RIPARIAN RESTORATION IN THE SOUTHWEST: SPECIES SELECTION, PROPAGATION, PLANTING METHODS, AND CASE STUDIES

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Abstract

Riparian plant communities, though small in overall area, are among the most valuable natural areas in the Southwest. The causes of degradation of southwestern riparian zones range from excessive cattle and elk grazing in montane watersheds to invasive woody exotic species and lack of natural flooding in the cottonwood forests, "bosque," of low elevation river valleys. Goals of riparian restoration include erosion control, channel stabilization, runoff reduction, and enhancement of wildlife and fishery habitat. Plant species and stock types selected for restoration efforts must be appropriate for the site characteristics. Relevant site characteristics include elevation, soil texture and chemistry, and depth to water table. Vegetative propagation methodologies including pole cutting production, mound layering, and large containerized stock have been developed to provide cost effective plant production of riparian species. Plant materials and planting methods range from dormant pole cuttings placed vertically or horizontally to unusual container stock types such as 30 inch tall pots. Case studies are presented on the restoration of the cottonwood forests along the middle Rio Grande and Gila River and of montane riparian areas in the Apache-Sitgreaves National Forests.

Key Words

Plant materials, stock type, pole cuttings, tallpots, treepots, capillary fringe, water table, salinity, soil texture

Properly functioning riparian areas serve key roles in providing fish and wildlife habitat, preserving water quality and water supply, and providing recreational opportunities. A comprehensive assessment of criteria useful in judging riparian area condition and attributes that constitute a proper functioning condition for lotic areas has been developed and refined by an interagency team (Prichard and others 1993; Prichard and others 1998). The team defined a properly functioning riparian area as having "adequate vegetation, land form, or woody debris" to "dissipate stream energy, filter sediment, aid ground-water recharge, aid in floodplain development, stabilize streambanks, and maintain channel characteristics." These functions of a riparian area "in accordance with its potential" should result in attributes including "channel stability, less erosion, good water quality, good water availability, forage, and fish and wildlife habitat."

The interagency team developed a checklist of attributes and processes dealing with hydrology, vegetation, erosion, and deposition (Prichard and others 1998). The hydrology attributes of a proper functioning riparian area include:

1) the floodplain is inundated relatively frequently;
2) beaver dams, if present, are active and stable;
3) dissipation of stream energy is controlled by sinuosity, width/depth ratio, and gradient consistent with the landform, geology, and bioclimatic region;
4) the riparian area should be widening or should have reached its maximum potential extent; and,
5) the condition of the upland watershed has not resulted in the degradation of the riparian area.

The vegetation attributes of a proper functioning riparian system include:

1) the age class distribution of the riparian plant community indicates the recruitment of young individuals and the maintenance of older individuals;
2) the species composition of the riparian area is diverse;
3) the characteristic soil moisture of a riparian-wetland area is indicated by the species present;
4) species with root masses capable of protecting against high flow events are present on the streambanks;
5) the condition of the riparian plant community is healthy and robust;
6) vegetative cover is sufficient to protect streambanks and dissipate energy during high flow events; and,
7) the riparian plant community can provide sufficient large woody debris to act as an agent to modify the hydrology if necessary for proper functioning.

The erosion and deposition attributes of a riparian area that is functioning properly include:

1) the energy of high flow events can be dissipated by floodplain and channel characteristics such as overflow channels and woody debris;
2) for channel types forming point bars, these point bars are being revegetated;
3) lateral movement of stream channel is associated with natural sinuosity;
4) channel lowering is not occurring at an unnatural rate; and,
5) excessive erosion or deposition is not occurring.

NATURAL PROCESSES AND MANAGED ACTIVITIES CAUSING DEGRADATION OF RIPARIAN ZONES

The continuum of southwestern riparian zones from alpine to hot deserts are susceptible to an array of natural and human-generated processes that can degrade the proper functioning of these critical watershed areas. At lower elevations, agricultural development and flood control have imposed both structures and management resulting in severe disruptions of natural regeneration of the floodplain cottonwood forests. Dams have prevented or limited natural flooding which has eliminated the sediments and hydrologic regime required for the germination and establishment of the cottonwood and willow species that dominate the overstory in these forests. Levees have been constructed which constrain the floodplain extent and restrict the natural meanders of the river systems. Channeling streambeds to reduce flooding and increase water transport efficiency has resulted in human-dominated water conveyance systems. Drainage of riparian zones to create agricultural lands has altered shallow aquifers directly connected to rivers. River flow management prevents flooding and assures conveyance of water to downstream users. These hydrologic regimes have resulted in an artificial hydrographs unsuitable to the natural regeneration or maintenance of these cottonwood forests. The near complete loss of natural cottonwood regeneration has resulted in the invasion of exotic woody species, Russian-olive *(Elaeagnus angustifolia L.)* and saltcedar *(Tamarix ramosissima* Ledeb.), and the accumulation of enormous fuel loads, making these degraded riparian areas very susceptible to wildfire. These floodplain cottonwood forests do not contain fire-adapted native species as do some forestlands at higher elevations and thus little natural regeneration occurs after fire.

At higher elevations, catastrophic wildfires can result in direct destruction of riparian areas. Massive erosion and deposition of sediments resulting from wildfire in forested watersheds destroy fisheries and wildlife habitat, recreational facilities, roads, and water supplies for communities. Despite these deleterious effects, the results of wildfire can regenerate decadent riparian plant communities over time. The destruction of riparian vegetation directly by cattle and elk grazing has resulted in vast stretches of streams that do not support properly functioning ecosystem processes. Watersheds suffering from long-term overgrazing are more susceptible to extreme flood events resulting in accelerated rates of channel lowering. This landscape alteration can destroy and prevent the regeneration of riparian plant communities and concurrently increase sediment deposition in low gradient stretches and alter downstream riparian areas. Past logging practices involving poorly designed and sited roads and skid trails, as well as inadequate buffer zones surrounding streams, have contributed to the degradation of montane riparian plant communities. Historic trails that have become roads in the national forest system were developed with ease of access as the dominant feature, often resulting in roads dissecting riparian areas and perturbing stream courses. The recreational facilities in forestlands are generally situated streamside, resulting in intensive vehicle and foot traffic in the surrounding riparian areas.

The quantity, quality, and timing of water supply as well as wildlife and fishery habitat and recreational opportunities depend on the proper functioning of riparian plant communities. The many and varied natural processes and human controlled activities that are disrupting these critical riparian areas should serve as an impetus to preserve pristine stream systems and their accompanying riparian plant communities, as well as to develop cost effective restoration techniques. The discussion that follows will address the importance of species selection, techniques to propagate riparian plant materials, and the installation and maintenance of this planting stock to facilitate restoration of riparian zones. Case studies will address the riparian restoration practices employed in a number of southwestern ecosystems during the past decade.

SPECIES SELECTION

The appropriate species to establish in degraded riparian zones may or may not be those present before the disturbance occurred. Some processes can alter the growing environment to such an extent that the pre-disturbance species are no longer suitable candidates. As an example, the imposition of flood control dams and managed flows can alter the salinity of soils by eliminating flooding. The effects of these water control structures and flow regimes on river hydrology and alluvial processes can modify the depth to ground water and the seasonal pattern of water table fluctuation. In such a case, the increased salinity may not allow establishment of the pre-disturbance species and a persistently deep water table may allow only certain planting stock types to be successfully used. In many instances, evaluation of plant communities in proper functioning riparian areas in the bioclimatic region will provide a guide to appropriate species.

General guidance as to appropriate species can be ascertained by site factors such as elevation and bio-climatic region. Dick-Peddie (1993) presents elevation ranges of greatest dominance for common riparian trees and shrubs in New Mexico (see Table 1). These elevation zones show the appreciable range where these species can dominate, taking into consideration the span of latitudes New Mexico covers.

An intensive study of willow *(Salix)* species on the Apache-Sitgreaves National Forests has determined the elevation range of occurrence on hundreds of sites on numerous watersheds between 5,500 and 10,000 feet (Granfelt 2001). This data has been summarized and analyzed (see Table 2) to provide average elevation, weighted average elevation based on number of sites, as well as minimum, maximum, mode, and number of sites where each species was found.

Bioclimatic or ecoregion can determine species suitability in addition to elevation and latitude. As examples, Arizona sycamore *(Platanus wrightii S.* Wats.) is only a dominant species at midelevations in southwest New Mexico and southeast Arizona; Arizona walnut *(Juglans major* (Torr.) Heller) can be a co-dominant species in southwest New Mexico mountains; little walnut *(Juglans microcarpa* Berl.) can be a co-dominant in southeast New Mexico (Dick-Peddie 1993).

Table 1. Elevation zones of greatest dominance of riparian trees and shrubs in New Mexico as presented by Dick-Peddie (1993).

Species	Common Name	Maximum Elevation (ft)	Minimum Elevation (ft)
Picea pungens Engelm.	blue spruce	10,700	8,200
Salix bebbiana Sarg.	Bebb willow	10,200	8,600
Populus tremuloides Michx.	quaking aspen	10,200	7,200
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung	thinleaf alder	9,500	8,000
Acer glabrum Torrey	Rocky Mountain maple	9,200	7,700
Cornus sericea L.	redosier dogwood	9,200	7,200
Acer grandidentatum Nutt.	bigtooth maple	9,400	6,900
Populus angustifolia James	narrowleaf cottonwood	9,300	6,300
Acer negundo L.	boxelder	8,300	5,900
Salix amygdaloides Anderss.	peachleaf willow	7,700	5,400
Salix irrorata Anderss.	bluestem (dewystem) willow	7,000	5,000
Alnus oblongifolia Torr.	Arizona alder	7,000	4,700
Populus x acuminata Rydb. (pro sp.) *[angustifolia x deltoides]*	lanceleaf cottonwood	6,800	4,700
Juglans major (Torr.) Heller	Arizona walnut	6,700	4,500
Populus fremontii S. Wats	Fremont cottonwood	6,600	4,700
Fraxinus velutina Torr.	velvet ash	6,500	3,800
Platanus wrightii S. Wats	Arizona sycamore	6,400	4,100
Sapindus saponaria L. var. *drummondii* (Hook. & Arn.) L. Benson	western soapberry	5,500	3,700
Celtis laevigata Willd. var. *reticulata* (Torr.) L. Benson	netleaf hackberry	5,100	3,300

Some of the species in Table 1 are obligate riparian species (for example, willows and cottonwoods); others are facultative or semiriparian in that they often are found in upland areas. As examples, New Mexico locust *(Robinia neomexicana* Gray) and aspen *(Populus tremuloides* Michx.) are often found in montane riparian zones, but also form dense stands on mountain slopes after disturbance (Dick-Peddie 1993). Obligate species are not always found in typical streamside environments. As an example, in north-central New Mexico, narrowleaf cottonwood *(Populus angustifolia* James) has invaded mine overburden where the lack of competing vegetation, in part, allows soil moisture levels to build up sufficiently to support this species (Dreesen and Harrington 1999).

Closed basin riparian environments in the southwest such as alkali sinks or playas often have saline soils and support distinctive groups of species. Saline tolerant riparian species dominate such environments (Dick-Peddie 1993) and include such woody species as fourwing saltbush *(Atriplex canescens* (Pursh) Nutt.), pale wolfberry *(Lycium pallidum* Miers), and greasewood *(Sarcobatus vermiculatus* (Hook.) Tort.). Saline soils are also encountered in floodplain riparian areas especially those perturbed by flood control structures and flow management such as in the Middle Rio Grande Valley. Surveying sites before restoration activities should involve soil sampling (surface and

Table 2. Elevation zones of greatest dominance of riparian trees and shrubs in New Mexico as presented by Dick-Peddie (1993).

Salix Species	Minimum Elevation (ft)	Maximum Elevation (ft)	Average Elevation (ft)	Weighted Average Elevation (ft)	Mode Elevation (ft)	Number of Sites	Elevation Range (ft)
boothii Dorn	9250	9500	9375	9300	9250	6	9000-9500
arizonica Dorn	8500	9500	9000	9000	9000	5	8500-10000
monticola Bebb	7250	9500	8375	8800	9000	81	6900-9500
bebbiana Sarg.	6750	9500	8200	8800	8750	304	6000-10200
ligulifolia (Ball) Ball ex Schneid,	6250	8500	7475	7500	7500	85	3500-8900
irrorata Anderss.	5500	9000	7250	7475	7500	176	4500-9200
lucida Muhl. ssp. lasiandra (Benth.) E. Murr.	6000	8750	7350	7375	7500	78	3700-8300
exigua Nutt.	5500	8250	7075	7050	6750	89	1100-8500
lasiolepis Benth.	5500	7000	6250	6425	6500	39	3900-8000
laevigata Bebb.	5500	6750	6125	6325	6750	18	1700-6900
gooddingii Ball	5500	6750	6125	6025	6125	14	150-7500

subsurface) which can be a costly endeavor. Electromagnetic induction measurements can cost effectively indicate whether salinity levels throughout the soil profile are below threshold limits for establishment of Rio Grande cottonwood *(Populus deltoides ssp. wislizenii (S.* Wats.) Eckenw.) and Goodding's willow *(Salix gooddingili)* (Sheets and others 1994). High salinity in surface soils is not always an indicator of salinity problems throughout the soil profile; evaporation can concentrate salts as a surface crust. Proper species selection and planting stock type strongly influence revegetation success whether high salinity alluvium occurs only on the surface or not. In the Middle Rio Grande Valley, floodplain forest overstory components, Goodding's willow and Rio Grande cottonwood, have low salinity tolerance. In contrast, understory species such as fourwing saltbush, pale wolfberry, and screwbean mesquite *(Prosopis pubescens* Benth.) can tolerate appreciably higher soil salinity levels (Taylor and McDaniel 1998a; Taylor and McDaniel 1998b). If high salinity is a problem only as a surface crust and subsoil and groundwater salinity are not excessive, pole plantings of low tolerance species can be successful because adventitious root development occurs in a favorable environment.

Alluvium texture is of primary importance in determining suitable restoration species. Lotic systems with fast moving water deposit coarse alluvium of low fertility and high aeration. In contrast, lentic systems deposit fine alluvium (silts and clays) with higher fertility and less aeration. In general, lotic systems are conducive to the establishment of woody riparian trees and shrubs, while lentic systems are suitable for herbaceous wetland and marsh plants. Riparian areas which once supported woody species can evolve as the stream gradient declines, allowing the deposition of fine alluvium and the creation of conditions more suitable for wetland plants. Conversely, extreme flood events can alter low gradient stream sections to higher gradients, allowing coarse alluvium development leading eventually to a woody riparian habitat. Many failures of riparian restoration can be linked to errors in attempting to introduce woody species into lentic areas where only wetland herbaceous species will thrive.

The depth to ground water plays a key role in determining suitable riparian species. The primary rooting zone for obligate riparian plants is the capillary fringe above the water. The thickness of the capillary fringe is affected by the alluvium texture, with finer textured alluvium having a broad zone of unsaturated soil with high moisture content. A thicker capillary fringe zone is advantageous in the sense of having greater water content per unit volume but is disadvantageous in the lower aeration resulting from less air-filled pores. The consequence of woody riparian species generally requiring highly aerated soils often leads to suitable restoration sites having a thin capillary fringe with lower water content but more air filled pores.

The fluctuation of ground water levels in riparian areas is dependent on the connection of the shallow aquifer to the stream; thus, as the stream water level changes the depth to ground water changes. Changes in stream level are reflected in an annual hydrograph of stream discharge whether controlled by natural processes or by human manipulation. The ground water fluctuations resulting from the variation in stream flow requires monitoring by shallow wells to determine the extent and timing of ground water level changes. This data is the basis for determining the planting stock type that will allow root access to the capillary fringe and provide a high potential for successful plant establishment. In addition, this data is needed in species selection because species vary in optimum depth to ground water. As an example, the pole planting prescription for Rio Grande cottonwood at the Bosque del Apache National Wildlife Refuge is a ground water depth between 6 and 12 ft (1.8 to 3.6 m). However, the prescription for Goodding's willow is 4 to 8 ft (1.2 to 2.4 m) (Taylor and McDaniel 1998).

Stream channel alteration by down-cutting coupled with lack of flooding due to water management structures has resulted in many riparian areas having such deep water tables and depleted near-surface soil water content that upland vegetation has invaded and proved much better adapted to the present hydrologic regime. In such situations, pole plantings may allow the establishment of riparian woody vegetation, but it is understood that such artificial regeneration will not create a self-perpetuating riparian plant community.

RIPARIAN PLANT MATERIAL STOCK TYPES

As explained above, certain riparian situations will require specific stock types in order to optimize successful and cost-effective riparian restoration. In the Middle Rio Grande Valley and in many other low elevation cottonwood forest (bosque) environments, the depth to ground water over much of the historic floodplain is too great to permit the use of traditional stock types with shallow root systems without appreciable aftercare. One gallon treepot stock (4 in. x 4 in. x 14 in.) (10 cm x 10 cm x 36 cm) of riparian understory shrubs such as New Mexico olive *(Forestiera pubescens* Nutt. var. *pubescens)* and skunkbush sumac *(Rhus trilobata* Nutt) planted in the bosque require several water applications per year for a few years to obtain acceptable survival rates. The expense in irrigating such out-plantings has prompted an emphasis on pole and whip plantings of large dormant cuttings and use of 30 in. (81 cm) tallpot containerized stock in such environments. Most cottonwoods and willows have good adventitious root development from large vigorous cuttings and have proved to be successfully established via pole plantings.

Experimental field plantings and wildland plantings (Los Lunas Plant Materials Center 1994; Los Lunas Plant Materials Center 1998) have shown that other species outside the Salicaceae family have some promise as pole/whip cuttings. These understory species include seepwillow *(Baccharic salicifolia (*Ruiz & Pavon) Persoon in the Asteraceae), desert false indigo *(Amorpha fruticosa* L. in the Fabaceae), New Mexico olive (in the Oleaceae), and desert willow *(Chilopsis linearis* (Cav.) Sweet in the Bignoniaceae). None of these species have the fast growth rate of most cottonwoods and willows nor do they attain the ultimate size of cottonwoods or tree willows, thus pole production is not as rapid. In addition, these species appear to be more exacting in some cultural factors. These species do not appear to tolerate long storage periods in water as do pole cuttings taken from Salicaceae species.

Several species have been successfully established in riparian areas from rooted poles/whips (desert false indigo, New Mexico olive and desert willow). The rooted poles of these species as well as Arizona sycamore and Arizona alder *(Alnus* *oblongifolia* Torr.) have been produced by mound layering techniques described in a later section.

The factors that promote the use of pole plantings to access deep soil moisture in the capillary fringe have prompted other planting stock alternatives other than pole/whip plantings. The improved out-planting success found with tall containers in desert situations (Bainbridge 1994; Bainbridge and others 1995; Miller and Holden 1992) implies that access to deep soil moisture or greater soil volumes may be enhancing plant establishment. The ability of riparian woody plant root systems grown in tall containers to quickly contact soil moisture in situations where the capillary fringe is deep should afford greater likelihood of survival and growth. Determining whether to use such an approach involves comparing the cost and effort of using cheap shallow containerized stock which are easily planted but will require supplemental water versus using more expensive deep stock types which are more difficult to grow and plant but require no aftercare.

PLANT MATERIAL PRODUCTION OF RIPARIAN SPECIES

Pole Production Protocol

The current protocol for producing dormant pole cuttings of Rio Grande cottonwood, plains cottonwood *(Populus deltoides* ssp. *moni4fera (Air.)* Eckenw.), and narrowleaf cottonwood at the Los Lunas Plant Materials Center (LLPMC) is based on an evolution of cultural techniques developed through over 15 years of pole production experience. The optimum soil types for pole production are coarse textured (loamy sands to sandy loams) to provide high aeration potential; this also necessitates more frequent but lower irrigation volumes. Fields at the LLPMC are flood irrigated and are typically laser-leveled which allows uniform distribution of shallow depths of water. Most of the fields are 300 ft (91 m) in length from the irrigation riser to the distal end. The rows of trees are generally spaced at 10 ft (3 m) intervals. In order to facilitate later seedling planting, a single rip 18 in. (0.4 m) deep is formed along the intended planting line. A mulch-laying machine is used to put down 36 in. (91 cm) wide woven ground cover fabric (Dewitt EarthmatTM) and to bury the fabric edges; the rip is centered as close as possible to the center of the mulch row. After securing the fabric ends in shallow trenches, holes for seedlings are formed at a spacing of 18 to 24 in. (0.4 to 0.6 m) using the flame from a propane-fired weed burner nozzle. By rapidly applying the flame to the desired planting location, a hole 3 to 4 in. (8 to 10 cm) in diameter is easily burned in the fabric by experienced personnel.

Planting usually occurs in June or July. Depending on the seedling container size and location of the rip versus the hole in the fabric, either dibbles or augers are used for planting. Generally, 10 in.^{3} (164 ml) containers (Super Cell SC-10) can be dibbled, but larger diameter containers (for example, Deepot 16) require planting holes augered using 2 or 3 in. (5 to 8 cm) diameter bits powered by gasoline engines or electric drills powered by portable generators. A dose of 1 teaspoon (-6 g) of controlled release fertilizer (for example, Osmocote Plus or Sierra 3 to 4 month duration) is placed in the bottom of the dibbled or augered hole prior to planting. Containerized cottonwoods from seed collected at specific localities are generally used to maximize genetic diversity but maintain local ecotypes. Cutting-propagated stock can also be used if seed is unavailable, superior clones are desired, faster transplant production is required, or genetic diversity is not of primary importance.

Seedlings are placed in the hole and back filling is accomplished by piling a small mound of loose soil around the base of each seedling with a shovel. Planting is done in the morning to allow sufficient time to flood irrigate the field the same day. The initial flood irrigation is sufficient to disintegrate the sandy soil mounds and fill any voids around the root balls. During the first several weeks after planting, the fields are flooded with 1 to 2 in. (2.5 to 5 cm) of water twice a week. After about the first month, watering intervals are lengthened to once a week. Because the LLPMC is situated in a cold desert climate with minimal winter precipitation, the fields are flood-irrigated at the end of the water season of our local irrigation district. In exceedingly dry winters, these fields can be flood-irrigated once or twice from irrigation wells. During the second growing season, the watering interval is increased to once every 2 weeks. Side dressing of nitrogen fertilizer (usually urea) is applied several times during the growing season. Phosphorus and potassium are banded adjacent to the edge of the mulch once a year. During subsequent years, the irrigation interval can be lengthened to once every 3 weeks, but the fertilizer regime remains as stated above. The harvest of poles can begin during the winter following the second field-growing season when pole lengths of 12 to 15 ft (3.7 to 4.6 m) can be achieved with butt diameters of 2 to 3 in. (5 to 8 cm). Typically, pole harvesting is initiated in January and extends until bud break (usually late March to early April). During pole harvest, side branches are pruned at the branch collar leaving only a few small branches at the top. The poles are bundled in groups of 5 with twine and transported to a staging area where the butt ends are placed in water tanks to assure maximum hydration before transporting and planting.

The initial pole harvest from a field involves severing the single stem at 4 to 6 in. (10 to 15 cm) above the ground. The following growing season this stump will sprout numerous stems, some reaching 6 to 8 ft (1.8 to 2.4 m) in the first year and producing pole-size stems after one to two additional years. The stumps with numerous stems are pruned in the late fall and winter to reduce the number of stems to the 5 to 6 most vigorous vertical stems.

Mound Layering to Produce Rooted Poles/Whips

A number of riparian species that can not be established from traditional dormant pole cuttings might be established from a rooted pole cutting. One technique to produce large rooted cuttings is mound layering. Two methods of mound layering have been investigated at the LLPMC: an intensive method and a low resource input method.

The intensive system has been tested with Arizona sycamore and Arizona alder. This alder species is a poor producer of adventitious roots under conventional vegetative propagation conditions; however, this sycamore species is capable of modest rooting success and possibly might be established via traditional pole plantings. The intensive system is described in detail in the propagation protocol available on the Native Plants Network (Anonymous 2000) and in Dreesen and Harrington (1997). In summary, a bottomless inverted nursery container is placed over an established plant in the nursery during the winter. The container is filled with a soil-less media and outfitted with micro-sprinklers (for example, Roberts Spot-Spitters®). The media is top-dressed with controlled release fertilizer in the spring. The large rooted and etiolated stems of Arizona sycamore produced by this technique had 100% and 73% survival, respectively, 3 months after transplanting into large containers.

The low input method makes use of a bottomless inverted container, but in this case the established plants are in flood irrigated fields. The containers are filled with field soil and watered strictly by precipitation and upward capillary movement when the field is flood irrigated. The year following mound formation, the stems are harvested for planting as rooted poles. The initial field trial comparing rooted versus non-rooted poles showed survival percentages for desert false indigo of 93% versus 50%, New Mexico olive of 100% versus 60%, and desert willow of 50% versus 17% (Los Lunas Plant Materials Center 1996).

Production of Cuttings and Seed of Montane Species in a Cold Desert Environment

The LLPMC is situated at an elevation of 4800 feet where the hot Chihuahuan Desert converges with the cold deserts of the Four Corners region. This cold desert environment experiences daily maximum temperatures exceeding 100'F (38'C) in summer and winter lows typically in the teens. The soils and waters are fairly alkaline. The establishment of stock plants of montane riparian species for seed and cutting production was needed to avoid the cost of travel for propagule collection, to avoid the possibility of finding no acceptable propagules, and to attempt to ensure vigorous stock plants by proper irrigation and fertilization. Early attempts with several montane willows *(Salix irrorata* Anderss. and *Salix monticola* Bebb) planted in sandy flood-irrigated fields were unsuccessful. The next approach involved planting in organic-rich beds. Trenches 18 in. (0.5 m) wide, 24 in. (0.6 m) deep, and 20 ft (6 m) long were excavated with a backhoe. These trenches were filled with potting soil reclaimed from pots with dead plants which had been stockpiled for a year; the mix contained variable proportions of spaghnum peat moss, composted pine bark, perlite, and pumice. One-gallon treepot stock plants from cuttings or seed were transplanted into these beds. The beds are irrigated with microsprinklers (for example, Roberts Spot-Spitters®).

Fertilization usually involves controlled release fertilizer top-dressing with a dose appropriate for the size of the stock plant. Sulfur is top-dressed each year to counteract the alkalinity of the irrigation water. Several montane species have thrived in these beds and yielded the following propagules: bluestem willow *(Salix irrorata)* seed and cuttings, blue elderberry *(Sambucus nigra L.* ssp. *cerulea* (Raf.) R. Bolli) seed, red-osier dogwood *(Corpus sericea L.)* seed and cuttings, littleleaf mock orange *(Philadephuc microphylluc* Gray) seed, smooth sumac *(Rhusglabra L.)* seed, and park willow *(Salix monticola)* cuttings.

Vegetative Propagation of Large Containerized Riparian Plants

Forest disturbances, mentioned previously, have resulted in many montane riparian forest communities lacking adequate vegetation to ensure proper riparian function. Many of these montane riparian systems are located in narrow, steep drainages from foothill locations up to alpine regions. Efforts in the past to use techniques developed for lower elevation have proved to be ineffective both from a cost standpoint as well as an ecosystem restoration tool. The difficult access to many of these areas by large equipment significantly reduces the feasibility of using dormant poles. Rapidly dropping water tables also restrict the suitability of smaller container or bare-root planting stock. However, large (one-gallon and bigger) containerized stock types have worked consistently in many trials. The advent of new container configurations (for example, Steuwe & Sons, Inc. Tree PotTM) has allowed for the development of more effective stock types for these types of plantings. The narrower and deeper pot designs generate a deeper root system, allowing transplants in a montane riparian planting environment to maintain contact with the capillary fringe for a longer period of time than is the case with shallower and wider stock types with the same root volume. These stock types can be planted using hand tools, thereby eliminating the need for large equipment that is required to install large, dormant poles.

The Mora Research Center has established many cottonwood and willow riparian species native to the southwest using the larger container systems. Vegetative propagation has used stem cuttings ranging 1 to 3 cm in diameter and 40 to 60 cm long. No use of exogenous plant growth regulators has been required to achieve acceptable rooting percentages (> 90%) during the past three years of trials. The pot system we have been testing has been the Steuwe & Sons Inc. 1-gallon "Tall One." In preliminary trials, we examined several media types containing various ratios of peat, perlite, vermiculite, and sand. Nursery growth and one-year survival observations indicate no differences between media in either growth or survival. However, from a management perspective, the media mixes containing sand were considerably heavier and more difficult to transport and plant. Subsequent trials and operational production has used a 2:1:1 mixture of peat:perlite:vermiculite. A slow release fertilizer, Osmocote 14-14-14, 3 to 4 month, is incorporated into the media at a rate of 1kg per cubic meter. We have found in preliminary trials that coating the interior of the pots with a copper containing root pruning compound (Spin Out®), improves the growth of the plants considerably (Harrington and Dreesen 2001, unpublished data).

Cuttings are collected in late winter to early spring while the cuttings are dormant. If necessary, the cuttings are stored under refrigerated conditions until needed. When ready, the stem cuttings are pushed into pots containing media until just the upper 10 to 20 cm (or approximately 3 leaf nodes) remain above the media. Cuttings are irrigated on an as needed basis. A typical initial irrigation regime would water the containers once every five days. Once root initiation and shoot growth has commenced the irrigation frequency increases to once every two or three days. At the end of the production regime, containers are usually being irrigated once a day. Typical production duration is 12 to 14 weeks. We have found irrigating with micro-emitters in each pot is effective in both irrigating the plant and reducing labor costs associated with irrigation. Current production of this stock type is exclusively outdoors. We have found over the past several years that adequately sized plants can be achieved in outdoor production. Final plant size is dependent on the species being planted with the cottonwoods and large willow species capable of producing shoots of one to two meters in height. Some of the smaller shrub-form willows may achieve final shoot height of only 70 to 150 cm in this production system.

Special Seed Propagation Techniques

Collection, Cleaning, and Solving of Cottonwood and Willow Seed

Cottonwoods and willows are dominant woody species in riparian areas in many ecoregions. Although propagation of most *Populus* and *Salix* species (exceptions *P. tremuloides* and S. *scouleriana* Barratt ex Hook.) by vegetative (stem) cuttings is a traditional technique, there are situations when seed propagation may be desirable for reasons of genetic diversity or limited vigorous cutting stock availability. Seed can be obtained from the wild if collectors can be on site during the brief period immediately before seed dissemination. At the LLPMC, seed of both *Salix scouleriana* and *Salix irrorata* have been collected from stock plants propagated from non-juvenile cuttings. In the case of *Salix scouleriana*, seed produced stock plants can bear seed within 4 to 5 years. Catkin collection is typically planned to coincide with the appearance of cotton emerging from the partially open capsules (Schreiner 1974). With small seed lots, willow catkins can be harvested and placed in paper bags to trap seed released as capsules open during drying (several days at room temperature).

Salix seed can be cleaned using a methodology similar to that described by Schreiner (1974) for *Populus* seed using an air stream and soil screens. A compressed air source and a set of soil screens in a series from top to bottom of 250 m, 500 m, 125 m are employed; the seed and catkins are placed between the 250 m and 500 m screens. A jet of compressed air is blown through the top screen in a swirling fashion; the seed is dislodged and remains on the 125 m screen with the cotton and empty catkins remaining in the 500 m screen. We have tried a similar approach using screens with larger openings for Rio Grande and plains cottonwood with little success. The technique presently used involves drying the cottonwood catkins in porous fiber bags for several days and then hammer-milling the capsules and seed at 600 rpm with no air suction and using a 1/8" exit screen. The resulting mixture of seed, cotton, and broken capsules is cleaned with a two screen seed cleaner (#8 upper screen and a' /16" lower screen) with very low airflow. A number of successive passes through the seed cleaner will result in little inert material remaining in the seedlot. Both *Popular* and *Salix* seed are sown within a few days after cleaning before viability declines significantly.

The seed of willow is typically sown in plug trays with no covering while cottonwood seed can be sown in final containers (for example, SC-10) or plug cells with a light covering. The surface must be kept continuously moist; germination of willow seed is often apparent after two days. Thinning of seedlings will be required and is usually performed in the final containers after the seedlings are of sufficient size to make clipping feasible.

Wet Tumbling Seed Treatment

One unconventional seed treatment applied at the LLPMC involves tumbling seed in water, or wet tumbling. Dry tumbling of seed has been one approach for seed scarification that has been investigated (Dreesen and Harrington 1997; Bonner and others 1974). The objective of wet tumbling can also involve scarification if an abrasive is incorporated in seed/water slurry. The addition of gravel and water facilitates abrasion due to the force imparted to the grit by the tumbling gravel. The size of gravel used is typically several times the diameter of the seed being treated. The grit can be a carborundum material used for rock polishing or a sharp sand. Although this treatment method may effect some seed coat degradation, other effects may be more important, such assuring complete imbibition in well-aerated water and the leaching of water soluble germination inhibitors in the seed coat. A typical treatment would involve wet tumbling for several days to a week with daily changes of water.

For a few species, this treatment appears to be a practical substitute for cold stratification. Two currant species (*gibes aureum* Pursh. and *Gibes cereum* Douglas) and pale wolfberry have required 2 to 3 months of cold stratification to achieve acceptable germination in past trials. Wet tumbling followed by one to two weeks of after-ripening in a warm moist environment has resulted in germination without cold stratification. The dry seed of another important riparian species, redosier dogwood, has required one hour scarification in concentrated sulfuric acid and then 2 to 3 months of cold stratification for acceptable germination. Using newly picked fruit, rapid germination has been achieved by wet tumbling the fruit with 1/2 to 3/4 in. (1 to 2 cm) gravel. Most of the pulp is removed in the first day of tumbling and separated by screening and float/sink manipulations in water. After pulp removal, the seed is wet tumbled for several more days with daily water changes. The imbibed seed is then after-ripened and initial germination starts in about 7 to 10 days and continues for several weeks. Although a limited number of species have been tested with wet tumbling, many additional species may benefit from this treatment.

Standard Containerized Seedling Production Procedures

The most common containerized stock type we have employed for riparian restoration is a one gallon treepot. In montane situations, this container size is generally adequate for acceptable rates of survival with little aftercare except protection from herbivores such as cattle and elk. As described above, in lower elevation cottonwood forests, understory shrubs planted as one-gallon treepot stock typically require supplemental watering for the first few years to become established. The routine propagation methodology employed at the Los Lunas Plant Materials Center is outlined below:

Stock Type: One gallon treepot, 4"x4"x14"

Target Root System: Consolidated root mass sufficient to prevent root ball disintegration during out-planting

Propagation Environment: Greenhouse 70 °F (21 °C) day, 55'F (13'C) night during winter, maximum summer temperature 85 °F (29 °C). A watering bench with minisprinklers automatically waters plug trays once a day in early morning. The watering bench is covered with a copper-coated fabric (Texel Tex-R® Forestry fabric) to reduce root egress from the plug cells; this fabric covers a filter fabric (Dewitt soil separator fabric) which acts to pull excess water out of plug cells via capillary water movement.

Plug Tray Seeding: Dry or pretreated seed (for example, wet tumbled, dry tumbled, acid scarified, or hydrogen peroxide soaked) are sown in plug flats with square deep cells (288 or 512 cells per flat). Media is a commercial soilless mix (Sunshine #1); plug trays are loosely filled with dry to slightly moist media, leveled off, and then lightly compressed with an empty plug tray. The number of seed sown depends on size and estimated germination. Small or fluffy seed are dispersed as evenly as possible. Larger and more easily handled seed are sown with a goal of 2 to 5 seed per cell. Very small seed is not covered if its size will allow the seed to be washed into the media with overhead sprinkling. Larger seed with a possible light requirement are lightly covered with perlite. Fluffy seed receive a light covering of media enough to provide contact between seed and the moist plug media. Larger seed is covered with 2 to 5 mm of media.

Cold Stratification: Those species which require cold stratification are typically sown in plug trays as described above and placed on the watering bench for several days to ensure that the media is thoroughly moist and seed are imbibed. The seeded plug flats are covered with an inverted empty plug flat to allow the 4 to 5 seeded flats to be stacked with the inverted flats acting as spacers. These stacked flats are placed in clean or disinfected polyethylene bags (in other words, re-used soil-less media bags) and are sealed with twistties; these bags contain perforations punched by the media manufacturer that allow some air exchange. These bagged plug tray stacks are placed in a walk-in cooler held at 40 °F (4 °C) and periodically checked for signs of germination or the necessity for adding moisture. When germination has started or when a sufficient stratification period has passed, the plug flats are moved to the greenhouse and placed on the watering bench.

Intermediate Container Type and Volume: Ray Leach Super Cell - 10 in.^{3} (164 ml) volume, 1.5 in. (3.8 cm) diameter, and 8.25 in. (21 cm) depth.

Growing Media: Mix of 2 parts Sunshine #1 or #2 with 1 part perlite. six lb (2.7 kg) of controlled release fertilizer (CRF) Osmocote Plus 15-9-12 incorporated per cubic yard (765 1) of mix. For plants started in the greenhouse during winter, 8 to 9 month release CRF is used, but for spring grown material, 3 to 4 month release CRF is used.

Production Time in Intermediate Container: The time required to produce a seedling ready for transplanting into a one gallon tree pot is very dependent on species and the time of year in the greenhouse. Fast growing species like most riparian species can be ready in 3 to 4 months from germination. Slow growing species can take over a year.

Planting Technique: The filled Super Cells are dibbled to provide a hole for the plug seedling. The plug seedling root ball is removed using a flat powder spatula with a blade about 6 mm wide and 30 mm long attached to a handle. The blade is plunged along the side of root ball and the seedling plug is levered out of the cell. The plug is dropped into the dibbled hole and the media is pressed around the root ball with fingers. Top watering firms and fills any voids around the plug. If excessive numbers of seed have germinated, excess seedlings can be cut off during the plug transplanting process or later after the seedlings are well rooted.

Establishment Phase: The Super Cell seedlings in the greenhouse are watered with soluble fertilizer at every other watering. The fertilizer solution is Peters Peat Lite Special 20-10-20 at a rate of 200 mg/l nitrogen. Thinning of seedlings down to one per container can occur during this phase, usually when the seedlings are 2 to 4 cm tall. **Rapid Growth Phase:** Fertigation continues as described above.

Hardening Phase: The goal is to have the Super Cell seedlings ready to move outside in early May after the last freeze but before excessively hot outdoor temperatures. In the outdoor nursery, larger seedlings may require watering every day, smaller seedlings generally every other day. The seedlings are fertigated about once a week with Peters Peat Lite Special 20-10-20 at a rate of 200 mg/l nitrogen.

Final Container Type and Volume: One gallon treepot, 4"x4"x14" (10 cm x 10 cm x 36 cm), 173 in^3 (2.83 l) volume.

Growing Media: Commercial nursery canning mix of aged screened softwood bark, pumice, and sphagnum peat moss.

Total Time in Final Container: The fastest growing species, like most riparian species, can be ready in one year after transplanting, if transplanting occurs in May. The slowest growing species can take 3 or more years.

Planting Technique: The treepots are filled with media and dibbled with a Super Cell planting dibble. Controlled release fertilizer (CRF) is top-dressed at planting or soon thereafter. Osmocote Plus and Sierra CRF have been used. For pots transplanted in late spring, a 5 to 6 month delivery CRF is used. Seedlings transplanted later in the summer receive a 3 to 4 month delivery CRF. The treepots are supported in cages 36 in. x 36 in. x 8 in. tall (91 cm x 91 cm x 20 cm) constructed of 4 in. x 4 in (10 cm x 10 cm) wire mesh fencing; each cage holds 81 pots.

Establishment Phase: Watering frequency in this phase in usually three times a week for riparian species. Plants are typically grown without shade.

Rapid Growth Phase: Watering frequency can be as often as every day for very large riparian plants with substantial leaf areas.

Hardening Phase: The watering frequency is reduced in late September to early October to promote hardening-off. The treepot cages are surrounded by straw bales before winter to lessen temperature fluctuations and provide some insulation for the root systems.

Tallpot Production Methods

The Los Lunas Plant Materials Center has developed a specific pot configuration that helps solve some difficulties found with earlier tallpot designs such as weight, pot materials expense, and plant removal and planting. The pots are constructed of 4 in. (10 cm) diameter PVC thin walled sewer pipe. The 30 in. (76 cm) sections (1/4 of the standard 120 in. pipe length) are split lengthwise on opposite sides for about 27 in. (69 cm) with the top of the pipe remaining intact to maintain the pot as one piece. Nesting one side of the split pot into the other side tapers the pot; this taper is maintained with 3 or 4 wraps of 0.5 in. (1.3 cm) filament tape along the length of the pot. The split sides and taper make it easier to remove the root ball and the splits provide 2 slots that help to prevent root spiraling and provide increased aeration. The bottom of the split wrapped pipe is covered with a 6 in. x 6 in. (15 cm x 15 cm) piece of needlepunched non-woven copper-coated fabric (Texel Tex-R® Forestry fabric) and attached with a cross of filament tape and an additional circumferential wrap. The copper hydroxide coating is oriented toward the inside of the pot to limit root egress. Capillary connection is maintained between the fabric pot bottom and the ground cover fabric in order to prevent a perched saturated zone in the bottom of the tallpot.

A standard nursery mix (composted pine bark, pumice, and peat) is used to plant containerized seedlings. One-gallon tree pots have been transplanted into the tallpots; some of the root mass has to be removed from the corners of the root ball to allow placement and back-filling. Smaller containerized stock is also used for potting up: Super Cells (10 in^3, 164 ml), Deepots D16 (16 in3, 262 ml), Deepots D40 (40 in3, 656 ml), and treebands (3 in. x 3 in. x 9 in.). Controlled release fertilizer (3 to 4 month delivery) at rate of 15 to 20 g is generally top-dressed after transplanting. The initial method of supporting the pots involved stands constructed from 4 in. x 4 in. wire mesh 36 in. wide (10 cm x 10 cm mesh 91 cm wide) sandwiched horizontally between straw bales. Groups of tallpots are enclosed by straw bales to moderate pot temperature during summer and winter. The short life of the bales resulting from decomposition has prompted a new strategy for maintaining tallpots. The latest method involves a 32 in. (81 cm) high enclosure constructed of 6 in. (15 cm) tongue and groove concrete block ("speed-block") with 12 in tall 4 in. x 4 in. (30 cm tall 10 cm x 10 cm) wire mesh cages inside the enclosure to support the individual tallpots. The blocks are filled with sandy soil and the outside is lined with straw bales for insulation. Species with fast growth rates can be ready for outplanting one year after transplanting from one gallon tree pots into tall pots and can be ready in two years after transplanting from smaller containers.

PLANTING PROCEDURES FOR DIVERSE STOCK TYPES OF RIPARIAN SPECIES

Planting of Dormant Pole Cuttings and Whips

Various types of equipment have been employed for drilling holes for pole plantings ranging from hand-operated bucket augers with 8 ft (2.4 m) handles to large truck mounted augers typically used for power pole installation. The LLPMC has been using one type of auger for 8 years. A fourwheel drive farm tractor outfitted with a front-end loader has been adapted by replacing the loader bucket with a hydraulically powered auger head and an 8 ft (2.4 m) long 9 in. (23 cm) diameter bit with full flighting. The principal circumstance where this drilling approach has been unsuccessful is in dry sands or in cobbly alluvium where the hole frequently collapses. Trial and error probing of riparian zones will usually provide locations where the alluvial conditions allow full depth holes to be completed into the water table. When back-filling holes after pole placement, a tree guard 5 ft (1.5 m) tall and 18 in. (46 cm) in diameter constructed from poultry wire is inserted partially into the hole to anchor the tree guard. A team of 4 people (one equipment operator; two people planting poles, back-filling, and installing guards; and, one person supplying poles and guards) can install 35 poles per hour.

The tool used for planting coyote willow *(Salix exigua* Nutt.) whips is an electric spline drive rotary hammer that can accommodate a 1 in. (2.5 cm) diameter 36 in. (91 cm) long carbide-tipped bit. Coyote willow is planted where ground water is shallow so this tool provides a hole into the ground water or into the capillary fringe. The rotary hammers are especially useful when frozen soils are encountered which happens often during the late winter/early spring planting period. A portable generator is required capable of starting and running the 9 amp rotary hammer motor. A team of 4 people (2 drilling and 2 planting) can install 200 whips per hour.

If proper alluvial conditions are encountered, appropriate planting procedures are followed, and after-planting care is used, success rates around 90% at 5 years after planting can be achieved. Coarse alluvium with low salinity capable of supporting a hole into the water table is required to maximize success. If extreme fluctuations in ground water level are expected, the pole needs to be planted below the water table to ensure that the capillary fringe will surround the butt end of the pole during periods of maximum ground water depth. Planting requirements include a dormant vigorous large diameter cutting of sufficient length to extend into the water table and leave a substantial aboveground stem (at least 5 ft (1.5 m)). The cuttings should be kept well hydrated during storage and transport. Aftercare including tree guards (poultry wire cylinders) to protect from beavers and control of defoliating insects (for example, cottonwood leaf beetle *(Chrysomela scrippta))* will improve establishment success if these pests are present in significant numbers. Exclosures to prevent domestic livestock and elk browsing of pole plantings are also required in situations where browsing pressure is substantial.

Planting Willows and Cottonwoods in One-Gallon Treepots in Montane Riparian Areas

The treepot stock type is conducive to planting with hand tools such as shovels or post hole diggers. Smaller, powered equipment such as back pack or wagon mounted augers are also effective. The most appropriate tool depends on a number of factors including the number of units to plant, access to the planting site and the planting site itself. Outplanting success is highly dependent on several site factors. First, as is the case with most riparian plantings, the root system must be planted well into the capillary fringe zone in order for adequate new root growth and establishment to occur. We have found that coordinating planting with spring snow-melt often achieves the best results. A second site factor is providing protection following planting. Domestic livestock and/or elk and deer have damaged many trial plantings. Fencing or another form of protection is essential to ensure planting success. Finally, following the same guidelines associated with planting smaller forestation stock (in other words minimizing the amount of root pruning; not leaving an exposed root ball on the surface, etc.) will contribute to better survival rates.

Planting Methods for 30 inch Tallpots

The auger used for pole planting (8 ft (2.4 m) long, 9 in. (23 cm) diameter bit) is also used for 30 in. (76 cm) tallpot installation. As with pole planting, the hole is drilled to the water table, but loose soil is removed only from the top 30 in. (0.8m). This full depth hole penetrates any hardpan or other alluvial layers that might restrict root penetration into the capillary fringe. Most riparian woody species form well consolidated root balls if sufficient production time is available. The root ball can be slid out of the pot after the tape and fabric bottom are removed. If the plant has an immature root system, the tape wraps and fabric bottom can be removed, and then the plant in the pot is placed in the planting hole. The pipe can be slowly lifted from the root ball while simultaneously back-filling the hole to prevent the disintegration of the root mass. If the plant canopy is too large to fit through the top of the not. the slots can be extended so that the Dot is split into two sections. Tree guards can be installed when back-filling if beaver or rabbit damage is expected. A team of 4 people can install 10 to 15 plants per hour.

In upland situations or where ground water is very deep, supplemental water may be required to enable establishment. The LLPMC has been testing the use of watering tubes to provide deep pipe irrigation. This approach has proven to be a highly successful irrigation method in desert environments (Bainbridge and others 2001). One watering tube design uses a 3 in. (7.6 cm) PVC sewer pipe cut into lengths of 30 in. (76 cm) and 10 in. (25 cm). The bottom half of the 30 in. (76 cm) section has transverse slot perforations cut in opposite sides of the pipe. The 10 in. (25 cm) section is joined to the 30 in. (76 cm) section with a coupler that is held by friction (not cemented). This configuration allows the top portion of the pipe above ground to be removed when the watering tube is no longer needed. The buried bottom section is left in place to prevent root disturbance and is back-filled with soil. When in use, the watering tube is capped to prevent evaporation and animal entry. This design is costly in terms of materials and labor for fabrication. Another more cost-effective design was developed making use of heavy weight plastic seedling protection tubes (Protex Pro/Gro Tubes) 24 in. (61 cm) in length. Bottomless one gallon treepots are inserted (friction fit) in each end of the tube to extend its length and provide additional rigidity to prevent tube collapse during back filling. The bottom treepot ends up in an inverted position when installed. An inverted 3.5" square pot is inserted inside the top treepot to serve as a cap.

The 9 in. (23 cm) diameter hole provides sufficient space for the tallpot root mass as well as the watering tube for deep pipe irrigation. At the time of planting, water is applied to the soil surface to aid in filling backfill voids as well as providing near surface moisture. The watering tubes are filled with water at planting to charge deep soil moisture. Trials with starch-based water absorbent polymers have been conducted to determine whether the slow release of water in the tubes is superior to water alone. It is anticipated that one or two water applications per year for a few years using deep pipe irrigation may be sufficient to provide high rates of establishment depending on precipitation timing and amounts.

RIPARIAN RESTORATION IN THE MIDDLE RIO GRANDE VALLEY

As described in the introduction, the riparian zone in the Middle Rio Grande Valley suffers many assaults on its biological integrity. Flood control structures and flow management regimes have prevented natural flooding necessary for cottonwood and willow regeneration. These activities have also resulted in the buildup of salts in the former floodplain. Exotic woody species have invaded vast stretches of the floodplain which were cottonwood forests historically. These exotics have also magnified the potential of severe wildland fires near urban corridors because of the massive fuel loads produced by these noxious invaders.

Some of the most successful projects in removing one of the primary exotics, saltcedar, have been conducted at the Bosque del Apache National Wildlife Refuge. Mechanical removal uses a three step process of aerial stem removal, root plowing, and root raking at a total cost of about $1,500/ha (McDaniel and Taylor 1999). The second control approach involves aerial application of herbicide (imazapyr plus glyphosate) followed by prescribed burning of dead standing saltcedar at a total cost of about $300/ha (McDaniel and Taylor 1999).

Bosque del Apache National Wildlife Refuge used pole plantings of Rio Grande cottonwood and Goodding's willow in their early restoration efforts following saltcedar control (Taylor and McDaniel 1998b). Later investigation proved that natural recruitment was possible subsequent to over-bank flooding during peak river flows in late May and early June; regeneration was greatest in sand deposits resulting from secondary channel development (Taylor and others 1999). Large areas of historic floodplain at the Refuge were later restored using controlled flooding of land cleared of saltcedar; careful management of declining water levels in impoundments after flooding allowed establishment of a predominance of cottonwoods and willows and little saltcedar.

Other approaches to simulate natural regeneration have examined the use of micro-irrigation on historic floodplain sites that no longer experience natural flooding (Dreesen and others 1999). Maintenance of high surface soil moisture during seed dissemination, germination, and early growth stages of Rio Grande cottonwood has resulted in successful establishment. Micro-irrigation frequency is decreased and water depth application is increased gradually for several years until roots access the capillary fringe above the natural water table and the riparian vegetation is self-sufficient.

Planting along the Santa Fe River near Cochiti Pueblo

A section of the Santa Fe River within Cochiti Pueblo land is a perennial stream fed by springs and possibly seepage from Cochiti Lake. This riparian zone had been severely degraded by cattle grazing for decades prior to 1994. The Pueblo constructed fenced exclosures at 3 sites along the stream in 1993. The LLPMC installed 1250 Rio Grande cottonwood, lanceleaf cottonwood *(P opulus x acuminata* Rydb. (pro sp.) *[angustifolia x deltoides])*, and Goodding's willow poles in February 1994. At the three sites, the capillary fringe was encountered in all augered holes, but ground water was not encountered in any holes at the maximum auger depth of 8 ft (2.4 m). During the first growing season, the plantings suffered severe defoliation from a cottonwood leaf beetle infestation that affected long term survival. After 4 growing seasons, the survival of Rio Grande cottonwood accessions ranged from 42% to 85% and Goodding's willow ranged from 60% to 76% (Los Lunas Plant Materials Center 1997). Poles planted close to the stream have annual height growth of about 6 ft (1.8 m). After 4 growing seasons, these trees had heights approaching 30 ft (9 m) and calipers exceeding 10 in. (25 cm). The poles planted farthest from the stream have survived but put on little growth.

Riparian Mitigation on the Corrales Reach of the Rio Grande

Riparian restoration studies were conducted on the Rio Grande north of Albuquerque as part of a Army Corps of Engineers project mitigating disturbance of riparian vegetation resulting from the rebuilding of 10 miles of levees. The Los Lunas Plant Materials Center installed approximately 18,000 pole and whip cuttings in 1997 and 1998. Cottonwood survival averaged 85% after the first growing season when data from all accessions were pooled. On those sites with a shallow water table (3 to 5 feet, 0.9 m to 1.5 m) and soils with sufficient cohesion to allow holes to be drilled to ground water, cottonwood survival was 98% after one year and 92% to 95%

after two years (Los Lunas Plant Materials Center 1998). On those sites with dry gravelly sands, the holes collapsed preventing the pole from being placed into ground water; cottonwood survival ranged from 65% to 79% after one year. Goodding's willow survival was 87% on good sites after two growing seasons. On poor sites, survival ranged from 48% to 72% at the end of the first growing season.

The average survival of poles of New Mexico olive, desert false indigo, and seepwillow were 70%, 60% and 52%, respectively, after 2 years. Survival ranged from 30% to 84% on the various sites when data for these 3 species are pooled. This variability probably resulted from differing soil conditions among sites as well as inconsistent pole hydration periods for different lots of poles. Coyote willow planted using rotary hammers at one site had survival percentages of 99% after 2 years. Because the coyote willows were densely planted (about one foot apart), the whips were not protected from beaver at one site, with the result of total decapitation of over 5000 willow whips. Subsequently, these willows vigorously resprouted, probably as result of carbohydrate reserves stored in the 3 ft (0.9 m) stem section planted below ground. New Mexico olives in one gallon treepots were planted at site with a water table depth of 4 to 5 feet (1.2 to 1.5 m) in October 1996 and 1998. A portion of the plants was planted under the canopy of the cottonwood gallery forest. The transplants were surface watered several times during the initial fall and again the next year. Survival after 2 years under the cottonwood canopy was 85% (Los Lunas Plant Materials Center 1998).

RIPARIAN RESTORATION WITHIN THE SOUTHWEST REGION'S NATIONAL FORESTS

Gila River Bird Area Stream Bank Stabilization Project

The Silver City Ranger District on the Gila National Forest initiated a project in 1991 to stabilize stream banks on the Gila River which had experienced severe erosion during high peak flows because woody vegetation had been removed so the floodplain could be farmed. Over one and half miles of streambanks were stabilized. The slope of the cut bank was reduced to less than 45 degrees. A temporary berm was constructed between the active channel and the cut bank and alluvial material was removed to reduce the depth to the water table. Over 10,000 poles (primarily Fremont cottonwood *(Populus fremontii S.* Wats) and Goodding's willow) were planted. In addition, one half mile of abandoned irrigation ditches were re-hydrated and planted with approximately 2,300 boxelder *(Acer negundo L.)*. The emphasis on boxelder results from this species being the preferred nesting tree in this area for the endangered southwestern willow flycatcher. The positive results of this restoration project have been the renewal of a degraded streambank riparian forest, the stabilization of streambanks, and the movement of wildlife back into this riparian area, including the southwestern willow flycatcher.

Riparian Restoration Experience on the Apache-Sitgreaves National Forests

Livestock Management and Exclosure Fencing

Riparian restoration has been emphasized for the last 12 years on the Apache-Sitgreaves National Forests of Arizona. Primarily, riparian improvement has been accomplished through improved livestock grazing plans. These plans include exclusion of use in sensitive areas, while other areas are monitored closely and stock is rotated out as soon as utilization levels are achieved. Due to a high degree of elk utilization early in spring, livestock may not be allowed onto certain areas at all during some years. Plantings of riparian species have been successful only in areas that are fenced to exclude all large ungulates including elk. Numerous elk exclosure fences have been installed on the Forest both in riparian areas and in areas targeting aspen reproduction. Most of these fences consist of 8 ft (2.4 m) tall hogwire (two 4 ft (1.2 m) sections) attached to 12 ft (3.6 m) T-posts, but some electric fence has been used to keep elk out during the growing season. Damage to fencing by animals is inevitable and continual maintenance is necessary to keep it intact. Electric fencing is effective, but has led to entanglement and death of a few elk trying to jump the fence. Much of the electric fencing is being replaced with hogwire or woven wire fencing. Hogwire fenced areas have also been jumped, usually from the tops of hardened snowdrifts, resulting in these elk being held inside the exclosure until a gate can be opened and the animals herded out.

Objectives of Riparian Plantings

Several objectives have been considered with plantings of riparian species on the Apache--Sitgreaves National Forest. The primary objective has been to restore woody species to riparian areas that for one reason or another have lost them. Such plantings can never restore the full diversity or number of plants present originally, but they can restore a self-sustaining island of plants that provide a seed source, which hopefully will help colonize adjacent areas within the drainage. In places, plantings of riparian woody species can be used in conjunction with bioengineering techniques to help stabilize stream banks. These areas are normally very limited in size and do not entail whole stream reaches. Another common use for riparian woody species is in limited areas that may require riparian plants more from an aesthetic need rather than driven by ecological function. Woody riparian species often provide ample shade and are closely tied to numerous recreational values associated with riparian areas. Lastly, outplantings of artificially propagated plants that are either rare or threatened or endangered species may help sustain such species until they can again become self sufficient and reproduce on their own. In the past, limited attempts to reproduce Arizona willow *(Salix ariionica* Dorn) on the Forest have had very modest successes, but part of the reason for failures may have been tied to planting into unsuitable ecological settings. Thorough knowledge of ecological requirements is needed to replenish threatened and endangered species, but such critical information is usually lacking or, at best, scanty.

Planting Techniques

Depending on the application or purpose of various plantings, different techniques have been used with varying success. Riparian plantings have been successfully combined with bioengineering techniques to stabilize eroding stream banks. In one case, long willow cuttings *(S. monticola, Salix geyeriana* Anderss., and *Salix irrorata)* were incorporated into log cribs to help tie loose soils together and also prevent elk from pulling the cuttings out of the cribbing. This planting technique worked fairly well and resulted in dense clusters of willows growing out of the front side of nearly vertical crib walls. Elk browsing did occur, but did not significantly damage the structure. Willow fascines have also been tried along creek side, but a combination of factors reduced their effectiveness. Quite often, volunteer groups who enjoy cooler weather in Arizona's higher elevations, especially during summer, do such work. This season unfortunately does not coincide with the best time to transplant cuttings, as they are not dormant and are often in full leaf or in flower. This significantly contributes to a lower success rate.

Massive plantings of willow cuttings have been successfully installed in late fall. In order to help stabilize a stream bank with a small adjacent floodplain, a massive number of dormant cuttings were planted nearly horizontally at creek side. A small bulldozer was used to cut a gently sloping shelf into a raw bank at creek side. The shelf was slightly higher at creek side than against the bank by about 1 to 2 ft (0.3 to 0.6 m). The long cuttings were then laid out onto the shelf at a rate of about 10 per lineal foot (33 per m), allowing about the top 2 to 3 ft (0.6 to 0.9 m) to protrude beyond the shelf out over the creek. The remaining 4 to 6 ft (1.2 to 1.8 m) of the cuttings were then buried by the bulldozer while simultaneously cutting the bank down to a manageable slope. This approach allowed the branch tips to be exposed, while the long buried sections could grow roots. The sloping shelf also allowed the cuttings to be installed so that the butt ends were lower than the tips. The elevation of the shelf was within the capillary fringe of the sandy-loam soils, which kept the cuttings moist but not wet. The active channel of this small stream was vegetated with sedges and rushes, pointing to saturated soil conditions, which willows cannot tolerate. Planting only in the capillary zone avoids excessive moisture and anaerobic soil conditions. This planting technique restored a long section of stream bank with relatively little hand labor, and resulted in nearly 100% survival and establishment of cuttings. The project was put to the test the following spring when an unusually high flow passed through the area during snowmelt. It survived with minimal damage.

Similar near-horizontal willow plantings have been successfully installed in a number of locations on the Forest in the fall. One area entailed planting a fill slope below a parking lot in a busy recreation area near a lake. The cuttings were inserted into small shelves opened in the slope with a backhoe, then back-filled and compacted. The cuttings survived over-wintering well and grew into healthy shrubs, which stabilized the fill slope, provided screening of the parking lot from view, and discouraged visitors from descending the slope instead of using the stairway.

Live staking has been successfully implemented in several areas both in spring and fall using narrowleaf cottonwood. Stakes were made from large stems about 2 in. (5 cm) diameter and 1 to 1.5 ft (0.3 to 0.5 m) long, cut at an angle on the bottom and straight on the top. These were driven into soft soils along stream banks with hand sledges and left to sprout. Success rates varied by area, some survived nearly 100%, others about 10%. Lower success rates were usually associated with areas that dried out excessively during summer. Narrowleaf cottonwood has also been successfully established from 4 to 5 ft (1.2 to 1.5 m) long poles. These were planted with all their branches intact in 2 to 3 ft (0.6 to 0.9 m) deep auger holes during spring while buds were still dormant. Other areas were planted with 6 to 8 ft (1.8 to 2.4 m) long dormant poles planted into a long trenches excavated with a backhoe. These trees survived relatively well provided they remained moist. Ephemeral washes can be challenging to plant. Wet years may induce planting too high on the banks to keep them out of saturated soils, while dry years may result in planting them within the active channel which then scours out the plantings. Several years of plantings may be required to establish a desired quantity of plants in such an area.

Riparian Soil Considerations

It cannot be emphasized enough that various riparian species require specific soil conditions and will not survive if planted into unsuitable conditions. As mentioned earlier in this paper, most soil limitations are intimately associated with aeration. Fine-grained sediments only provide limited aeration, but will draw capillary moisture to higher elevations above the water table. This allows some leeway in selecting planting sites for woody species requiring aerated soils by planting further away from active channels or perhaps higher up on the banks. Too often we see wellmeaning volunteers planting willow or cottonwood cuttings into streambanks of saturated wet meadows, where success rates for woody species are near zero. The challenge in coarser grained soils is to plant in areas that maintain moisture but are not saturated. However, soils made of coarse alluvial sands and gravels only provide a very narrow band of capillary moisture, which risks either drought conditions or saturation with a small change in water table elevation. Saturated soils lack sufficient aeration and quickly turn anaerobic. Generally, anaerobic conditions are more often encountered in finergrained soils. Coarse-grained soils maintain aeration through higher permeability rates that allows better gas exchange, and ground water also tends to mix with aerated surface waters to maintain a limited level of oxygenation.

SUMMARY

Site assessment examining such factors as water table depth and fluctuation, soil texture, soil salinity, and browsing pressure from livestock and wildlife is a prerequisite to successful riparian restoration. These factors, along with elevation and ecoregion considerations, will aid in the selection of appropriate restoration species. A number of plant material stock types and planting techniques are available to land managers challenged with restoring riparian areas in the Southwest. Stock types such as pole cuttings and tallpots offer opportunities to accomplish cost-effective establishment in demanding low elevation riparian environments. Larger containerized materials and unconventional methods of outplanting cuttings offer the potential for increased restoration success in montane environments.

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