Dendrochronological Analysis of Goodding Willows in Grand Canyon National Park

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Abstract. In Grand Canyon National Park, dendroecological information on Goodding willow (*Salix gooddingii*) provided an estimate of the age structure of the population and the growth rate patterns. Goodding willow, a dominant riparian tree species before the construction of Glen Canyon dam, currently is at risk due to water flow regulation destroying habitat and competition with tamarisk (*Tamarix chinensis*). Lab analyses of annual rings revealed periods of growth suppression and release. The four chronologies (upper river, mid-river, lower river, and a control site) were created to help to examine climatic influence and river regulation impacts on willow growth. The age structure analyses showed a lack of Goodding willow recruitment at the upstream site of Lees Ferry and midstream site of Cardenas Creek. It appeared that the altered flood regime caused by Glen Canyon dam, as well as possibly the increase of tamarisk invaders, have adversely affected willow recruitment along the Colorado River up to the Lake Mead area. In contrast, classic J-shaped curves existed for the downstream site of Pearce Ferry near Lake Mead and the control side stream site of Diamond Creek, representing stable or expanding populations. The dendrochronological results of this study demonstrated impacts of Glen Canyon Dam flow regulation on the Goodding willow establishment and growth rate. Specifically, data showed the importance of flood events like the 1983 record post-dam flood to establishment of new stands of Goodding willows.

Key words: Demography, flood control, Glen Canyon Dam, size structure, tree rings.

Along the Colorado River within Grand Canyon National Park, Goodding willow (*Salix gooddingii*) is the only large willow found below

Glen Canyon Dam (Turner and Karpiscak 1980). Goodding willow, a dominant riparian tree species prior to the construction of Glen Canyon dam in 1963, currently is at risk due to water flow regulation destroying habitat and competition with tamarisk (*Tamarix chinensis*). Little recruitment and high mortality are evident in upstream populations that are now comprised mainly of decadent individuals. Goodding willow recruitment and establishment are dependent on periodic floods (Reichenbacher 1984). Although rare for the majority of the park, Goodding willows are abundant on exposed benches of sediments near Lake Mead. Yet even this population may be in danger from fluctuating lake levels.

Glen Canyon Dam has strongly influenced the Colorado River and its riparian vegetation since dam completion in 1963. Located 15 river miles upstream from Lees Ferry, the dam regulates the river's flow through a daily cycle based on electricity demands with little seasonal variation (Howard and Dolan 1981). Consequences of this river regulation include lower mean annual maximum flows (Fig. 1), flood control, higher median flows, colder and less variable river temperatures, sediment trapping, and beach erosion (Thomas et. al. 1960, Carothers and Dolan 1982, Stevens 1983).

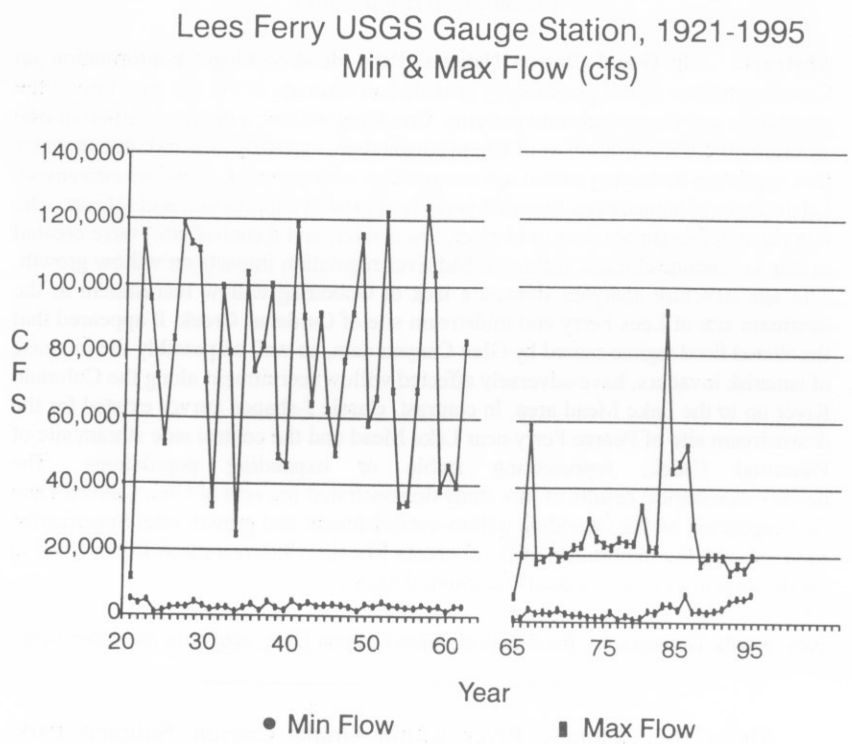

Fig. 1. Yearly minimum and maximum flows, in cubic feet per second (cfs) for the Colorado River, recorded at Lees Ferry, Arizona.

These changes due to river regulation provide a stable habitat for riparian vegetation (Turner and Karpiscak 1980). Currently, the riparian vegetation communities consist of old high water and new high water bands, reflecting the flood lines before and after Glen Canyon Dam construction. For the majority of Grand Canyon National Park, old high water vegetation consists of mesquite (*Prosopis glandulosa*) and catclaw (*Acacia greggii*) while new high water zone includes tamarisk, mesquite, seep-willows (*Baccharis* spp.) and coyote willow (*Salix exigua*) (Stevens 1983).

Before dam construction, frequent high level flooding limited the amount of vegetation along the Colorado River in Grand Canyon National Park (Clover and Jotter 1944). Following the construction of the dam in 1963, riparian vegetation expanded and diversified (Carothers and Aitchison 1976, Purcherelli 1986, Stevens and Waring 1988). Although many species have increased their distribution since dam construction, Goodding willow appears not to be recruiting in most of the Grand Canyon National Park. Possible reasons for the lack of willow seedlings are the decline in sediment quality and expanding competing vegetation. However, Goodding willows are becoming established at sites in Upper Lake Mead, possibly due to ample bare sediments.

Dendrochronological information can provide an estimate of the health of the willow population. Tree ring patterns reflect climatic influences and river regulation impacts on establishment and growth. Demographic field studies also help in analyses of willow responses to flood flows (Stromberg et al. 1991). In this study, we compared dendrochronological evidence of willow establishment and growth rate to flow records. Of particular interest was the impact of Glen Canyon Dam after 1963 and the record post-dam flood in 1983 (recorded at 92,600 cubic feet per second, or 2,622 cubic meters per second).

Age, size, and growth rate data on willows throughout the river corridor in the Grand Canyon National Park provided for a more complete understanding of the fate of this species. This research was part of an extensive demographic study of Goodding willows in the Grand Canyon. The larger study seeks to detect broad scale shifts in willow distribution from the upper to lower Grand Canyon region.

Study Site

The Colorado River extends for 277 miles (447 km) through Grand Canyon National Park in Arizona. Park boundaries officially start at Lees Ferry (river mile 0) and end below Grand Wash Cliffs (at the beginning of Lake Mead, river mile 277; Fig. 2). In this stretch, the Colorado River ranges from 76 to 300 feet (23 to 91 m) in width, with an average depth of 35 feet (10.6 m), and descends from an elevation of 3,116 feet to 1,200 feet (949 m to 365 m) (Stevens 1983). Reflecting elevational differences, the mean annual

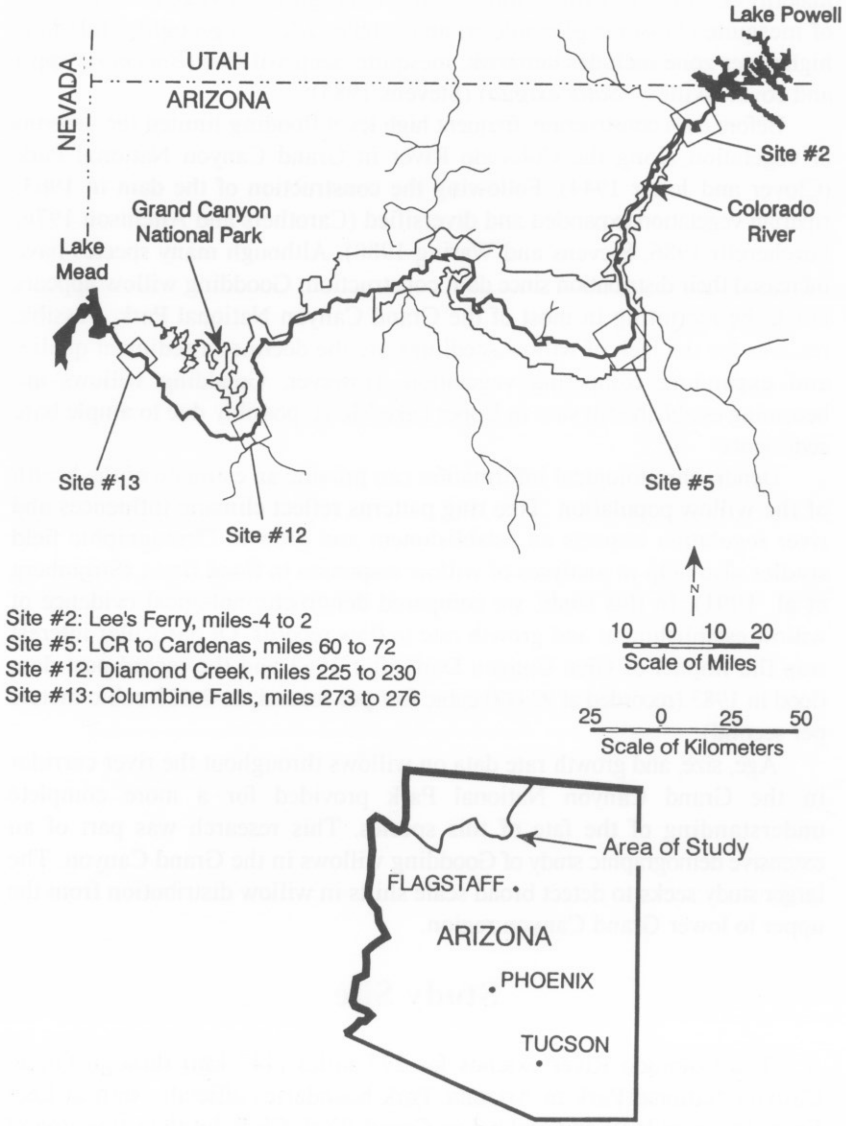

Fig. 2. Study sites for Goodding willow research in Grand Canyon National Park, Arizona.

air temperature varies from 63°F (17.2 °C) at Lees Ferry to 66°F (18.9°C) at Lake Mead, while the annual precipitation is highly variable with summer monsoons from mid-July to September (Sellers and Hill 1974). Mean yearly precipitation is 5.8 inches (14.7 cm) upstream at Lees Ferry, 8.4 inches (21.3 cm) midstream at Phantom Ranch, and 4.6 inches (11.7 cm) downstream at Lake Mead (Stevens 1983).

This study included Goodding willow samples from the entire stretch of the Colorado River through Grand Canyon National Park. Three main regions contain populations of willows: (1) Lees Ferry (river mile 0), (2) Cardenas Creek (around river mile 71), and (3) above Pearce Ferry (river mile 267-274; Fig. 2). To include willows not affected by Colorado River regulation influences, we also studied a side canyon at Diamond Creek (river mile 226). In addition, we examined scattered individual willows accessible by boat at river mile 209 and 220 and at Granite, Unkar, and Nevilles Rapids.

Methods

Field Methods

We collected dendroecological information from 290 Goodding willows, which we cored approximately 10 cm above the ground, and measured diameters at ground height (dgh). Tree condition data included stem count, number of dead stems, and beaver or flood damage. At each field site, numbered tags were attached to cored willows to designate permanent plots, while marked aerial photographs were used to denote plot boundaries. Permanent plots are important for long-term research on willow regeneration, establishment, and mortality along the Colorado River in Grand Canyon National Park.

Laboratory Methods

Following the procedures of Stokes and Smiley (1968), successively finer grades of sandpaper were used to reveal annual rings in mounted cores. We used binocular microscopes for counting tree rings to indicate tree age at coring height. Ring-width chronologies were helpful for examining influences of climate, physical disturbance, and river flow on tree growth. A computer-compatible incremental measuring machine was used to assist in determining ring widths (to the nearest 0.01 mm) on 15 willows systematically selected in each of the four main sampling areas. In addition, visual cross-dating allowed for comparison with the computer cross-dating results.

The following programs were used for creating the tree-ring chronologies for each of the four main sites. First, the tree ring program COFECHA (Holmes 1983) was used to assist in locating missing rings or measurement errors in the tree-ring measurement series. Next, the program ARSTAN (Cook and Holmes 1992) was used to create tree ring chronologies by detrending and indexing the measurement series, then created a mean chronology. This study used a cubic spline fit (preserving 50% of the variance) division to compute indices, and a biweight robust mean to enhance the common signal. The detrending option of a cubic spline fit removed the ring-width variance attributed to tree growth geometry (smaller rings as tree ages due to greater tree diameter) (Fritts 1976). For each chronology, the earliest year included was based on a minimum of 5 of the 15 measured cores being represented, while the last year was always 1994.

Results and Discussion

Age Analyses

Overall, 77% of the 290 cores removed during this study contained piths (the other 23% dated to minimum age due to rotten centers). The percentage of willows with pith dates varied by site (28% of Lees Ferry, versus 83% of Cardenas Creek and 98% of Pearce Ferry). Overall age structure (all sites combined) followed a typical J-shape curve showing the majority of trees established since the dam construction in 1963 (Fig. 3). Note, however, that the largest willows yielded estimates of only a minimum age due to rotten centers (hence, they are not included in the age structure diagram).

Comparing the three river sites (Fig. 3), only the upstream site of Lees Ferry contained willows dating back to the 1930s. Of the 80 willows sampled at Lees Ferry (representing nearly 100% of the population at that location), 65% of the willows were multi-stemmed, 38% possessed one or more dead stems, 12% were completely dead, and 20% exhibited beaver damage. The vast majority of willows at this site could not be dated either because of rotten centers (60%) or because of tree death (12%). Of the willows having complete ring structure and piths at this site, a peak in establishment occurred from 1983–1986 (post-1983 flood establishment displayed in Fig. 1). The age-distribution histogram for this site indicated a lack of willow recruitment (Fig 3). Besides the influence of the dam, another explanation for this age distribution shape may be that the willow population was invaded by another species (tamarisk). Yet, since 72% of these cores lacked complete ages, size structure analyses may provide more useful summary data.

At the midstream site of Cardenas Creek, the oldest Goodding willows dated back to the 1950s. Of the 60 willows sampled, 50% were multi-stemmed, 22% had at least one dead stem (none were completely dead), and 42% showed beaver damage. At this site, 83% of the willows were dated to the pith, while only 17% had rotten centers. Establishment periods at Cardenas Creek included 1966–1968 and 1974–1976 (after an increase in

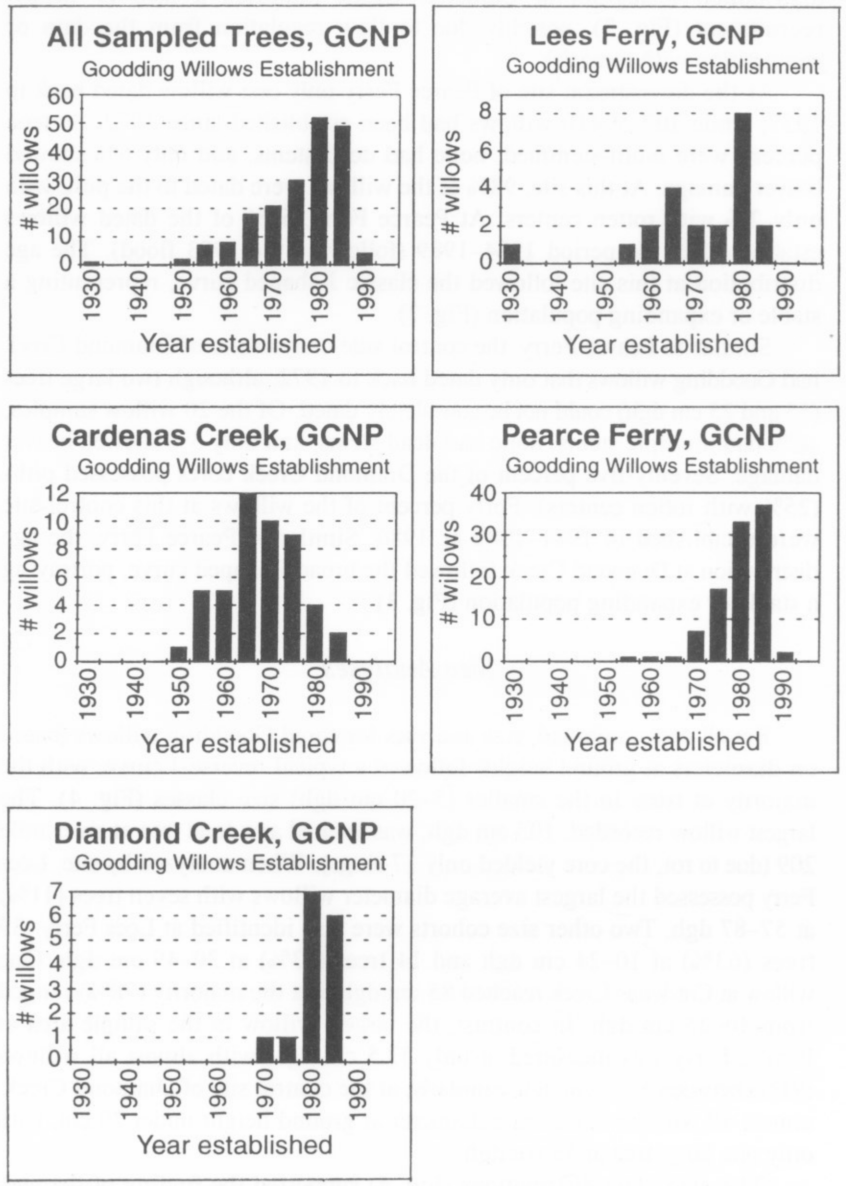

Fig. 3. Age structure analyses by site for Goodding willows, based on 5-year establishment periods, Grand Canyon National Park, Arizona, 1930–1995.

maximum flow in 1973, shown in Fig. 1). Similar to Lees Ferry, the age-distribution histogram at Cardenas Creek indicated a lack of willow recruitment (Fig. 3), possibly due to flow regulation from the dam or competition with tamarisk.

At the downstream site of Pearce Ferry only one willow dated back to 1957, while 107 of 110 willows had been established since 1972. Sixteen percent were multi-stemmed, none had dead stems, and only 6% showed beaver damage. At this site, 98% of the willows were dated to the pith, with only 2% with rotten centers. At Pearce Ferry, 58% of the dated willows established in the period 1984–1989 (following the 1983 flood). The age distribution at this site followed the classic J-shaped curve, representing a stable or expanding population (Fig. 3).

Similar to Pearce Ferry, the control side-canyon site of Diamond Creek had Goodding willows that only dated back to 1972, although two large trees (55 and 25 cm dgh) could not be completely dated. Of the 20 willow samples, 40% had multiple stems, none had dead stems, and only 5% showed beaver damage. Seventy-five percent of the Diamond Creek cores possessed piths (25% with rotten centers). Forty percent of the willows at this control site were established in 1981–1982 or 1986. Similar to Pearce Ferry, the age distribution at Diamond Creek followed the broad J-shaped curve, portraying a stable or expanding population (Fig. 3).

Size Analyses

For all sites combined, size analyses for cored Goodding willows (based on diameters at ground height) followed a typical reverse-J curve, with the majority of trees in the smaller (5–20 cm dgh) size classes (Fig. 4). The largest willow recorded, 105 cm dgh, was located as a lone tree at river mile 209 (due to rot, the core yielded only 17 rings). When analyzed by site, Lees Ferry possessed the largest average diameter willows with seven trees (11%) at 57–87 dgh. Two other size cohorts were also identified at Lees Ferry: 39 trees (63%) at 10–24 cm dgh and 14 trees (23%) at 30–49 cm dgh. One willow at Cardenas Creek reached 85 cm dgh, but the majority (78%) ranged from 10–25 cm dgh. In contrast, the largest willow in the sample area at Pearce Ferry was measured at only 33.5 cm dgh, with almost all willows (91%) between 5–19 cm dgh. Similarly, at the control site of Diamond Creek, almost all willows achieved a diameter at ground height under 20 cm, with only one large tree at 55 cm dgh.

The size class distributions (Fig. 4) supported the finding of the age-distribution histograms (Fig. 3). Both Lees Ferry and Cardenas Creek showed a lack of willows in the 0–9 cm dgh size classes, but included scattered individuals in the >40 cm dgh classes. This was interpreted as a population with little to no recruitment. Conversely, the Pearce Ferry and Diamond

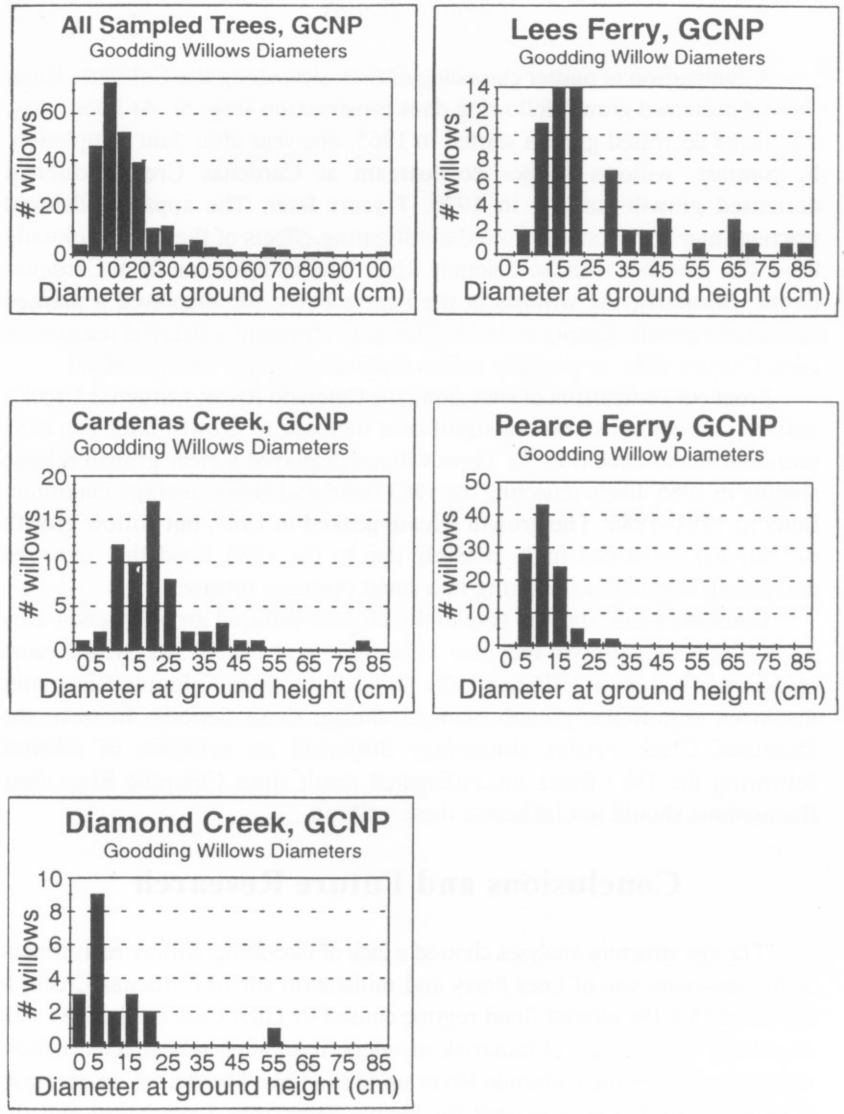

Fig. 4. Size structure analyses (diameter at ground height) by site for Goodding willows, Grand Canyon National Park, Arizona.

Creek sites displayed a classic reverse-J shaped curve with greatest numbers of willows in the smaller size classes (expected in a stable of expanding population).

Growth Trends

A comparison of master chronologies from sites along the Colorado River showed decreased growth following dam construction (Fig. 5). At Lees Ferry, significant decreased growth started in 1965, one year after dam completion. In contrast, willows farther downstream at Cardenas Creek exhibited decreased growth starting in 1970, 7 years later. The apparent delayed reactions may have resulted from the mitigating effects of the Little Colorado River that junctions with the Colorado River 9 miles upstream from Cardenas Creek. Similarly, the willows at the Pearce Ferry site displayed a marked decrease in growth starting in 1971. This may represent a delayed reaction to Glen Canyon dam, or possibly reflect fluctuating levels in Lake Mead.

From our comparison of sites along the Colorado River, Cardenas Creek's master chronology showed a significant increase in growth after the 1983 post-dam record flood (Fig. 5). These willows displayed a clear growth release starting in 1985, likely reflecting the 1983 flood and above average maximum flows in 1984–1986. The growth release peaked in 1987, but willow growth overall has remained high, possibly due to the 1983 flood that removed competing vegetation (resulting in a stand thinning release).

Diamond Creek showed potentially climate-induced growth trends. Key years of decreased growth included 1976–1977 and 1980–1982, with 2 years of increased growth in 1975 and 1978. None of the three Colorado River sites displayed significant growth changes during these periods. In turn, the Diamond Creek master chronology displayed no evidence of releases following the 1983 flood, an anticipated result since Colorado River flow fluctuations should not influence these willows.

Conclusions and Future Research

The age structure analyses showed a lack of Goodding willow recruitment at the upstream site of Lees Ferry and midstream site of Cardenas Creek. It appeared that the altered flood regime caused by Glen Canyon dam, as well as possibly the increase of tamarisk invaders, have adversely affected willow recruitment along the Colorado River up to the Lake Mead area. In contrast, classic J-shaped curves existed for Pearce Ferry near Lake Mead and the control side stream site of Diamond Creek, representing stable or expanding populations.

The dendrochronological results of this study demonstrated impacts of Glen Canyon Dam flow regulation on the Goodding willow establishment and growth rate. Specifically, data showed the importance of flood events like the

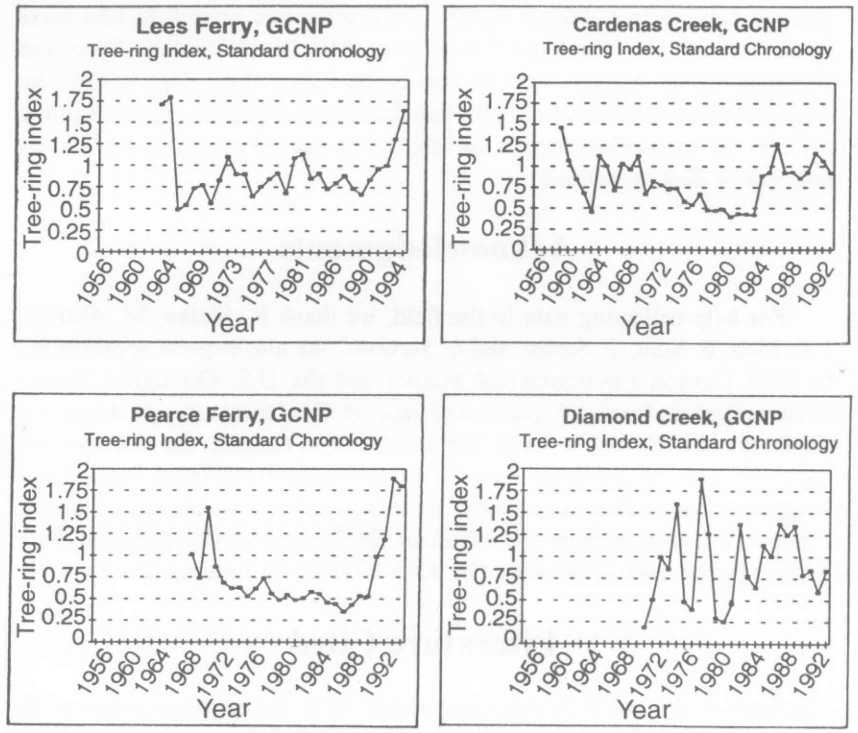

Fig. 5. Tree-ring growth records (1956–1994) for Goodding willows, displayed as standard chronologies by site, Grand Canyon National Park, Arizona.

1983 record post-dam flood to produce growth releases. Such large releases are essential to maintain populations of Goodding willow in the Grand Canyon ecosystem. The master chronology of one of the three river sites (Cardenas Creek) showed a significant increase in growth starting in 1985, likely reflecting increased sediment and nutrient availability that occurred as a result of the 1983 flood and above average maximum flows in 1984–1986. The sustained willow release may indicate that the 1983 flood caused stand thinning and reduced competition.

Our continuing demographic studies will help to detect broad scale shifts in the species distribution from the upper canyon (Lees Ferry) area to lower Grand Canyon (Pearce Ferry) region. Future studies will include analyses of willow seedling locations, willow sex ratios, impacts of beaver and rust (plant disease), effects of competition with exotic plants (especially tamarisk), and influence of soil on establishment. In addition, this study will continue to analyze dendrochronological results, comparing tree growth to lake level fluctuations in Lake Mead and flow records of the Little Colorado River and Diamond Creek. Finally, we will also be analyzing these data against the instrumental climate records to show that the growth variation observed in the cores is not caused by climatic variations but instead by alteration in river flow due to dam operations.

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