GEOMORPHIC REQUIREMENTS FOR ESTABLISHMENT AND MAINTENANCE OF COTTONWOOD FOREST

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ABSTRACT

The relation between streamflow and establishment of bottomland trees is conditioned by the dominant fluvial process or processes acting along a stream. For successful establishment, plains cottonwood requires bare, moist surfaces protected from disturbance. Channel narrowing, channel meandering, and flood deposition promote different spatial and temporal patterns of establishment. During channel narrowing the requirements are met on portions of the bed abandoned by the stream, and establishment is associated with a period of low flow lasting one to several years. During channel meandering, the requirements are met on point bars following moderate or higher peak flows. Following flood deposition the requirements are met on flood deposits high above the channel bed. Flood deposition can occur along most streams, but where a channel is constrained by a narrow valley this process may be the only mechanism that can produce a bare, moist surface high enough to be safe from future disturbance.

The effects of flow alterations on cottonwood forests in western North America have generated substantial concern because of the important habitat and aesthetic values of these communities. Consideration of such effects in water management decisions has been hampered by the apparent variability of responses of these forests to flow alteration and other influences. However, when the relation between flow and tree establishment is placed in a geomorphic context, much of that variability is explained, and prediction of changes in the forest is improved.

Watershed development often leads to calls for construction of dams to reduce peak flows and for bank stabilization efforts to impede channel migration and decrease sediment load. However, floods, sediment deposition, and channel change are essential for establishment of disturbance-dependent species like plains cottonwood. Managers need to be aware that they cannot have both a channelized, regulated stream and a naturally reproducing stand of plains cottonwood.

INTRODUCTION

One focus of the Stream and Riparian Ecology Section is to assess the effects of hydrologic alterations on riparian vegetation in arid regions of the western United States. This article summarizes our research investigating the relationship between streamflow, channel geometry, and establishment of plains cottonwood (Friedman, 1993; Scott et al., 1993a; Scott et al. 1993b; Segelquist et al., 1993; Eggleston et al., 1994; Scott et al., in press; Friedman et al., in press; Friedman et al., in review).

The first woody plants to dominate bare, wet sediment along streams often

demonstrate rapid growth, intolerance of shade, tolerance of nutrient scarcity and burial, release of large numbers of seeds following peak flows, and lack of seed dormancy (Sigafoos, 1964; Hupp, 1992). In the western Great Plains, the dominant tree in this group is the plains cottonwood (*Populus deltoides* subsp. *monilifera*). Because bottomlands are typically the only locations in this region wet enough to support trees, cottonwood forests provide important habitat structure for wildlife (Brinson et al., 1981) .

Spatial and temporal patterns of cottonwood forests are determined to a large extent by flow during the establishment phase (Scott et al., 1993b). However, the relation between flow and establishment varies from site to site. Along one stream cottonwoods may establish following high flows, while along another they establish during low flows. We have found that this variation results from differences in the fluvial-geomorphic processes that form surfaces suitable for establishment.

Plains cottonwood produces abundant seeds, but these seeds become established only under a narrow range of conditions. An abundant crop of wind- and water-dispersed seeds is released early each summer in association with peak flow (Johnson, 1994). The seeds can germinate immediately, but lose germinability under field conditions within a few weeks (Moss, 1938; Ware and Penfound, 1949; Johnson, 1994). Freshly deposited alluvium typically provides ideal substrate for germination and establishment. Because it is intolerant of shade and germinates poorly in plant litter, cottonwood is incapable of becoming established from seed under an existing stand of trees (Johnson et al., 1976) or herbs (Friedman, 1993). This trait often leads to even-aged stands. Young seedlings require a continuously moist substrate during at least the first week of growth (Moss, 1938). Root growth during the first month is slow (Burns and Honkala, 1990), but later in the first growing season, seedlings are able to extend a taproot deep enough to survive declines in the water table of as much as 1 m (Mahoney and Rood, 1991; Segelquist et al., 1993). Therefore, the vulnerability of cottonwood to dry conditions decreases rapidly with age. However, adults can be killed by severe droughts such as occurred in the 1930's (Albertson and Weaver, 1945). Plains cottonwood is tolerant of burial and able to sprout from buried stems (Everitt, 1968). In spite of these adaptations, extensive mortality can occur as a result of floods (Osterkamp and Costa, 1987) and ice scour (Johnson, 1994). Unlike balsam poplar (*Populus balsamifera*), narrowleaf cottonwood (*P. angustifolia*), aspen (*P. tremuloides*), and sandbar willow (*Salix exigua*), plains cottonwood rarely reproduces from root sprouts (Scott et al., 1993a). Intensive livestock grazing and trampling, especially in the late summer, can kill or stunt cottonwood seedlings and saplings (Kauffman et al., 1983).

In summary, successful establishment of plains cottonwood from seed occurs only in channel positions that are moist, bare, and protected from subsequent disturbance (Everitt, 1968; Noble, 1979; Bradley and Smith, 1986; Johnson, 1994). As cottonwood root systems mature they can tap into a water table several meters below the surface (Sprackling and Read, 1979). Therefore, if a flood removes the overstory, cottonwood stump sprouts may occur even if the ground surface is dry.

FLUVIAL PROCESS AND COTTONWOOD ESTABLISHMENT

A suitable environment for establishment of plains cottonwood can be produced by many fluvial processes. In this paper we

concentrate on three important processes--narrowing, meandering, and flood deposition--which produce different spatial and temporal patterns of trees and different relations between flow regime and establishment (Scott et al., in press). These processes can act alone or in combination. Where the dominant process changes along a stream, patterns of trees may change accordingly.

Narrowing

Channel narrowing refers to abandonment by the stream of a portion of former channel bed. Thus, we include establishment of trees and shrubs in a former channel following avulsion. Establishment by channel narrowing is most important in streams subject to large fluctuations in width. For this reason, narrowing is more important in braided streams than in meandering streams (Schumm, 1969), and more important in arid regions than in humid regions (Wolman and Gerson, 1978).

Channel narrowing can occur as a response to flood-induced widening (Schumm and Lichty, 1963; Burkham, 1972; Osterkamp and Costa, 1987), climate change (Schumm, 1969), construction of upstream dams (Williams and Wolman, 1984), changes in land management (Nadler and Schumm, 1981), introduction of exotic bottomland plant species (Graf, 1978) or as part of a cyclic, autogenic process (Patton and Schumm, 1981). The immediate cause of narrowing is usually a period of one to several years of flows insufficient to rework the entire channel bed. This allows establishment of vegetation on the bed. The newly established vegetation promotes deposition of fine sediment (Osterkamp and Costa, 1987) and increases resistance to erosion (Smith, 1976), thus stabilizing the channel at a narrower width.

Populations of cottonwood established during channel narrowing are usually not strictly even-aged (Friedman, 1993); individuals in a stand may have been established at any time within a period of several years of relatively low flow (Friedman et al., in press). Stands usually have an irregular shape whose longest axis is parallel to the direction of flow. Where narrowing occurs rapidly, young individuals are inundated infrequently and are usually not flood-trained (bent downstream into a decumbent position). The germination point of trees and shrubs established during channel narrowing is at the elevation of the channel bed at the time the surface was abandoned by the stream (Friedman et al., in press).

Meandering

Meandering streams are characterized by low width-to-depth ratios and progressive channel movement. The process of meandering is most important along low-gradient streams with low discharge variability and sediment load dominated by suspended sediment (Schumm, 1969). Infrequent events can have long-lasting effects on the geometry of meandering streams, especially in arid and semiarid regions (Schumm and Lichty, 1963; Burkham, 1972; Wolman and Gerson, 1978). However, most of the sediment deposition on point bars is carried out by moderate flows with recurrence intervals less than 5 years (Wolman and Miller, 1960). Cottonwood forests produced as a result of meandering generally take the form of a series of parallel, arcuate bands of even-aged trees. These bands develop on point bars, and are therefore parallel to the direction of flow at the time they were established (Everitt, 1968; Noble, 1979). On the point-bar side of the channel, the age of bands increases with distance from the channel.

Stands on the cutbank side are older and not necessarily parallel to the present direction of flow. Because establishment is on a surface subject to frequent deposition, young stems may be repeatedly flood-trained (Everitt, 1968). The establishment surface of an adult tree is at the elevation of a young point bar--typically below the present flood plain, but above the channel bed (Everitt, 1968; Bradley and Smith, 1986).

Along a meandering stream, progressive movement of the channel protects trees and shrubs on former point bars from flood disturbance. This results in the preservation of a large number of bands on the flood plain. If a band is not removed by erosion, the cottonwoods are eventually replaced by shade-tolerant woody species (Weaver, 1960; Johnson et al., 1976) or by grassland (Hefley, 1937; Lindauer, 1983).

Flood Deposition

Flood deposition and erosion occur along most streams, but are especially important for cottonwood establishment where lateral channel movement is constrained by a narrow valley. Because the channel is not moving, the only locations that are safe from subsequent scouring are those at high elevations. Only the greatest flows produce bare, moist substrate at these high elevations. Therefore, along a constrained channel trees occur in a small number of even-aged groups. The germination point of individuals is at a high elevation relative to the channel bed and close to the present ground surface. Flood-training is rare because the high establishment surface is rarely inundated.

We examined patterns of plains cottonwood establishment within a post-glacial section of the upper Missouri River in the Montana plains, where the river is constrained by a narrow valley (Scott et al., 1993a; Scott et al., in press). At most locations within this section, sandstone and shale formations inhibit lateral channel movement, and cottonwood stands, where they occur, consist of narrow, linear bands on a narrow terrace. Along nine cross sections we excavated cottonwoods in order to determine the precise year and elevation of establishment. Most cottonwood establishment occurred in years with a peak mean daily flow greater than 1,400 m^3/s (49,434 cfs), or in the two years following such a flow. These years include 35 out of the 111 years of record, and account for establishment of 47 of 60 trees examined, a highly significant relationship. Infrequent establishment of cottonwood trees is not the result of scarcity of seed or seedlings. Seedlings become established most years on bare, relatively low surfaces deposited by the river. However, the high elevation of establishment of almost all trees established before the last major flood (1978) indicates that only individuals on high flood deposits are able to survive subsequent floods and ice jams.

Floods can cause tree establishment either directly, through the process of flood deposition, or indirectly, by initiating an episode of channel narrowing. For example, along a sandbed stream in the Great Plains, deposits left on low terraces by a catastrophic flood in 1965 were too high, and therefore dry, to allow establishment of cottonwood from seed; however, many cottonwoods on these surfaces resprouted from the stumps of flood-damaged trees. In addition, the flood widened the stream, and during subsequent decades of narrowing, extensive cottonwood establishment occurred at or near the elevation of the channel bed (Friedman et al., in press).

CAUSES OF COTTONWOOD FOREST DECLINE

Impacts of stream alterations on bottomland tree communities in western North America have generated substantial concern because of the important habitat and aesthetic values of these communities. Consideration of these impacts in water management decisions has been hampered by variability of responses of bottomland tree communities to flow alteration. Placing the relation of flow to vegetation in the appropriate geomorphic context helps explain this variability and may improve prediction of the effects of proposed flow alterations on bottomland vegetation.

Where meandering is the dominant fluvial process, a reduction in peak annual flows could decrease the rate of meandering, leading to decreased cottonwood establishment. This argument has been used to explain many cases of cottonwood forest decline downstream of dams in North America (Johnson, 1992; Bradley and Smith, 1986; Rood and Mahoney, 1990).

To the extent that cottonwood reproduction on dammed, meandering streams is limited by a shortage of bare, moist sites, it should be possible to restore stands of cottonwood using natural seedfall in artificially disturbed, irrigated locations. We used an experimental approach to test this hypothesis along Boulder Creek, a dammed Colorado stream with little cottonwood reproduction for the last several decades (Friedman et al., in review). We tested the effects of disturbance (sod removal), irrigation, and addition of seed on plains cottonwood establishment. In unirrigated, undisturbed plots mean cottonwood density was 0.03 seedlings/m^2. Irrigation or disturbance alone produced mean cottonwood densities of 0.39 and 0.75 seedlings/m^2. Plots that were both irrigated and disturbed produced a mean cottonwood density of 10.3 seedlings/m^2. The effects of irrigation and disturbance on cottonwood establishment were significant ($p<0.005$); added seed had no significant effect ($p=0.78$). The few cottonwood seedlings in unirrigated plots were in low positions susceptible to scour by future moderate flows. We concluded that cottonwood establishment along Boulder Creek is limited by the scarcity of bare, moist sites safe from future scour. Seeds produced by the six female trees in the 1-km study reach were sufficient to colonize suitable sites formed by natural or artificial means.

Braided channels often respond to a reduction in peak flows with an episode of channel narrowing. Thus in contrast to meandering channels, braided channels can respond to an upstream dam by undergoing a pulse of cottonwood establishment. However, once the stream has narrowed to a new stable width, further cottonwood establishment can occur only following flows high enough to remove existing vegetation. For example, as a result of decreases in discharge and sediment load extensive channel narrowing and cottonwood establishment have occurred in the 1900's along the Platte and North Platte Rivers in Nebraska and along the South Platte and Arkansas Rivers in Colorado. In the last three decades narrowing and cottonwood establishment have decreased or ceased as the river has approached a new steady-state width (Johnson, 1994). As the cottonwoods in these forests die they will probably be replaced by shade-tolerant tree-species in relatively humid regions (Johnson, 1994), and by shrubland and grassland in more arid regions, where shade-tolerant bottomland trees do not occur.

A better appreciation of the relevant geomorphic processes can help establish appropriate management objectives for bottomland forests. Often objectives are formulated in terms of protecting the current

situation from degradation. However, the current location and extent of forest does not always represent a reasonable management objective. Plains cottonwood is a disturbance-dependent pioneer species. Future trees can be expected to become established not under their parents, but on new deposits of sediment created by the stream. Moreover, existing stands may be relicts of the geomorphic processes associated with a past flood or former flow regime. In eastern Colorado, many of the most extensive riparian forests occur along streams that have experienced large floods in the last century (Osterkamp and Costa, 1987; Friedman, 1993; Friedman et al, in press). In cooperation with professors and students at Colorado State University, we have recently begun a systematic investigation of forests and alluvial deposits at several streams in eastern Colorado. Our goals are to determine whether floods do generate large cottonwood forests, and whether floods like those that have occurred in the last hundred years are exceptional occurrences or events that can be expected to recur once or twice a century.

Watershed development often leads to calls for construction of dams to reduce peak flows, and for bank stabilization efforts to impede channel migration and decrease sediment load. However, floods, sediment deposition, and channel change are essential for establishment of disturbance-dependent species like plains cottonwood. Managers need to be aware that they cannot have both a channelized, regulated stream and a naturally reproducing stand of plains cottonwood.

Thus far we have emphasized the importance of conditions during the first few years of life in determining the pattern and abundance of adult cottonwoods; however, adult mortality also influences these patterns. Factors contributing to adult mortality include flood scouring (Yanosky, 1982), cutbank erosion of a meandering river, ice impact (Sigafoos, 1964), fire (Nanson and Beach, 1977), drought (Albertson and Weaver, 1945), and beaver damage (Bradley and Smith, 1986), as well as disease, timber harvest and land clearing. These factors dominate patterns of some populations, but in most cases the underlying pattern determined through establishment is still clear.

Alluvial groundwater declines are common in the Great Plains as a result of groundwater pumping and in-channel mining of sand. We examined the effect of sand-mining on the alluvial water table and the riparian cottonwood population along Coal Creek, an ephemeral Colorado stream (Eggleston et al., 1994). Twice-monthly groundwater measurements and annual assessments of cottonwood crown volume were made along mined and unmined reaches beginning prior to the onset of mining. Mining lowered the water table from 1.45 m at the channel edge to 0.94 m at the valley wall. In the first growing season following mining there was a decrease in crown volume of mature cottonwoods ranging from 35% at the channel edge to 5% at the valley wall. By the following August, 63% of the trees had died. Change in crown volume in control transects ranged from -8 to 10% over the same period. We conclude that decreases in water table greater than about 1 m sustained for at least two years can cause extensive cottonwood mortality.

CONCLUSIONS

Establishment of plains cottonwood from seed occurs almost exclusively on bare, moist surfaces protected from disturbance. These conditions can be produced by several different fluvial processes, including narrowing, meandering, and flood deposition.

These processes are associated with different flow magnitudes and produce different spatial and temporal patterns of trees. Because of the importance of bottomland forests as habitat, managers need to be able to predict how a flood-plain landscape would be affected by a change in flow regime. Such predictions require an understanding of the locally dominant fluvial processes. Where stream alterations now prevent natural formation of suitable surfaces for establishment, such surfaces can be formed artificially through carefully timed sod removal and irrigation.

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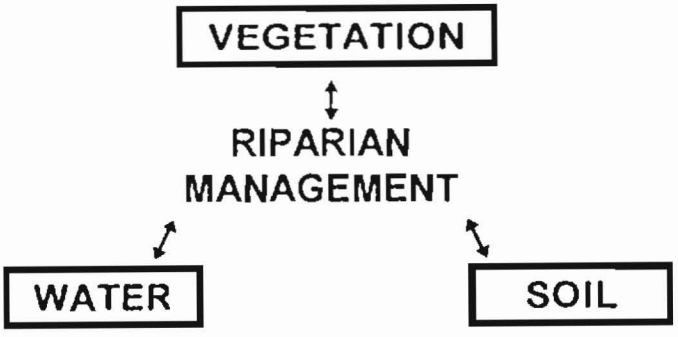

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