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VASCULAR RIFFLE FLORA OF APPALACHIAN STREAMS: THE ECOLOGY AND EFFECTS OF ACID MINE DRAINAGE ON *JUSTICIA AMERICANA* (L.) VAHL[1]

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ABSTRACT

Luxuriant growths of the emergent aquatic plant *Justicia americana* (L.) Vahl have been observed on gravel bars and riffles of larger, unpolluted streams throughout the upper Ohio River drainage basin. This plant, however, is conspicuously absent or severely suppressed in stream reaches influenced by acid mine drainage (pH consistently or intermittently depressed to 5.5 or less). The gravel shoals and riffles of the acid streams are either barren or dominated by other emergent species, especially *Eleocharis acicularis*. The elimination of *J. americana* from suitable habitat has been observed to adversely affect channel morphology, substrate composition, general aesthetic quality and aquatic stream life in the region.

INTRODUCTION

This paper reports some observations on the distribution of *Justicia americana* (L.) Vahl in relation to acid drainage from bituminous coal mining operations in the upper Ohio River drainage basin and discusses possible fluvial and biological consequences of the colonization or absence of *Justicia.*

Justicia americana is a stout-based colonial plant, abundant in most of the larger, low to moderate gradient streams of the upper Ohio River basin (Koryak, 1978; and Strausbaugh and Core, 1952). In those streams where it occurs, this emergent herbaceous aquatic perennial is usually the dominant plant of gravel and cobble riffles and bars (Clovis, undated; and Koryak, 1978). The dense colonial stands are fairly uniform in height, ranging from 0.2 to 1 meter (Fernald, 1950).

The root system of *Justicia* is very extensive with abundant thick cord-like stolons and rhizomes (Fernald, 1950). These subterranean stems form a web that binds the substrate, collects sediment, and tenaciously resists scouring and other mechanical disruption. This root-stem network and entrained materials create a low but durable bench, typically elevated roughly 5 to 25 centimeters above the adjacent channel area.

The range of *Justicia americana* extends from Quebec and Ontario west to Michigan and south to Georgia and Texas (Fassett, 1975). This range overlaps the Appalachian coal fields where sulfuric acid from coal mine drainage degrades numerous streams. The source of the H_2SO_4 is primarily from the oxidation of pyrite and marcasite (both having the composition FeS_2). These pyritic sulfur forms occur in coal, and in rock and clay found above and below coal seams. The sulfides are uncovered in the process of coal mining, and exposed to the oxidizing action of air, water, and sulfur-oxidizing bacteria. The end products are water soluble and the basic reaction is:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$$

Justicia americana has been recognized as an important biological component of Appalachian streams. Hill (1981) investigated *J. americana* distribution and productivity in the Virginia portion of the New River. He determined that the productivity of *J. americana* was 4 to 5 times greater than any other aquatic species in this Ohio River basin Appalachian stream, and that in spite of its limited distribution, contributed to 12 percent of the total aquatic macrophyte organic matter. *J. americana* productivity and standing crop in the New River averaged 23.3g ash free dry weight (AFDW) $m^{-2}d^{-1}$ and 2524g AFDW m^{-2} respectively.

Kondratieff and Voshell (1979) point out that aquatic vegetation can significantly influence invertebrate distribution and abundance. Specifically, they noted that mayfly productivity and diversity in the North Anna and South Anna Rivers of Virginia was high where *Justicia* was abundant. The ephemeropteran *Heterocloeon curiosum* was associated especially with upright stems of *Justicia americana* in the North Anna River.

Ortmann (1919), in his classic monograph of the freshwater pearly mussels or naiades (Mollusca: Unionidae), reported forty mussel taxa for the Ohio River drainage of Pennsylvania. Of these forty mussels, he described a frequent or distinct association with *Justicia americana* for eight.

Six of these mussel taxa are generally considered as small river, riffle organisms: *Lampsilis fasciola* (Rafinesque 1820), *Quadrula cylindrica* (Say 1817), *Quadrula verrucoa* (Rafinesque, 1820), *Ellipsaria fasciolare* (Rafinesque 1820), *Eurynia fabalis* (Lea 1831) and *Eurynia iris* (Lea 1830). According to Ortmann, whose work is still considered the most in-depth study of the naiades (Burch, 1975), the six animals listed above are associated with the lively currents and gravelly substrates of riffles interrupted by *Justicia* patches. They were usually most abundant near the edge of the plant growths.

The two remaining mussels Ortmann associated with *Justicia, Lampsilis ovata ventricosa* (Barnes 1823) and *Strophitus edentulus* (Say 1829), are quiescent water organisms that he found to be abundant within the shelter of the *Justicia* growths.

While he discussed a number of plant-mussel relationships in lakes, in his entire massive monograph, *Justicia americana* is the only plant mentioned in relation to mussel habitat in streams.

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The richest unionacean mussel fauna in the world is found in North America. There are a total of 227 species north of Mexico (Burch 1975). Most of these occur within or are limited to the distribution range of *Justicia,* and a very substantial percentage of these mussel species prefer gravel riffles. Therefore it is not unlikely that there exists mussel-*Justicia* associations in addition to those described by Ortmann.

The availability of food and shelter for aquatic organisms in *Justicia* stands is readily apparent. A less obvious but probably even more important aspect of *Justicia* colonization of riffles occurs outside the stands, in the adjacent gravel riffles of low to moderate gradient streams. Because the dense root and stem benches formed in patches of *Justicia* constrict riffles and provide well defined low flow channels, adjacent riffle areas are generally silt free and of sufficient depth and velocity to support abundant and diverse riffle faunas.

Conversely, where *Justicia* has been eliminated by acid mine drainage, gravel riffles generally lack low-flow channel definition. These riffles show a tendency to be broad, shallow and silted with depressed faunal communities.

This paper presents observations that show that *Justicia americana* is very sensitive to acid mine drainage pollution and the hypothesis that the elimination of *Justicia* from suitable habitat represents a very significant and previously unrecognized secondary adverse effect of mine drainage pollution on Appalachian region streams.

METHODS

Relationships between vascular riffle flora, acid mine drainage and riffle channel morphology and ecology became apparent over more than eight years of routine water quality and riffle zoobenthos monitoring of streams in the Pittsburgh Engineer District. In the 40,000 square kilometer area of the Pittsburgh District (Fig. 1), both chemical data and Surber invertebrate samples were collected at approximately 200 riffle stations. Observations of the riffles, including floral characteristics, were routinely made.

Since acid mine drainage is widespread and of special interest in the basin, a considerable percentage of the sampling stations

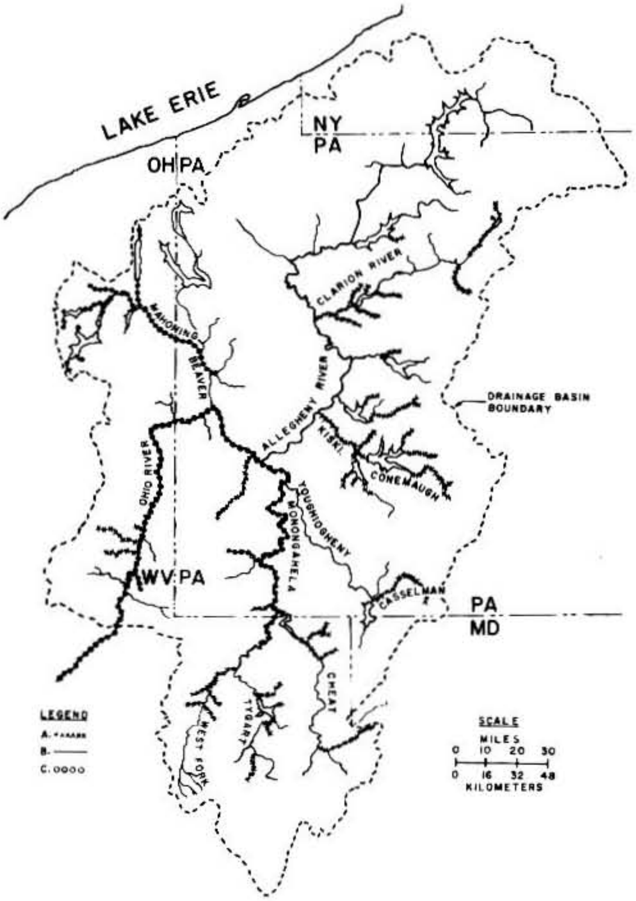

FIGURE 1. Distribution of *Justicia americana* and the extent of significant acid mine drainage pollution in inventoried streams of the upper Ohio River drainage basin. (A) Mine drainage polluted stream reaches where *Justicia* is sparse or absent. (B) pH circumneutral streams where *Justicia* is moderately to highly abundant. (C) pH circumneutral streams where *Justicia* is sparse or absent from apparently suitable habitat.

TABLE 1.

Chemical characteristics and occurrence of Justicia americana in selected major stream reaches of the upper Ohio River drainage basin.

Stream Reach	Sampling Station Location (River Kilometer*)	*Justicia americana* Present	pH # OBS	pH MEAN	pH MAX	pH MIN	ALKALINITY mg/1 as $caCO_3$ # OBS	MEAN	MAX	MIN
Laurel Hill Creek	0.7	yes	8	7.0	7.5	6.3	8	12	15	9
Casselman River	15.2	no	41	6.5	7.7	4.5	41	9	44	0
Upper West Fork River	104.2	yes	48	6.9	7.8	6.1	49	32	54	8
Lower West Fork River	19.3	no	29	6.7	7.3	4.9	34	43	72	5
Tygart River, Upstream of Ford Run	72.8	yes	6	6.7	7.6	6.2	7	13	22	5
Tygart River, Downstream of Ford Run	34.6	no	8	6.3	7.5	5.4	121	11	26	3
Kiskiminetas River	17.9	no	17	5.1	6.4	3.8	17	3	15	0
Upper Cheat River	70.4	yes	187	6.7	7.7	6.0	187	11	63	3
Lower Cheat River	0.5	no	17	5.2	6.5	4.1	5	3	9	0
Conemaugh River	11.6	no	232	4.2	6.6	2.6	231	0.5	21	0
Upper Clarion River	79.7	yes	88	6.7	7.9	5.9	88	14	61	2
Lower Clarion River	26.6	no	77	5.7	7.8	4.0	75	3	12	0
Allegheny River	48.8	yes	8	7.2	7.7	6.7	9	34	44	25

*Distance from mouth of stream.

TABLE 3

Summary of macroinvertebrate data collected at three different habitat types of one Justicia americana constricted riffle in the Tygart River and also at a downstream riffle mildly degraded by mine drainage and barren of Justicia.

	At a Riffle Barren of *Justicia* (Tygart River km 55.5)	Within Different Portions of a Riffle Constricted by *Justicia* (Tygart River km 71.1)		
		At Point of Maximum Constriction of the Low-Flow Channel (29% of Total Width)	*At a Less Constricted Portion of the Low-Flow Channel* (55% of Total Width)	*Within Stolon-Rhizome Network of Justicia Bench*
Average Number of Taxa/Surber Sample	5	19	8	9
Average Number of Organisms/m²	167	5963	431	1458
Average Dry Weight of Organisms mg/m²	43	1376	218	367

ide precipitates reduce cover and cover diversity, while often smothering periphyton, benthic invertebrates and eggs and larvae of gravel spawning fishes (Koryak et al 1972). For the most part these adverse effects can be related directly to the physical and chemical quality of the mine drainage polluted water. However, among the indirect and secondary biological impacts of mine drainage pollution on stream riffles of the Appalachian region, it appears that the losses of cover, food and low-flow channel definition that result when *Justicia americana* is inhibited are also very significant adverse impacts.

An example of the degree and extent of influence *Justicia* channel constriction can have on riffle benthic macroinvertebrates can be seen in Table 3. This table is a summary of Surber sample macroinvertebrate results for two riffles of the Tygart River. The Tygart River drains 3560 km^2 of north central West Virginia. The main channel is 210 km long with an average slope of 2.5 m/km. One riffle sampled is located at km 55.5, in an intermittently and moderately acid degraded reach of the river which *Justicia* has only recently begun to colonize and where it is still sparse. The other riffle is located upstream of any significant mine drainage pollution at km 71.1 and is choked with *Justicia*. At the point of maximum constriction of the km 71.1 site, *Justicia* benches have constricted the low-flow channel to approximately 29% of the total channel width.

In terms of invertebrate dry weight as mg/m^2, the deepest, swiftest and coarsest substrate portion of the km 71.1 *Justicia* constricted riffle (cobble sized rocks colonized by *Podostemum ceratophyllum*) was 60.0% more productive than a considerably less constricted (approximately 55% of total channel width) clean gravel substrate portion of the same riffle complex and 3200% more productive than the moderately acid polluted riffle of the Tygart River 15.6 km downstream. The average invertebrate community in the area of maximum *Justicia* constriction was also more than 200% more diverse than at the broader portion of the *Justicia* riffle and nearly 400% more diverse than the riffle in the nearby mildly acid degraded reach. The invertebrate community with the *Justicia* stem-root network was also examined. While this area was not as productive and diverse as the low-flow channel in the area of maximum constriction, it was comparable to what was found in the less constricted portion of the same riffle complex and considerably more productive and diverse than the invertebrate community that occurred in the acid influenced downstream riffle.

The comparison of Tygart River benthic faunal communities in the area of maximum riffle constriction of the *Justicia* dominated riffle with the less constricted area of the same riffle is most likely a realistic reflection of the influence of *Justicia* constrictions of riffle fauna. The comparison of any *Justicia* constricted riffle with a riffle where the plant has been inhibited by mine drainage, however, would be necessarily complicated by differences in water chemistries between such sites. Generally, the same acid pollution that inhibits the growth of the macrophyte would also be expected to suppress the faunal community of the riffle. This consistent and significant variable makes it difficult to evaluate the effects of *Justicia* on riffle organisms independently of water chemistry. However, when the more easily determined effects of the *Justicia* constrictions on riffle channel morphology and substrate are considered, it is possible to draw some inferences from studies of channelized and silt polluted streams, which also typically are deficient in low-flow channel definitions. The substrates of these sites frequently consist of unconsolidated, abrasive mixtures of shifting sand, silt and small rocks not well suited for invertebrate colonization (Hynes, 1971; Congdon, 1971; Hanson and Muncy, 1971; Cordone and Kelley, 1961; and Tarpelee et al, 1971, cited in U.S. Army 1976). Conversely Brusven et al (1974) demonstrated that channel constriction in silted streams increases sediment transport and improves invertebrate and fish habitat. In terms of fish habitat, the significance of silt free riffles becomes apparent when it is considered that approximately 50 percent of the more than 100 species of fish known to inhabit the upper Ohio River drainage basin utilize clean gravel to reproduce.

In summary, the effects of *Justicia americana* on the riffle ecology of Appalachian streams appear to be very significant and complex and would likely be a fertile area for further research.

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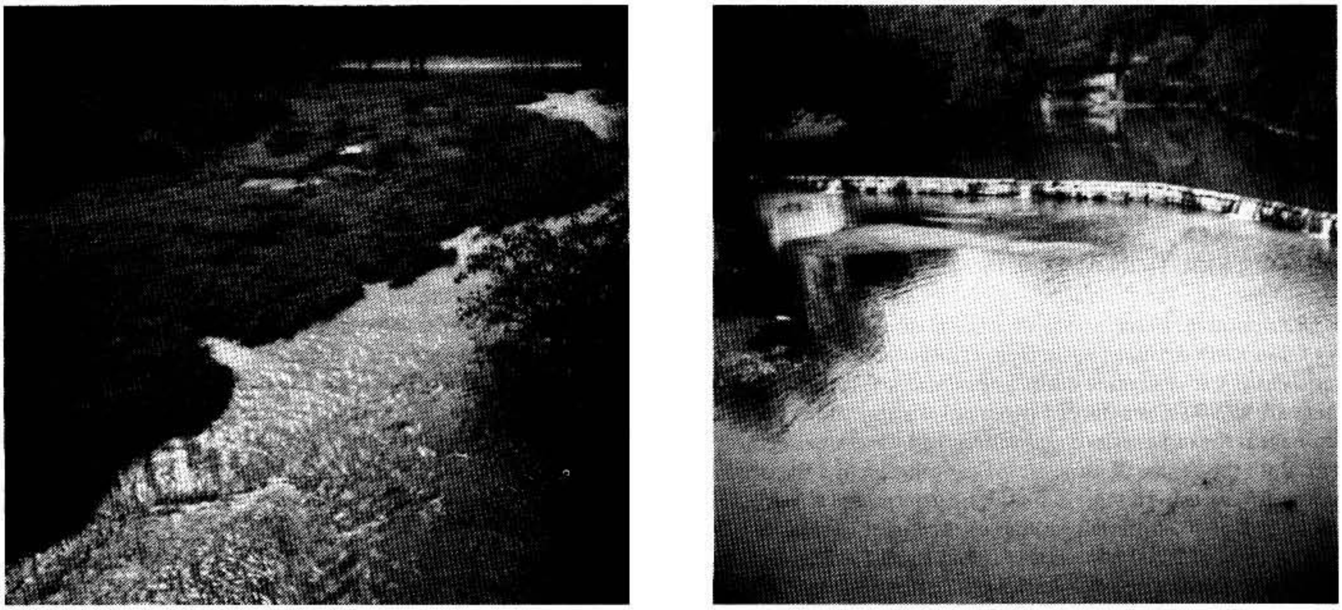

FIGURE 2. Two mill dam tailrace riffles on the West Fork River at low flow. (2a) A *Justicia americana* colonized riffle at stream km 77.4. (2b) A mine drainage polluted and barren riffle at km 15.3.

of plants were observed in the lower, mine drainage degraded portion of this stream. Similarly Clarkson and Moore (1971) found only 3 taxa of aquatic plants at only one location in the lower West Fork River. However, rather than present a general dissertation on the pollution tolerances of aquatic plants, the intention of this discussion is to draw attention especially to the sensitivity of *Justicia americana*. The pH sensitivity of this particular plant is especially noteworthy because of the prominence of *J. americana* in the riffle ecology of Appalachian streams and because of the widespread problem of acid mine drainage in the region.

EFFECTS ON CHANNEL MORPHOLOGY AND SUBSTRATE COMPOSITION OF RIFFLES

The West Fork River of north central West Virginia provides an excellent example of the effects of *Justicia* on channel morphology and substrate composition of stream riffles. The West Fork River is a sand and gravel based stream of moderate gradient (average slope 0.4 m/km). The river drains 2.283 km^2 and its mainstem is 170 km long. The West Fork receives mine drainage along most of its length but 52% (3,360 kg/day acidity as $CaCO^3$) of the river's acid load enters from one tributary at km 36. From km 36 downstream to the km 0, the stream experiences pH limiting water quality (Sack et al, 1976).

On the West Fork River, scattered *Justicia americana* was first observed near km 116. From km 103 to 52 this aquatic plant was exceptionally lush on all gravel bars and riffles. It was still relatively common between km 52 and km 36, where the river receives some acid pollution. In the significantly degraded reach below km 36, gravel bars and riffles were generally barren of *Justicia* or any other aquatic plant except for *Eleocharis acicularis*.

Table 2 is a tabulation of total and low-flow channel widths at riffles along the West Fork River. The measurements were taken during a low-flow period when the stream discharge was 0.0011 $m^3/s/km^2$ or 7% of the average annual discharge. In the *Justicia* colonized riffles between km 103 and km 52, the average width of the low-flow channel was 29% of the total channel width. Downstream of km 36, where the plant was eliminated, the average low-flow channel width of riffles increased to 71% of the total channel width. A comparison of the effects of *Justicia* at two nearly physical identical sites is also available on the West Fork River. Figures 2a and 2b are photographs taken on the same day at riffles below very similar mill dams at West Fork River km 77.4 and km 15.3 respectively. The principal difference between these two sites is that km 77.4 is not influences by mine drainage and has abundant *Justicia* while the site at km 15.3 is mine drainage degraded and has no aquatic plants. At the km 15.3 site, the low-flow channel was constricted to 81% of the total channel width while at the km 77.4 site a constriction of 24% of total channel width was evident. The comparison of physically similar sites and low-flow tabulations suggest that additional riffle constriction attributable to *Justicia* alone can range up to 57% of total channel width at low flows and it is our judgment that this degree of influence on channel width is not unusual.

It is also our judgment that *Justicia* colonized riffles such as shown in Figure 2a. are much more aesthetically pleasing than barren sites as exemplified by Figure 2b.

Low-flow channel constriction of the *Justicia* colonized riffles resulted in greater low-flow water depths and increased flow velocities in the riffles, with subsequently increased localized substrate scouring and sorting. The substrate of the higher velocity *Justicia* constricted riffles of the West Fork River were relatively well-sorted, clean rocks and gravel with heavy periphyton growth. The stream substate of the broad, shallow riffles in the lower section of the river on the other hand was generally unconsolidated with heavy deposition of fine sediment.

RELATIONSHIP TO RIFFLE FAUNA

Acid mine drainage adversely affects aqautic organisms in several different manners. Besides direct toxicities from acid and heavy metals, mine drainage associated siltation and metal hydroxwere selected to be representative of stream reaches upstream and downstream of major acid polluted tributaries.

Water chemistry and Surber macroinvertebrate samples were collected and analyzed according to EPA recommended methods. The chemical parameters analyzed and the sampling frequencies were highly variable for each station but always included pH, alkalinity and acidity measurements.

DISTRIBUTION AND ACID MINE DRAINAGE

Distributional observations of *Justicia americana* in the upper Ohio River drainage basin (Fig. 1) indicate that this plant is very sensitive to acid mine drainage pollution. Within this basin there are 40,000 kilometers of perennial stream, and acid mine drainage is the most serious and widespread water quality problem. Both the degree of mine drainage pollution and the occurrence of *Justicia* in suitable habitat were determined along 2,800 kilometers of 105 different reaches of the larger streams in this area. A total of 2,200 kilometers of 66 different stream reaches were observed to be free of significant acid pollution (pH greater than 5.5) and approximately 600 kilometers of 39 different reaches were found to be frequently or chronically acid degraded. Without exception, *Justicia* was sparse or entirely absent from all 39 of the mine drainage polluted reaches. On the other hand, it was moderately to luxuriantly abundant on riffles and gravel shoals along 1,600 kilometers of 49 stream reaches that were not significantly acid degraded.

A single-factor analysis of variance (ANOVA) was used to examine the observed distribution in relation to the presence of mine drainage pollution. Acid mine drainage was chosen as the independent variable and was evaluated at two levels, present and absent. The presence of *Justicia* was the dependent variable and each stream reach was considered a replicate. Replicates were assigned a value of one if *Justicia* was present, and zero if the plant was absent. The results of the ANOVA show that acid mine drainage degradation is clearly significant (at a 99.9% confidence level) in determining if a given stream can support *Justicia americana*.

Figure 1 is a map showing the approximate extent of inventoried acid polluted and non-acid polluted stream reaches in the basin. Table 1 is a summary of pertinent water quality characteristics for stations representative of reaches of larger streams in the basin that were judged to be suitable *Justicia* habitat. The occurrence of *Justicia* as either moderately to highly abundant or as sparse to totally absent is indicated in both the figure and the table. From the data in Table 1, pH values in the range of 5.5 appear to be the lower limit of pH tolerance for the plant. Except for two reports from the acid degraded Kiskiminetas River, where we have never detected the plant, our observations of the distribution of *Justicia* in the Pennsylvania portion of the Ohio River basin is compatible with the distribution presented by Wherry et al (1979).

The 207 km length of the Monongahela River and a 210 km reach of the upper Ohio River are two large inventoried stream segments with apparently adequate water quality which, as of 1978, had not been colonized by *Justicia*. Both of these rivers are pooled by low head navigation dams. However, in a 116 km long reach of the Allegheny River that is similarly canalized to maintain commercial navigation, *Justicia* was abundant.

Differences in channel forms, substrates, and recent water quality histories may explain the variation in the emergent aquatic plant types of the Allegheny and Monongahela Rivers. In the Allegheny River, *Justicia* was usually abundant where the river channel was braided. It grew on lightly silted gravel shoals and around the numerous islands of the Allegheny River that are of glacial gravel origin. This type of habitat is not abundant on the Monongahela River, which has a generally undiversified ditch-like channel form and no islands (Koryak 1978). Also, the Monongahela River has a recent history of severe mine drainage pollution. This condition persisted into the early 1970's and *Justicia americana* was not among the 12 species of aquatic macrophytes collected by Clarkson and Moore (1971) in the mine acid waters of the upper Monongahela River and major polluted tributaries. Clovis (1971) found only four stems in one clump in the lower acid-polluted reach of one of these tributaries, the Cheat River. He noted, however, that the plant was common in the upper Cheat River, which is only mildly influence by mine drainage. It now appears that the previous water quality pollution of the Monongahela River has been the most significant factor limiting *Justicia* colonization because, since 1978, the plant has been observed in increasing abundance along the upper 50 km of the mainstem of the river.

In spite of apparently suitable stream order, gradient, channel form, substrate and water quality, only a few scattered strands of *Justicia* have been found along the mainstem of the upper Ohio River. Except to note that no species of emergent aquatic vegetation are particularly abundant along the upper Ohio River mainstem, we are unable to explain the disjunct scarcity of *Justicia* in this stream. Another major area of unexplained *Justicia* paucity was along streams on the Mahoning River Basin in a glaciated portion of north eastern Ohio.

It should be noted here that *Justicia americana* is not the only aquatic plant observed to be adversely affected by acid mine drainage. For example, a total of 23 taxa of vascular aquatic macrophytes were found along the acid free reaches of the upper West Fork River of north central West Virginia, but only 4 taxa

TABLE 2

Total and low-flow (7% of mean annual flow) channel widths at riffles along the West Fork River.

Riffle Location (West Fork River km)	Total Channel Width at Riffle (m)	Low-Flow Channel at Riffle	
		Width (m)	% of Total Channel Width
Unpolluted Reach Upstream of km 36.2			
103.4	34	5.8	17
103.3	34	18	53
90.6	35	11	31
88.2	27	5.5	20
77.4	58	14	24
			MEAN 29%
Acid Mine Drainage Polluted Reach Downstream of km 36.2			
35.6	49	23	47
32.5	52	46	88
23.2	52	43	83
22.6	46	35	76
22.5	34	23	68
15.3	37	30	81
7.2	61	34	56
			MEAN 71%

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