ABSTRACT

Luxuriant growths of the emergent aquatic plant Justicia americana (L.) Vahl have been observed on gravel bars and ripples 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 ripples 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 ripples 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 H₂SO₄ is primarily from the oxidation of pyrite and marcasite (both having the composition FeS₂). 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:

\[ 2\text{FeS}_2 + 7\text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 \]

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 23.3 g ash free dry weight (AFDW) m⁻² d⁻¹ and 2524 g 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: Lampsis fasciola (Rafinesque 1820), Quadrula cylindraca (Say 1817), Quadrula verrucosa (Rafinesque, 1820), Ellipisaria fasciculare (Rafinesque 1820), Eury尼亚 fabalis (Lea 1831) and Euryphia 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 ripples interrupted by Justicia patches. They were usually most abundant near the edge of the plant growths.

The two remaining mussels Ortmann associated with Justicia, Lampsis ovata ventricosa (Barnes 1823) and Siphonites 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 Ortman.

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

| Table 1: Chemical characteristics and occurrence of Justicia americana in selected major stream reaches of the upper Ohio River drainage basin. |

<table>
<thead>
<tr>
<th>Stream Reach</th>
<th>Sampling Station Location (River Kilometer*)</th>
<th>Justicia americana Present</th>
<th>pH</th>
<th>ALKALINITY mg/l as caCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laurel Hill Creek</td>
<td>0.7</td>
<td>yes</td>
<td>8</td>
<td>7.0</td>
</tr>
<tr>
<td>Cressman River</td>
<td>15.2</td>
<td>no</td>
<td>41</td>
<td>6.5</td>
</tr>
<tr>
<td>Upper West Fork River</td>
<td>104.2</td>
<td>yes</td>
<td>48</td>
<td>6.9</td>
</tr>
<tr>
<td>Lower West Fork River</td>
<td>19.3</td>
<td>no</td>
<td>29</td>
<td>6.7</td>
</tr>
<tr>
<td>Tygart River, Upstream of Ford Run</td>
<td>72.8</td>
<td>yes</td>
<td>6</td>
<td>6.7</td>
</tr>
<tr>
<td>Tygart River, Downstream of Ford Run</td>
<td>34.6</td>
<td>no</td>
<td>8</td>
<td>6.3</td>
</tr>
<tr>
<td>Kiskiminetas River</td>
<td>17.9</td>
<td>no</td>
<td>17</td>
<td>5.9</td>
</tr>
<tr>
<td>Upper Cheat River</td>
<td>70.4</td>
<td>yes</td>
<td>187</td>
<td>6.7</td>
</tr>
<tr>
<td>Lower Cheat River</td>
<td>0.5</td>
<td>no</td>
<td>17</td>
<td>6.5</td>
</tr>
<tr>
<td>Conemaugh River</td>
<td>11.6</td>
<td>yes</td>
<td>332</td>
<td>6.4</td>
</tr>
<tr>
<td>Upper Clarion River</td>
<td>8.7</td>
<td>yes</td>
<td>88</td>
<td>6.7</td>
</tr>
<tr>
<td>Lower Clarion River</td>
<td>26.6</td>
<td>no</td>
<td>77</td>
<td>5.7</td>
</tr>
<tr>
<td>Allegheny River</td>
<td>48.8</td>
<td>yes</td>
<td>8</td>
<td>7.2</td>
</tr>
</tbody>
</table>

*Distance from mouth of stream.
ide precipitates reduce cover and cover diversity, while often
smothering periphyton, benthic invertebrates and eggs and lar-
vae 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 km² 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/m², the deepest,
swiftest and coarsest substrate portion of the km 71.1 Justicia con­
stricted riffle (cobble sized rocks colonized by Podostemum
eratophyllum) was 60.0% more productive than a considerably
less constricted (approximately 55% of total channel width) clean
gavel 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 con­
strictions of riffle fauna. The comparison of any Justicia con­
stricted riffle with a riffle where the plant has been inhibited
by mine drainage, however, would be necessarily complicated by dif­
erences 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 independ­
ently 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 Muney, 1971; Cordone and Kelley, 1961; and Tarpee
(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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### 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.

<table>
<thead>
<tr>
<th>At a Riffle Barren of Justicia (Tygart River km 55.5)</th>
<th>Within Different Portions of a Riffle Constricted by Justicia (Tygart River km 71.1)</th>
<th>Within Stolon-Rhizome Network of Justicia Bench</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Point of Maximum Constriction of the Low-Flow Channel (29% of Total Width)</td>
<td>At a Less Constricted Portion of the Low-Flow Channel (55% of Total Width)</td>
<td></td>
</tr>
<tr>
<td>Average Number of Taxa/Strata Sample</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Average Number of Organisms/m²</td>
<td>167</td>
<td>5963</td>
</tr>
<tr>
<td>Average Dry Weight of Organisms mg/m²</td>
<td>43</td>
<td>1376</td>
</tr>
</tbody>
</table>
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 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 km² 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 CaCO₃) 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 m³/s/km² 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 physically 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 influenced 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 substrate 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 aquatic organisms in several different manners. Besides direct toxicities from acid and heavy metals, mine drainage associated siltation and metal hydrox-
were 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 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**

<table>
<thead>
<tr>
<th>Riffle Location (West Fork River km)</th>
<th>Total Channel Width at Riffle (m)</th>
<th>Low-Flow Channel Width (m)</th>
<th>% of Total Channel Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpolluted Reach Upstream of km 36.2</td>
<td>103.4 34 11 17</td>
<td>103.3 34 18 53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90.6 35 11 31</td>
<td>88.2 27 5.5 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>77.4 58 14 24</td>
<td>Mean 29%</td>
<td></td>
</tr>
<tr>
<td>Acid Mine Drainage Polluted Reach</td>
<td>35.6 49 23 47</td>
<td>32.5 52 46 88</td>
<td></td>
</tr>
<tr>
<td>Downstream of km 36.2</td>
<td>32.3 52 43 83</td>
<td>22.6 46 35 76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.5 34 23 68</td>
<td>15.3 37 30 81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2 61 34 56</td>
<td>Mean 71%</td>
<td></td>
</tr>
</tbody>
</table>
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