RESEARCH AS AN INTEGRAL PART OF REVEGETATION PROJECTS [1]

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Abstract: Little data concerning autecological needs of desert riparian plant species is available, but the need for revegetation is great. This need results in projects being initiated without knowledge of on site conditions or needs of species planted. Research, superimposed on revegetation projects, can yield data necessary to intelligently implement revegetation projects. Our approach involves: (1) selecting sites on the basis of appropriate preliminary sampling, (2) preparing a planting design after determining distribution of soil/salts on site, (3) planting experimental/control trees at soil sampling points (4) monitoring these experimental trees during the irrigation phase. Research data are used to increase vigor and/or reduce or maintain future costs.

In 1977 the U. S. Bureau of Reclamation provided us with funds to summarize knowledge and to undertake studies of the autecology of native riparian plant species found along the lower Colorado River. Time was devoted to learning known procedures used to grow these species in revegetation projects. We discovered that little was known about autecological requirements or revegetation procedures; immediate research attention was needed concerning a large number of factors. This paper deals with just these; effects of tillage, length of irrigation period, salinity and browsing on growth.

Careful record keeping is the first requisite. Simple experiments can also be built into many projects, once the observation starts to yield information that can be translated into testable hypotheses. Here I present an approach permitting data acquisition that is relatively easy and inexpensive, that can be used for management and research. The approach involves (1) preliminary analysis on prospective sites as a prelude to wise site selection, (2) random soil sampling at points where plant species will be planted to map soil/salinity distribution on the site, (3) use of these points for planting trees for addressing research objectives, and (4) use of the research trees for monitoring the project's irrigation phase.

Definitions

Foliage volume—The space, expressed in cubic meters, occupied by a tree. For cottonwood (*Populus fremontii*) and willow trees (*Salix* spp.) this space is roughly approximated as: foliage volume = $(-1.14 + 1.4 \text{ height})^2$, $r^2=0.985$, $P<0.001$. This equation is based on 678 cottonwood and willow trees from the Colorado and Kern Rivers in California.

Browsed—any tree with several centimeters of one or more limb tips, including but not restricted to, the tallest limb, bitten off by deer. Control—In experimental situations controls represent a random sample of the "normal" situation; in our work "normal" conditions include:

1. Tilling with an auger 4.7 cm in diameter to the water table.
2. Planting cottonwood/willow trees where electroconductivity is <2.0 millimhos/cm[3].
3. Irrigating for 72 days over a 90 day period at a rate of 32 liters delivered over a 4 hour period through pressure compensating emitters or at modified rates that would maximize growth during the irrigation phase. During the irrigation period the objective was to maximize growth for all trees, including experimental trees—effects after irrigation ends are those we're interested in.
4. Planting healthy appearing saplings 40 cm tall or taller 8-12 weeks after potting. Cuttings are started from local genetic stock in 4-liter pots.

Electroconductivity (EC)—a measure of the total dissolved ions measured in millimhos/cm[3]. Soil EC's are determined from distilled water extracts of saturated soil pastes.

Growth—height from ground level to top of tallest upstretched leaf at planting subtracted from height similarly measured at any time after planting. It is a simple measure of vigor, related to crown diameter of cottonwood/willow trees as: Crown Diameter = 0.44 +0.84height. (Anderson & Ohmart 1982).

Vigor—measure of change in plant growth or foliage volume through time after planting.

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[1] Presented at the California Riparian Systems Conference; September 22-24, 1988; Davis, California.

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Experimental Approach

Experimental design should include, among other things (Green 1979), clear statements of questions being investigated, sample sizes large enough to yield meaningfully interpretable data, random sampling ("representative" or "typical" places are not random), (4) controls.

To illustrate the experimental approach I present data for one revegetation project. The site, on the Kern River Preserve, Weldon, Kern Co. California encompassed 12 ha. Tree spacing was 6.2 m in rows 6.2 meters apart. Allowing for some loss for road construction, there are about 100 trees per 0.4 ha (total 3000 trees). To map soil and EC conditions, 8 percent (240) of the planting points were sampled. The question was whether vigor would differ for two sets of trees: (1) those irrigated at 32 liters per day for 90 days versus those irrigated (same rate) for less than 40 days and (2) for trees planted after tillage to 65-75 percent of surface to water table depth versus those planted after tillage to the water table. Labor cost associated with irrigation for less than a 90-day period and tilling less than to the water table could be substantial. Thus, irrigation and tilling were good points on which to launch research. In all experimental and test situations we endeavor to maximize growth during the irrigation phase. We can quite confidently predict results during this phase. We must also be able to predict what will happen after we leave the site. The research data will allow us to develop this predictability. Data for additional variables are presented by Anderson and Laymon (1989).

Controls were 150 trees chosen randomly from the grid. The first set of trees-those irrigated for less than 45 days–were subdivided into three equal sized categories; those irrigated 17, 27, and 37 days. For the second set of trees, soil was tilled 65-75 percent of the surface to water table depth for 25 trees.

Several ancillary questions were addressed, two of them are discussed in this paper: What effect will salinity and browsing have on vigor? Evaluation began during the second growing season (care during the first year reduces impacts). Since I found nothing in the published literature specifically stating the tolerance of cottonwood/willow trees to salinity levels, they were investigated early because salinity problems abound in desert areas (Fig. 1). Browsing is common in riparian areas; it seemed reasonable to what impacts this might have on affected trees.

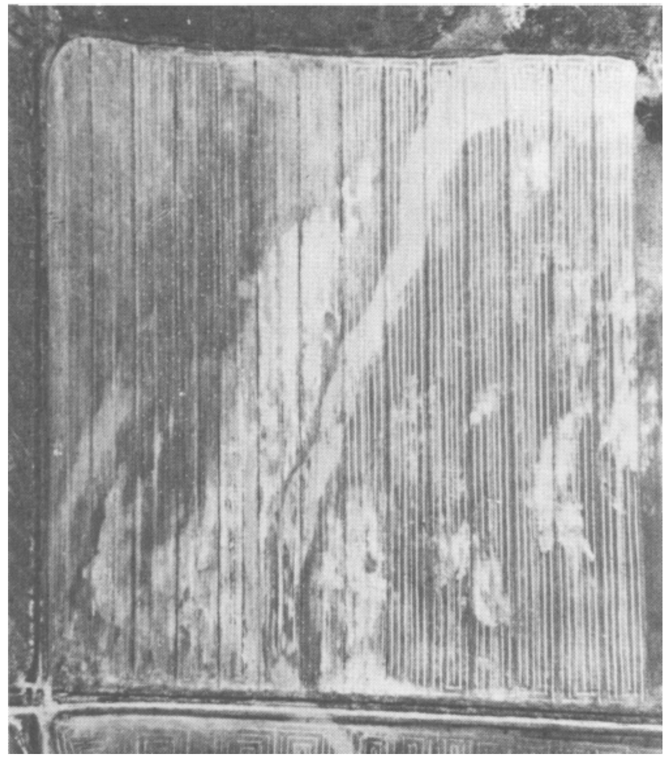

Figure 1– Aerial photograph of a field illustrating the variation in superficial soil characteristics.

Results

Length of Irrigation Period

After two growing seasons cottonwood trees irrigated for less than 90 days did not differ significantly (P>0.05) from controls in height, total growth, foliage volume, or mortality (table 1).

Because of the small sample size (n=78) and the restriction of the work to this single set, I am reluctant to reduce the length of the irrigation period to less than 90 days. The work should be repeated at least once more in the same general area (Kern River) with a larger sample.

Earlier experimentation involved irrigation periods spanning 150-480 days along the Colorado River, near Blythe, California. That study included data from two full-scale revegetation projects together encompassing 50 ha and including 1349 experimental trees of four species (Anderson and Ohmart 1982). Trees irrigated for 150 days were equally as productive after 3 years as trees irrigated for a longer period, other factors being equal. Irrigation time was reduced to 90 days for 60 experimental trees. In this time roots grew to the water table, 3 meters below the surface. The 90 day period was tried on a full scale project, involving 1200 trees, along the Rio Grande near Presidio, Texas

(Anderson and Ohmart 1986). Success there led to use of this irrigation period as the control; thereafter, shorter periods represented experimental variables.

While the Kern River results alone would not warrant using even a 90-day irrigation period in another valley, our total research experience suggests that a 90-day period is safe over a large portion of the desert Southwest.

Depth of Tillage

On the Kern River project trees planted after tilling to the water table were significantly taller, total growth was greater, foliage volume was significantly greater and mortality was lower after two growing seasons than for those trees planted after tilling to 65-75 percent of the depth to the water table (Table 2). While the difference in mean height was 30 percent of the height of controls, the difference in mean foliage volume was 73 percent of the foliage volume of controls. This relationship between height and foliage volume is expected, since as height doubles foliage volume is approximately squared.

Table 1 - Table 1-Data after two growing seasons for cottonwood trees irrigated for 17 days, 27 days and 37 days at 32 liters per day. Controls were irrigated for 90 days. For all trees tillage was to the water table.

Characteristics	Days Irr.	N	Mean	S.E.	Percent mortality
Height (cm)	17	26	233.0	12.1	7.7
	27	26	237.2	12.0	3.8
	37	26	232.1	14.5	11.1
	90	144	220.2	6.7	8.9
Growth (cm)	17	26	51.6	5.94	
	27	26	49.0	6.07	
	37	26	49.1	10.59	
	90	144	43.8	4.37	
Foliage volume (m^3)	17	26	2.92	0.07	
	27	26	3.05	0.08	
	37	26	3.02	0.43	
	90	144	2.84	0.22	

Growth=growth in the second growing seasons in

Table 2 - Effects of tillage after two season on height, growth, and foliage volume of cottonwood trees planted along the Kern River. For experimental trees tillage was to about 75 percent of the depth to the water table; tillage was to the water table for controls. Average water table depth was 1.2 meters.

Characteristic	N	Mean	S.E.	Percent mortality
Height (cm)				
Tillage 75 pct	21	153.9	20.1	41.2
Controls	14	220.2	6.7	8.9
Growth (cm)				
Tillage 75 pct	21	-7.0	38.3	
Controls	14	111.3	11.1	
Foliage Volume (m3)				
Tillage 75 pct	21	1.03	0.31	
Controls	14	3.77	0.29	

Growth=growth in the second growing season in cm.

These data (Table 2) taken alone speak strongly against tilling to depths short of the water table. In fact, by the time the Kern River revegetation project had begun I had already experimentally determined (Colorado River) with 936 trees where tillage was the only variable being tested that tilling less than to the water table for cottonwood/willow trees would almost certainly result in large losses in vigor (Anderson and Ohmart 1982). This finding was substantiated with data where tillage was one of the variables in multivariate tests for an additional 2000 trees (Unpublished data on file, Revegetation and Wildlife Management Center, Blythe, California.) When work began on the Kern River there was little doubt that tillage to the water table should be the control condition and deviations in tillage depth should represent experimental variables. The relationship to vigor is so predictable that an equation developed for cottonwoods on the Colorado, where depth to the water table is 3 meters, can be used to accurately predict the observed data presented here for the Kern River, where average depth to the water table is just over 1 meter. Failing to till soil to the water table will result in large decreases in productivity and high mortality.

Electroconductivity

Electroconductivity effects were evaluated by comparing trees planted at points where EC's were less than 2.0 millimhos/cm^3 with trees at points where EC's were greater than 2.0 millimhos/cm^3 at a depth of 1.2 meters or this level and at the water table (high EC groups). These divisions were based on previous work (e.g. Anderson and Ohmart 1986) indicating that losses in productivity have begun at ECs of 2.0 millimhos/cm^3.

Within the high EC group were three subgroups: (1) soil EC's greater than 2.0 millimhos/cm^3 at 1.2 meters but less than this at the water table; (2) soil and water table EC's greater than 2.0 millimhos/cm^3; (3) water table EC's greater than 2.0 millimhos/cm^3 but EC's at 1.2 meters less than 2.0 millimhos/cm^3. For trees in subgroups (1) and (2) height was less than for trees in the low EC group, but not significantly different ($P=>.05$). Trees growing with water table EC's greater than 2.0 millimhos/cm^3, but <2.0 at 1.2 m, mean height differed significantly ($P<0.05$) from the low EC group (table 3). Growth in the second season revealed that for all groups of trees in soil with high EC's growth was significantly ($P<0.05$) less than trees in low EC soil.

Table 3 - Effects of electroconductivity (EC) in millimhos/cm³ on vigor of cottonwood planted along the Kern River. Tillage was to the water table and no trees were affected by browsing. Data are for two growing seasons.

	EC's at 1.2 m	WT	N	Mean	S.E.	Percent mortality
Height	>2.0	<2.0	27	224.4	12.6	For groups
	>2.0	>2.0	18	237.2	11.6	>2.0=12.1
	<2.0	>2.0	31	245.2	8.8	
	<2.0	<2.0	65	256.6	8.0	0.0
Growth	>2.0	<2.0	27	91.4	24.4	
	>2.0	>2.0	18	105.2	14.2	
	<2.0	>2.0	31	127.5	11.2	
	<2.0	<2.0	65	158.0	10.7	
Fol.Vol.	>2.0	<2.0	27	4.00	0.47	
	>2.0	>2.0	18	4.75	0.60	
	<2.0	>2.0	31	5.25	0.52	
	<2.0	<2.0	65	6.01	0.55	

WT=water table, Growth=growth in the second growing seasons in cm. Fol.Vol (Foliage Volume) is in m³; height in cm

These data alone suggest not planting where EC levels exceed 2.0 millimhos/cm³. One might tentatively conclude that cottonwood/willow trees are salt sensitive. However, we have tested the tolerance of salinity for 574 willows and 726 cottonwoods in two separate full-scale revegetation projects on the Colorado River (Unpublished data on file, Revegetation and Wildlife Management Center, Blythe, California.) On the Rio Grande planting where ECs were less than 2.0 millimhos/cm³ was the normal situation, but 52 experimental trees were planted where EC's were greater than 2.0 millimhos/cm³. Equations from the Colorado River quite accurately predicted the level of loss on the Rio Grande (Anderson and Ohmart 1986).

By the time work began on the Kern River, new predictive equations had been developed, which predicted losses on the Kern River within 4.3 percent on average for 273 trees after 2 years (Anderson 1988). Collectively these data support arguments against planting cottonwood/willow trees at points where EC levels exceed 2.0 millimhos/cm³ unless foliage volume losses of 30 percent are acceptable after two seasons. Losses increase with time. Data presented (table 3) are for two growing seasons; by 9 July of the third season trees in soils with EC's greater than 2.0 millimhos/cm³ had an average foliage volume of 3.8 m³. Those growing where EC's are less than 2.0 had foliage volume of 7.1 m³. Thus, midway through the third growing season trees in the high EC group have 46 percent less foliage volume than those in the low EC group. Colorado River equations indicate that by year's end the difference will be in the order of 67 percent.

Browsing

Trees browsed by deer were significantly ($P=<0.05$) smaller in all measurements than trees not browsed (table 4). After 2 years the difference in height between browsed and not browsed was 27 percent of trees not browsed, the difference in foliage volume was 60 percent (table 4).

Table 4 -Effects of browsing by deer on height, and growth during the second growing season, and foliage volume of cottonwood trees planted along the Kern River. For all trees tillage was to the water table. Mean EC values did not vary significantly between browsed and unbrowsed trees.

	Category	N	Mean	S. E.	Percent mortality
Height	Browsed	46	193.7	9.4	11.8
	Not browsed	141	264.1	6.1	0.0
Growth	Browsed	46	99.3	15.4	
	Not browsed	141	122.7	9.8	
Fol.Vol.	Browsed	46	2.47	0.36	
	Not browsed	141	6.25	0.32	

Alone these data suggest that browsing has a large negative impact on growth of cottonwood trees browsed trees one or more times during the first year. Loss of apical meristem results in considerable damage; below ground damage is often more extensive than that above ground (Harper 1977). Data presented above are from the end of the second growing season. Midway through the third season the browsed trees had 75 percent less foliage volume than nonbrowsed trees.

These data (table 3) are from a single site in one locality, thus more data are needed on the effects of browsing on cottonwood/willow. However, the literature cited above and reviews by Belsky (1986, 1987), in concert with these data indicate that browsing will damage trees; we recommend that trees be protected if extensive browsing is expected.

Site Selection, Planting and Irrigation Monitoring

Site Selection

Wise site selection is not possible until a relatively large data base exists concerning autecological requirements of various species. Results summarized in this report provide at least a modest basis for determining site suitability. Preferably a number of sites will be available for revegetation, thus permitting selection of the one most suitable for the species one wishes to plant. For example, for cottonwood/willow trees, the site should have low EC's, well-drained sandy soil, and a relatively shallow (4 meters or less) water table. In many localities soil type is highly correlated with salinity.

Site suitability was determined by (1) dividing the area on paper into 0.4 ha plots; selecting at random half of these for sampling, (2) collecting soil samples at plot centers and determining surface to water table depth, (3) classifying soil samples from the first and third quarters of the profile and determining ECs at these levels, (4) noting vegetation on each plot for determining competitive potential, and determining the best method of site preparation, and (5) determining EC's on water table samples.

Greater sampling intensity than suggested here (Anderson and Ohmart 1982, 1986) indicated this abbreviated method, a compromise between data needs and cost, will yield data adequate for evaluating general field suitability. A 20 ha site would include 25 samples.

Although 25 samples provide some indication of EC distribution on the site, for mapping it would result in too much guessing–and large losses in productivity. Maps of EC distribution (fig. 2) are based on samples from 5-10 percent of all points 6.8 meters apart (250-500 samples in 20 ha). Distribution of soil types and depth to the water table can also be mapped. With this information the planting design can put trees only in places where the chances of loss because of poor soil or salinity conditions are low.

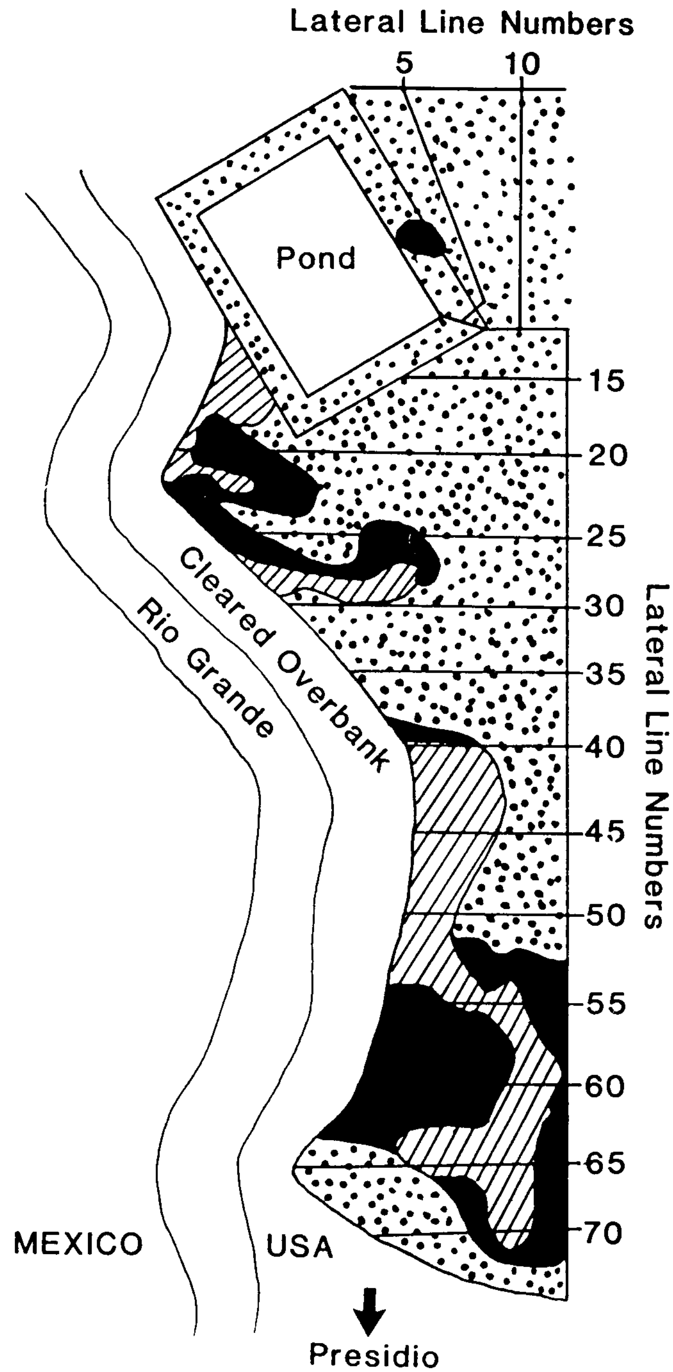

Figure 2– Electroconductivity (millimhos/cm^3) of soil 61 cm below the surface. Stippled = EC<2.0; black = EC 2.0-4.0, diagonal = EC>4.0.

Planting and Monitoring Irrigation

Trees are planted at all points, (augered holes) including those sampled for mapping, and can be used to monitor the project during the irrigation phase. Tree height is measured weekly and expressed as growth per day since the last measurements were taken. These data are entered on the computer immediately after collection. Interpretation involves paying close attention to trees growing most and those growing least. In the areas where we have worked (Rio Grande near Presidio, Texas, Colorado River near Blythe, California, to Kern River near Weldon, California) altitudes vary from about 75 meters to 750 meters, and growth rates during June-July average 10-15 mm/day. If daily growth rates fall below this it can be assumed that something is wrong.

Recognition of problems involves considering the location of trees showing poorest and best growth on the site. Slow growers often share an autecological factor. For example, if EC levels are high in the general area where trees are not growing, the problem may be alleviated by increasing irrigation rates, thus increasing leaching. In one project, slow growing trees were located where depth to the water table was above average. Growth rates were increased immediately by increasing the irrigation rate. On the same site, another group of slow growing trees was located, primarily, in places where depth to the water table was less than 1 meter. In this case growth rates increased dramatically by decreasing the irrigation rate. The initial hypothesis here should be that these trees were probably insufficiently aerated. Sometimes interpreting monitoring data requires sophisticated considerations; the best informed staff should do the monitoring.

This process of monitoring, even though it includes experimental trees, in no way compromises the experimental efforts, in fact, it enhances such efforts by ensuring that experimental trees do not suffer from improper irrigation during the irrigation phase. Since all experimental (including control) trees are randomly distributed on the site, and sample sizes are reasonably large, irrigation merely becomes a controlled variable. Ordinarily no impacts of treatments are apparent at the end of the irrigation phase; the experiment really doesn't begin until after irrigation ends.

Conclusions

Hopefully the four part approach outlined above will be useful to others doing revegetation projects in Southwest desert riparian situations. The first step, preliminary site analysis, allows for selection of a site generally suitable for the plant species one desires to plant. The second step, intensive random soil sampling on the chosen site, allows mapping soil/salinity conditions across a site. This done, a planting design can be tailored to site conditions—few trees will be planted where productivity will be low. Salt tolerant species can be planted on the saline portions of the site. Trees planted at points where soil sampling was done can be used to monitor growth during irrigation. Monitoring on a weekly basis permits early recognition and treatment of problems. Finally, the same sampling points can be used for planting trees for research purposes. Well designed research studies yield data valuable for increasing productivity (e.g. recognition of the extent of salt tolerance by various species) and reduce costs (e.g. by recognizing that shorter irrigation periods do not reduce productivity). The process is obviously cyclic; one must have done research (step 4) before preliminary data (step 1) can be meaningfully interpreted. The value of the procedure improves with completion of each cycle.

What is sacrificed if one or more of these steps is omitted? This is an important and difficult question to answer. I have been developing and refining the approach for a decade but cannot provide a precise answer. However, I offer the following, that we use in our work, as guidelines.

Elimination of the weekly monitoring may reduce productivity by 20 percent. On the Colorado River and lower Rio Grande failing to do preliminary sampling in concert with a decision to plant cottonwood/willow trees could result in nearly total failure half or more of the time; on the Kern River 5-10 percent of the time (Anderson 1988). Failure to map salinity levels could cost 30 percent in productivity on the Kern River and 50-75 percent on the Rio Grande and Colorado River. Uncontrolled competition for nutrients, space and light by weeds could account for 40 percent loss (Anderson and Ohmart 1984, 1986). Losses can quickly mount to disastrous proportions. The procedure helps us and will hopefully help others to reduce these losses.

Although helpful, the procedure still needs refinement, including more data on some of the fundamentals discussed in this paper. Fertilization has been held constant in all experiments, but productivity can probably be increased with refinements in the use of fertilizers. More work is needed on irrigation rates that will maximize productivity and leaching. Needed refinements will be made when—if—funding agencies recognize the need for it.

Acknowledgments

Support from the U.S. Bureau of Reclamation, U. S. Boundary and Water Commission, California Department of Fish and Game and The Nature Conservancy is gratefully acknowledged. Comments from an anonymous reviewer were useful in revising early drafts of the manuscript.

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