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Life History, Ecology and Conservation of Riparian Cottonwoods in North America

by

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Introduction

The life history and ecology of plants are closely related to the natural dynamics of their environment. In the case of poplars, the life history and ecology of riparian cottonwoods are interrelated with the patterns and processes of riverine systems. In this chapter, we describe some of the key features of riverine environments and the life history of riparian cottonwoods from seed dispersal and germination through maturity and senescence. Our intent is to reveal the fundamental ecological relationships between riparian cottonwoods and the alluvial floodplains they inhabit. On the basis of these relationships, we propose some approaches to the conservation and restoration of riparian cottonwoods.

The riparian cottonwoods of North America include: *P. angustifolia, P. balsamifera and P. trichocarpa* from the *Tacamahaca* section; and *P. deltoides,* and *P. fremontii* from the *Aigeiros* section. These dioecious species are widely distributed throughout North America (See Eckenwalder in Chap. 1). In general, members of the *Tacamahaca* section are found at higher elevations and latitudes (*i.e.*, high gradient riverine systems of montane and young piedmont valley floodplains), whereas members of the *Aigeiros* section are primarily limited to lower elevations and latitudes (*i.e.*, lower gradient riverine systems of mature piedmont valley floodplains). Contact zones between species, particularly between members of different sections, occur at critical ecotones (See Whitham in Chap. 11) where contact gives rise to a broad range of natural hybrid complexes (See Eckenwalder in Chap. 1).

Environmental Characteristics of Riverine Systems

The river systems and alluvial floodplains inhabited by riparian cottonwoods are the product of a complex array of interrelated fluvial geomorphic processes (Leopold 1994, Leopold *et al.* 1964). Given the complexity of fluvial processes, this chapter can present only a brief description of the hydrogeomorphic features of riverine systems. A more in-depth treatment and summary of fluvial geomophology can be found in Leopold *et al.* (1964), Dunne and Leopold (1978), Leopold (1994) and Rosgen (1994).

The physical appearance and character of a river and its floodplain are a product of the continual modification of the river channel by streamflow and sediment regime (Leopold 1994, Rosgen 1994). Local and regional differences in fluvial geomorphology result in a broad range of river types (i.e. meandering to braided channels) with variable width, depth and rates of lateral migration (Rosgen 1994). As shown in a generalized view (Fig. 1), river channels meander within the alluvial floodplain. These meanders reflect a balance between erosional and depositional processes within the river channel. Erosion of the concave bank is balanced by deposition on the adjacent convex bank (Fig. 1). As the concave bank recedes due to erosion, the point bar builds outward from the convex bank into the channel (Fig. 1). As a result, the form of the channel remains, but its position changes. Floodplains are typically built and continually modified by this process of point-bar extension (Leopold 1994).

Although portions of the floodplain may be far removed from active channel processes, they remain hydrologically linked to the main channel by the alluvial water table. The floodplain is directly linked with main channel processes (erosion and accretion of sediments) primarily during flooding events (flows exceeding bankfull stage, Fig. 1). Historical patterns of channel movement and processes of floodplain formation are readily apparent in aerial photos of extant floodplains and riparian forests (Figs. 2 and 8).

Most erosional and depositional events that affect channel morphology occur in high flow periods, typically during spring snowmelt and periodic stormflows. Such flows are characterized as either bankfull stage (Fig. 1), which occurs approximately every other year (1.5-2 yr intervals), or the less frequent overbank flooding events (5-10+ yr intervals; Leopold 1994, Rosgen 1994). After high flow events, water levels decline, exposing bare mineral soils within the alluvial floodplain, commonly along point and gravel bars (See Fig. 1). These barren, yet moist, alluvial soils are critical microsites for colonization by cottonwoods via wind- and water-dispersed seed (See Figs. 1 and 6). These microsites are also vulnerable to subsequent scouring and depositional processes during flooding.

Regional variation in climatic patterns modifies fluvial geomorphic processes. For example, many arid and semi-arid regions of the western U.S. are dominated by higher levels of precipitation in winter relative to summer months, while humid regions of the Midwest have a more uniform distribution of precipitation throughout the year. Major mountain systems, such as the Cascades and the Rocky Mountains, further modify these regional precipitation patterns. This climatic variation affects many of the fluvial processes that control river channel morphology (Leopold *et al.* 1964, Dunne and Leopold 1978, Leopold 1994). For example, sporadic heavy rains are more prevalent in arid regions. Such sporadic, yet intense storms accelerate terrace erosion (i.e. channel widening) and/or valley evacuation (i.e. channel downcutting) (Huckleberry 1994). In humid regions, small, light rainstorms are more prevalent and promote valley deposition (i.e. alluviation). In the arid Southwest, geologic evidence shows that the relative dominance of these geomorphic processes shifted as periods dominated by arid conditions (1880-1920) evolved towards more humid climatic conditions (1950-1980) (Leopold 1994).

Climate and watershed position strongly influence alluvial water table characteristics. As shown in Figure 3, alluvial water tables occur at shallower depths under humid than arid conditions. Water table characteristics also differ within a watershed, as valley and channel slope vary from steep, narrow floodplains at high elevations (*i.e.,* high riverine gradients of montane floodplains) to relatively flat and wide alluvial floodplains at low elevations (*i.e.,* lower riverine gradients of mature piedmont valley floodplains). In steep gradient reaches, water tables may fluctuate rapidly, whereas water levels remain more constant in broad, flat floodplains. Large, alluvial floodplains are also closely-linked with regional aquifers that tend to moderate water table fluctuations (Leopold 1994, Leopold *et al.* 1964). As a result of these linkages, larger floodplains are relatively complex hydrogeomorphic systems in which interactions between fluvial processes and alluvial groundwater systems (*i.e.,* hyporheic zones) may have profound effects upon riparian cottonwood forests (Stanford and Ward 1993); they warrant further investigation.

The environmental features of riverine systems provide a variable water supply and periodic, yet repeated, disturbances to which riparian cottonwoods have adapted. But there is variability in fluvial processes from year to year, and it has significant effects on the long-term health and vigor of riparian cottonwood forests.

Life History and Ecological Properties of Riparian Cottonwoods

Comprehensive life history and demographic studies of riparian cottonwoods are limited, yet general patterns emerge that link the nature and timing of fluvial processes with the expression of life history traits in these species (Rood and Mahoney 1990; Johnson 1992, 1994; Stromberg 1993, Stromberg *et al.* 1991, 1993, 1996a; Scott *et al.* 1996). Key life history and ecological properties of riparian cottonwoods are summarized in Tables 1 and 2, while relationships between the expression of these traits and stream discharge are shown in Figure 4.

Sexual reproduction and establishment

Being dioecious, cottonwood trees are either male or female. In both sexes, the flowers are clustered in catkins, which tend to be borne in the upper tree crown. Male and female catkins are readily distinguished from one another, as male catkins are typically smaller and reddish-purple, whereas female flowers and catkins are significantly larger and greenish in appearance. Males commonly initiate flowering before females and both sexes flower approximately 1-2 wk prior to leaf initiation in the early spring (March-April). Flowering and pollination thus coincide with springtime peaks in riverine flow (Fig. 4), though significant variation in the timing and duration of flowering exists within and between species (Table 2). In part, phenological variation within and between species reflects environmental differences between plants growing at different elevations and latitudes (Dunlap 1991, Farmer 1993). Under the cool, short-growing season of high latitudes and elevations, flowering may not begin until late May, while at lower elevations and latitudes flowering will have ceased in most populations by mid-April. In the arid Southwest, flowering by *P. fremontii* is over by late February to early March (Reichenbacher 1984, Asplund and Gooch 1988, Stromberg *et al.* 1991). Significant phenological variation in flowering period has also been reported within populations (Dunlap 1991, Farmer 1993), occasionally spanning a range of more than two months. Such intrapopulation variance in flowering appears greater in *P. deltoides* than in other species (Farmer 1966; Brian Stanton, pers. comm.). Additional studies are needed to clarify genetic-environmental interactions controlling the timing of flowering and pollination (See Stanton and Villar in Chap. 5).

Wind-dispersed pollen fertilizes the ovule within 24 hr of landing upon the receptive stigma (See Stettler, Zsuffa and Wu in Chap. 4 and Stanton and Villar in Chap. 5). The process of ovule ripening and seed maturation is temperature-dependent, with seed formation and dispersal occurring within 3 to 6 wk following fertilization (Fig. 4, Tables 1 and 2; See also Stettler *et al.* in Chap. 4). Upon maturation, cottonwood seeds are extremely small, weighing approximately 0.3 to 0.6 mg per seed (Schreiner 1974, Hardin 1984, Zasada and Phipps 1990), and contain little or no endosperm. Females produce a large and dependable crop of seed, more or less annually. Estimates of annual seed production by large, mature individuals of *P. deltoides* have been reported to exceed twenty-five million seeds per tree (Bessey 1904, Schreiner 1974). Yet age- and size-specific studies of seed production have been limited (Hardin 1984) and merit further investigation.

Cottonwood seeds, borne by numerous fluffy, cotton-like hairs, are dispersed long distances by wind and water. Although no studies have specifically documented dispersal distance, general observations suggest that most of the seed is deposited within a few hundred meters of the mother plant. The potential for long-range disperal (several km or more) via convective wind currents clearly exists. However, methodological constraints associated with the large, air-borne seed crop of these

Table 1. Life History Traits and Ecological Properties of *Populus angustifolia, P. balsamifera & P. trichocarpa* (*Tacamahaca* Section).

Life History Traits/Ecological Properties	Species Characteristics
Reproduction:	
Flowering time	Apr-May(*P. balsamifera*)[7]
	Mar-May (*P.trichocarpa*)[6]
Seed dispersal time	May-Jul(*P. balsamifera*)[7]
	May-Jun(*P.trichocarpa*)[6]
Seed weight	0.3mg(*P. balsamifera*)[7]
Dispersal agents/distance	Air&water/several km (All spp)
Asexual traits	Cladoptosis (*P.trichocarpa*)[6]
	Root suckering & crown breakage
Germination/Establishment:	
Seed viability (natural conditions)	1-2wk(*P. balsamifera*)[7]
	1-2wk(*P.trichocarpa*)[6]
Seed germination	24 hr/moist,bare soil (All spp)
Seedling root growth rates	6-8mm/d(*P. balsamifera*)[1]
	4-12+mm/d(*P.trichocarpa*)[5,9]
Soil pH	6-8(*P. balsamifera*)[7]
	5-7(*P.trichocarpa*)[6]
Growth/Maturation:	
Age at reproductive maturity	8-10yr (*P. balsamifera*)[7]
	7-10yr (*P.trichocarpa*)[6]
Lifespan	100-200yr (*P. angustifolia*)[8]
	100-200yr (*P. balsamifera*)[1,7]
	100-200+yr (*P.trichocarpa*)[6]
Plant height at reprod. maturity	8-13.5m(*P. balsamifera*)[1]
	10-16.8m(*P.trichocarpa*)[6]
Plant dbh at reprod. maturity	8-11.7cm(*P. balsamifera*)[1]
	12-20cm(*P.trichocarpa*)[6]
Mature stand density (trees/ha)	38.3-91.5/ha(*P. angustifolia*)[2,3]
	88.9-120/ha(*P. balsamifera*)[1,3]
	110-294/ha(*P.trichocarpa*)[6]
Rooting depths of mature stands	3 to ≥ 5+m (All spp.)

Sources: 1 Peterson & Peterson (1992); 2 Szaro (1990); 3 Shaw (1991); 4 Lee *et al.* (1991); 5 Reed (1995); 6 DeBell (1990), Dewit and Reid (1992); 7 Zasada and Phipps (1990); 8 Baker (1990); 9 Mahoney and Rood (1991, 1992).

Table 2. Life History Traits and Ecological Properties of *Populus deltoides* & *Populus fremontii* (*Aigeiros* Section) in North America.

Life History Traits/Ecological Properties	Species Characteristics
Reproduction:	
Flowering time	Mar-Apr(*P. deltoides*)[8-10] Feb-Mar(*P. fremontii*)[6,12,13]
Seed dispersal time	May-Aug(*P. deltoides*)[8-10] Mar-Apr(*P. fremontii*)[6]
Seed weight	0.3-0.6mg(*P. deltoides*)[4,9,10]
Seeds/tree/yr	25+million(*P. deltoides*)[5,9,10]
Dispersal agents/distance	Air&water/several km(All spp)
Asexual traits	Limited to crown breakage & flood-related disturbance
Germination/Establishment:	
Seed viability (natural conditions)	1-2 wk (*P. deltoides*)[9,10] 1-3 wk (*P. fremontii*)[7]
Seed germination	24 hr/bare,moist soil (All spp)
Seedling root growth rates	4-6mm/d (*P. deltoides*)[16] 4-12mm/d (*P.fremontii*)[6,7,15]
Soil pH	5.5-8 (*P.deltoides var. delt.*)[9]
Soil salinity	0-1500mg/l (*P. fremontii*)[17]
Growth/Maturation:	
Age at reproductive maturity	5-10yr (*P.d.var.delt.*)[5,9] 10yr (*P.d.var. occ.*)[5,10] 5-10yr (*P. fremontii*)[6]
Lifespan	130+yr (*P. fremontii*)[3,19] 100-150+yr (*P.deltoides*)[9,10]
Plant height at reprod. maturity	10-15m(*P. deltoides*)[9,10]
Plant dbh at reprod. maturity	12-20cm(*P. deltoides*)[9,10]
Mature stand density (trees/ha)	192/ha(*P. deltoides*)[11] 50-400+/ha(*P. fremontii*)[1,6,19]
Rooting depths of mature stands	3 to ≥ 5+m (All spp.)[14,18]

Sources: 1 Strahan (1983); 2 Szaro (1990); 3 Shanfield (1983), Howe & Knoff (1990); 4 Bessey (1904); 5 Schreiner (1974); 6 Reichenbacher (1984); 7 Horton *et al.* (1960) & Fenner *et al.* (1984); 8 Farmer (1966); 9 Cooper (1990); 10 Van Haverbeke (1990); 11 Johnson *et al.* (1976); 12 Asplund & Gooch (1988); 13 Stromberg *et al.* (1991); 14 Jackson *et al.* (1987); 15 McBride *et al.* (1988); 16 Segelquist *et al.* (1993)and Stromberg *et al.* (1993, 1996a); 17 Jackson *et al.* (1990) & Shafroth *et al.* (1995); 18 Stromberg *et al.* (1996b); 19 Hunter *et al.* (1987) & Szaro (1989) species have prevented quantitative studies on the nature and timing of long-distance dispersal. The best evidence for effective dispersal (and associated gene flow) is the common lack of genetic differentiation among populations, with the bulk of genetic variation (e.g. in isozymes > 90%) being found within populations (See Farmer in Chap. 2).

Seed dispersal typically coincides with declining river flows following springtime snowmelt and stormflows (Fig. 4), thereby increasing the probability of seeds landing in favorable microsites along the river channel. In some instances, seed dispersal may persist well into the summer months. For example, seed dispersal has been observed in mid-July among populations of *P. deltoides* along the upper Missouri River (Johnson *et al.* 1976) and Central Platte River (Johnson 1994) and late-August in the lower Mississippi Valley (Farmer 1966, Brian Stanton, pers. comm.). This late shedding of seed by *P. deltoides* may reflect an adaptation to summer rainfall and periodic summer flooding on rivers within its natural range.

Seed viability is very short, generally lasting only 1-2 wk under natural conditions (Tables 1 and 2; , Horton *et al.* 1960, , Fenner *et al.* 1984, Cooper 1990, Debell 1990, VanHaverbeke 1990, Zasada and Phipps 1990). Once a seed becomes wet, viability will be lost in 2-3 days if a favorable microsite is not encountered. Low seed viability has also been reported in relation to high levels of air humidity. The short-term viability of seeds is clearly a limiting factor in the life cycle of cottonwoods, as germination must occur within a relatively short time period. In some cases, seeds may not be fully viable when dispersed from the mother plant (*P. fremontii,* Fenner *et al.* 1984). These seeds typically become viable within a few days following dispersal; however, the pattern and mechanism of post-dispersal seed viability requires additional study.

On appropriate microsites, germination is rapid. The root radicle emerges from the seed, enters the soil, and cotyledons begin to expand within 24 hr (Reed 1995). Young roots are noted for their development of "collet hairs" at the base of the hypocotyl (Moss 1938, Noble 1979). These hairs are anatomically distinct from root hairs and attach quickly to sand and silt particles to provide anchorage and absorption (Noble 1979, Johnson 1994).

In late spring and early summer, germinating seeds and seedlings are commonly found in large numbers along point bars as well as other moist, exposed substrates within alluvial floodplains (Figs. 5 & 6). Seedling densities have been reported to range from as few as 20 to more than 4000 per square meter (Strahan 1983, Mcbride and Strahan 1984, Lee *et al.* 1991, Johnson 1994, Reed 1995, Stromberg *et al.* 1991, 1993). Temporal and spatial variation in favorable microsites appears to be the primary determinant of seedling recruitment (See mortality zones in Fig. 6). The growth and development of seedlings is closely correlated with the relative abundance of light and soil moisture (Rood and Mahoney 1990, Mahoney and Rood 1991, 1992). Given the lack of endosperm, full sunlight is critical as seedlings are highly dependent upon photosynthate derived from cotyledons and juvenile leaves for sustained growth and development. As a result, cottonwood seedlings are poor competitors in vegetated sites (Johnson et al. 1976, Fenner *et al.* 1984, Johnson 1994). The soil must also be moist throughout the early stages of seedling establishment (1-2 wk), and seasonal declines in water tables regulate patterns of seedling recruitment throughout the first growing season (Mahoney and Rood 1991, 1992, Selquist *et al.* 1993, Johnson 1994). If the rate of water table decline exceeds the rate of root growth (4-6 mm/d for most species, but up to 12 mm/d in *P. trichocarpa*, Tables 1 and 2), water deficits lead to seedling mortality. Early germinating seedlings can tap groundwater at depths of 75 cm by the end of the growing season, and in some instances reach depths greater than 150 cm (Johnson 1994, Reed 1995). Rates of root growth and seedling establishment are also higher in fine, silty sands than coarse, gravelly soils (Kocsis *et al.* 1991). The impact of high surface temperatures is partially moderated by narrow juvenile leaves, yet periods of high evaporative demand accentuate seedling water deficits and drought-induced mortality (Johnson 1994). Vulnerability to drought persists until sapling roots reach alluvial water tables at depths of two meters or more (Fig. 6).

While cottonwood seedlings and saplings are intolerant of drought, they are tolerant of inundation and siltation (Fig. 7, Smit 1988, Rood and Mahoney 1990, Mahoney and Rood 1992). This tolerance helps cottonwoods survive extended periods of inundation (three to four weeks or more) during establishment and in subsequent years. Inundation and siltation eliminates many competitors, thus aiding seedling/sapling growth by keeping recruitment zones relatively open. While seedlings are tolerant of inundation, springtime flooding also eliminates many seedlings adjacent to the main channel by physical scouring (Figs. 6 and 7, Bradley and Smith 1986, Rood and Mahoney 1990). The lack of cottonwoods along some steep-gradient reaches and small watersheds may be due to post-dispersal scouring. In some instances, scouring by winter ice also leads to extensive seedling and sapling mortality (Johnson 1994).

The complexity of interactions between fluvial processes and seedling recruitment reveals a critical "bottleneck" in the life history of riparian cottonwoods. Low flows during seed dispersal are necessary to expose open, moist microsites for germination and recruitment. In contrast, higher "peak" flows during the dispersal phase may prevent exposure of microsites for recruitment until after the seeds have been dispersed or lost their viability. Higher flows following the dispersal phase may also bury or scour newly germinated seedlings. As a result, the location of germinating seedlings relative to the main channel influences subsequent patterns of seedling recruitment and mortality (See mortality zones in Figs. 6 and 8, Bradley and Smith 1986, Selquist *et al.* 1993, Johnson 1994, Stromberg *et al.* 1991, 1993, 1996a). Under conditions of low riverine flows and seasonal drought, proximity to the main channel would be advantageous as seedlings not established in moist soils would likely succumb to drought. Yet, these seedlings would be vulnerable to physical scouring in subsequent years. A reversal in recruitment success may occur in years dominated by higher riverine flows and cool, moist growing conditions that enable recruitment above the scour zone of the main channel. However, these seedlings would remain vulnerable to drought-induced mortality. Given the nature of these interactions, it is apparent that the conditions essential for seedling recruitment are not met on an annual basis (Baker 1990, Rood and Mahoney 1990, Johnson 1994). In fact, suitable conditions occur irregularly (Barnes 1985, Johnson 1994), on intervals of five to ten years or longer (Figs. 6 and 8, Bradley and Smith 1986, Baker 1990, Stromberg *et al.* 1991, 1993, Hughes 1994, Johnson 1994).

Major differences in river channel morphology may also influence spatial and temporal patterns of seedling recruitment, as the distribution of suitable microsites change in relation to the dominant fluvial processes of a given river system (Johnson 1994, Scott *et al.* 1996). For example, along low-gradient meandering streams in the arid Southwest, small floods allow for frequent (≤ 5 yr) episodes of seedling establishment on point bars in what has been described as an incremental-replenishment model (Hughes 1994). On less sinuous arid-region rivers, such as the Hassayampa River, cottonwoods establish in large numbers at infrequent intervals, after large, erosional floods that scour sediment from terraces (Stromberg *et al.* 1993). This pattern has been referred to as a general-replenishment model, characterized by infrequent (ca. 30-50 yr recurrence intervals), large floods that set up recruitment conditions over large areas of the floodplain (Stromberg *et al.* 1993, Hughes 1994). In effect, temporal and spatial variation in fluvial processes result in a highly variable environmental regime for riparian cottonwoods, yet life history traits associated with reproduction and establishment converge upon the sequence of fluvial events following springtime snowmelt and stormflows. Future studies should explore the dynamic nature of these events and seek to quantify the physiological and genetic components of life-history variation relative to the timing and duration of fluvial geomorphic processes.

Asexual reproduction

Asexual reproduction is widespread among riparian cottonwoods (Tables 1 and 2). The most common mode of asexual reproduction is crown breakage and tree fall during wind storms and flooding events (Fig. 4). Broken branches can become buried in sediment, where they subsequently sprout and develop vigorous shoots. Crown damage and disturbance of shallow roots may also promote root suckering in some species, though this form of suckering is less common among *Aigeiros* species (Rood *et al.* 1994). Cladoptosis, the shedding of branchlets via formation of an abscission layer during winter months or following pollen release in the spring (Fig. 4), is a unique form of asexual reproduction common to *Tacamahaca* species but absent in *Aigeiros* species (Galloway and Worrall 1979, Dewit and Reid 1992).

Within native stands, the proportion of trees established from sexual vs. asexual propagules will vary with species, climatic condition and drainage basin. In some instances, asexual propagules may outcompete seedlings, though few studies have sought to document the relative role of sexual vs. asexual propagules in native stands (Rood *et al.* 1994, Stromberg *et al.* 1996a). In either case, asexual propagation offers an alternative pathway to establishment in a highly variable riverine environment and, as a result, significantly influences the genetic structure of riparian cottonwood populations (Rood *et al.* 1994, Reed 1995, Stromberg *et al.* 1996a).

Establishment of riparian cottonwoods in non-alluvial habitats

Many of the ecological and life history properties associated with the establishment of cottonwoods in riparian habitats can result in their colonization of non-alluvial environments. During early spring and summer, the bare, moist mineral soils required for germination and establishment are readily found in adjacent agricultural fields and forest clearings. Given sufficient precipitation during the growing season, cottonwood seedlings can establish in great numbers in these disturbed environments. As a result, the establishment of *P. trichocarpa* and *P. deltoides* in agricultural fields and forest clearings is common in moister regions of North America, such as the Pacific Northwest and Midwest, especially lands cleared along upper floodplain terraces (J.H. Braatne and P.E. Heilman, pers. observations). In the Great Lakes Region, seedlings and young stands of *P. deltoides* and *P.*

balsamifera are also commonly observed along the margins of lakes and wetlands. In general, these isolated individuals and/or small stands of riparian cottonwood represent an opportunistic event as they are invaded and eventually dominated by secondary successional forest species.

Growth and maturation

Similar as in other plants, the nature and timing of environmental stress determine relative rates of growth and development in riparian cottonwoods. Early stages of sapling growth and stand development are influenced by seasonal flooding, drought, grazing, fire and other site-specific conditions. Vulnerability to drought persists until sapling roots reach the moist soil associated with late-season alluvial water tables at depths of two meters or more (Fig. 6). Major flooding events (10- to 50-yr floods) eliminate young saplings as well as mature trees, though losses associated with these floods are often compensated by additional seedling recruitment on newly, exposed microsites. In general, *Aigeiros* species are more drought-tolerant than *Tacamahaca* species (see Blake *et al.* in Chap 17). In fact, morphological and physiological adaptations to a warmer, drier climatic regime may account for the relative dominance of *Aigeiros* species at lower elevations and latitudes relative to the *Tacamahaca* species (Braatne *et al.* 1992, Hinckely *et al.* 1992, see Eckenwalder in Chap. 1). For example, stomata of *Aigeiros* species close rapidly in response to increasing air and soil-water deficits, while leaf orientation (ca. perpendicular to sun) minimizes heat loads (Hinckley *et al.* 1992, see also Isebrands and Ceulemans in Chap. 16 and Blake *et al.* in Chap. 17). Differences in frost tolerance and susceptibility to xylem embolism may also account for major differences in species distributional patterns (Tyree *et al.* 1994, see also Chaps. 16 to 18). Additional ecophysiological studies are needed to assess relationships between physiological adaptation to environmental stress and species distributional patterns.

Height growth during the early stages of sapling development may be limited, as energy is preferentially allocated to rapidly-growing roots. Two to three-year old cohorts of *P. fremontii* ranged from 5 to 50 cm tall (Stromberg *et al.* 1991, 1996a), while similar age classes of other species typically range from 25 to more than 60 cm tall (Cordes 1991, Stobbs *et al.*1991, Peterson and Peterson 1992, Reed 1995). Once their root systems have become established, height growth is rapid and may reach 10 to 15 m upon the attainment of reproductive maturity (Tables 1 and 2).

Age of reproductive maturity and the lifespan of riparian cottonwoods vary among species, though quantitative studies of these demographic parameters are generally lacking for natural populations. The age at which reproductive maturity is attained ranges from 5 to 10 yr for most cottonwoods (Tables 1 and 2), though *Aigeiros* species typically reach reproductive maturity earlier than *Tacamahaca* species (Reichenbacher 1984, DeBell 1990, Cooper 1990). On average, *Aigeiros* poplars also appear to be shorter-lived than *Tacamahaca* poplars. Ages of older trees from 100 to 150 yr have been observed for *Aigeiros* species, while *Tacamahaca* species may live more than 200 yr (Cooper 1990, DeBell 1990, VanHaverbeke 1990, Zasada and Phipps 1990, Stromberg 1993). Although these data provide a general background on patterns of reproductive maturity and longevity, these life history and demographic parameters require more extensive study in natural populations.

Studies of sex ratios in natural populations of riparian cottonwoods have been limited. Balanced sex ratios (1:1) have been reported for populations of *P. deltoides* growing along the lower Mississippi River (Farmer 1964) and the Hocking River in Ohio (Hardin 1983) . In contrast, Comtoi *et al.* (1986) documented skewed sex ratios among *P. balsamifera* populations in northern Quebec. In this study, males were more common in extreme environments, whereas females typically dominated more protected and nutrient-rich environments. Other researchers have also observed skewed sex ratios in riparian cottonwoods in western North America. In some populations of *P. trichocarpa*, males dominate warmer and drier habitats, whereas other populations are either completely male or female and seemingly independent of environmental conditions (J.H. Braatne, unpub. data and pers. observations). Given the widespread habitat partitioning between genders in *Salix* spp. (Dawson and Bliss 1989, 1993) and *Acer negundo* (Dawson and Ehleringer 1993), the possibility for habitat partitioning between male and female cottonwoods deserves more attention. Further research is needed to determine the cause and consequences of skewed sex ratios in riparian cottonwood populations.

Mature stand densities are highly variable within and among species (Tables 1 and 2); reported values range from 40-192+/ha for *Aigeiros* species (Johnson *et al.* 1976, Strahan 1983, Reichenbacher 1984, Szaro 1989, Stromberg *et al.* 1991, 1993) to 82-294+/ha for *Tacamahaca* species (DeBell 1990, Zasada and Phipps 1990, Peterson and Peterson 1992). Given seedling and sapling requirements for light, no regeneration by seed occurs within cottonwood stands. Any small shoots observed within mature stands are due to asexual propagation (root suckering and/or rooting of broken branches). As a result, riparian cottonwood forests often appear as linear strips of even-age/size stands; each stand representing a discrete period of propagule establishment and growth (Figs. 6 and 8). In places where the river channel has moved systematically in a uniform direction, an age/size gradient develops with young stands of small trees nearest the river and older stands of larger trees found farther from the channel (Figs. 6 and 8). Mature stands of cottonwood may remain within the active floodplain or occur at slightly higher elevations on secondary terraces. As stands mature and become increasingly isolated from active fluvial processes, sex ratios may become skewed (J.H. Braatne, unpub. data), and stands are invaded by secondary successional forest species (Johnson *et al.* 1976). Of increasing concern is the relative dominance of older, relictual cottonwoods and lack of younger stands of riparian cottonwood throughout the western North America (Fig. 9). The causes and consequences of these recent declines in riparian cottonwoods are discussed in the following section.

Conservation and Restoration of Riparian Cottonwood Forests

As noted in previous sections, cottonwoods are often the dominant forest species in many of the riparian habitats in western North America. These riparian forests have special importance for humans and are extremely rich wildlife habitats (Fig. 10, Finch and Ruggiero 1993). For example, although riparian vegetation occurs on less than 1% of the western North American landscape, it provides habitat for more bird species than all other vegetation types combined (Knopf *et al.* 1988).

Due to their rapid growth and sometimes ragged appearance (due to cavitation-induced branch and crown dieback, Tyree *et al.* 1994), riparian cottonwoods have sometimes been considered as undesirable weeds ('cottonweeds'). However, these trees often serve as the foundation for the riparian forest ecosystem and are especially valued in the otherwise treeless semi-arid regions of western North America. Unlike wetter areas to the east (Wilson 1970) and west (Szaro 1990), a loss of riparian cottonwoods in many semiarid riparian areas is not compensated by enrichment from other tree species. If these cottonwoods die, so does the riparian forest ecosystem.

Causes of decline in riparian cottonwood populations

Only small remnants of once abundant riparian cottonwood forests survive in most regions of the southwestern United States (Fig. 9). Estimates of the magnitude of riparian vegetation loss and degradation range from 70% to 95% for the Southwest (Johnson and Haight 1984, National Research Council 1992). Even more severe declines have been experienced in the heavily developed areas of California, such as the Sacramento Valley, which has lost about 98.5% of the riparian forests that existed in 1850 (Sands and Howe 1977). Losses in the more northerly areas of Colorado, Idaho, Wyoming, Montana and Alberta have lagged behind the decline in California, although similar patterns are emerging. The causes of declines in riparian cottonwoods are numerous; similar types of impacts occur across different areas, but their relative significance differs among regions (see Table 3).

In many areas in western North America the heaviest pressure on riparian cottonwoods is related to livestock grazing (Table 3). Cattle browse and trample seedlings and saplings, thereby preventing replenishment of the forest. Management efforts to control livestock grazing include rotational grazing and exclusion fencing. This limits cattle use of riparian areas for short periods of time (ca. 5 yr) to allow younger trees to outgrow their most vulnerable stage.

Another major cause of the decline of riparian cottonwoods is river damming and water diversion (Tables 3, 4 and 5). Declines of cottonwoods downstream from dams in semi-arid regions of North America are well documented (Tables 4 and 5). Fortunately, these impacts are site specific since it is largely the pattern of downstream flow regulation, rather than simply the presence or absence of dams that determines the effect on riparian ecosystems. Although cottonwood decline has been common, occasional increases of cottonwoods have occurred following damming and stream flow modification, thus confirming that river type and flow patterns are critical factors in influencing riparian cottonwood forests (Rood and Mahoney 1990, Johnson 1994, Scott *et al.* 1996).

In many semi-arid areas, onstream reservoirs are managed to conserve spring snowmelt which will later be diverted offstream for irrigation during summer. Dam operation can result in abrupt reductions in flow and sedimentation in late spring and early summer as well as in insufficient flows through the hot, dry period of mid-summer. Both the abrupt flow reduction (Mahoney and Rood 1991) and the low summer flows probably contribute to drought stress which results in cottonwood die-back and mortality. Cottonwood seedlings are particularly vulnerable since they have limited, shallow root systems. The retention of sediments by dams also decreases the potential availability of microsites for seedling establishment. Due to the vulnerability of seedlings, recruitment of replacement trees is significantly impacted by river damming and water diversion. Without periodic recruitment, the cottonwood forest will suffer gradual decline as previously established trees age and die. Older trees appear more vulnerable to drought stress as they are physiologically

Table 3. Negative impacts on riparian cottonwood forests across western North America. Impacts are listed in likely descending order of importance. The ranking would vary across river systems (Revised from Rood and Mahoney 1990).

Factor	Comment
1. Livestock Grazing	Cattle graze and trample seedlings. Overgrazed regions are characterized by a deficiency of seedlings and saplings, and forests decline as older trees die out.
2. Water Diversion	Following river damming or the construction of diversion weirs, water is diverted offstream for irrigation. Subsequent instream flows are often insufficient, creating drought stress and accelerating mortality.
3. Domestic Settlement	Clearing for homes, roads, bridges and various other uses. Pressure is generally proportional to human population density.
4. Exotic plants	Characterized by natural (and artificial) disturbance, riparian areas are especially vulnerable to encroachment of exotic plants. Introduced trees include the salt cedar (*Tamarix pentandra*) and Russian olive (*Elaeagnus angustifolia*), and aggressive noxious weeds such as leafy spurge (*Euphorbia esula*) also occur.
5. Onstream Reservoirs	Many riparian areas have been flooded by reservoirs. The rate of dam construction in the United States has declined over the past two decades but some damming is likely to continue in Canada.
6. Channelization	In many areas, extensive programs have attempted to straighten rivers and armor banks. Such actions inhibit the dynamic meandering of rivers that is essential for cottonwood replenishment.
7. Agricultural Clearing	Clearing for pasture or crop production occurs where the proximity of floodplains to river water provides inexpensive irrigation. Agricultural clearing was more extensive in the early 1900's, and little net change has occurred in many areas since 1950.
8. Gravel Mining	River valleys are prime areas for sand and gravel extraction. In addition to the areas excavated, roads, buildings and screening plants often involve forest clearing. Although aesthetically offensive, abandoned gravel pits are sometimes areas of cottonwood recruitment, particularly through root suckering.

9. Direct Harvesting	During early white settlement of western North America, poplars were harvested to provide building materials for forts and homes as well as fuel wood for heating and riverboat engines. Such use is presently minor in most regions.
10. Beavers	Beavers are a natural component of many riparian ecosystems and contribute to various processes, including cottonwood rejuvenation after beaver harvesting. However, an imbalance between beavers and trees may result from the loss of natural predators of beavers and the loss of some trees. The present consumer preference away from natural furs has reduced trapping, an artificial measure that controlled beaver populations through the past century.

decrepit and generally located on higher terraces where their root systems become isolated from alluvial waters due to excessive surface water diversion and groundwater extraction.

Cottonwoods are especially vulnerable to drought-induced xylem cavitation (Tyree *et al.* 1994). In some instances, vulnerability to cavitation may contribute favorably to natural systems since it results in shoot pruning during drought periods to reduce transpirational water loss. However, in flow-reduced systems, cavitation can result in significant shoot mortality and crown die-back, particularly if drought stress is prolonged (Albertson and Weaver 1945). These consequences are typical of problems along flow-reduced dammed rivers, although different patterns of flow regulation can also create other problems for riparian cottonwood forests (Table 5). Temporal and spatial patterns in cottonwood decline can be diagnostic in revealing the specific negative impact(s) of river damming and flow diversion.

Conservation and restoration strategies

An important prerequisite for the conservation of riparian cottonwoods is a greater recognition of both their value and their vulnerability. (See Whitham in Chap. 11, for a special reference on the need to protect natural cottonwood hybrids and riparian hybrid zones). Back in the 1950's and 1960's, there were active programs to clear riparian woodlands in an effort to reduce transpirational water loss in semi-arid regions (National Research Council 1992, U.S. Department of Interior 1994). The ineffectiveness of such 'phreatophyte control' programs was soon revealed since the loss of the stabilizing streamside vegetation resulted in

Table 4. Reports of negative impacts of river damming on downstream riparian cottonwood forests in western North America. (This is a chronological listing based on a Table in Rood and Mahoney (1990), revised and expanded here).

Author (date)	River	Region	*Populus*	Comments
Johnson et al. (1976)	Missouri	N. Dakota	*P. deltoides*	Reduced tree growth and fewer seedlings
Brown et al. (1977)	various	Arizona	*P. fremontii*, *P. angustifolia*	Reduced abundance
Ohmart et al. (1977)	Colorado	California	*P. fremontii*	Reduced abundance Absence of seedlings
Crouch (1979)	South Platte	Colorado	*P. deltoides*	Reduced abundance
Behan (1981)	Missouri	Montana	*P. deltoides*	Reduced abundance Absence of seedlings
Reily and Johnson (1982)	Missouri	N. Dakota	P. deltoides	Reduced tree growth
Brothers (1984)	Owens	California	*P. fremontii*	Reduced abundance
Stine et al. (1984)	Rush Ck.	California	*P. balsamifera*	Reduced abundance
Strahan (1984)	Sacramento	California	*P. fremontii*	Fewer seedlings
Fenner et al. (1985)	Salt	Arizona	*P. fremontii*	Conditions unsuitable for seeding establish.
Bradley and Smith (1986)	Milk	Alberta/ Montana	*P. deltoides*	Reduced abundance Fewer saplings
Akashi (1988)	Bighorn	Wyoming	*P. deltoides*	Reduced abundance
Rood and Heinze-Milne (1989)	St. Mary, Waterton, & Belly	Alberta	*P. deltoides*, *P. trichocarpa**, *P. angustifolia*	Reduced abundance
Howe and Knopf (1991)	Rio Grande	New Mexico	*P. fremontii*	Absence of seedlings
Smith et al. (1991)	Bishop Ck.	California	*P. fremontii*, *P. balsamifera*	Smaller leaves, lower transpiration and H2O potential
Snyder and Miller (1991)	Arkansas	Colorado	*P. deltoides*	Reduced abundance
Stromberg and Patten (1991)	Bishop Ck.	California	*P. fremontii* *P. balsamifera*	Reduced tree diameter growth, crown cover, and survival

Stromberg and Patten (1992)	Bishop & Pine Cks.	California	*P. trichocarpa*	Increased mortality, reduced growth
Johnson (1992)	Missouri	North Dakota	*P. deltoides*	Fewer saplings
Rood et al. (1995)	St. Mary	Alberta	*P. deltoides*, *P. trichocarpa*, *P. angustifolia*	Reduced abundance, Absence of seedlings
Rood et al. (1996)	Marias	Montana	*P. deltoides*, *P. trichocarpa*, *P. angustifolia*	Absence of seedlings

* discrimination of *P. balsamifera* and *P. trichocarpa* is difficult, particularly in areas where both species co-occur and hybridize.

increased erosion, reduced retention of rainfall, and subsequently falling rather than rising alluvial water tables. Although phreatophyte control programs are seldom practiced anymore, other state and federal resource management programs often fail to promote conservation of riparian woodlands (National Research Council 1992, U.S. Department of Interior 1994, Shafroth *et al.* 1995).

With greater appreciation of riparian cottonwoods, more attention should be directed to protect unregulated streams and rivers. Rather than allocating riparian lands to various purposes and later protecting selective reaches of a river system, conservation planning should begin by identifying valuable riparian zones and ensuring their protection prior to further regional development.

Along dammed streams and rivers, firmly legislated commitments are required to ensure the delivery of sufficient flows and sediment to allow the survival, growth and reproduction of riparian cottonwoods and other riparian vegetation. The U.S. Department of Interior has recently sought to counteract damming effects along the Colorado River by mimicking natural flood and sedimentation regimes. Such efforts are essential for the development of new approaches to the restoration of vegetation along regulated streams and rivers. However, it will also be critical to guarantee sufficient instream flows during drought years. While it may be difficult to justify instream flows solely for riparian vegetation, maintenance of these flow regimes also improves water quality and fisheries as well as other aesthetic and recreational river resources, benefitting human as well as ecosystem health.

Table 5. Contributing factors to the decline of western riparian cottonwood forests following river damming or water pumping from wells (Revised from Rood and Mahoney 1990).

Proposed cause	Comments	References
I. Hydrological changes:		
A. Reduced water availability	Diversion of water offstream or well pumping creates a water deficit, resulting in drought stress, slow growth, and increased mortality	Brown et al. (1977), Brothers (1984), Stine et al. (1984), Hardy BBT Ltd. (1988), Rood et al. (1989), Reily and Johnson (1982) Smith et al. (1991), Snyder and Miller (1991), Stromberg &Patten (1991), Stromberg &Patten (1992), Rood et al. (1995) Scott et al. (1996)
B. Reduced flooding	Spring flooding is essential to create moist seedbeds for seedling establishment.	Brown et al. (1977), Ohmart et al. (1977), Johnson et al. (1976) Reily and Johnson (1982) Johnson (1992) Rood et al. (1995)
C. Stabilized Flows	Dynamic flows are essential for seedling establishment.	Strahan (1984), Fenner et al. (1985) Howe and Knopf (1991) Johnson (1992) Rood et al. (1996)
II. Geomorphological changes resulting from hydrological alterations:		
A.Reduced meandering and channelization	With reduced flooding, channel migration and the creation of seedbeds are reduced	Ohmart et al. (1977), Johnson et al. (1976), Bradley and Smith (1986), Howe and Knopf (1991) Snyder and Miller (1991) Johnson (1992)

Riparian restoration programs have been promoted along various rivers in western North America (National Research Council 1992, Friedman *et al.* 1995, Scott *et al.* 1996), yet the role of riparian cottonwoods in many of these revegetation programs remains unclear. Riparian restoration requires the integrated management of both the land and water, creating complexities in both biological and physical resources and complicating administration which invariably involves multiple private, regional, state or provincial, and federal participants (National Research Council 1992, U.S. Department of Interior 1994).

Restoration programs will involve a combination of approaches related to flow regulation, land-use policies, and intervention to promote stream channel restoration and revegetation (National Research Council 1992). Revegetation measures may include deliberate seeding of suitable riparian zones where a shallow water table would promote seedling survival. In some instances, plowing and sod removal in combination with limited irrigation may also be required to promote natural seedling establishment (Friedman *et al.* 1995). In areas lacking native seed sources, rooted seedlings and saplings as well as unrooted cuttings, whips and poles may be propagated and transplanted into suitable riparian habitats (Hoag 1993, Briggs 1994). In revegetation programs, native species should be used, and a range of genotypes should be propagated in a manner that encourages biodiversity. Site scarification, the mechanical disturbance of the substrate, may also be used to propagate cottonwoods that already exist on site. Scarification will promote root suckering and thus may be most effective for *Tacamahaca* species including *P. trichocarpa*, *P. balsamifera* and *P. angustifolia*. Although root suckering of the *P. deltoides* and *P. fremontii* (Sect. *Aigeiros*) is uncommon, even these species appear to respond to some mechanical disturbance.

In spite of active cottonwood restoration programs along various rivers and streams, only a limited number of published reports on these activities exist, particularly in refereed journals (See Friedman *et al.* 1995, Shafroth *et al.* 1995). There is a serious information deficiency on these topics. Researchers and riparian resource managers who have experience in cottonwood restoration are encouraged to publish their findings as they will be of considerable interest for riparian cottonwood restoration not only in western North America, but also in other parts of the world.

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1 Generalized view of river channel and floodplain dynamics. Diagrammatic plan view and cross-section indicating the relative balance between erosion of the concave bank and accretion of material in a building point bar. Bankfull condition shows that the level of the floodplain is the same as the top of the point bar. (Modified from Leopold 1994)

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3 Generalized relationship between water table depth and distance from streambank for different climatic regimes and fluvial geomorphic settings. (Modified from Reichenbacher 1984)

4 Generalized timing and duration of reproductive events for riparian cottonwoods in relation to the annual pattern of stream discharge.

5 All cottonwoods are prolific seed producers and initial viability is almost complete. Consequently, if seeds land on moist, mineral soils, extensive mats of seedlings result. However, almost all of these seedlings die due to drought stress and complete mortality often follows dewatering when stream flows are diverted for irrigation or other uses. (Photo by S.B. Rood)

6 Patterns of seed dispersal, germination and establishment in relation to microtopographic position and river stage of a meandering river. (Modified from Bradley and Smith 1986)

7 Cottonwood saplings in the flooded Oldman River at Lethbridge, Alberta. The diversity of sapling form reflects the occurrence and hybridization of three species, the Plains Cottonwood, *Populus deltoides* var. *occidentalis*, the narrowleaf cottonwood, *P. angustifolia*, and the black cottonwood, *P. trichocarpa*, or balsam poplar, *P. balsamifera*, that are difficult to distinquish without female flowers. All riparian cottonwoods are very flood-tolerant, capable of surviving weeks or even months of inundation. (Photo by S.B. Rood)

8 Successful seedlings and some clonal saplings originate in arcuate bands that track specific elevations along meandering rivers and especially, at point bars at the end of meander lobes. The curving bands of even-aged saplings or trees originated from specific flood events and provide a hydrological history of the river. Here, sapling bands of narrowleaf cottonwoods and plains cottonwoods occur at a meander lobe along the Oldman River near Lethbridge, Alberta. (Photo by S.B. Rood)

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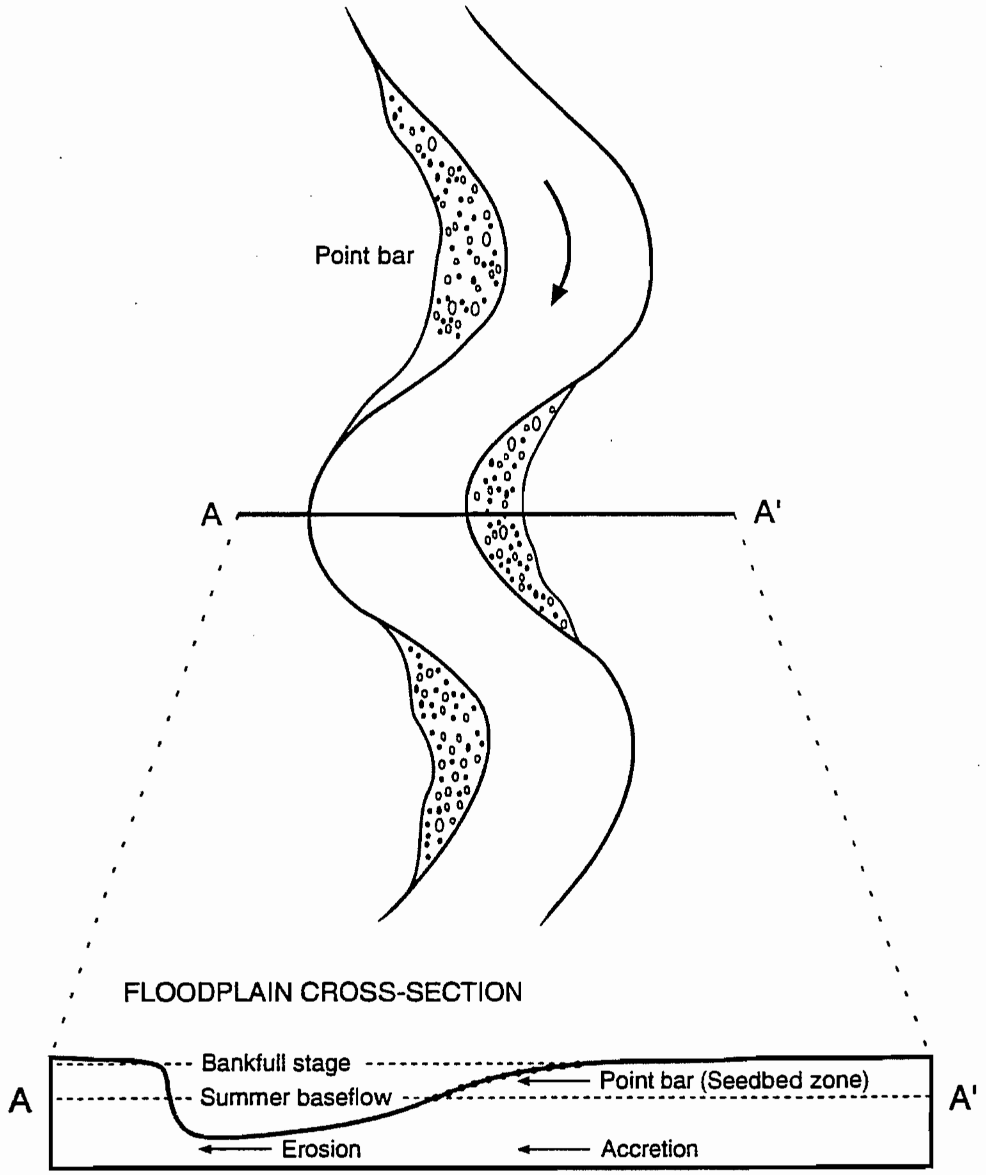
Fig. 1



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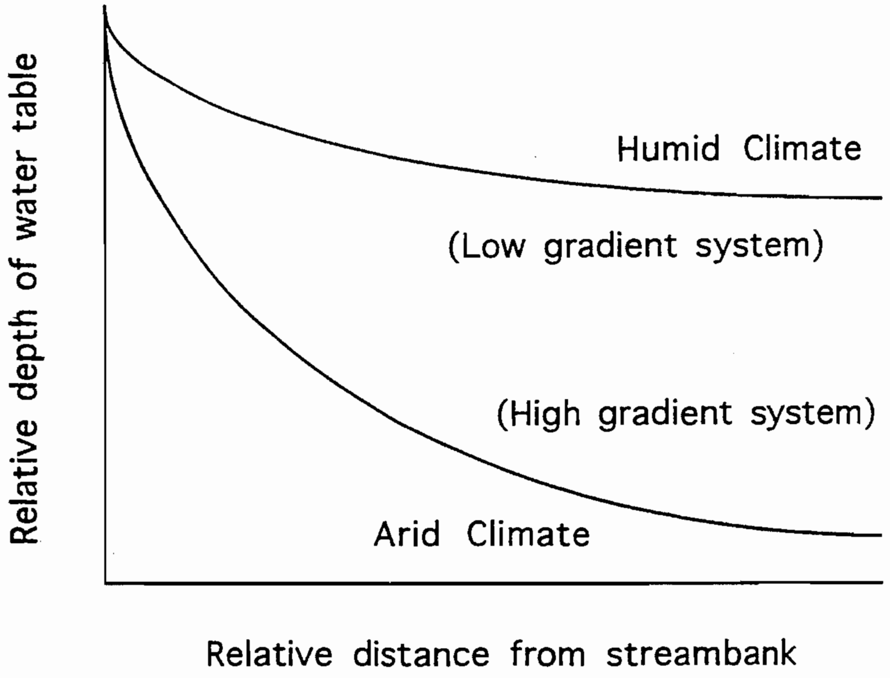


Figure 3. Generalized relationship between water table depth and distance from streambank for different climatic regimes and fluvial geomorphic settings.
(Modified from Reichenbacher 1984)

Fig. 4

Timing and Duration of Reproductive Events

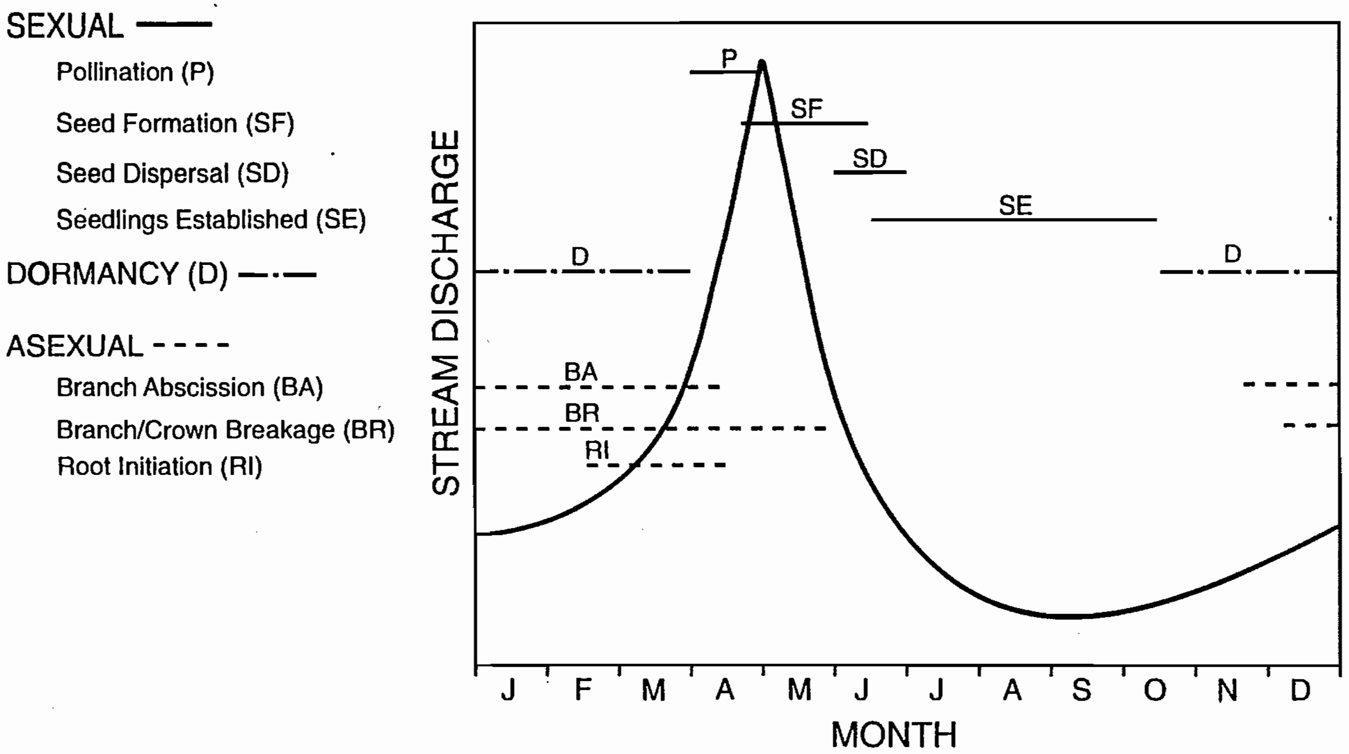
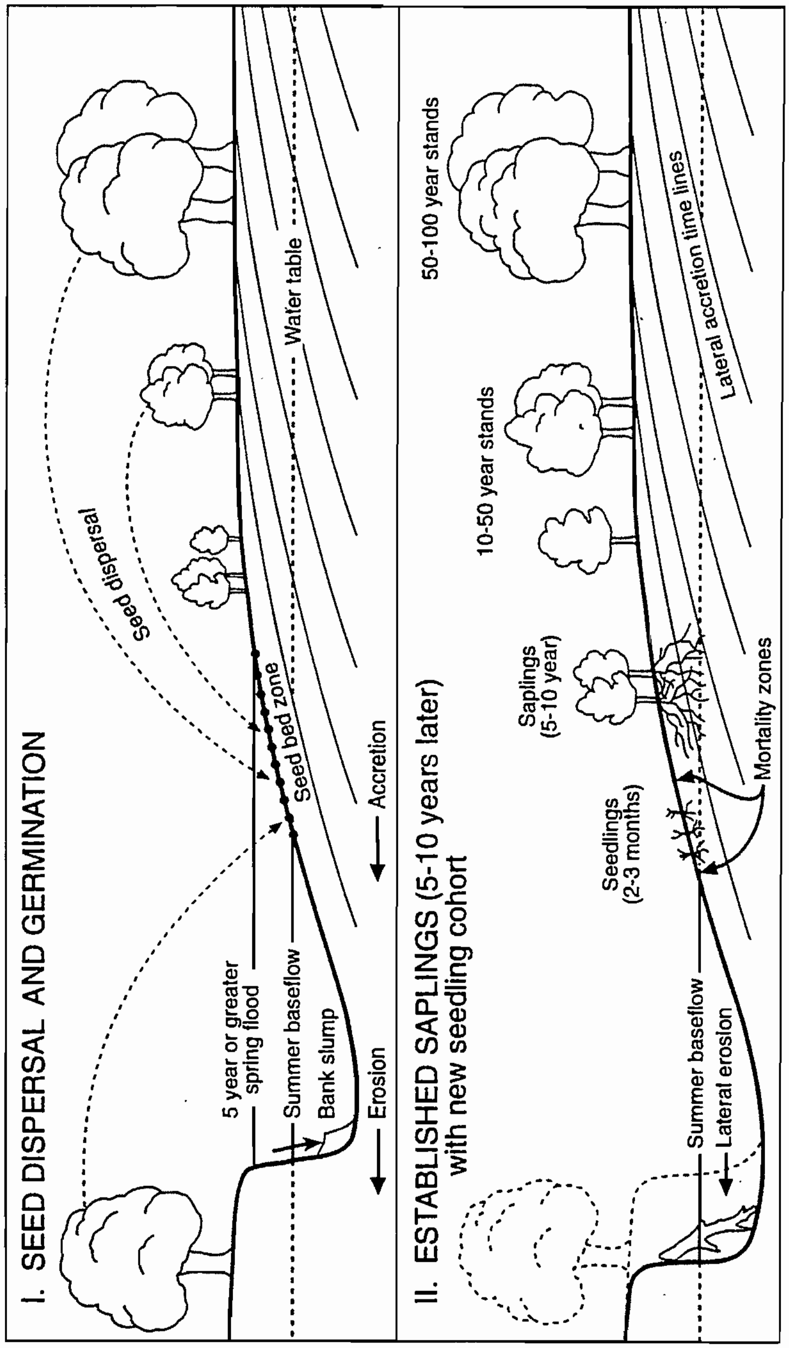


Fig. 6



I. SEED DISPERSAL AND GERMINATION

II. ESTABLISHED SAPLINGS (5-10 years later) with new seedling cohort

(Modified from Bradley and Smith 1986)

Fig. 2

Fig. 5

Fig. 7

Fig. 8

Fig. 9

Fig. 10

TECHNICAL NOTES

USDA-Natural Resources Conservation Service
Boise, Idaho

TN PLANT MATERIALS NO. 23

September 1993

HOW TO PLANT WILLOWS AND COTTONWOODS FOR RIPARIAN REHABILITATION

Many riparian areas in the West need rehabilitation. Abuses in the past have caused the destruction of vegetation and accelerated bank and bottom erosion (Kauffman and Krueger 1984; Skovlin 1984; Platts 1981; Thomas and others 1979). Recent emphasis on water quality, aesthetics, wildlife, and fisheries has prompted new interest in methods for revegetating eroding stream channels (Carlson 1992; Carlson et al. 1991). The Interagency Riparian/Wetland Plant Development Project, USDA Natural Resources Conservation Service (SCS) Plant Materials Centers (PMCs), and others are developing new native and introduced varieties of willows and cottonwoods to better meet the needs of riparian rehabilitation. Numerous questions have been asked about rehabilitating riparian zones with willows and cottonwoods. This Technical Note describes a step by step procedure for planting willow and cottonwood cuttings.

Site Considerations

Careful planning before planting is necessary to ensure the solution does not create more problems than those already identified.

> * Management (planned grazing system, livestock exclusion, etc.) must be in-place to maintain or improve riparian vegetation. Without proper management, planting efforts could be destroyed (Crouse and Kindschy 1984; Van Haveren and Jackson 1986).
>
> * If native willows or cottonwoods are not found in the vicinity, planting may not be a good option.
>
> * Willow and cottonwood plantings apply only to situations where the rehabilitation time frame is long enough to allow them to become established and stabilize the site. Structures may be more appropriate in emergency situations.
>
> * Unrooted cuttings can be used on sites that range from flat to near vertical slopes. Risk of wash-out and mortality are higher with steeper slopes.

A reconnaissance upstream and downstream from the site selected for revegetation may save time and effort. If there are willows and cottonwoods on adjacent sites, check soil and site conditions and compare them to conditions at the revegetation site. Plantings will be most successful on sites similar to these stable vegetated areas. Risk of mortality will increase as soil, site, and water column parameters depart from those of the vegetated sites.

There are reasons for vegetation not growing on the disturbed site. Some parameters to inventory in addition to management at the revegetation site include: high streamflow

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There are reasons for vegetation not growing on the disturbed site. Some parameters to inventory in addition to management at the revegetation site include: high streamflow velocities, sharp outside curves, vertical to near vertical or undercut banks, hanging streambanks, mixed stratigraphy of cohesive materials over gravel, and evidence of mass soil slumping. When these parameters are present, revegetation can still be considered, but it is much more difficult because the time period required for stabilization increases, the planting schedule must accelerate, and additional soil losses can be expected.

These conditions indicate structures or bioengineering techniques not covered in this Technical Note need to be included in the planning considerations.

Some data suggests vegetative protection may be adequate if maximum streamflow velocities are less than 8 feet per second. Structural and bioengineering techniques should be considered for velocities greater than 8 feet per second. Woody materials should be considered with velocities less than 8 feet per second. Woody materials in conjunction with herbaceous species should be considered for velocities less than 5 feet per second. Herbaceous materials alone can be used for velocities less than 3 feet per second.

Structures or bioengineering techniques may be needed in situations where the toe of the bank is unstable. In these situations, refer to SCS Engineering Field Handbook, Chapter 16.

Species Selection

During the reconnaissance, identify willow and cottonwood species, soil and site conditions they are growing in, and the moisture regime. If species identification is a problem, at least identify the growth form and conditions where plant is growing. Species identification is important so proper plants can be matched at the revegetation site.

Species have several different growth forms. Willows come in all sizes, from small shrubs to large trees. Some willows sucker profusely while others mature with a large dense basal area. Cottonwood species have narrow to wide crowns and some sucker while others have very shallow root systems. For the most part, small to medium size shrub-type willows and rhizomatous or creeping-type willows are used for planting within the channel banks. These can be planted as live poles or as bundles (fascines). Tree-type willows and cottonwoods are normally selected for the upper bank and floodplain areas.

Mature size and growth form will affect species selection. Large species can partially block or deflect currents. If the mature basal size of the selected species will block more than 10% of the surface width at normal streamflow, another species should be considered.

There are many species of willows that occur naturally in different habitats. Upland willow species are found in relatively dry areas not necessarily associated with seeps, bogs, or high water. Wetland willows are found growing in standing water or saturated conditions and are adapted to long periods of inundation.

If spreading of planted species is considered a problem, selection might include only male clones. Both willows and cottonwoods have male and female plants. Selecting male plants will reduce spreading from seeds.

More shade will be produced with tall and/or wide canopy species. This may be important to water temperatures and fish habitat. Concentrate tree species on the southerly side of stream to achieve the most shade over the widest area.

Stem flexibility is important for species at waterline to mid-bank on streams with high velocities, debris loads, and ice flows (Parsons 1963; Platts and Rinne 1985). Species with deep or rhizomatous root systems might be better suited to streams with severe ice flows (Platts and Rinne 1985).

Livestock and wildlife can adversely impact the riparian zone. Some plant species such as willow, cottonwood, golden current, waterbirch, chokecherry, dogwood, serviceberry, mockorange and silver buffaloberry are fairly palatable. It may be advantageous to plant unpalatable species, like Hawthorne, on the mid-bank to top bank and floodplain areas rather than more palatable species. Other less palatable species include: woods rose, skunkbush sumac, Douglas spirea, and common snowberry.

Grazing can also reduce reproduction of young plants, particularly those that reproduce by seed. Species selection of strong suckering or rhizomatous species may be an advantage. Improper grazing management can adversely impact even these species. A grazing management plan is needed whenever planting riparian areas that are grazed.

Aesthetics can usually be improved by selecting more than one species to provide differences in size, shape, color, and texture. More than 1 species or clone also increases resistance to pests and diseases, in addition to increasing diversity for wildlife. However, the species planted at the waterline should be a single species for the full length of any one reach so that varying sizes and shapes do not cause the force of water to move behind that planted line.

Most species of willow and cottonwood have good fire tolerance and resprout well after fire. Many cottonwoods are more susceptible to fire as they mature. Both are also very well adapted to high density plantings one would plant to achieve a barrier effect.

There may be times when native species will not meet the landowners objectives. Introduced species can be considered in the revegetation plan. Refer to the Idaho Tree Planting Handbook for plant characteristics.

Species Distribution or Planting Design

A planting design should be developed to show where each species is to be planted on the site. The entire problem section should be planted, not just parts of a reach or curve. This will reduce the chance of water eroding behind the planting.

Each species grows in specific ecological zones along the stream channel and flood plain (Carlson et al. 1992). For example, rhizomatous willows are often found and usually should be planted on inside curves (gravel, silt and sand bars) of a stream channel. Inside curves or point bars undergo less erosion from moving water, but have a longer inundation period. Rhizomatous willows are rarely found on sharp outside curves.

Shrubby species are normally planted on outside curves of a stream channel as a continuous barrier. Outside curves incur more erosion from streamflow, but have a shorter inundation period. Plant the entire reach with the same species. Taller shrubby species may also be planted mid-bank to upper bank and on the floodplain for diversity and additional stabilization or as a buffer zone.

Plant tree species up the bank from the shrubby species or on top of the bank. The shrubby species provide protection for the tree species when planted in this manner.

The reconnaissance survey will help identify these relationships. See "Spacing" section to help in planting design and to help determine numbers of plants or cuttings needed.

Type of Planting Stock

Cuttings, whips, plugs, conetainers, bare-root, potted, clumps, and paper-sleeved planting stock are all viable alternatives (Carlson et al. 1992; Dirr and Heuser 1987; Platts et al. 1987).

General advantages of nursery stock include: good potential root development, good carbohydrate reserves, few pest problems, readily available for many species, and no money and labor is needed from the buyer to collect the stock.

Disadvantages of nursery stock include: more expensive than hardwood cuttings collected near the revegetation site, short root systems can wash out easily, short root system may not reach moist soil during the growing season, and roots of grasses and weeds are in the same zone competing for moisture and nutrients.

Stem cuttings can be divided into softwood, semi-hardwood (greenwood), and hardwood categories. Hardwood stem cuttings can also be divided into deciduous, narrowleaf evergreen, and broadleaf evergreen (Dirr and Heuser 1987). This Technical Note will concentrate on deciduous hardwood cuttings from moderate age stem materials. Deciduous hardwood cuttings of willow and cottonwood species are generally recommended over other types of cuttings because of the high concentration of pre-formed, dormant root primordia located throughout the length of the stems (Densmore and Zasada 1978; Carlson 1938, 1950; Haissig 1970, 1974).

Pole cuttings (large diameter unrooted stems) are recommended for most plantings from water line to mid-bank. Pole cuttings of willows and cottonwoods are also recommended on upper-banks and floodplains where the water table is relatively deep. Pole cuttings usually provide the only means to reach this moisture and establish a high concentration of roots for that portion of the stem within the moist zone.

Pole cuttings have the additional advantage of being relatively inexpensive. They are easy to harvest and store. They are also much easier to plant. High mortality can occasionally occur, but this is somewhat offset by lower costs, ability to rapidly plant large numbers, and ease of replanting the following year.

Generally, whips (less than 3/8 inch diameter) are not recommended because energy reserves in the stem are limited and they are more susceptible to cytospora canker, a fungus causing twig dieback (Biggs et al. 1983; Briggs 1991).

Plugs, conetainers, bare-root, potted, and paper-sleeve planting stock are best when used:

* on mid-bank to upper-bank or floodplain where long periods of inundation or water erosion is minimized.

* where adequate moisture is available -- i.e. natural precipitation is adequate for species selected or plants are irrigated.

* where there is no competing vegetation or a 30" diameter area around plant is scalped of competing vegetation at planting time.

* where plants have a low risk of physically being pulled or eroded out due to shallow rooting systems during the establishment period.

Source of Cuttings from Commercial Stock

Willows and cottonwoods have been used extensively for riparian rehabilitation because they are easily established from cuttings. Cuttings can often be obtained from commercial nurseries or from native stands located near rehabilitation sites. When buying cuttings from commercial sources, released varieties of adapted species should always be specified.

PMCs and Projects conduct extensive research and testing with native willows and cottonwoods collected from service area states having similar climate, soils, and topography. Once a willow or cottonwood meets the testing criteria, it is released to the public. Commercial nurseries and growers then propagate the species on a much larger scale for sale. The released variety name is the key to getting a plant adapted to conditions similar to where it was tested. All named varieties have documentation that describes growth characteristics, performance, and selection criteria. This ensures they are the same stock as originally tested.

Plugs, conetainers, bare-root, potted, and paper-sleeved nursery stock purchased through nurseries should be rooted from local materials. This could be from a local ecotype or the same watershed, but should not be from more than 200 miles east or west or 100 miles north or south or more than 2000 feet elevation difference from planting site. Ask the nursery where the stock came from. See Idaho Tree Planting Handbook for more information.

Source of Cuttings from Native Stands

Native willow and cottonwood stands located near the rehabilitation site are another source of cuttings. Native stands of willow and cottonwood usually have or have had insect and disease infestations which can stress the plants in the potential "mother" stand. Low water years and long periods of drought may also stress the plants. This stress means that the stem cuttings may not have peak energy reserves. Low energy reserves translate into lower establishment success.

When planning the number of cuttings to harvest, take these stress indicators into account. Always obtain permission to harvest from the landowner, private or public, before starting to cut.

Timing of Harvest

Establishment success is significantly increased if cuttings are taken from live, dormant willows either in late fall, winter, or very early spring before the buds start to break. Densmore and Zasada (1978) found that spring collections survived better than fall collections. However, studies in Idaho have found no such differences (Hoag 1991; Hoag et al. 1991; Hoag et al. 1992). See "Storage" section for procedures when harvesting well before the projected planting date.

Cutting Diameter

Cuttings should generally be 3/4 inch diameter or larger depending upon the species (Briggs and Munda 1992; Hoag 1991; Hoag et al. 1991; Hoag et al. 1992; Fenchel et al. 1988). Rhizomatous or spreading willow stems will rarely get much bigger than 3/4 inches in diameter. Tree-type willows can be several inches in diameter. Larger diameter cuttings have more energy and stored reserves than smaller diameter cuttings. Highest survival rates are obtained using cuttings 2 to 3 inches in diameter. Cuttings as large as 8 inches have been tested with excellent success (Carlson et al. 1991; Hoag et al. 1992). However, the larger the cutting diameter, the longer the cutting should be, and the deeper the hole should be to support it. The deciding factor for selecting the cutting diameter is the planting method you will use (see

Planting Methods). Larger diameter and longer cuttings will be needed for more severely eroding sites and where the water table is deeper. When planting into rock riprap, cuttings should be larger than 3 inches, preferably 4-5 inches. They will not bend or break when pushed between the rocks in the riprap.

Cutting Length

Cutting length is largely determined by the depth to the mid-summer water table and erosive force of stream at the planting site (Briggs and Munda 1992; Fenchel et al. 1988; Hoag 1991; Hoag et al. 1991; Hoag et al. 1992). Plantings can occur at the water line, up the bank, and on top of bank in relatively dry soil, as long as cuttings are long enough to reach into the mid-summer water table. Make sure:

* Several inches of cutting are in the mid-summer water table.

* 3-4 buds are above the ground.

* no less than 1/2 the total length is in the ground.

* If long periods of inundation exceeding 30 days are likely, cuttings should be long enough to extend 6-12 inches above the expected high water line.

* If weeds are a problem, the cutting should extend above herbaceous growth in summer to receive adequate light and below weed root mass to minimize competition (Hoag et al. 1991; Platts et al. 1987).

When planting for bank stabilization, the cutting should extend 2-3 feet above ground so as it leafs out, it can provide immediate bank erosion protection. The cutting should be planted as much as 3-5 feet into the ground if it is not this deep, moving water can erode around cutting and rip it out of the ground. Tests have shown that even with establishing root systems as long as 15-28 feet, the erosive power of a stream can rip a short cutting out of the ground (Hoag 1991; Hoag et al. 1991; Hoag et al. 1992).

Harvest of Cuttings

Once cutting size and source location has been determined, the actual cutting process can begin. Lopping shears, pruning shears, a small wood saw, brush cutters, or a chain saw can be used to harvest cuttings. Size of the cuttings will determine what you use to cut them.

* Make clean cuts. Ensure all equipment is sharp.

* Use live wood at least 1 year old or older. However, very old wood should not be used (Briggs and Munda 1992; Fenchel et al. 1988). Chmelar (1974) indicated that larger and older wood is required to propagate species that are difficult to root. The best wood is 4-5 years old and smooth barked not deeply furrowed.

* Avoid suckers, current year's growth, because they lack the stored energy reserves necessary to consistently sprout when planted.

* No more than 1/3 of any one individual plant should be removed. In the case of rhizomatous species, no more than 40% of the plant should be removed.

* Select branches which will not impair the source willows health and appearance.

* When harvesting from native stands, make sure the stand will not be denuded or destroyed by your cutting activity.

* Consider removing cuttings from inside the crown area rather than the more visually obvious exterior area. Try to spread your harvesting activity throughout the stand.

* Cut the apical bud plus several inches off cutting before planting it. The apical bud (bud at tip of branch) draws too much energy from stored reserves, reducing chance of survival. The upper part of the stem also has the flowering parts (Kay and Chadde 1992). By cutting it off, energy is redirected to the root and branch primordia in the lower part of stem.

* Trim off all side branches so cutting is one single stem.

* A processing alternative is to cut the top of cutting with a horizontal cut and bottom of cutting with a 45° cut. This allows quick recognition of cutting top (see Sealing Harvested Cuttings).

* Care should be taken to select materials free-of splitting, disease, and insect damage.

Sealing Harvested Cuttings

One of the most important steps in this process is the identification of **TOP** of cutting. If cutting is planted upside down, significant mortality will occur. To identify which end is the top of cutting, look at the leaf scar and emerging buds. Buds emerging from leaf scar always point up. Another key is the stem. It is usually a smaller diameter near top of cutting, but this is not always obvious. The leaf scars are the most reliable key.

When the top of cutting has been identified, you should seal it. Dipping the TOP 1-2 inches of cutting into a 50-50 mix of light colored latex paint and water, prevents excessive transpiration of water from cutting. This also reduces the possibility of diseases entering the open top of the cutting after it has been planted. In many cases, cuttings sprouted the first year, but died the second year from disease or desiccation over the hot summer months. Perhaps the best reason for painting the top of cuttings is it helps inexperienced planting crews plant cuttings properly, with the top up! It also helps locate the cuttings more easily for subsequent planting evaluations. This technique is inexpensive, easy, and effective.

Storage

The preferred timing for harvesting willow and cottonwood cuttings is when they are dormant. To minimize storage time, harvest cuttings in early spring and plant immediately there after. If this is not possible, cuttings can be harvested in late fall or winter and stored in a large cooler at 24-32°F until just before planting. Cuttings can be stored for several months in a cooler (Platts et al. 1987). Whether cuttings are kept in a cooler, root cellar, garage, or shop floor, make sure the storage area is dark, moist, and cool at all times. If cuttings are stored at higher temperatures, a fungicide should be applied to prevent damage caused by pathogens or saprophytes (personal communication, D. Darris, Corvallis PMC manger, 1993)

Cold storage in a moist potting medium or moist peat can stimulate callus formation of cuttings and speed rooting once planted. For large numbers of cuttings, this is usually impractical and costly.

Treatment of Cuttings

In Interagency Riparian/Wetland Plant Development Project tests, fertilization, treatment with rooting hormone, or treatment with a fungicide did not significantly affect the rooting of willow and cottonwood pole cuttings (Hoag 1991; Hoag et al. 1991; Hoag et al. 1992; Fenchel et al. 1988; Ogle 1990). Many willows and cottonwoods are very easy to root without special treatment. These treatments increase cost, labor requirements, and time necessary to plant without significantly increasing survival.

Pre-plant Soaking of Cuttings

Prior to planting, all cuttings should be soaked for a minimum of 24 hours, whether they are stored or harvested and immediately planted (Hoag 1991; Hoag et al. 1991; Hoag et al. 1992). Some research recommends soaking the cuttings for as much as 10-14 days (Briggs and Munda 1992; Fenchel et al. 1988). The main criteria is that cuttings should be removed from water prior to root emergence from the bark. This normally takes 7 to 9 days (Peterson and Phipps 1976). Soaking is important because it initiates root growth processes within the inner layer of bark in willows and cottonwoods.

Only the bottom 1/3 of the cutting need be placed in water. However, soaking the entire cutting is not detrimental (avoid soaking latex painted top if possible). Soaking can be accomplished in a garbage can, irrigation ditch, stream, pond, lake, or other body of water that is deep enough as long as the cuttings are protected from sun and wind exposure during soaking process. Soaking significantly increases the survival rate of the cuttings (Briggs and Munda 1992; Fenchel et al. 1988; Hoag 1991; Hoag et al. 1991; Hoag et al. 1992; Peterson and Phipps 1976).

Spacing Considerations

Plant the cuttings about 1-3 feet apart for shrubby types and about 6-12 feet apart for tree-types. In areas where you expect erosion, plant shrubby types 1-1.5 feet apart to better protect the banks. Exact spacing between tree-types further up the bank and shrubby types below should be based on crown characteristics and height. General ideas on spacing can be found in the Idaho Tree Planting Handbook. However, crowding cuttings a little will not stress them because they will not lack water and will provide better protection to the bank.

When to Plant

Willow and cottonwood cuttings have been successfully planted from early spring to late fall.

* Preferably, cuttings should be planted in early spring after spring runoff occurs in streams or after high water drops to typical levels on reservoirs, ponds, or lakes.

* Rooted stock should be planted in early spring after frost has left soil. See Idaho Tree Planting Handbook for additional information. Avoid planting cuttings or rooted stock in heat of summer because of the stress it places on them.

* When planting multiple sites along a stream, sites may need to be planted in different years.

* A successful planting on an inside meander could force water to the outside curve before planting on outside curve is fully established, thus increasing risk of failure.

- * Rhizomatous species often are planted on inside curves and once established can spread rapidly.

- * Consideration should be given to planting outside curves first and allowing time for establishment. Delay planting inside curve until two or three years later. The inside curve is often not eroding and will begin to heal without planting.

Planting Methods and Planting

Cuttings:

Tractor-mounted posthole diggers, one- or two-person posthole diggers, soil augers, planting bars, shovels, soil probes, or simply pushing the cutting into moist soil have all been used successfully to plant willow and cottonwood cuttings. When selecting the appropriate planting method, you should keep several things in mind.

- * It is essential to have good contact between cutting and soil for roots to sprout. Air pockets around the cutting will kill the roots.

- * Avoid damaging buds when inserting the cutting into the hole.

- * Additional soil may be needed to get good soil to stem contact. Preference should be given to native soil nearby to encourage mycorrhizal formation and/or nodule formation by nitrogen-fixing organisms.

- * Carefully tamp the soil around the cutting firmly several times as you fill the hole.

- * The planting depth will determine the planting method. Deeper holes will be easier with a power auger or a soil auger.

- * Experimentation with planting methods before starting will ensure the right equipment has been selected. This would also be a good time to train the planting crew on use of equipment, safety and planting techniques.

Clump Planting:

Clump plantings can be used in areas where heavy runoff occurs or where the water column directly impacts the vertical banks (personal communication, D. Ogle, Idaho-Utah Plant Materials Specialist, 1993). These areas are difficult to plant and establish with traditional methods.

- * The basic procedure is to locate clumps of willows that are accessible to a backhoe.

- * The backhoe digs up a clump of willows, travels back to the planting site, and places the willow clump in a predetermined location by pushing out a hole as it deposits the clump.

- * Generally, clumps are placed close together along the entire problem section of stream to keep water from cutting around the planting. Pulling or pushing soil from the streambank above willow clumps and packing it behind clumps will improve establishment success and assist in bank shaping.

- * Root bunches (sod) of rhizomatous grass species can be placed behind the willow clumps to speed up recovery time of the near vertical banks. Some minor bank shaping will improve establishment of the herbaceous material. Grass species can also be seeded by hand.

* Planting should be done following high water flows in the spring to reduce chance of ripping clumps out before the roots start to spread.

* Temporary protection, such as steel posts with woven wire, sunlight degradable netting, etc., may be necessary to hold willow clumps in place until they are well established which can take 2-3 years. Usually, this is only necessary in areas were high velocities impact the bank.

Other Planting Stock:

See the Idaho Tree Planting Handbook for information on planting nursery stock.

Permits

The landowner is responsible for all permits prior to any planting. The completed plan should be copied as needed and provided to landowner for submission to the state Department of Water Resources and/or US Army Corps of Engineers. Each state has specific permitting requirements and landowner is responsible for locating appropriate agency. Normally any work done in a stream channel requires notification and approval by these agencies and the issuance of permits before starting any work.

Management and Maintenance

Preserve or initiate management that will keep, maintain, and improve the planting and other riparian vegetation. Proper management is necessary to maintain healthy, competitive plants that function for the intended objectives. This is as important as the planting itself to ensure rehabilitation of the riparian area. Some maintenance will be needed on site for several years after planting. Vegetation should be evaluated and monitored annually. Some replanting will be needed in succeeding years. If you don't replant the first or second year, your continuous barrier could be jeopardized. Once water gets behind the willow line you have planted, it is extremely difficult to repair the damage.

Monitoring of the site is necessary so any in-stream dead organic material (i.e. old logs, dead root masses, branches, etc.) can be removed before stream flow is deflected or gravel bars form. It is much easier to prevent this kind of damage than it is to repair it. As willows age and start to develop their growth patterns, some will probably need to be trimmed or cut to stimulate smaller and denser growth. Subsequent trimming should be done in the dormant season so willows will not be slowed during the growing season. During the establishment period, leave standing dead branches in the clump plantings to reduce stream flow velocities, thus protecting the establishing clumps.

If livestock use the area, a grazing plan should be developed. Little to no grazing should occur during the establishment period. This can take 2-5 years depending on growing conditions. Larger planting stock may be more resistant to grazing pressure, but should be monitored closely to avoid serious damage.

Temporary fencing may be necessary to control livestock and wildlife use of the plantings during the establishment period. Permanent fencing is an option to prevent grazing by livestock and/or wildlife. Consideration should be given to the creation of "riparian pastures", i.e. grazing units that include riparian zones and flood plains as a majority of the pasture. These riparian pastures often include high maintenance fences as a result of heavy grazing pressure from both livestock and wildlife. Water gaps for livestock should be planned at inside curves. These areas have reduced erosion potential, are generally gravelly, and can be planted to a rhizomatous willow that will resprout easily. Access to water gaps can also be protected with gravel or concrete pads if heavy trampling problems arise or if water access at inside curves is not possible.

Finally it is critical to protect streamsides and plantings from continuous use during long winter feeding periods. Feed grounds should be located away from streamside areas. If this is not possible, the area should be fenced and water gaps provided so direct access to riparian corridor is controlled.

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