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THE STATUS OF RIPARIAN WETLANDS IN WEST-CENTRAL INDIANA STREAMS

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ABSTRACT: Riparian wetlands' assessments were made along Big Raccoon, Big Walnut, and Deer Creeks (Putnam County and vicinity) in 1993-94 and along the middle Wabash River from Delphi to Merom, Indiana, in 1983 and 1994. Among the three tributaries, the riparian border along Big Raccoon Creek afforded the least protection (32% of the sites surveyed were less that 3 m wide). The riparian border of Big Raccoon Creek also had the greatest incidence of severe and moderately eroded banks (40%) and the most open canopy (60% of the sites surveyed were less than 50% shaded). The riparian border of Big Walnut Creek was better protected (more than 50% of its riparian border measured more than 9 m in width, and a majority of the sites had more than 50% shading). However, approximately 30% of the banks along Big Walnut Creek were exposed to moderate to severe erosion. Deer Creek had the best developed riparian border (70% of its sites had good riparian protection (> 9 m), about 80% of its sites were shaded, and less than 25% of its banks were in a state of moderate to severe erosion). Five hundred and eighteen kilometers of the middle Wabash River were surveyed. Bare banks composed 28.82 km (5.56%) of its border, and 27.21 km (5.25%) of its banks had only 1-2 trees. These figures are both lower than the 1983 estimates. At that time, 37.92 km (7.32%) of the river's border had bare banks, and 35.0 km (6.76%) had only 1-2 trees. By 1994, young willow groves had colonized some previously bare banks. The well-being of the Wabash River ecosystem is highly dependent on the environmental health of its tributaries. The riparian wetlands of the Wabash River and three of its tributaries are currently incapable of providing adequate protection from agricultural nonpoint source pollution.

KEYWORDS: Agriculture, NPS, riparian, streams, wetlands.

INTRODUCTION

National estimates suggest between 50% to 70% of the assessed surface waters in the nation are adversely affected by agricultural nonpoint source pollution. The primary cause is soil erosion from cropland and overgrazing as well as pesticide, herbicide, and fertilizer application (U.S. Environmental Protection Agency, 1986). Approximately 40% of Indiana's 20,000 miles of permanent rivers and streams are estimated to be damaged due to major impacts from agriculture (Indiana Department of Environmental Management, 1990). This figure is undoubtedly an underestimate.

About two-thirds of the Wabash River basin is agricultural cropland, the highest proportion within the Ohio River basin (ORSANCO, 1990). The water quality of many large bodies of surface water improved during the 1980s, because of better waste treatment at municipal and industrial point sources of pollution. Due to the better treatment of municipal and industrial wastes, agricultural activities are now recognized as the predominant determinants of water quality and ecosystem health degradation in many Midwestern rivers, including the Wabash River (Gammon, 1993, 1994) and its tributaries (Gammon, *et al.*, 1990; Gammon and Gammon, 1993).

Until recently, wetlands were considered a nuisance to be obliterated by draining, clearing, inundating, or filling with solid wastes. From the mid-1950s to the mid-1970s, an average of 458,000 acres of wetlands per year were eliminated from the contiguous United States. During the next decade, losses were reduced to 290,000 acres per year (Dahl, 1990; Dahl and Johnson, 1991). Agricultural development accounted for 87% of the wetland conversion from the mid-1950s to the mid-1970s, and similar development was responsible for 54% of the losses from the mid-1970s to the mid-1980s (U.S. Department of the Interior, 1994).

Riparian wetlands are periodically flooded lands adjacent to flowing waters that support characteristic biotic communities. These wetlands are not included in the overall estimates of wetlands loss, because riparian wetlands are variably narrow and difficult to assess (Dahl, pers. comm.).

Hupp (1988) argued that the word "riparian" is often loosely used to include the entire floodplain, even when it may be flooded only on the average of once every two years (Wolman and Leopold, 1957). He suggested that the term should refer only to bank or channel-shelf features and vegetation. Cowardin, *et al.* (1979) avoided the term entirely in their classification of wetlands and defined wetlands as "....lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water." For the purposes of their classification, wetlands must have one or more of the following three attributes: 1) at least periodically, the land supports a vegetation composed predominantly of hydrophytes; 2) the substrate consists predominantly of undrained hydric soil; and/or 3) the substrate is a nonsoil which is saturated with water or covered by shallow water at some time during the growing season of each year.

The riparian ecosystems found throughout Indiana, including the west-central section to be discussed here, consist primarily of bottomland forests and their inhabitants. The original riparian community was probably dominated by tree species such as those found by Lindsey (1962) at Beall Woods (now Beall Woods State Park) near Keensburg, Illinois. He found that a high proportion of trees at Beall Woods exceeded 76 cm (30 inches) in basal diameter. A year earlier, he found that none of the stands which were examined along the Wabash River from Logansport to Vincennes, Indiana, represented the original, presettlement type (Lindsey, *et al.,* 1961), and "....it appeared that every example of such superb timber had been sacrificed..."

Lindsey, *et al.* (1961) found that the chief species on first bottoms or lowest terraces were black willow (*Salix nigra*), silver maple (*Acer saccharinum*), American elm (*Ulmus americana*), and cottonwood (*Populus deltoides*), with important contributions from sycamore (*Platanus occidentalis*), red elm (*Ulmus rubra*), cork elm (*Ulmus thomasi*), boxelder (*Acer negundo*), white ash (*Fraxinus americana*), and hackberry (*Celtis occidentalis*). On the less frequently flooded second terraces, a shift occurred to species which were less water tolerant but more shade tolerant.

Lindsey, *et al.* (1961) also reported that on the cut banks of the Wabash and Tippecanoe Rivers, rapid erosion undermined and toppled trees of any size. However, erosion proceeded slowly where old elms sheathed the steeply sloping banks with a network of exposed, living roots, mostly several centimeters in diameter, which effectively protected both the trees and the banks.

Representatives of these same species still border Indiana's streams and rivers. However, "...the floodplains were rapidly cleared..." after settlers discovered that rich bottomlands would grow the best corn after the trees had been cleared (Petty and Jackson, 1966, p. 275). As a result, little of the original ecotone remains to buffer water courses from agricultural activities. Furthermore, some headwaters have been transformed into straight "ditches" or "drains" whose main function is to facilitate removal of excess water from agricultural fields during rainy periods. They frequently have steep grassy or bare banks with a narrow crown of low woody growth.

MATERIALS AND METHODS

Wabash River. The middle Wabash River has been studied since 1967 (Gammon, 1993, 1994). The first riparian survey was undertaken in 1983, because an accelerated rate of tree cutting had been observed along the river corridor during the previous several years. The middle Wabash River includes approximately 265 km (165 miles) of river between Delphi and Merom, Indiana (Figure 1). For the purposes of this survey, this section of the river was divided into 12 Reaches of unequal length (Table 1).

Surveys of the Wabash River's near-shore riparian wetlands were made during the summers of 1983 and 1994. The 1983 evaluation was made from the river's surface by boat. A boat was also used in 1994 for examining river banks between Delphi and Montezuma, Indiana, while the survey from Montezuma to Merom, Indiana, was made using a light plane.

Three classes of riparian condition were determined: 1) banks which were devoid of trees (although some brushy growth might be present); 2) banks with one or two trees growing between the river's edge and the fields beyond; and 3) banks with more than two trees. Distinguishing between categories (2) and (3) was sometimes difficult and created most of the judgmental problems. Few pastures or grassland communities occur within the Wabash River corridor, where most of the tilled fields abut directly on the riparian border. No attempt was made to determine the width of forested riparian borders because of constraints of time and funding.

Big Raccoon, Big Walnut, and Deer Creeks. These three tributaries are located roughly at the epicenter of the Wabash River basin and drain most of Putnam County as well as small portions of Montgomery, Boone, and Hendricks Counties (Figure 1). Big Raccoon Creek drains directly into the Wabash River near Montezuma, Indiana, while the other two streams form the headwaters of the Eel River, which flows into the White River near Worthington, Indiana. The drainage basins of these watersheds total 1,487 km^2 (574 mi^2) or 1.74% of the total Wabash River basin (85,500 km^2).

Included in the study were: 1) the Big Raccoon Creek mainstem (an Order 3 stream (see below)) and its tributaries upstream from the Mansfield Reservoir; 2) Big Walnut Creek (an Order 4 stream) and its tributaries upstream from Reelsville, Indiana; and 3) Deer Creek (an Order 3 stream) and its tributaries upstream from Putnamville, Indiana.

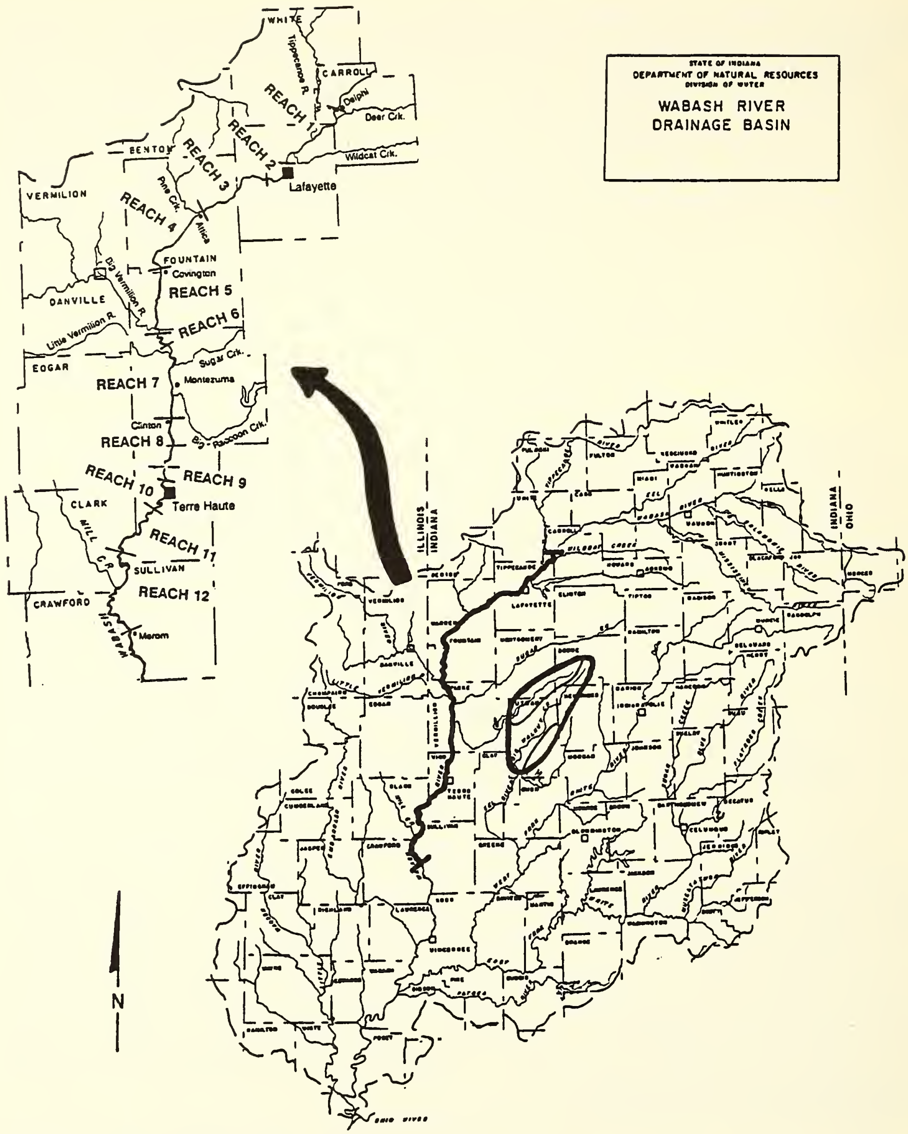

Figure 1. The Wabash River drainage basin showing the location of the riparian studies along the Wabash River and three of its tributaries with an enlargement of the Reaches on the middle Wabash River.

The upper Big Raccoon and Big Walnut Creeks originate in the poorly drained soils of the Tipton Till Plain Section of the Central Till Plain Natural Region (Homoya, *et al.,* 1985). Most of the original vegetation (75%) was removed for agriculture, and drainage problems were addressed by channelizing the beds of the original sluggish streams. The streams grow in size as they flow southwestwardly into the Entrenched Valley Section of the Central Till Plain with

Table 1. The location of the study Reaches for the middle Wabash River. All the Reaches are within Indiana unless otherwise noted.

Reach	River Mile (Rkm)	Description of Location
1	330 to 313 (531-502)	Delphi to Lafayette
2	312 to 302 (501-486)	Lafayette and West Lafayette area
3	301 to 286 (485-460)	Lafayette to Attica
4	285 to 269 (459-433)	Attica to Covington
5	268 to 251 (432-404)	Covington to Coal Creek
6	251 to 246 (404-396)	Cayuga Electric Generating Station
7	247 to 233 (396-375)	Cayuga Electric Generating Station to East Lilly
8	232 to 218 (374-351)	East Lilly to Otter Creek
9	217 to 212 (349-341)	Wabash Electric Generating Station
10	213 to 203 (343-327)	Terre Haute area
11	202 to 186 (325-299)	Terre Haute STP to Darwin, Illinois
12	185 to 160 (298-257)	Darwin, Illinois, to Merom

its steeper topography and larger forests. Deer Creek flows almost entirely within this Section. All of the streams studied lie within the Eastern Corn Belt Plain Ecoregion of Omernik and Gallant (1988), except for the lower part of Big Walnut Creek, which lies within the Interior River Lowlands Ecoregion.

A total of 123 sites were evaluated for the quality of their habitat, including riparian conditions: 43 sites were located on Big Raccoon Creek, 63 on Big Walnut Creek, and 17 on Deer Creek. Most of the sites were located near bridges, and measurements were taken either upstream or downstream depending on the section selected for electrofishing. Each site consisted of a 100-meter long section of stream divided into 10 transects spaced approximately 10 m apart. Stream width was determined with a metric field tape. Water depth (cm) was measured at intervals of approximately 0.7 m along each transect. The predominant substrate type was categorized at each measured depth point as mud (M), sand (S), gravel (G), rock (R), bedrock (B), or clay (C).

The width of the riparian wetland on both streambanks was estimated to a maximum of 50 meters. Bank angle and height of the highwater mark were also determined on both streambanks.

Habitat quality was quantified using a weighted numbering system which included eight instream and nearstream characteristics similar to those developed by Platts, *et al.* (1983). An overall quantitative expression of habitat quality for aquatic life was obtained by adding the scores.

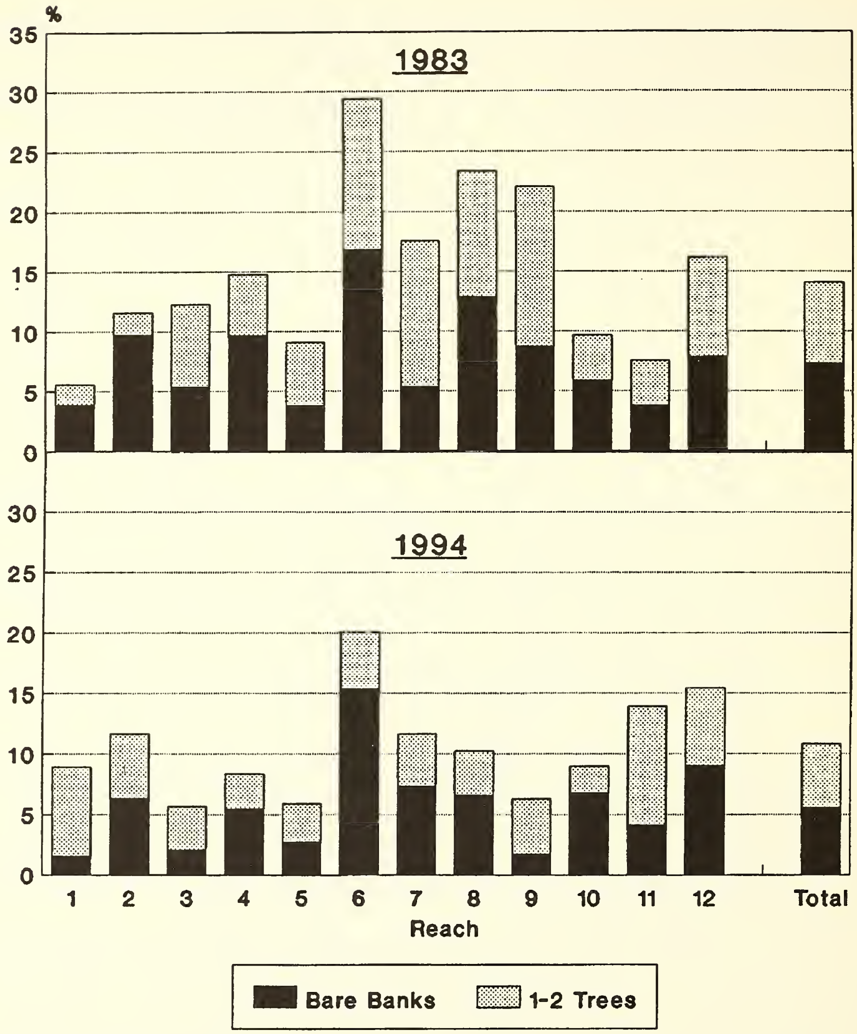

Figure 2. Percent bare banks and banks with only 1-2 trees between the edge of the Wabash River and the associated agricultural fields in 1983 and 1994.

Three of the categories dealt specifically with the character and extent of the riparian wetlands: 1) the completeness of the riparian zone (1-15 points); 2) the percent canopy cover (1-10 points); and 3) the primary vegetation of the riparian zone (1-10 points). Each category was subdivided into four classes with a range of several points in each class.

Other stream characteristics included stream gradient, sinuosity, drainage basin area, and stream order. These characteristics were determined using U.S. Geological Survey maps (scale = 1:24,000). The smallest permanent streams were designated as Order 1. Second order streams begin where two Order 1 streams join and end where another Order 2 stream enters (Strahler, 1957), and so on for higher order streams. Many of the small intermittent streams indicated by dashed

Table 2: The results of the 1994 survey of eroding banks and banks with only 1-2 trees on the Wabash River from Delphi to Merom, Indiana.

Reach	Total Bank Length (km)	Bare Banks (km)	Banks With 1-2 Trees (km)	Bare + Banks With 1-2 Trees (km)	Bare + Banks With 1-2 Trees (%)
1	58	0.89	4.29	5.18	8.93
2	30	1.90	1.59	3.50	11.65
3	50	1.04	1.81	2.84	5.69
4	54	2.96	1.52	4.48	8.30
5	56	1.54	1.78	3.33	5.94
6	16	2.46	0.75	3.20	20.02
7	42	2.94	1.81	4.75	11.30
8	46	3.04	1.66	4.70	10.22
9	18	1.74	0.82	2.56	14.22
10	32	2.17	0.72	2.89	9.04
11	54	2.24	5.28	7.52	12.92
12	81	7.33	5.18	12.51	15.44
	518 km	28.82 km	27.21 km	57.46 km	11.09 %

lines on U.S. Geological Survey maps flowed continuously throughout the summer of 1993 because of frequent rains. These tiny streams were included as Order 0 streams. The area of watershed serving each site was obtained either from U.S. Geological Survey maps using a planimeter or from the values published by Hoggatt (1975). Riparian sites were grouped into two classes based on whether the drainage basin area was greater or less than 52 km^2 (20 mi^2).

RESULTS

Wabash River. In 1994, 28.82 km (5.56%) of bare banks and 27.21 km (5.25%) of banks with only 1-2 trees were found within the 518 km of the middle Wabash River (Table 2). These estimates are lower than those of 1983, when 37.92 km (7.32%) of bare banks and 35.0 km (6.76%) of areas with 1-2 trees were found.

The proportion of bare banks along the Wabash River in 1994 was highest in Reach 6 at the Cayuga Electric Generating Station, where virtually the entire outer bank of the large oxbow is bare (Table 2). More than 9% of the banks in Reach 12, the longest Reach (extending from Darwin, Illinois, to Merom, Indiana), was barren of woody growth (Figure 2). Other sections with relatively high percentages of bare banks included Reaches 2, 6, 7, 8, and 10.

The extent of banks protected minimally with only 1-2 trees in 1994 was greatest (9.77%) in Reach 11 (Terre Haute, Indiana to Darwin, Illinois). Reach 1 (Delphi to Lafayette, Indiana) also contained many short sections with limited bank protection. In most other Reaches, the proportion of banks with only 1-2 trees was less than the proportion of bare banks.

In 1994, many groves of small willows were found growing on banks which were bare or only thinly vegetated in 1983. Most were small patches, but some

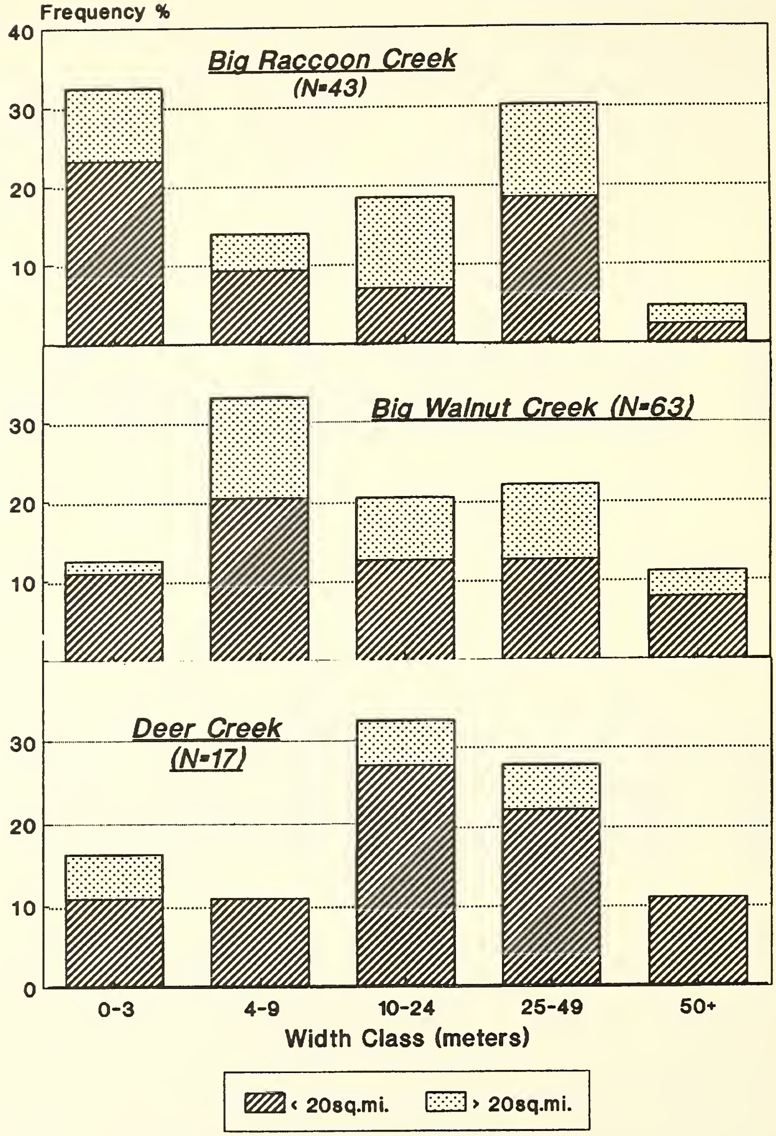

Figure 3. The width (m) of the riparian wetlands in three west-central Indiana stream systems.

fairly extensive groves occurred in the following areas: Clinton, Indiana, at the mouth of Otter Creek; the oxbow river bend south of I-70 at Terre Haute; and upriver from York, Illinois. Some portion of the lower values of bare or minimally protected banks found in 1994 as compared to the 1983 may be attributable to this pioneering invasion of willows. Another portion may be attributed to interpretive differences.

Big Raccoon, Big Walnut, and Deer Creeks. The width of the riparian wetlands flanking these three stream systems reflects the intensity of agricultural

Table 3. The width in meters of riparian wetlands measured at collecting sites in the Big Raccoon Creek, Big Walnut Creek, and Deer Creek watersheds in 1993-94.

Width Class (meters)	Size of Watersheds $< 52\ km^2$	$> 52\ km^2$
Big Raccoon Creek (N = 43)		
0 - 3	10 (23.3%)	4 (9.3%)
4 - 9	4 (9.3%)	2 (4.7%)
10 - 24	3 (7.0%)	5 (11.6%)
25 - 49	8 (18.6%)	5 (11.6%)
50+	1 (2.3%)	1 (2.3%)
Big Walnut Creek (N = 63)		
0 - 3	7 (11.1%)	1 (1.6%)
4 - 9	13 (20.6%)	8 (12.7%)
10 - 24	8 (12.7%)	5 (7.9%)
25 - 49	8 (12.7%)	6 (9.5%)
50+	5 (7.9%)	2 (3.2%)
Deer Creek (N = 18)		
0 - 3	2 (11.1%)	1 (5.6%)
4 - 9	2 (11.1%)	-
10 - 24	5 (27.8%)	1 (5.6%)
25 - 49	4 (22.2%)	1 (5.6%)
50+	2 (11.1%)	-

development in their watersheds. Big Raccoon Creek was the least buffered, and Deer Creek was the most buffered (Table 3, Figure 3). Approximately 33% of the sites on Big Raccoon Creek were flanked by riparian wetlands less than 3 m wide as compared to only 13% for Big Walnut Creek and 17% for Deer Creek. The riparian widths of about one-third of the sites on Big Raccoon and Big Walnut Creeks exceeded 25 m, while nearly 40% of the sites on Deer Creek were similarly protected.

The woody vegetation of the riparian wetlands was dominated by saplings and shrubs in all three creek systems (Table 4, Figure 4). Grasses predominated at 23% of the sites on Big Raccoon Creek and at 41% of the sites on Deer Creek, a reflection of the incidence of pastures bordering these streams. Trees predominated at only 11% of the sites on Deer Creek and 8% of the sites on Big Raccoon Creek and barely exceeded 20% in the Big Walnut drainage.

Shading of the stream surface is especially important in small streams, where cool water temperatures are essential for the survival of such residents as smallmouth bass and darters. For streams with drainage basin areas smaller than 52 km^2, the proportion of shading was much greater over Deer Creek and Big Walnut Creek than over Big Raccoon Creek (Table 5, Figure 5), where the vertical canopy coverage was less than 50% at about 60% of the sites.

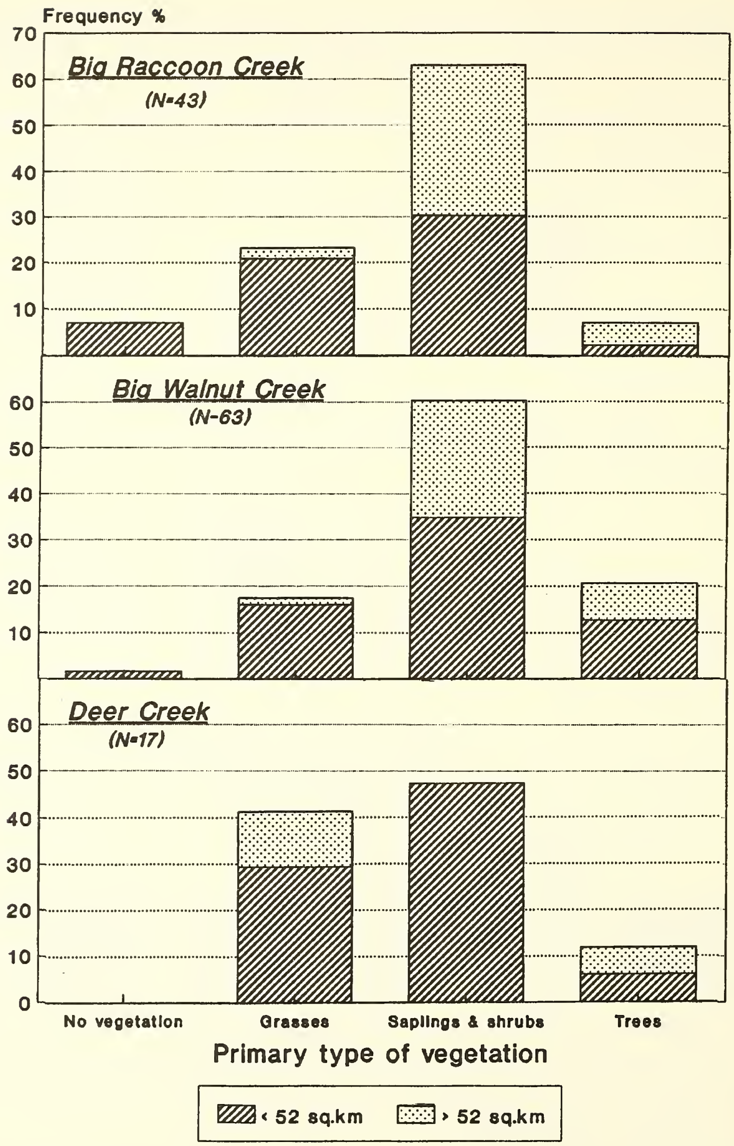

Figure 4. The primary vegetation of riparian wetlands in three west-central Indiana stream systems.

The evaluation of the riparian wetlands' condition was based on the degree of disturbance (e.g., bank erosion, presence of gullies, etc.) or the lack thereof. More than 45% of the sites on Big Walnut Creek were well-protected as compared to about 30% of the sites on Deer Creek and 20% of the sites on Big Raccoon Creek (Table 6, Figure 6). Severe bank erosion occurred at about 10% of the sites located on Deer and Big Walnut Creeks and at 23% of the sites on Big Raccoon Creek.

Table 4. The primary vegetation of riparian wetlands at collecting sites in the Big Raccoon Creek, Big Walnut Creek, and Deer Creek watersheds in 1993-94.

Primary Vegetation	Size of Watersheds $< 52\ km^2$	$> 52\ km^2$
Big Raccoon Creek (N = 43)		
No vegetation	3 (7.0%)	-
Mainly grasses	9 (20.9%)	1 (2.3%)
Saplings and shrubs	13 (30.2%)	14 (32.6%)
Mainly tree	1 (2.3%)	2 (4.7%)
Big Walnut Creek (N = 63)		
No vegetation	1 (1.6%)	-
Mainly grasses	10 (15.9%)	1 (1.6%)
Saplings and shrubs	22 (34.9%)	16 (25.4%)
Mainly trees	8 (12.7%)	5 (7.9%)
Deer Creek (N = 17)		
No vegetation	-	-
Mainly grasses	5 (29.4%)	2 (11.8%)
Saplings and shrubs	8 (47.1%)	-
Mainly trees	1 (5.9%)	1 (5.9%)

DISCUSSION

Forested riparian wetlands in small to mid-size streams can moderate water temperatures, provide important sources of organic matter, reduce sediment and nutrient inputs, stabilize stream banks, and provide physical in-stream habitat for aquatic life.

Natural small streams are cool and thermally stable with low rates of primary production, because light may be reduced to only 1-3% of full sunlight. Their inhabitants are behaviorally and physiologically adapted to reduced light and cool temperatures (Naiman, *et al.,* 1992). Removal of the trees from along normally shaded small streams may lead to dramatic increases in diurnal water temperature to levels which can be intolerable to thermally sensitive macroinvertebrates and fish. The exposure of streams to full or partial sunlight also stimulates the growth of periphyton, which may substantially alter the diurnal pattern of dissolved oxygen concentration through phytosynthesis, especially in nutrient-rich agricultural landscapes.

An additional delayed problem may develop when the dense riparian canopy is completely removed from small streams. Willows and cottonwood may quickly invade the stream edge, constrict the channel, and obstruct the flow of water. The resulting growth may have to be controlled every 2 to 3 years in order to maintain flood flow capacity (McCall and Knox, 1978).

The benthic macroinvertebrates of small- and medium-sized streams are adapted to utilize leaf litter as their primary source of energy, thereby fueling

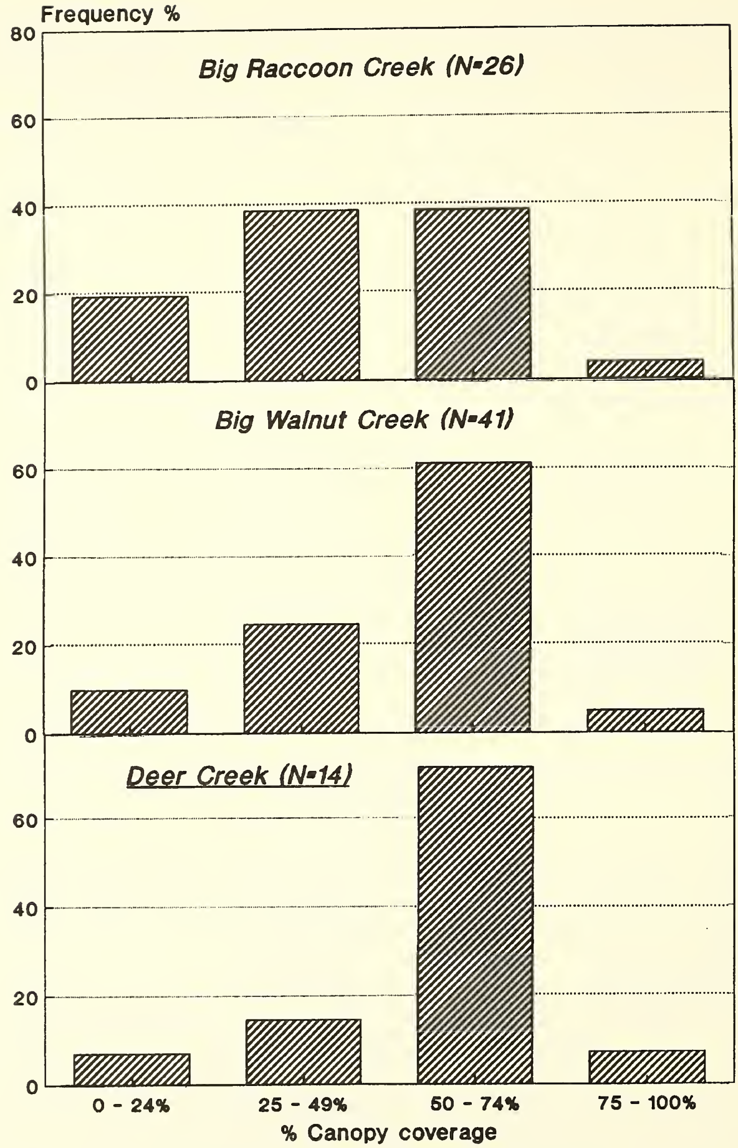

Figure 5. Canopy coverage (%) in three west-central Indiana streams.

the entire ecosystem. The macrobenthos of large river ecosystems consume the overabundant phytoplankton and detritus, which proliferates in many Midwestern rivers, because of the high nutrient inputs from both tributary and mainstem sources.

Riparian wetlands buffer streams from sediment originating from disturbances such as road-building, logging, mining, building construction, and agriculture. This buffering relationship is complex, because of differences in topography, geologic material, soils, and climate, but relatively narrow riparian buffer strips act effectively to remove a substantial portion of the sediment carried

Table 5. Canopy coverage (%) at sites in the Big Raccoon Creek, Big Walnut Creek, and Deer Creek watersheds with drainage basin areas less than 52 km^2 in 1993-94.

Canopy Coverage %	Number	Percent %
Big Raccoon Creek (N= 26)		
0 - 24	5	19.2
25 - 49	10	38.5
50 - 74	10	38.5
75 - 100	1	3.8
Big Walnut Creek (N = 41)		
0 - 24	4	9.8
25 - 49	10	24.4
50 - 74	25	61.0
75 - 100	2	4.9
Deer Creek (N = 14)		
0 - 24	1	7.1
25 - 49	2	14.3
50 - 74	10	71.4
75 - 100	1	7.1

by sheet erosion (Peterson and Correll, 1984; Kovacic, *et al.,* 1990; Osborne and Kovacic, 1993). The use of grassy waterways in field depressions to reduce soil erosion in Cornbelt States is a familiar rural feature.

Riparian wetlands also trap sediments during flood events, which otherwise would be deposited on agricultural fields. When floodwaters exceed bankful capacity, most of the coarse suspended sediment is deposited within the strip of riparian forest close to the stream bank. In sections with no riparian forest, coarse sand piles are deposited on agricultural fields, rendering them unsuitable for the growth of typical crops. Condit and Roseboom (1989) concluded that stream channel erosion into floodplain rowcrop fields constituted the primary flood damage to landowners in the Court Creek watershed in Illinois.

Riparian vegetation plays a role in intercepting sediment and nutrients leached and eroded from agricultural fields before they can enter streams, reservoirs, and rivers. Without an adequate riparian buffer, sediment and nutrients readily move into small tributaries. Upon delivery to open, sunlit rivers and reservoirs, the nutrients stimulate rampant growth of nuisance phytoplankton.

Kovacic, *et al.* (1990) and Osborne and Kovacic (1993) examined the effectiveness of forested and grass-vegetated buffer strips for reducing shallow subsurface inputs of nutrients from agriculture to the East Branch of the Embarras River, an Illinois tributary of the lower Wabash River. The riparian forest was 16 meters (52 feet) wide and dominated by mature (> 40 years) cottonwood (*Populus*

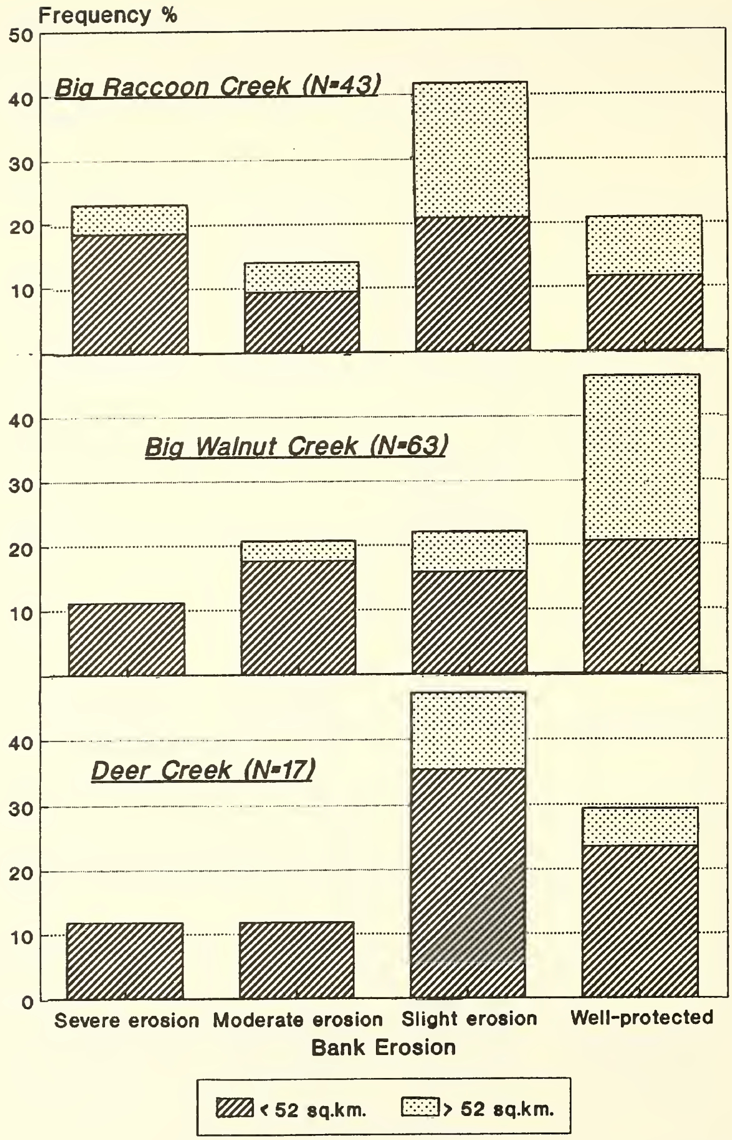

Figure 6. Bank erosion assessment of three west-central Indiana stream systems.

deltoides) and silver maple (*Acer saccharinum*). The riparian grassland was a 39-meter (152-feet) wide strip of reed canary grass (*Phalaris arundinacea*). Groundwater was sampled from various positions and depths from an upland planted in conventional corn and soybeans and from the forested, grass, and rowcrop buffer strips over a 17 month period. Concentrations of dissolved (DP) and total phosphorus (TP) and nitrate-N were determined following major precipitation events. Both the forested and grass buffer strips acted as nutrient sinks for much of the year, but released DP and TP during the dormant season. Forests were more effective than grassland in reducing nitrate-N in groundwater

Table 6. The condition of riparian wetlands at collecting sites in the Big Raccoon Creek, Big Walnut Creek, and Deer Creek watersheds in 1993-94.

Riparian Wetland Condition	Size of Watersheds < 52 km^2	> 52 km^2
Big Raccoon Creek (N = 43)		
Frequent breaks and severe erosion	8 (18.6%)	2 (4.7%)
Moderate erosion	4 (9.3%)	2 (4.7%)
Slight erosion	9 (20.9%)	9 (20.9%)
Well-protected	5 (11.6%)	4 (9.3%)
Big Walnut Creek (N = 63)		
Frequent breaks and severe erosion	7 (11.1%)	-
Moderate erosion	11 (17.5%)	2 (3.2%)
Slight erosion	10 (15.8%)	4 (6.3%)
Well-protected	13 (20.6%)	16 (25.4%)
Deer Creek (N = 17)		
Frequent breaks and severe erosion	2 (11.8%)	-
Moderate erosion	2 (11.8%)	-
Slight erosion	6 (35.3%)	2 (11.8%)
Well-protected	4 (23.5%)	1 (5.9%)

but were less efficient in retaining TP and DP. About 94% nitrate-N was removed from groundwater by 10 m (32 feet) of forest and 97% by 16 m (52 feet). Grass was less efficient; 50% nitrate-N was removed after passing through 14 m (45 ft) of grassland, and 90+% was removed by a strip 39 m (128 feet) wide. Attempts to measure nutrients in groundwater seeping through the stream bed failed, because tiled fields upstream sometimes elevated instream concentrations of nitrate-N to more than 20 mg/L.

Riparian wetlands also function to preserve bank stability. One characteristic of unregulated rivers and streams is a high degree of variability in discharge. During periods of flooding, the roots and trunks of streambank trees absorb the grinding force of floating ice sheets, woody debris, and suspended sand and gravel which would otherwise erode or even relocate the stream channel. Farnworth, *et al.* (1979) have reviewed the impacts of sediment and nutrients on the aquatic biota. In the lower 19 km (12 miles) of Sugar Creek, more than 30 acres of cropland was eliminated over a 23 year period (1955-1978) through accelerated lateral erosion assisted by removal of the riparian wetlands. Furthermore, during a wet summer, the actively eroding banks were responsible for depressing the fish community (Gammon and Riggs, 1983).

Lateral erosion may be impacting the fish communities of Big Raccoon, Deer, and Big Walnut Creeks at the present time, since severe erosion was found at 23%, 12%, and 11% of the sites on these three streams, respectively. Damage to adjacent cropland is probably also high. Hansen (1971) estimated that eroding banks contributed 55% of the increased sediment load in a 26 mile section of Pine River in Michigan and that a 74% reduction could be achieved by stabilizing 40% of those banks. The use of dormant willow posts to stabilize eroding banks (Condit and Roseboom, 1989) is currently being used on an experimental basis in the Big Walnut Creek basin (B. Fisher, pers. comm.).

The elimination of riparian wetlands along the middle Wabash River is clearly a major concern, because approximately 5-7% of its banks are devoid of woody vegetation and another 5-7% provide a minimal buffer consisting of 1-2 trees between the croplands and the river's edge. Furthermore, these minimal wetlands consist mostly of many short segments which could easily be undermined, resulting in a subsequent surge in the rate of lateral erosion. The ecological effects that eroding banks may have on the Wabash River ecosystem are unknown.

As indicated previously, the inadequate riparian buffers of its tributaries, as well as the mainstem, contribute to the current oversupply of nutrients entering the Wabash River mainstem. During the summer, masses of diatoms and other phytoplankton, at times exceeding 100,000 cells/ml with chlorophyll-a approaching 200 µg/L, produce a yellow-brown turbidity in the river. Phytoplankton respiration is responsible for 50-70% of the dissolved oxygen deficit; and 60%-77% of the total carbonaceous BOD was attributable to nonpoint sources (i.e., agricultural (HydroQual, Inc., 1984)). This oxygen deficit together with the excessive turbidity negatively influenced the entire river and caused localized fish kills in the past (Gammon and Reidy, 1981; Parke and Gammon, 1986). Nitrate-N, ammonia-N, and phosphate concentrations are all higher in the upper Wabash River than farther downriver, probably as a result of the extensive tiling of agricultural fields and the channelization of tributaries in this area. Clearly, the ecological health of the Wabash River is strongly dependent upon the ecological health of its tributaries.

The estimated width of the riparian wetlands along the tributaries may not accurately reflect their width along the entire stream corridor. Compared to the streams sampled in this study, the riparian condition of streams in the northern third and southwestern quarter of Indiana may be even more deteriorated, because of the high proportion of land which is organized into drainage enterprises (U.S. Department of Agriculture, 1987).

The disappearance of wetlands and a belated recognition of their importance to the quality of surface waters led to the convening of a National Wetlands Policy Forum, which recommended a policy "to achieve no overall net loss of the nation's remaining wetlands base and to create and restore wetlands, where feasible, to increase the quantity and quality of the nation's wetland resource base" (The Conservation Foundation, 1988). The maintenance of existing wetlands and the reestablishment of wetlands, including riparian wetlands, could help to reduce agricultural nonpoint source pollution of streams and rivers and improve the total aquatic ecosystems, not only in flowing waters, but also in lakes and reservoirs.

The treatment of wastewater generated by population centers, industries, and mines by constructing wetlands has received widespread attention (Cooper and Findlater, 1990). However, agricultural engineering activities along these lines are proceeding at a slow pace in Indiana. In Illinois, Dr. David Kovacic (pers. comm.) is currently creating wetlands, which will receive field drainage from tiles, in order to evaluate their effectiveness. General design principles, landscape locations, and case studies of natural and constructed riverine wetlands for the control of diffuse non-point source pollution by agriculture are presented by Mitsch (1992).

Efforts to restore agriculturally disturbed streams must focus upon those factors which have the greatest influence on biotic communities, factors which can realistically be altered through physical alteration and/or local management (Richards, *et al.,* 1993). Long-term restoration efforts should include activities which reduce surface and lateral erosion, reduce nutrient and pollutant delivery, and enhance the physical structure of stream channels. Severely eroding banks can be stabilized with rip-rap, willow cuttings, lunker, and A-jack installations. Access to streams by cattle and hogs can be limited by fencing. Plowing to the river's edge should be eliminated. In-channel modifications and additions may be desirable in low-gradient headwaters. However, restoration efforts must include reestablishing adequate riparian wetland buffer zones which provide more long-term benefits and may be more cost effective. Riparian borders at least 10 m wide should be established on all Order 3 or larger streams. Research should be undertaken to determine how wide the riparian border should be for smaller Order streams.

One positive agricultural trend is the rapid adoption of no-till methods of farming. In 1990, only 7.5% of corn and soybeans were grown under no-till practices in Putnam County. However, by 1993, 50% of fields were no-till, and, in 1994, approximately 60% were no-till. Fisher (pers. comm.) estimates that reductions in field erosion in Putnam County are about 250 x 10^6 tons of soil annually with attendant decreases in phosphate and nitrate-N runoff to streams. These positive trends are of potential value to stream ecosystems only if streams are well buffered by riparian corridors.

The riparian wetland assessments indicate that Big Raccoon Creek has the thinnest riparian vegetated border (32% sites < 3 m wide), the greatest incidence of severe and moderately eroding banks (40%), and the most open canopy (60% sites < 50% shaded). Big Walnut Creek was somewhat better with more than 50% of its riparian border measuring more than 9 m in width and a majority of its sites having more than 50% shading; however, more than 30% of its banks are exposed to moderate to severe erosion. The riparian wetlands along Deer Creek were in the best condition with more than 70% of its sites having good protection (> 10 m), about 80% of its sites were shaded, and less than 25% of its banks showed moderate to severe erosion.

The riparian wetlands bordering these tributaries currently do not provide the stream ecosystems with sufficient protection from agricultural activities, the predominant determinant of stream water quality. The ecological problems resulting from this inadequate protection extend into the larger rivers and reservoirs of which they are a part. A comprehensive evaluation of flowing waters throughout the State is needed, and programs should be started to seek for and to propose solutions to those problems.

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