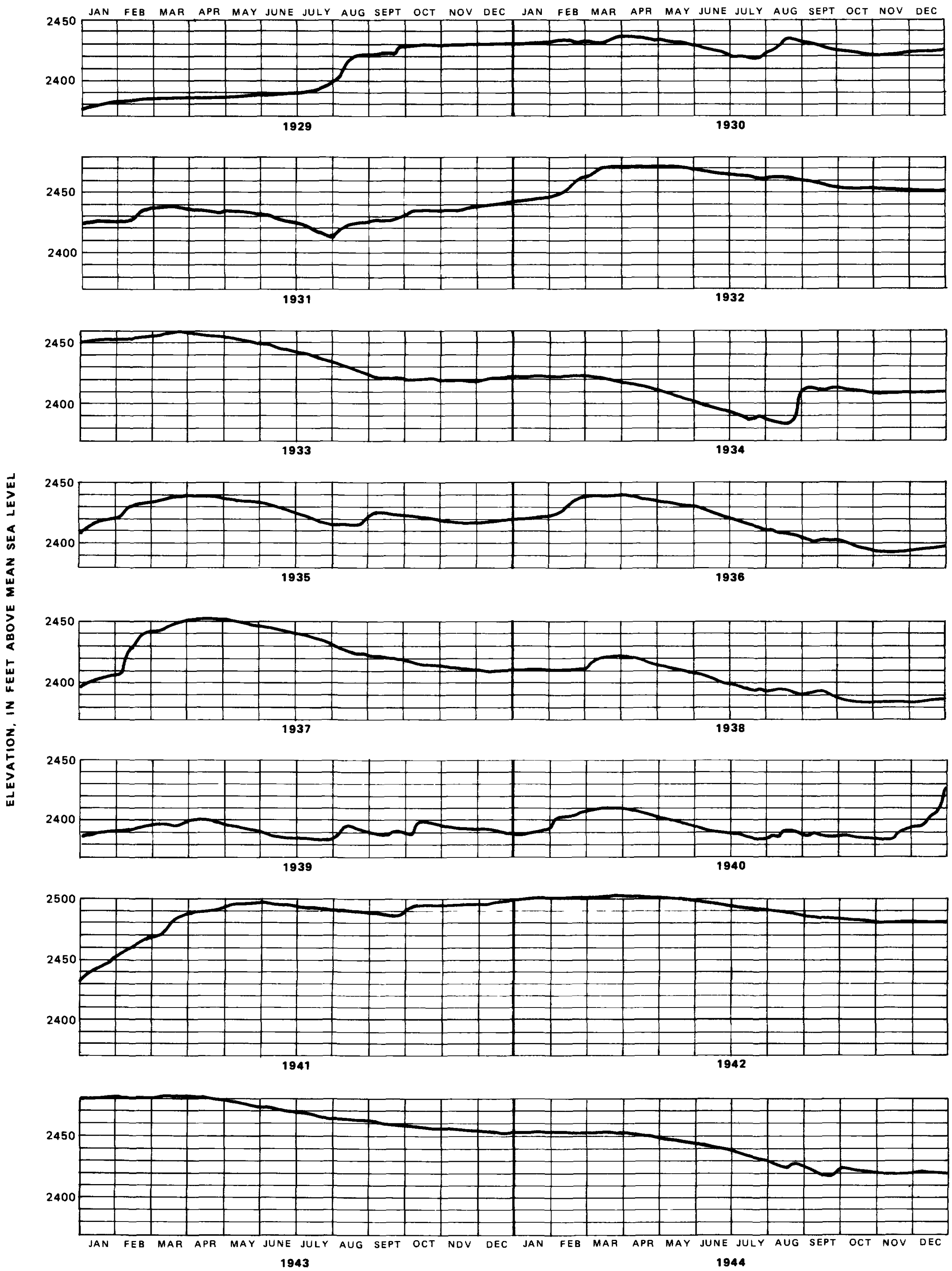

FIGURE 9.—Water-surface level, San Carlos Reservoir. (From Thorp and Brown, 1951.)

available. In contrast, the long-lived seeds of seepwillow were probably germinating and producing new plants on the recently exposed shore. According to the 1937 map, the area was covered by seepwillow (fig. 8). By early May the first saltcedar seeds would have been ripe; by this same time the water level had receded to about 752.8 meters (2,470 ft). This contour marks the upper boundary of a large parcel of saltcedar seen on the 1937 map. The main season of saltcedar and seepwillow seed production is roughly May to September (D. K. Warren, oral commun., 1970) and coincides with the period when the water level in the reservoir receded from about 752.8 meters (2,470 ft) to 748 meters (2,455 ft). The soil surface that became exposed during that interval of time might have been dominated 5 years later by a stand of saltcedar except that during the winter of 1931–32 the lower half of this new saltcedar stand was inundated by a rising reservoir and any phreatophytes present were killed. The level began its descent in March, once again before saltcedar seeds were available. This resulted in saltcedar above the March level and seepwillow below.

SEED PRODUCTION

Saltcedar seeds were collected in seed traps on the project during the flowering season in 1968 (D. K. Warren, oral commun., 1970). In the densest saltcedar stand sampled, viable seeds settled on the soil surface at the rate of 15 seeds per square centimeter (about 100 seeds per square inch) over the entire season. Seed distribution this dense is comparable to the rate among certain short-lived desert annuals (Tevis, 1958) but is probably unusual for trees. Seeds of saltcedar may be produced at the rate of 500,000 seeds per mature plant per season (Tomanek and Ziegler, no date). The copiously produced seeds are efficiently disseminated by either wind or water and may be carried to new areas far from the point of origin.

Sexual maturity in most trees is reached only after several years or even decades. This fact slows the rates at which these plants become established. Following the random introduction of a seed into a new site, several years must elapse before the new plant generation is capable of reproduction. In saltcedar this delay does not occur—seedlings often produce flowers during their first year (Tomanek and Ziegler, no date; Merkel and Hopkins, 1957). Once a few plants gain a foothold in a new area, seeds are soon produced in large numbers to give this plant competitive advantage over such plants as cottonwood and willow which may require several years to reach sexual maturity.

Season of seed production and means of seed dissemination are similar in seepwillow and saltcedar. The volume of seed produced is perhaps vastly different between the two, however. Seepwillow is dioecious (as are willow and cottonwood) and approximately half of the sexually mature plants in a stand produce flowers that yield only pollen; the other half of the population produces seeds. This may reduce the reproductive potential of seepwillow and give saltcedar a competitive advantage.

SALTCEDAR AS A XEROPHYTE

Meinzer (1927) coined the term phreatophyte to describe plants that depend on ground water for their moisture supply. For such plants, rainfall alone is insufficient to promote growth and survival over extended periods. Among the plants listed by Meinzer, and later by Robinson (1958), as phreatophytes are several that may at times grow in situations other than where ground water is available. To these less demanding plants the name "facultative phreatophyte" can be applied to distinguish them from obligate phreatophytes—plants which are closely restricted to areas of ground-water availability.

Mesquite and saltcedar, the two most abundant plants on the project in 1964, are facultative phreatophytes. Both often occur in habitats where ground water is unavailable, although saltcedar probably always begins growth in locations where moisture is readily accessible for several weeks or more. Seepwillow and cottonwood are probably obligate phreatophytes and are, therefore, closely confined to areas of shallow ground water or surface water.

The broad ecologic amplitude of saltcedar is probably another reason for its success in invading riparian habitats in Southwestern United States. Once it has become established, profound changes in moisture supply will not completely eliminate it. A notable example can be seen around the shores of San Carlos Reservoir where saltcedar became established as the lake level receded from the high stage of 1942. Twenty-two years afterward, saltcedar still dominates areas that before inundation were occupied by creosotebush and other highly adapted desert species (fig. 10).

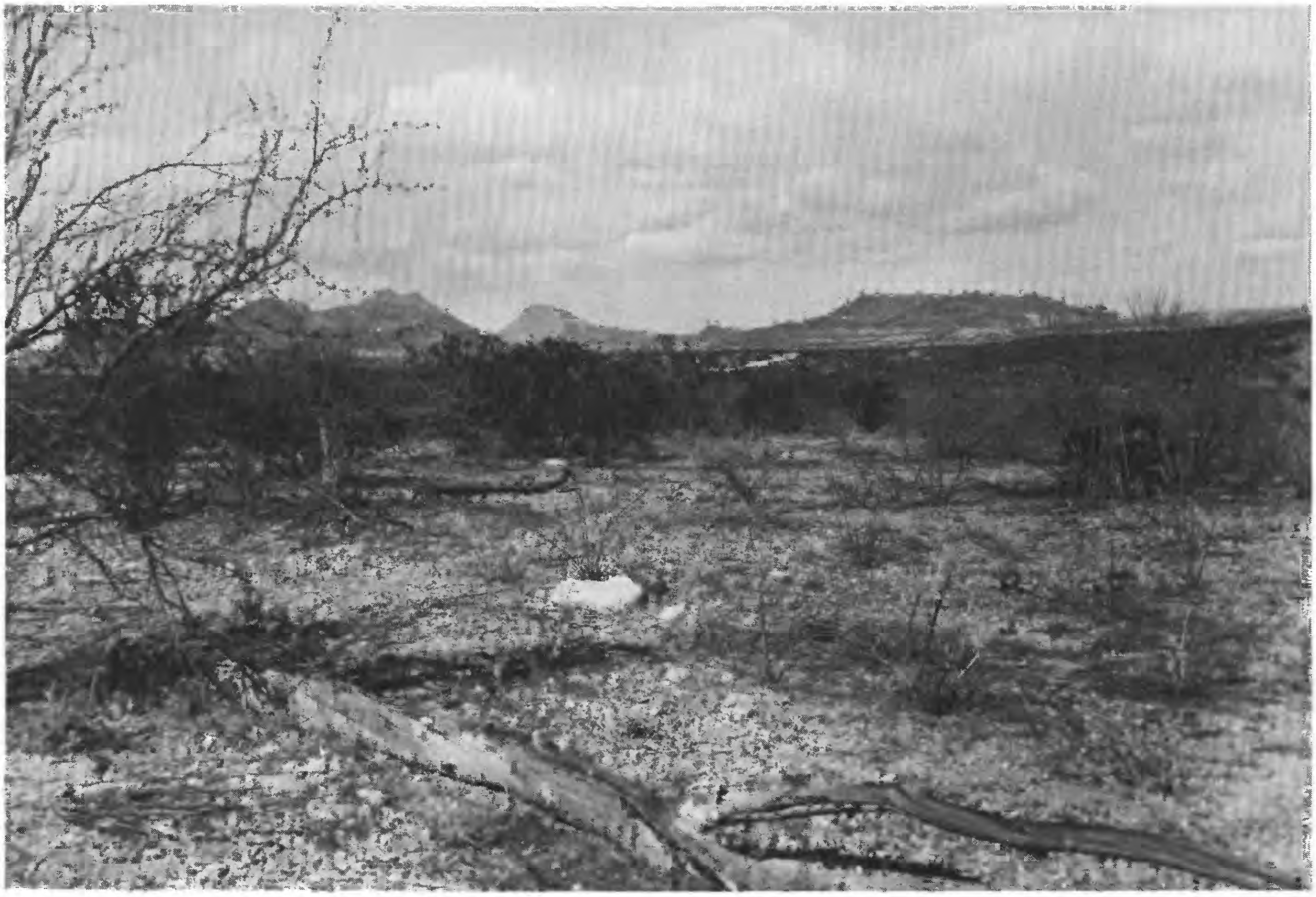

FIGURE 10.—View along old shoreline of San Carlos Reservoir. Driftwood marks location of 1941–42 high-water line. Creosotebush (dark shrubs) and other native plants grow to left of line in area not inundated. To right of line, in area where native plants were killed when covered by water, scattered saltcedars still dominate after 22 years. Date of photograph: February 14, 1964.

SUMMARY AND CONCLUSIONS

Vegetation changes along a 24-kilometer (about 15-mile) reach of the Gila River valley during the past half century have not followed the pattern typical of earlier changes. Judging from early journals, photographs, surveyor's notes, and maps, the original flood-plain vegetation here and on adjacent reaches comprised forests of cottonwood and willow; thickets of seepwillow, arrowweed, and seepweed; and low woodlands of mesquite. These vegetation groupings were altered at irregular intervals by erosion, deposition, and inundation. Although the mosaic of vegetation types was relatively unstable, the pattern of change fell within well-defined limits.

Today the situation is much different. Instead of many species occupying the various habitat types on the flood plain, these sites are dominated by a single introduced species, saltcedar. Instead of a state of perpetual succession, such as that still found on some streams of the region (Campbell and Green, 1968), one plant species dominates large areas. The heterogeniety of the past has given way to the present uniform condition.

There are many examples of alien plants competing successfully with indigenes. Usually a major disturbance of the habitat is necessary for the alien to first become established. Indeed, saltcedar invasion in the Southwest has been directly linked with man-induced changes in stream regimes such as dam building and channel clearing (Harris, 1966). While Coolidge Dam has undoubtedly led directly to the dense stands of saltcedar in the lower two-thirds of the study area, the increase in saltcedar in the upper one-third cannot be attributed directly to the reservoir since this area is outside the reservoir limits. In subreach 1, the time of saltcedar's most rapid invasion did not coincide with unusual flooding or other major disruption of the flood-plain environment. Instead, on subreach 1 the barren flood plain produced by the 1905–17 floods was first reoccupied by the native seepwillow and cottonwood. By 1937 saltcedar was the dominant on very little area along this reach (fig. 4), although it was mixed with seepwillow as subdominant over large acreages. From a position of relatively minor importance, saltcedar rapidly increased at the expense of seepwillow (pl. 1 and frontispiece). Thus, the greatest rate of saltcedar increase occurred 20 years or more after large floods had caused a major habitat disruption and occurred after native phreatophytes had already regained occupancy of the old flood plain. This evidence indicates that saltcedar not only competes successfully with the native plants but can eliminate them. It also seems likely that saltcedar is capable of maintaining its hold on the invaded areas indefinitely.

The hydrologic implications of the dense permanent cover of saltcedar are: (1) a decrease in streamflow, (2) an increase in area inundated by floods, and (3) an increase in the quantity of sediment deposited in areas of heavy saltcedar growth (Robinson, 1965). It is likely that saltcedar more drastically affects the hydrologic regime of flood plains than do native phreatophytes. This would be expected from the speed with which saltcedar invades newly opened areas, the density of the initial population, and its rapid growth rate. Compared to the native phreatophytes, saltcedar stands not only increase the flood hazard by choking normal channels, but its use of water may be greater than that of the plants it replaces (Gatewood and others, 1950).

The biologic implications of the permanent saltcedar cover are poorly understood. The livelihood of many organisms would undoubtedly be drastically curtailed by the replacement of one dominant plant by another, just as many organisms would be affected by the elimination of a dominant plant by a major flood. Whether plants are removed by floods, by competition, or by bulldozers, organisms wholly dependent on the removed plants will also be eliminated. The native seepwillow and cottonwood were removed by the flood of 1905; they became reestablished by the mid-1930's but had virtually disappeared by the early 1960's, the void being occupied by saltcedar. Twice, then, within the first half of the 20th century, the cottonwood forests and the seepwillow thickets have been decimated. To the extent that saltcedar supplies the needs of the organisms from the previous biotic communities, the habitat disruptions will have little impact.

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