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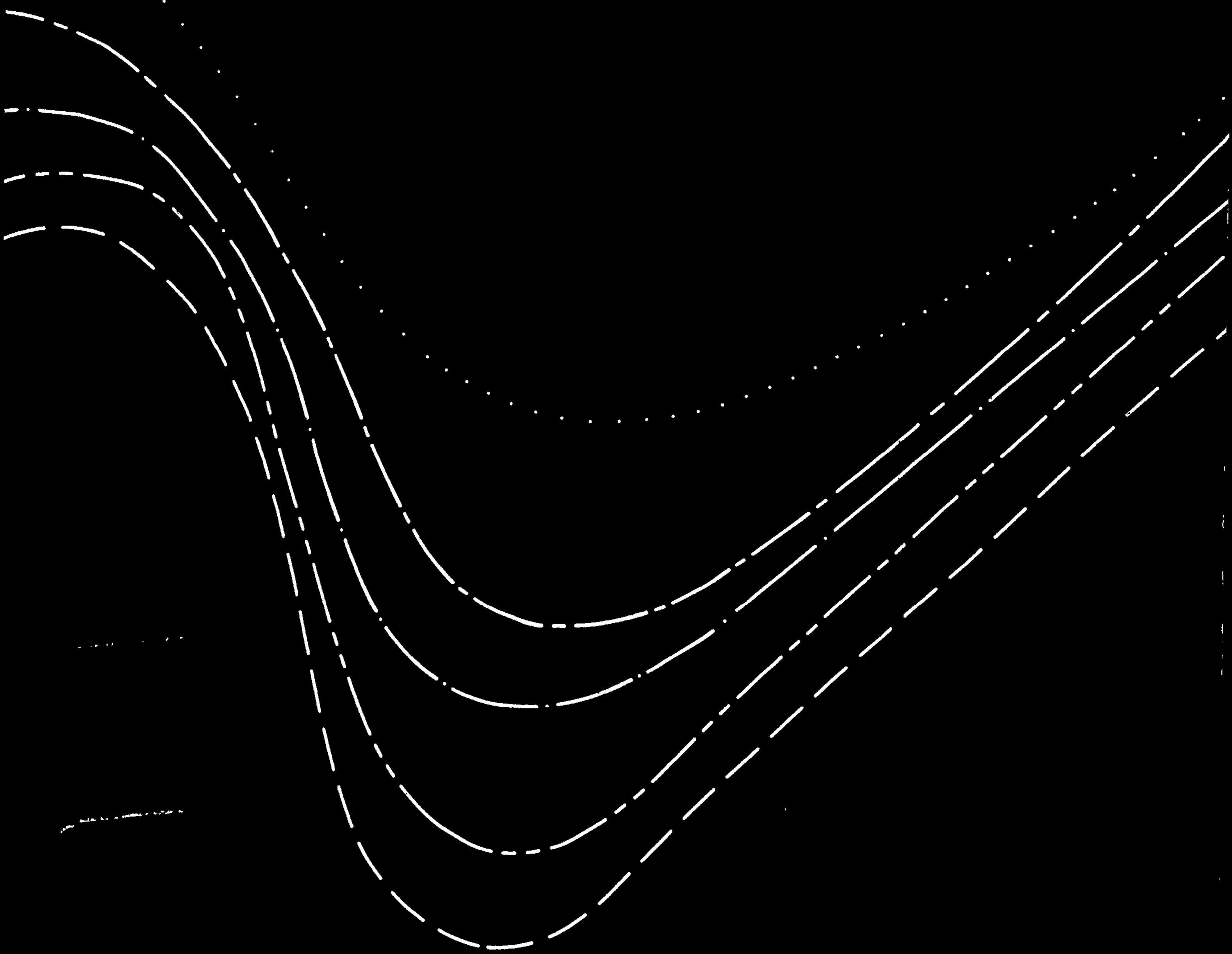
GEOMORPHIC AND VEGETATIVE RECOVERY PROCESSES ALONG MODIFIED STREAM CHANNELS OF WEST TENNESSEE



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attenuates with time to a minimum and, in conjunction with reduced rates of channel widening, results in small variations in the width-depth ratio.

Variations in projected width-depth ratios also occur due to gross differences in the character of the channel alluvium. As indicated by Schumm (1960), channels cut through silt-clay alluvium tend to be narrower and deeper than those in sediments that contain greater percentages of coarse material. Although Schumm's "M" (percentage of silt-clay in the channel perimeter) was not calculated in this study, those channels that have been described as the "loess tributaries" display generally lower width-depth ratios than the sand-bed streams over the long term. Projected mean width-depth ratios for the loess tributaries and the sand-bed streams after 40 years of adjustment range from 4.0 to 6.4, and from 6.8 to 11.4, respectively. Similarly, after 115 years of adjustment, the estimated width-depth ratios for the fine-grained channels range from 4.3 to 6.8, and for the sand-bed channels, from 7.4 to 13.1. The discrete ranges given above are more a function of the lack of channel bed-level recovery along the loess tributaries (which keeps the channels deep) than of differences in widening rates due to greater cohesion in the channel banks. Furthermore, the loess tributaries have some of the greatest widening rates recorded during the study, and this is attributed to substantial amounts of channel bed-level lowering.

There are many uncertainties involved in projecting natural processes and forms 100 years into the future. Data presented in this section and tables 26 through 28 are estimates of the long-term channel geometry along adjusting channels in West Tennessee. The attenuation of processes such as bed-level change and channel widening have been accounted for through time and location within the general framework of the models of channel evolution and bank-slope development. However, variables such as further direct human intervention, land-use changes and low-frequency climatic events cannot be incorporated into this analysis and therefore create a degree of unreliability.

Riparian-Vegetation Recovery

The most apparent characteristic of unstable bank conditions is a general lack of woody-riparian vegetation. The rate of bank widening is perhaps the most influential factor determining the type and abundance of riparian species. Bank accretion also affects species presence; high accretion rates appear to limit the presence of many species through suffocation of the root zone. Together, bank widening and accretion exert a pervasive influence on the riparian-vegetation community. The unstable banks are typically unshaded, which might also affect the early stages of revegetation; many stable-site species are relatively shade tolerant.

Natural or man-induced disturbance in vegetation systems have received considerable attention recently among students of plant ecology (White, 1979). Channel-bank responses to channelization (direct and indirect) are a major disturbance to riparian vegetation along West Tennessee channels. Little previous study has been directed toward the analysis and interpretation of plant ecological recovery on channelization-disturbed banks (Hupp and Simon, 1986).

Results of this part of the study pertain mostly to the bank forms and woody vegetation of strictly riparian zones (below the top-bank or flood-plain level). Along channelized reaches, the distinction between banks and flood plain is relatively clear. However, along some swampy, stable upstream reaches this topographic distinction may be blurred. Thirty-eight species of woody plants were identified along the channel banks of the study streams (table 29); this does not include vines such as blackberry and herbaceous perennial species. Seventy-seven species of trees and shrubs in total, that occur on riparian surfaces, flood plains, and fluvial wetlands were identified.

Table 29.--*List of woody riparian species in West Tennessee*

[This table provides explanation for species code in tables 30 and 31 and figures 57 and 58]

Species code	Name	
	Scientific	Common
ALSE	*Alnus serrulata*	Alder
ASTR	*Asimina triloba*	Pawpaw
ACNE	*Acer negundo*	Boxelder
ACRU	*Acer rubrum*	Red Maple
ACSA	*Acer saccharinum*	Silver Maple
ARSP	*Aralia spinosa*	Hercules Club
BENI	*Betula nigra*	River Birch
CACA	*Carpinus caroliniana*	Ironwood
CACO	*Carya cordiformis*	Bitternut
CELA	*Celtis laevigata*	Sugarberry
CEPO	*Cephalanthus occidentalis*	Buttonbush
COAM	*Cornus amomum*	Red Willow
CRSP	*Crataegus spp.*	Hawthorn
FOAC	*Forestiera acuminata*	Swamp Forestiera
FRPE	*Fraxinus pennsylvanica*	Green Ash
GLTR	*Gleditsia triacanthos*	Honey Locust
JUNI	*Juglans nigra*	Black Walnut
LIST	*Liquidambar styraciflua*	Sweetgum
MAPO	*Maclura pomifera*	Osage Orange
NYAQ	*Nyssa aquatica*	Water Tupelo
PLOC	*Platanus occidentalis*	Sycamore
PODE	*Populus deltoides*	Cottonwood
PRSE	*Prunus serotina*	Black Cherry
QUBI	*Quercus bicolor*	Swamp Red Oak
QUFP	*Quercus falcata* Var. *pagodaefolia*	Cherrybark Oak
QULY	*Quercus lyrata*	Overcup Oak
QUNI	*Quercus nigra*	Water Oak
QUPH	*Quercus phellos*	Willow Oak
QURU	*Quercus rubra*	Red Oak
RHGL	*Rhus glabra*	Staghorn Sumac
ROPS	*Robinia pseudoacacia*	Black Locust
SACA	*Sambucus canadensis*	Elderberry
SANI	*Salix nigra*	Black Willow
TADI	*Taxodium distichum*	Bald Cypress
TIHE	*Tilia heterophylla*	Basswood
ULAL	*Ulmus alata*	Winged Elm
ULAM	*Ulmus americana*	American Elm
ULRU	*Ulmus rubra*	Slippery Elm

Several sites had woody vegetation that did not germinate in place; this includes sites where top-bank plants have been carried to mid-bank locations on slump blocks. Slumped vegetation is not included in species-presence analyses. Sites without in situ woody plants indicate substantial bank instability (Hupp and Simon, 1986). Species presence by site are listed in table 30. Eighty sites are included in species-presence analyses. The most common species on disturbed West Tennessee streams is river birch (*Betula nigra*), occurring in 75 percent of the study sites. Also important in re-establishment are black willow (*Salix nigra*, 68 percent), silver maple (*Acer saccharinum*, 55 percent), sycamore (*Platanus occidentalis*, 55 percent), boxelder (*Acer negundo*, 54 percent), cottonwood (*Populus deltoides*, 29 percent), and green ash (*Fraxinus pennsylvanica*, 26 percent). Common bank species along unmodified reaches include river birch, sycamore, silver maple, green ash, and boxelder mixed with ironwood (*Carpinus caroliniana*, 25 percent), sweetgum (*Liquadambar styraciflua*, 20 percent), overcup oak (*Quercus lyrata*, 14 percent), cherrybark oak (*Quercus falcata* var. *pagodaefolia*, 10 percent), water oak (*Quercus nigra*, 10 percent), and American elm (*Ulmus americana*, 8 percent). Bald cypress (*Taxodium distichum*, 13 percent) and tupelo gum (*Nyssa aquatica*, 10 percent), are common bank species in backwater swampy reaches. Black willow is conspicuously unimportant along undisturbed reaches with no mature forest while other species such as river birch and silver maple that are found along disturbed reaches, are relatively common along most West Tennessee stream reaches. The Hatchie River is used as an ecological measure of the undisturbed natural system (table 30); all sites along this stream are in stage I of the channel evolution model.

To test vegetative recovery through species response and establishment, dendrogeomorphic and species-presence data were compared. This analysis provides information concerning riparian environments that support specific species or suites of species. The 80 sites categorized by stage of bank-slope development and site variables (widening rate, accretion rate, percent vegetative cover; fig. 46) provide a set of dependent variables that is used in the following statistical analyses of species-presence data. Widening rates (total widening in ft/yr), accretion rates (mean rate of accretion in in/yr), and percent woody vegetative cover (mean percent cover) were each separated into 5 categories, for ease of statistical operations. The categories for the site variables are listed in table 23. All sites listed in table 30 were used in parts of the categorization. Because of missing data points, however, two sites were omitted in the widening categorization, four sites in the accretion categorization, and two sites in the vegetative cover categorization. The five categories for each of the main variables (widening rate, accretion rate, and percent vegetative cover; table 23) were chosen to avoid wide ranges in the number of possible sites per category, which tends to bias subsequent statistical operations performed on the contingency tables. The descriptor terms of each category lead to a proper interpretation of widening and accretion rates, however, the wide range of cover values may make the descriptors somewhat misleading. For example, medium cover would indicate a substantial amount of bank cover, but a value of only 26 percent would fall into this category. Likewise, a value of 51 percent, slightly better than half, falls into the high-cover category.

Table 30.--*Summary of woody species present at selected stream sites*

[ALSE	*Alnus serrulata*	FOAC	*Forestiera acuminata*	QUNI	*Quercus nigra*
ASTR	*Asimina triloba*	FRPE	*Fraxinus pennsylvanica*	QUPH	*Quercus phellos*
ACNE	*Acer negundo*	GLTR	*Gleditsia triacanthos*	QURU	*Quercus rubra*
ACRU	*Acer rubrum*	JUNI	*Juglans nigra*	RHGL	*Rhus glabra*
ACSA	*Acer saccharinum*	LIST	*Liquidambar styraciflua*	ROPS	*Robinia pseudoacacia*
ARSP	*Aralia spinosa*	MAPO	*Maclura pomifera*	SACA	*Sambucus canadensis*
BENI	*Betula nigra*	NYAQ	*Nyssa aquatica*	SANI	*Salix nigra*
CACA	*Carpinus caroliniana*	PLOC	*Platanus occidentalis*	TADI	*Taxodium distichum*
CACO	*Carya cordiformis*	PODE	*Populus deltoides*	TIHE	*Tilia heterophylla*
CELA	*Celtis laevigata*	PRSE	*Prunus serotina*	ULAL	*Ulmus alata*
CEPO	*Cephalanthus occidentalis*	QUBI	*Quercus bicolor*	ULAM	*Ulmus americana*
COAM	*Cornus amomum*	QUFP	*Quercus falcata* Var. *pagodaefolia*	ULRU	*Ulmus rubra*]
CRSP	*Crataegus spp.*	QULY	*Quercus lyrata*		

Stream	Bank evolution stage	Station number	River mile	Number of species	Species code
North Fork Obion River	IV	07025600	5.9	0	
	V	07025500	10.0	0	
	IV	07025400	18.0	6	ACNE BENI CEPO FRPE SANI ULRU
	IV	07025375	21.1	2	BENI FRPE
	III	07025340	26.4	10	ACNE BENI CACA FRPE LIST PLOC QUPH TIHE ULRU
	VI	07025320	34.9	6	ACNE ACRU BENI CACO LIST PLOC
South Fork Obion River	V	07024800	5.8	8	ACNE ACSA BENI PLOC QUPH SACA SANI ULRU
	V	07024550	11.4	3	ACSA BENI SANI
	IV	07024525	16.8	0	
	IV	07024500	19.2	3	BENI SANI
	IV	07024460	23.2	2	BENI SANI
	VI	07024430	28.5	10	ACSA BENI JUNI NYAQ PLOC PODE QURU SANI TADI TIHE
	VI	07024350	33.8	3	BENI SANI TADI
Rutherford Fork Obion River	V	07025100	4.9	5	ACNE BENI SACA SANI
	V	07025050	10.4	2	BENI SANI
	IV	07025025	15.2	3	BENI RHGL SANI
	IV	07025020	17.1	1	BENI
	IV	07025000	17.9	7	ACNE ACSA BENI CRSP PLOC RHGL SANI
	IV	07025001	24.5	3	ACNE ACSA BENI
	VI	07024900	29.9	6	ACNE ACRU BENI CACA PLOC ULAM
	VI	07024888	39.4	5	BENI ACNE LIST PLOC ULAM
	VI	07024880	43.3	7	ALSE ACRU BENI CACA NYAQ PLOC ULAM
Obion River	V	07027200	20.8	3	ACSA PODE SANI
	II	07027180	25.6	2	PODE SANI
	V	07026300	34.2	3	ASTR PODE SANI
	V	07026250	42.4	3	ACSA PODE SANI
	V	07026000	53.7	3	ACNE ACSA SANI
	V	07025900	62.2	5	ACSA FRPE PLOC PODE SANI
	V	07024800	68.5	8	ACNE ACSA BENI PLOC QUPH SACA SANI ULRU
Davidson Creek	V	07025917	2.2	4	ACNE PODE SACA SANI
	IV	07025913	5.8	3	ACNE PODE SANI
	IV	07025909	7.5	2	ACNE SANI
	III	07025905	9.0	9	ACNE ACRU ACSA CELA FRPE MAPO PODE RHGL SANI
North Fork Forked Deer River	VI	07029105	3.8	4	ACSA BENI PODE SANI
	V	07029100	5.1	3	ACSA PLOC SANI
	IV	07029040	13.6	2	ACSA BENI
	V	07028840	18.8	3	ACSA BENI SANI
	IV	07028835	20.2	0	
	IV	07028820	23.9	0	
	I	07028500	34.6	6	ALSE ACNE ACRU BENI FRPE ULRU
	I	07028410	41.6	5	ACNE ACSA BENI PLOC SANI
South Fork Forked Deer River	V	07028200	3.3	3	ACSA BENI SANI
	IV	07028150	5.6	6	ACNE ACSA BENI PLOC SANI ULRU
	IV	07028100	7.9	0	
	IV	07028050	11.9	0	
	IV	07028000	13.3	1	ACSA
	IV	07027800	16.3	0	
	IV	07027720	27.6	0	
	III	07027680	33.7	8	ACSA CACA FRPE JUNI LIST PLOC ULAM

Table 30.--*Summary of woody species present at selected stream sites*--Continued

Stream	Bank evo- lution stage	Station number	River mile	Number of species	Species code
Pond Creek	IV	07029080	1.1	2	ACSA SANI
	IV	07029075	3.1	1	SANI
	IV	07029070	7.3	1	SANI
	IV	07029060	11.4		SANI
Hatchie River	I	07030025	49.5	13	ACSA BENI CACA CACO CELA FOAC LIST PLOC QULY TADI ULAM QUFP QUBI
	I	07030000	68.4	13	ACSA BENI CACA CACO CELA FOAC QUPH PLOC QULY TADI ULAM QUFP QUBI
	I	07029900	80.8	16	ACSA BENI CACA CACO FOAC FRPE LIST PLOC PRSE QULY QUNI QUPH ULAM QUFP QUBI
	I	07029650	121.1	8	ASTR ACSA BENI CACA PLOC QULY QUNI QUFP
	I	07029500	135.1	10	ACNE ACSA BENI CACA FOAC FRPE LIST PLOC QUPH SANI
	I	07029430	162.3	12	ACSA BENI CACA FRPE LIST NYAQ PLOC QULY QUNI TADI ULAM QUFP
	I	07029400	181.8	5	ACSA BENI FRPE PLOC ULAM
Porter Creek	V	07029445	1.5	9	ALSE ACNE ACRU BENI LIST SACA SANI
	V	07029440	8.8	9	ALSE ACNE ACRU BENI LIST PLOC SACA SANI
	IV	07029439	11.2	8	ALSE ACNE BENI LIST PLOC PODE SANI
	VI	07029438	13.9	6	ALSE ACNE BENI FRPE PLOC SANI
	IV	07029437	17.1	6	ALSE ACRU BENI PLOC PODE SANI
Cub Creek	VI	07029450	1.5	12	ALSE ACNE BENI CACA COAM FRPE LIST PLOC PODE RHGL SANI
	VI	07029449	2.2	6	ALSE ACNE BENI CACA PODE SANI
	V	07029448	5.7	5	ALSE BENI CACA SANI ULAL
	IV	07029447	6.9	6	ALSE ACRU BENI ULAL ARSP
Cane Creek	IV	4	3.6	8	ACNE ACSA FOAC FRPE RHGL PLOC PODE SANI
	IV	8	7.1	8	ACNE ACSA FRPE PLOC PODE PRSE RHGL SANI
	IV	12	10.2	5	ACNE FRPE PLOC PODE SANI
	IV	16	12.6	9	ACNE ACSA FRPE GLTR MAPO PODE RHGL ROPS SANI
Wolf River	IV	07031700	9.1	13	ACNE ACSA BENI CELA FRPE GLTR PLOC PODE QULY ROPS SANI ULAL QUFP
	IV	07031650	18.9	8	ACNE ACSA BENI FOAC GLTR PLOC SANI ULAL
	IV	07030610	23.6	6	ACNE ACSA BENI PLOC SACA SANI
	I	07030600	31.2	8	ACNE ACRU ACSA BENI CACA PLOC SANI ULAM
	I	07030500	44.4	6	ACNE ACSA BENI PLOC SACA SANI
	I	07030395	57.5	13	ACNE ACRU BENI FRPE NYAQ PLOC PODE QULY QUNI QUPH SACA SANI TADI
	I	07030392	69.9	9	ACNE BENI CACA NYAQ QULY QUNI SACA TADI ULAM

Standardized residuals as computed from contingency tables show species associations; positive and negative, for each of the 15 site categories. Positive associations are those with positive residual values, whereas negative associations are those with negative residual values. These values reflect species "preference" and "avoidance" patterns for the categorized site variables. Residual values between +1 and -1 are not considered particularly meaningful. A complete listing of all standardized residuals for 38 riparian species is given in table 31. Residual values for 12 selected species are graphically displayed in figure 55.

Black willow and river birch, the two most commonly occurring riparian species along disturbed reaches, tolerate moderate amounts of widening and accretion (fig. 55). Black willow in particular tolerates high accretion rates and is one of the few common species that does not have a positive association for very high cover (fig. 55). This suggests an important role in the initial stabilization of banks. However, after substantial cover occurs on the bank, closing canopies limit the continued dominance of black willow, due to its high light requirement (U.S. Department of Agriculture, 1965). River birch, a common pioneer, remains an important species after canopy closure (high and very high cover percentage, fig. 55) and is part of the suite of species along unmodified West Tennessee streams (Hatchie River; table 30).

Green ash and cottonwood are present in the early-to-middle stages of bank recovery. Both tolerate medium- or high-widening rates (fig. 55). Green ash is a shade-tolerant species (U.S. Department of Agriculture, 1965) with many of the same residual-value patterns of the "natural" species such as bald cypress and overcup oak (fig. 55). Cottonwood occurs in a wide range of environmental conditions, including sites with high-accretion rates like its relative, black willow (fig. 55). Cottonwood has no residual values with an absolute value much greater than 2; this suggests that its use as an indicator species is limited, with the possible exception of bank accretion.

Bald cypress and overcup oak characterize undisturbed banks or levees Hatchie River; table 30). Their residual-value patterns are strikingly similar (fig. 55). Water oak and American elm (fig. 55) are also "natural" bank or bottomland species. Note the rather striking associations (fig. 55) with only very high cover, very low widening, and low to medium accretion, with negative associations for all other site categories. This suggests rather "rigid" adaptations for stable sites, as opposed to the "elastic" adaptation pattern (large ecological amplitude) that appears to be characteristic of early- and mid-recovery species (pioneers). Thus the presence of these undisturbed site species indicate re-stabilized conditions associated with late stage V or VI. The dominant presence of species like black willow and river birch suggests previous channel-bank instability, mass wasting, and subsequent high-accretion rates associated with early- and mid-stage V. Absence or near absence of in situ woody plants indicates the general condition of bank instability associated with stage IV.

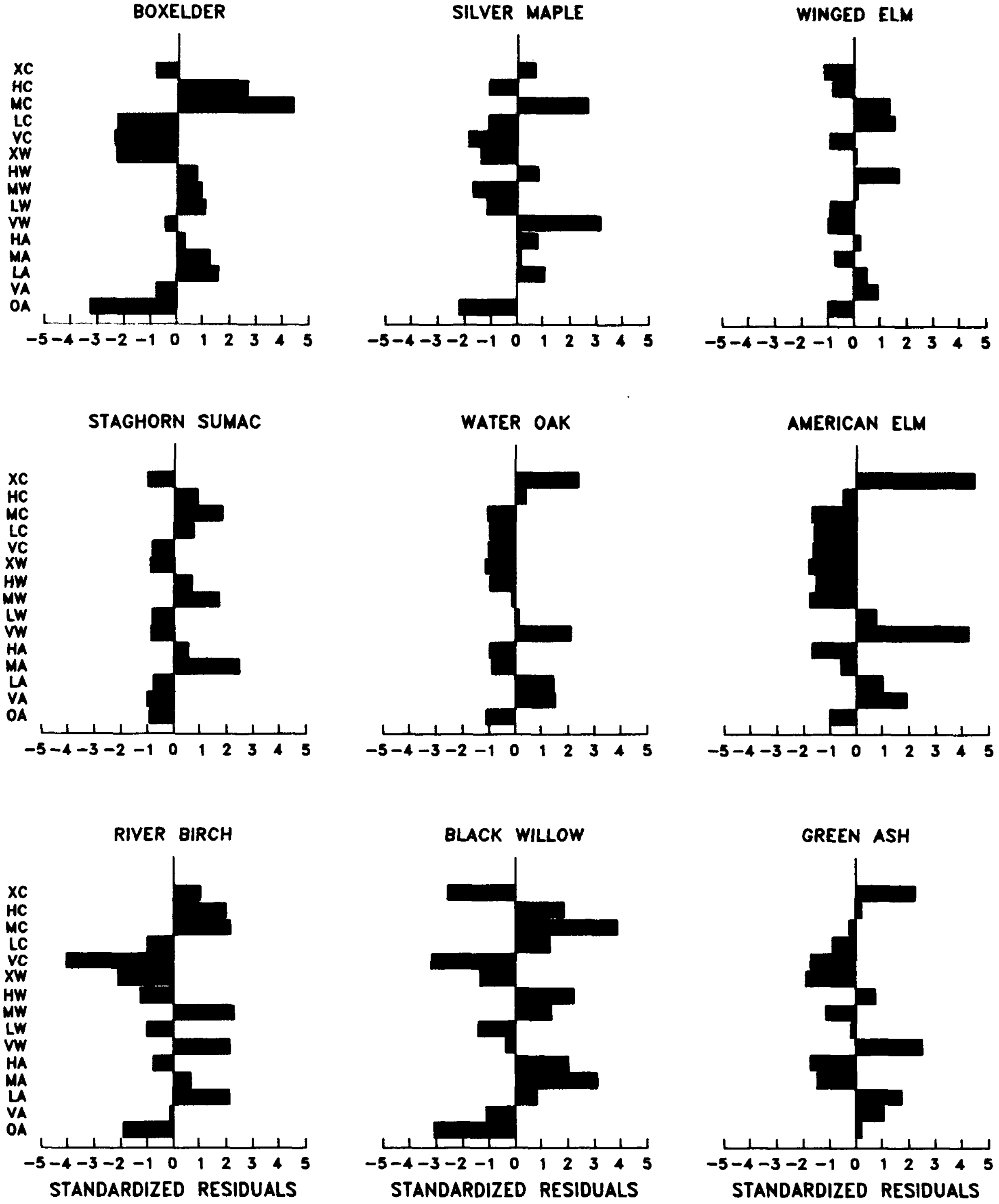
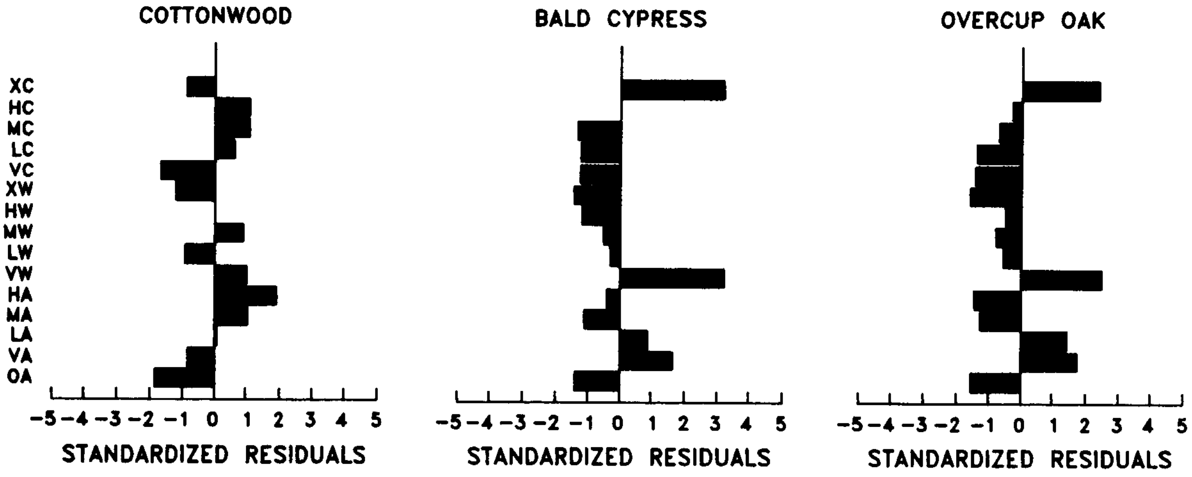


Figure 55.—Standardized residuals for each site-variable category showing site "preferences" for 12 selected riparian plants.



EXPLANATION

XC	VERY HIGH COVER
HC	HIGH COVER
MC	MEDIUM COVER
LC	LOW COVER
VC	VERY LOW COVER
XW	VERY HIGH WIDENING
HW	HIGH WIDENING
MW	MEDIUM WIDENING
LW	LOW WIDENING
VW	VERY LOW WIDENING
HA	HIGH ACCRETION
MA	MEDIUM ACCRETION
LA	LOW ACCRETION
VA	VERY LOW ACCRETION
OA	ZERO ACCRETION

Figure 55.--Standardized residuals for each site-variable category showing site "preferences" for 12 selected riparian plants--Continued.

Table 31.--*Standardized residuals for species association of 38 woody riparian species by bank condition and vegetation cover*
[Quantitative definitions of widening, accretion, and cover are provided in table 23]

Species		Percent[2]	Standardized residuals[1]														
			Bank widening					Bank accretion					Vegetation cover				
Code	Name	occurrence	Very low	Low	Medium	High	Very high	Zero	Very low	Low	Medium	High	Very low	Low	Medium	High	Very high
BENI	Betula nigra	62.50	2.14	-1.00	2.28	-1.25	-2.15	-1.89	-0.06	2.14	0.72	-0.76	-4.07	-1.00	2.14	1.99	1.04
SANI	*Salix nigra*	53.88	-0.32	-1.41	1.44	2.29	-1.33	-3.11	-1.06	0.91	3.14	2.10	-3.26	1.36	3.84	1.90	-2.63
ACSA	*Acer saccharinum*	42.67	3.23	-1.10	-1.66	0.84	-1.33	-2.17	0.02	1.13	0.19	0.86	-1.84	-1.10	2.71	-1.06	0.73
PLOC	*Platanus occidentalis*	41.38	3.36	0.12	-1.04	0.36	-2.71	-1.55	0.14	1.22	1.54	-0.65	-3.36	-3.24	1.78	2.79	1.77
ACNE	*Acer negundo*	36.64	-0.46	1.07	0.93	0.73	-2.34	-3.26	-0.80	1.60	1.26	0.28	-2.49	-2.36	4.38	2.55	-0.96
CACA	*Carpinus caroliniana*	19.40	3.21	0.90	-0.83	-1.82	-1.55	-0.83	1.11	1.25	-0.89	-0.61	-1.96	-1.20	-0.72	-0.10	3.25
LIST	*Liquidambar styraciflua*	16.81	3.68	-1.00	0.77	-1.67	-1.99	0.10	0.29	0.78	-0.70	-0.37	-1.80	-1.74	-0.48	0.95	2.58
ALSE	*Alnus serrulata*	15.95	0.32	0.58	2.26	-1.26	-1.92	-1.87	0.41	0.07	1.05	0.44	-1.74	1.33	-0.39	2.74	-1.54
FRPE	*Fraxinus pennsylvanica*	15.52	2.52	-0.13	-1.14	0.77	-1.89	0.25	1.10	1.75	-1.46	-1.72	-1.72	-0.89	-0.24	0.25	2.22
PODE	*Populus deltoides*	15.52	1.09	-0.89	0.95	-0.01	-1.22	-1.84	-0.80	0.11	1.10	1.97	-1.72	0.63	1.09	1.10	-0.88
ULAM	*Ulmus americana*	14.22	4.25	0.80	-1.74	-1.51	-1.80	-1.02	1.97	1.10	-0.50	-1.63	-1.63	-1.57	-1.69	-0.50	4.41
ACRU	*Acer rubrum*	12.93	0.72	0.16	1.35	-1.43	-0.97	-0.90	0.88	-0.49	1.45	-0.75	-1.54	0.16	-0.83	4.21	-1.23
QULY	*Quercus lyrata*	11.64	2.54	-0.54	-0.77	-0.46	-1.60	-1.55	1.82	1.48	-1.23	-1.45	-1.45	-1.40	-0.70	-0.27	2.40
SACA	*Sambucus canadensis*	11.64	-0.70	0.32	2.37	-0.46	-1.60	-1.55	-0.32	0.56	2.62	-0.62	-1.45	-1.40	2.54	1.66	-1.09
TADI	*Taxodium distichum*	9.05	3.21	-0.26	-0.47	-1.17	-1.39	-1.35	1.67	0.94	-1.07	-0.33	-1.26	-1.22	-1.31	-0.01	3.13
NYAQ	*Nyssa aquatica*	7.76	1.70	0.94	-0.30	-1.08	-1.28	-1.24	1.17	1.18	-0.99	-0.16	-1.16	-1.12	-1.20	1.32	1.92
QUFP	*Quercus falcata* Var. *pagodaefolia*	7.76	3.64	-1.12	-1.24	-0.01	-1.28	-1.24	2.03	1.18	-0.99	-1.16	-1.16	-1.12	-0.23	-0.99	2.76
ULRU	*Ulmus rubra*	7.76	-0.23	-0.09	-1.24	2.12	-0.36	0.64	-0.54	2.29	-0.99	-1.16	-1.16	-0.09	2.67	-0.99	-0.59
FOAC	*Forestiera acuminata*	6.47	3.12	-1.01	-1.13	0.19	-1.16	-1.13	1.53	0.27	-0.89	0.03	-1.05	-1.01	-0.04	-0.89	2.35
QUNI	*Quercus nigra*	6.47	2.07	0.11	-0.10	-0.98	-1.16	-1.13	1.53	1.48	-0.89	-1.05	-1.05	-1.01	-1.09	0.36	2.35
QUPH	*Quercus phellos*	6.47	-0.04	0.11	-0.10	1.35	-1.16	-0.10	0.60	1.48	-0.89	-1.05	-1.05	-1.01	1.02	0.36	0.53
CACO	*Carya cordiformis*	5.17	2.54	-0.90	0.14	-0.87	-1.03	0.14	0.94	0.51	-0.79	-0.94	-0.94	-0.90	-0.97	0.60	1.88
ULAL	*Ulmus alata*	5.17	-0.97	-0.90	0.14	1.71	0.08	-1.00	0.94	0.51	-0.79	0.27	-0.94	1.59	1.37	-0.79	-1.15
CELA	*Celtis laevigata*	3.88	1.85	-0.78	-0.86	0.73	-0.89	-0.86	2.59	-0.71	-0.68	-0.80	-0.80	-0.78	0.58	-0.68	1.33
QUBI	*Quercus bicolor*	3.88	3.19	-0.78	-0.86	-0.75	-0.89	-0.86	1.40	0.82	-0.68	-0.80	-0.80	-0.78	-0.83	-0.68	2.49
RHGL	*Rhus glabra*	3.88	-0.83	-0.78	1.75	0.73	-0.89	-0.86	-0.97	-0.71	2.52	0.58	-0.80	0.78	1.85	0.92	-0.99
GLTR	*Gleditsia triacanthos*	2.59	-0.68	-0.63	-0.70	2.99	-0.72	-0.70	0.66	-0.58	-0.55	1.03	-0.65	-0.63	2.59	-0.55	-0.80
JUNI	*Juglans nigra*	2.59	2.59	-0.63	-0.70	-0.60	-0.72	0.89	-0.78	-0.58	-0.55	1.03	-0.65	-0.63	-0.68	-0.55	2.02
MAPO	*Maclura pomifera*	2.59	0.96	-0.63	0.89	-0.60	-0.72	-0.70	-0.78	-0.58	-0.55	2.71	-0.65	-0.63	0.96	-0.55	0.61
QURU	*Quercus rubra*	2.59	0.96	1.11	-0.70	-0.60	-0.72	2.48	-0.70	-0.58	-0.55	-0.65	-0.65	-0.63	-0.68	-0.55	2.02
TIHE	*Tilia heterophylla*	2.59	0.96	1.11	-0.70	-0.60	-0.72	0.89	-0.78	-0.58	1.39	-0.65	-0.65	-0.63	-0.68	-0.55	2.02
ARSP	*Aralia spinosa*	1.29	-0.47	-0.44	1.74	-0.42	-0.51	-0.49	1.48	-0.41	-0.39	-0.46	-0.46	2.00	-0.47	-0.39	-0.56
ASTR	*Asimina triloba*	1.29	1.82	-0.44	-0.49	-0.42	-0.51	-0.49	1.48	-0.41	-0.39	-0.46	-0.46	-0.44	-0.47	-0.39	1.42
CEPO	*Cephalanthus occidentalis*	1.29	-0.47	-0.44	-0.49	2.10	-0.51	-0.49	-0.55	2.22	-0.39	-0.46	-0.46	-0.44	1.82	-0.39	-0.56
COAM	*Cornus amomum*	1.29	-0.47	-0.44	1.74	-0.42	-0.51	-0.49	-0.55	-0.41	-0.39	1.90	-0.46	-0.44	-0.47	2.35	-0.56
CRSP	*Crataegus spp.*	1.29	-0.47	-0.44	-0.49	2.10	-0.51	-0.49	-0.55	-0.41	2.35	-0.46	-0.46	-0.44	1.82	-0.39	-0.56
PRSE	*Prunus serotina*	1.29	1.82	-0.44	-0.49	-0.42	-0.51	-0.49	-0.55	2.22	-0.39	-0.46	-0.46	-0.44	-0.47	-0.39	1.48
ROPS	*Robinia pseudoacacia*	1.29	-0.47	-0.44	-0.49	2.10	-0.51	-0.49	1.48	-0.41	-0.39	-0.46	-0.46	-0.44	1.90	-0.39	-0.56

[1] Positive values denote preference patterns; negative values denote avoidance patterns; and values between +1 and -1 are insignificant.

[2] Percentage of sites at which the indicated plant is present.

Winged elm (*Ulmus alata*) and staghorn sumac (*Rhus glabra*) are often found along reaches that have previously experienced severe degradation. These two species are not normally considered to be riparian plants and are mentioned here to illustrate how banks, now so high that their upper portions are above most fluvial activity can support upland species (fig. 55). Their low vegetative cover "preferences" and tolerance to substantial widening make these plants good indicators of bank-disturbance conditions that resemble upland mass-wasting conditions.

Silver maple (*Acer saccarhinum*) and boxelder (*Acer negundo*) are common along recovering reaches. Although these species are present in stable riparian forests, many banks in the later stages of recovery may support these two species singularly or in tandem to the near exclusion of other species. Boxelder and silver maple site-variable patterns (fig. 55) typify species characteristic of middle- to late-bank recovery.

Species Distribution--Six-Stage Model

Data on species presence and site characteristics can be placed within the framework of the bank-slope-development model (Simon and Hupp, 1986a; Simon, 1989). The remainder of this discussion on species presence will be presented in relation to this six-stage bank-slope-development model (table 4, and, figure 30).

Species cover during stage I is always at or near 100 percent and the greatest number of species occurs here and along stage III reaches, which are vegetatively similar. Fourteen sites (table 30) were identified as stage I, principally along the Hatchie River and the upstream sites of the Wolf River. Stage I streams, in general, represent the "natural" geomorphic and botanical condition in West Tennessee. Stage II reaches are the constructed stage that have been recently straightened, dredged, and cleared of all woody-riparian vegetation. This stage is extremely short-lived; degradation or aggradation, depending on location in system, begins almost immediately.

Three sites are determined to be in stage III (table 30), although it undoubtedly exists in more areas not covered in our sampling scheme. Vegetatively, this stage resembles stage I areas, but geomorphically this stage is quite distinct. The banks are steeper and the channel bed has degraded considerably. This typically leaves mature riparian trees that were previously rooted at or below the low-water elevation, at mid-bank elevations now high and dry (fig. 56). Commonly a few trees have toppled into the channel. Imminent bank widening is apparent from the over-heightened and steepened banks and from the exposed and inclined old-tree bases and root systems. Vegetative-cover values drop dramatically as soon as mass wasting begins during stage IV.

Figure 56.--Upstream view of Davidson Creek near U.S. Highway 51; site is a typical reach during degradation stage (stage III).

Stage IV, the threshold stage, was investigated at 36 sites listed in table 30. The near absence of in situ vegetative cover is among the most striking characteristics of this stage. Vegetative cover values of approximately 20 percent represent maxima for this stage, and these values occur only in protected areas (typically on inside bends). Mean vegetative cover for this stage is just under 10 percent; 22 percent of the sites in stage IV are devoid of in situ woody plants. However, herbaceous species such as giant knotweed, cocklebur, and various grasses may form dense stands on these banks during the summer months. Such stands give the bank a falsely stable appearance. Reaches in late stage IV may support some of the early pioneer species in protected low-bank areas. The plants found here tolerate moderate amounts of bank instabilities and are present in low numbers. These numbers increase as widening subsides and low-bank areas of the reach move into stage V.

Stage V is the initial recovery stage. Eighteen sites were identified as stage V sites. This stage is characterized by relatively high accretion rates on the low- to mid-bank surfaces and relatively active widening on the vertical faces and upper bank. Mean vegetative cover for this stage is about

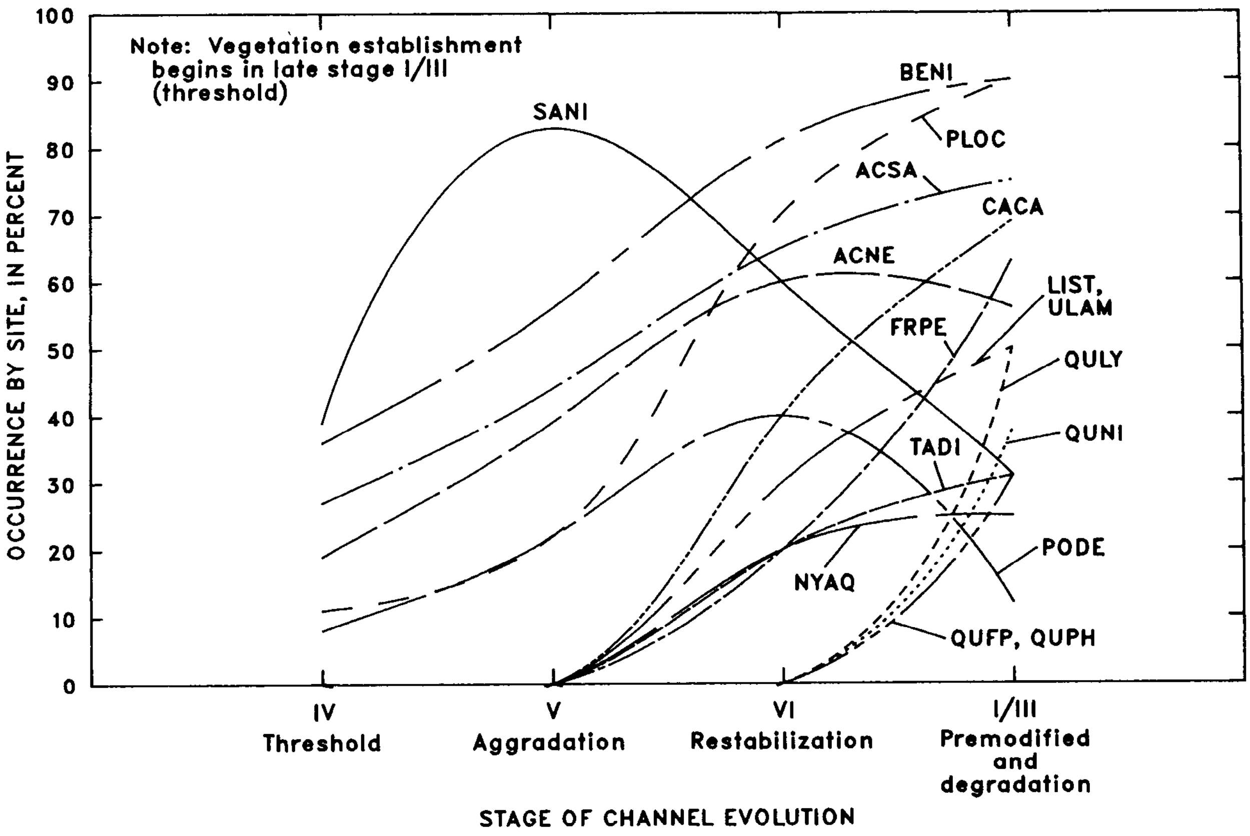
30 percent, and 6 percent of the sites lack in situ woody vegetation. There usually is less herbaceous vegetation here than in stage IV, owing to the high accretion rates and woody cover that may cause considerable shading. Black willow and river birch occur on more than 50 percent of these sites. Species richness increases in stage V. Mid-recovery species such as sycamore, green ash, cottonwood, and silver maple frequently invade areas adjacent to and upslope of the commonly dense thickets of black willow or river birch. All of these species tolerate relatively high accretion rates (fig. 55).

Stage VI reaches are largely recovered reaches with a meandering low-flow channel, relatively low banks, and tree-size vegetation occurring across the entire bank section down and into the low-flow channel. Ten sites were identified as stage VI; these are typically the most upstream sites and are the result of channel work at the turn of the century or in the 1940's. Species typical of stage I/III reaches begin to establish in stage VI including American elm (*Ulmus americana*), ironwood (*Carpinus caroliniana*), sweet gum (*Liquadambar styraciflua*), bald cypress (*Taxodium distichum*), and tupelo (*Nyssa aquatica*). Bottomland-oak species may be present on old levee surfaces, or areas of slightly higher elevations. Vegetative-cover values are at or near 100 percent at all sites. Outside bends suffer only from fluvial cutting, while inside bends are sites of point-bar development and subsequent vegetation establishment. Hydrologically, stage VI reaches can again have a prolonged hydroperiod (annual period of inundation) on the flood plains. The hydroperiod is often absent from this location along degraded reaches that are still recovering (stages III-V) because of increased channel capacity. The vegetation on stage VI reaches is not as mature or diverse as stage I. However, in all other aspects (vegetative, geomorphic, and hydrologic), stage VI reaches are basically recovered from channelization.

Vegetation Recovery and Life History

Patterns of vegetative recovery after channelization can be estimated, when considered in terms of the six-stage model. Vegetation-recovery patterns for 16 species are shown in figure 57 (table 29). Stage II has been omitted from figure 57 because all vegetation typically is removed. Stages I and III, being vegetatively similar, are placed at the end of the stage scale (fig. 57) as, given enough time, stage VI reaches will closely approach stage I reaches. If subsequent downstream channel work takes place, the degradation and recovery processes will begin again.

The initial species to colonize channelization-affected reaches are willow, river birch, silver maple, box elder, sycamore, and cottonwood (stage IV, fig. 57). Asexual reproduction by runners or cuttings is common in most of these species. In addition, these species grow rapidly and produce abundant seeds that are short-lived. Dispersal in these species is by wind, water, or both, and all disseminate their seeds in middle to late spring (Fowells, 1965; Harlow and Harrer, 1969). The timing of seed dispersal coincides with the typical decrease in water levels in late spring. Thus, seeds from these trees may be deposited on fresh bank substrates created by mass wasting, bank accretion, fluvial reworking,



EXPLANATION

SPECIES CODE AND SCIENTIFIC NAME

ACNE	ACER NEGUNDO
ACSA	ACER SACCHARINUM
BENI	BETULA NIGRA
CACA	CARPINUS CAROLINIANA
FRPE	FRAXINUS PENNSYLVANICA
LIST	LIQUIDAMBAR STYRACIFLUA
NYAQ	NYSSA AQUATICA
PLOC	PLATANUS OCCIDENTALIS
PODE	POPULUS DELTOIDES
QUFP	QUERCUS FALCATA
QULY	QUERCUS LYRATA
QUPH	QUERCUS PHELLOS
SANI	SALIX NIGRA
TADI	TAXODIUM DISTICHUM
ULAM	ULMUS AMERICANA

Figure 57.——Vegetation–recovery patterns for 16 species by stage of channel evolution. Percent of occurrence is the total number of sites where species was present relative to the total number of sites in a given stage.

and late-spring exposure. The life-history characteristics of stage IV-V species make them particularly suited for establishment and growth along disturbed channels. If sites are relatively stable and accretion is not excessive, the successful establishment of these species is probable.

Variations in species patterns among stage IV-V sites may result from variations in the timing of water-elevation recession, rafting of viable seeds during high water, and the variability of seed release mechanisms among the individual species. The most successful pioneer species, black willow and river birch, are particularly tolerant of high accretion rates and shallow secondary sliding of accreted material, through layering and stem sprouting, respectively. Black willow and cottonwood (a related species) are the two species that reach maximums prior to stage I-III and have a substantial reduction of occurrence by stage I-III (fig. 57). These two species are probably limited by the low-light conditions of the subcanopy in mature "natural" riparian settings. All of the stage IV/V species are relatively short-lived and by stage VI, their dominance is substantially reduced due to sequential replacement by stable-site species (stage VI and I-III, fig. 57).

Stage I/III sites may have river birch present but the site may be a typical cypress-tupelo swamp, whereas an early stage V site may have river birch present to the near exclusion of all other species. Stage VI sites and some late stage V sites experience the gradual reduction of dominance by the "pioneer" species through the establishment of stable-site species (fig. 57). Thus, by stage I/III, two distinct suites of vegetation have become established, in addition to the initial suite in late stage IV (fig. 57). The second suite, which includes ironwood, green ash, sweetgum, American elm, bald cypress, and tupelo, is characteristic of southeastern bottomlands and represents the riparian plant community of relatively mature "natural" sites. All of these species, except sweetgum, are largely confined to bottomlands and have seeds that are dispersed by wind or water (Fowells, 1965). These plants have seeds that live up to 2 years as opposed to pioneer species whose seeds live only a few days to a week.

The last suite of vegetation includes the bottomland oaks, overcup oak, water oak, cherry bark oak (*Q. falcata* var. *pagodaefolia*), and willow oak (*Q. phellos*). Oaks produce heavy short-lived seeds that are normally animal-dispersed. The oaks tend to occur on natural and manmade levees, or on slightly elevated parts of the bottomland.

Thus, each of the three suites of tree species involved in vegetation recovery from channelization, have distinct life-history characteristics. The data suggest a trend from (1) fast-growing, short-lived trees with light, short-lived water- or wind-borne seeds, and a tolerance for bank disturbance and high-light conditions in the late stage IV and stage V part of bank recovery to, (2) long-lived, shade-tolerant trees with very specific growth requirements, long-lived water- or wind-borne seeds, and low tolerance to bank disturbance in stage VI to, (3) heavy-seeded, long-lived oak trees that share the bottomland with stage VI species after nearly complete ecologic and geomorphic recovery.

Perhaps the most important trend evident in figure 57 is the steadily increasing diversity of plants from stage IV to I/III. Species diversity has long been recognized to generally increase with physical site stability. Species-presence data by stage of bank-slope development are listed in table 32.

Table 32.--*Indicator species and percent presence for threshold (stage IV), aggradation (stage V), and restabilization (stage VI) stages*

Species	Species code	Presence in percent
Species Tolerant of Bank-widening Disturbances (Late Stage IV Pioneers)		
Salix nigra	SANE	39
Betula nigra	BENI	36
Acer negundo	ACNE	19
Acer saccharinum	ACSA	17
Platanus occidentalis	PLOC	11
Populus deltoides	PODE	8
Alnus serrulata	ALSE	8
Unvegetated		22
Species Tolerant of High Deposition Rates (Stage V Pioneers)		
Salix nigra	SANI	83
Betula nigra	BENI	56
Acer saccharinum	ACSA	44
Acer negundo	ACNE	39
Sambucus canadensis	SACA	33
Platanus occidentalis	PLOC	22
Populus deltoides	PODE	22
Alnus serrulata	ALSE	17
Unvegetated		6
Recovery Species (Stage VI)		
Acer saccharinum	ACRE	65
Betula nigra	BENI	90
Plantanuss occidentalis	PLOC	70
Acer negundo	ACNE	60
Salix nigra	SANI	60
Alnus serrulata[1]	ALSE	50
Populus Deltoides	PODE	40
Carpinus caroliniana	CACA	40
Acer Rubrum	ACRU	30
Liquidambar styraciflua	LIST	30
Ulmus americana	ULAM	30
Betula Nigra	BENI	20
Nyssa aquatica	NYAQ	20
Taxodium Distichum	TADI	20
Fraxunus pennsylvanica	FRPE	20
Unvegetated		0

[1] Only on sand/gravel bedded streams.

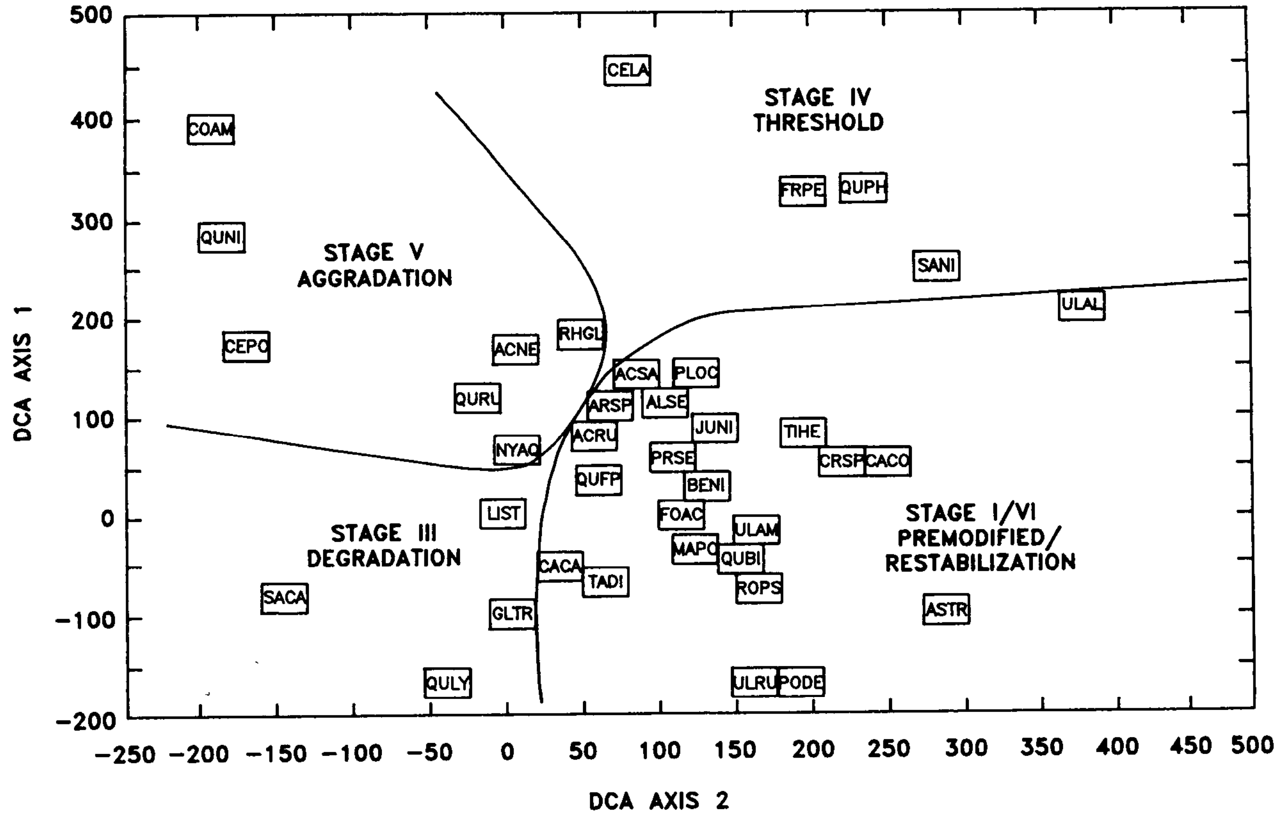
Species Ordination

Ordination is a type of multivariate analysis that examines numerous variables simultaneously. Ordination allows for the classification of vegetation data, in this case frequency data converted to standardized residuals (table 31). This classification is based entirely on species-presence data, apart from environmental data, leaving environmental interpretation to a subsequent, independent step (Gauch, 1982). The result of ordination is a two-dimensional array such that the spatial arrangement of species, or site variables, places similar species or sites close by and dissimilar ones far apart.

Both the species and site ordinations were performed using the computer program DECORANA (Hill and Gauch, 1980)--a detrended correspondence analysis (DCA). Results of the species ordination are shown in figure 58; the site ordination is shown in figure 59. In both, the entities are spread across two multivariate axes. The distance between entities can be considered analogous to "ecological distance." For example, very high cover (XC) and very low widening (VW) group closely together (fig. 59) and, conversely, this group is ecologically distant from very low cover (VC) and very high widening (XW).

The ordination of species shows clusters of species in groups (fig. 58). Inspection of the pattern (fig. 58) allows for each group to be independently associated with a particular stage of bank-slope development. The boundary lines are placed on figure 58 on the basis of computed residual values for each species. DCA axis-1 is largely one of stability, and the second axis is largely one of time since disturbance, or pioneer versus mature (figs. 58, 59). The stage IV clusters of species, largely disturbance-associated plants, are easily separated from the other stage clusters. However, the separation between stage V and stage VI is largely one of interpretation, as would be expected. The difference between stage V and stage VI may be thought of as an environmental gradient beginning with stabilizing but relatively active banks, through to stable natural-bank conditions. Thus, a stability gradient is revealed in figure 59 with the upper left corner the most unstable, and the lower right corner, the most stable.

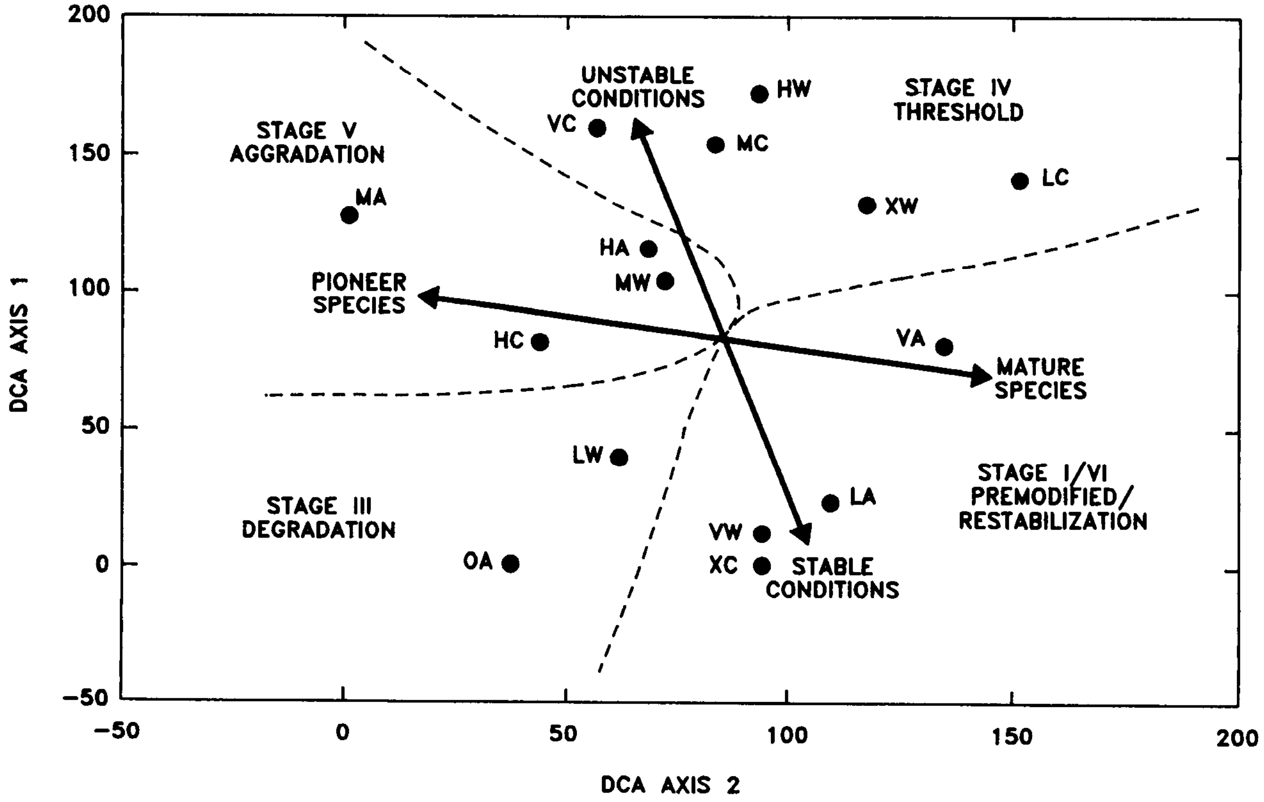
The environmental gradients are perhaps better revealed in the site-variable ordination (fig. 59). The same general bank-slope-development stage pattern is also shown for the species ordination. The site variables can be associated with the various stages of bank-slope development (fig. 59). This ordination reflects the geomorphic processes and characteristics outlined in the bank-slope-development model. Site conditions naturally cluster in groups that can be identified with specific stages of the model. Thus, the ordination of species-presence data supports the conceptual framework of the bank-slope-development and channel evolution models; and indicates that patterns of species distribution may be used to infer levels of ambient bank stability.



EXPLANATION
SPECIES CODE AND SCIENTIFIC NAME

ALSE	ALNUS SERRULATA	NYAQ	NYSSA AQUATICA
ASTR	ASIMINA TRILOBA	PLOC	PLATANUS OCCIDENTALIS
ACNE	ACER NEGUNDO	PODE	POPULUS DELTOIDES
ACRU	ACER RUBRUM	PRSE	PRUNUS SEROTINA
ACSA	ACER SACCHARINUM	QUBI	QUERCUS BICOLOR
ARSP	ARALIA SPINOSA	QUFP	QUERCUS FALCATA
BENI	BETULA NIGRA	QULY	QUERCUS LYRATA
CACA	CARPINUS CAROLINIANA	QUNI	QUERCUS NIGRA
CACO	CARYA CORDIFORMIS	QUPH	QUERCUS PHELLOS
CELA	CELTIS LAEVIGATA	QURU	QUERCUS RUBRA
CEPO	CEPHALANTHUS OCCIDENTALIS	RHGL	RHUS GLABRA
COAM	CORNUS AMOMUM	ROPS	ROBINIA PSEUDOACACIA
CRSP	CRATAEGUS SPP.	SACA	SAMBUCUS CANADENSIS
FOAC	FORESTIERA ACUMINATA	SANI	SALIX NIGRA
FRPE	FRAXINUS PENNSYLVANICA	TADI	TAXODIUM DISTICHUM
GLTR	GLEDITSIA TRIACANTHOS	TIHE	TILIA HETEROPHYLLA
JUNI	JUGLANS NIGRA	ULAL	ULMUS ALATA
LIST	LIQUIDAMBAR STYRACIFLUA	ULAM	ULMUS AMERICANA
MAPO	MACLURA POMIFERA	ULRU	ULMUS RUBRA

Figure 58.—Results of species ordination from detrended correspondence analysis (DCA). (Axes 1 and 2 are the first two principal components.)



EXPLANATION

VW	VERY LOW WIDENING
LW	LOW WIDENING
MW	MEDIUM WIDENING
HW	HIGH WIDENING
XW	VERY HIGH WIDENING
OA	ZERO ACCRETION
VA	VERY LOW ACCRETION
LA	LOW ACCRETION
MA	MEDIUM ACCRETION
HA	HIGH ACCRETION
VC	VERY LOW COVER
LC	LOW COVER
MC	MEDIUM COVER
HC	HIGH COVER
XC	VERY HIGH COVER

Figure 59.—Results of site-variable ordination from detrended correspondence analysis (DCA). (Axes 1 and 2 are the first two principal components.)

SUMMARY AND CONCLUSIONS

Dredging and straightening of alluvial channels in West Tennessee has caused significant adjustments in channel plan and profile. The removal of riparian vegetation during channel construction, and subsequent episodes of bank widening, resulted in increased streamflow velocities through a reduction in channel roughness. An interdisciplinary approach including geomorphology, soil mechanics and slope stability, dendrochronology, and plant ecology was used to determine geomorphic and vegetative-recovery processes along adjusting stream systems during the course of channel evolution.

A model of channel evolution was used to differentiate varying process-response mechanisms over the course of fluvial adjustment. Stage I, the premodified condition, is followed by the construction phase (stage II) where vegetation is removed, the channel deepened, and channel gradients and bank slopes steepened. Degradation (stage III) follows and is characterized by an increase in bank heights and angles until critical conditions of the bank material are exceeded, and the banks fail by mass-wasting processes (stage IV). Aggradation begins in stage V, and low-bank stability is achieved through a reduction in bank heights and bank angles. Stage VI (restabilization) is characterized by the relative migration of bank stability upslope (as determined by establishing woody-riparian species), point-bar development, and incipient meandering.

A quantitative model of bed-level adjustment over time and space was used to estimate amounts of bed degradation and aggradation at 5-year intervals, into the next century. A power equation relating channel-bed elevation to time used the exponent "b" as the primary indicator in describing the magnitude of channel bed-level changes. Maximum amounts of change occurred in reaches in the vicinity of the area of maximum disturbance (greatest imposed gradient change) and decreased nonlinearly with distance upstream. Aggradation took place downstream of this area of maximum disturbance, with the greatest rates occurring near stream mouths. Following a 10- to 15-year period of degradation, "secondary aggradation" occurred due to excessive incision and gradient reduction.

Channel-bank instabilities were induced by incision and undercutting of the bank toe, and resulted in channel widening by mass-wasting processes. Common failure types included rotational, planar, slab, and "pop out" (due to excess pore-water pressure). Failures generally occurred during or after recession of river stage due to bank saturation and the loss of support afforded by the flowing water (rapid drawdown condition). Highly degraded reaches, such as along Cane Creek, widened rapidly--up to 16 ft/y.

Drained shear-strength determinations were done on bank materials using a borehole-shear-test device that provides information on cohesion and the angle of internal friction of the material. Mean values of cohesion and the angle of internal friction for the loess-derived alluvium were 1.26 pounds per square inch and 30.1 degrees, respectively (168 tests). These direct-shear measurements were then used to calculate factors of safety and to construct bank-stability charts. Planar failures were found to be more critical in most cases, but rotational failures tended to produce higher rates of channel widening. An approximate threshold factor of safety of 2.0 was determined, indicating that for stream banks of loess-derived alluvium, the factor of safety of 1.50 commonly used in channel design, may be marginal. Factors of safety varied as expected with the stages of channel evolution. Critical bank conditions calculated for each site over a range of bank heights and bank angles were used to develop slope-stability charts for the purpose of assessing the relative bank stability of sites. These were based on ambient-field and saturated-bank conditions.

A nomograph was developed for the purpose of determining stable-bank configurations for worst-case conditions (saturation during rapid drawdown) at given cohesive strengths. Potential bank instabilities can also be estimated by using the nomograph and by noting possible changes in bank height as a result of channel-bed degradation.

Rates and amounts of channel widening calculated using dendrogeomorphic, soil mechanics, and survey techniques compared closely with each other. These values differed by the amount of channel-bed degradation, the strength of the bank materials, and the degree of fluvial undercutting (pronounced if on outside bends). Projections of future channel widening were based on the extension of a "temporary angle of stability" upslope, until it intersects the flood-plain surface. Estimates of further top-bank widening were then made by subtracting the distance between this point and the present top-bank edge. Initial stable-bank configurations were estimated from temporary angles of bank stability; obtained independently by soil mechanics, and dendrogeomorphic techniques. The two values were 23 and 24 degrees, respectively.

Estimates of long-term width/depth ratios for the loess tributary streams and for the sand-bed streams after 40 years of adjustment range from 4.0 to 6.4, and from 6.8 to 11.4, respectively. After 115 years of adjustment, estimated width-depth ratios for the fine-grained channels range from 4.3 to 6.8, and for the sand-bed channels, from 7.4 to 13.1. These estimates (with their inherent uncertainties) were determined from estimates of channel bed-level changes (from the power equation), and from estimates of projected channel widening. A 10- to 15-year period of degradation, followed by either 25 or 100 years of aggradation was assumed for each site.

Data from dendrogeomorphic and plant-ecologic analyses described trends of channel response and recovery. Patterns of riparian-species distributions are strongly associated with the stages of channel evolution. Vegetation re-establishment during late stage IV and stage V indicates ameliorating bank conditions and the inception of low-bank stability. The most common pioneer species in this study were black willow, river birch, silver maple, and boxelder. Dating of these species was used to determine the timing of initial bank stability. Stages I and III had the most diverse riparian species; stage IV banks often had no woody species due to the highly unstable nature of the channel banks.

Contingency-table and standardized-residual analyses indicated species "preference" or "avoidance" for particular site characteristics such as widening, accretion, and woody vegetative cover. Distinct differences exist between pioneer and mature species for specific site characteristics. This indicates that vegetative reconnaissance of an area can be used for at least preliminary estimation of bank-stability conditions.

Detrended-correspondence analysis displayed vegetation patterns and delineated species assemblages associated with the six stages of channel evolution. Ordination of site variables (channel widening, bank accretion and woody vegetative cover) based on species data alone reflected the hydrogeomorphic characteristics of the six-stage model of channel evolution. Site conditions clustered in groups that can be identified with specific stages of the model. This analysis supports the conceptual framework of the channel-evolution model, and it indicates that patterns of species distribution can be used to infer ambient channel stability.

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