EFFECT OF INDUSTRIAL POLLUTION ON THE AQUATIC AND SHORE ANGIOSPERM FLORA IN THE OTTAWA RIVER, ALLEN AND PUTNAM COUNTIES, OHIO[1, 2]

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ABSTRACT

Industrial wastes are continually being emptied into rivers and streams across the country. This paper considers the effect that these wastes have had on the species composition, distribution, and abundance of individuals of the late summer aquatic and shore angiosperm flora in the industrially polluted Ottawa River downstream from Lima. This flora is compared with the flora in the Ottawa River upstream from Lima and with the flora in the nearby Auglaize River, both of which are not significantly polluted by industrial wastes. The flowering plants in northwestern Ohio rivers mostly belong in two categories: (1) southern species usually restricted to rivers, and (2) widespread species infrequent or common in rivers, but also in other wet habitats. Each species in the former group, being restricted, probably has a narrow ecological tolerance, whereas those in the latter group, being widespread, apparently have a wider ecological amplitude. Water-quality data from several published reports on the pollution of northwestern Ohio rivers reveals the great magnitude of the pollution in the Ottawa River downstream from Lima. A floristic survey of this grossly polluted portion of the river shows that many of the southern, ecologically narrow species, such as *Justicia americana, Lippia lanceolata, Physostegia virginiana, Samolus parviflorus, Saururus cernuus*, and *Rumex verticillatus*, are rare or absent, whereas many of the more tolerant widespread species are frequent or even abundant. Particularly noteworthy in the latter group are several species of *Polygonum* (*P. coccineum, P. hydropiper, P. lapathifolium, P. pensylvanicum, P. punctatum*) and *Sagittaria latifolia*. By comparison, in the portion of the Ottawa River upstream from Lima and in the Auglaize River, both of which lack appreciable industrial pollutants, it is the southern, more restricted river-bottom species that are present; the widespread species (such as the species of *Polygonum*) are also present, but in far less abundance than is true in the Ottawa River downstream from Lima.

Waste waters from industries are continually being emptied into streams, rivers, ponds, and lakes across the country. The effect that these industrial waste waters or industrial pollutants may have on the aquatic and shore angiosperm flora has been little studied. We here consider the effect of industrial pollution on the species composition, distribution, and abundance of individuals of the late summer aquatic and shore angiosperm (flowering plant) flora in the industrially polluted lower portion of the Ottawa River downstream from the city of Lima,

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Ohio, and compare it with both the portion of the Ottawa River upstream from Lima, which lacks any appreciable content of industrial pollutants, and the lower portion of the Auglaize River (in Allen, Putnam, and northern Auglaize Counties), a nearby river which, in its lower course, is not significantly polluted (fig. 1).

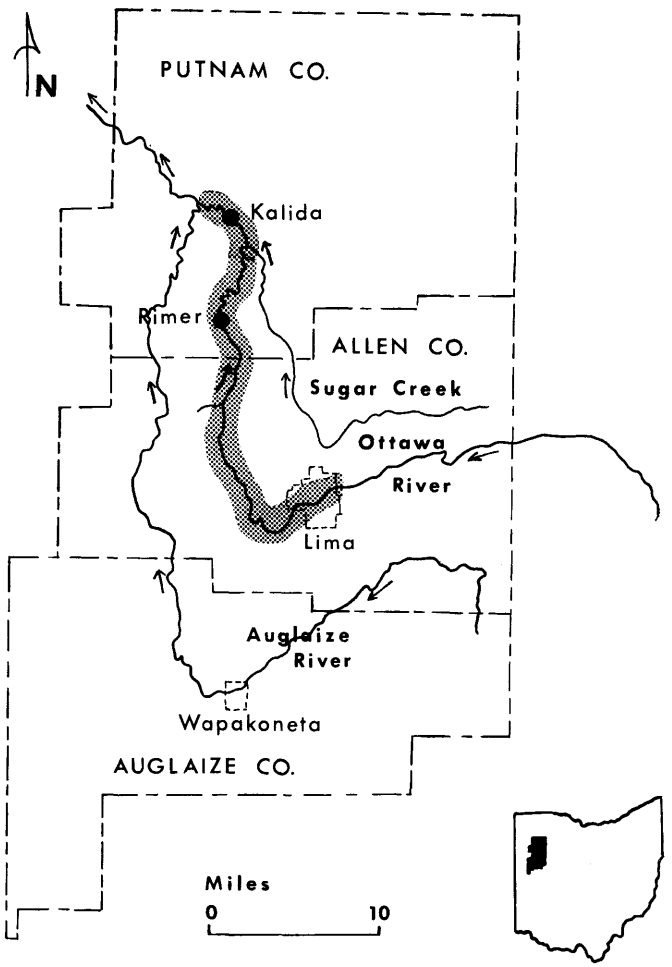

FIGURE 1. Map of the Ottawa and Auglaize Rivers in Putnam, Allen, and Auglaize Counties, northwestern Ohio. Stippled section represents the industrially polluted portion of the Ottawa River downstream from Lima. Arrows indicate the direction of water flow.

The Ottawa River

The Ottawa River originates in the once-extensive Hog Creek Marsh of Washington Township in northwestern Hardin County, about eight miles northwest of the town of Kenton, where the river is more commonly known as Hog Creek (sometimes the entire river is referred to as Hog Creek). It flows westward into Allen County along the south edge of the Fort Wayne End Moraine to Lima, beyond which it bends to the north, crossing the Fort Wayne Moraine, and flows northward across Allen County. It empties into the Auglaize River in Putnam County about 37 miles north of Lima (about 2.5 miles northwest of Kalida).

The Ottawa River drains about 365 square miles of Wisconsin glacial till plain in northwestern Ohio, where the drift varies in thickness from a few feet and the dolomite bedrock is exposed in the river bottom, to over 200 feet. During late summer, the river has a low flow exposing muddy and silty banks. These habitats are suitable for the colonization and growth of aquatic and shore plants. The number of species observable in full development and flower is at a maximum at this season, and therefore presents an ideal time for field study.

Floristic Survey of the Ottawa River

From the results of field studies by the senior author over the past two summers, it has been possible to classify the marsh, shore, and floodplain species of northwestern Ohio with respect to their habitats and phytogeography. The flowering plants in northwestern Ohio rivers mostly belong in two categories: (1) those species, usually restricted to rivers, which have southern affinities and whose ranges are primarily in the Mississippi drainage basin (Mississippi Embayment Species), but which extend northward into the rivers of northwestern Ohio; and (2) those species, infrequent to common in rivers but also occurring in other wet habitats, which are generally widespread in North America. Each species in the former group, being somewhat restricted in range and habitat, probably has a narrow ecological tolerance, whereas those species in the latter group, being more widespread and of variable habitats, apparently have a wider ecological amplitude.

Initial observations by the senior author in September, 1967, along the lower portion of the Ottawa River between Kalida and Rimer (in Putnam County) revealed that its aquatic and shore angiosperm flora was considerably different from that along other major northwestern Ohio rivers (such as the Auglaize, Blanchard, Little Auglaize, Maumee, Portage, Sandusky, and St. Marys). The Putnam County portion of the Ottawa River lacked most of the distinctive southern river-bottom species, such as *Hibiscus militaris*, *Justicia americana*, *Phystostegia virginiana*, *Rumex verticillatus*, and *Saururus cernuus*, which usually grow either in shallow water in the stream or along the low silty muddy banks. Instead of these species, there was an abundance, and dominance, of several species of *Polygonum*, particularly *P. coccineum*, *P. hydropiper*, *P. lapathifolium*, *P. punctatum*, and *P. pensylvanicum*.

With the intent of obtaining a better understanding of this floristic difference, we investigated the bottom and shore angiosperm flora of the Ottawa River, in September 1968, at all points where bridges cross this river in Allen and Putnam Counties. A list of 13 of the major study sites is given in Table 1. Sampling of the Ottawa River throughout the lower portion of its length, from Kalida to Lima, revealed that the flora, as had been observed in 1967 in the portion between Kalida and Rimer, was predominately composed of species of *Polygonum*. In contrast, the upper portion of the Ottawa River, upstream from Lima, contained a flora that was similar to that of many other rivers of northwestern Ohio in having a distinctive southern river-bottom species composition. The species of *Polygonum* were either few in number or absent. The distribution pattern of the most significant species of these two groups are:

Southern species rare or absent from the Ottawa River downstream from Lima, but present upstream from Lima.	Widespread species with increased abundance in the Ottawa River downstream from Lima, but few in number or absent upstream from Lima.
Amaranthus tuberculatus	*Polygonum coccineum*
Helenium autumnale	*Polygonum hydropiper*
Justicia americana	*Polygonum lapathifolium*
Lippia lanceolata	*Polygonum pensylvanicum*
Phystostegia virginiana	*Polygonum punctatum*
Samolus parviflorus	*Sagittaria latifolia*
Saururus cernuus	
Rumex verticillatus	

TABLE 1

Locations and dates of field work at 13 major study sites along the Ottawa River, with a list of 14 of the most significant species studied. Numbers refer to an estimated abundance of the plants at each site, as explained in the footnote below

Location of Study Sites	Date	Species List												
		Southern River Bottom Species								Widespread Species				
		Amaranthus tuberculatus	*Helenium autumnale*	*Liptia lanceolata*	*Justicia americana*	*Physostegia virginiana*	*Samolus parviflorus*	*Saururus cernuus*	*Rumex verticillatus*	*Polygonum coccineum*	*Polygonum lapathifolium*	*Polygonum pensylvanicum*	*Polygonum hydropiper*	*Polygonum punctatum*	*Sagittaria latifolia*
Downstream from Lima														
Putnam County														
County Road P, Between Sections 17 and 20, Union Township, ca. 3 miles south of Kalida.	23 September 1967 18 September 1968	At this site the banks are steep, the water is deep, and aquatic and shore plants are mostly absent.												
County Road 17, NE ¼ Section 31, Sugar Creek Township, ca. 2 miles north of Rimer.	23 September 1967 18 September 1968	1									3	3	2		2
State Route 189, NE ¼ Section 7, Sugar Creek Township, west edge of Rimer.	23, 24 September 1967 9 September 1968	1	1	1						3	3	3	2	2	2
Allen County														
Neff Road, E ½ Section 31, Sugar Creek Township, ca. 2.8 miles north of Elida.	9, 18 September 1968									3	3	3			2
State Road, Between Section 6 and Section 31, Sugar Creek Township, ca. 2 miles north of Elida.	18 September 1968	1									3	3		2	2
Crites Road, Corner Sections 5, 6, 7, 8, Sugar Creek and American Township, ca. 1 mile north of Elida.	9, 18 September 1968	1									3	3	2	2	2
Copus Road, NE ¼ Section 29, American Township, ca. 0.5 miles south of Allentown.	9 September 1968		1								3	3			
Below Erie-Lackawanna R.R. W ½ Section 1, Shawnee Township, Lima.	18 September 1968										3	2	1		2
Upstream from Lima														
Allen County														
Roush Road, SW ¼ Section 29, Bath Township ca. 1 mile east of Lima City Limits.	9 September 1968 20 October 1968	2	1	2	3	2						1	1	1	1
Fetter Road, NE ¼ Section 27, Bath Township, ca. 2.5 miles East of Lima City Limits.	18 September 1968 20 October 1968	2	1	2	3			1				1	1	1	
Thayer Road, Between Sections 23 and 24, Bath Township, ca. 4 miles east of Lima City Limits.	9 September 1968 20 October 1968	2	1	2	3	2	1					1	1	1	1
Cool Road, Between Sections 19 and 24, Bath and Jackson Townships, ca. 2.5 miles NW of Lafayette.	11, 18 September 1968 20 October 1968	2	1	2	3		1					1		1	
Center Road, Corner Sections 15, 16, 21, 22, Jackson Township, ca. 1.5 miles NE of Lafayette.	10, 18 September 1968 20 October 1968	2	2	2		2	1	3	2			1	1	1	

Species abundance at each study site.

1 One or few plants present.

2 Usually many plants scattered and not appearing dominant.

3 Numerous plants, dominant, and often in large clumps or colonies.

Those species known to be present at each major study site are recorded in Table 1. Blank spaces in this table, however, do not necessarily mean that the species was absent, but simply that it may not have been observed. These differences in species composition, and in the distribution and abundance of the plants upstream and downstream from Lima, were significant and prompted explanation.

Observations along the Ottawa River downstream from Lima revealed that the water was generally dark greenish-black in color, that the low shore line was also black in color, and that strong petrochemical and phenolic odors were detected. In contrast upstream from Lima, the water was muddy and brown in color, with much the same appearance as that of the other major rivers in northwestern Ohio (published reports of similar observations are cited below). Our observations suggested that the reason for the differences in both the appearance of the river and the floristic composition downstream from Lima was severe pollution.

Sources of Pollution

The major rivers throughout northwestern Ohio are polluted in many sections and the various degrees by wastes from several sources: (1) agricultural (chemical nutrients and silt from farmlands), (2) domestic or municipal (sewage, organic pollutants), and (3) industrial (mostly chemical compounds) (Fed. Water Poll. Contr. Adm. Rep., 1968). Agricultural wastes are entering northwestern Ohio streams and rivers throughout their entire lengths. These wastes are therefore widespread and more or less uniformly distributed. Any effects produced on the aquatic and shore angiosperm flora by these pollutants would probably, because of their rather uniform influence throughout the length of the river, be difficult to detect at this stage of our knowledge. Therefore the contrast in species composition in the Ottawa River probably cannot be attributed to agricultural wastes.

Domestic and industrial wastes are generally more prevalent and concentrated downstream from small towns or large cities. Because both of these kinds of wastes occur in the same area, it becomes difficult to determine which source of pollution may be affecting the flora. Municipal waste-water treatment facilities at Lima are given a status of "adequate" by the Ohio Department of Health (Rep., 1966). On the other hand, industrial pollution is quite severe downstream from the industrial complex at Lima because of the presence, in toxic concentrations, of chemical compounds such as oils, phenols, ammonia, nitrates, sulfates, cyanides, etc. that are released into the river water (Public Health Serv. Rep., 1965, p. 60–61; Ohio Dept. Health Rep., 1966, p. 18–56; Fed. Water Poll. Contr. Adm. Rep., 1968, p. 42). According to the 1968 Federal Water Pollution Control Administration Report, the Ottawa River downstream from Lima, during low flow periods, "is composed entirely of the effluent" from Lima's sewage plant and the industrial complex, because the "entire flow above these waste discharges is diverted to augment Lima's water supply." Polluted water is readily observable in the Ottawa River in Lima. Grossly polluted waste water is particularly noticeable at the dam (fig. 2) near the Erie-Lackawanna Railroad, where many of the pollution-tolerant species, especially species of *Polygonum*, were observed. Because this site is upstream from the municipal sewage plant, domestic pollution has little influence on the composition of the flora. These observations indicated that it was the industrial wastes that were responsible for changing the water quality, which in turn affected the plants to the extent that floristic differences were readily observed in the Ottawa River upstream and downstream from Lima.

Historical Background

The composition of the flora and the quality of the water of the Ottawa River before the industrial era at Lima are not known, because of the lack of any available

records. However, information on the Ottawa River can be inferred from general knowledge on the original and changing conditions of Ohio Rivers, as summarized in the following discussion from Trautman (1957). Between 1750 and 1800, the rivers were generally narrow and deep in places, having banks covered with brush and trees. The bottoms were largely composed of sand, gravel, boulders, bedrock, and/or organic debris, but essentially free of clayey silts. Submersed aquatic vegetation was probably abundant in quiet, rather clear, unshaded river waters.

Between 1801 and 1850, clearing of forests, draining of marsh land, and digging of drainage ditches for agricultural use began. Organic pollutants from sawmills, breweries, and slaughter houses were dumped into the rivers. These and other events which were to follow set into motion the beginnings of changes in the quality of Ohio river waters.

During the period from 1851 to 1900, a rapid growth of cities and a corresponding growth in industries occurred. As industries increased in number, they

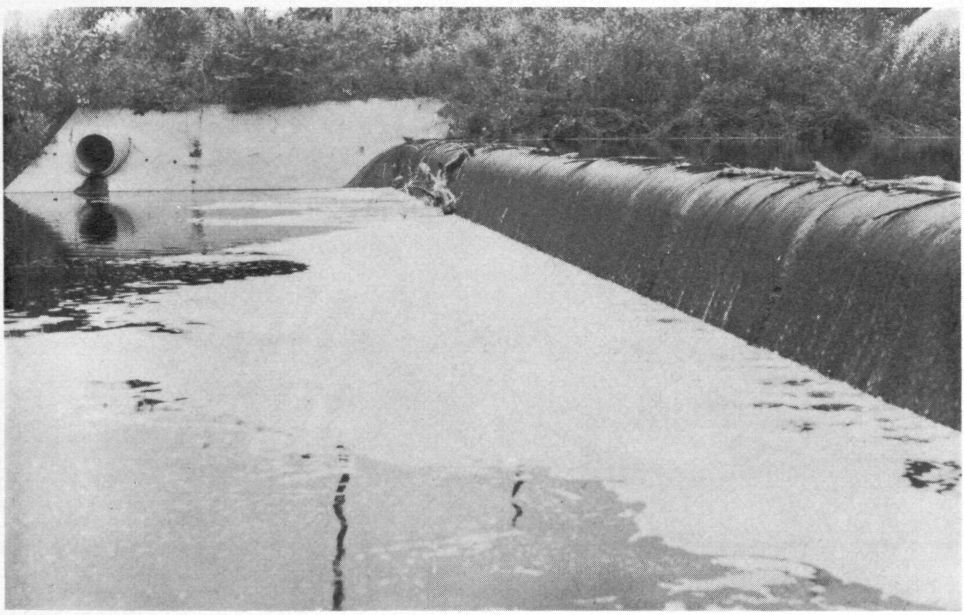

FIGURE 2. Industrially polluted Ottawa River at dam near the Erie-Lackawanna Railroad in the southwestern part of Lima upstream from the Lima municipal sewage plant. Photograph by W. A. Wentz, W ½ Sec. 1, Shawnee Twp., Allen County, 18 September 1968.

dumped ever-increasing amounts of deleterious wastes into the rivers. After 1860, references to turbid waters and the siltation of stream bottoms became increasingly numerous and, by 1890, erosion of agricultural land, the resultant turbidity of the waters, and the siltation of the bottoms became almost universal. As a result of these growing conditions, many sections of Ohio streams and rivers were being badly polluted by industrial, domestic, and agricultural wastes. The disappearance of submersed aquatic vegetation was well under way by 1900.

In the forepart of the twentieth-century, according to Trautman (1957), ditching and draining of the land, dredging of the streams, and tiling of the fields continued at an increasing rate. Many streams and rivers once flowing with water throughout the year developed greater variations in flow, with some periods of great volume and other periods of diminished or intermittent flow. Industrial, domestic, and agricultural pollutants became more prevalent, turbidity and silta-

tion continued to increase at an alarming rate, and submersed aquatic vegetation decreased or even disappeared from extensive portions of many rivers.

The Ottawa River is certainly no exception to the above described general pattern. Baxter (1906, p. 76) wrote that "Hog Creek, before the forests were cleared away and the lands drained by canals, was as pretty a little stream as any to be found." In the early 1840's, at the time of the organization of the city of Lima, Leeson (1885, p. 471) said that "Hog Creek wound its course through this section, in a crystal stream, leaping over ledge and ledge of its rocky bed here [at Lima], creeping by shady groves there, rushing on tumultously to join its waters with the parent river farther north. . . . These were days when men had time to appreciate the beauties of nature. Now the scene is changed. That crystal stream is gone, and in its bed a thousand noxious ponds, in which even the frog refuses to make a home, poison the atmosphere. Progress has accomplished all this for the river of the past." From this historical account, it appears that the Ottawa River was badly polluted as early as 1885. In fact, according to Leeson (1885, p. 476–480), many of the industries in Lima were founded during the period from 1870–1885. One of the most important, from the viewpoint of industrial waste water, was the oil refining industry. The first oil well in Allen County was drilled, in the spring of 1885, on the bank of the Ottawa River. A second well was completed in the fall of 1885. Out of these early discoveries, Lima became the "hub" of the oil industry in northwestern Ohio (Miller, 1906, p. 182). The influence of industrial pollution on the flora and fauna of the Ottawa River downstream from Lima thus appears to have begun about 1885 and to have extended over a period of some 85 years. As a result, today this river is "grossly polluted—the worst in the entire Maumee Basin" (Public Health Serv. Rep., 1965, p. 60).

Present Water Quality

A comparison of the quality of the Ottawa River water from below (downstream from) and above (upstream from) Lima with drinking and public water standards (Table 2) reveals the great magnitude of the pollution in the Ottawa River below Lima (Public Health Serv. Rep., 1965, p. 60–61; Ohio Dept. Health Rep., 1966, p. 18–56; Ohio Water Comm. Rep., 1967, p. 120–121, 218–219; Patrick, 1961, p. 220; Public Health Serv. Rep., 1962). This pollution is primarily caused by several major industries in Lima, which (according to Public Health Serv. Rep., 1965, p. 61; Ohio Dept. Health Rep., 1966, p. 68–72; Ohio Water Comm. Rep., 1967, p. 230–233) are a metal finishing company, a meat packing plant, a wood preserving company, a chemical industrial complex, and an oil refinery, which empty oils, phenols, ammonia, nitrates, sulfides, cyanides, and other chemical pollutants into the Ottawa River (Table 3). As a result the river degenerates rapidly at Lima and never recovers biologically throughout its length, a total of 40 miles. Partial recovery occurs beyond its mouth in the Auglaize River by dilution with the water from the Auglaize River. Farther on downstream in the Auglaize River (in Putnam, Paulding, and Defiance Counties), the ecologically narrow, southern river-bottom species of flowering plants are present. The flora of this portion of the Auglaize River is similar to that in the Ottawa River upstream from Lima.

Downstream from Lima, according to the water quality data given in the reports on pollution and cited in Table 2, the Ottawa River is characterized not only by very low dissolved-oxygen levels, but also by extremely high phenol and ammonia concentrations, coliform and streptococci bacterial counts, and threshold odor numbers. The color of the river water ranges through various shades of green, red-orange, or black, depending upon when and where observations are made along the river. Oil is much in evidence in the water, on the water surface, and along the bank throughout its reach from Lima to its mouth (fig. 3). During the

TABLE 2

Water quality information for the Ottawa and Auglaize Rivers compared to drinking and public water quality standards, as quoted from the references cited in the accompanying footnote

Water Quality Characteristics	Source of River Data	Ottawa River			Auglaize River	Data Source	Drinking and Public Water Standards
		Downstream from Lima	Downstream from Lima	Upstream from Lima	Allen and Putnam Counties		
		Near Lima	Near Mouth				
1. Physical Characteristics							
Water Color.	0	Green, Red-Orange, Black		Brown	Brown		———
Water Appearance.	0	Oily	Oily	Muddy	Muddy		———
Condition of Mud Banks of River.	0	Black	Black	Brown	Brown		———
Odor							
Threshold Odor Median.	2	240.6	64.0	8.4	9.7	2	Not to exceed 24 (at 60° C) as a daily average.
						5	3
Threshold Odor Range.	2	47.1–807.2	12.0–400.0	6.2–13.5	6.7–49.8		———
2. Chemical Characteristics							
Dissolved solids in mg/l under low-flow conditions.	2	Over 750	Over 750	———	0–500	2,5	Not to exceed 500 as a monthly average
	3	434–813	597–686	441–554	391–491		
Hardness as $CaCO_3$ in mg/l under low-flow conditions.	2	251–350	351–450	———	251–350		———
	3	272–486	387–397	385–425	264–343		
	4	———	———	207.0 and 252.5	———		
Chlorides in mg/l.	3	6.8–90	42–79	15–25	28–63		
	4	———	———	10.8 and 16.8	———	5	250
Sulfates in mg/l.	3	93–361	216–261	160–182	98–136	5	250
Iron in mg/l.	3	.01–.26	.02–.10		.02–.10	5	0.3
	4	———	———	0.00 and 0.004	———		
Dissolved Oxygen in mg/l (ppm).	1	Below 1	Below 2	Approximately 5	Below 4		———
Per Cent of Dissolved-Oxygen Tests that gave results less than 4 mg/l.	2	40–100	40–100	10–20	0–10		———
Biochemical Oxygen Demand in mg/l.	1	20–215	10–85	———	———		———
Average Phenol Concentration in μg/l.	2	20.1+	20.1+	3.1–6	0–3		———
Maximum Phenol Concentration in μg/l.	2	101+	101+	0–10	10.1-100 to 0–10	5	1
Average Soluble Phosphate Load in lb./day.	2	1,000–10,000	1,000–10,000	400–1,000	400–1,000 to 1,000–10,000	2	No Limits Established
Ammonia Concentration in mg/l.	1	22–127	12–136	———	———		———
3. Bacteriological Characteristics							
Median Total Coliform Concentration in Organisms per 100 ml.	2	5,000+	5,000+	2,400–5,000	1,000–2,400 to 5,000	2	Not to exceed 5,000 per 100 ml. as a monthly average value.
	1	6,200–2,300,000		———	———		
Median Fecal Coliform Concentration in Organisms per 100 ml.	2	10,000	10,000	0–500	0–500 to 500–1,000		
	1	42,000		———	———		
Median Fecal Strep Concentration in Organisms per 100 ml.	2	5,000+	1,000–5,000	1,000–5,000	1,000–5,000		———
	1	10,000		———	———		

Sources of Data for Water Quality Information in Table 2.

Abbreviation	Reference
0	Authors Observations.
1	Public Health Service. 1965. Report on Pollution of Lake Erie and Its Tributaries, Part 2 Ohio, Indiana, and Michigan Sources. U. S. Dept. Health, Educ., and Welfare, Public Health Service. U. S. Government Printing Office, Washington, D. C. p. 51–101.
2	Ohio Dept. Health. 1966. A Report on Recommended Water Quality Criteria for the Maumee River Basin Including Interstate Waters Ohio-Indiana and Ohio-Michigan. Div. Eng. Ohio Dept. Health, Columbus, Ohio. 81 p.
3	Ohio Water Commission. 1967. The Northwest Ohio Water Development Plan, A Comprehensive Program for all Phases of Water Management. Prepared for Ohio Water Commission, Dept. Nat. Res., [by] Burgess & Niple, Ltd., Consulting Engineers, Columbus, Ohio. 299 p.
4	Patrick, Ruth. 1961. A study of the numbers and kinds of species found in rivers in eastern United States. Proc. Acad. Nat. Sci. Phila. 113: 215–258.
5	Public Health Service. 1962. Drinking Water Standards. U. S. Dept. Health, Educ., and Welfare, Public Health Service Publ. No. 956. U. S. Government Printing Office. 61 p.

FIGURE 3. Industrially polluted Ottawa River about 5 miles downstream from the dam at the Erie-Lackawanna Railroad and the industrial complex in the southwestern part of Lima. The dominant species, as noted by the tall plants on the island and on the far bank, is *Polygonum lapathifolium*. The exposed muddy soil on the island is very black because of oil residues. Photograph by R. L. Stuckey, at the crossing of state route 117, Center Sec. 4, Shawnee Twp., Allen County, 18 September 1968.

TABLE 3

Types of industries that discharge wastes to the Ottawa River or its tributaries at Lima, Ohio, as taken from Public Health Service Report (1965, p. 61), from Ohio Department Health Report (1966, p. 68–72), and from Federal Water Pollution Control Administration Report (1968, p.97). Data from the latter report were obtained during 1964–1966

Type of Industry	Chemical Pollutants
A Metal Finishing Company	Oil (24 lbs/day, 1965 report), Cyanide, Chrome, Cadmium, Nickel.
A Meat Packing Company	Organic Material.
A Wood Preserving Company	Oil (19 lbs/day, 1965 report), Phenol (7.7 lbs/day, 1965 report).
A Chemical Industrial Complex	Phenol (440 lbs/day, 1968 report), Ammonia (1,800+ 400 lbs/day, 1968 report), Cyanide (75 lbs/day, 1968 report), Urea, Nitrates, Nitric Acid, Carbon Dioxide, Aceto-and-Acrylo Nitriles.
An Oil Refinery	Oils, Phenols, Sulfides.

times of low flow in summer, strong petrochemical and phenolic odors are present over the stream.

Upstream from Lima, the Ottawa River is not grossly polluted, because dissolved-oxygen values are higher and bacterial counts and threshold odor numbers are much lower (table 2). The water is muddy and brown in color, having much the same appearance as the other major rivers of northwestern Ohio. Its odor has been described as "earthy-musty" (Ohio Dept. Health Rep., 1966, p. 75). Amounts of chlorides, sulfates, and iron are low and therefore are not part of the pollution problem.

Relation of the Flora to Pollution

A comparison of the species composition and the general abundance and distribution of each species in the Ottawa River upstream and downstream from Lima is given in Table 4. The species are categorized into four groups. The species of groups 1 and 2 demonstrate the most significant floristic differences, whereas those species in groups 3 and 4, discussed later, are of less significance.

TABLE 4

Comparison of species[1] composition and abundance[2] differences of herbaceous angiosperms[3] from the bottom and water's edge of the Ottawa River upstream and downstream from the City of Lima (in Allen and Putnam Counties) and of the Auglaize River downstream from the City of Wapakoneta (in Allen, Putnam, and northern Auglaize Counties)

Group 1. Southern species generally *restricted* to river bottoms in northwestern Ohio, but generally *absent* downstream from the city of Lima. (Species sensitive to pollution.)

Species	Ottawa River		Auglaize River
	Downstream from Lima	Upstream from Lima	
Justicia americana (L.) Vahl. (Water-willow)	Absent	Common	Common
Saururus cernuus L. (Lizard's Tail)	Absent	Common	Infrequent
Physostegia virginiana (L.) Benth. (False Dragonhead)	Absent	Infrequent	Infrequent
Rumex verticillatus L. (Water Dock)	Absent	Infrequent	Infrequent
Samolus parviflorus Raf. (Water-pimernel)	Absent	Infrequent	Infrequent
Carex frankii Kunth (Frank's Sedge)	Absent	Rare	Expected
Lycopus rubellus Moench (Water Horehound)	Absent	Rare	Expected
Lippia lanceolata Michx. (Fog-fruit)	Rare	Common	Frequent
Helenium autumnale L. (Sneezeweed)	Rare	Frequent	Frequent
Eclipta alba (L.) Hassk. (Yerba-de-Tago)	Rare	Rare	Expected
Scirpus americanus Pers. (Three Square Bulrush)	Rare	Rare	Rare
Amaranthus tuberculatus (Moq.) Sauer (Water-hemp)	Infrequent	Common	Common
Hibiscus militaris Cav. (Rose Mallow)	Absent	Absent	Frequent
Strophostyles helvola (L.) Ell. (Wild Bean)	Absent	Rare	Absent

Group 2. Widespread species generally *infrequent* to *common* in river bottoms in northwestern Ohio, but especially *common* downstream from the city of Lima. (Species tolerant of pollution.)

Species	Ottawa River		Auglaize River
	Downstream from Lima	Upstream from Lima	
Polygonum hydropiper L. (Water-pepper)	Common	Infrequent	Infrequent
Polygonum persicaria L. (Lady's-thumb)	Common	Infrequent	Infrequent
Polygonum pensylvanicum L. (Pinkweed)	Common	Infrequent	Frequent
Sagittaria latifolia Willd. (Arrowhead)	Common	Infrequent	Infrequent
Polygonum coccineum Muhl. (Smartweed)	Common	Absent	Infrequent
Polygonum lapathifolium L. (Smartweed)	Common	Absent	Infrequent
Polygonum punctatum Ell. (Water Smartweed)	Frequent	Frequent	Frequent

Group 3. Widespread species generally *common* in river bottoms in northwestern Ohio, but generally *infrequent* to *common* throughout the length of the Ottawa River. (Species tolerant of or indifferent to pollution.)

Species	Ottawa River		Auglaize River
	Downstream from Lima	Upstream from Lima	
Echinochloa pungens (Poir.) Rydb. (Wild Millet)	Common	Common	Common
Leersia oryzoides (L.) Sw. (Rice cut-grass)	Common	Common	Common
Ambrosia trifida L. (Giant Ragweed)	Common	Frequent	Common
Urtica dioica L. (Stinging Nettle)	Common	Frequent	Common
Arctium minus (Hill) Bernh. (Common Burdock)	Frequent	Frequent	Expected
Bidens frondosus L. (Beggar's Ticks)	Frequent	Frequent	Frequent
Lycopus americanus Muhl. (Water Horehound)	Infrequent	Frequent	Expected
Mimulus ringens L. (Monkey Flower)	Infrequent	Frequent	Frequent
Alisma plantago-aquatica Raf. (Water-plantain)	Infrequent	Infrequent	Infrequent
Cyperus esculentus L. (Yellow Nut-grass)	Infrequent	Infrequent	Infrequent
Eleocharis erythropoda Steud. (Creeping Spike-rush)	Infrequent	Infrequent	Infrequent
Impatiens capensis Meerb. (Spotted Touch-me-not)	Infrequent	Infrequent	Infrequent
Lemna minor L. (Lesser Duckweed)	Infrequent	Infrequent	Infrequent
Rorippa islandica (Oeder ex Murray) Borbás var. *fernaldiana* Butt. & Abbe (Yellow Cress)	Infrequent	Infrequent	Expected
Rorippa sylvestris (L.) Bess. (Creeping Yellow Cress)	Infrequent	Infrequent	Infrequent
Rumex altissima Wood (Pale Dock)	Infrequent	Infrequent	Expected

Scirpus validus Vahl. (Soft Stem Bulrush)	Infrequent	Infrequent	Infrequent
Solanum nigrum L. (Black Bittersweet)	Infrequent	Infrequent	Expected
Bidens cernuus L. (Stick-tight)	Infrequent	Expected	Expected
Lindernia dubia (L.) Pennell (False Pimpernel)	Infrequent	Expected	Infrequent
Eragrostis hypnoides (Lam.) BSP. (Love Grass)	Rare	Expected	Expected
Ludwigia palustris (DC.) Fern. & Grisc. (False Loosestrife)	Rare	Expected	Infrequent
Asclepias incarnata L. (Swamp Milkweed)	Absent	Frequent	Frequent
Penthorum sedoides L. (Ditch Stone-crop)	Absent	Frequent	Expected
Lycopus uniflorus Michx. (Water Horehound)	Absent	Infrequent	Expected
Scutellaria lateriflora L. (Mad-dog Skullcap)	Absent	Infrequent	Expected
Cyperus erythrorhizos Muhl. (Umbrella Sedge)	Rare	Rare	Expected
Cyperus ferruginescens Boeckl. (Umbrella Sedge)	Rare	Infrequent	Rare

Group 4. Widespread species generally *common* in roadside and drainage ditches and *infrequent* in river bottoms in northwestern Ohio, but *absent* downstream from the city of Lima. (Species relationship to pollution not known.)

Species	Ottawa River	
	Downstream from Lima	Upstream from Lima
Eleocharis obtusa (Willd.) Schultes (Spike-rush)	Absent	Rare
Eupatorium perfoliatum L. (Boneset)	Absent	Infrequent
Juncus torreyi Coville (Rush)	Absent	Infrequent
Scirpus atrovirens Willd. (Bulrush)	Absent	Infrequent
Sium suave Walt. (Water-parsnip)	Absent	Infrequent
Sparganium eurycarpum Engelm. (Bur-reed)	Absent	Infrequent
Verbena hastata L. (Blue Vervain)	Absent	Infrequent
Verbena urticifolia L. (White Vervain)	Infrequent	Infrequent
Spartina pectinata Link (Cord Grass)	Rare	Expected

[1]Species nomenclature follows Fernald (1950).

[2]Explanation of the terms used to describe species abundance.

Common. Plants in large numbers and in many places along the river; usually seen at every study site.

Frequent. Plants usually few in number and in most places along the river; usually seen at many study sites.

Infrequent. Plants few in number and only occasional along the river; usually seen at two or more study sites, but fewer than four sites.

Rare. Plants few in number and known to occur in only one or two places along the river.

Absent. Plants not seen along the river.

Expected. Plants not seen along the river, but based on the species occurrence in other northwestern Ohio Rivers, they should occur in the river under consideration.

[3]Voucher specimens from various study sites along the Ottawa and Auglaize Rivers are deposited in The Ohio State University Herbarium.

Group 1 contains the southern, ecologically narrow species that are frequent in northwestern Ohio rivers and thus would be expected to be frequent or common in the Ottawa River downstream from Lima. It is this group which contains those species that have apparently been reduced in numbers or eliminated by pollution. In contrast, group 2 contains species of widespread occurrence that are generally infrequent in northwestern Ohio rivers, but which are tolerant of pollution and are extremely common in the industrially polluted waters of the Ottawa River downstream from Lima. This combination of the reduction in or elimination of certain species, generally common elsewhere in northwestern Ohio rivers, and the local increased abundance of other species, generally infrequent elsewhere in northwestern Ohio rivers, presents reasonably good evidence that it is industrial pollution that has produced the contrast in abundance, distribution, and species composition of the aquatic and shore angiosperm flora in the Ottawa River.

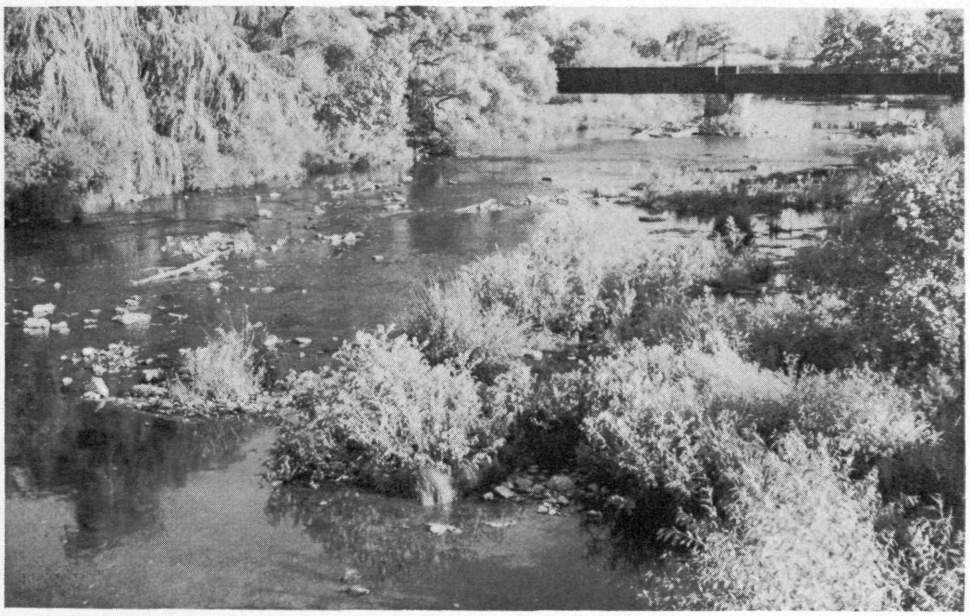

FIGURE 4. Polluted Ottawa River at the west edge of Rimer where the river is wide and shallow over partially exposed dolomite bedrock. The plants most common in clumps in the central foreground are *Polygonum lapathifolium*. Photograph by R. L. Stuckey at the crossing of state route 189, NE ¼ Sec. 17, Sugar Creek Twp., Putnam County, 23 September 1967.

Of the 14 southern species sensitive to pollution (Group 1), nine were not found in the Ottawa River downstream from Lima. Of those that were absent, *Justicia americana* was noted at four different locations along the lower reaches of Sugar Creek, including one site closer than a quarter of a mile to the Ottawa River at Putnam County Road 16–O, Section 16, Union Township. *Physostegia virginiana* was observed near the mouth of Honey Run, a small tributary in Allen County along State Road in Section 31 of Sugar Creek Township. *Helenium autumnale* was seen in both the lower portions of Sugar Creek and Honey Run. These observations reveal that some of the southern species are present in the lower portion of the river valley and are able to grow in the less polluted tributary waters of the Ottawa, but not in the grossly polluted Ottawa River itself downstream from Lima. Of those southern species (*Amaranthus tuberculatus*, *Eclipta alba*,

Helenium autumnale, *Lippia laceolata*, and *Scirpus americanus*) that were found in the lower portion of the Ottawa River, all of them were found in Putnam County at Rimer about 21 miles downstream from Lima. At this locality, dolomite bedrock is present in portions of the river bottom, so that, when the water level is low in late summer, exposing the low shore and bedrock, a favorable habitat is available for these shore species (fig. 4). In addition, recorded dissolved-oxygen values were considerably higher here (median of about 6.2 mg/1 during June-September 1965, compared to values from 0 to 4 mg/1, according to Ohio Dept. Health Rep., 1965, fig. 10) than anywhere else along the Ottawa River downstream from Lima.

The most tolerant of the southern river-bottom species appears to be *Amaranthus tuberculatus*, which was observed at four sites in the Ottawa River downstream from Lima. Species in the genus *Amaranthus* generally have wide ecological tolerances, enabling them to grow in various habitats and disturbed places. Many species of *Amaranthus* are common widespread weeds in our flora. *Amaranthus tuberculatus* has, in various parts of its range in the Mississippi Valley and Great Lakes region, become locally abundant as a weed, especially in man-disturbed habitats along wet ditches and lowland fields where these habitats are adjacent to natural rivers and streams (Sauer 1957, 1962). It therefore is not surprising that *A. tuberculatus* survives the pollution of the lower Ottawa River and occurs locally downstream from Lima. However, the species was not observed at the site in Lima where industrial wastes were being emptied into the river at the dam below the Eric-Lackawanna Railroad.

The widespread species have been placed into three categories in Table 4 (Groups 2, 3, 4). Group 2 consists of those species (dominantly of *Polygonum*) which are common downstream from Lima, but are generally infrequent or rare upstream from Lima. These species appear to be quite tolerant of industrial pollution. With increased siltation in the river over the years and the reduction in and/or elimination of the southern river-bottom flora, these widely tolerant species must have moved into and colonized the habitats that normally would be occupied by the southern species. These tolerant species have become very common throughout the polluted portion of the river.

Group 3 comprises species which are infrequent to common throughout the entire length of the river, and which seem to be very little affected by pollution. Many of these species occur both upstream and downstream from Lima with approximately equal abundance. Two noticeable exceptions are *Ambrosia trifida* and *Urtica dioica*, which are more abundant downstream from Lima than upstream. Both of these species occur away from the water's edge on the floodplain, which below Lima, is much broader than it is above the city. It appears, therefore, that the observed differences in abundance of these two species are related to the availability and extent of the habitat rather than to the pollution.

Group 4 is composed of those species absent downstream from Lima and generally infrequent upstream from Lima. These are species that are normally infrequent throughout northwestern Ohio rivers, so their limited distribution in the Ottawa River is not surprising. Because of their infrequent or occasional occurrence, any relationship to pollution can not be suggested on the basis of the data presently available.

At the southwestern edge of Lima, between the access road to the municipal sewage treatment plant and the Erie-Lackawanna Railroad (western half of Section 1, Shawnee Township), is an outlet for effluent from a large industrial complex. At and directly below this outlet, the river bottom and shore flora in September 1968 consisted mostly of *Alisma plantago-aquatica*, *Ambrosia trifida*, *Cyperus erythrorhizos*, *C. esculentus*, *C. ferruginescens*, *Echinochloa pungens*, *Eleocharis erythropoda*, *Lemna minor*, *Polygonum hydropiper*, *P. lapathifolium*, *P. pensylvanicum*, *P. persicaria*, *Potamogeton foliosus*, *Sagittaria latifolia*, and *Scirpus*

validus. These species, which belong to groups 2 and 3 (Table 4) are evidently highly tolerant of the chemical pollutants that enter the river at this place. Throughout Lima the black water of the Ottawa River is considerably polluted and primarily supports an abundant growth of *Lemna minor* and *Sagittaria latifolia*.

Comparison of the Flora in the Ottawa and Auglaize Rivers

There may be some question that the differences in the floristic composition of the Ottawa River might be attributed to differences in upstream and downstream habitats. Therefore, a nearby portion of the Auglaize River (referred to here as the lower Auglaize) in Allen, Putnam, and northern Auglaize Counties was studied for purposes of floristic comparison with the Ottawa River. Water in the Auglaize River receives domestic and industrial pollution at Wapakoneta, but recovers biologically only a few miles downstream (Public Health Serv. Rep., 1965, p. 60) and, for over 50 miles on downstream, there is little evidence of any pollution, as shown by water-quality data (Table 2). The Auglaize River has a similar gradient

FIGURE 5. Muddy, silty bottom of the Auglaize River about 12 miles downstream from Wapakoneta. The predominate herbaceous species in the river bottom is *Justicia americana* with some *Saururus cernuus*. Similar scenes can be found in the Ottawa River upstream from Lima. Photograph by R. L. Stuckey at the crossing of National Road, NW ¼ Sec. 35, Logan Twp., northern Auglaize County, 17 September 1968.

and flows over drift and bedrock that are similar to those of the Ottawa River. Thus, under normal conditions, the floras of the lower portions of both rivers should also be similar to each other, as should the floras of the upper portions of both rivers. Any major differences that might occur between the two floras should be related to differences in upstream and downstream habitats.

The water quality data, however, differ markedly in the two rivers. Values for water color, dissolved oxygen, threshold odor numbers, phenol concentrations, and bacterial counts for the Auglaize River downstream from Wapakoneta (Table 2) are drastically lower than are those for the Ottawa River downstream from Lima, but are similar to the data for that portion of the Ottawa River upstream from Lima. Floristically the two rivers are also different (Table 4). The lower Auglaize River contains most of the southern river-bottom species (fig. 5), as well as almost

all of the widespread species of Groups 2 and 3 (Table 4), whereas the species of *Polygonum* are generally infrequent. Data for the species in Group 4 for the Auglaize River are incomplete and are not included in Table 4. However, a considerable similarity exists between the floras of the lower portion of the Auglaize River and of that portion of the Ottawa River upstream from Lima (Table 4). With respect to species composition and the abundance and distribution of plants, the floras of both the lower Auglaize and upper Ottawa Rivers are similar to those of other northwestern Ohio rivers where industrial pollution is either weak or absent. Because water-quality data and floristic composition have been shown to be similar for the "non-polluted" lower portion of the Auglaize River and the "non-polluted" upper portion of the Ottawa River, it therefore appears that the floristic composition of the lower portion of the Ottawa River is truly related to the presence of industrial pollutants, rather than to differences in upstream and downstream habitats. Reasons for the variations in abundance or distribution of any one species might be related in part to the presence or absence of certain chemical macro- or micro-nutrients, trace elements, and/or distribution of the bottom silt, mud, or bedrock. To determine critical factors, specific investigations must be carried out for each species.

According to a Public Health Service Report (1965, p. 60), the water in the Auglaize River in and immediately below Wapakoneta is polluted by municipal and industrial wastes. During low-flow periods in 1964, the river was covered with a black septic sludge. Dissolved oxygen was at zero. Pollution-sensitive organisms were absent, and median coliform density was at 140,000 organisms per 100 ml, with a range of from 1,200 to 11,000,000. Although a detailed study of the flora in the Auglaize River in and immediately below Wapakoneta has not been conducted, our brief observations there in September, 1968, revealed a dominance of species of *Polygonum* along its shore. It appears that the flora in the portion of the Auglaize in and just below Wapakoneta is somewhat similar to, but less strongly affected by pollution than, the flora in the polluted Ottawa River downstream from Lima. Follow-up studies are needed for more complete floristic comparison.

SUMMARY

Significant differences in the species composition and distribution and abundance of individuals in the aquatic and shore angiosperm flora of the Ottawa River have been recognized upstream and downstream from Lima. Industrial pollution of the Ottawa River downstream from Lima has been demonstrated in several reports (Public Health Service Rep., 1965; Ohio Dept. Health Rep., 1966; Ohio Water Commission Rep., 1967; Federal Water Pollution Control Administration Rep., 1968). A survey and analysis of the polluted portion of the river shows that many of the southern, ecologically narrow species of plants, such as *Justicia americana, Lippia lanceolata, Phystostegia virginiana, Samolus parviflorus, Saururus cernuus,* and *Rumex verticillatus,* have apparently been reduced in number or eliminated, whereas many of the more tolerant, widespread species continue to survive and locally even show an increase in abundance. Particularly noteworthy are several species of *Polygonum* (*P. coccineum, P. hydropiper, P. lapathifolium, P. pensylvanicum, P. punctatum*) and *Sagittaria latifolia.* By comparison, in that portion of the Ottawa River upstream from Lima and in the Auglaize River, where appreciable industrial pollutants are lacking, both the southern river-bottom species and most of the widespread species are present, although there is a very noticeable decrease in the abundance of the species of *Polygonum.* It appears that this floristic difference has come about by the effects of toxic concentrations of industrial wastes on the plants in the Ottawa River downstream from Lima. A change in species composition and in abundance of individuals is potentially possible at any site where industries empty chemical wastes in toxic

concentrations into waters. From these data we can predict, at least in part, the kind of flowering plant flora that probably would develop along any river in northwestern Ohio, and perhaps elsewhere in midwestern United States, if chemical wastes from industries are emptied in toxic concentrations into a river.

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