Shafroth et al., 2002). However, increased recruitment does not necessarily result in greater seedling survival, and higher densities may have a negative impact on seedling survival (Augspurger and Kelly, 1984; Clark and Clark, 1984) and growth (Condit et al., experimental design had four treatments and five replicates per treatment.

For us to have access to newly recruited cottonwood seedlings, a separate impoundment adjacent to the one with the experimental plots, was flooded timed with natural seed rain of cottonwoods to create a “seedling bank”. Once the D_{min} plots were established, about one-week-old seedlings were transplanted from the seedling bank to the experimental plots. Seedlings were cored out along with soil attached to the roots to keep fine roots undisturbed. The average height of seedlings at transplant was 4 cm. Seedlings were planted in the designated experimental plots during evening to avoid high daytime temperatures. Plots were watered twice a day during the first month to ensure seedling survival, after which watering frequency was reduced to once a day and finally to twice a week. Lack of precipitation and unusually high summer temperatures during 2003, made watering of the plants necessary.

2.2.1. Biomass estimation

After allowing plants to grow for three months, individuals from selected plots were clipped at ground level in October (before the plants shed their leaves with the onset of winter). Out of the five replicates for each treatment, one replicate was randomly selected from each treatment as a ‘sacrificial’ plot and all plants from the selected plots were clipped. Plants in the rest of the plots were left for future monitoring of the effects of neighbor distances on tree growth. Dead plants were not included in biomass estimation. Measurements of plant height, length and width of the largest leaf, stem diameter, number of leaves were taken for all the plants. Clipped plants were dried at 42 °C to a constant mass and weighed to nearest 0.001 g. The same measurements were taken simultaneously for the plants in the experimental plots. We developed nondestructive regression models for estimating seedling biomass for each treatment. Therefore, instead of using one model to predict biomass of plants for all treatments, four different models were developed and used to represent each treatment. Variables were selected based on Mallows’ $C_{(p)}$ (Littell et al., 2002). For estimating biomass of plants in different treatments, we used the following equations:

a. Treatment:Neighbor distance = 5 cm

Model Fit:$C_{(p)} = 3.95$, $p = 4$, $R^2 = 0.95$

$\text{Biomass}_{5\ \text{cm}}$

($\chi^2_1 = 4.03$, $P = 0.04$) probability of seedling survival in cottonwoods. Seedlings had a slightly greater chance of survival (74%) when they were positioned in the core region and a lower chance of survival when on the edge (69%).

4.3. Effect of treatment on seedling morphology

Morphological characteristics (number of leaves, length and width of the largest leaf, diameter of stem) of seedlings differed among plants (MANOVA:Pillai's Trace, $F_{18,\ 27} = 1.97$, $P = 0.054$) growing in the four treatments. When the neighbor distance among seedlings was 15 cm, seedlings of cottonwoods had greater mean stem diameter than when the neighbor distance was 5 cm. Seedlings were shorter when the neighbor distance was 5 cm, compared to 15, 25, and 35 cm. Mean number of leaves was the lowest at neighborhood distances of 5 and 25 cm. Also, there is no significant difference in mean number of leaves between 15 and 25 cm distances (Fig. 3). The pattern of longer and wider leaves increases significantly from 5 cm to neighbor distances of 15, 25 and 35 cm. Between the 15, 25 and 35 cm distances, there was no monotonic trend in the leaf measurements (Fig. 4). Therefore, seedlings had wider and longer leaves when neighbors were at least 5 cm away, and thus, less clustered.

5. Discussion and conclusion

Biomass accumulation by cottonwood seedlings of the altered riparian habitats in southwestern US varied with distance to neighbors. Seedlings had lower biomass at relatively both large and small neighbor distances. At an estimated optimum 15 cm distance, seedlings had the greatest biomass. Cottonwood seeds are wind and water dispersed, which often results in their aggregation in seedling clusters. Seedling densities >500 plants/m^2 were observed in our study and by Taylor et al. (1999). Recruitment of seedlings in such high densities is usually followed by a low survivorship (88% mortality by the end of 3 years, Scott et al., 1999, and about 65% mortality in the first year of growth, see Bhattacharjee, 2005).

Seedling recruitment is an essential precursor to restoration of degraded riparian areas (Briggs et al., 1994), as other means, such as pole plantings are extremely cost and labor intensive (Taylor et al., 1999). Most riparian restoration efforts tested ways of recruiting high densities of seedlings (Rood and Mahoney, 1995; Shafroth et al., 2002; Sprenger et al., 2002; Taylor et al., 1999). The lack of natural flooding events has reduced recruitment of seedlings (Howe and Knopf, 1991) and based on the low seedling survival during the first year, it may seem necessary to recruit the largest number of plants possible. This to an extent would be similar to episodic recruitment that would happen naturally in the event of a flood. However, the numbers of seedlings that make it to the stage of a mature tree are quite low (Taylor et al., 2006). Therefore, densities (median biomass/plant at 20 plants/0.20 m^2 plot was 0.79 g against 17.54 g when there was one seedling in the plot). In this study, biomass per plant at a density of 4 plants/0.25 m^2 was about 16 g and about 10 g at the density of 40 plants per plot. Results of competition experiments conducted by

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