1996

# Factors influencing black cottonwood (Populus trichocarpa ) recruitment on the upper Clark Fork River western Montana

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## Recommended Citation

Clayton, Stephen R., "Factors influencing black cottonwood (Populus trichocarpa ) recruitment on the upper Clark Fork River western Montana" (1996). *Graduate Student Theses, Dissertations, & Professional Papers*. 6774.
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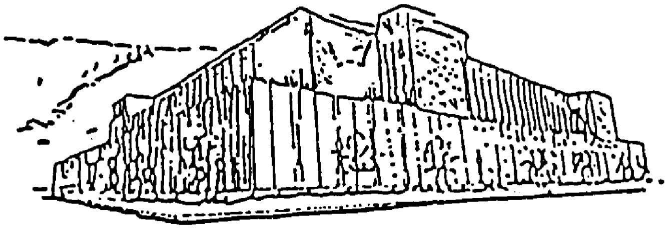

# FACTORS INFLUENCING BLACK COTTONWOOD (*Populus trichocarpa*) RECRUITMENT ON THE UPPER CLARK FORK RIVER, WESTERN MONTANA

by
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B.A. Stanford University, 1990
presented in partial fulfillment of the requirements
for the degree of
Master of Science
The University of Montana
1996

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5-9-96

Date

Clayton, Stephen R., M.S., May 1996 Resource Conservation

Factors Influencing the Black Cottonwood (*Populus trichocarpa*) Recruitment on the Upper Clark Fork River, Western Montana (93 pp.)

Director: Paul L. Hansen PLH

This study, conducted during the summer of 1995, examined factors influencing black cottonwood (*Populus trichocarpa*) recruitment on the upper Clark Fork River in western Montana. Because cottonwood seedling recruitment can be limited by an absence of bare alluvial substrate, I tested the effect of two site preparation treatments designed to create bare substrate—plowing by hand with a shovel and herbiciding with Roundup®—on cottonwood seedling recruitment. On an older, established point bar, the treatments had no significant (alpha=0.10) effect on cottonwood seedling establishment or survival. Although treatments to create bare substrate had no significant effect, the depth to the water table (measured with piezometers) at the time of seed release was highly correlated with seedling establishment ($r_s=0.789$, $p<0.0005$). Also, the rate of water table decline through the first growing season influenced where seedlings established and how long they survived on both the treated plots and on new sediment deposits. Although over 1,200 seedlings/$m^2$ established in some plots, few seedlings survived the summer. Highest cottonwood seedling survival occurred in those plots where the water table was within 20 cm of the ground surface during the time of seed release (early July) and where the water table dropped no deeper than 50 cm by early September. The first three weeks (June 30–July 19) were the most critical as seedlings only survived where the water table declined at an average rate of less than 0.5 cm/day. Over the next three weeks (July 19–August 9), some seedlings survived average drops of 2.0 cm/day. However, for the entire season, drops of about 0.5 cm/day led to greatest survival. Even though seedlings established at equal rates on sand (less than 2 mm) and gravel deposits, significantly more seedlings survived on the gravel. I cored 139 mature cottonwoods and mapped stands by age class in 25-year intervals. The oldest cored tree was 135 years, and the average lifespan of cottonwoods in the study reach appears to be about 100-150 years. Cottonwood stands occupy 22% of the riparian study area, and the site has one of the highest densities of cottonwoods on the upper Clark Fork River. However, only 5% of the area currently occupied by cottonwoods is covered by stands less than 50 years old, and, of this 5%, about 75% is covered by stands less than 10 years old. Potential factors contributing to the lack of younger trees are addressed, and opportunities for black cottonwood management and future research are discussed.

# ACKNOWLEDGEMENTS

Funding for this project was provided by The Nature Conservancy of Montana with additional support from the Riparian and Wetland Research Program at the University of Montana. I am very thankful to both organizations; without their support, this project would not have occurred.

Many individuals provided invaluable guidance at different critical stages of this research project. Thanks to my committee chair, Dr. Paul Hansen, and my other committee members, Dr. Ray Callaway, Dr. Don Bedunah, and Dr. Robert Ehrhart, for helping me define and develop my initial study direction and for advising me along the way. Bernie Hall and Bob Petty of The Nature Conservancy of Montana also helped me identify this study opportunity. I thank Mrs. Margaret Wallace for allowing me the privilege to access her property. At the University of Montana, Dr. David Patterson provided important statistical guidance and kindly loaned my some of his prized books, and Dr. Tom DeLuca allowed me to use the soils lab. A special thanks to my cousin, Jason Wonderlich, who spent two weeks of his summer with me when the going was getting tough and I needed a boost of energy. We had a good time coring big trees, fighting mosquitoes, and wading through a few wetlands, including one spot that ended up being over my head, let alone his.

This project would not have been successful without the support of numerous individuals associated with the Riparian and Wetland Research Program who pitched in and helped me throughout the project. Mike Merigliano and Brad Cook both spent time in the field with me and provided important advice while ensuring that I sought out my own answers. Bill Thompson and Bob Ehrhart did everything from loaning me tools to challenging my reasoning for certain parts of the study. Erik Ringelberg, Tom Parker, Jay Hall, and Ryan Benedetti were there to help me when I was stumped and rescue me when I encountered computer problems. Carol Winters helped me with logistical challenges throughout the summer. All the GIS analysis and maps in this report would not have been possible without the guidance of Jim Johnson and the hard work of Dalice McIntyre. Thanks to all.

Thanks also to my brothers, Mike and Joe, for their support and to our parents, Bill and Diane, for laying the foundation for my appreciation and respect of the natural world and encouraging me along the way. Finally, thanks to my wife, Jennifer, for her extraordinary patience, understanding, and support during this challenging project.

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# INTRODUCTION

## THE IMPORTANCE OF RIPARIAN ECOSYSTEMS

In the past 20 years, research and management activities related to riparian ecosystems have accelerated as the importance of these ecosystems has been recognized. Although riparian areas occupy less than one percent of the Western landscape (Knopf and others 1988), they provide many ecological benefits (Thomas and others 1979). Riparian vegetation contributes organic matter to aquatic food webs (Cummins 1974, Vannote and others 1980, Gregory and others 1991) and influences water quality by stabilizing streambanks, filtering sediment, and controlling water temperatures (Gregory and others 1991)—thus providing fish habitat (Meehan and others 1977). Riparian areas also provide habitat for many other species. More than three-quarters of wildlife species in eastern Oregon (Elmore and Betscha 1987) and in the Owens River in the Sierras (Kondolf and others 1987) depend upon riparian habitat. Neotropical migrants moving through Arizona use riparian areas for "stop-over habitat" (Stevens and others 1977). In California, riparian systems provide habitat for 83% of amphibian and 40% of reptile species (Brode and Bury 1981). In southern Alberta, riparian cottonwood forests provide habitat for over 40 mammal, six amphibian, and four reptile species (Rhodes 1991). In western Montana, 59% of the land bird species use riparian habitats for breeding purposes, and 36% of those breed only in riparian areas (Mosconi and Hutto 1982). Many endangered bird species depend upon riparian habitat (Laymon 1987). Knopf and others (1988) conclude, riparian vegetation "provides habitats for more species of birds than all other vegetation types combined."

These same riparian areas which provide important ecological benefits are also the focus of different, and often competing, human uses such as farming, grazing, logging, mining, water quality, and recreation (Thomas and others 1979, Hansen and others 1995). The cumulative impact of these uses may be most expressed, although not always visibly, through its effects on cottonwood trees (*Populus* spp.). Many cottonwood forests throughout western North America are aging, but not regenerating enough to maintain themselves (Rood and Mahoney 1993). Because cottonwoods are the dominant, and often exclusive, tree in many riparian areas of the West, the loss of the cottonwoods can have "catastrophic consequences" (Rood and Mahoney 1990). As Rood and Mahoney (1991) state, "If the cottonwoods die, so goes the entire [riparian] forest ecosystem." Thus, the problems affecting cottonwoods provide a specific example of some of the general problems plaguing riparian areas. By addressing the problems associated with cottonwoods, we may also, as a result, manage riparian habitat in a more responsible manner.

## THREATS TO COTTONWOOD ECOSYSTEMS

Cottonwood ecosystems have been impacted by many factors (Rood and Mahoney 1993). Dams alter the duration, magnitude, and frequency of floods; the rate of sediment deposition; and the rate of lateral channel migration (Leopold and others 1964, Dunne and Leopold 1978). These changes to the natural hydrologic cycle can decrease the recruitment of cottonwood seedlings and increase the mortality of older cottonwoods (Johnson and others 1976, Brown and others 1977, McBride and Strahan 1984, Fenner and others 1985, Bradley and Smith 1986, Rood and Mahoney 1990, Stromberg and Patten 1992).

Land uses which remove or modify vegetation, both in the uplands and in the riparian zones, affect cottonwoods directly and indirectly. Throughout the watershed, activities such as logging and mining can alter the natural stream hydrograph by increasing peak discharges and reducing the duration of runoff (Meehan and others 1977, Gordon and others 1992). In the floodplains, cottonwoods are cleared for timber, gravel mining, agriculture, and urbanization (Rood and Mahoney 1993). Groundwater pumping has been implicated in the death of mature cottonwoods and the prevention of seedling establishment (Johnson and others 1976, Fenner and others 1985), and diversions for irrigation can reduce summer flows, thus compounding cottonwood mortality. Extended low summer flows contribute to drought stress in seedlings and old trees (Rood and Mahoney 1993). Similarly, the depth of the groundwater affects the survival of older cottonwoods (Rood and Mahoney 1990).

Although riparian systems provide forage, shade, thermal cover, and water for livestock and wildlife (Elmore and Betscha 1987, Johnson 1992, Kay 1994), browsing and trampling by livestock (Crouch 1979, Shanfield 1981, Kauffman and Krueger 1984, Rhodes 1991, Rood and Mahoney 1993) and native ungulate populations (Chadde and others 1988, DeBell 1990, Kay 1994) have limited cottonwood regeneration. Browsing and trampling can remove protective vegetation, reduce bank stability, and increase erosion

(Glinski 1977, Meehan and others 1977, Crouch 1979, Behan 1981, Platts and Nelson 1985, Gordon and others 1992).

Riparian areas attract many people because riparian systems provide a variety of recreational opportunities, are physically attractive and often accessible, and are generally cooler in the summer (Martin 1981). Recreationists can increase erosion on trails and at access points for boating and canoeing (Martin 1981) and destroy vegetation with off-road vehicles (Barry 1981). Campgrounds have also been built in cottonwood gallery forests (Hansen and others 1995). To develop responsible management solutions to some of the factors threatening cottonwood ecosystems, we need to understand cottonwood ecology.

## COTTONWOOD ECOLOGY

Cottonwoods are not shade tolerant (Read 1958, Roe 1958, Everitt 1968, Behan 1981, DeBell 1990) and thus are unable to reproduce sexually in large numbers in their own shade. Although sexual reproduction with root sprouts is an extensive form of reproduction (Rood and Mahoney 1993), this method is only effective for about the first 20-25 years of the trees' lives (Read 1958, Wilson 1970). Essentially, asexual reproduction prolongs a stand but does not actually regenerate it (Wilson 1970, Behan 1981, Hansen and others 1995). Also, Stromberg and Patten (1992) found that most root sprouts were limited to those areas where considerable sunlight was reaching through the canopy. For these reasons which suggest that asexual reproduction is more of a short-term solution to cottonwood regeneration, I focused my study on recruitment of cottonwood seedlings by sexual reproduction.

For cottonwoods to survive in an area long-term, stands must be replenished on a landscape scale (Shafroth and others 1995) within a time period comparable to the species' life span (Mahoney and others 1991). As a pioneer species, cottonwoods rely on natural disturbance to regenerate and colonize new areas. Cottonwoods colonize alluvial bars along with willow (*Salix* spp.), and together these species persist until gradually the cottonwoods dominate over the willow thickets (Everitt 1968, Wilson 1970, Noble 1979). Once the cottonwood stands reach about 50 years of age, they begin to decline (Wilson 1970). They are succeeded primarily by green ash (*Fraxis pennsylvanica*) in North Dakota (Everitt 1968) and South Dakota (Wilson 1970) and eastern Montana (Hansen and others

1995) or by conifers such as Douglas fir (*Pseudotsuga menziesii*) or ponderosa pine (*Pinus ponderosa*) in western Montana (Hansen and others 1995). In cases where other tree species do not follow the cottonwood, the stands are converted to herbaceous communities (Behan 1981, Rood and Mahoney 1993, Hansen and others 1995).

Cottonwoods commonly live 100-150 years (Shaw 1976, Nanson and Beach 1977, Baker 1990) although they have been reported to live up to 200 (Shaw 1976, Behan 1981, Stromberg and others 1991) or 300 years (Merigliano 1996). Even though the reported maximum ages vary, the process by which cottonwoods establish is consistent. Unlike many species which regenerate periodically, cottonwood recruitment leading to long-term survival is episodic as demonstrated by the fact that mature trees in the same stand are of uniform age (Read 1958, Everitt 1968, Nanson and Beach 1977). The time interval between successful stand establishments can be quite long. Although many seedlings may establish in one summer, the chance of these seedlings surviving long enough to grow into a mature stand is quite low.

Bradley and Smith (1986) reported that stands of Great Plains cottonwood (*Populus deltoides* var. *occidentalis* Rydb.) established on the Milk River in southern Alberta about once every five years on average. Baker (1990) found that narrowleaf cottonwood (*Populus angustifolia* James) recruitment occurred about once every 10-15 years on the Animas River in southwestern Colorado. According to Stromberg and others (1991), successful Fremont cottonwood (*Populus fremontii*) recruitment takes place about once every 12 years on the Hassayampa River in Arizona. On the long extreme, Everitt (1995) found that only one Fremont cottonwood cohort which regenerated by seed has survived in the past century along an approximately 40 km reach of the Fremont River in southeastern Utah.

The establishment of cottonwood seedlings and long-term survival to form a stand, is influenced by many factors which vary temporally and spatially. (The word "seedling" is used in this thesis to describe a cottonwood plant which sprouted from seed and is in its first season of growth.) Although many seeds are released, seedling establishment is limited by hydrologic and geomorphic factors occurring before seed dispersal, during the first growing season, and during the subsequent winter and spring. For example, seeds must land on bare, moist substrate; seedlings must access adequate moisture during their first season; and seedlings must survive ice scour, inundation, and sediment deposition in subsequent years. Together this combination of limiting factors creates a small window of time for seedlings to establish in their first year and a narrow land area where they can survive long-term—thus the infrequent, irregular, and episodic recruitment.

The supply of cottonwood seed is rarely limiting. Black cottonwood begin flowering and producing seed at 10 years of age (Schreiner 1974). As "prolific seed producers" (Rood and Mahoney 1990), cottonwoods generate an abundance of seed (DeBell 1990). Behan (1991) reports production on the level of over 20,000 per ounce, and Bessey (1904) estimated that a mature cottonwood produced about 28 million seeds annually. Despite the tremendous production, cottonwood seeds only remain viable for about two weeks, and, even within this period, viability declines with age (Moss 1938, Engstrom 1948, Ware and Penfound 1949, Read 1958, Fenner and others 1984, DeBell 1990). Therefore, sexual recruitment becomes a function of timing and availability of sites for seedling establishment.

Cottonwood seedlings require moist, newly-deposited alluvium that is free of competition from other species and exposed to full sunlight (Read 1958, Roe 1958, Behan 1981, Hansen and others 1995). On moist ground, cottonwood seeds will germinate immediately, within 24-48 hours (Engstrom 1948, Ware and Penfound 1949, Read 1958, Fenner and others 1984, Shaw 1991). Germination can also occur if seeds are floating or resting in water (Hosner 1957), and seeds can survive up to 32 days of inundation with no measurable influence on germination (Hosner 1957). In contrast, seeds will not survive unless they have a constant supply of water during the first few weeks following dispersal (Ware and Penfound 1949, Read 1958, Schreinger 1974).

Cottonwood regeneration can be limited by the lack of bare, moist sediment deposits normally created by peak spring flows followed by reduced summer flooding (Bradley and Smith 1986, Rood and Mahoney 1990, Stromberg and others 1991, Everitt 1995). The bare, moist sediment required for seedling germination is deposited on active point bars as the high flows recede (Bradley and Smith 1986, personal observation). In addition to being deposited by floods, bare sediment can also be created by channel narrowing and channel meandering (Scott and others 1996).

Once bare substrate has been created by large flow events, the timing and quantity of subsequent runoff determines where seedlings establish and if they survive. Low flows in the spring may expose more of the active channel to seedling establishment (Stromberg and others 1991, Johnson 1994), but peak flows following seed release can kill seedlings which may have established (Johnson 1994). Seedlings require a constant supply of moisture so sustained moderate flows with a gradual tapering off throughout the summer are ideal. If the water table drops faster than the roots are able to access moisture, the seedlings will suffer drought stress and mortality (Fenner and others 1984, McBride and Strahan 1984, Rood and Mahoney 1990, Mahoney and Rood 1991, Mahoney and Rood 1992). Mahoney and Rood (1993) clearly summarize the ideal conditions for cottonwood seedling establishment: "A peak flow precedes seed release to prepare new seed beds. Initial stage decline is fairly rapid, exposing large areas that are moist and barren. The stage decline in the latter part of the critical period is slow enough that roots of the new seedlings are able to maintain contact with the receding water table."

Using models based on data from the Animas River in Colorado, Baker (1990) found that good seedling years (when lots of seedlings established but did not survive) were characterized by a cool and wet year, especially with a cool and wet fall, and these conditions occurred with a mean recurrence interval of about 3.4 years between 1914 and 1984. Stand origin years (when seedlings established and then survived long enough to grow and reproduce) were associated with years of both high spring flows and high fall discharges resulting from thunderstorms (Baker 1990). This supports Noble's (1979) observation that a sustained river elevation throughout the growing season contributes to seedling survival. Hydrologic conditions suitable for stand origin had a mean recurrence interval of about 12 years (Baker 1990).

As suggested by the longer time interval between stand origins than between good seedling years, seedling survival is limited by many other factors in addition to bare, moist substrate. Although seedlings closest to the active channel itself may have access to more moisture during the growing season, seedlings in this same location are also the most vulnerable to natural disturbances at other times of the year. In order for seedlings to survive, conditions must be "hydrographically quiet" (Everitt 1995) without extreme high or low flows in the few years following establishment. Ice scour during the winter can uproot young seedlings or break off their tops if the ice freezes around them and then floats up (McBride and Strahan 1984, Johnson 1994, Hansen 1996, personal observation). (See Scrimgeour and others [1994] for a hydrological and ecological review of the effects of river ice break-up on lotic ecosystems.) Winter survival is related to duration of inundation, amount of ice scouring, and plant age (McBride and Strahan 1984, Johnson 1994). Everitt (1968) reported that the lower limit of cottonwood distribution is determined by the plant's physiological tolerance to submergence, and Hosner (1958) found that cottonwood seedlings cannot survive inundation for more than 16 days. Shaw (1976) commented that inundation for this long is unlikely following seedling establishment, and he has observed that most seedlings and saplings can survive short-term flooding with no negative long-term effects, as long as the entire gravel bar is not washed away (Shaw 1991). Finally, seedlings and saplings must be able to survive being buried by sediment at an average rate of 16 cm/yr in the first 10 years following establishment (Bradley and Smith 1986).

As they mature, cottonwood saplings become less flexible than some willow (*Salix* spp.), white alder (*Alnus rhombifolia*), and mule fat (*Baccharis viminea*) species of the same age (McBride and Strahan 1984). However, as cottonwood root systems develop, the trees are better able to withstand drought conditions (Bradley and Smith 1986, Rood and Mahoney 1990). Ultimately, long-term survival is limited to establishment in locations along the river banks where the trees are low enough to access moisture yet high enough (or protected enough) to escape the detrimental effects of ice and floods (McBride and Strahan 1984, Stromberg and others 1991, Johnson 1994, Scott and others 1996).

## STUDY PURPOSE AND OBJECTIVES

Because of the ecological importance of cottonwood, I explored factors affecting black cottonwood (*Populus trichocarpa*) regeneration on the upper Clark Fork River. I focused my study on the effects of vegetative, hydrologic, geomorphic, and edaphic factors on the recruitment and survival of cottonwood seedlings during their first growing season. My approach to this study was both observational and experimental—from the beginning and throughout the summer. Before implementing any of my treatments, I spent several weeks exploring the study site by walking the entire river reach on both sides—watching how the river stage changed; observing where and how much the banks were eroding; looking at vegetation distribution patterns; finding signs of beaver (*Castor canadensis*), elk (*Cervus* *elaphus*), white-tailed deer (*Odocoileus virginianus*), and moose (*Alces alces*) activity; watching where the elk and cattle congregated and grazed; looking at the distribution of cottonwood stands; and watching the trees and shrubs leaf out.

The purpose of my research was to describe quantitatively and qualitatively the current condition of the cottonwoods and identify active management opportunities for improving cottonwood regeneration on the study reach of the Clark Fork River. To achieve this goal, I divided my research into three interrelated, but independent objectives; two were observational studies, and one was a controlled experiment. Each objective is previewed here and then developed in its own chapter of this thesis.

1) Describe the current age class distribution of the black cottonwoods by coring at least 125 representative trees and mapping the cottonwood stands by age classes.

2) Determine if active management steps could contribute to an increase in black cottonwood seedling recruitment by creating a bare seedbed using two site preparation treatments and monitoring the establishment and survival of the 1995 cohort of seedlings with respect to treatment and rate of water table decline.

3) Monitor the establishment and survival of the 1995 cohort of black cottonwood seedlings which establish on naturally-created, recent sediment deposits and determine if establishment and survival differ by soil texture or rate of water table decline.

## STUDY AREA

### History of the Upper Clark Fork Valley Since the 1800s

The Clark Fork River is located in the Northern Rocky Mountains in southwestern Montana. The study area is located along the upper Clark Fork River between the towns of Goldcreek and Drummond (Figure 1). Like many Western rivers, the upper Clark Fork River has been altered by human use for many years. The vegetation, hydrology, and geomorphology of the river have been influenced by years of mining, grazing, timber harvesting, agricultural diversions, and river channelization. Fur trappers first entered the upper Clark Fork in the 1820s, and beaver trapping lasted until the 1840s when the market for and supply of beavers declined (Horstman 1984). In 1831, Warren Ferris, a trapper in

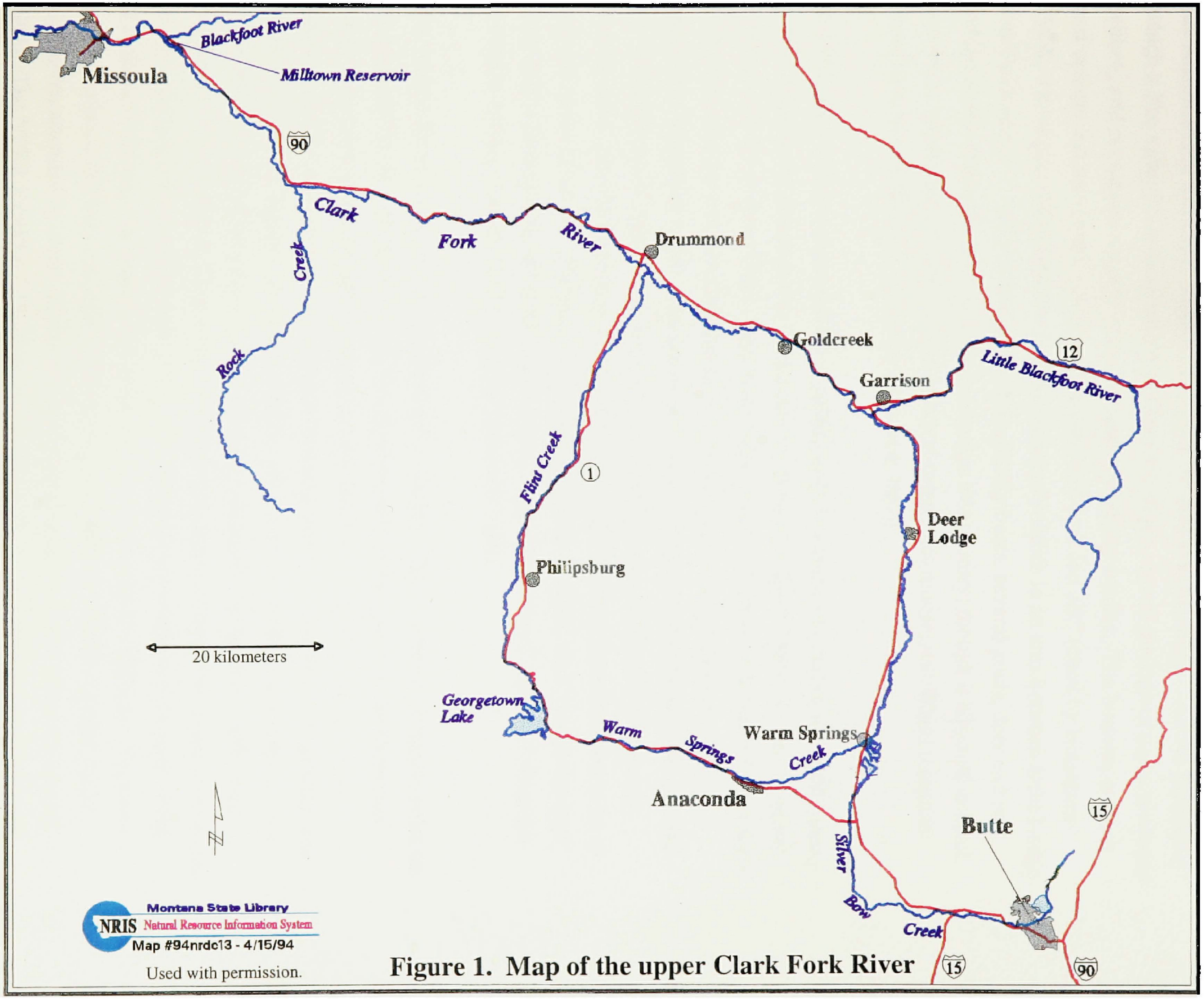

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Figure 1. Map of the upper Clark Fork River

the American Fur Company brigade, described the region in his diary: "All the streams by which it [the valley] is intersected are decorated with groves and thickets of aspen birch and willow, and occasional clusters of currant and gooseberry bushes. The bottoms are rich and verdant and are resorted to by great numbers of deer and elk" (cited by Horstman 1984). Ferris goes on to describe the abundance of wildlife in an area between Deer Lodge and Goldcreek: ". . . our hunters killed three grizzly bears, several goats, deer and two buffaloes; the latter, however, is seldom found in this country; though it abounds in black and white tailed deer, elk, sheep, antelopes and sometimes moose, and White mountain goats have been killed here" (cited by Horstman 1984).

In 1852, gold was first discovered in Montana in Gold Creek, and during the 1860s nearly every stream in the drainage was prospected for gold (Horstman 1984). In the upstream tributaries of Silver Bow Creek, Gold Creek, and other drainages, ditches and flumes were built (including one over the Continental Divide) to supply water for placer mining operations (Horstman 1984). The placers were soon replaced with hydraulic mining, the use of high pressure hoses to wash away whole stream banks and beds (Malone and Roeder 1976, cited by Horstman 1984). By 1872, the Clark Fork was described to be as "muddy as the Missouri" (Holmes 1931, cited by Horstman 1984) with "coffee-colored" water below Bearmouth, and Gold Creek carried "large quantities of 'tailings'" from the hydraulic mining (Smalley 1883, cited by Horstman 1984).

The Mullan Road, a wagon road connecting Fort Benton, the uppermost navigable point on the Missouri River, with Walla Walla, the uppermost navigable point on the Columbia River, was constructed through Montana in 1860 (Horstman 1984). The road was reportedly built rapidly in western Montana "partially due to the fact that little grading was necessary along the Upper Clark Fork. But in order to avoid grading around the river's bluffs, the road made many crossings of the river's meanders" (Hamilton 1957, cited by Horstman 1984). Between Deer Lodge and Missoula, the road forded the river seven times and crossed two bridges (Horstman 1984). The railroads soon followed the path of the Mullan Road through the upper Clark Fork valley. On August 22, 1883, the Northern Pacific Railroad (NPRR) was joined at the town of Goldcreek with the Golden Spike Ceremony, attended by many dignitaries, including former President Grant (Horstman 1984). The NPRR included 10 bridges on the upper Clark Fork between its confluence with the Little Blackfoot River and Missoula, and "at two points between Garrison and

Missoula, new channels were cut to straighten the river bed, while dikes of piles, brush and rocks were thrown across the old channel" (Smalley 1883, cited by Horstman 1984). A competing railway, the Chicago, Milwaukee, and St. Paul Railway (the Milwaukee), followed the same path and further manipulated the river. The Milwaukee Railroad was completed in 1908 only to have 120 km of newly-laid track washed out by a historically-large flood that same year (Horstman 1984).

Cattle were first brought to the upper Clark Fork valley in the 1850s, and in 1862-63 Johnny Grant was reported to have "3 or 4000 head [of cattle], besides horses and mules" (White 1966, cited by Horstman 1984). Many ranches were located in riparian areas, "the sheltered, well-watered drainages, near wild hay meadows for horse pasture" (Horstman 1984). Granville Stuart, writing between 1852-1864, observed that cattle were "fattened on grasses" during the winters in areas "without shelter other than that afforded by willows, alders and tall rye grass along the streams" (cited by Horstman 1984). Many prosperous cattle ranches existed in the 1860s, but "mountain ranges were also overcrowded and overgrazed by the early 1870's" (Horstman 1984), and overgrazing associated with droughts was reported again in the 1930s (Horstman 1984).

Agriculture developed to support the mining and ranching industries, and grain crops and hay were well-established in the Deer Lodge valley by 1870 (Horstman 1984). Later, as logging operations cleared the forests, more farms were developed (Horstman 1984). The railroads fostered development of the lumber industry, and in the 1880s mills were built in the upper Clark Fork valley to supply materials for building more railroads in western Montana (Horstman 1984). During the development of the upper Clark Fork watershed, riparian trees may have been used by miners and ranchers for fuel, fenceposts, and building materials—similar to the situation from the rest of Montana (Hansen and others 1995). However, I was unable to find any documents which specifically addressed historical use of cottonwoods in the upper Clark Fork region. (Shaw [1976] reported that settlers in southwestern Alberta found cottonwoods unsuitable for building materials because the trees were too crooked and subject to early decay; also, because the logs tended to smolder instead of burn, cottonwood made poor firewood [Shaw 1976]). Agricultural demands for irrigation, compounded by droughts, required water diverted from the Clark Fork River, and irrigation companies were formed along the river from 1860 to 1935 (Horstman 1984).

In the 1870s, copper was discovered in the silver mines at Butte, and in 1882 the copper market flourished as the demand for copper for recent inventions increased (Horstman 1984). Copper mining continued through the 1980s. The Dunkleberg Mining District, which includes some tributaries above the study site, was mined for silver, lead, and zinc (Alt and Hyndman 1986). Since the discovery of gold in 1852, well over a century of mining has left its mark on the upper Clark Fork River. The 100-year floodplain of the Clark Fork River from the river's origin near Anaconda to the Milltown Dam near Missoula, about 193 km downstream, is now on the National Priorities List (Superfund) because of concerns associated with heavy metals tailings. U.S. Interstate 90 now also follows a path through the valley close to that of the railways. Together the road and the railroads "straightjacket" the river, causing it to be functionally channelized for multiple stretches.

Despite this long period of heavy use, the upper Clark Fork watershed today continues to support ranching, hay production, timber harvesting, and limited mining. The river and its main tributaries (Little Blackfoot River, Flint Creek, and Rock Creek) are also popular with fishermen. During a one-year observational study in 1978 and 1979, the upper Clark Fork River recreational use was estimated at over 41,000 recreational visits, with fishing being the predominate use (Hagmann 1979). Based upon a mail survey, Montana Department of Fish, Wildlife, and Parks estimated over 30,000 angler days on the upper Clark Fork River in the 1989 license year (McFarland 1992). Also, unlike many Western rivers, the main stem of the upper Clark Fork River is not regulated by a dam.

### Study Site

I conducted the majority of my field research during the summer of 1995 on a reach of the upper Clark Fork River about 8 km downstream from the town of Goldcreek. Although I didn't find any gold as the miners had almost 150 years earlier, I did learn a lot about the ecology and hydrology of the area.

The study site is located on a private cattle ranch owned by the same family since 1865. The Nature Conservancy of Montana has acquired a conservation easement on some of the ranch property. The ranch, which is located in Powell and Granite counties, is approximately 88 km southeast (upstream) of Missoula. The river reach within the study site includes about 7 river km and is located approximately 1,246 m above sea level. Although I did spend time exploring three tributaries on the ranch which drain into the Clark Fork River to better understand the interconnectedness of the system, I focused my research and observations on the riparian habitat in the river's floodplain, an area of about 230 ha (Figure 2).

The vegetation in this reach of the upper Clark Fork River is typical of an alluvial floodplain west of the Continental Divide in the Northern Rockies (Hansen and others 1995). The main tree species are black cottonwood (*Populus trichocarpa*), quaking aspen (*Populus tremuloides*), Rocky Mountain juniper (*Juniperus scopulorum*), with occasional ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*). Shrubs include mountain alder (*Alnus incana*), water birch (*Betula occidentalis*), red-osier dogwood (*Cornus stonifera*), Drummond willow (*Salix drummondiana*), sandbar willow (*Salix exigua*), black hawthorne (*Crataegus douglasii*), currant (*Ribes* sp.), woods rose (*Rosa woodsii*), and common snowberry (*Symphoricarpos albus*). Grass and forb species include smooth brome (*Bromus inermis*), spikesedge (*Elerocharis* spp.), reed canarygrass (*Phalaris arudinacea*), field horsetail (*Equisetum arvense*), Rocky Mountain iris (*Iris missouriensis*), common cattail (*Typha latifolia*), curled dock (*Rumex crispus*), common dandelion (*Taraxacum officinale*), redtop (*Agrostis stolonifera*), common timothy (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), spotted knapweed (*Centarea maculosa*), Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia esula*), and common tansy (*Tanacetum vulgare*). Taxonomic nomenclature follows Dorn (1984) for willows (*Salix* spp.) and Hitchcock and Cronquist (1973) for all other taxa.

The geology of the area is mostly Tertiary basin fill with some Cretaceous sediments in the uplands (Alt and Hyndman 1986). Soils are primarily coarse, well-sorted alluvial deposits (loamy sand, Brady 1990) consisting of Entisols and Inceptisols (Cook 1995).
Climate data is from the NOAA Drummond Aviation station (No. 2500) located about 13 km downstream from the study site in Granite County at an elevation of 1,198 m. Continuous data is available for the station from 1963 to 1989. (I obtained provisional 1995 climate data.) The area receives an average of 340 mm of precipitation per year, with the majority of that occurring in the spring and summer. The 1995 summer and fall temperatures were relatively close to normal, but the precipitation was almost two times

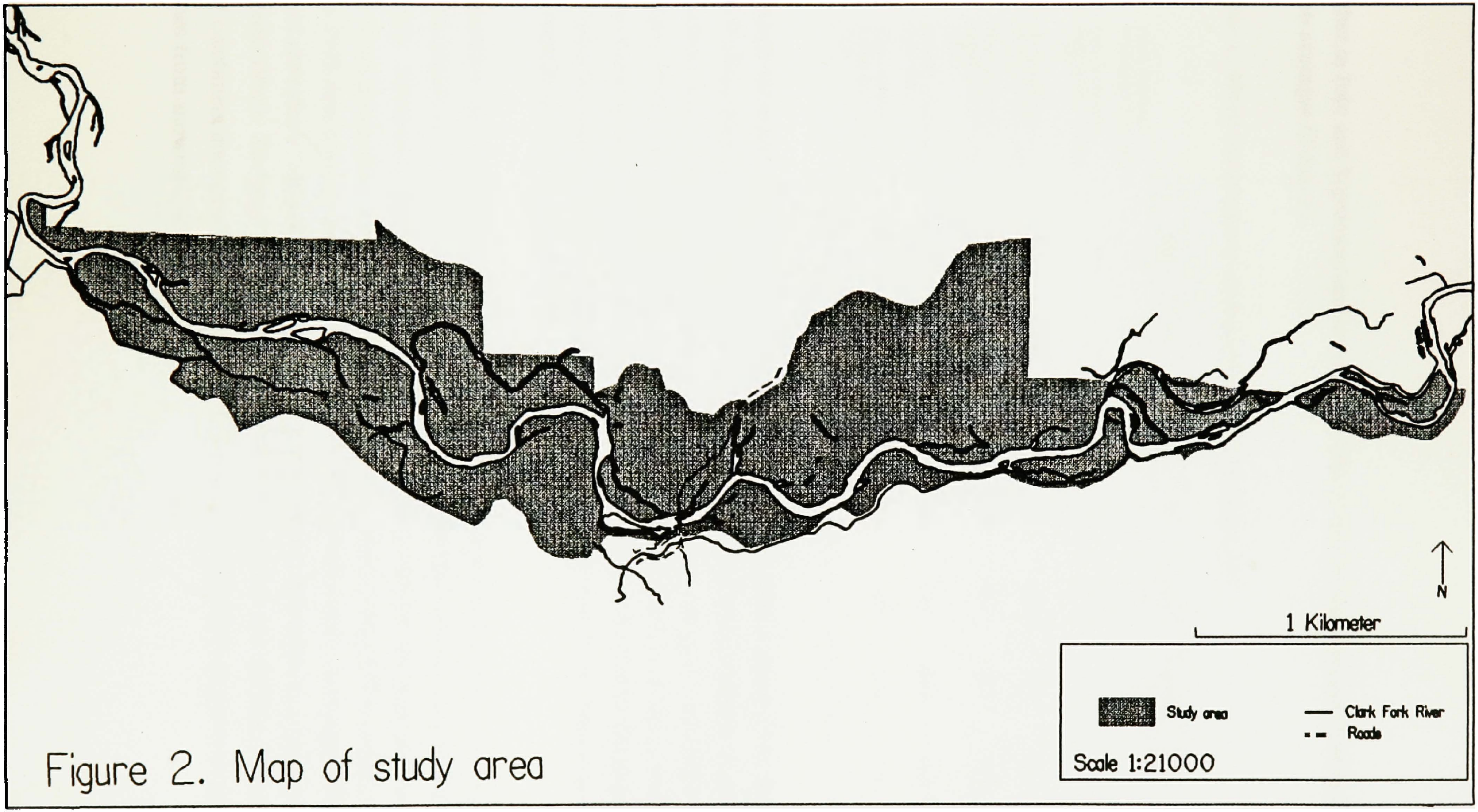

Figure 2. Map of study area

higher in July and September and two times lower in August and October than the long-term averages (Table 1).

Table 1. Mean temperatures and rainfall for Drummond, MT

| | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|
| Mean minimum temperature (°C) 1995 | -2.8 | 0.6 | 4.4 | 6.7 | 4.4 | 2.8 | -2.2 |
| Mean minimum temperature (°C) 1963-1989 | -2.2 | 2.2 | 6.1 | 7.2 | 6.7 | 2.2 | -2.2 |
| Mean maximum temperature (°C) 1995 | 12.8 | 18.9 | 22.2 | 27.2 | 27.8 | 22.2 | 12.2 |
| Mean maximum temperature (°C) 1963-1989 | 14.4 | 19.4 | 23.9 | 28.9 | 28.3 | 21.7 | 15.0 |
| Monthly precipitation (mm) 1995 | 23.6 | 36.3 | 48.3 | 58.2 | 14.7 | 69.9 | 11.4 |
| Mean monthly precipitation (mm) 1963-1989 | 25.9 | 44.7 | 50.8 | 30.5 | 34.8 | 31.8 | 20.6 |

Through the study reach, the river has an average channel width of about 27 m (Riparian and Wetland Research Program 1995a). The channel is composed primarily of gravel substrates and is meandering with a low gradient, point bars, and pools and riffles (C4, Rosgen 1994); some braided, wide sections with eroding banks (D4, Rosgen 1994) also exist (Riparian and Wetland Research Program 1995a). Using the FEMA designation, the 100-year floodplain averages about 912 m wide through the study reach (Riparian and Wetland Research Program 1995a).

Streamflow data used for the study reach is from the USGS Clark Fork River at Gold Creek station (No. 12324680) located 8.5 river km upstream from the study site in Powell County. There are no major tributaries entering the river between the gage and the study site. Continuous data is available from the site for the water years 1978 to present (water year 1995 data is provisional), and all data is reported as mean daily discharge (MDD), which provides a "reasonable combination" of peak flow and duration in a single parameter (Everitt 1995). The gage is located at an elevation of 1,269 m, and the river drains a 4,413 km$^2$ catchment above this point. The river has a mean flow of 523 cfs, most of which comes from snowmelt in the spring.

Similar to the management on many Western rivers, the study area is grazed by cattle. In addition, elk are abundant, and white-tailed deer, moose, and beaver are also present on the study site. For various reasons, I was unable to use exclosures to control for the influence of trampling and browsing by cattle and big game on seedling establishment and survival in this study. However, throughout the summer I monitored the location of the cattle and elk by observing the animals and signs of their presence to estimate the trampling and browsing pressure on the seedlings and saplings. The area which contained the study site where I applied site preparation treatments to monitor seedling establishment (Chapter 3) only had three cows and three calves in it for a few weeks in early July, and these animals were not observed near the experimental plots. Elk, however, were observed on the experimental plots on occasion. In contrast, from late April to winter at least 200 cows and calves were present in the areas where natural seedling establishment was monitored (Chapter 4).

# CHAPTER TWO:
# THE DISTRIBUTION OF COTTONWOODS BY AGE CLASS

## INTRODUCTION

Cottonwood forests provide an important habitat component for many wildlife species. Bald eagles (*Haliaeetus leucocephalus*) require the large branches of cottonwoods for nesting (Arno and Hammerly 1984), and colony-nesting great blue herons (*Ardea herodias*) nest in rookeries in cottonwoods (Parker 1980). Red-tailed hawks (*Buteo jamaicensis*) also nest in mature cottonwoods. Many cavity nesting birds, such as American kestrels (*Falco sparverius*), wood ducks (*Aix sponsa*) and neotropical migrants, also rely on older cottonwoods. Elk and moose may eat cottonwood bark and buds in the winter and rely on cottonwood stands for cover (Costain 1989, Kay 1994). Beaver also use cottonwood for food and building materials (Allen 1983). All of these species were observed using the cottonwood forest habitat in the study area.

The study area contains some of the best remaining cottonwood habitat along the upper Clark Fork River. Cottonwood is absent from much of the upper Clark Fork above the study site. Not until about 21 river km upstream of the study site does the average percent canopy cover of cottonwood increase above 2% of the total riparian-wetland hectares (lands within the FEMA 100-year floodplain to which inventory access was allowed) (Riparian and Wetland Research Program 1995a). In the study region, mean cottonwood cover is 17%, and beyond this subreach average cottonwood canopy cover is not above 17% for another 80 river km (Riparian and Wetland Research Program 1995a). The structural cover provided by the cottonwood forest on the study site benefits many species at this time, but the cottonwood stands appear to be maturing in age and declining in health. To complement the other components of my research, which focused on cottonwood seedling establishment, I measured the current age and distribution of cottonwoods on the study site to establish a historic record.

Because cohorts establish episodically, tree age obtained by ring counts from cores taken with an increment borer can be used for mapping (Everitt 1968, Nanson and Beach 1977, Merigliano 1996). The age of a stand generally increases with increased distance from the channel (Everitt 1968, Bradley and Smith 1986), and the age of the stands can be used to help determine historic channel locations and rates of channel movement (Everitt 1968, Nanson and Beach 1977, Merigliano 1996).

Using mapping as a tool, I examined the current temporal (tree ages) and spatial (tree locations) distributions and asked the following questions. What is the current age class distribution of cottonwoods along this reach? How old are the mature trees? Where are they located? Are there stands of young cottonwoods (seedlings, saplings, and poles)? Where are the younger stands located? Could past and current management on the study site be affecting the cottonwood regeneration?

# METHODS

## Stand Mapping and Core Sampling

I quantitatively described age class distributions of cottonwoods at the study site by coring trees and mapping locations of stands by age. Using aerial photos from a 1988 flight of the Clark Fork River (9/8/88; Flight 153.719; 9-4015; 6 Lens 137503) at a scale of 1:6000, I made color copies at 200% magnification. Before going into the field, I divided the maps into polygons which corresponded with polygons used for a previously-conducted riparian inventory on the property (Riparian and Wetland Research Program 1995a). I chose to use the same large-scale polygon delineation process so that my age class data would complement the earlier work.

Once in the field, I divided each polygon into stands by selecting trees that appeared to be in the same cohort. Working with my aerial photos, I developed and used the following protocol for defining a stand and for selecting representative trees to sample. To count as a stand, there had to be a minimum of 10 trees (including root sprouts). I spent time walking around and through each area to find clues to help delineate the stand such as a row of trees running along a small, curved depression (often an old oxbow). I also drew the boundary of each stand on my maps. If one tree or a few trees were alone, but within one tree height of another stand, I included them in the adjacent stand.

The original land area of each stand was most likely larger, especially for older stands which have since had trees knocked down by river channel movement, beaver, wind, or old age. (The longer a tree lives, the greater its probability of being knocked down; Everitt

[1968] terms this process "exponential decay of area" after the curves used to describe radioactive decay.) However, I was interested in determining the amount of area currently occupied by each age class so, in the field, I drew my stands to only include live, standing trees.

I classified stands as "seedling" (less than 1.4 m tall or less than 2.5 cm dbh [1.5 m]); "sapling" (greater than 1.4 m tall and 2.5-12.7 cm dbh); "pole" (12.7-22.9 cm dbh); or "mature" (greater than 22.9 cm dbh) (Riparian and Wetland Research Program 1995b). Although in theory all the trees in one stand established at a similar time so each stand could only be assigned to one category, I had some stands which ended up having trees which fit the sapling, pole, and mature categories all in one stand. In these situations, like Everitt (1968), I attributed the smaller sizes to being root sprouts, and I assigned the stand to the age class of "mature." In cases where "seedling," "sapling," and "pole" existed together, I assigned the stand the youngest category I used for mapping (≤25 years).

I used a systematic procedure to select the sample trees from each stand. The trees which I cored had to represent trees from the date of stand origin (not root sprouts) (Everitt 1968) and had to meet the following appearance criteria:

- mature relative to other trees in the stand (greater than 22.9 cm dbh [Riparian and Wetland Research Program 1995b]; darker-colored, deeply-furrowed bark extending high up the tree [Merigliano 1995]; taller; and distinctly larger dbh)
- healthy (less than 30% of the canopy was decadent [Riparian and Wetland Research Program 1995b] and not rotten sounding when thumped with rock at dbh)
- no (or limited) beaver damage

I cored representative trees with a 12.7 mm diameter, 50.8 cm long increment borer by taking one core sample per tree at dbh, measured the dbh, and noted anything special about the tree (e.g. site of red-tailed hawk nest). I cored one to four trees per stand depending upon the size of the stand, and I cored a total of 139 mature cottonwood between July 2 and August 8.

Using methodology developed by Merigliano (1995), I dried the cores in a core box, glued them into boards which I had routed out, and then sanded the cores with 120-600 grit sandpaper. I counted the growth rings by using a 10x hand lens and bright light and graded the cores by quality (poor, fair, good, and excellent) and whether or not I had hit the pith.

The diffuse-porous (Sigafoos 1964) wood of cottonwoods makes the rings very difficult to define in the cores compared to the distinct rings in ring-porous wood (Everitt 1968). The issue of whether cottonwoods have false rings has not been resolved. Everitt (1968) questioned whether the rings visible in the wood were annual in origin and suspected that more double or absent rings may occur in climatic stress environments. Ultimately, Everitt (1968) concluded that, along the Little Missouri River, false rings and absent rings "cancel each other out fairly well, so that roughly one growth ring is produced, at least in the more vigorous younger trees." Mahoney and others (1991) compared cores and disks (stem cross sections) and concluded that cores underestimate tree age by about 7 years for trees 100 years old. Stromberg and Patten (1990) used annual ring widths to model growth response of black cottonwoods to hydrologic variables, and Johnson and others (1976) used tree cores from cottonwoods and other species to compare mean annual growth rates.

Even though the most accurate age data can only be obtained by excavating the original root flare because of tree-to-tree variation below ground (Scott and others 1996), many researchers have used the coring procedure for comparing relative tree and stand ages in cottonwoods (Everitt 1968, Shaw 1976, Nanson and Beach 1977, Bradley and Smith 1986, Baker 1990, Stromberg and Patten 1992, Everitt 1995, Merigliano 1995). Aside from root flares, core rings may be the best measurement. Everitt (1968) found that "ring counts differed by no more than 10 percent in each grove, although tree diameters and heights varied by as much as a factor of 5."

Using the GIS software PAMAP 4.2 (Essential Planning Systems 1995), I digitized the stand boundaries by using the original 1988 aerial photo set as my base map. Although I was not within the accepted parameters of error for registering my photos into GIS (0.01% for skew and 0.03% for scale mismatch, Essential Planning Systems 1995), I decided that in the end I would be more accurate by using the digitizer instead of freehand drawing a map and the stands and then calculating the stand area with a planimeter. I mapped each tree by putting its age on its location and each stand by its age class, keying off the oldest core age for each stand because any younger ages are likely from root sprouts and are not stand origin trees (Everitt 1968). Pole, sapling, and seeding stand ages were assigned by observation of height, some ring analysis (n=55), and stem diameter. After looking over my original field notes, the aerial photos, and the working GIS maps, I redrew several stand boundaries to better represent the stands by age class. To determine the area currently occupied by each age class, I assigned stand age classes in intervals of 25 years (≤25, 26-50, 51-75, 76-100, 101-125, ≥126) (Everitt 1968, Merigliano 1996) and used PAMAP to calculate the respective areas.

### Statistical Analysis Methods

Although I cored a total of 139 trees, only 83 (60%) of them met the core quality standard I developed for analysis. I only used cores where I had hit the pith and which I had graded as "good" or "excellent" (basically there could not be any decomposed or missing sections and the rings had to be clear). Shaw (1976) also reported that about 40% of the trees he cored had heart rot, and Cordes (1991) also experienced difficulty in aging older cottonwoods because of rotten cores. I used Pearson correlation analysis (Hamilton 1990) to compare dbh and age.

I mapped the locations of all 139 trees that I cored, but I only used the data from the 83 best cores for assigning stand ages (described in the previous section) and computing the summary statistics. Because I assigned stand ages to wide intervals (25 years) (Everitt 1968, Merigliano 1996), any minor discrepancies in age should be negligible in the mapping (Everitt 1968). However, rather than performing statistical comparisons between stands assigned to the broad age class intervals (Harper 1977), I focused on characterizing factors influencing cottonwood ecology in the study area.

## RESULTS

Approximately 22% of the 230 ha of total riparian area on the study site is currently occupied by cottonwood. This is consistent with the 17% figure for this river subreach reported by the Riparian and Wetland Research Program (1995a). The cottonwoods ranged in age from 1 to 135 years. Figure 3 shows the stands by age class for the upstream reach, and Figure 4 shows the same for the downstream reach (the bridge

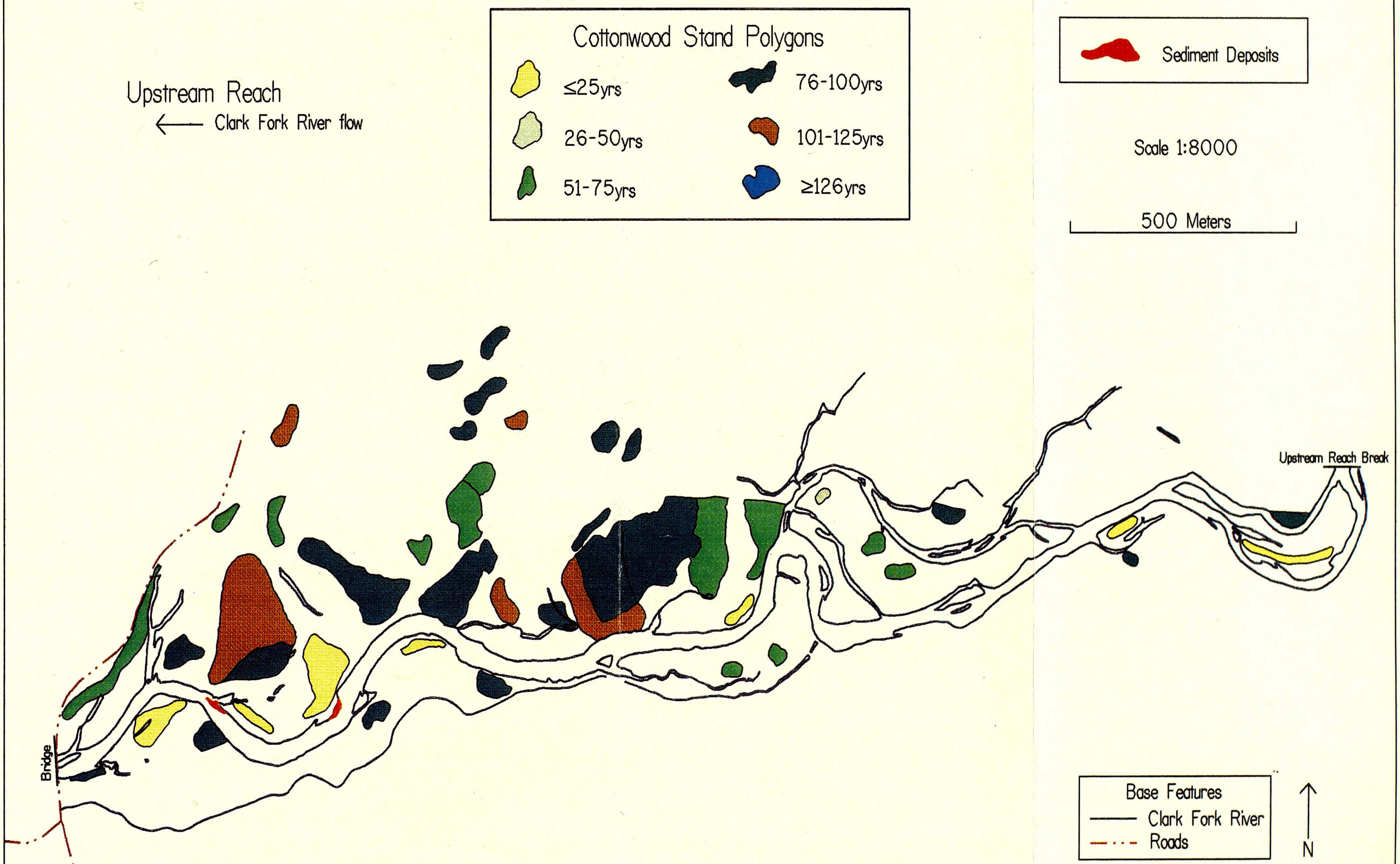

Figure 3.
Plan view of cottonwood stands and sediment deposits in the upstream reach

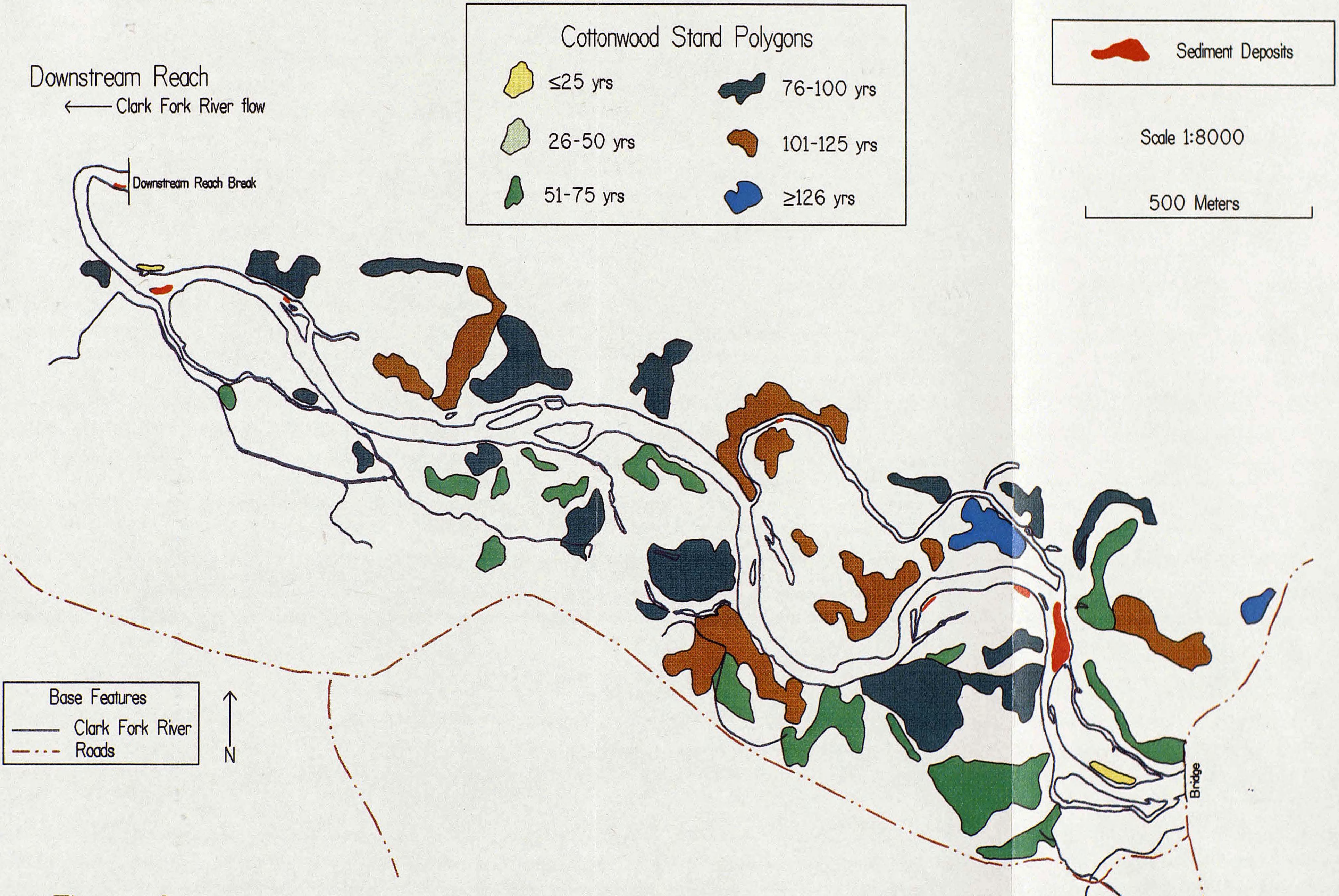

Figure 4.
Plan view of cottonwood stands and sediment deposits in the downstream reach

crossing the river serves as the break point). Because I only mapped currently standing trees, the maps show more patch-shaped stands of trees than traditionally-expected arcuate bands of trees. Also, because I grouped trees which were further away than one tree length from each other into separate stands, I may have "fractured" stands which would have been "joined" by any trees which have since been blown over or cut down by beaver. Similarly, trees on two sides of historic overflow channels (visible in aerial photos), ended up being put into separate stands instead of the same stand. These factors may have contributed collectively to the non-traditional stand shapes.

The distribution of stands on the maps is somewhat consistent with previous observations that stands further from the channel are generally older (Everitt 1968, Bradley and Smith 1986). Although this situation does not jump out from these maps when looking on a large scale, it becomes more apparent on a smaller scale. For example, in examining individual meanders, younger stands are often present more on the inside of turns (where the sediment is being deposited on point bars), and older stands are more common on the outside of the meanders (where the channel is migrating toward and will, in time, wash away the older trees). Cases where old trees separate young trees from the channel may be an artifact of my sampling methodology. Because I only cored trees that did not sound rotten, I probably biased myself away from stand origin trees and toward root suckers even though both visually appeared mature. Finally, the maps show a marked lack of young stands (≤25 yrs) in the downstream reach compared to the upstream reach.

Figure 5 shows the amount of total cottonwood area currently occupied by each age class. The age class of 76-100 years occupies the most land area, 21.8 ha, which is 42% of the total 51.8 ha of land currently occupied by cottonwoods. Only 2.4 ha (5%) is occupied by stands younger than 25 years, and, as mentioned above, the majority of these stands are located adjacent to the river in the upstream reach. The smallest area is occupied by stands in the 26-50 year age class.

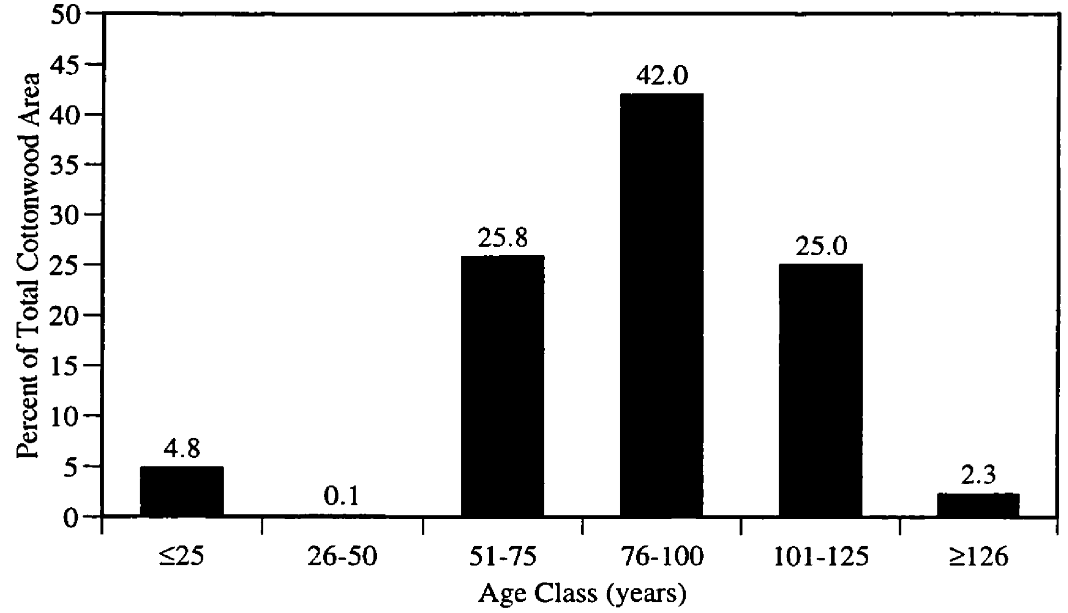

Figure 5. Percent of total cottonwood area currently occupied by each age class

The mean age of the mature trees along the entire study area was 78 years with a minimum of 30 and a maximum of 135. The maximum age for trees in the area appears to be about 150 years, but the average life span is probably about 100-150 years. Mean dbh of mature trees was 56.6 cm. Although dbh is sometimes used as a predictor of age for cottonwoods (Brady and others 1985), the practice is normally discouraged because of the lack of correlation in this species (Everitt 1968, Mahoney and others 1991, Stromberg and Patten 1992). I too found little correlation between dbh and age (r=0.453).

## DISCUSSION

The summary statistics I calculated for the ages of mature cottonwood trees on the study site are likely underestimates of the true respective population ages for several reasons. First, the coring height at which the sample was taken (1.5 m) is influenced by many factors, such as the time required to grow to coring height, browsing by cattle and wildlife, and cutting by beaver. Second, the deposition of sediment around the trunk over time affects the dbh height. Bradley and Smith (1986) estimated that sediment was deposited on point bars at an average rate of 16 cm/yr for the first 10 years and then 2 cm/yr for the next 80 years. Nanson and Beach (1977) had reported a much lower mean sedimentation rate of

6.1 cm/yr over a longer time period of 50 years, and then 0.8 cm/yr for about the next 200 years. However, despite the different rates, after 80 years, the amount of deposited sediment would be about 3.2 m in both cases. Shaw (1976), however, found no correlation between tree age and depth of sediment, and he attributed this to the high degree of variability of floods between stands. Third, the quality of the cores influences the age estimates. I missed the exact pith on some cores, and the subsample of cores which I was able to analyze excluded those from trees with cellularly decomposed centers, which presumably come from older trees. This assumption is also supported by Everitt's (1968) observation that counts greater than 100 are likely underestimates of true age.

Even though the relative ages may be conservative, they are useful for gaining a general idea of how old the cottonwoods are on the study site. These ages are consistent with some of those reported for other cottonwood species at other locations. Shaw (1976) found that narrowleaf cottonwood and balsam poplar (*Populus balsamifera*) live 100-150 years on rivers in southwestern Alberta, and Nanson and Beach (1977) also reported that balsam poplar live 100-150 years on the Beatton River in northeastern British Columbia. Baker (1990) reported a similar maximum age for narrowleaf cottonwood on the Animas River in southwestern Colorado. On the Missouri River in Montana, Behan (1981) reported that plains cottonwood can live as long as 200 years, and Stromberg and others (1991), working with Fremont cottonwood in the Southwest, also found that 200 years is about the maximum age. Merigliano (1996) aged many black cottonwood on the South Fork of the Snake River in Idaho that were older than 200 years and some that were almost 300 years old. However, growth slows substantially after about 80 years, and the trees begin to appear old after 150 years (Merigliano 1996). I was unable to find any studies, other than the present one, which reported cottonwood ages on the upper Clark Fork River.

Some cottonwoods on the study reach of the upper Clark Fork River may be living longer than the maximum age I reported. However, from the general appearance of the cottonwoods on the study site and from the amount of rotting observed in the cores, I suspect that many of the trees along the study reach are approaching their maximum age. Even though Merigliano (1996) also reported a similar appearance of old age after 150 years, he found much less cellular decomposition in the core samples, even in the trees almost 300 years old. The difference in maximum ages across various regions may be a function of moisture and the associated susceptibility to fungi (Merigliano 1996) or climatic factors such as wind, winter temperatures, or some combination of these factors and others (Hansen 1996).

The lifespan of cottonwoods on the study site may be a function of several other factors as well. Older cottonwoods may not be as present in the study area because around the turn of the century many pole and mature trees may have been harvested for fuel or building materials (Riparian and Wetland Research Program 1995a). Consequently, any trees present today would have needed to be too small to be of useful value at that time in order to escape harvest and continue to grow. Cottonwoods may have also been cleared for agriculture. Other factors, such as tailings from historic mining activity and past and current agricultural diversions, may also influence the lifespan of the cottonwoods.

The marked lack of trees in the 26-50 year age class and the distribution of these young stands may be a function of several independent or related factors. Part of the lack of stands in the 26-50 year age class may be an artifact of my sampling methodology. I did not core trees less than 22.9 cm dbh, and many of the trees in this age class may have fallen into this size class. Also, when found with mature trees, poles were attributed to being root sprouts, and the stands were assigned to the age class of the larger dbh, and presumably older, trees. However, just because I did not core pole-sized trees does not mean I failed to look for and map them. The few poles that I did find were growing with seedlings and saplings, and, because the poles did not appear to be older than 25 years, I assigned the stands to the ≤25 year class. I did not find any stands that were solely pole-sized trees.

Despite the limitations of sampling, several other factors may have reduced the abundance of younger trees. Interestingly, of the 4.8% of trees in the ≤25 year age class, almost 75% are less than 10 years old—based upon field observations and ring counts of established seedlings and saplings. The presence of saplings younger than 10 years old and the absence of trees 10-50 years old suggests at least three possible causes. First, seedlings and saplings are establishing, but not living beyond 10 years. Second, regeneration occurred during those 40 years, but the trees were subsequently removed. Third, there was a 40-year gap in recruitment. Although relatively-long gaps (40 years) between periods of cottonwood recruitment can occur (Scott and others 1996), the causes of these gaps are not well understood, and the broad 25-year intervals complicate attempts to distinguish the exact periods of recruitment (Harper 1977).

The presence of trees younger than 10 years may be a function of past and current livestock and wildlife management practices on the study site. Seven of the nine young (≤25 years) stands are located upstream of the bridge even though my preliminary analysis of additional sediment deposition data (Riparian and Wetland Research Program 1996) suggests that the amount of surface area of sediment deposits in the upstream and downstream reaches is similar. Based upon my observations, grazing pressure is greater downstream of the bridge and on both the north and south sides of the channel. At least 200 cows and calves were in this area from late April until winter. In contrast, upstream of the bridge, cattle do not have access to the north side of the river. And, on the south side, the furthest upstream portion of the river is fenced to limit cattle watering access to a specific area, and I only observed three cows and their calves in the lower portion for a few weeks in early July.

The existing vegetation suggests that past management also varied by region of the study area. For example, red-osier dogwood, a preferred browse species and indicator plant for determining riparian health (Hansen and others 1995), is abundant in some sections upstream of the bridge, but absent from most sections in the downstream areas. In the downstream reach, vegetation indicative of heavy grazing, such as common snowberry and woods rose, dominates (Hansen and others 1995). Similarly, the northeast section (upstream and north side) has a diverse shrub and tree composition, and it includes multiple canopy layers. By comparison, the southwest area (downstream and south side) is composed mostly of a single canopy layer of older cottonwoods with a herbaceous understory, and juniper is the only tree that appears to be reproducing successfully there.

But, if it is assumed that grazing management (e.g. number of head and rotation patterns) has been consistent for many of the almost 150 years of ranch operation, the lack of cottonwoods in the 10-50 year age class seems to be an anomaly. Wildlife may have had an effect. Elk populations were reported to be as high as 900 animals (compared to an estimated carrying capacity of 300 head) at times during the past 25 years (Nielsen 1996) and browsing by elk may have contributed to the 40-year gap. However, the potential impacts of cattle and elk on cottonwood were not quantified in this study.

Hydrologic factors may have also caused the apparent 40-year gap. A high ice flow event may have scoured out all stands near the channel. Therefore, even if pole-sized trees had established 10–50 years ago, they would not have been present when I sampled. Climate may have contributed to a 40-year period of no recruitment. The lack of trees 10-50 years old may not be due to a 40-year lack of high flows large enough to create sediment deposits. However, if several of the years in which high flows occurred were also years in which cold spring temperatures killed cottonwood flower buds, the production of seed could have been reduced enough in those years to prevent seedlings from establishing even though sediment was available (Patten 1996).

## SUMMARY

Cottonwood trees growing in the study reach appear to be living a maximum of 150 years, but little regeneration is occurring as evidenced by the age class distribution. If stands were being replenished at a rate roughly equal to that which they are maturing, then more of the total cottonwood area would be occupied by stands less than 50 years old. Currently, less than 5% of the total cottonwood area is occupied by stands younger than 50 years old. Many independent or related factors may have contributed to this lack of young stands. The lack of younger stands suggests that some steps may need to be taken to ensure that cottonwood can regenerate along this study reach and the rest of the upper Clark Fork River. To investigate the potential for active management to promote seedling recruitment, I developed an experiment that is explained in Chapter 3.

# CHAPTER THREE:
# THE INFLUENCE OF SITE PREPARATION AND WATER TABLE DECLINE ON COTTONWOOD SEEDLING RECRUITMENT

## INTRODUCTION

Many factors control when and where cottonwoods regenerate; however, some factors may have a greater influence than others. Because regeneration appears to be limited more by timing and site availability than seed availability (Chapter 1), I focused the present component of my research on the effects of bare substrate and level of the water table on the survival of newly-established cottonwood seedlings during their first growing season. Although I collected the data for these factors at the same time, I developed the experiment so that the influences of these two factors on seedling survival could be studied both independently and together.

### Bare Substrate

To offset some of the negative impacts to cottonwoods (Chapter 1), active management steps may be required to help facilitate cottonwood regeneration. One such approach could focus on increasing seedling recruitment and survival (Lee and others 1991, Friedman and others 1995). Cottonwood seedling vigor is reduced by competition for moisture, especially that from sod (Read 1958, Behan 1995), and herbaceous growth in the spring can reduce the availability of sites for cottonwood germination (Crouch 1979). Therefore, active site preparation has been proposed as a method to reduce this vegetative competition by creating bare surfaces for seedlings. For example, appropriately-located river terraces could be plowed or scarified to reduce the coverage of grasses and small shrubs and create a bare seedbed, thus simulating the deposition of sediment by floods or the scarifying effect of ice (Brown and others 1977, Behan 1981, Rood and Mahoney 1990, Tiedemann 1994, Friedman and others 1995). Cottonwoods have been observed to sprout in disturbed or artificially-clearly moist soil areas along river channels (Everitt 1968, Hansen 1996, Tiedemann 1996, personal observation).

After designing and implementing the study, I learned about the only other site preparation study I know of which was conducted by Friedman and others (1995). Working along Boulder Creek in Colorado, they tested the effects of site disturbance and irrigation on cottonwood seedling survival along the stream banks. To prepare a bare seedbed, they removed the top 16.5 cm of sod using a track-mounted excavator. They found that site disturbance alone resulted in greater seedling densities after one growing season. (As would be expected, they also found that seedling densities were greatest in those plots which were both disturbed and irrigated.) However, the long-term practicality of this type of site disturbance is questionable, and the removal of the top soil layer, as the authors also admit, could have many other effects that could confound the results (Friedman and others 1995).

Based upon the past observations, I designed my study to address questions such as the following. Does vegetative competition limit the establishment and survival of cottonwood seedlings? Is it possible to artificially create the bare substrate conditions required for cottonwood regeneration? If so, which site preparation treatments would be the most effective? Does seedling survival differ depending upon what treatments are used? Ultimately, answers to these questions could be applied to help increase the amount of land surface available to cottonwoods for regeneration in riparian zones which are typical cottonwood habitat.

### Water Table

On the same plots where I applied the treatments to create a bare seed bed, I also monitored the water table to assess the effect of water table decline on cottonwood growth and survival, a factor in need of more study (Mahoney and Rood 1992). Several studies have looked at the relationship between a constant water table and plant growth. Working in a greenhouse, Mueller-Dombois (1964) reported that an optimal depth to water table existed for conifer seedling growth and that the optimal depth differed for each species. Using planters, Schwintzer and Lancelle (1983) found that wax-myrtle (*Myrica gala*) biomass was greatest on sandy soils with a water table within 15-29 cm of the surface and that plants growing on a very high water table (within 3 cm of the surface) had the lowest biomass, presumably because of low aeration. At depths beyond 29 cm, growth was increasingly limited; however, root length did increase as the depth to water table increased (Schwintzer and Lancelle 1983). In a planter experiment with a consistently declining water table at different depths, Shafroth and others (1995) found that few cottonwood seedlings survived the first growing season when the water table started more than 30 cm below the surface.

Some studies have addressed the influence of a dynamic water table on the establishment and survival of cottonwood and willow seedlings. However, most of these studies on a dynamic water table have been limited to greenhouse, common garden, and planter experiments (Table 2), and the studies have focused on cottonwood species growing east of the Continental Divide and in the Southwest. I was unable to find reports of any cottonwood studies done west of the Continental Divide in Montana which focused on seedlings of black cottonwood, the dominant species in western Montana (Hansen and others 1995). Research has been conducted on black cottonwood in northern Idaho by Mosley and Bursik (1994), in southeastern Idaho by Merigliano (1994), and in southwestern Idaho by Tiedemann (1986).

Table 2. Reported rates of survival and root growth for first-year cottonwood seedlings in various lab and planter experiments with dynamic rates of water table decline

| Reference | Experimental Design | Populus species | Soil texture | Mean root growth rate (cm/day) | Fastest rate of water table decline that seedings can survive* (cm/day) | Optimal rate of water table decline for seedling survival (cm/day) | Mean maximum taproot length for first growing season (cm) |
|---|---|---|---|---|---|---|---|
| Fenner and others (1984) | rootboxes in greeenhouse | P. fremontii | not reported | 0.6 | not reported | 0.6 | 72-162 (theoretical) |
| Mahoney and Rood (1991) | rhizopods in lab | P. deltoides x P. balsamifera | "half sand, half gravel" | 0.4 | 2.0-4.0 | 1.0 | 17.5 (observed when harvested after 46 days) |
| Stobbs and others (1991) | rhizopods in lab | P. deltoides x P. balsamifera | "1 part sand to 2 parts gravel" | not reported | 4.0 | 1.0 | not reported |
| Segelquist and others (1993) | outdoor planters along banks of Cache La Poudre River | P. deltoides monilifera | 6% gravel, 94% sand, <1% clay and silt | 0.4 | 0.7 | 0.4-0.7 | 27-39 (observed when harvested after 98 days) |

*For this table,"survival" occurred when at least 29% of the germinated seedlings lived until the end of the experiment (when it was reported) although in most cases it was much higher, as high as 40%.

For each of the experiments summarized in Table 2, the most successful seedling establishment was usually associated with the rate of water table decline that most closely replicated the natural decline rate for the respective river system. Also, these studies consistently reported that cottonwood seedlings are not able to survive situations where the water table declines faster than some threshold rate, usually about 0.7 to 2.0 cm/day. On the other hand, a constant water table at the surface was normally not associated with the highest rate of survival. Although a water table that declines too fast can cause seedling mortality, some decline is required to promote growth of the seeding taproot to a depth sufficient enough to stabilize the seedling in high flows and access water during low flows

(Fenner and others 1984, Mahoney and Rood 1991, Stobbs and others 1991, Mahoney and Rood 1992).

In addition to these lab and planter experiments, one study, conducted in the field on the regulated Oldman River in southern Alberta, observed rates of natural cottonwood seedling establishment and analyzed seedling root growth rates. Virginillo and others (1991) reported a mean rate of root growth of about 0.32 cm/day. When examined collectively, the lab and planter experiments and this single field study suggest a general trend: as the experimental conditions become more natural, and thus, arguably, more harsh, the optimal rate for a water table decline which can still support seedling survival is reduced.

I examined the correlation between water table decline and seedling survival in the field. However, it is difficult to test the effects of water table decline under field conditions (Mahoney and Rood 1991). Because of the difficulty in measuring groundwater levels, they are often overlooked (LaBaugh 1986) or calculated as the residual of water-budget equations (Carter 1986) in wetland studies. Most field research conducted on the influence of dynamic water tables on riparian vegetation has relied upon a variety of sources for estimating groundwater levels. For example, some researchers used or extrapolated data from local, previously-established groundwater monitoring wells (Kondolf and others 1987, Stromberg and others 1991). Johnson (1994) used plot elevation as an indirect measure of depth to water table. Auble and others (1994) modeled inundation duration by constructing a stage-discharge relationship for each plot while assuming static channel geometry.

I used piezometers to measure the water table (Faulkner and others 1989, Wetlands Research Program 1993, Cook 1994). By monitoring the change of the water table in a natural environment, I analyzed the interaction between water table level and seedling survival and asked the following questions. Was the water table correlated with precipitation and river discharge? Was the water table at a uniform depth away from the river channel? Could seedlings survive the same rate of water table decline in the field that they reportedly had in the lab and planter experiments? Was there a critical period during which the water table had to be close to the surface to ensure seedling establishment and survival? How close to the surface? When and for how long? What was the maximum average daily rate of water table decline seedlings could survive?

# METHODS

## Study Site Selection

After several weeks of field reconnaissance during late May and early June, I selected a large, well-established point bar, which I named Elk Calf Bar (ECB) after almost stepping on an elk calf laying on the bar on a sunny, spring afternoon. I chose ECB as the site for my experiment for several ecological and logistical reasons. Ecologically, ECB appeared representative of most bars on the study reach that I had observed during my initial explorations and representative of typical point bars I am familiar with on Western rivers. For example, ECB includes plant species such as black cottonwood (*Populus trichocarpa*), sandbar willow (*Salix exigua*), mountain alder (*Alnus incana*), water birch (*Betula occidentalis*), spikesedge (*Elerocharis* spp.), common cattail (*Typha latifolia*), common timothy (*Phleum pratense*), smooth brome (*Bromus inermis*), redtop (*Agrostis stolonifera*), Kentucky bluegrass (*Poa pratensis*), leafy spurge (*Euphorbia esula*), and spotted knapweed (*Centarea maculosa*). As mentioned earlier, elk and cattle were present occasionally on ECB, but not for the whole season like they were on most of the study site.

Logistically, ECB is accessible for education programs but is away from visibility of the bridge (which may help to reduce any potential vandalism), and it can be photographed from up on a bluff to monitor change over time. In addition to trying to capture the variation for my research, I also designed this experiment with the understanding that the site would serve as a continuous, long-term study/monitoring site and that data from my research could serve as baseline information (for the water table on ECB), as recommended by Brown and others (1977).

For the purposes of my specific experiment, there were no large trees which would create shade, but many young (5-10 years old), short (0.6-0.9 m tall) cottonwoods were present. The presence of young cottonwoods suggested that an ample supply of natural seed had previously been dispersed and theoretically its source would still be available to "seed" my experiment. ECB has a relatively gradual slope up from bankfull capacity to the top terrace (average slope=4.5%), but it also includes distinct microtopography. There are also patterns of vegetation that appear to be correlated with soil surface texture (e.g. cottonwood seedlings growing on gravels and grasses and forbs dominating the sandy soils).

## Experimental Design

Even though overall ECB appeared relatively homogeneous due to similar vegetation, soils, and slope, I used a complete block design experiment to account for any spatial variation. I started by systematically establishing three rectangular blocks using the following methodology. On June 16, when the river was running at 1,810 cfs, I visually selected the longest axis of Elk Calf Bar roughly parallel to the river and paced it off to a total length of about 182 m (100 paces with ca. 1.8 m/pace) while following a compass bearing of 070°. To evenly space the blocks across the bar, I paced back and placed a marker at the points corresponding to 25, 50, and 75 paces. Using a Lietz/Sokkisha C3A automatic level, we lined up these three points on the long axis line and then established one transect at each point by shooting right angles off the axis line. These three transect lines served as the east (upstream) boundaries for each block.

Using the three transects as our respective references, we established the three blocks using twine as a marker. I named the blocks by their position relative to the direction of the streamflow: "upper" (on the eastern and upstream end), "middle," and "lower" (on the western and downstream end) (Figure 6). Each block was 4 m wide, but the total length of each block varied. The middle and lower blocks started 10 m above a clear topographic break marking bankfull capacity of the river and extended up and across the bar to 5 m below bankfull capacity of an old overflow channel, which defined the higher terrace comprising the south border of the point bar. Because some of the upper block was underwater during the time we established the blocks, the upper block started at 20 m above bankfull, but it also extended to 5 m below bankfull capacity of the old overflow channel. The total lengths for each block were: upper (66.4 m), middle (83.6 m), and lower (85.3 m). We then used more twine to divide each of the three blocks into three plots to accommodate the two treatments and the control. Each plot was 1 m wide, ran the length of its block, and was separated by a 0.5 m buffer strip from the adjacent plot in the block. When we had finished, we had three blocks (upper, middle, and lower) with three plots within each block, for a total of nine plots on ECB. (An expanded view of the plots inside a block is shown later in Figure 7.)

Prior to applying the treatments, I recorded the location of all existing older cottonwood seedlings and saplings that were in the treatment rows. I wanted to be sure that my results would not be confounded if these seedlings were to resprout from the roots and resemble

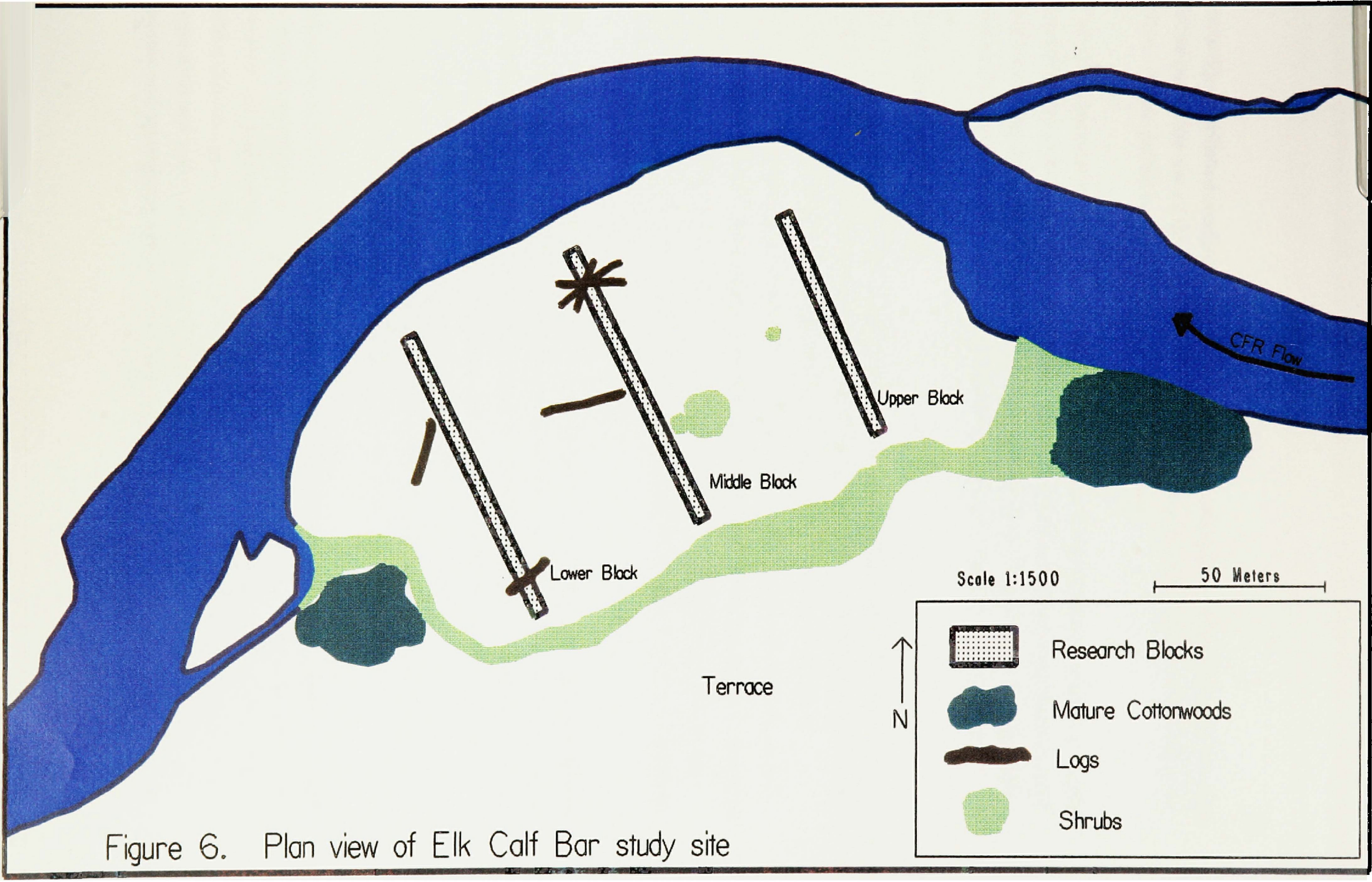

Figure 6. Plan view of Elk Calf Bar study site

sexually-established seedlings. Once cataloged, these existing seedlings received the same treatment as the rest of the plot—sprayed in the herbicide plots and pulled out of the plow plots. Those pulled up from the plowed plots were aged.

I assigned the treatments systematically to avoid effects of the herbicide outside the targeted treatment plots. Because the wind was blowing a little on the day of the application and I wanted the herbicide to blow away from the other two plots in each block, I assigned the herbicide plots to be those on the east end (downwind and upstream) of each block.

### Treatment Applications

On June 16, starting around 2:00 p.m., I applied the herbicide treatment to the three upstream plots, one within each block. I applied Roundup® at the recommended rate of 6 fl. oz./gallon water with a Solo® backpack sprayer. I used a total of 32 fl. oz. of Roundup® for all three plots combined so the actual application rate was 0.14 fl. oz./$m^2$ (32 fl. oz/235.30 $m^2$). Roundup®, a glyphosate-based herbicide, is designed to persist no more than seven days and has shown no residual activity beyond this point (Monsanto Company 1994). In the future, if an herbicide is used, Rodeo® is recommended because of the proximity to the river.

Because the river was quite high and the ends of the herbicide plots were underwater (some by as much as 60 cm), I did not apply the treatments here so the five lowest quadrats were not included in the treatment portion of the study. After spraying was completed at 3:30 p.m., a light rain fell for about 20 minutes. However, the existing vegetation began to droop within a few days, and, after 14 days, the effect of the herbicide was obvious as just the three targeted treatment plots had turned into brown strips across their entire lengths. This difference in vegetative cover persisted for the entire growing season.

For my second treatment, on June 17 and 18, I attempted to replicate the action of a plow or disk being pulled by a tractor over an area. Unfortunately, the horsepower was not from a tractor, but from my hands. I did my best to turn over the soil in the three plow plots with a shovel—just as one would do when turning up sod to put in a new garden. The vegetation and soils varied greatly from a thick mat of Kentucky bluegrass in a dark, organic soil up near the old overflow channel to spotted knapweed in sandy soils to deeprooted young cottonwoods in coarse, rocky soil. The most visible change occurred, as expected, in the grass, and the least visible change occurred in the rock where, in some cases, it was difficult to tell I had even tried to move the rocks. The sandy soil demonstrated an intermediate level of change.

The effect of my plowing disturbance persisted for the entire growing season in the form of the turned up soil. However, the vegetation gradually reestablished in these treatment strips, so from a distance the plow treatment appeared to be less altered than the herbicide treatment over the course of the summer. By early August, some of the herbicide plots had been reinvaded by a little vegetation, and the plowed plots had been reinvaded even more. Nonetheless, both the herbicide and the plow treatments had much less above-ground cover than the control plots. In fact, the lack of tall grasses and forbs in the treated plots was still obvious in February 1996 under 254 mm of snow cover (personal observation).

### Piezometer Placement

On June 18 and 21, I systematically placed one piezometer every 7 m along the original transect lines (the upstream border of the herbicide plot) in each of the three blocks for a total of 37 piezometers. Although systematic sampling is limited by the risk of falling into a periodic pattern (Greig-Smith 1957, Eberhardt and Thomas 1991), I was not too concerned with falling into a pattern because the bar appeared relatively homogeneous. Nonetheless, there was some variation in microtopography, vegetation, and soils that I mentioned earlier. I was faced with the tradeoff of needing to capture this variation versus the investment of time and energy to place the piezometers and monitor them. I wanted to place the piezometers at the maximum distance which still captured the variation. Therefore, prior to any placement, I took time to stretch a tape measure along each block and look at the "lay of the land and vegetation"—essentially the distribution of the three factors (topography, vegetation, and soil surface composition) along each block. After observing the areas, I decided that I could capture the variability by placing the piezometers every 7 m. I placed my first piezometer at the end of each block closest to the river (thus at the 20 m, 10 m, and 10 m points) and then placed another piezometer every 7 m up to the end of each block, for a total of 37 piezometers.

I pounded the piezometers—steel pipes 120 cm long with an inside diameter of 15.9 mm—into the ground with a sledge hammer and steel pounding cap until they reached a depth of

1 m (Cook 1995). (Some of the piezometers were slightly bent in the process, and a few would not go in the full meter; they still functioned, and I made the necessary corrections when collecting data.) I then inserted a plastic "dipstick" with a PVC cap into the piezometer to serve as the measuring device and to prevent water from leaking into the well from above.

### Data Collection

On July 10, we surveyed ECB with the Lietz/Sokkisha C3A automatic level to determine the elevation of each piezometer relative to the bankfull capacity mark of the respective block. Although the exact location of bankfull capacity is often debated in the literature (Gordon and others 1992), there was a very clear break in topography on the point bar which I used as my study site: at each point that I determined to be bankfull capacity for each block, the vegetation stopped, the soil texture changed, and the bank abruptly dropped off about 45 cm. I chose to use bankfull capacity as my reference point instead of high water or low water level (Everitt 1968, McBride and Strahan 1984, Johnson 1994) or channel bottom (Harris 1986) because the water levels fluctuate and because bankfull capacity is, arguably, more consistently located and more stable than channel bottom. Some studies, which were usually working on a broader scale, simply measured "to the channel," leaving the reader guessing what point was actually used.

Using methodology developed by Cook (1994), I determined the water level at each piezometer by slicking the dipstick with a "water finding paste," KolorKut (KolorKut Products, Houston, TX), and measuring the depth at which the color change occurred. I monitored the piezometers approximately once a week until the second week of August and then every few weeks until early September for a total of ten readings. Piezometers are designed to measure the depth to the free water surface, not the moisture present in the soil from capillarity (Wetlands Research Program 1993). However, as with many measurement tools, there are sources of measurement error associated with the use of piezometers. For example, sand or clay can plug the opening thus preventing water from moving into the pipe, or water can be displaced during the readings (Wetlands Research Program 1993).

In addition to monitoring the piezometers weekly, I monitored seedling densities. Because I completed my treatments by June 18 as scheduled, the plots were ready when the cottonwood seed was naturally dispersed. The seed release at the study site started on June 22, peaked on June 30, and finished on July 12 (personal observation). To compare the seedling densities by treatment, I used distance from bankfull capacity (defined by piezometer location) as a blocking factor because I suspected that distance from the main channel would be a factor influencing seedling survival. I established a set of three 0.25 $m^2$ quadrats, one in each treatment plot, at each piezometer and halfway between each piezometer (Figure 7). Therefore, I ended up with one block of three quadrats every 3.5 m, for a total of 70 blocks (these blocking factors "blocks" are not to be confused with the upper, middle, and lower "blocks" of the study design) and 205 quadrats on the entire ECB. I assumed that depth to water table was consistent for each of the three quadrats within each block because the furthest quadrat was only 3 m away in the downstream direction and because the topography and soils were similar across the three quadrats. I also assumed that the distance to the seed source was roughly equally because seed trees were on the downstream and upstream ends of, and across the channel from, ECB. This complete block design allowed me to accomplish two things: 1) compare seedling densities between the treatments and 2) compare seedling densities as a function of the water table depth.

I counted the number of cottonwood seedlings in 0.25 $m^2$ quadrats on three dates. The first date, July 16, was approximately two weeks after the peak of the seed release, and most of the seedlings that were going to germinate and establish should have been visible by July 16. The other counts were on August 9, after the river discharge had dropped from 936 to 260 cfs, and September 8, near the end of the growing season.

### Statistical Analysis Methods

Blocking by distance from bankfull capacity, I used Friedman two-way analysis of variance by ranks (Daniel 1990) to test for significant differences in seedling establishment (number of seedlings sprouted above the ground surface on the July 16 count) and seedling density (number of live seedlings per quadrat at each count) across the three treatments. I also gathered historical and 1995 data on the local climate and the Clark Fork River discharge and compared the response of the water table to precipitation and discharge. I used Spearman correlation coefficients (Daniel 1990) to test the relationships between seedling densities and depth to water table. All tests were conducted at the 0.10

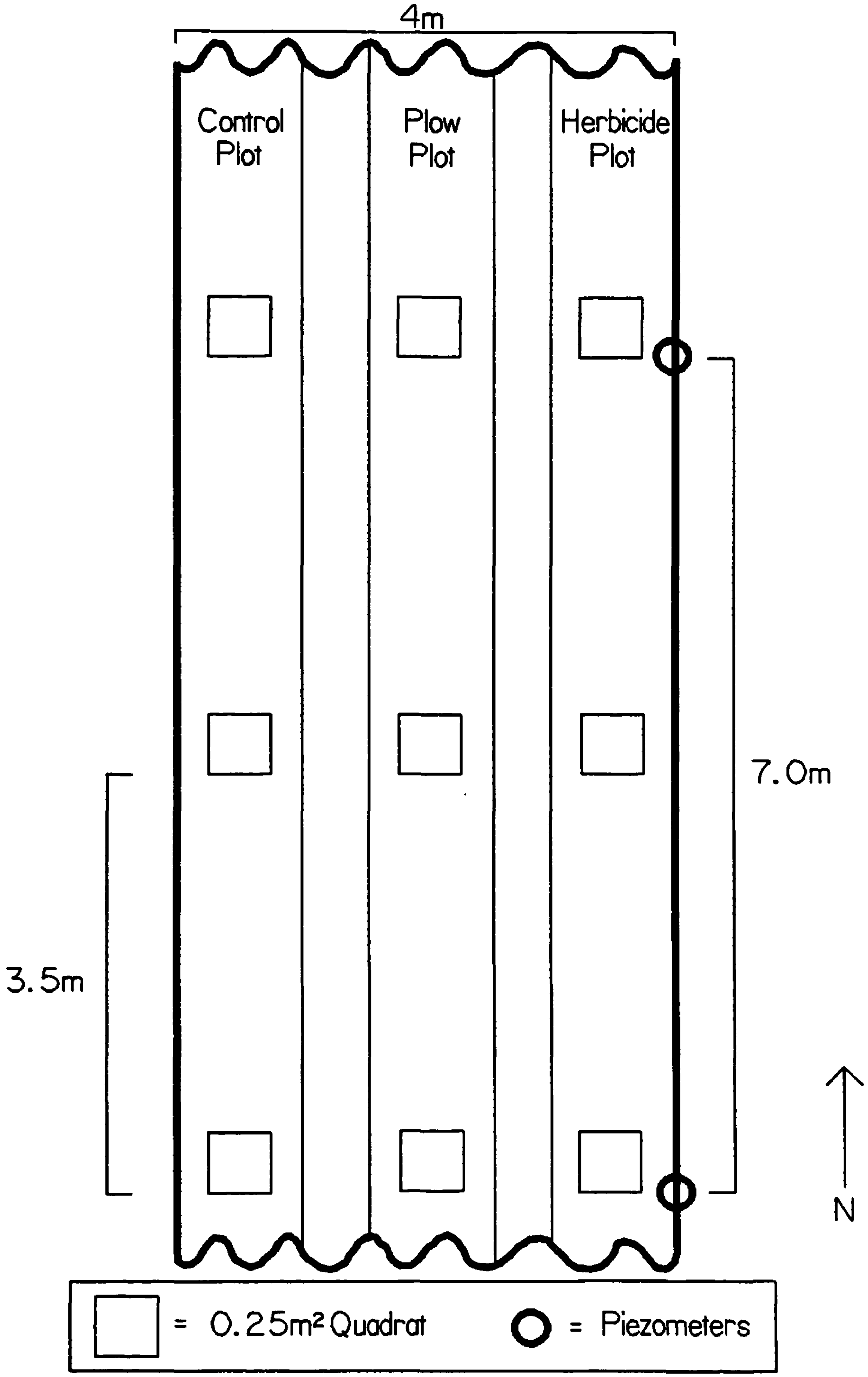

Figure 7. Elk Calf Bar study design example

significance level. I used the computer statistical packages, Student Systat 1.0 (Berk 1994) and Student Data Desk 4.1 (Velleman 1993), for all my analyses.

### Measurement of the Water Table

Because the piezometers were spaced every 7 m and the quadrats were placed every 3.5 m, I did not have a water table depth measurement for the intermediate quadrats. Therefore, I assigned a water table depth to the intermediate quadrats by averaging the water table depths from the two adjacent piezometers for the same date. Although this was the best available approximation of water table for the intermediate quadrats, this average reading could be influenced by differences in subsurface soil texture. (I also used this same approach to assign an elevation to each intermediate set of quadrats.)

The water table readings essentially sampled two continuous variables, the depth of the water table and the point in time when the water table was at that depth. From these data, I calculated an average daily rate of water table decline for each block by using piezometer readings from four dates (June 30, July 19, August 9, and September 8) which had complete data and coincided with the dates for seed release.

## RESULTS

### Cottonwood Seedling Identification

The small size of the seedlings made them very difficult to count—let alone identify—especially on the first count. I knew this was going to be a challenge and, to try and train my eye, earlier in the spring I collected some cottonwood seed along the Clark Fork River in Missoula and grew it in a planter at home so that I would know what to look for. However, despite this measure, I was still unsure on the first count. Almost all of the seedlings, cottonwood and other species', were very small with two basal leaves. Although Read (1958) and DeBell (1990) provide overviews on plains cottonwood and black cottonwood respectively, I was unable to find any articles or books with pictures of cottonwood seedlings. Therefore, to help others in the future, I have included photographs here of one cottonwood seedling a few days old and some others about two months old (Figure 8).

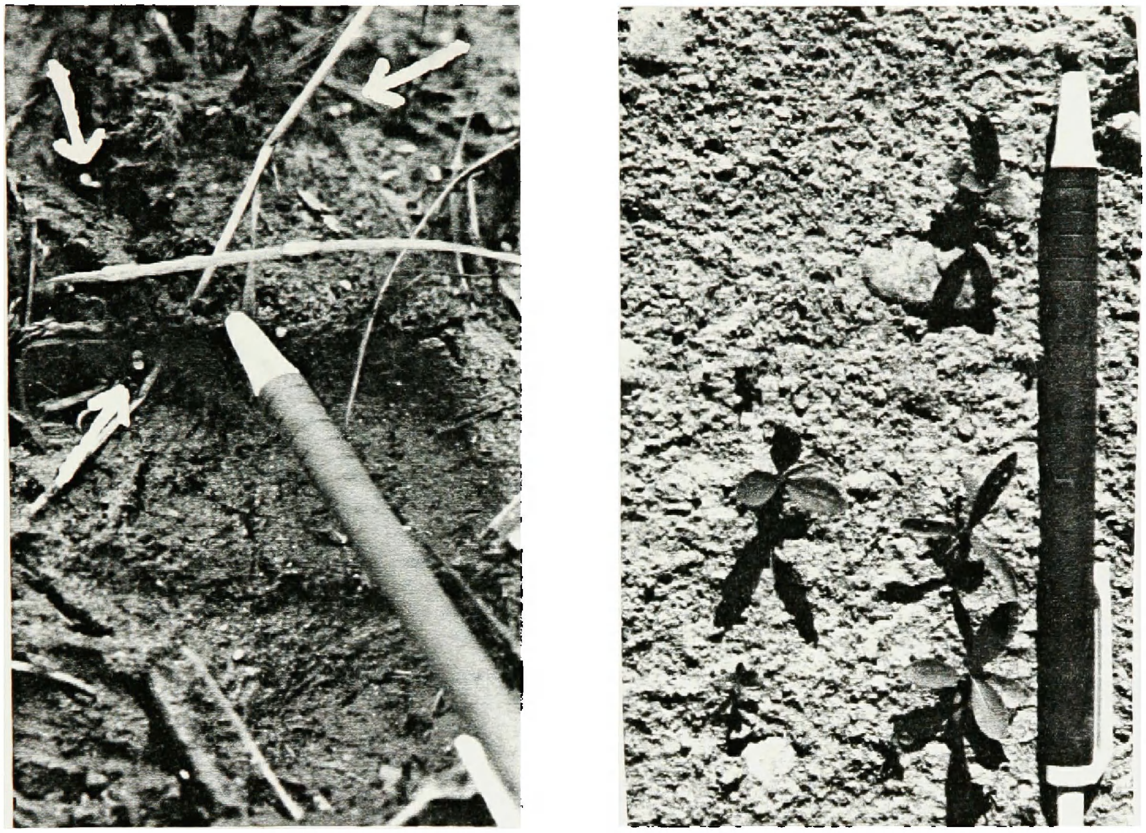

Figure 8. Photographs of black cottonwood seedlings approximately three days old (at end of arrows) and two months old

By the second count, I had defined several characteristics which made it easier to distinguish the cottonwood seedlings from similar species. The cottonwood seedlings had leaves that were lanceolate in shape, not pubescent or glaucous, and serrated at the distal end. Also, the stems were usually red, although this was not so effective as a clue because seedlings from other species also had red stems. However, because of the difficulty in distinguishing cottonwood seedlings, the July 16 count may have included seedlings of other species as well.

### Effect of Treatments on Seedling Survival

Cottonwood seedling establishment (July 16) did not differ significantly by treatment ($p=0.165$). And there was even less difference in seedling densities by treatment on either of the two subsequent count dates, August 9 ($p=0.828$), and September 8 ($p=0.966$). After determining that water table levels had a significant influence on seedling survival (see next section), I came back and revisited the effect of treatments on survival by examining just those blocks where the water table was high (within 20 cm of the ground surface on June 30). However, there was still no significant difference in seedling densities by treatment on any of the three counts dates. (All three p values were greater than 0.565.)

The densities at which seedlings established in this study were less than the maximum establishment densities reported in the literature. The maximum seedling density per 0.25 $m^2$ quadrat for the July 16 count was 168 seedlings. This value for seedling establishment is far less than maximum densities in excess of 4,000 seedlings/$m^2$ reported for the South Platte River in Colorado (Sedgwick and Knopf 1989). This density is closer to, but still less than, the maximum seedling densities of over 1,000/$m^2$ reported for rivers in southern Alberta (Lee and others 1991) and the 1,342 seedlings/$m^2$ I observed for this date on the new sediment deposits (Chapter 4).

Even though over 100 seedlings established in a few quadrats, few seedlings survived the summer. Figure 9 shows total seedling densities for all quadrats combined for each treatment on the three count dates.

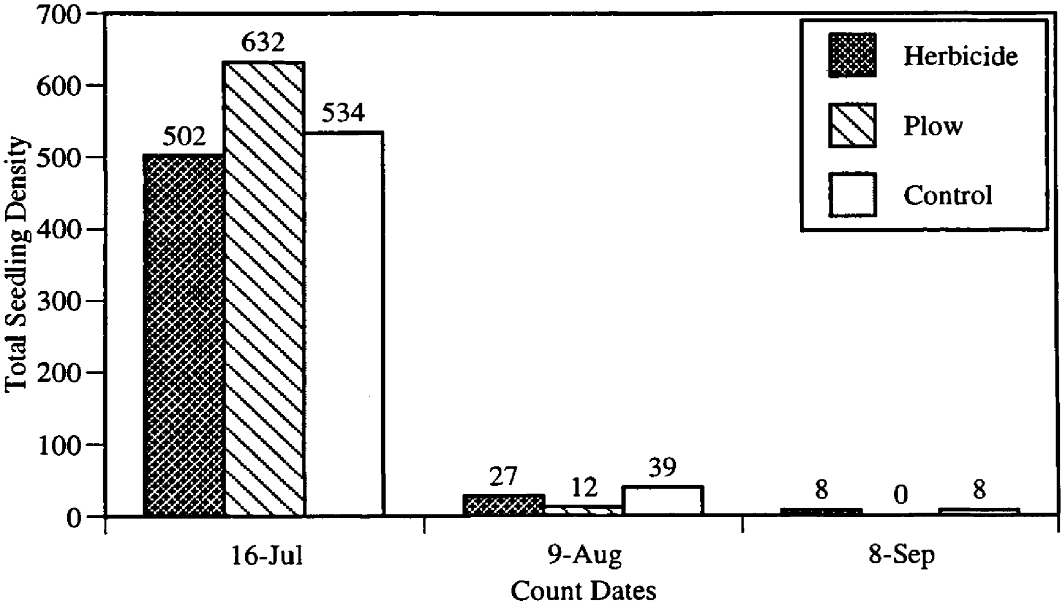

Figure 9. Total seedling density by treatment at each count date

### Water Table Interactions

In addition to using the piezometer data to monitor the response of seedling survival to the rate of water table decline, I also examined how the water table responded to precipitation and discharge and if the water table remained at a uniform level with increasing distance from the stream.

The Clark Fork at Gold Creek gage is very close to the study site (8.5 river km upstream) relative to the distances used in other studies which were sometimes over 32 km. However, between the gage and the study site, some water losses probably occur to evapotranspiration and at least two agricultural diversions. There are no major tributaries entering over the distance so any additions would be a result of precipitation. I do not know if the river has gaining or losing reaches, or both, over this distance so I do not know the influence which groundwater has on streamflow in this area. However, because of the close distance, the gage readings should be relatively accurate for the study site (aside from influences of the seasonal irrigation diversions). Daily discharge fluctuations between June 15 and September 15 appear to follow changes in precipitation (Figure 10).

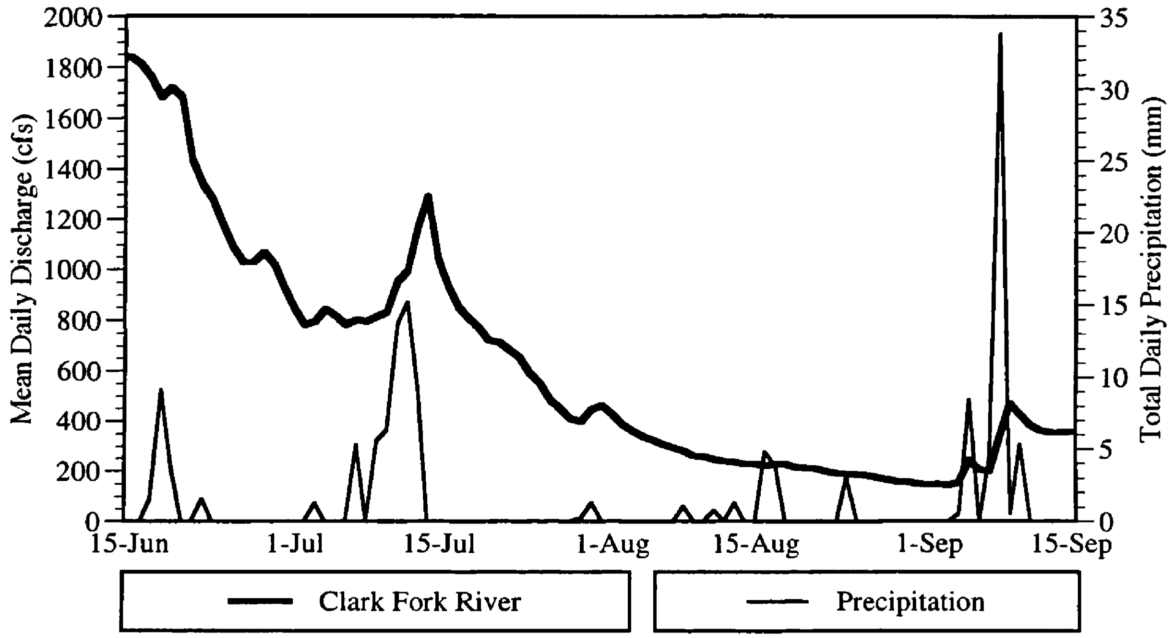

Figure 10. Summary of daily precipitation and discharge, June 15–September 15, 1995

Comparisons of median values for the water table readings show that the water table started high, increased with the peak from the rain, slowly declined, and then rose again at the end of the summer, probably corresponding to when many of the diversions for irrigation were turned off (Figure 11). (Figure 17 in Chapter 4 shows the hydrograph for the entire 1995 water year.)

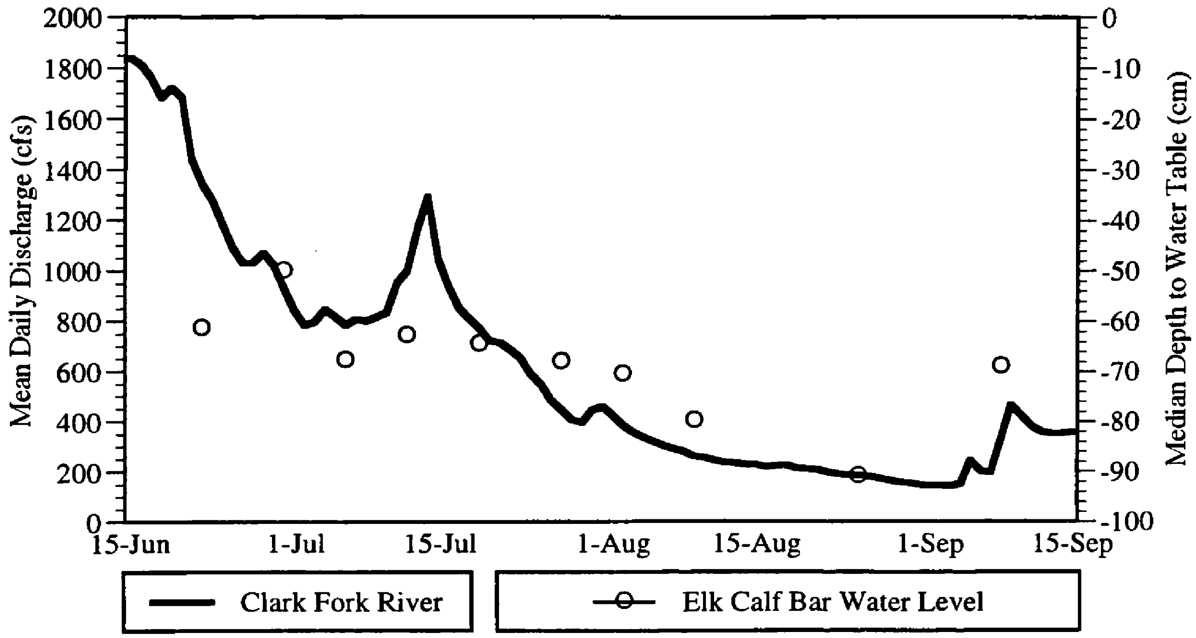

Figure 11. Summary of daily discharge and water table levels on Elk Calf Bar, June 15–September 15, 1995

Depth of the water table fluctuated close to the channel, but remained relatively uniform beyond 50 m from the channel. Figures 12-14 show the water table levels in relation to the ground surface on five dates for all three blocks on ECB: upper, middle, and lower. For all three cross-sections, the water table appeared to be most variable within about 40-50 m of bankfull capacity, a distance which was roughly similar to an elevation within about 70 cm of bankfull capacity. Beyond this distance and elevation, the water table was relatively constant across the whole summer. This difference may occur because the areas closest to the channel in both horizontal and vertical distance may be most responsive to fluctuations in river discharge and stage. Other researchers have also found that water table fluctuations followed changes in streamflow (Hurr 1983, Kondolf and others 1987, Mahoney and Rood 1991). Hurr (1983) reported rapid response, usually within 24 hours, of the water table to temporary changes in river stage in areas along the river as wide as 760 m. Hurr (1983) also reported diurnal fluctuations in ground water levels caused by diurnal changes in the evapotranspiration rate.

Between July 19 and August 9, the river discharge declined from 767 cfs to 467 cfs, and the water table on ECB followed the river's drop. For all 37 piezometers combined, the water table dropped an average of 23 cm during this period. Plots within 40-50 m of bankfull capacity experienced drops as high as 50 cm. Most likely, the water table

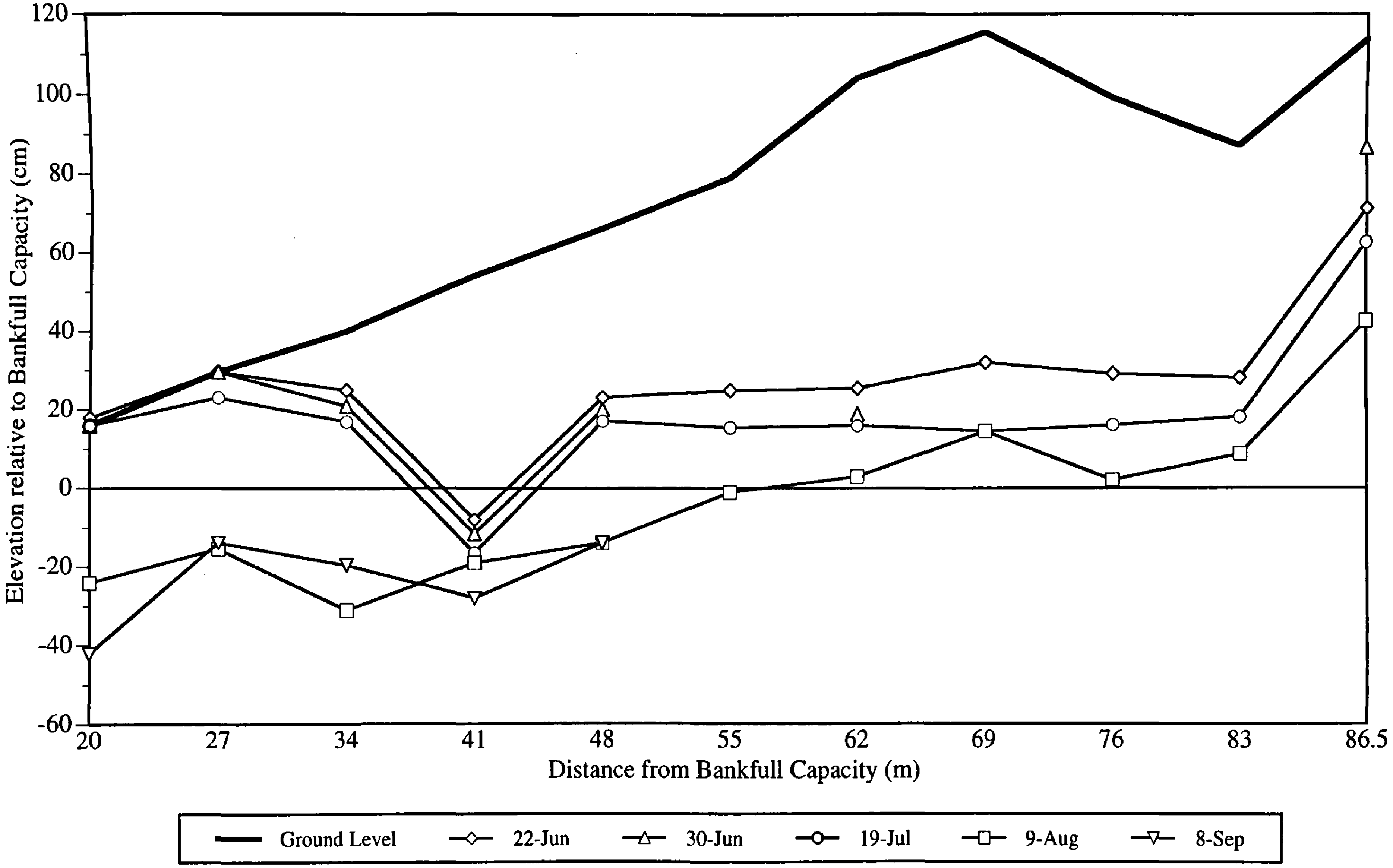

Figure 12. Water table levels for the upper block on Elk Calf Bar, summer 1995

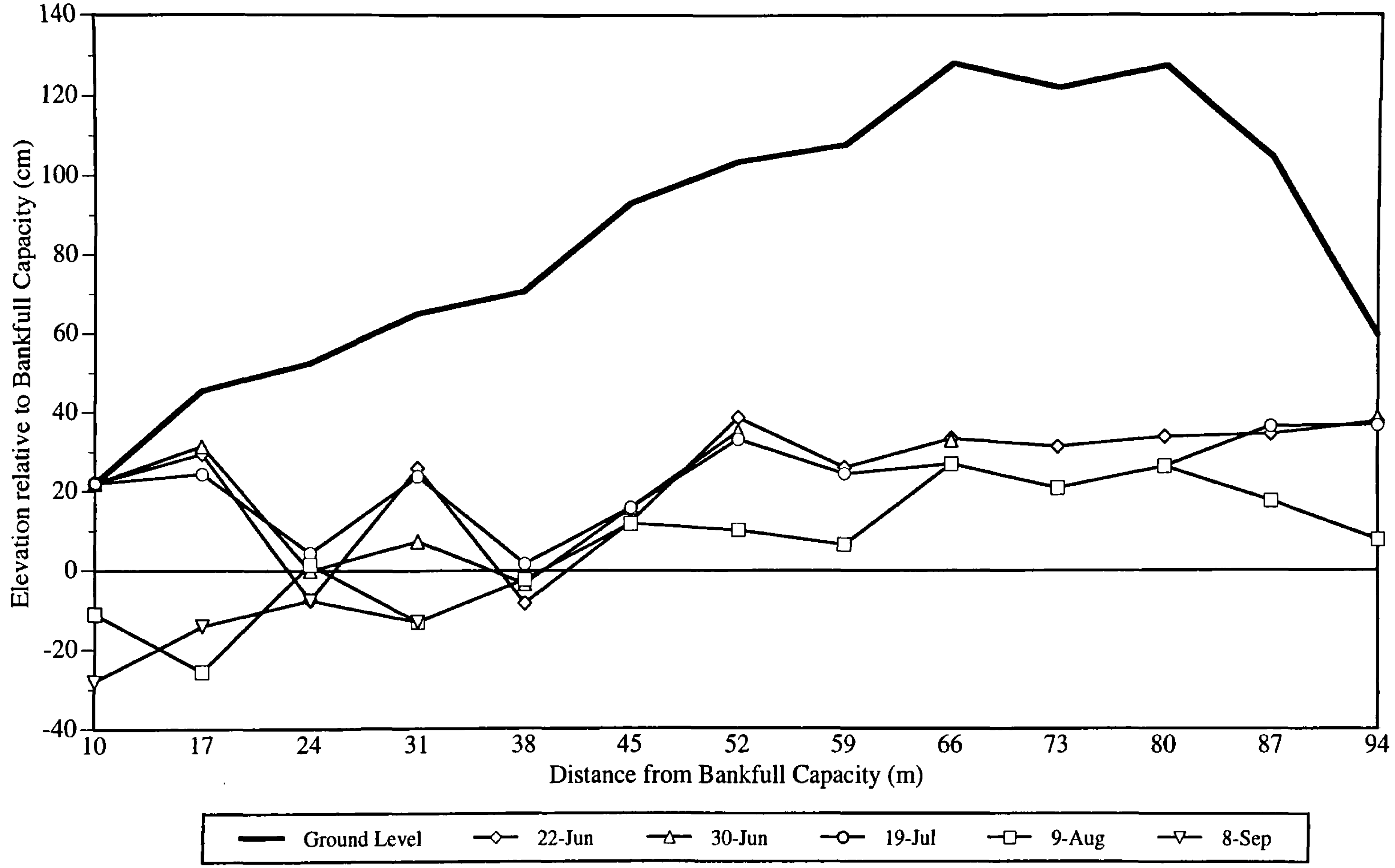

Figure 13. Water table levels for the middle block on Elk Calf Bar, summer 1995

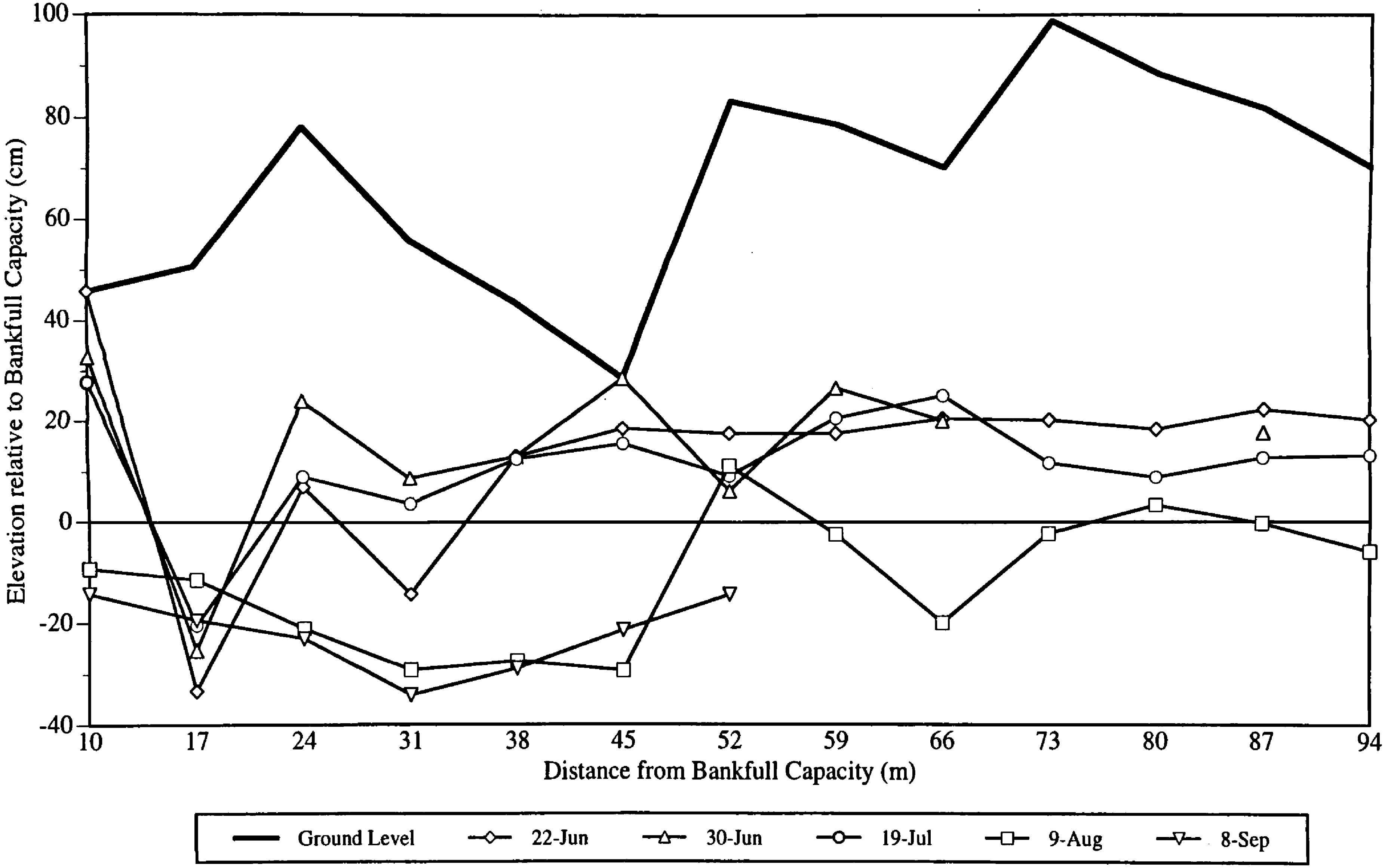

Figure 14. Water table levels for the lower block on Elk Calf Bar, summer 1995

decreased at a faster rate than the root growth of the three-week old seedlings, and this rapid decline in the water level contributed to the high seedling mortality during this period.

### Effect of Water Table Decline on Seedling Survival

Although seedling survival did not differ by treatment, there was a pattern to the survival. The seedlings growing closest to the main channel survived the longest. As shown in Figures 12-14, the quadrats closest to bankfull capacity had the highest water table. Putting these factors together suggests, as would be expected and as alluded to above, that seedlings growing in quadrats where the water table was high established and survived longer than seedlings growing where the water table was low.

Because there was no significant difference in total densities by site preparation treatment, I pooled the values for the blocked quadrats into one value (average of the quadrats) for all the following analyses. Also, to most accurately assess how rate of water table decline influenced seedling establishment and survival, I examined the subset of quadrats (n=11) where the water table was within 20 cm of the ground surface on June 30, the peak date of seed release. I chose 20 cm as the threshold value for three primary reasons. First, the water level on June 30 was a key factor in determining seedling establishment (Figure 15). The correlation between seedling density on July 16 and the water level on June 30 ($r_s$=0.789, p<0.0005) was the most significantly correlated relationship of any count date and any water table level throughout the summer. Second, only 20% of the seedlings established in quadrats where the water table was deeper than 20 cm on June 30. Third, this 20% which did establish in quadrats with a lower water table was probably relying exclusively on precipitation, which was twice the long-term average for the month of July, and not the water table for moisture. Therefore, by limiting my analysis to only those quadrats where the water table started near the surface, my results are not distorted by slow water table drops in quadrats with an initial water table depth too low to support seedling survival.

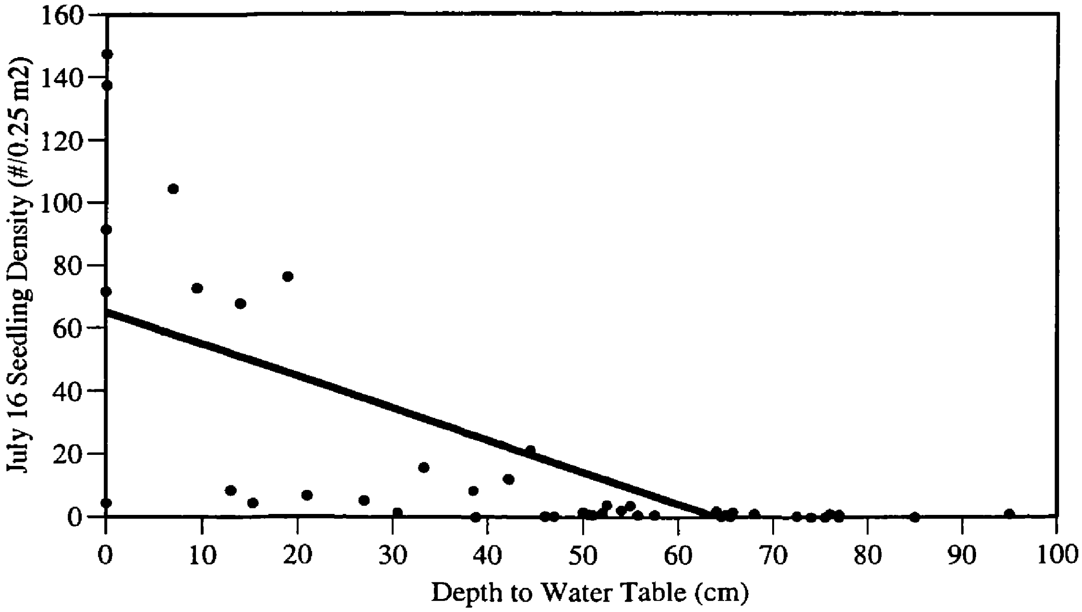

Figure 15. Relationship of initial water table level (June 30) and cottonwood seedling establishment (July 16)

The average daily rate of water table decline influenced how many seedlings established and survived. More seedlings established and lived longer in those quadrats where the water table dropped at a slower rate. However, seedling densities were significantly correlated with water table decline in only two situations. First, seedling establishment (July 16 count) was significantly negatively correlated ($r_s$=-0.868, p<0.0005) with the average daily rate of water table decline for the period from peak of seed release (June 30) to mid-July (July 19) (Figure 16). Second, the final seedling count (September 8) was significantly negatively correlated ($r_s$=-0.479), 0.05<p<0.10) with the average daily water table decline for the summer (June 30–September 8). Although not significantly correlated, seedling counts were affected by rate of water table decline for other periods of the summer as well. Between July 16 and August 9, some seedlings survived water table drops of close to 2.0 cm/day.

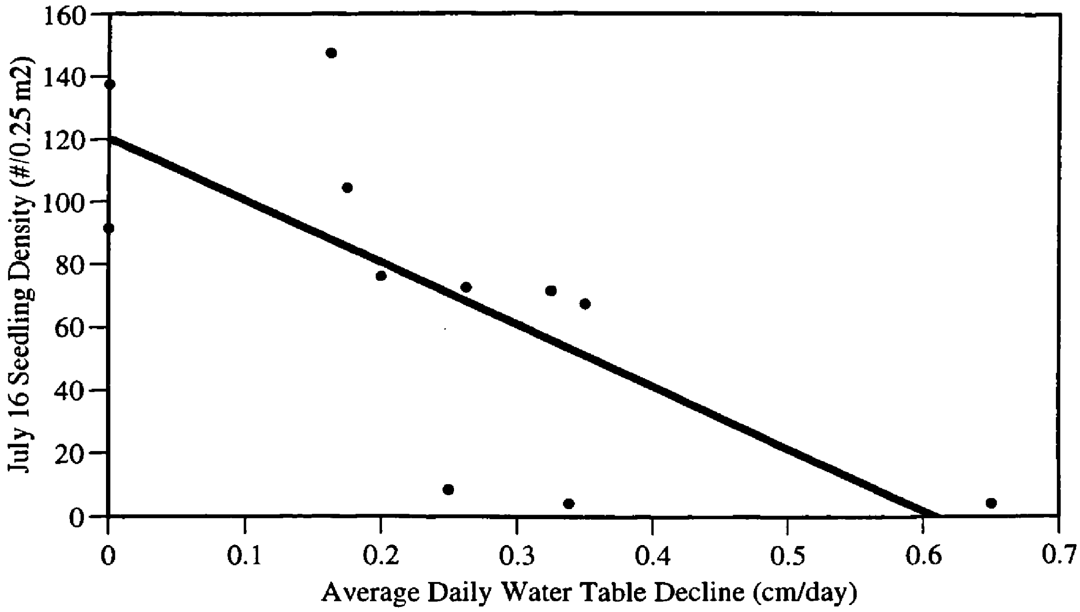

Figure 16. Relationship of June 30–July 19 rate of water table decline and cottonwood seedling establishment (July 16)

For the entire season (June 30–September 8), seedling survival was highest in those quadrats where the water table started within 20 cm of the ground surface and dropped at an average rate of about 0.5 cm/day—so that the water table ended up about 50 cm deep in early September. At any point in the summer, seedlings were not able to survive average rates of water table decline greater than about 2.0 cm/day. Also, in analyzing all 205 quadrats, no seedlings survived where the water table started below 20 cm or dropped below 77 cm at any point during the summer.

The relatively short length of cottonwood seedling roots can help explain the high mortality associated with the low water table. On two occasions, I collected very small samples of seedlings from another area on the study site and recorded the root lengths. On August 25, I carefully dug up 9 seedlings and determined a mean root length of 7 cm. On October 13, I dug up 5 seedlings with a mean length of 11 cm. These mean root growth rates of only 0.10 cm/day and 0.13 cm/day are much less than those reported in Table 2 and much slower than the rate of growth needed to stay up with the average rates of water table decline discussed above.

## DISCUSSION

Site preparation treatments which created bare substrate did not significantly influence cottonwood seedling establishment and survival during the first growing season. However, although there was not a statistical difference between treatments (because the median values were very similar), total seedling densities were greatest in the plow plots for the first count. This result may be due to microclimatic factors. The plow treatments created a much rougher surface contour compared to the other two treatments where the ground surface itself was not disturbed. The roughness may have helped to trap seed blowing along the ground and to create a microclimate for the seed to establish where moisture and light were available and the wind was decreased. While conducting another component of this study, I found one elk hoof print that was full of cottonwood seed while the surrounding area with a smoother surface hardly had any seed on it. I also observed many seedlings growing in the plowed quadrats on ECB that were tucked down in the crevasses between "clods" of soil.

Similarly, Friedman and others (1995) found that sod removal, a treatment more similar to my plowing than herbiciding, increased mean seedling densities. Sod-removed plots had mean densities of 0.75 seedlings/m$^2$ whereas undisturbed plots had mean densities of only 0.03 seedlings/m$^2$ (Friedman and others 1995). In their study, all treatments were conducted in plots within 30 m of the channel, much closer than many of the quadrats in my study which were located as far as 94 m from the channel.

Initial advantages of establishing in plow plots may have declined over the course of the summer because the plow plots were more quickly reinvaded by other species than the herbicide plots. Thus, competition for light and moisture may have been more intense. The advantage of reduced vegetative competition in the herbicide plots would have persisted through the end of the season. In summary, although the survival rates do show patterns which may be related to treatments, there were no statistically significant differences.

On the other hand, the level of the water table and the rate of water table decline were highly correlated with seedling survival during certain periods of the summer and appeared to play a major role in determining when and where seedlings established and survived. The water table level on the date of the peak seed release (June 30) was a key factor determining whether seedlings established. No seedlings survived the summer in quadrats where the water table was below 20 cm on June 30 or where the water table dropped below 77 cm at any point in the summer. The apparent importance of depth to water table in this study is similar to that for previous field studies which have correlated water table decline with cottonwood seedling mortality. McBride and Strahan (1984) found that the seedling survival rate was 93% in plots where the water table was within 1 m (ca. 20 cm) of the surface. However, no seedlings survived their first season in plots where the water table was deeper than 1 m (McBride and Strahan 1984). In the one site preparation study, Friedman and others (1995) found that plots irrigated with a sprinkler had greater first-year seedling densities (0.39 seedlings/m$^2$) at the end of the season than unwatered plots (0.03 seedlings/m$^2$) did.

The rate of water table decline also influenced seedling establishment and survival. Seedling survival was highest where the water table dropped less than 0.5 cm/day, especially during the first three weeks. Seedlings were not able to survive rates of water table decline greater than 2.0 cm/day at any point in the summer. Results from the present study are very consistent with those of previously-discussed studies (Table 2). Using rootboxes in a greenhouse, Fenner and others (1984) reported maximum seedling survival with water table drops of 0.6 cm/day. Segelquist and others (1993) found that seedling survival in planters along the Cache La Poudre River in Colorado was greatest with water table declines of 0.4-0.7 cm/day. Similarly, Virginillo and others (1991) reported mean growth rates of 0.32 cm/day in seedlings growing along the banks of the Oldman River in southern Alberta.

Other researchers have also reported high mortality rates for cottonwood seedlings. Lee and others (1991) found that despite having initial densities greater than 1,000 seedlings/m$^2$, few seedlings survived until mid-summer. They too attributed the high mortality to drought stress. Johnson (1994) also reported a pattern of mortality for first-year seedlings similar to that which I observed: "extremely high initial values were followed by a trough of low mortality."

The fact that more first-year seedlings survived only in the quadrats where the water table was relatively high for the whole summer supports the distributional pattern I originally observed with the existing older cottonwood seedlings growing on ECB. Although not shown in a figure, 96% of the existing seedlings and saplings (n=164) were growing in areas that were both within 50 m of bankfull capacity in distance and within 70 cm of bankfull capacity in elevation. According to the three cross-sections in Figures 12-14, this zone supports a higher water table throughout the growing season because of its lower elevation relative to the stage of the river.

Other factors could also have influenced the survival of seedlings. Precipitation was twice the long-term average in the first month following seed release (July). Therefore, more seedlings may have established in plots with lower water tables than would normally occur. Also, although large amounts of seed were released, the pattern of distribution seemed to vary spatially along the river. For example, there appeared to be more seeds under mature cottonwood stands than in open areas. The pattern of seed deposition on the microhabitat level may have been influenced by the presence or absence of vegetation; that is, the taller vegetation in the untreated plots may have trapped seeds which were "headed for" an adjacent plot. My observations that the rougher-surface plots trapped more seed would suggest that this potential seed interception could be a factor. However, because my densities per quadrat from the first count (July 16) showed no significant difference across treatments, I assumed that the seedlings established at relatively equal rates across all three treatments.

Also, the accuracy of the counts may have influenced the results. For example, because of the existing vegetative cover in the control plots, seedlings were harder to spot and count in the control plots than in the plow and herbicide plots. Consequently, counts for the control plots may be the most conservative (underestimated) of the three. On the other hand, the thick vegetation also may have reduced the establishment of seedlings in the control plots by preventing seeds from reaching the ground surface (Stromberg and others 1991, personal observation).

Several factors may have influenced the accuracy of piezometer readings. First, the water table was determined by measuring the distance on the dipstick between the ground level and the point at which the paste changed color from brown to yellow or red, and often the zone of transition between the colors extended about 3–4 cm so the exact point was difficult to determine. Second, because the readings were done weekly, the readings picked up the highest point of the water table in that week-long period, not necessarily the depth of the water table on the exact reading date. If the water was at its highest level on the day of the next reading, this one high water table value would be entered for two consecutive readings because the stick would change colors as soon as it was put back in the well. Therefore, the reading could be as much as a week late compared to the depth on the date of the reading. (The only way around this that I have thought of it is to take the instantaneous reading on the reading day by wiping and reslicking the stick. However, with 37 wells and the other components of my study, this was not feasible time-wise.) Finally, the elk caused some disturbance by sampling the white caps on the piezometers. On a few occasions, they pulled out or broke off the sticks so I was unable to obtain complete data for the whole summer. In retrospect, other methods such as putting chalk on a measuring tape (Faulkner and others 1989) may have been more efficient for this project because of the abundance of wells and potential for disturbance. Nonetheless, despite these sampling limits, the piezometers did allow me to monitor the water table level throughout the summer.

The ability to infer from my results may be limited because I did not randomly assign treatments to the plots (to prevent herbicide effects outside the plot) and because I did not use a random starting point to place my piezometers and subsequent sampling quadrats (to be a standard distance from a reference point [bankfull capacity] and to correlate seedling survival with depth to water table). Additionally, the three blocks on ECB are subsamples or "pseudoreplicates" (Hurlbert 1994). By expanding the study and using other point bars as replicates, I would have reduced the potential problems associated with pseudoreplication (Eberhardt and Thomas 1991, Hurlbert 1994). Finally, in presenting my results, I have not tried to apply a guise of misleading statistics. Instead of using statistics improperly and sending subsequent research down the wrong path (Eberhardt and Thomas 1991), I have tried to present clearly the results with the hope that any knowledge gained from this experiment will be helpful in designing future studies in this field. Despite some potential shortcomings of this experiment now recognized with hindsight, I am comfortable with my reasoning for designing the study in the manner that I did at the time. Hopefully, others reading this in the future will be able to learn from my mistakes. As Eberhardt and Thomas (1991) write, "Since truly definitive single experiments are rare in any field of endeavor, progress is actually made through sequences of investigations." I hope my study will serve as an important one of these investigations.

## SUMMARY

Although there may have been a slight effect favoring seedling establishment on plots where the ground surface was rougher, seedling establishment and survival throughout the first growing season did not differ significantly between the herbicide, plow, and control plots. However, the depth to the water table at the time of seedling establishment and the rate of the water table decline through the first growing season largely influenced where seedlings established and how long they survived. The results of this field experiment are consistent with previous research on the influence of a dynamic water table on cottonwood seedling establishment and survival. Seedling survival was greatest in quadrats where the water table was within 20 cm of the ground surface during the time of seed release and where the water table declined at an average rate of less than 0.5 cm/day for the first three weeks and less than 2.0 cm/day for the next three weeks. Seedling densities were greatest in plots with water tables less than 50 cm deep at the end of the season (September 8). Seedling establishment and survival may also be influenced by factors such as access of the seed to the soil surface, soil surface roughness, and soil texture.

To complement this experimental portion of my research, I designed an observational study, explained in Chapter 4, to observe factors influencing the establishment and survival of cottonwood seedlings on unmanipulated, naturally-created, fresh sediment deposits.

# CHAPTER FOUR:
# THE ESTABLISHMENT AND RECRUITMENT OF COTTONWOOD SEEDLINGS ON RECENT, NATURALLY-DEPOSITED SEDIMENT

## INTRODUCTION

The natural establishment of cottonwoods is limited by many factors, one of which is the availability of bare substrate deposited by large flows or exposed by channel meandering or narrowing (Chapter 1). Although Everitt (1995) reported that stand replenishment only occurred once in the past century, the average interval between periods of episodic seedling establishment leading to long-term survival of stands has been reported to range from five years (Bradley and Smith 1986) to 10-15 years (Baker 1990).

During the late spring of 1995, the upper Clark Fork River experienced the largest flow in nine years since it had peaked at 3,970 cfs (mean daily discharge [MDD]) on February 2, 1986. The largest flow on record for this station occurred on May 22, 1981, when the river reached 9,100 cfs (MDD). The largest flow since the 1870s on the upper Clark Fork was in June 1908, and it has been estimated as a 100-year event (CH2M HILL 1989). Other high flow events have occurred on the upper Clark Fork River in 1868, 1876, 1879, 1893 (Courchene 1989), and other basin-wide events have occurred in 1898, 1899, 1938, 1948, and 1975 (CH2M HILL 1989). (The recurrence interval of events such as the 100-year flood is most accurately calculated with instantaneous peak flows and not with MDD [Gordon and others 1992]. Although I was unable to find the instantaneous peak flow estimation for the 1908 flood, the instantaneous peak flows at the Gold Creek station for the 1981 and 1995 events were 12,000 cfs and 4,060 cfs respectively. See Baker [1994] for an excellent critique of flood-frequency analysis.)

Although much smaller than the historic 1908 and 1981 events and smaller than the 1986 event, the 1995 event, which reached 3,560 cfs (MDD) on June 6, created the fresh sediment deposits required for cottonwood recruitment. Taking advantage of this timely opportunity, I observed the processes by which the deposits were formed; and I monitored the establishment and survival of seedlings from a time well before seed release (late May) until the end of the summer (mid October). I designed this portion of my study to be more observational than experimental and to complement the more manipulative components of my research.

### Soil Texture

Because of hydrologic and geomorphic processes, soil texture often differs across sediment deposits (Gordon and others 1992). These differences in substrate size have been shown to influence the composition and distribution of the pioneer vegetation species which establish on the deposits. McBride and Strahan (1984) found that sandbar willow (*Salix hindsiana*) and red willow (*S. laevigata*) established on smaller sediments (less than 0.2 cm) and that mule fat dominated on larger sediments (greater than 1.0 cm). Fremont cottonwood (*Populus fremontii*) established preferentially on intermediate-sized sediments (0.2-1.0 cm) (McBride and Strahan 1984). Similarly, although more subjectively, Everitt (1968) and Wilson (1970) reported that willow species establish on the "muddier" (Everitt 1968), finer-textured soils and that cottonwood develop on the coarser soils. Shaw (1976) found that a gravel bar composition of 40% sand (smaller than 0.5 cm) and 60% gravel was essential for establishment of several cottonwood species. He also found that sandbar willow (*S. interior*) (also called *S. exigua*) would only grow on sandbars, but cottonwoods would never appear on these bars composed of substrate smaller than 0.5 cm (Shaw 1991).

In addition to generally monitoring the natural process of seedling recruitment, I was specifically interested in answering the following types of questions. Does soil texture influence the rate of cottonwood seedling establishment and survival? More specifically, do establishment and survival differ by the amount of sand, silt, and clay in the soil? Also, do establishment and survival differ depending upon what percent of the soil is composed of gravel or sand?

### Water Table

In connection with soil texture, the rate of water table decline also influences seedling establishment and survival. Researchers who studied the rate of water table decline on cottonwood seedling survival in laboratory and planter experiments concluded that seedlings cannot survive rates of water table decline averaging more than about 2.0 cm/day (see Chapter 1, Chapter 3, and Table 2). Virginillo and others (1991) assessed cottonwood seedling recruitment in the field and concluded that root growth rates of 0.32 cm/day were inadequate to follow a total seasonal drop in river stage of 44 cm. McBride and Strahan (1984) found significantly higher seedling densities in plots within 1 m of the water table than in plots greater than 1 m from the water table. Based upon the work done on ECB in the present study, seedling survival was greatest in quadrats where the water table was near the surface during the time of seed release and the water table declined at an average rate of about 0.5 cm/day (Chapter 3).

Although these previous studies and my work on ECB provided some understanding of seedling survival under partially-manipulated conditions, I was curious about how the rate of water table decline was related to seedling survival under natural conditions in the field. Specifically, I wanted to explore the following types of questions. Is seedling establishment and survival dependent upon how slowly the water table declines? What other factors, aside from soil texture and water table depth, might influence the establishment and recruitment of cottonwood seedlings during their first season?

## METHODS

### Study Design

In late May and most of June, I explored the entire study reach of the upper Clark Fork River. I watched as the river rose and then peaked on June 6. As the river declined, I began to note the location of fresh sediment deposits. Working with this reconnaissance information, I walked the river banks again on the days when the seed release was at its peak (June 30 and July 1), and I located bars with fresh sediment on them. Then, looking just at the fresh sediment areas, I subjectively selected locations for my study plots by using a specific protocol. I placed 1 $m^2$ plots in areas that met the conditions recognized in the literature as critical to cottonwood establishment (see Chapter 1). I put the plots on sunny, bare, moist substrate that was within 1 m distance of the water's edge, but not underwater. I tried to select some plots composed primarily of sand and others of gravel. I felt it was very important to time the selection of my plots with the natural seed dispersal process so that my plots would only be chosen from that surface area which was available for seeds to naturally land on during the time of peak seed release. I selected a total of 16 plots, 10 on various point and side bars along the river and six in a straight line on one side bar. I placed at least one plot on every bar which I had earlier identified as a fresh sediment bar. The bars I sampled are mapped in Chapter 3 on Figure 3 for the upstream sediment deposits and Figure 4 for the downstream deposits. I marked the plots by pounding one 35.6-cm piece of rebar in each corner. Although the bars had an unequal number of sample plots, each sediment bar served as a replicate so my overall population was new sediment bars along this reach of the Clark Fork River.

### Data Collection

Within each of the 16 plots, I counted seedlings in one 0.25 $m^2$ quadrat. I counted the seedlings on four dates: July 16, August 9, September 8, and October 13. I chose the first three dates for the same reasons described in Chapter 3, and I added October 13 because I wanted to note the survival into the fall months. I did not use flags to mark the quadrats as I did not want to attract attention from boaters and fishermen; however, I was able to ensure I went back to the same spot for each count by always placing my 0.25 $m^2$ PVC sampling grid in the upstream corner on the river side of the larger 1 $m^2$ plot. During each count visit, I also noted the condition of the plot—for example, if it had been trampled by livestock or elk or if individuals of another plant species were present. As occurred with the count on ECB, the July 16 count may have included seedlings of unknown species that I was not able to distinguish from the cottonwoods.

I also placed one piezometer on the upstream side of each of 10 plots (see Chapter 3 for explanation and discussion of measurement challenges). Compared to ECB, I was able to install the piezometers into these fresh sediment deposits with much less effort. In fact, on a few of them, I was almost able to push the piezometers in a full meter just by hand. I monitored the 10 piezometers approximately once a week from July 6 until the second week of August and then every few weeks until September 8 for a total of eight readings.

On October 13, I collected one soil sample from the center of each plot (actually just off the center so I would not disturb the seedlings I was monitoring in the 0.25 $m^2$ quadrat) with a garden hand trowel with a 5 x 15 cm blade. I took 2-3 shovelfuls of soil down to about 20 cm. I stored the samples in opened plastic bags in my basement until January 1996. On January 10 and 11, 1996, I analyzed the samples in the University of Montana School of Forestry Soils Lab to determine particle size. First, I dry-sieved the samples down to 2 mm, then, after oven drying the fine fraction for 16 hours at 110°C, I conducted particle size analysis on it using the hydrometer method (Gee and Bauder 1986) to determine percents sand, silt, and clay. I also sorted the coarser portion of the sample with the sieves, but I ended up pooling the various larger sizes for use in this paper into one gravel category (soil particles > 2 mm).

### Statistical Analysis Methods

I used Mann-Whitney U difference of medians (Daniel 1990) to test densities of cottonwood seedlings by soil category across the 16 plots on the first and last count dates. I used Spearman correlation coefficients (Daniel 1990) to test the relationships between seedling densities and depth to water table. All tests were conducted at the 0.10 significance level. I used the computer statistical packages, Student Systat 1.0 (Berk 1994) and Student Data Desk 4.1 (Velleman 1993), for all my analyses.

## RESULTS

### Sediment Deposition

The temperature, and especially the precipitation, from May to October 1995 were much different than normal (see Chapter 1). The Clark Fork River flooded to a maximum of 3560 cfs on June 6, the highest MDD in the last nine years. Figure 17 shows MDD for the 1995 water year.

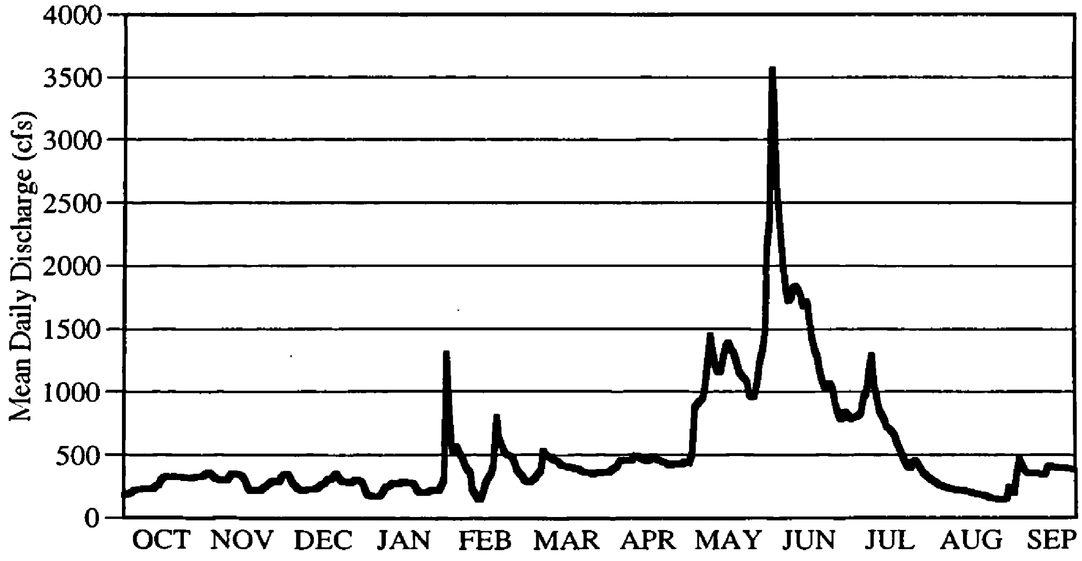

Figure 17. Hydrograph for the Clark Fork River at Gold Creek, water year 1995

The high flow in 1995 helped to create lots of fresh, deep sediment deposits. Deposits were as deep as 30 cm in some places, but they appeared to have an average depth of about 15 cm.

### Effect of Soil Texture on Seedling Survival

As expected for an alluvial deposit, the soil samples in this riparian area were well-sorted, but they turned out to be even better sorted than I anticipated. The particle size analysis revealed that the samples (n=16) were almost identical in percent sand, silt, and clay, except for one plot which had more silt and clay. Excluding the one plot, the average soil components were 83% sand, 3% silt, and 14% clay (loamy sand, Brady 1990). The remaining sample was 30% sand, 42% silt, and 28% clay (clay loam, Brady 1990). Because of the similarity between the vast majority of the samples, I did not assess the effect of percents sand, silt, and clay on seedling survival.

However, I did examine the soil samples on a broader scale. I grouped the sand, silt, and clay into the fine fraction, and I grouped the remaining larger size classes (2 mm - 31.8 mm) into the coarse fraction. I then assigned each sample to a category depending upon which of the two size classes dominated. Samples with more than 50% of their particles in the larger size class were labeled as "gravels," and the remainder as "sands."

The cottonwood seedling densities on the first count (July 16) ranged from 0 to 331 seedlings/0.25 $m^2$, with a median value of 43. This maximum initial density is comparable with the maximum densities of 1,000 seedlings/$m^2$ on rivers in southern Alberta (Lee and others 1991) but considerably less than maximum densities in excess of 4,000 seedlings/$m^2$ along the South Platte River in Colorado (Sedgwick and Knopf 1989). However, this establishment density is much greater than the maximum density of 672 seedlings/$m^2$ observed on ECB for this same date (Chapter 3), and the median value is roughly four times larger than the average establishment densities of 23 to 55 seedlings/$m^2$ on Dry Creek in California (McBride and Strahan 1984).

Even though seedlings established (July 16 count) at equal rates on the gravel and sand soils (p=1.000), seedling density on October 13, at the end of the growing season, was significantly higher on the gravel plots (p=0.064) (Figure 18).

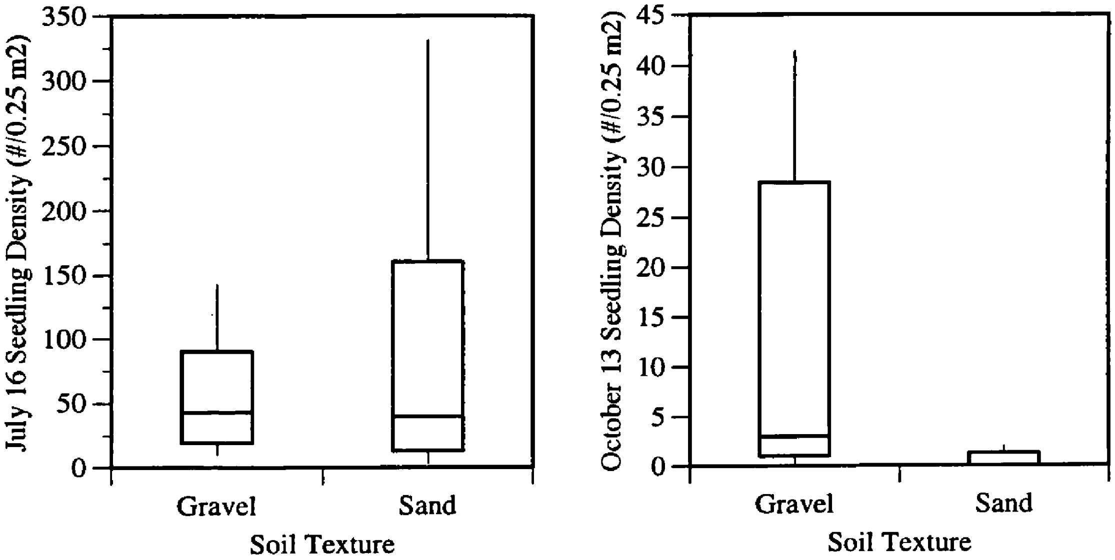

Figure 18. Comparison of establishment seedling density (July 16) and final seedling density (October 13) by soil texture

## Water Table Interactions

Compared to the water table on ECB (Figure 11), the water table on the new sediment deposits was much more responsive to changes in discharge over the course of the summer (Figure 19). The median depth to water table was also much closer to the ground surface. For example, on July 12, many of the piezometers were underwater, some by as much as 21.5 cm, because of the high discharge from almost a week of rain. On July 27, the median water level was still near the soil surface. Even as late as August 9, the median water level was only 32.0 cm below the ground surface. The responsiveness to the river's discharge and the higher median water tables on the new sediment deposits are likely a result of the fact that these plots were closer to the water surface in both distance and elevation than the plots on ECB which were at least 10 m from and at least 20 cm above the river (Chapter 3).

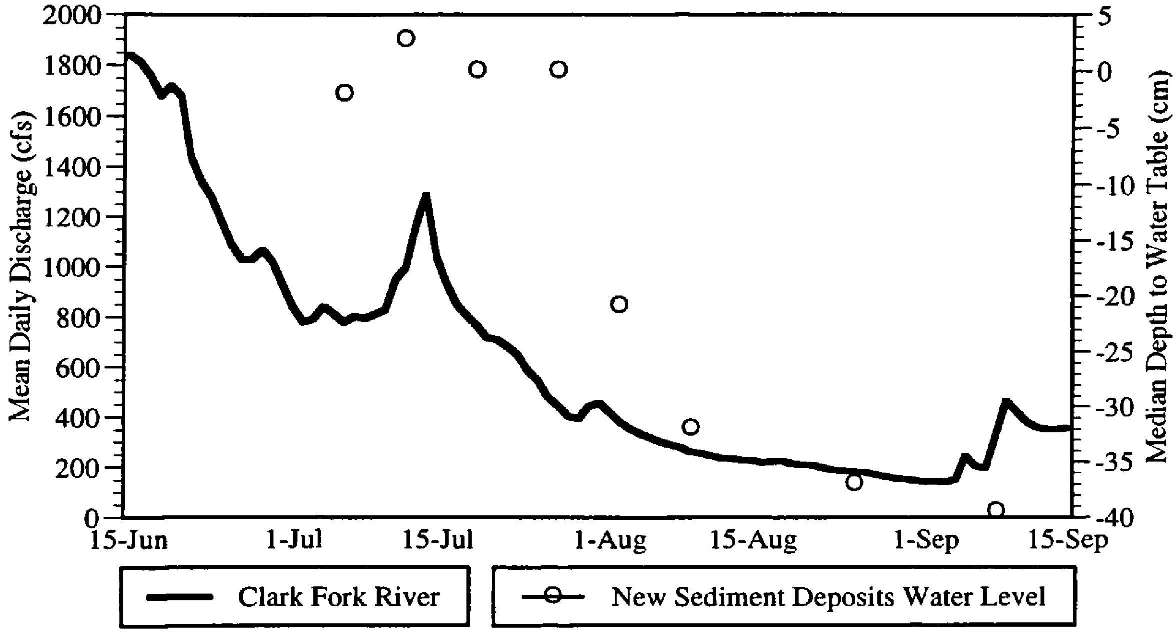

Figure 19. Summary of daily discharge and water table levels on new sediment deposits, June 15–September 15, 1995

## Effect of Water Table Decline on Seedling Survival

For the new sediment deposits where water table levels were measured (n=10), seedling densities were highest on those plots where the water table declined slowly. Although this trend was evident for the whole summer, seedling survival was significantly correlated with rate of water table decline in only one period. Seedling densities on the August 9 count were significantly negatively correlated ($r_s$=-0.523, $0.05<p<0.10$) with the average daily rate of water table decline between July 19 and August 9 (Figure 20), the period when the river dropped precipitously. Seedlings grew more tolerant of faster rates of water table decline later in the summer. In early July, seedlings did not survive average rates of water table decline greater than 0.5 cm/day, but by August some seedlings survived drops close to 2.0 cm/day. However, no seedlings survived in plots where the water table dropped below 56 cm at any point during the season.

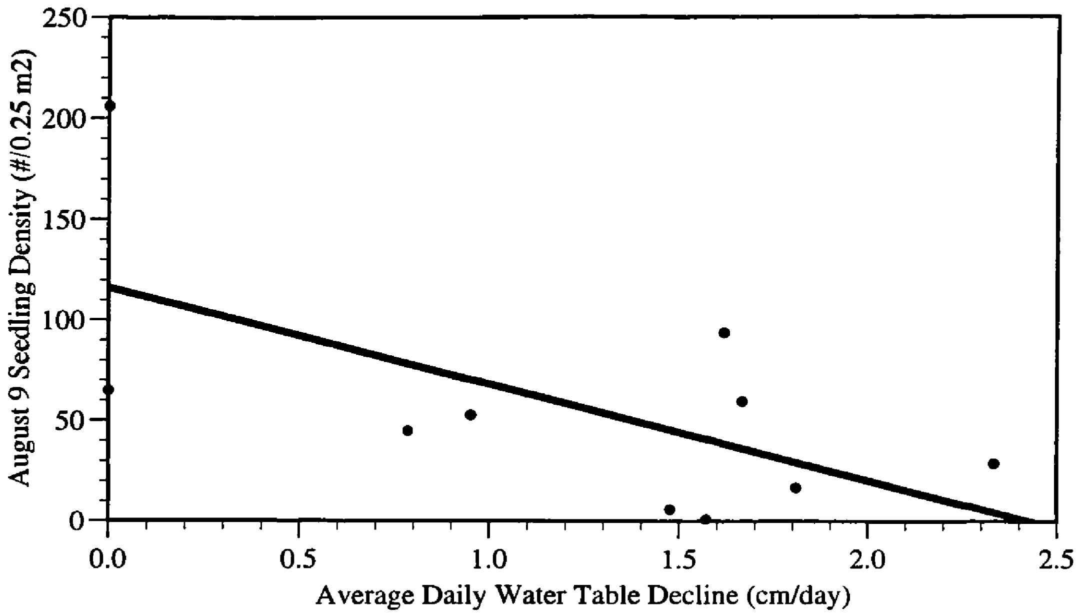

Figure 20. Relationship of July 19–August 9 water table drop and August 9 seedling density

## DISCUSSION

By observing the first-year process of establishment on the new sediment deposits and combining this information with the general patterns I observed on the rest of the study site, specifically ECB, I gained a better understanding of different factors potentially influencing cottonwood seedling recruitment. The results from my observations of seedling establishment and survival on the new sediment deposits suggest that coarse-textured soils and a high water table facilitate higher survival of cottonwood seedlings. However, many factors beyond those I measured are likely involved. For example, as mentioned earlier, twice the normal amount of precipitation for the month of July probably influenced the water table either directly or indirectly and may have increased seedling establishment over that which would have occurred in a year with more normal precipitation levels.

The relationship between soil texture and seedling survival is worth examining in greater detail. For a declining water table, commonly-accepted theory on soil texture and water holding capacity suggests that finer textured soils hold more water, and at a higher level, than coarse textured soils because of capillarity (Brady 1990), thus promoting higher seedling survival. Mahoney and Rood (1992) found that cottonwood seedlings grown in sand had greater height, leaf number, leaf area, and plant health than identical seedlings grown in gravel when seedlings in both soil groups were treated with increasing rates of water table decline ranging from 2.0–10.0 cm/day.

My finding that survival was higher on gravel than on sand contradicts this hypothesis that finer textured soils lead to greater cottonwood seedling survival. However, my results do fit with the existing vegetation pattern I observed on ECB when I first explored the study site early in the summer. On the older point bar, young cottonwoods were growing on the larger, coarser substrate, and grass and forbs dominated the finer textured soils. This vegetation pattern is probably a result of many factors, some of which are directly and indirectly related to the capillary action issue.

Three theories might help explain why I found young cottonwoods primarily on the coarse textured soils, and they could be summarized as "establishment," "competition," and "sediment trapping." First, as noted earlier, cottonwoods establish preferentially on coarser soils and willows on finer soils (Everitt 1968, Wilson 1970, Shaw 1976, McBride and Strahan 1984, Shaw 1991). Second, grasses, with many fine, shallow roots, may have a competitive advantage for moisture and nutrients on finer textured soils while cottonwoods, by virtue of a taproot, possess a competitive advantage for moisture on coarser soils (Behan 1995, Hansen 1996). Third, grass and cottonwood seedlings may establish on similar soils, but because the grasses act as better sediment filters during inundating flows, more fine sediment settles around the grass creating the potentially-misleading appearance that the grass "preferentially chose" the fine textured soil to establish upon in the first place. This last idea is buttressed by the fact that when I tried to place wire marking flags on ECB even the soils that appeared to be fine textured right at the surface were actually full of rock and very difficult to insert the wire into just a few centimeters below the surface. Observations by Nanson and Beach (1977) also support this theory that by increasing resistance to flow, dense vegetative cover promotes greater sediment deposition.

In addition to these theories, I would like to propose another idea based upon the results I observed this summer with the seedling establishment and survival on the new sediment deposits. The difference in survival between the two soil texture categories, sand and gravel, may not be a function of water holding capacity or vegetative competition. Rather, I suspect that trampling from cattle and elk was a primary factor affecting survival. Other authors have reported negative effects of trampling and browsing by cattle and horses (Glinski 1977, Behan 1981, Fenner and others 1985) and elk and moose (Kay 1994). Kay (1994) found that repeated browsing by native ungulates in Yellowstone National Park has reduced tall willow, aspen, and cottonwood communities by approximately 95% since the late 1800s. On the study site, cattle and elk were around the new sediment deposit plots during the summer. With the first-year seedlings, I think that trampling had more of an influence than browsing because the seedlings were so small (see Chapter 3) that the cattle and elk probably did not browse them. Therefore, difference in survival rates may be a function of the degree of protection from trampling provided to the seedlings by the soil substrate.

Coarse soils meant better survival. The gravel plots may have been able to support more of an animal's weight than sand plots. As an example, we can compare two plots that were similar in many ways except for the percent of coarse soil they contained. NSD #9 and NSD #10 were located only 2.5 m from each other on a side bar of freshly-deposited sediment, and their water table readings were very similar (less than 4 cm difference). During the first five weeks, July 6 to August 9, their water tables were almost identical, except NSD #9 was sometimes slightly higher. However, the plots did differ in their percent coarse fragments; NSD #9 had no coarse fragments, and NSD #10 had 72% coarse fragments. The initial seedling density counts (July 16) for both plots were 331 and 43 seedlings/0.25 $m^2$ quadrat for NSD #9 and NSD #10 respectively. Between July 16 and August 9, elk walked in the plots. On August 9, the counts were 206 and 45 respectively. Between August 9 and September 8, there was more sign that the elk had been in the plots. (My field notes on September 8 read "elk tracks bigtime," and the PVC cap had been broken off one of the two dipsticks.) On September 8, zero seedlings were alive in NSD #9, but 33 of the original 43 seedlings were still alive in NSD #10. Obviously this is a small sample, but it does help to illustrate the overall pattern that higher survival did occur on the plots with more than 50% coarse fragments.

Although trampling appeared to be a major factor affecting seedling survival, the potential influence of trampling on cottonwood seedlings should be studied further. Hanley and Taber (1980) found that elk and deer trampling and browsing affected species composition by limiting shrub abundance in a red-alder floodplain community. Rhodes (1991) reported that cattle, concentrated in more confined areas in the winter, cause significant trampling and clipping of cottonwood seedlings. Although Crouch (1979) did find that grazing can open up suitable habitat for cottonwood establishment, he concluded that virtually all the cottonwood seedlings that sprouted were eaten by the cattle. DeBell (1990) reported that browsing and trampling of black cottonwood saplings by elk and deer can decimate small isolated stands. Marcum (1975) found that elk in western Montana preferred riparian areas, and Nielsen (1996) stated that elk in the study region during the 1980s spent almost 11 months of the year in the riparian area. However, the specific hypothesis that trampling by elk and cattle limits cottonwood recruitment on this study site could only be tested through the use of exclosures on different soil substrates and with a larger sample size.

## SUMMARY

Seedling establishment densities on the new sediment deposits were greater than some of those previously reported in the literature. Seedlings survived longer in plots where the water table dropped at a slower rate. The water table was highly variable, probably in response to changes in river discharge. Although soil texture for particles smaller than 2 mm was very similar, the percent of soil particles in sand and gravel size categories did differ. Cottonwood seedlings established on the sample plots without showing preference for either the sand or gravel. However, seedlings growing on the gravel had much higher densities at the end of the first season. This result supports observations I made of existing vegetation that more cottonwoods are growing on coarser substrates than on finer substrates. Although many factors could be involved, survival rates may have differed because fine textured soils appeared to provide less structural protection from elk and cattle trampling than coarse textured soils did.

# CHAPTER FIVE:
# PUTTING THE PIECES TOGETHER: OPPORTUNITIES FOR MANAGEMENT AND FUTURE RESEARCH

## INTRODUCTION

Having used the previous three chapters to independently discuss factors influencing the distribution and recruitment of black cottonwoods growing on the study reach of the upper Clark Fork River, here I synthesize these components—thus acknowledging their interconnectedness both ecologically and managerially. Although long-term survival is influenced by many factors—most visibly beavers and the powerful scouring force of ice in the winter— that were beyond the scope of this study, this study did assess some of the factors involved in the first step toward cottonwood stand replacement, namely first-year establishment and survival. In this final chapter, I first summarize the general principles which emerged from the study. Then I incorporate these principles into recommendations for management opportunities and future research.

1) Based upon field observations and approximate tree ages obtained by coring, black cottonwoods (*Populus trichocarpa*) in the study area appear to reach a maximum age of roughly 150 years, and the average lifespan appears to be about 100-150 years.

2) Some natural regeneration of cottonwoods is occurring as evidenced by the presence of stands younger than 25 years. However, less than 5% of the total area occupied by cottonwood is covered by stands less than 50 years old. Cottonwood recruitment may be limited by a number of independent or combined factors.

3) Water table depth on the established point bar (ECB) appeared to fluctuate with the river discharge within about 50 m of bankfull capacity, but the water table stayed relatively uniform at a distance of 50-94 m from the channel.

4) Site preparation treatments designed to enhance cottonwood seedling recruitment by removing vegetative competition and creating bare substrate had no statistically significant effect on seedling establishment and survival.

5) Although not significantly different, seedling establishment was greater in the plots treated with plowing. This may be due to microclimate factors, such as a rougher soil surface which trapped cottonwood seed blowing on or near the ground and a moist, wind-protected area down between the "clods" of soil.

6) Seedlings which did establish and survive were located very close to bankfull capacity of the river channel. No seedlings survived the first season if they established more than 34 m in distance and 45 cm in elevation from bankfull capacity. This establishment pattern was consistent with an existing pattern of young cottonwood distribution where 96% of older seedlings and saplings were growing within 50 m distance and 70 cm elevation of bankfull capacity.

7) Highest cottonwood seedling survival occurred in those plots where the water table was within 20 cm of the surface during the time of seed release (late June–early July) and where the water table dropped no deeper than about 50 cm by early September. Of this 10 week period, the first three weeks (late June–mid July) were the most critical. In plots with a high starting water table, seedlings only survived where the water table declined at an average rate of less than 0.5 cm/day during the first three weeks. Over the next three weeks (mid July–early August), some seedlings survived average drops of close to 2.0 cm/day. However, for the entire season, drops of about 0.5 cm/day led to greatest survival.

8) Seedling establishment did not significantly differ by soil texture of the new sediment deposits, but seedling densities at the end of the summer were significantly greater for the seedlings growing on gravel than for the seedlings growing on sand. Although this could be a function of many factors, my observations suggest that seedlings growing on gravel were better protected from trampling by elk and cattle.

Because only 5% of the existing cottonwood stands along the study reach appear to be younger than 50 years and because 100-150 years appears to be the maximum lifespan for cottonwood trees in this study area, the cottonwood ecosystem may not replenish itself and persist in this reach of the upper Clark Fork River if current conditions do not change. As discussed earlier, cottonwoods on the study site are providing a broad range of benefits for humans and wildlife. For example, cottonwoods are helping to stabilize stream banks with their roots and providing educational opportunities for school children viewing the great blue heron rookery. In addition to herons, bald eagles, kestrels, and neotropical migrants nest in the cottonwoods. Elk, moose, white-tailed deer, and beaver also rely upon the cottonwood habitat in this area for food and shelter.

With a better understanding of the cottonwood ecosystem and factors influencing it on the study site, managers are now in a better position to evaluate management objectives. Protection and regeneration of the cottonwood ecosystem does not require that past management practices be eliminated or that past management was bad or wrong. Rather, now with new information, the roles of cottonwoods can be better understood; and, if so desired by managers, the regeneration of cottonwoods can be prioritized as a management objective. Some potential management practices could be implemented now, and others should be studied further; both are addressed in this final section.

## COTTONWOOD MANAGEMENT

### Maximizing the Opportunity for Cottonwood Recruitment in Browsed Areas

On many Western rivers, livestock and unregulated wildlife populations have affected riparian communities by grazing, browsing, and trampling plants. On the study site, elk and cattle may be influencing cottonwood regeneration by browsing and trampling seedlings and saplings. The lack of cottonwoods between 10-50 years of age may be related to the high elk populations in the 1970s and 1980s and the past and current grazing management.

Because cottonwood seedlings are establishing naturally, recruitment might be increased by maximizing the opportunity for seedlings which do establish to survive long-term. One method would be to protect seedlings from trampling and browsing. Cottonwood seedlings which establish in areas along the river could be fenced using portable electric fence for at least the first 10 years (Hansen 1996) to 20 years (Behan 1981) to protect them from trampling and allow the cottonwoods time to grow tall enough to withstand browsing pressure. After this time, these stands would likely no longer need to be fenced.

Furthermore, in areas where older cottonwood seedlings, saplings, and poles are already established, another option to supplement the temporary fencing exclosures could be tried.

Based upon field observations, although cattle were in the regions below the bridge from late April until the winter, the cattle did not start to browse the cottonwoods until mid-July. Therefore, grazing would not have to be eliminated to make cottonwood recruitment a management objective, rather only the timing of the grazing schedule would need to be modified. If cattle are moved from the areas where young cottonwoods are growing to areas away from the river by mid-July, the seedlings and saplings would not be browsed by the cattle. Moving cattle out of the cottonwood areas at that time would also coincide with protecting the new seedlings during the critical period when they are experiencing drought stress and when the majority of the trampling-induced mortality occurred in this study.

Figures 3 and 4 (Chapter 2) show the location of seedling and sapling stands which could be protected from trampling and browsing. By maximizing the opportunity for young cottonwoods to survive long-term, land managers can help ensure that cottonwoods stands replenish and thus continue to provide important benefits for years to come.

### The Potential for Site Preparation Treatments on Rivers Where Sediment is Not Naturally Deposited

In this study, site preparation treatments did not increase cottonwood recruitment. For rivers where sediment is being deposited naturally, site preparation is not recommended for multiple reasons. First, site preparation treatments had no statistically significant effect on seedling establishment or survival. Second, seedling establishment and survival were much lower on the manipulated plots than on the naturally-deposited sediment plots even though the latter areas were subject to more trampling pressure by elk and cattle. Third, many factors, such as winter ice flows, play a major role in determining where seedlings establish and survive, and the role of ice can be difficult to understand. Fourth, site disturbance may increase access opportunities and create a competitive advantage for undesirable species such as noxious weeds. Fifth, site disturbance could increase the amount of non-point source pollution from erosion and have negative effects on fisheries and water quality. Finally, site manipulation can be expensive. For these reasons, active site preparation steps—designed to increase the amount of bare sediment to promote cottonwood recruitment—are not recommended on rivers where sediment is already available. Rather, in situations where seedlings are establishing naturally and not surviving to form stands, active management steps focusing on other options, such as those identified above, should be used.

However, many Western rivers are regulated, and, as a result, sediment is not being regularly deposited with peak spring flows at a rate sufficient to support the replenishment of cottonwood stands. In these cases, site preparations to create bare sediment and thus reduce vegetative competition may be worth considering despite the potential drawbacks of site preparation mentioned above. Although the use of site preparation treatments on regulated rivers is beyond the scope of this study, some of the lessons learned in this study may be applicable. I have addressed several important issues here which should be resolved prior to implementing any site preparation treatments. Potential sites must meet several specific requirements; otherwise seedlings will not survive. First, a local cottonwood seed source must be available. Second, based upon results from the present study, the water table should be close (within 20 cm) of the ground surface at the time of seed release. Third, for the entire growing season, the water table should decline at an average rate of about 0.5 cm/day—especially in the first three weeks following seed release. Fourth, the water table should not drop below 50 cm by early September. Fifth, in this study on an established point bar with an average slope of 4.5%, no seedlings established farther than 34 m in distance and 45 cm in elevation from bankfull capacity—so treatments beyond these distances may not be effective. The information for determining site suitability can be gathered by looking at existing vegetation and landform and also monitoring the level of the ground water.

In addition to addressing the factors identified above, the role of winter floods and ice flows needs to be examined. Winter ice flows can kill many seedlings. During the ice breakup in March 1996 on the upper Clark Fork River, ice bent over piezometers on the study site that were located as far as 60 m from bankfull capacity and in plots higher than 1 m above bankfull capacity (personal observation). The final effect of the 1996 winter ice jams on the seedlings in this study has yet to be assessed, but, based upon observations thus far, few seedlings, if any, are expected to still be in place and alive. McBride and Strahan (1984) and Johnson (1994) reported 100% seedling mortality over the winter months. The best efforts to establish seedlings in those areas closest to the channel where they will be assured a high water table can all be lost with one ice flow. Also, although discharge can be controlled on regulated rivers, the influence of yearly fluctuations in precipitation and temperature during the establishment period must also be addressed.

Once these issues have been identified, any site disturbance treatment should occur in the fall when the river is at its lowest level so that the maximum amount of treated surface area will be exposed to seedlings during the next spring. However, just as ice determines the lowest limit of long-term survival in the winter, the maximum stage of the river at the time of seed release defines the lower limit of seedling establishment in the spring by determining the amount of bare sediment above the water surface and exposed for seedling establishment. Therefore, the normal height of the river stage at the time of seed release in the spring must be known, and any treatment below this point on the river bank is probably wasted effort. Those applying site treatments must also weigh the risk of increased invasion of noxious weeds. Finally, the use of plowing, instead of herbicide, is recommended to create the bare areas. In the present study, the plowed areas had higher seedling establishment which may have resulted from microclimate factors, and there is less risk of side effects from herbicide on the aquatic and riparian habitats. Before any widescale site preparation work is implemented in an attempt to increase cottonwood recruitment on regulated rivers, more research should be completed to assess the interactions of the issues discussed here.

## FUTURE RESEARCH

### Monitoring the Process of Seedling Establishment

Several components of the present study took experiments which had been conducted in labs and planters one step further by assessing cottonwood seedling establishment and survival under natural field conditions. To build upon this work in the future and monitor additional factors influencing seedling recruitment on naturally-deposited sediment, I recommend incorporating the following steps:

1) On a river similar to the upper Clark Fork, keep all the sampling plots within 10-15 m (20 m if the slope is very gradual) of bankfull capacity.

2) Make quadrats 1 $m^2$ and count densities in the whole 1 $m^2$ area.

3) Place one piezometer in every quadrat and monitor the water table weekly throughout the growing season and monthly at other times. Use chalk and not paste for measuring water table depth.

4) Conduct seedling establishment and survival counts weekly for the first four weeks. Mark some randomly selected seedlings and monitor their survival.

5) Use exclosures to evaluate the impact of wildlife and livestock on cottonwood regeneration.

6) Measure soil moisture and temperature. Describe the soil conditions on the sites by collecting soil cores to a depth of 1 m. Measure particle size, percent organic matter, nutrients, and pH at several soil depths. Heilman (1981, cited by DeBell 1990) stated that the occurrence of black cottonwood in the Pacific Northwest may be restricted by high soil acidity (low pH) on fine-textured soils when other site factors are favorable. From work in British Columbia, Smith (1957) reported that black cottonwood would grow poorly on soils with a pH below 5.5 and that a pH from 6.0-7.0 supported optimum growth.

7) Carefully excavate and measure root lengths and stem/leaf biomass of a large random sample of seedlings from the quadrats at the end of the growing season.

8) Calculate the inundation frequency for the plots by using plot elevation, stage-rating curves, channel cross-section dimensions, and return intervals for peak flows.

9) Determine the potential for ice scour using a statistical model similar to that which Johnson (1994) developed.

10) Monitor the water tables for a longer period of time. Zobeck and Ritchie (1984) suggest that water table depths cannot be accurately measured with studies shorter than three years in length.

These steps would allow for more accurate correlation between soil texture, rate of water table decline, root and shoot growth, the role of herbivores, and seedling survival in a field setting. Such a study would move beyond the greenhouse, but it would also have more control over some of the potentially-confounding variables than I had.

## Opportunities for Future Research

Cottonwood regeneration on the upper Clark Fork River and on many other Western rivers is influenced by many factors that were beyond the scope of this study. Of these other factors mentioned throughout this report, I recommend that future research in this area emphasize three primary factors that may be influencing black cottonwood recruitment on the upper Clark Fork River.

First, address the effects of river channelization by the interstate and the railroad on cottonwood recruitment. Because channelization accelerates the downward erosion process and transfers the river's energy downstream (Gordon and others 1992), there is likely little opportunity for cottonwood seedlings to establish in channelized areas because much less sediment is deposited in these zones. This lack of cottonwoods, often combined with a lack of other plant species with binding root masses, compounds the problem of bank instability because no vegetation can establish and help stabilize the banks and reduce erosion. On the other hand, in areas where the river is no longer "straightjacketed," the river appears to be dissipating its energy with lots of lateral channel migration. Over time, this process creates sediment deposits from flooding and braided channels. Opportunities for cottonwood recruitment in these areas may be very high. However, the role of ice must also be addressed in these settings.

Second, water in the upper Clark Fork valley has been used for mining and agriculture for many years. Because water table depth and rate of decline were critical factors influencing where cottonwood seedlings established and survived, agricultural diversions may be affecting cottonwood recruitment on the upper Clark Fork River. Because diversions occur prior to seed release and continue throughout the summer, the timing of diversions coincides with a critical time for seedlings. During 1995, on the study reach, water was diverted from the river from mid-June until early September, the period of seedling establishment. By affecting the quantity of water, diversions may indirectly influence the availability and quantity of bare sediment area which can support seedling establishment and survival. As a function of sediment distribution and slope, diversions may influence the starting water level, the rate of water table decline, and the lowest water level of the season. Furthermore, diversions may be causing drought stress to mature cottonwoods and thus increasing the mortality rate.

Third, and finally, the reach of the upper Clark Fork River from Warm Springs to Bonner has been influenced by a long history of mining. Mine tailings may be limiting the establishment of cottonwood seedlings and contributing to the mortality of mature cottonwoods. The potential effects of mine tailings on cottonwoods should be addressed in future work.

Because cottonwood stands require an entire stream reach in order to replenish themselves, effective management solutions, from the start, must look and work on a broad scale. Public and private landowners must work together and realize that upstream management often causes downstream effects, both positive and negative. As pressures on riparian ecosystems continue to escalate with increasing human populations and development, cottonwood forests will likely continue to be affected. Decisions we have made as a society in the past continue to affect us today. Similarly, the decisions we make now regarding the conservation and use of our natural resources will have an influence for years to come. Having identified some current and future opportunities for black cottonwood management and research, I hope this study contributes to responsible decision-making.

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