Hydrobiologia **219**: 269–279, 1991.
M. Munawar & T. Edsall (eds),
Environmental Assessment and Habitat Evaluation of the Upper Great Lakes Connecting Channels.

The Detroit River: effects of contaminants and human activities on aquatic plants and animals and their habitats[1]

B.A. Manny[1] & D. Kenaga[2]
[1]*U.S. Fish and Wildlife Service, National Fisheries Research Center – Great Lakes, Ann Arbor, MI 48105, USA*; [2]*6191 Pollard, East Lansing, MI 48823, USA*

Key words: water, sediments, oil, heavy metals, PCBs, plankton, clams, fish, and birds

Abstract

Despite extensive urbanization of its watershed, the Detroit River still supports diverse fish and wildlife populations. Conflicting uses of the river for waste disposal, water withdrawals, shipping, recreation, and fishing require innovative management. Chemicals added by man to the Detroit River have adversely affected the health and habitats of the river's plants and animals. In 1985, as part of an Upper Great Lakes Connecting Channels Study sponsored by Environment Canada and the U.S. Environmental Protection Agency, researchers exposed healthy bacteria, plankton, benthic macroinvertebrates, fish, and birds to Detroit River sediments and sediment porewater. Negative impacts included genetic mutations in bacteria; death of macroinvertebrates; accumulation of contaminants in insects, clams, fishes, and ducks; and tumor formation in fish. Field surveys showed areas of the river bottom that were otherwise suitable for habitation by a variety of plants and animals were contaminated with chlorinated hydrocarbons and heavy metals and occupied only by pollution-tolerant worms. Destruction of shoreline wetlands and disposal of sewage and toxic substances in the Detroit River have reduced habitat and conflict with basic biological processes, including the sustained production of fish and wildlife. Current regulations do not adequately control pollution loadings. However, remedial actions are being formulated by the U.S. and Canada to restore degraded benthic habitats and eliminate discharges of toxic contaminants into the Detroit River.

1. Introduction

For many years, the channels connecting the Great Lakes, including the Detroit River, have been used for the disposal of toxic wastes that impaired beneficial uses of these waters and their biological resources (EC & EPA, 1988; Hartig & Thomas, 1988). Since 1974, each of these channels has been recognized as a pollution problem area and more recently as an 'area of concern' by the International Joint Commission because pollution impaired their use as drinking water or prevented the consumption of fish from them (Hartig & Thomas, 1988). Part of each channel falls under the jurisdiction of both Canada and the United States.

In 1985, the U.S. and Canada conducted a study of the Upper Great Lakes Connecting Channels to integrate scientific information and develop recommendations for restoring beneficial

[1]Contribution 738 of the National Fisheries Research Center-Great Lakes, 1451 Green Road, Ann Arbor, MI 48105, U.S.A.

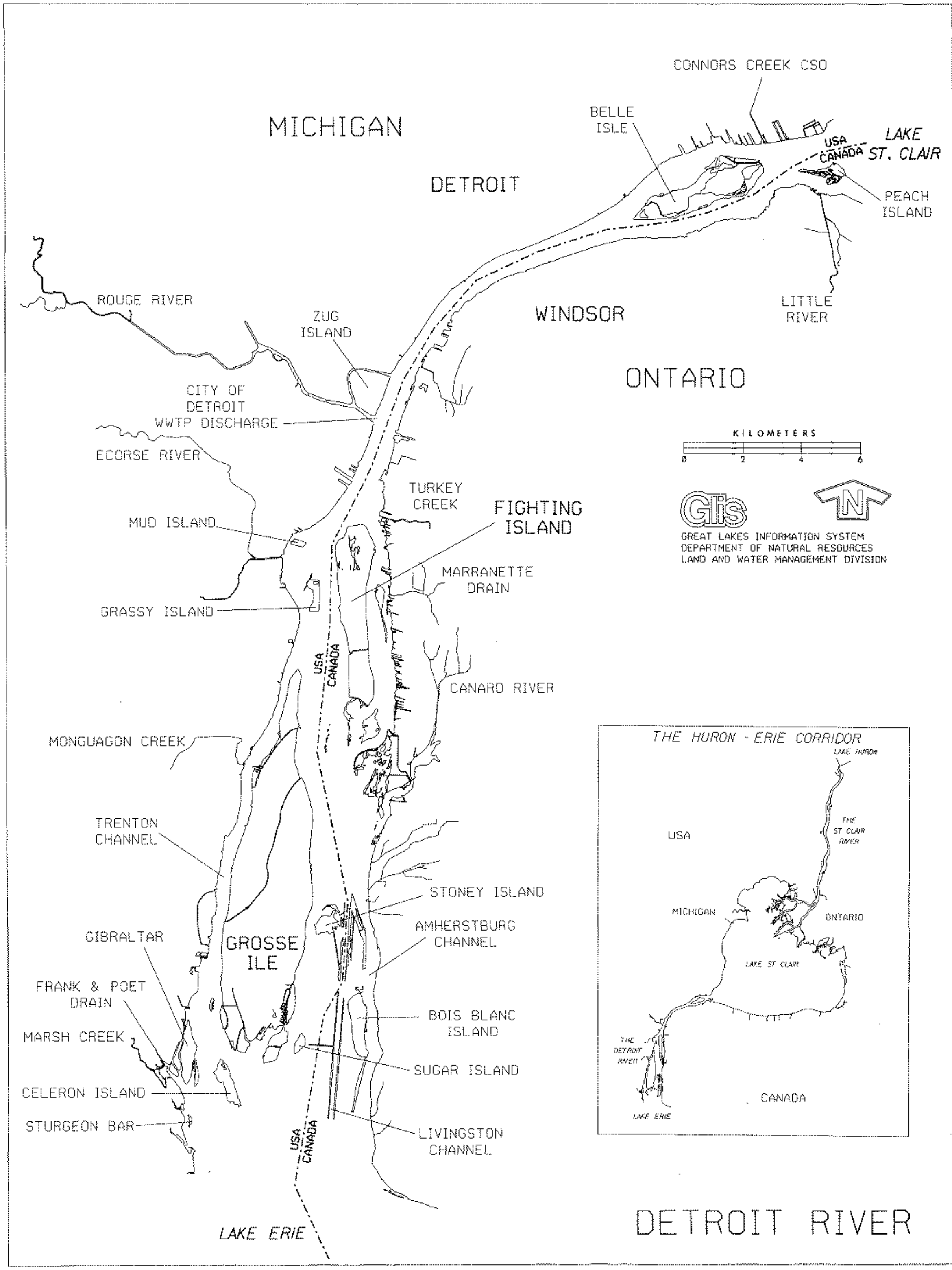

Fig. 1. The Detroit River, showing localities of special interest in this study.

uses in these areas (EC & EPA, 1988). Scientific studies were conducted to identify and measure sources of contaminants and their impacts on beneficial uses, to determine the adequacy of existing control measures, to recommend additional pollution controls, and to recommend surveillance needed to monitor the effects of restoration efforts. The findings of these and earlier studies, which focused on the Detroit River, its biota, and habitats, are summarized in two reports (EC & EPA, 1988; Manny *et al.*, 1988), upon which we drew freely in preparing this publication.

2. Description of the study area

The Detroit River forms the lower third of the strait or channel connecting Lakes Huron and Erie and is bisected by the border between Canada and the United States (Fig. 1). The Detroit River is 51 km long and falls only 0.9 m (Derecki, 1984). The upper 21 km is 700 to 1000 m wide, less than 15 m deep, and contains two islands. The lower 30 km is 1500 to 6000 m wide, less than 9 m deep, and contains 10 islands. The Trenton Channel lies between the U.S. shoreline and the largest island, Grosse Ile. Extensive excavation was required to construct channels for commercial navigation in the river and about $4 million is spent each year to maintain channel depth by dredging (USACE, 1981). Water velocities average 0.3 to 0.9 $m\ s^{-1}$ but exceed 1.7 $m\ s^{-1}$ in main channels. Water passes from the head to the mouth of the river in about 20 h. The mean annual river temperature is about 10 °C; monthly temperatures vary from 0.5 to 22 °C (Muth *et al.*, 1986).

Tributaries and wastewater discharges add much sediment to the river. The principal tributaries are the Rouge and Ecorse Rivers; the Frank & Poet drain, and Marsh and Monguagon Creeks in Michigan and the Little River, Turkey Creek, Marranette drain, and the Canard River in Ontario (Fig. 1). The total combined discharge of these tributaries (about 32 $m^3\ s^{-1}$) is equal to the combined effluent of the eight Detroit-area wastewater treatment plants (EC & EPA, 1988), and is less than 1 percent of the river's average flow of 5240 $m^3\ s^{-1}$. The Detroit River provides habitat for at least 82 species of phytoplankton, 31 species of aquatic macrophytes, 300 species of macrozoobenthos, 65 species of fish, and 27 species of waterfowl (Manny *et al.*, 1988). In colonial times, coastal wetlands bordered most of the Detroit River but now only 31 small, isolated wetlands covering 1380 ha remain in the river (Manny *et al.*, 1988). Since 1955, despite improvements in water quality, the abundance of the most common submersed plant, wild celery (*Vallisneria americana*), has declined by 72 percent in the lower Detroit River, coincident with declining use of the river by diving ducks, such as the canvasback duck (*Aythya vallisneria*); (Schloesser & Manny, 1990). Habitat is provided for coldwater fishes from September to June, but such fishes move out during the period of maximum water temperature from July to September (Manny *et al.*, 1988).

More than 80 political jurisdictions exist within the river's 1844 square km watershed, including the cities of Detroit, Michigan and Windsor, Ontario with a combined population of about 5 million people (EC & EPA, 1988). About 90 percent of the river's Canadian watershed is agricultural or undeveloped (Manny *et al.*, 1988). The river's U.S. watershed is 30 percent agricultural, 30 percent residential, 10 percent industrial, and the remainder is urban. About 46 km of the U.S. shoreline is privately owned and 87 percent of it has been filled and bulkheaded (Muth *et al.*, 1986). Most of the Canadian shoreline is also privately owned but less of it has been filled and bulkheaded (Manny *et al.*, 1988). Historically, ice formed across the river from December to March. Presently, the river seldom freezes over because commercial vessels ply the river throughout the winter and large volumes of heated effluent are added continuously to the river by waste discharges. The river is a major source of drinking water (five water intakes) and a source of process or cooling water for more than 30 industries and power plants. As the busiest waterway for commerce on the Great Lakes, the river transports 60 million metric tonnes of iron ore, coal, limestone, grains, and other cargoes worth over a billion dollars each year (USACE, 1984). Recreational boating, primarily for fishing, is well established on the Detroit River. In 1983–85, anglers spent 1.4 million hours on the river and caught over 1.4 million fish, mostly white bass (*Morone chrysops*), walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens flavescens*) (Haas *et al.*, 1985).

3. Sources of contamination

Each day, eight municipal sewage treatment plants, utilizing pollution control measures costing nearly $500 million, discharge nearly 3 million m^3 of effluent into the river (EC & EPA, 1988). Power plants, steel mills, petroleum refineries, salt mines, and manufacturers of chemicals, automobiles, and plastics, primarily on the U.S. shore, add another 3 million m^3 of effluent per day. Since 1977, wastes from many industries have been diverted to municipal sewage treatment plants. As a result, the Detroit Waste Water Treatment Plant discharge in the Detroit River is now the principle source of 15 troublesome contaminants, including polychlorinated biphenyls (PCBs), hexachlorobenzene, cadmium, nickel, chromium, zinc, phenol, ammonia, phosphorus, oil and grease, and cyanide (EC & EPA, 1988). Sixty-six permitted industrial discharges along the U.S. shore contribute additional oil and grease, ammonia, iron, phosphorus, phenols, cyanide, copper, chromium, cadmium, cobalt, zinc, nickel, polyaromatic hydrocarbons, PCBs, and hexachlorobenzene (Table 1). The 214 combined sewer overflows on the U.S. shore are the primary source of lead and mercury (Table 1); 26 combined sewer overflows from the City of Windsor discharge smaller amounts of contaminants

Table 1. Estimated mean annual loadings of contaminants to the Detroit River from various sources, 1979–1986 (from EC & EPA, 1988).

Contaminant	Total measured annual loading (thousands) of kilograms)	Percentage of loading from each source					
		Point sources		Tributaries		Combined sewer overflows	
		Michigan	Ontario	Michigan	Ontario	Detroit	Windsor
Chloride	623,207	21.6	63.9	12.3	1.2	0.2	0.8
Suspended solids	57,608	33.7		50.0	1.9	14.4	
Oil and grease	15,720	77.8	0.4			21.0	0.8
Ammonia	11,693	77.6	5.3	6.2	5.4	5.3	0.2
Iron	1,561	75.7	7.8	2.7	0.1	5.1	8.6
Phosphorus	916	49.4	9.1	16.6	11.3	12.7	1.0
Zinc	316	54.4	19.5	17.0	0.6	6.2	2.3
Nickel	74	49.6	8.4	10.0	24.3	6.6	1.0
Phenol	55	64.0	34.6			1.2	0.2
Lead	49	16.3	22.0	19.4	1.7	31.7	8.8
Cyanide	44	97.9	1.9				0.2
Copper	38	27.4	24.5	24.9	0.5	19.9	2.9
Chromium	16	71.3				28.7	
Cadmium	6	52.6	5.9	13.0	0.1	25.3	3.1
PAHs*	2	82.9	13.3				3.8
Mercury	2	2.4	0.1	1.1	0.1	96.2	0.1
PCBs*	0.20	37.8	5.6	22.1	0.1	33.9	0.6
Cobalt	0.02	99.0	0.5				0.5
Hexachlorobenzene	0.001	96.7				3.3	

* PAHs = polyaromatic hydrocarbons, and PCBs = polychlorinated biphenyls.

(Marsalek & Ng, 1987). Combined sewer overflows are also estimated to add 14 percent of the phosphorus and suspended solids, 22 percent of the oil and grease, 28 percent of cadmium, 29 percent of the chromium, 23 percent of the copper, and 35 percent of the PCBs entering the Detroit River (Table 1). These estimates are conservative because inputs from combined sewer overflows occur during rainfall events and are therefore difficult to sample adequately (Pollman & Danek, 1988). Moreover, sediments in discharges from some combined sewer overflows contain high concentrations of suspended particles, PCBs, and other contaminants that accumulate in the river (Kenaga, 1986; Kenaga & Crum, 1987; Marsalek & Ng, 1987).

Accidental spills of hazardous substances can result in shock loadings that are equal to or greater than annual loadings from regulated discharges and are a major source of some contaminants elsewhere in the upper connecting channels (Edsall *et al.*, 1988). From 1973 to 1979, there were 581 spills of petroleum products totaling over 700 m^3 and 45 spills of other hazardous substances totaling over 334 m^3 into U.S. waters of the Detroit River, primarily from land-based facilities (Manny *et al.*, 1988). The amounts of contaminants spilled into Ontario waters of the river were probably smaller, but records are not available. Additional toxic substances probably enter the river from the 110 sites of ground water contamination located within 3 km of the river and on islands in the river (EC & EPA, 1988).

Trace metals and organic contaminants adsorbed to fine-grained particles that enter the river settle in depositional zones adjacent to islands and shorelines (Fallon & Horvath, 1985). Zinc, nickel, chromium, cobalt, copper, and lead accumulate in the fine clay fraction (< 13 μm dia.) and in a large-sized silt fraction of 48 to 63 μm (Mudroch, 1985). Sediments in many areas of the lower Detroit River are heavily contaminated with hazardous and toxic substances, including PCBs and heavy metals (Hamdy & Post, 1985; EC & EPA, 1988; Nichols *et al.*, 1990). Such substances are loosely bound to sediments by adsorption and cation-exchange processes and may be easily released if sediments are disturbed (DePinto *et al.*, 1987). To prevent the escape of contaminants and contamination of the food chain, polluted sediments dredged from the Detroit River are confined in sealed enclosures (IJC, 1982).

4. Levels of contamination in river sediments

The large volume of clean water that enters the Detroit River from Lake St. Clair maintains river water quality in an acceptable range for aquatic life (Manny *et al.*, 1988). However, river sediments are seriously contaminated with a variety of toxic organic substances and heavy metals (Table 2). Many of these contaminants, which are only slightly soluble in water, are present in the sediments in concentrations that are greatly in excess of the Canadian guideline for open water disposal of dredged sediments. In 1981, levels of PCBs were ten times higher in sediments along the U.S. shore than along the Canadian shore (Thornley & Hamdy 1984; Kauss & Hamdy, 1985). In 1986, the highest PCB concentration yet found in Detroit River sediments (40 mg kg^{-1}) was found along the Michigan shore about 5 km

Table 2. Contaminant levels (mg kg^{-1} dry wt) in Detroit River sediments and Ontario pollution guideline for each (compiled from IJC, 1982; Limno-Tech Inc., 1985; Lum & Gammon, 1985; Bertram *et al.*, 1991).

Contaminant	Level (range)	Guideline
Volatile solids	11 000–379 000	60 000
Oil and grease	100–29 000	1 500
Polychlorinated biphenyls	0.02–3.8	0.05
Cyanide	0.5–0.8	0.1
Mercury	0.04–56	0.3
Lead	4.8–960	50
Zinc	21–5 300	100
Iron	15 800–3 710 000	10 000
Chromium	4–330	25
Copper	0.5–380	25
Cadmium	0.3–17	1
Nickel	5–293	25
Hexachlorobenzene	0.0031–0.36	none
Octachlorostyrene	0.001–0.01	none

downstream from Belle Isle (Kenaga, 1986; Kenaga & Crum, 1987). Mercury levels in sediment declined in the Detroit River between 1968 and 1980 but cadmium, chromium, copper, lead, nickel, and zinc concentrations in sediments increased significantly during that period, especially around the mouth of the Rouge River and in the Trenton Channel (Thornley & Hamdy 1984; Nichols *et al.*, 1991).

5. Effects of contaminants on Biota

5.1. General

The demonstrated effects of contaminants on Great Lakes biota include mutagenicity, carcinogenicity, phototoxicity, body deformities, and reproductive dysfunction (Henry *et al.*, 1989). The effects of measurable sublethal contaminant concentrations on individual organisms or their population, such as formation of external tumors on fish, are largely unknown. Mortality of burrowing mayflies, (*Hexagenia limbata*), reduces the productivity of their populations in contaminated areas of the connecting channels (Edsall *et al.*, 1991). Reproductive failure in populations of herring gulls (*Larus argentatus*), bald eagles (*Haliaeetus leucocephalus*), and double-crested cormorants (*Phalacrocorax auritus*) reduced the entire affected population (Gilbertson, 1988). Finally, there are human health concerns caused by bioaccumulation of contaminants in aquatic animals (Humphrey, 1983, 1988). The following biological effects have been demonstrated at various levels of the Detroit River food chain.

5.2. Bacteria

A bacterial luminescence assay using sediment pore water from 136 locations in the lower Detroit River showed that sediments were acutely toxic to *Photobacterium phosphoreum* at 25 locations, mostly in an area along the western shore of the Trenton Channel; sediments in this area also supported no benthic macroinvertebrates (Giesy *et al.*, 1988). Extracts of sediments from this area also contained toxic, synthetic, organic substances that caused mutations in *Salmonella microsomes* (Maccubbin, 1987; DePinto *et al.*, 1987; Furlong *et al.*, 1988).

5.3. Phytoplankton

Bioassessment of sediment toxicity to phytoplankton was determined by carbon-14 algal fractionation bioassays that were conducted with various dilutions of standard and chelator-treated elutriates (Munawar *et al.*, 1985). Toxicity, measured as a decrease in carbon assimilation by small ($<20\ \mu m$) phytoplankton, was directly related to the concentration of water soluble metals, such as zinc, manganese, cadmium, and lead. The results confirmed that sediment toxicity should not be evaluated as it presently is on the basis of sediment chemical measurements (IJC, 1982).

5.4. Zooplankton

Feeding and reproduction of zooplankton (*Daphnia pulicaria* and *Ceriodaphnia* sp.) were reduced 50–100 percent in 7-d bioassays in sediment elutriates (White *et al.*, 1987). Likewise, sediment porewater collected at 10 of 30 stations in the Trenton Channel was acutely toxic to *Daphnia magna* in 4-d bioassays (Giesy *et al.*, 1987).

5.5. Benthic macroinvertebrates

Contaminated sediments negatively affect benthic macroinvertebrates in the river. Because the quality and productivity of benthic habitats throughout large areas of the river are impaired (Thornley, 1985; EC & EPA, 1988), the river was designated an Area of Concern for remedial action (Hartig & Thomas, 1988). Sediment avoidance was measured in 2-d tests with the aquatic worm, *Stylodrilus* sp. (White *et al.*, 1987). In uncontaminated sediments, all worms burrowed, all remained buried, and none died; in sediments collected near Monguagon Creek in the Trenton Channel, only 10 percent of the worms remained buried and 53 percent died. Growth of larval midges (*Chironomus tentans*) in contaminated sediments from the Trenton Channel (0.02 to 0.08 mg d^{-1}) was slower than in uncontaminated sediments collected elsewhere in the river (0.48 to 0.53 mg d^{-1}) (Giesy *et al.*, 1987).

The production of burrowing mayflies (*Hexagenia limbata*) in April to October 1986 was significantly lower in the Detroit River (708 to 1 035 mg dry wt m^{-2}), where sediment concentrations of oil and metals exceeded established guidelines for disposal of polluted sediments, than in other areas of the upper connecting channels (980 to 3 481 mg dry wt m^{-2}), where sediment concentrations did not exceed the guidelines (Edsall *et al.*, 1990).

Unionid bivalves are used to monitor environmental contaminant concentrations because they accumulate many contaminants present in the environment (Nalepa & Landrum, 1988). Native Detroit River clams (*Lampsilis radiata siliquoidea*) contained concentrations of lead, cadmium, PCBs, and octachlorostyrene that were up to 59 times higher than concentrations of these contaminants in surficial sediments (0 to 10 cm) from which the clams were collected (Great Lakes Institute, 1984; Pugsley *et al.*, 1985). Perhaps coincidentally, the distribution and abundance of this clam, particularly young individuals, has decreased markedly in Lake St. Clair and western Lake Erie during the past 25 years (Nalepa & Gauvin, 1988; Thomas F. Nalepa, NOAA Great Lakes Environ. Res. Lab., Ann Arbor, Mich., pers. comm.). Caged, non-native clams (*Elliptio compalanta*) placed in the Detroit River for 18 months accumulated hexachlorobenzene, octachlorostyrene, PCBs, and polyaromatic hydrocarbons (Kauss & Hamdy, 1985). High tissue concentrations of these contaminants were found in clams along the U.S. shore near the Conners Creek combined sewer overflow, the Rouge River, and in the lower Trenton Channel. Lower tissue concentrations of these organochlorine residues were found in clams along the Ontario shore, indicating that sources of these substances were likely on the U.S. shore.

5.6. *Fishes*

Contaminated sediments also negatively affect fishes in the river. Larval channel catfish (*Ictalurus punctatus*) fed significantly more slowly when exposed to contaminated sediments from the Trenton Channel than when exposed to uncontaminated sediments (White *et al.*, 1987). Injection of 'eyed' eggs of rainbow trout (*Oncorhynchus mykiss*) with dilute extracts from Detroit River sediments increased mortality of embryos 2- to 3-fold, compared to that of control eggs injected only with solvent carrier. One year after injection, 3 percent of the surviving fish, injected as eggs with extracts from sediments collected near Mongaugon Creek, had liver neoplasms. Neoplasms and pre-neoplastic lesions were also found on brown bullhead (*Ictalurus nebulosus*), walleye, redhorse sucker (*Moxostoma* sp.), white sucker (*Catostomus commersoni*), and bowfin (*Amia calva*) collected in the lower Detroit River (Maccubbin, 1987). Dermal or oral neoplasms were found on 14.4 percent of the bullhead and on 4.8 percent of the walleye. Liver neoplasms were found in 15.4 percent of the bowfin. Spottail shiners (*Notropis hudsonius*) collected near Gibraltar, Michigan contained PCB concentrations (912 to 2 997 ng g^{-1}) that were significantly higher than those in these fish near the Canadian shore (153 to 316 ng g^{-1}) (Suns *et al.*, 1985).

The lower Detroit River is a major spawning ground for fishes that inhabit the river and western Lake Erie. All but one of the 39 fish species that spawn in or near the mouth of the Detroit River deposit their eggs on the bottom in contaminated sediments (Manny *et al.*, 1988). Heavy metals, such as chromium, that are present in Detroit River sediments can kill eggs and larvae of several of the fish species (Eisler, 1986) that use these historically important spawning grounds in the Detroit River; the eggs and larvae of other fishes that spawn there may also be threatened by these contaminants.

5.7. *Birds*

Eggs of the herring gull (*Larus argentatus*) collected near an industrial waste dump on Fighting Island from 1978 to 1982 contained the highest PCB and hexachlorobenzene concentrations measured anywhere in the Great Lakes basin (Struger *et al.*, 1985). Because these gulls eat fish, lay eggs containing organochlorine contaminants present near the nesting colony, and suffer high rates of reproductive failure (Peakall, 1988) they are monitored as part of a contaminant surveillance plan of the International Joint Commission (Gilbertson, 1988).

Carcasses of 13 diving ducks that foraged during winter on contaminated sediments near Mud Island in the Detroit River contained higher concentrations of more toxic and persistent forms of PCBs than did common carp (*Cyprinus carpio*), aquatic worms, and sediments collected at the same time and place (Smith *et al.*, 1985). Fifteen young-of-the-year diving ducks collected at the same time and place also contained high PCB concentrations (Kreis, 1988).

6. Discussion

In this paper we have attempted to describe contaminant concentrations in the Detroit River aquatic environment, relate that information to laboratory and site-specific field studies, and show existing contaminant concentrations produce adverse effects on aquatic life present in the river. Although the picture that emerges is incomplete, the evidence shows that large areas of river bottom habitat have been degraded by contaminants and that many animal populations in the river have been impacted by contaminants.

Levels of toxic substances in Detroit River sediments, such as oil, PCBs, and heavy metals often exceed standards and guidelines designed to protect aquatic life, particularly near urban industrial discharges. Point sources add the most contaminants to the river even though most discharges are regulated. Spills and combined sewer overflows are large unregulated sources of contaminants. Loadings of 'conventional pollutants' (e.g. oil, phenol, phosphorus) have decreased substantially since 1970, but accumulations of oil and heavy metals persist in the sediments in areas where benthic animal populations are greatly altered or eliminated. Fine-grained sediments in the lower river are heavily contaminated from historic, unregulated discharges and continue to expose aquatic biota to toxic substances.

There is a serious lack of information on the effects of specific toxic contaminants or complex mixtures of these contaminants on the aquatic food web, waterfowl, and aquatic mammals. However, it is readily apparent that plant and animal populations throughout large areas of the river have been disrupted and altered by destruction of habitat and chemical contamination of the water and sediments. In these respects, the Detroit River resembles many large rivers of the world that have been used for waste disposal by developed nations (Hynes, 1966; Oglesby *et al.*, 1972; Ajmal *et al.*, 1987; Fremling *et al.*, 1989; Lelek, 1989).

The primary environmental objectives set forth in the bi-national Great Lakes Water Quality Agreement (IJC, 1988) are restoring and maintaining the chemical, physical, and biological integrity of the Great Lakes, including the Detroit River, and eliminating the impacts of toxic substances on man's uses of their aquatic resources. The Agreement seeks to reduce or eliminate the discharge of any or all persistent toxic substances. Criteria for permissible quantities of contaminants in sediments are now being developed and remedial action plans are being formulated to restore all beneficial uses of the Detroit River (Hartig & Thomas, 1988). The draft plan for the Detroit River calls for monitoring tissue contaminant concentrations in river biota to measure remedial progress. Guidelines for such monitoring are being developed (IJC, 1986, 1987; Evans, 1988) and specific measures to reduce pollutant loadings to the Detroit River, including better monitoring of contaminant loadings by combined sewer overflows, have been proposed (EC & EPA, 1988). Compliance schedules in discharge permits for controlling combined sewer overflows are now required for most wastewater treatment plants that discharge into the Detroit River (Michigan Department of Natural Resources, Open files).

An overall reduction in the amount of wastes and toxic substances added to the Detroit River is needed to meet existing water quality objectives (IJC, 1988). By using less-toxic or non-toxic materials in manufacturing processes and by recycling usable materials from waste effluents, progress toward these objectives could be made now with available technology (Lawrence, 1988; Calvin *et al.*, 1988). Many uses of Detroit River water could be met by recycling heated effluents or by reclaiming wastewaters. Sewage may ultimately be disposed of on land rather than in rivers (Hynes, 1966). If so, the present practice of mixing toxic substances with sewage then discharging it into rivers may change to some form of centralized hazardous waste treatment, such as that used in Canada (Hrudey & Simpson, 1988). Habitat improvements (Gore & Petts, 1989) and protection of remaining island habitat in the river (Manny *et al.*, 1988) would enhance the survival of desirable plants and animals in the river. In the long run, such measures may be the most economical way to meet the water needs of modern society.

The potential risks to human health of consuming PCB-laden fish or waterfowl from the river have been noted (Smith *et al.*, 1985; Humphrey, 1988; Hebert *et al.*, 1990). Human exposure to ubiquitous contaminants, such as PCBs, is potentially higher from eating Great Lakes fish, than from direct exposure to terrestrial, atmospheric, or drinking water sources (Swain, 1983; Humphrey, 1983; Davies, 1988). Because Detroit River fish contain PCBs and mercury, these contaminants may be consumed by Detroit River anglers and their families. To protect human health, authorities in Michigan and Ontario have issued consumption advice for large carp, walleye, rock bass (*Ambloplites rupestris*), and freshwater drum (*Aplodinotus grunniens*) from the Detroit River (Ontario Ministry of Natural Resources, 1985; Michigan Department of Natural Resources, 1989). No consumption advisory has yet been issued for Detroit River waterfowl.

7. Acknowledgements

We thank T.A. Edsall, G.D. Haffner, R.G. Kreis, Jr., and J. Marsalek for bibliographic assistance and F.J. Horvath of the Michigan Department of Natural Resources for Fig. 1. This work was performed as part of a cooperative project between the U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency, under Interagency Agreement No. DW 14931214-01-0.

References

Ajmal, M., R. Khan & A. U. Khan, 1987. Heavy metals in water, sediments, fish and plants of river Hindon, U. P., India. Hydrobiologia 148: 151–157.

Bertram, P., T. A. Edsall, B. A. Manny, S. J. Nichols & D. W. Schloesser, 1991. Chemical contamination and physical characteristics of sediments in the upper Great Lakes connecting channels, 1985. U.S. Env. Protect. Agency, Great Lakes Ntnl. Program Off., 230 South Dearborn St., Chicago, IL. 60604. USA In Press.

Calvin, D. W., J. M. Rio & B. L. Haviland, 1988. Integrated waste management: An industrial perspective. In; N. W. Schmidtke (ed.), Toxic contaminants in large lakes. Vol. III. Sources, fate, and controls of toxic contaminants. Lewis Publishers, Chelsea, Mich.: 165–175.

Davies, K., 1988. Human exposure routes to persistent toxic chemicals in the Great Lakes basin: A case study. In; N. W. Schmidtke (ed.), Toxic contamination in large lakes. Vol. I Chronic effects of toxic contaminants in large lakes. Lewis Publishers, Chelsea, Mich.: 195–226.

DePinto, J. V., T. L. Theis, T. C. Young, D. Vanetti, M. Waltman & S. Leach, 1987. Exposure and biological effects of in-place pollutants: sediment exposure potential and particle-contaminant interactions. Clarkson Univ., Env. Eng., Rep. No. 87–9. 75 pp. + appendices.

Derecki, J. A., 1984. Detroit River, physical and hydraulic characteristics. Ntnl. Oceanogr. Atmos. Admin., Great Lakes Env. Res. Lab., Ann Arbor, Mich. GLERL Contrib. No. 417.

EC & EPA (Environment Canada & U.S. Environmental Protection Agency). 1988. Upper Great Lakes connecting channels study. Final report, Volume II. U.S. Env. Protect Agency, Chicago, Ill. 591 pp.

Edsall, T. A., B. A. Manny & C. N. Raphael, 1988. The St. Clair River and Lake St. Clair, Michigan: An ecological profile. U.S. Fish Wildl. Serv. Washington, D. C. Biol. Rep. 85(7.3). 130 pp.

Edsall, T. A., B. A. Manny, D. W. Schloesser, S. J. Nichols & A. M. Frank, 1991. Production of *Hexagenia limbata* nymphs in contaminated sediments in the Upper Great Lakes connecting Channels. Hydrobiologia 219: 353–361.

Eisler, R., 1986. Chromium hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish Wildl. Serv., Patuxent Wildl. Res. Center, Laurel, MD 20708. Biol. Rep. 85(1.6).

Evans, M. S. (ed.), 1988. Toxic contaminants and ecosystem health: a Great Lakes focus. John Wiley & Sons, New York. 602 pp. ISBN 0-471-85556-1.

Fallon, M. E. & F. J. Horvath, 1985. Preliminary assessment of contaminants in soft sediments of the Detroit River. J. Great Lakes Res. 11: 373–378.

Fremling, C. R., J. L. Rasmussen, R. E. Sparks, S. P. Cobb, C. F. Bryan & T. O. Claflin. 1989. Mississippi River fisheries: A case history. Large Rivers Symposium. Can J. Fish. Aquat. Sci. Spec. Pub. 106: 309–351.

Furlong, E. T., D. S. Carter & R. A. Hites, 1988. Organic contaminants in sediments from the Trenton Channel of the Detroit River, Michigan. J. Great Lakes Res. 14: 489–501.

Giesy, J. P., R. L. Graney, J. L. Newsted & C. J. Rosiu, 1987. Toxicity of in-place pollutants to benthic invertebrates. Interim Rep. to U.S. Env. Protect. Agency, Large Lakes Res. Sta., Grosse Ile, Mich. & Mich. State Univ., East Lansing, Mich.

Giesy, J. P., C. J. Rosiu, R. L. Graney, J. L. Newsted, A. Benda, R. G. Kreis, Jr. & F. J. Horvath, 1988. Toxicity of Detroit River sediment interstitial water to the bacterium *Photobacterium phosphoreum*. J. Great Lakes Res. 14: 502–513.

Gilbertson, M., 1988. Epidemics in birds and mammals caused by chemicals in the Great Lakes. In; M. S. Evans, (ed.) Toxic contaminants and ecosystem health: A Great Lakes focus. John Wiley & Sons, New York: 133–152.

Gore, J. A. & G. E. Petts, 1989. Alternatives in regulated river management. CRC Press. Boca Raton, Florida. 352 pp. ISBN 0-849-34877-3.

Great Lakes Institute, 1984. A case study of selected trace contaminants in the Essex region. Univ. Windsor, Ann. Rep. UP-175, Vol. 1: Physical Sciences. March 31. Windsor, Ontario.

Haas, R. C., W. C. Bryant, K. D. Smith & A. J. Nuhfer, 1985. Movement and harvest of fish in Lake St. Clair, the St. Clair River, and the Detroit River. U.S. Army Corps Engin., Detroit, Michigan. 141 pp.

Hamdy, Y. & L. Post, 1985. Distribution of mercury, trace organics, and other heavy metals in Detroit River sediments. J. Great Lakes Res. 11: 353–365.

Hartig, J. H. & R. L. Thomas, 1988. Development of plans to restore degraded areas in the Great Lakes. Env. Managem. 12: 327–347.

Hebert, C. E., G. D. Haffner, I. M. Weis, R. Lazar & L. Montour, 1990. Organochlorine contaminants in duck populations of Walpole Island. J. Great Lakes Res. 16: 21–26.

Henry, M., M. Mac, B. Manny, T. Kubiak & J. Gannon, 1989. Contaminants in the Great Lakes: a threat to fish and wildlife. U.S. Fish Wildl. Serv., Ntnl. Fish. Res. Center-Great Lakes, Ann Arbor, Mich. Unpubl. Rep.

Hrudey, S. E. & K. J. Simpson, 1988. Management of residues from centralized hazardous waste treatment facilities. In; N. W. Schmidtke, (ed.), Toxic contamination in large lakes. Vol. III. Sources, fate, and controls of toxic contaminants. Lewis Publishers, Chelsea, Mich.: 177–190.

Humphrey, H. E. B., 1983. Populations studies of PCBs in Michigan residents. In; F. M. D'Itri & M. A. Kamrin (eds), PCBs: Human and Environmental Hazards. Ann Arbor Sci. Publishers, Ann Arbor, Mich.: 299–310.

Humphrey, H. E. B., 1988. Chemical contaminants in the Great Lakes: The human health aspect. In; M. S. Evans (ed.), Toxic contaminants and ecosystem health: a Great Lakes focus. John Wiley & Sons, New York.: pp. 153–165.

Hynes, H. B. N., 1966. The biology of polluted waters. Liverpool Univ. Press. Great Britain. 202 pp. ISBN 0-820-16901.

IJC (International Joint Commission), 1982. Guidelines and register for evaluation of Great Lakes dredging projects. Rep. Dredging Subcomm. to Great Lakes Wat. Qual. Bd., Windsor, Ontario. 365 pp.

IJC. (International Joint Commission), 1986. Evaluation of sediment bioassessment techniques. Rep. Dredging Subcomm. to Great Lakes Wat. Qual. Bd, Windsor, Ontario. 123 pp.

IJC. (International Joint Commission), 1987. Guidance on characterization of toxic substances problems in areas of concern in the Great Lakes basin. Windsor, Ontario. 179 pp.

IJC. (International Joint Commission), 1988. Revised Great Lakes Water Quality Agreement of 1978, as amended by protocol signed November 18, 1987. Windsor, Ontario.

Kauss, P. B. & Y. Hamdy, 1985. Biological monitoring and organochlorine contaminants in the St. Clair and Detroit Rivers using introduced clams, *Elliptio complanatus*. J. Great Lakes Res. 11: 247–263.

Kenaga, D., 1986. Concentrations of PCBs in sediment depositional zones in the upper Detroit River along the United States shore, July 8 and 9, 1986 and the 18th Street sewer system, Detroit Michigan, July 14 and 15, 1986. Mich. Dept. Ntrl. Resources, Surf. Wat. Qual. Div., Lansing, Mich., Staff Rep. 13 pp.

Kenaga, D. & J. Crum, 1987. Sediment PCB concentrations along the U.S. shoreline of the upper Detroit River, and sediment and water PCB concentrations in two City of Detroit combined sewers with overflows to the Detroit River, July and October, 1986 and January 1987. Mich. Dept. Ntrl. Resources, Surf. Wat. Qual. Div., Lansing, Mich. Staff Rep. 6 pp.

Kreis, R. G., Jr. (ed.), 1988. Integrated study of exposure and biological effects of in-place sediment pollutants in the Detroit River, Michigan: An upper Great Lakes connecting channel. U.S. Env. Protect. Agency, Large Lakes Res. Lab., 9311 Groh Road, Grosse Ile, MI 48138, USA.

Lawrence, J. R., 1988. Wealth generator or environmental protector. The approach of a chemical company to process and product development under increasing environmental pressures. In; N. W. Schmidtke, (ed.), Toxic contamination in large lakes. Vol. III. Sources, fate, and controls of toxic contaminants. Lewis Publishers, Chelsea, Mich.: 121–149.

Lelek, A., 1989. The Rhine River and some of its tributaries under human impact in the last two centuries. Large Rivers Symposium. Can. J. Fish. Aquat. Sci. Spec. Publ. 106: 469–487.

Limno-Tech Inc., 1985. Summary of the existing status of the upper Great Lakes connecting channels data. 2395 Huron Parkway, Ann Arbor, Mich. 48104. 156 pp.

Lum, K. R. & K. L. Gammon, 1985. Geochemical availability of some trace and major elements in surficial sediments of the Detroit River and western Lake Erie. J. Great Lakes Res. 11: 328–338.

Maccubbin, A. E., 1987. Biological effects of in-place pollutants: Neoplasia in fish and related causal factors in the Detroit River system. Interim Rep. U.S. Env. Protect. Agency Large Lakes Res. Sta., 9311 Groh Road, Grosse Ile, Mich.

Manny, B. A., T. A. Edsall & E. Jaworski, 1988. The Detroit River, Michigan: an ecological profile. U.S. Fish. Wildl. Serv. Biol. Rep. 85(7.17). 86 pp.

Marsalek, J. & H. Y. F. Ng, 1987. Contaminants in urban runoff in the upper Great Lakes connecting channels area. Canada Centre for Inland Waters, Ntnl. Wat. Res. Inst., Burlington, Ontario, Canada. Rep. No. RRB-87-27.

Michigan Department of Natural Resources, 1989. Michigan fishing guide. East Lansing, Mich.

Mudroch, A., 1985. Geochemistry of Detroit River sediments. J. Great Lakes Res. 11: 193–200.

Munawar, M., R. L. Thomas, W. Norwood & A. Mudroch, 1985. Toxicity of Detroit River sediment-bound contaminants to ultraplankton. J. Great Lakes Res. 11: 264–274.

Muth, K. M., D. R. Wolfert & M. T. Bur, 1986. Environmental study of fish spawning and nursery areas in the St. Clair-Detroit River system. U.S. Fish Wildl. Serv., Ntnl. Fish. Res. Center – Great Lakes, Ann Arbor, Mich. Admin. Rep. 85–6. 53 pp.

Nalepa, T. F. & J. M. Gauvin, 1988. Distribution, abundance, and biomass of freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. J. Great Lakes Res. 14: 411–419.

Nalepa, T. F. & P. F. Landrum, 1988. Benthic invertebrates and contaminant levels in the Great Lakes: effects, fates, and role in cycling. In; M. S. Evans (ed.), Toxic contaminants and ecosystem health; A Great Lakes focus. John Wiley & Sons. New York.: 77–102.

Nichols, S. J., B. A. Manny, D. W. Schloesser & T. A. Edsall, 1991. Heavy metal contamination of sediments in the upper connecting channels of the Great Lakes. Hydrobiologia 219: 307–315.

Oglesby, R. T., C. A. Carlson & J. A. McCann, (eds.), 1972. River ecology and man. Proc. Internat. Symp., Univ. Massachusetts, June 20–23, 1971. Academic Press, New York. 465 pp. ISBN 0-12-524450-9.

Ontario Ministry of the Environment, 1985. Guide to eating Ontario sport fish. 135 St. Clair Ave, West, Toronto, Ontario, Canada, M4V 1P5. 254 pp.

Peakall, D. B., 1988. Known effects of pollutants on fish-eating birds in the Great Lakes of North America. In; N. W. Schmidtke, (ed.), Toxic contamination in large lakes. Vol. I, Chronic effects of toxic contaminants in large lakes. Lewis Publishers, Chelsea, Mich.: 39–54.

Pollman, C. D. & L. J. Danek, 1988. Contribution of urban activities to toxic contamination of large lakes. In; N. W. Schmidtke, (ed.), Toxic contamination of large lakes. Vol. III, Sources, fate, and controls of toxic contaminants. Lewis Publishers, Chelsea, Michigan.: 25–40.

Pugsley, C. W., P. D. N. Hebert, G. W. Wood, G. Brotea & T. W. Obal, 1985. Distribution of contaminants in clams and sediments from the Huron-Erie corridor. I – PCBs and Octachlorostyrene. J. Great Lakes Res. 11: 275–289.

Schloesser, D. W. & B. A. Manny, 1990. Decline of wild celery buds in the lower Detroit River, 1950–1985. J. Wildl. Managem. 54: 72–76.

Smith, V. E., J. M. Spurr, J. C. Filkins & J. J. Jones, 1985. Organochlorine contaminants of wintering ducks foraging on Detroit River sediments. J. Great Lakes Res. 11: 231–246.

Struger, J., D. V. Weseloh, D. J. Hallette & P. Mineau, 1985. Organochlorine contaminants in herring gull eggs from the Detroit and Niagara Rivers and Saginaw Bay (1978–1982): contaminant discriminants. J. Great Lakes Res. 11: 223–230.

Suns, K., G. Crawford & D. Russell, 1985. Organochlorine and mercury residues in young-of-the-year spottail shiners from the Detroit River, Lake St. Clair, and Lake Erie. J. Great Lakes Res. 11: 347–352.

Swain, W. R., 1983. An overview of the scientific basis for concern with polychlorinated biphenyls in the Great Lakes. In; F. M. D'Itri & M. A. Kamrin (eds), PCBs: Human and Environmental Hazards. Ann Arbor Sci. Publ., Ann Arbor, Mich.: pp. 11–48.

Thornley, S., 1985. Macrozoobenthos of the Detroit and St. Clair Rivers with comparisons to neighbouring waters. J. Great Lakes Res. 11: 290–296.

Thornley, S. & Y. Hamdy, 1984. An assessment of the bottom fauna and sediments of the Detroit River. Ontario Min. Environ., Toronto. 48 pp.

USACE (U.S. Army Corps of Engineers), 1981. Essayons. A history of the Detroit District. Detroit, Mich. 215 pp.

USACE (U.S. Army Corps of Engineers), 1984. Waterborne commerce of the United States, calendar year 1983. Part 3 – Waterways and harbors of the Great Lakes. U.S. Government Printing Office, Washington, D.C. 103 pp.

White, D. S., J. Bowers, D. Jude, R. Moll, S. Hendricks, P. Mansfield & M. Flexner, 1987. Exposure and biological effects of in-place pollutants (bioassays). Interim Rep. to the U.S. Env. Protect. Agency, Large Lakes Res. Sta., 9311 Groh Road, Grosse Ile, MI 48138, USA.