Cottonwood *(Populus deltoides)* Growth Response to Hydrologic Alteration, Overton Bottoms North, Missouri River Flood Plain

By Thomas M. Faust, Robert B. Jacobson, and Stephen G. Pallardy

Chapter 5 of

Science to Support Adaptive Habitat Management: Overton Bottoms North Unit, Big Muddy National Fish and Wildlife Refuge, Missouri

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Chapter 5
Cottonwood *(Populus deltoides)* Growth Response to Hydrologic Alteration, Overton Bottoms North, Missouri River Flood Plain

by Thomas M. Faust[1], Robert B. Jacobson[2], Stephen G. Pallardy[1]

Abstract

Cottonwood (*Populus* spp.) regeneration in arid and semi-arid regions of North America is a major concern because of documented population declines in the species. Declines have been associated with changes in flow regulation, or the lowering of ground-water altitudes due to flow regulation, or changes in channel morphology. This study assesses the potential impact of a constructed side-channel chute on cottonwood growth on the Missouri River flood plain in central Missouri. Dendrobands were placed on 75 trees across three transects and growth was measured each week June–September, 2004. Changes in growth rate were related to environmental attributes at each site. We hypothesized that an excavated side-channel chute would lower ground-water levels causing water stress in the cottonwood communities. Alternatively, we also hypothesized that the side-channel chute could provide enhanced ground-water recharge during periods of high river discharge. We found that increases in basal area were greater at sites closer to either the channel or the Missouri River, suggesting that the side-channel chute is affecting cottonwood growth by recharging ground-water levels during periods of high discharge. Temporal variations in growth rates were not apparent due to air temperature, solar radiation, or rainfall, and spatial variations did not relate to stand density.

Introduction

Declines in cottonwood communities throughout arid and semi-arid areas of the United States have prompted extensive research on the conditions necessary for regeneration and survival (Johnson, 2002; Shafroth and others, 2002). As obligate riparian species, cottonwood regeneration and survival have been linked to fluvial processes of erosion, deposition, flooding, and drought stress. Changes in these processes by rehabilitation actions may serve to enhance or diminish conditions conducive to survival. The constructed side-channel chute at the Overton Bottoms North Unit, Big Muddy National Fish and Wildlife Refuge, presented an opportunity to address the linkage between altered hydrology and effects on cottonwood growth in a relatively controlled field setting. In particular, we addressed the question of whether the chutes' evident effect on ground-water altitudes serves to enhance or diminish cottonwood growth.

Background

Riparian vegetation communities are thought to be structured by fluvial dynamics–flooding, erosion, and sediment deposition–which affect all aspects of riparian species' life-histories (Brinson, 1990; Mitsch and Gosselink, 2000; Decamps, 1997). Fluvial dynamics determine the type and size of regeneration sites, influence seedling and adult mortality, control water relations of the vegetation community, and influence availability of nutrients. In addition to dynamics associated with floods, riparian vegetation communities can also be stressed by lack of adequate moisture. This can occur during periods of natural drought (Reily and Johnson, 1982), because of anthropogenic changes in stream discharge (Rood and Mahoney, 1990; Segelquist and others, 1993), and due to changes in channel morphology (Scott and others, 2000).

Water stress has important implications for plant communities because it is probably the most limiting factor in plant growth (Kramer and Boyer, 1995). In riparian systems, water stress can be the result of both low- and high-water conditions; in this paper we are concerned primarily with water stress induced by low-water conditions. Low-water conditions induce water stress in plants when ground-water depths fall below a plant's rooting zone. This results in low levels of soil water potential. As soil moisture declines, water molecules adhere to themselves and soil particles, thereby hindering the continued flow of water into plants (Kozlowski and Pallardy, 1997).

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Plant water stress potentially leads to several different responses. Most woody plants have an evolutionary strategy of desiccation avoidance with the most prevalent response in woody plants being the closure of stomata on leaves. This increases leaf water potential resulting in the decline of water movement through the plant. The reduction in transpiration comes at a physiological cost to the plant because carbon dioxide (CO_2) also must enter the leaves through the stomata. The decrease of CO_2 entering the plant results in the reduction of photosynthesis, which has important implications for plant survival, growth, and competition. Plants have been found to respond to changes in water status through changes in carbon allocation; species in regions with high drought stress have high ratios of root carbon to stem carbon (Keyes and Grier, 1981).

The family Salicaceae, of which the genus *Populus* is a member, is thought to have evolved in response to the annual spring rise found on large rivers throughout the northern hemisphere (Karrenberg and others, 2002). Eastern cottonwood (*Populus deltoides*) is found throughout the midwest and southeastern U.S. along all major rivers and their tributaries. They survive on deep infertile soils with ground-water altitudes typically 0.6–1.8 m (meters) below the surface and rarely occur as well-formed trees at altitudes more than 5–7 m higher than average stream stage. Cottonwood seedling dispersal starts in May in the South and June in the North, continuing through mid-July in both regions (Burns and Honkala, 1990). Cottonwoods are prolific seeders with over 48 million seeds estimated on one tree. Cottonwood seeds are light and can disperse seeds over 30 m through the air (Johnson, 1965), or over much greater distances by water. Cottonwood germination is thought to be dependent on flooding to provide a bare-mineral soil substrate for the very shade-intolerant cottonwood seedlings (Karrenberg and others, 2002). The combination of seed-release coordinated with spring floods, large quantities of seedlings, high dispersal rates, and high shade intolerance is thought to be an evolutionary response to the depositional features created by the annual spring floods in most northern hemisphere rivers (Karrenberg and others, 2000).

Carbon allocation in cottonwoods is thought to be concentrated in roots (Woolfolk and Friend, 2003), at least in the early stages of life. Cottonwood seedling roots must grow to maintain contact with the ground water as the flood waters recede. Roots of first-year seedlings may grow as much as 1 m by the end of the growing season (Segelquist and others, 1993). As the seedlings develop, carbon allocation may be shifted to the stem (Coleman and others, 2004); as a shade intolerant species, competition for light requires rapid height growth. After the seedling stage, tree stem growth is a good measure of water stress because the stem receives the last investments of carbon allocation (Bloom and others, 1985).

Riparian cottonwood (*Populus* ssp.) communities throughout the arid and semi-arid west have undergone major shifts in species composition and areal extent, attributed to changes in hydrology (Rood and Mahoney, 1990; Johnson, 1994; Scott and others, 1997, Johnson, 2002; Shafroth and others, 2002). Cottonwood survival appears to be limited by different mechanisms among the studied river systems (Segelquist and others, 1993). In northern climates, cottonwood regeneration may be constrained by whether seeds are deposited high enough above the channel to avoid winter ice-scouring (Johnson, 1994; Scott and others, 1997; Auble and Scott, 1998). In other areas, cottonwood seedling survival is thought to be more strongly limited by decreased ground-water levels causing cavitation of the xylem (Rood and Mahoney 1990; Tyree and others, 1994). These authors provide evidence that the gradual decline of stream discharge after flooding allows the growing root system to maintain contact with the ground water and avoid cavitation. Water management projects, such as diversion for irrigation, can result in rapid decreases in flow and ground-water altitudes, causing drought mortality both in seedlings and adults (Tyree and others, 1994). Drought mortality can also have climatic causes. For example, Albertson and Weaver (1945) documented the effects of the 1930's drought on riparian communities; they found over 80 percent mortality of cottonwoods along a small stream in Kansas.

Purpose and Scope

The engineered side-channel chute at the Overton Bottoms North Unit, Big Muddy National Fish and Wildlife Refuge (fig. 1), presents a field-based opportunity to investigate the connections between ground-water and cottonwood growth. Ground-water dynamics are dependent on many factors such as the source of water, soil texture and stratification, and site geomorphology. In the case of the side-channel chute at Overton Bottoms North, geomorphology has been dramatically changed by excavation of the side-channel chute (Jacobson, this volume, chapter 1). We hypothesize that construction of the side-channel chute may have affected ground-water/cottonwood community connections in two ways: (a) lowering of ground-water levels due to enhanced drainage to the chute may lead to increased moisture stress in the communities adjacent to the chute (the "edge effect"), or (b) with high discharges, the chute may provide enhanced recharge of ground water with consequent increases of growth adjacent to the chute.

This field-based investigation explores these hypotheses within the Missouri River valley-bottom landscape. The intent is to increase understanding of the relative effects of geomorphology, ground-water flow, surface-water flow, surficial geology, climatic events and intra-community competition on cottonwood growth. While this study is not intended to define relations with statistical rigor, we hope that the understanding developed will provide guidance for adaptive management decisions and motivation for more rigorous testing of these ideas.

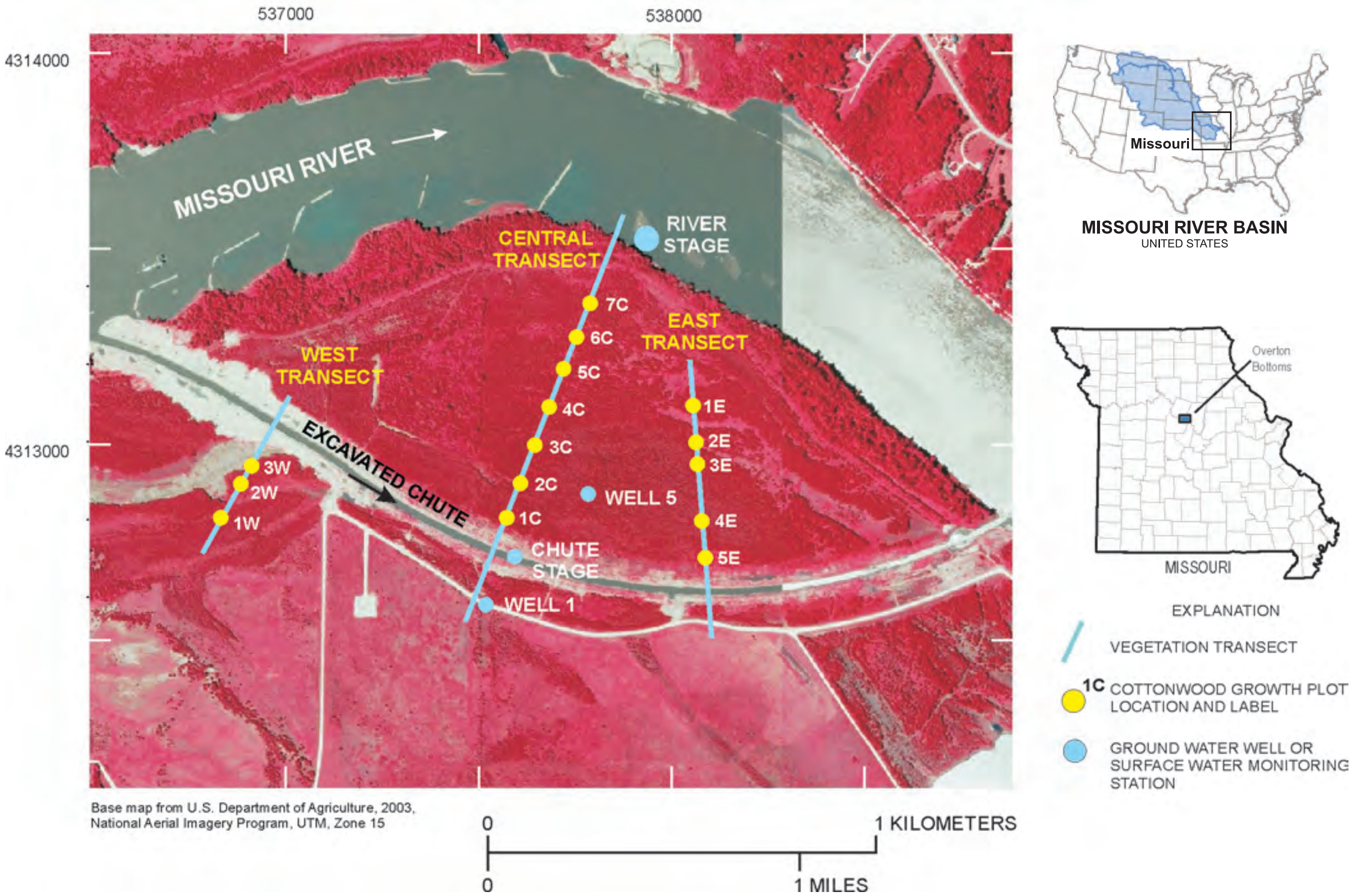

Figure 1. Location of the Overton Bottoms North Unit, Big Muddy National Fish and Wildlife Refuge, showing cottonwood growth-rate sampling transects, plot locations, and ground-water well and river-stage measurement locations.

Methods

Cottonwood growth was evaluated during summer 2004 on transects aligned perpendicular to the Overton Bottoms North side-channel chute (fig. 1). Data collection was coordinated with hydrologic and surficial geologic assessments in order to provide the most context to explain cottonwood growth rates.

Sampling plots were laid out along three transects (fig. 1, table 1). These transects are labeled as west, central, and east; the east and central transects are on the island created by the chute, while the west transect is on the mainland. Plot locations were mapped in the field with a handheld global positioning system (GPS) unit with typical accuracy of ±5 m. Plots were evaluated for inclusion in the study based on the following criteria: (1) the majority of the canopy had to be eastern cottonwood, (2) there were at least five cottonwoods with different diameters at breast height (dbh) ranging from 9–30 cm (centimeters) within a 10 m^2 (square meters) area, and (3) plots were located along the pre-determined transect. Fifteen plots were selected with nominal spacing at 100 m intervals (fig. 1, table 1); however, intervals were varied to ensure that plots were centered in cottonwood patches. For example, on the east transect spacing varied from 50 to 150 m to avoid patches of black willow (*Salix nigra*) trees.

Dendrobands were used to measure variation in cottonwood growth during the study. Dendrobands are simply thin stainless-steel bands that can be wrapped around a tree stem to measure variation in circumference over time (Cattelino and others, 1986; fig. 2). A spring keeps the dendroband under tension, and a caliper is used to measure changes in tree girth (circumference). Dendrobands were placed on five cottonwood stems per plot. Trees were selected based on three criteria: (1) the crown had to be in the canopy, (2) the trees had no signs of physical or insect damage, and (3) trees had a range of diameters. In addition, initial and final dbh were recorded on all trees selected for dendrobands.

Dendrobands were measured each week from June 21, 2004 to September 21, 2004, with a final measurement on October 5, 2004. The measurements were taken in an established plot order between 7:00 a.m. and 1:00 p.m., with the exception of the first week when bands were being applied

Table 1. Location data for growth-rate plots.

[UTM, Universal Transverse Mercator; NAVD 88, North American Vertical Datum; m, meters; cm, centimenter]

Transect	Plot Label	East UTM (m)	North UTM (m)	Surface altitude, NAVD 88, (m)	Distance to chute (m)	Distance to river (m)	Shorter distance to water (m)
West	1W	536846	4312804	176.9	265	551	265
	2W	536894	4312892	176.6	165	468	165
	3W	536919	4312936	176.3	115	450	115
Central	1C	537579	4312798	176.4	75	765	75
	2C	537615	4312892	176.8	175	665	175
	3C	537651	4312985	177.0	275	565	275
	4C	537686	4313079	177.0	375	465	375
	5C	537722	4313172	176.9	475	365	365
	6C	537758	4313265	177.0	575	265	265
	7C	537794	4313359	176.9	675	165	165
East	1E	538064	4313096	176.4	465	285	285
	2E	538068	4313046	176.2	415	335	335
	3E	538075	4312946	176.1	315	415	315
	4E	538086	4312796	176.7	160	505	160
	5E	538094	4312697	175.8	60	610	60

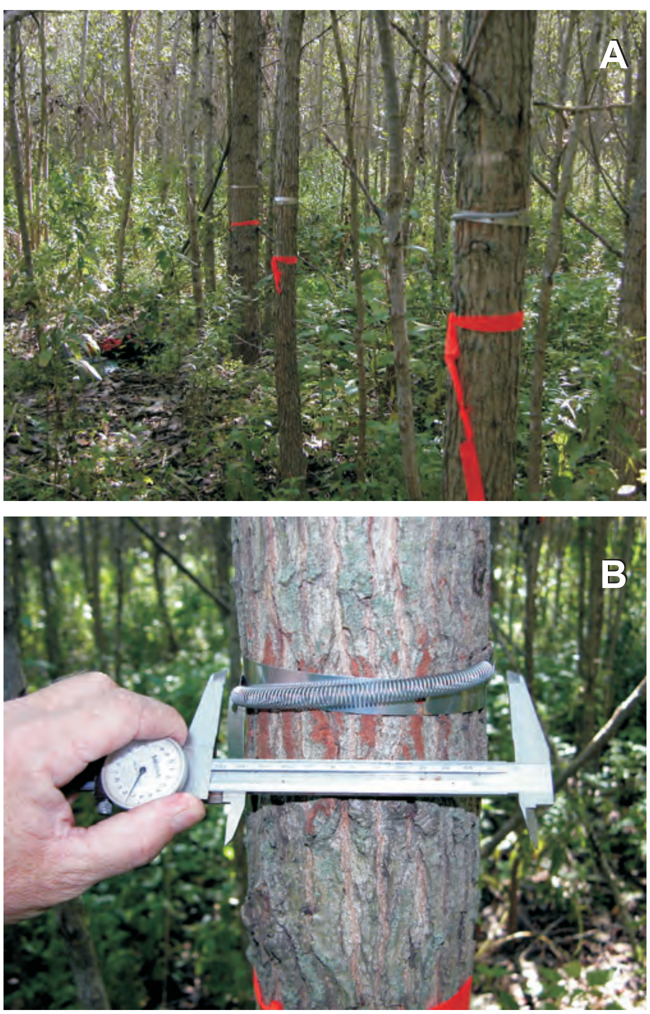

Figure 2. Growth-rate measurements. A. Typical plot showing density of cottonwood and trees selected for measurement. B. Dendroband and measurement with calipers.

(8:00 a.m.–6:00 p.m.) and August 24 when access to the site was not available until the afternoon (12:00–6:00 p.m.).

Increases in circumference were measured and converted to basal area and basal area increments (BAI) were used to estimate the percentage of growth in the sampled cottonwoods. To estimate the weekly BAI, the starting dbh was converted to a tree circumference and the weekly increase or decrease in the dendroband was added to this circumference. The circumference was then converted into the basal area for the tree that week and the previous week's basal area was subtracted from it.

Because basal area growth can also vary with competition among trees for light, water, or other resources, we also assessed total basal area and number of trees/ha (hectare) for each plot with dendrobands. The variable area plot method was used with the plot center chosen to incorporate all trees with dendrobands. Plot-scale basal area was estimated with a 10X meter prism and number of trees/ha was recorded in a 5-m radius plot (78.54 m^2). Both basal area and trees/ha were recorded by species (table 2).

For comparison with tree-growth rates, we also collected information on geomorphology, surficial geology, groundwater and surface-water hydrology, and climate. Surficial geologic and ground-water information was compiled from data presented in Holbrook and others (this volume, chapter 2) and Kelly (this volume, chapter 3). Surface-water hydrologic

Table 2. Summary basal area and density data for growth-rate plots.

[m, meters; ha, hectare]

		Basal area (m^2/ha)				Number/ha			
		Cottonwood	Boxelder	Black Willow		Cottonwood	Boxelder	Black Willow	
Transect	Plot Label	*Populus deltoides*	*Acer negundo*	*Salix nigra*	Total	*Populus deltoides*	*Acer negundo*	*Salix nigra*	Total
West	1W	90			90	4,000		400	4,400
	2W	70		10	80	2,700		4,700	7,400
	3W	80		10	90	4,600		2,800	7,400
Central	1C	130			130	2,200			2,200
	2C	80			80	3,200			3,200
	3C	70			70	1,100	100		1,200
	4C	120	10		130	1,100	600		1,700
	5C	100	20		120	1,000	800		1,800
	6C	70	10		80	800	600		1,400
	7C	110			110	2,000	400		2,400
East	1E	160			160	4,700			4,700
	2E	100			100	4,200		1,100	5,300
	3E	110			110	3,600			3,600
	4E	100			100	1,300			1,300
	5E	120			120	3,200			3,200

data were compiled from Boonville, Missouri streamflow gage (USGS stream-gaging station number 06909000), 8-river km (kilometers) upstream; surface-water altitudes were extrapolated to the study site based on regression models. Climatic data were compiled from the University of Missouri meteorological station at Sanborn Field, Columbia, Missouri, 20 km west of Overton Bottoms. The Sanborn Field site has a long, high-quality climatic record, but it is not a bottomland site; thus temperatures and solar radiation at Overton Bottoms may vary slightly from the values obtained from Sanborn Field.

Results and Discussion

The results of the study support the general hypothesis that ground-water changes associated with the side-channel chute can influence cottonwood growth. Generally synchronous trends in growth rates, river discharge, and ground-water altitudes support the idea that water availability was a primary control on cottonwood growth (figs. 3, 4). Increased growth rates adjacent to the chute during the early part of the season when discharges were relatively high support the idea that the side-channel chute was a source for enhanced ground-water recharge that resulted in increased cottonwood growth (figs. 5–8). Plots further from the channel had reduced growth rates during the same time period. Other spatial and temporal factors, including solar radiation, surficial geology, and density of stems in the plots, appear to have had secondary influences on growth rates.

Stem growth rates, averaged over all trees in the survey, showed an initial increase in late June, followed by a nearly steady decline toward an asymptote near zero, or slightly negative values, in early September (fig. 3*A*). The timing of the cessation of basal area growth is consistent with other studies that examined height growth in cottonwood seedlings. Pezeshki and Oliver (1985), for example, found that 88 percent of height growth in black cottonwood *(Populus trichocarpa)* seedlings occurred by late July.

The trend in decreasing growth rates is parallel to the general trend in decreasing river discharge and ground-water levels (fig. 3 and this volume, chapter 3). River discharge declined gradually throughout the summer. Water altitude in the side-channel chute averaged 174.2 m from June 21 to August 8, and the average declined to 173.2 m from August 8 to September 21. Small floods interrupted this general trend; some of the floods were associated with local rainfall and some originated from rainfall upstream (fig. 3*B*). The most notable floods were in mid-June, just before we began to record growth rates, and August 24 to September 9 at the end of the experiment. Growth rates do not show any clear relation to air temperature or solar radiation events, which were highly variable during this time period. Incident solar radiation and average air temperature both show slight decreasing trends as would be expected from mid- to late-summer.

The three increases in growth rates during the study could correspond to transient increases in ground-water altitude or to local rainfall. It may be that the three distinct peaks in growth rates (G1–G3 on fig. 3*A*) are lagged responses to small rainfall and flood events (and subsequent ground-water recharge) in

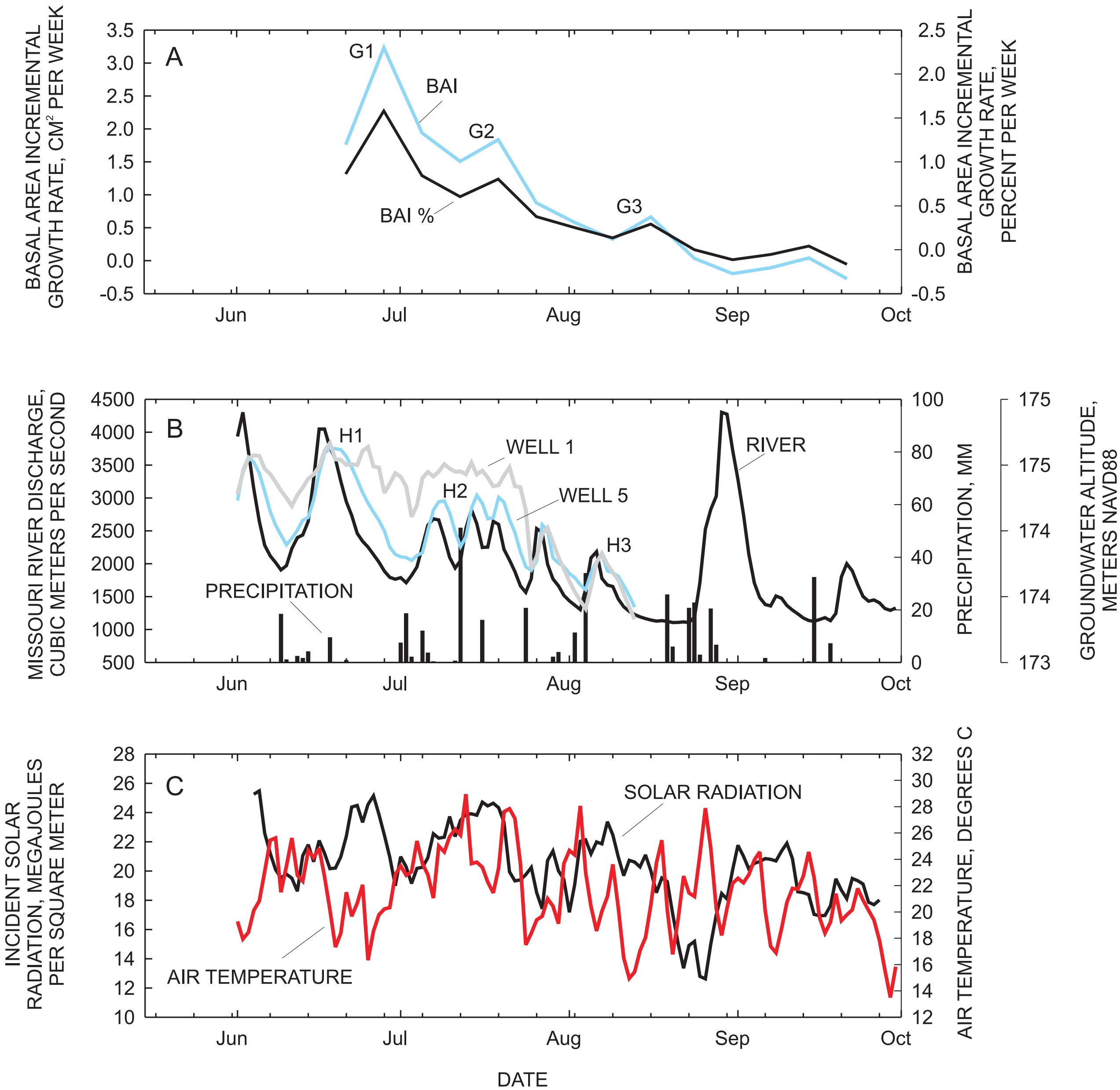

Figure 3. Average cottonwood growth rates and environmental variables. A. Total basal area increment and percent basal area increment weekly averages of all trees, all plots. G1–G3 mark correlated cottonwood growth events. B. River discharge at USGS stream-gaging station, number 06909000, Boonville, Missouri (USGS, 2005), ground-water altitudes in wells 1 and 5 (Kelly, this volume, chapter 3), and daily precipitation at Sanborn Field, Columbia, Missouri (University of Missouri, 2005). H1–H3 mark specific hydrologic events. C. Solar radiation and air temperature at Sanborn Field, Columbia, Missouri (University of Missouri, 2005).

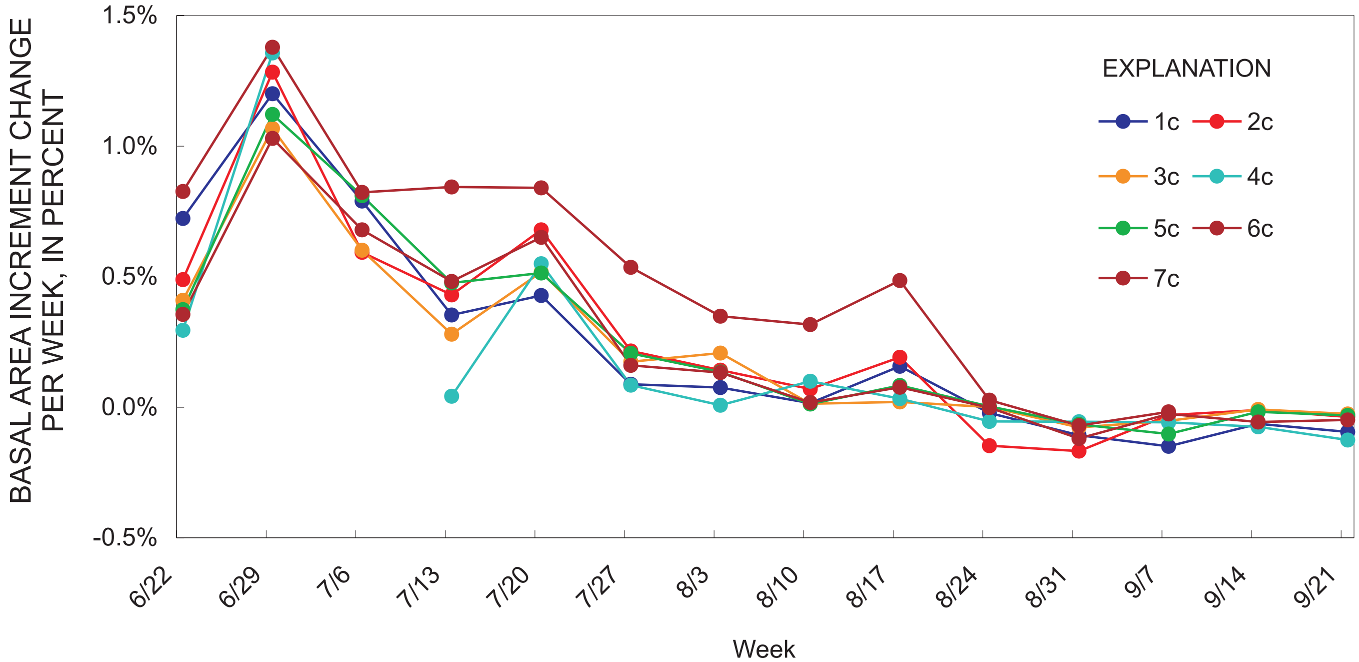

Figure 4. Growth rates of cottonwood by week for all plots on the central transect showing broadly synchronous trends.

mid-June, early-July, and early-August (H1–H3 on fig. 3*B*). Although it is impossible to separate the specific effects of local rainfall and river discharge in our dataset, the magnitude and timing of growth spikes appear to correlate better with river- and ground-water peaks than with local rainfall. A growth peak corresponding to the August 24–September 9 flood is notably absent. The trees were probably finished with basal area growth by late August (Pezeshki and Oliver, 1985).

The transient increases in growth rates would be consistent with the idea that cottonwood communities at Overton Bottoms North were undergoing water stress due to lowering of the ground-water altitude. Increased water stress led to lower basal growth rates as stomata closed and photosynthesis was limited by lack of CO_2. Transient increases in ground-water levels temporarily revived growth rates, as increased stomatal conduction allowed increased passage of CO_2 into the leaves (Pallardy and Kolowski, 1981).

Ground-water levels never fell below expected maximum rooting depths of cottonwood trees during this experiment. Two-year old black cottonwood seedlings, for example, have been found to have rooting depths of over 3 m and maximum rooting depths probably exceed 7 m (Pregitzer and Friend, 1996). These values are within the maximum depth of ground water (4.68 m) found at all well sites on the island at Overton Bottoms North (this volume, chapter 3). Although some roots probably maintain contact with ground water, trees typically have higher densities of roots in the upper levels of soil. For example, it is estimated that 80 percent of hybrid cottonwood roots were only 5 to 20 cm below the soil surface (Pregitzer and Friend, 1996). Thus it is probable that the higher ground-water levels maintained adequate soil-water conditions in zones of higher root density, thereby allowing for higher water and carbon uptake.

Growth rates showed complex spatial and temporal relations to geomorphic position, surficial geology, and site hydrology (figs. 5–7). In all three transects, growth rates were increased closer to the water source (the side-channel chute or the Missouri River) during the early part of the experimental period, with the exception of 4*C* and 1*E*. During August and September, growth rates became more uniform and low along the transects, in some cases declining at sites closer to the water source. Temporal variability in growth rates is also evident when plot locations are evaluated by distance to the closest water source (side-channel chute or Missouri River, fig. 8*A*–*C*). In general, these relations support the concept of an edge effect, in which the dominant influence of the side-channel chute is enhancement of tree growth through recharge of ground water during high river and chute discharge, and perhaps diminished growth rates during periods of low discharge when the side-channel chute acts to increase ground-water drainage.

Changes in ground-water altitudes lag behind surface-water altitudes and thereby tend to buffer surface-water influences (fig. 3*B* and this volume, chapter 3). During periods when surface-water altitudes in the side-channel chute and river were high, ground-water altitudes declined away from the river, possibly explaining the gradient of higher growth rates closer to the water source (fig. 6). In contrast, during periods when surface-water altitudes in the side-channel chute and river were low, ground water was “mounded” at higher

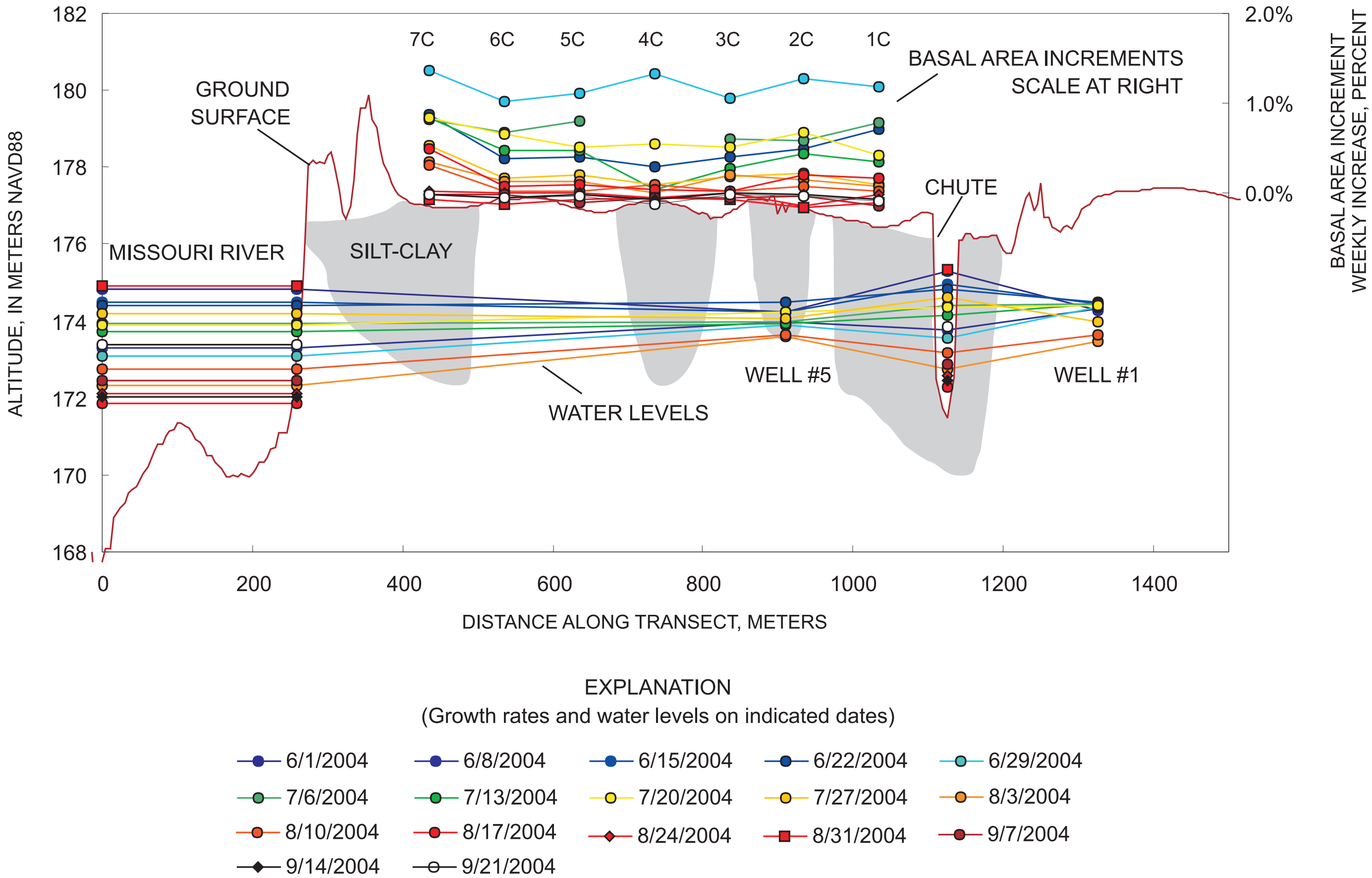

Figure 5. East transect, showing water levels and weekly cottonwood growth rates (basal area increment as percent). Section is oriented looking downstream. Colors for water levels and growth rates generally correspond to date, with June water levels and growth rates depicted in cool (blue and green) colors, changing toward warm colors (yellow to red to black) for late summer to fall dates. Silty-clay sediments indicated are fine channel-fill sediment from Holbrook and others, this volume, chapter 2. Sediments between and below the silty-clay channel fills are dominantly sand.

altitudes in the alluvium, possibly explaining the lower growth rates of trees near the water source (figs. 6, 8).

Some of the spatial variation in growth rates may be explainable by variation in soils and surficial geology along the transects. As indicated in figures 5–7 and discussed in this volume, chapter 2, fine-grained (silt-clay) surficial geologic units (channel-fill allounits) occur preferentially in swales whereas sandy units (point-bar allounits) underlie ridges. The combination of surficial geology and spatially variable ground-water influence potentially confounds interpretation of the role of the side-channel chute. For example, elevated growth rates at the ends and in the middle of the central transect (fig. 6) could relate in part to fine-grained soils that would have higher moisture-holding capacity. Surficial geologic controls are not as apparent on the east and west transects, however. We believe that the surficial geology is potentially a second-order influence on growth rates compared to ground-water altitudes. The relative influence of these factors cannot be assessed further with our available datasets.

The spatial trends in growth rate also do not appear to be the result of varying vegetation competition among the plots. There were two other tree species found on the plots: black willow and boxelder (*Acer negundo*). Basal area of all trees in the plot ranged from 70 m^2/ha to 160 m^2/ha, averaging 105 m^2/ha, with over 95 percent of this basal area cottonwood. The number of trees/ha ranged from 1,200 to 7,400 individuals/ha.; over 75 percent of these individuals were cottonwood. The mean number of trees/ha was 3,400. Growth rates generally increased as the number of trees/ha increased (fig. 5–9). The near-linear increase in growth rate with increase of stem density is inconsistent with intra- or inter-specific competition for light or other resources. This indicates that spatial variation in growth rates is unlikely to be related to variation in biotic interactions along the transects, and is much more likely to relate to site characteristics.

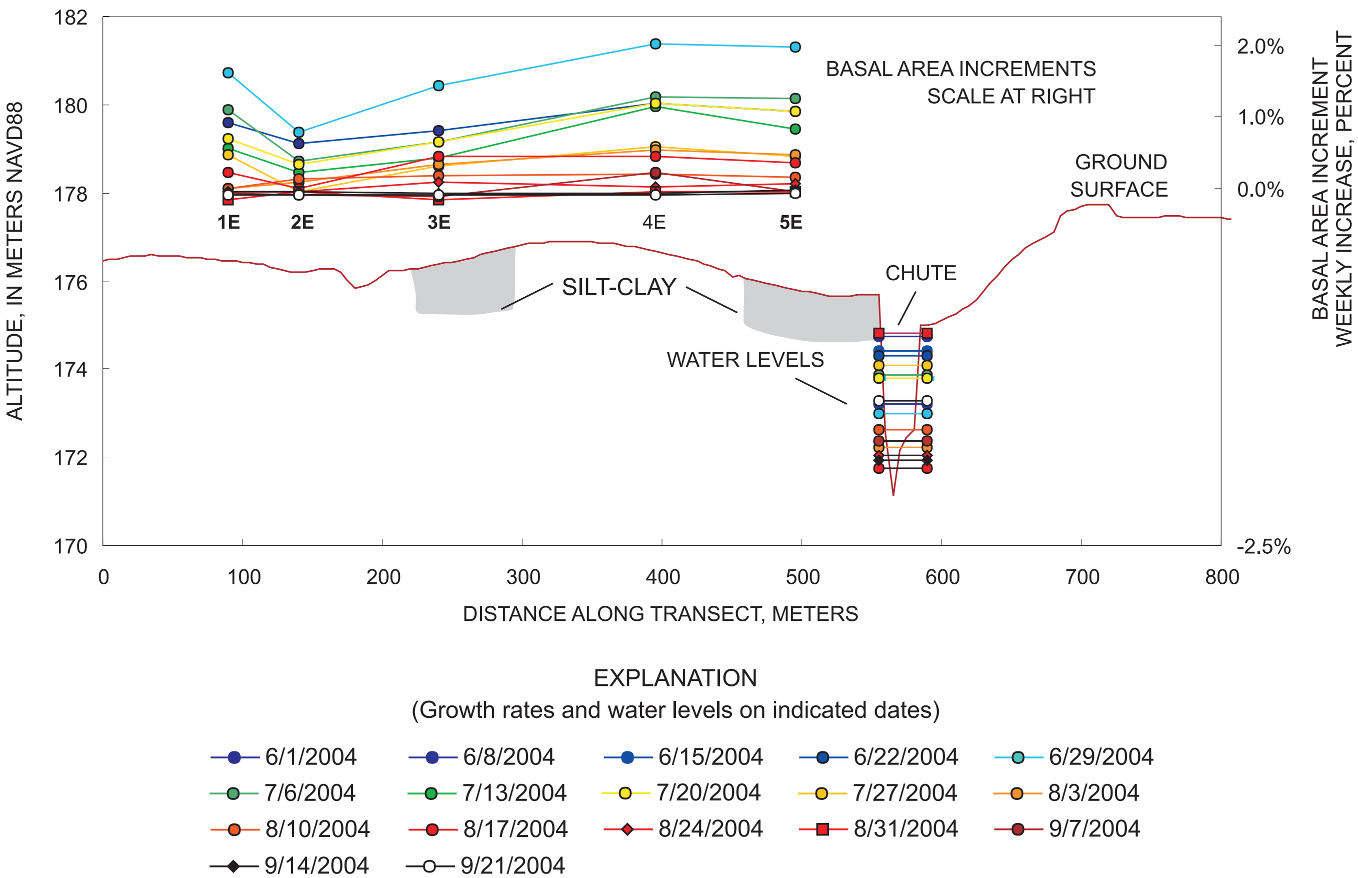

Figure 6. Central transect, showing water levels and weekly cottonwood growth rates (basal area increment as percent). Section is oriented looking downstream. Colors for water levels and growth rates generally correspond to date, with June water levels and growth rates depicted in cool (blue and green) colors, changing toward warm colors (yellow to red to black) for late summer to fall dates. Silty-clay sediments indicated are fine channel-fill sediment from Holbrook and others, this volume, chapter 2. Sediments between and below the silty-clay channel fills are dominantly sand.

The association between cottonwood growth rates and ground-water levels might be explained in part by increased nutrient availability associated with the water rather than being a direct effect of water on transpiration. Several authors have suggested that nitrogen availability can be a substantial limit to cottonwood growth (Woolfolk and Friend, 2003; Coleman and others, 2004). Cottonwood growth in plantations, for example, has been found to correspond positively to nitrogen additions (Woolfolk and Friend, 2003). Under natural conditions, Harner and Stanford (2003) found that cottonwood growing in the gaining reach of a stream had twice the basal area of cottonwood growing in the upstream losing reach. They attributed this to greater nutrient concentration in the gaining reach where microbially-enhanced, nutrient-rich water came to the surface. We did not measure nutrients associated with surface and ground water for this study. Because the study transects are far from the valley wall and poorly connected to upland drainage by either surface- or ground-water flow paths, the Missouri River is the only substantive potential nutrient source. We believe that the generally high nutrient availability in midwestern rivers like the Missouri (Mitsch and others, 2001) indicates that it is unlikely that nutrients are a limiting factor in cottonwood growth.

Another possibility is that growth rates responded to other variables that we did not measure. Consistency of time trends in growth rates among all plots (fig. 4) supports the idea that the primary factors affecting growth rate variability were relatively uniform across the plots. This broadscale consistency points to hydrologic or climatic factors as the primary controls, although these broad-scale factors may be mediated by plot-specific factors. However, the temporal patterns of growth were not clearly related to precipitation events or variability in temperature and solar radiation (fig. 3*A*, 3*C*). Spatial variations in growth rates relative to distance to water source support the inference that growth rates related directly to ground-water altitude. Ground water remains as the variable

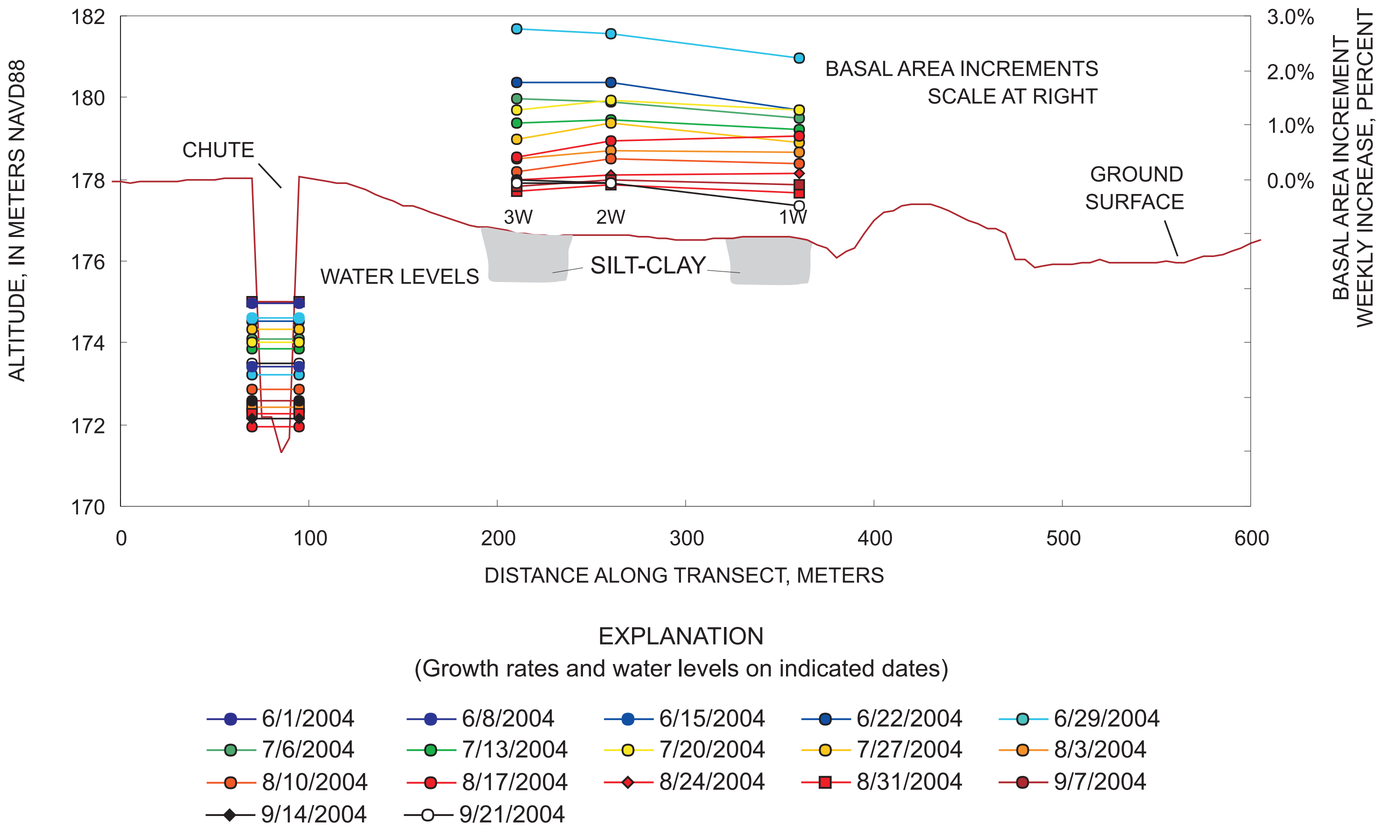

Figure 7. West transect, showing water levels and weekly cottonwood growth rates (basal area increment as percent). Section is oriented looking downstream. Colors for water levels and growth rates generally correspond to date, with June water levels and growth rates depicted in cool (blue and green) colors, changing toward warm colors (yellow to red to black) for late summer to fall dates. Silty-clay sediments indicated are fine channel-fill sediment from Holbrook and others, this volume, chapter 2. Sediments between and below the silty-clay channel fills are dominantly sand.

most likely to explain both temporal and spatial trends we observed in cottonwood growth rates.

The effects noted in this field experiment should be interpreted within the context of the long-term hydrologic variability of this portion of the Lower Missouri River. The summer of 2004 was relatively wet and characterized by large fluctuations in discharge (fig. 10); the discharge was commonly greater than the long-term daily median and events in mid-late May and late-July exceeded the 10th percentile of flow for that time of year. Although our results indicate that the side-channel chute provided enhanced ground-water recharge and consequent increases in cottonwood growth rates during this study, these results should not be extended to predict effects in a low-discharge year. Low-water conditions during this study only occurred after significant growth had stopped, so the effects of low water during the early part of the growing season cannot be assessed. Possibly, low water during the early part of the growing season might have had the opposite "edge effect" in which water stress and low growth would be more prevalent adjacent to the side-channel chute. Alternatively, in years with extended periods of high discharge, the chute could reduce cottonwood growth due to root hypoxia, which limits water uptake in plants. Results of ground-water monitoring over a multi-year timeframe (this volume, chapter 3) indicate that the overall trend has been for the side-channel chute to lower ground-water altitudes.

Conclusions

The results from this study support the hypothesis that during periods of high-river flow, the side-channel chute recharges ground water and enhances cottonwood growth. Cottonwood growth was found to be higher in plots closer to the river or side-channel chute. Cottonwood growth followed the decline of river and ground-water altitudes, and periods of increased water height were followed by periods of increased

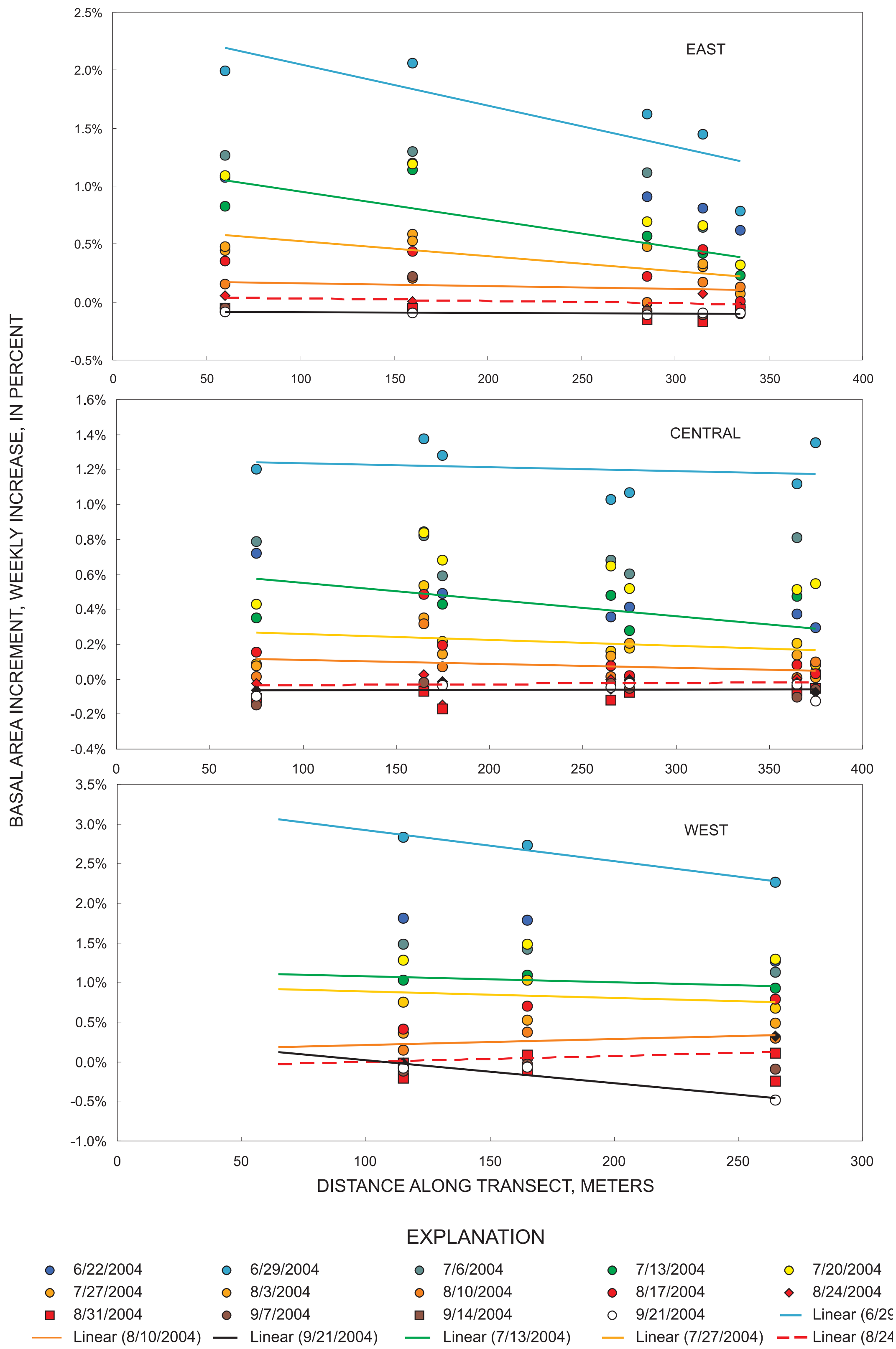

Figure 8. Basal area incremental growth rates as a function of distance from the nearest water source, either the Missouri River channel or the side-channel chute. Linear regression model lines are shown for approximately every other week to illustrate trend from higher growth rates nearest the water source early in the season to spatially uniform low rates late in the season.

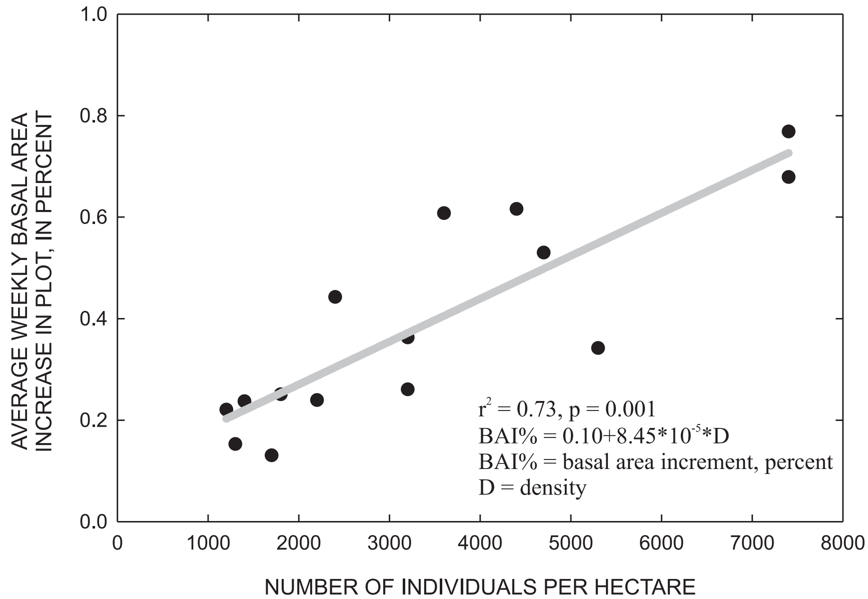

Figure 9. Relation between growth rate and density of individual trees in plots. The increase in growth rate with increasing density indicates a dominant site environmental control on growth rates rather than a light competition effect, which would have a inverse relation.

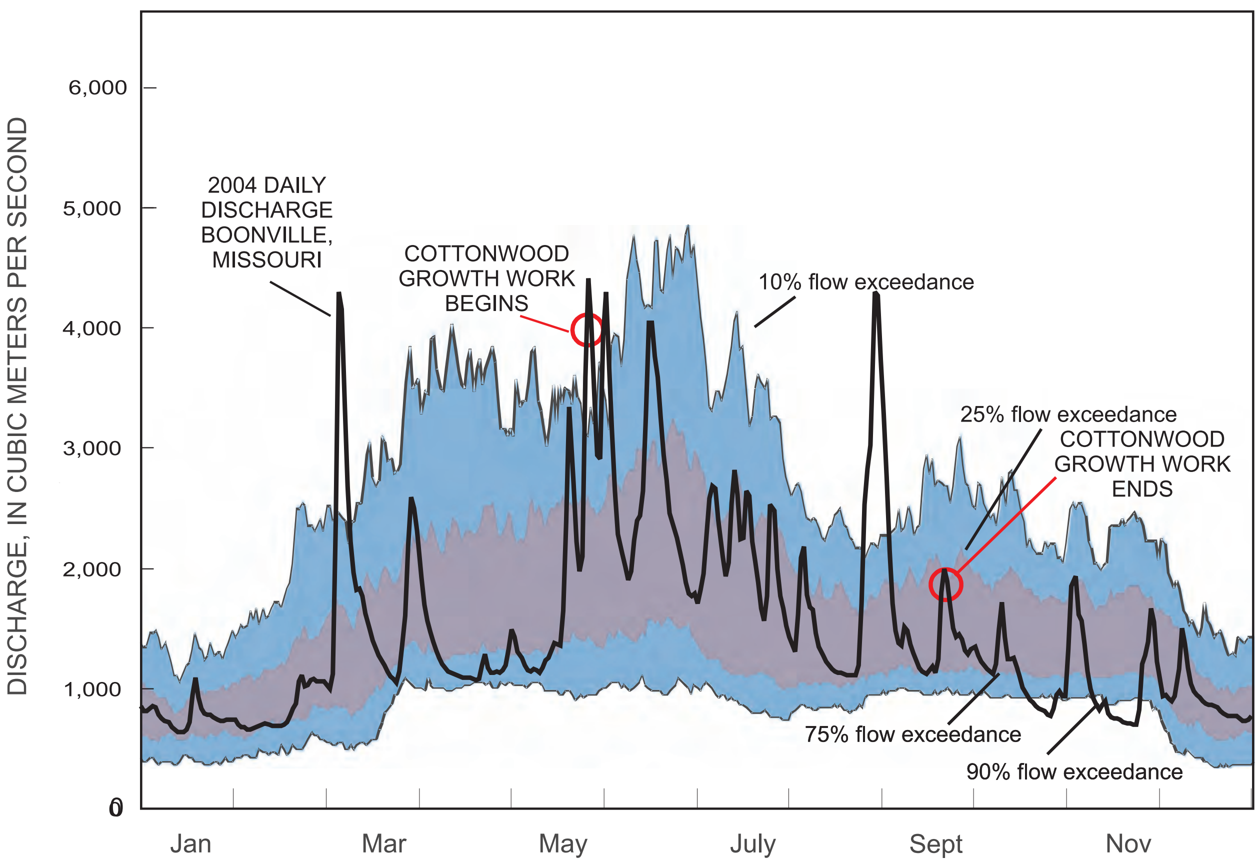

Figure 10. Missouri River discharge during 2004 compared to historical flow durations. 2004 was a relatively wet year, with daily discharges exceeding the 25 percent flow exceedance multiple times during the growing season.

cottonwood growth. In addition, variation in cottonwood growth could not be attributed to differences in air temperature, solar radiation, or competition for light.

Conclusions drawn from this study need to be considered in the context that the study occurred only for one, unusually wet season. The following year, 2005, the Missouri River basin experienced an extensive drought which could have altered the results of this study. For example, low river discharge may have resulted in the plots closest to the channel having the lowest growth rates due to the "edge" effect. However, the general conclusion that the side-channel chute is instrumental in altering ground-water levels and affecting cottonwood water relations would still be valid.

The side-channel chute was designed to provide more shallow-water habitat in the Missouri River flood plain, mainly to promote recovery of native and endangered aquatic species. While the alteration of ground-water flow has the potential to adversely affect riparian vegetation communities, this study indicates that there is not necessarily an acute trade-off between management of aquatic and riparian species. In this case, it is apparent that a side-channel chute can alter flood-plain hydrology in ways that have positive effects on growth rates of riparian cottonwood communities.

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