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Environmental Assessment and Habitat Evaluation of the Upper Great Lakes Connecting Channels.

Production of *Hexagenia limbata* nymphs in contaminated sediments in the Upper Great Lakes Connecting Channels[1]

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Abstract

In April through October 1986, we sampled sediments and populations of nymphs of the burrowing mayfly, *Hexagenia limbata* (Serville), at 11 locations throughout the connecting channels of the upper Great Lakes, to determine if sediment contaminants adversely affected nymph production. Production over this period was high (980 to 9231 mg dry wt m^{-2}) at the five locations where measured sediment levels of oil, cyanide, and six metals were below the threshold criteria of the U.S. Environmental Protection Agency and the Ontario Ministry of Environment for contaminated or polluted sediments, and also where the criterion for visible oil given in the Water Quality Agreement between the U.S.A. and Canada for connecting waters of the Great Lakes was not exceeded. At the other six locations where sediments were polluted, production was markedly lower (359 to 872 mg dry wt m^{-2}). This finding is significant because it indicates that existing sediment quality criteria can be applied to protect *H. limbata* from oil, cyanide, and metals in the Great Lakes and connecting channels where the species fulfills a major role in secondary production and trophic transfer of energy.

1. Introduction

We conducted a study to determine if contaminated sediments were adversely affecting the production of nymphs of the burrowing mayfly, *Hexagenia limbata* (Serville), in the St. Marys River, the St. Clair River, Lake St. Clair, and the Detroit River – the waterbodies that collectively compose the Upper Great Lakes Connecting Channels. Our study was an integral component of a broader investigation (EC & EPA, 1988) initiated in 1984 by U.S. and Canadian agencies to identify and quantify the effects of conventional pollutants and toxic substances on the biota of these channels. The Upper Great Lakes Connecting Channels were singled out for study because they were identified by the International Joint Commission (IJC, 1983) as Areas of Concern, where beneficial uses of water, sediments, or both were significantly impaired by human activities.

We selected *H. limbata* for study because, during its 2-yr nymphal life stage, it lives in burrows in the sediment, indiscriminately ingests sediment while feeding (Smock, 1983), and is sensitive to environmental pollutants, including oil and metals concentrated in the sediments (Fremling, 1964, 1970; NAS, 1973; Hiltunen & Schloesser, 1983; Malueg *et al.*, 1984a, 1984b; Burt *et al.*, 1988). *H. limbata* typically is abundant in the shallow, soft-bottomed portions of the Great Lakes and

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their connecting channels where water and sediment quality have not been substantially degraded by human activities (Veal, 1968; Hiltunen, 1971, 1980; Hamdy *et al.*, 1978; Fallon & Horvath, 1983; Hiltunen & Schloesser, 1983; Thornley & Hamdy, 1984; Schloesser & Hiltunen, 1986; Burt *et al.*, 1988; Mozley & La Dronka, 1988); in these areas it can have a central role in trophic relations, converting plant detritus into food for fish (Duffy *et al.*, 1987).

2. Materials and methods

We collected sediment and *H. limbata* nymphs at 11 stations in the Upper Great Lakes Connecting Channels in 1986 (Fig. 1). Some stations were established in areas remote from major pollution sources where nymphal densities were high, and others were in areas closer to pollution sources where nymphal densities were lower. Sediments at all 11 stations were primarily a mixture of clay and silt, or clay and sandy silt. We did not collect particle-size data or measure the organic content of the sediment, but such sediment was described by Hunt (1953) and Wright & Mattice (1981) as a preferred habitat for *H. limbata* because it was soft enough to permit the nymphs to burrow easily, and also was sufficiently cohesive to prevent the burrows from collapsing.

One or two samples of sediment for contaminant analysis were collected with a Ponar grab (0.05 m^2 jaw opening) at each station in June. Each sample was placed carefully in a large metal tub in a manner that preserved the *in situ* profile of the sediment and prevented the upper layers representing the sediment-water interface portion of the sample from contacting the tub or any other potential source of contamination. About 500 g of sediment in the upper 3 cm of the sample was scooped off with a clean, stainless steel spoon and placed in an acid-washed, acetone-rinsed glass jar. The jar was then capped with acetone-rinsed aluminum foil and placed on ice, in darkness, in an insulated container and transported to the laboratory. The samples were refrigerated and held in darkness in the laboratory until they were analyzed. Heavy metals were measured by Inductively Coupled Argon Plasma analysis with standard methodology (EPA, 1979a; Jarrell-Ash, 1979); cyanide was measured by dry weight basis following EPA (1979b) and Technicon Corporation (1980); and oil was measured by dry weight basis according to APHA (1980) and EPA (1974). We collected 15 samples monthly April through October (except July) at each station with the Ponar grab to provide nymphs for production estimates. The samples were washed over a U.S. Standard No. 30 sieve (0.65-mm mesh) and the nymphs and other sample residue on the screen were preserved in formalin-phloxine B solution. In the laboratory we placed each preserved sample in a shallow pan and extracted the nymphs manually. We then identified the nymphs according to Edmunds *et al.* (1976) and measured them to the nearest 0.5 mm at 7 × magnification.

One additional sample was collected at each station with the Ponar grab and No. 30 sieve, to provide data for a length-weight relation and a wet weight-dry weight relation for *H. limbata* in the study area. Live nymphs and the other sample residue on the screen were placed on ice, in a small amount of water and transported to the laboratory. The nymphs were extracted from the residue, blotted with a paper towel for 10 to 15 seconds, and weighed immediately. Nymphs used to provide data on live (wet) weight versus dry weight were placed in a drying oven at 100 °C for at least six hours, and then reweighed; the remaining live nymphs were measured, placed in formalin-phloxine B solution for at least 30 days and then re-measured to provide data onlive versus preserved length. Weights were determined to the nearest milligram and length measurements were made to the nearest 0.5 mm under 7 × magnification.

Preserved lengths in millimeters (L) were converted to wet weights in grams (W) by applying the length-weight equation,

$$\ln(W) = 2.82 \ln(L) - 11.09 \qquad (r^2 = 0.9655,\ n = 186),$$

and wet weights were converted to dry weight (D)

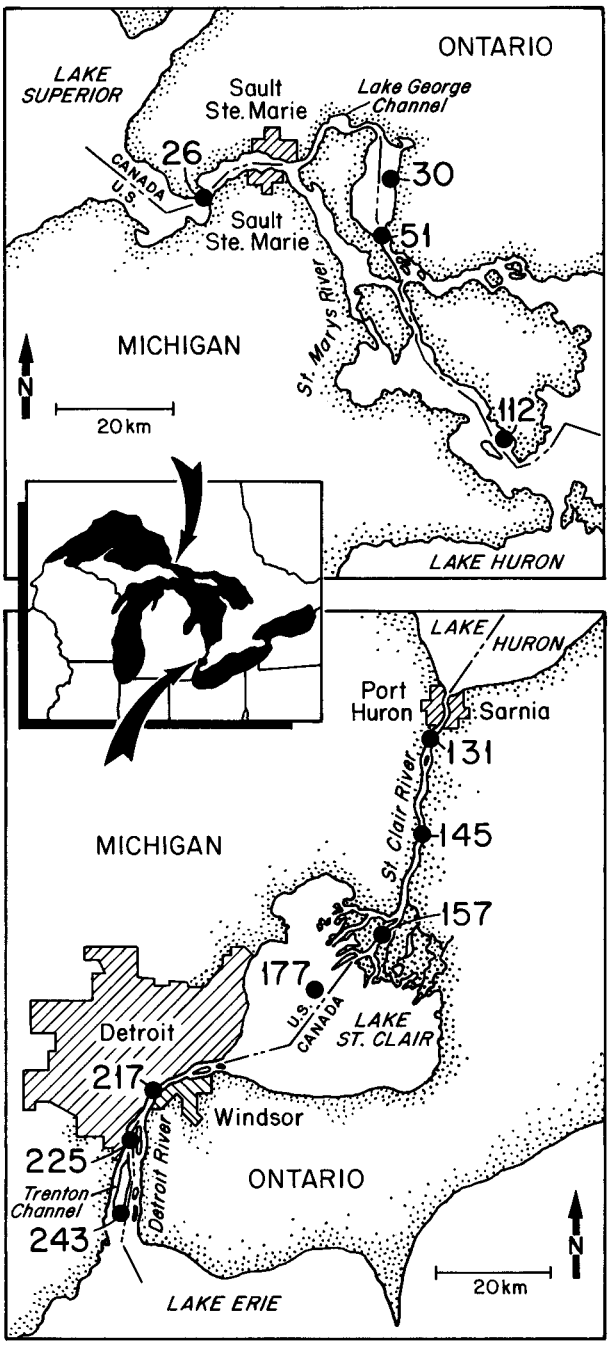

Fig. 1. Locations of the 11 stations at which *Hexagenia* nymphs and sediments were collected for study.

with the equation

$$\ln(D) = -1.5167 + 1.1189 \ln(W) \qquad (r^2 = 0.954,\ n = 100).$$

Production (Pw) and its variance $v(Pw)$ were estimated by using the size frequency method of Hynes as modified by Hamilton (1969) and equations from Krueger & Martin (1980).

Because Schloesser & Hiltunen (1984), and Schloesser *et al.* (1988) indicated that the cohort production interval (CPI) is about 730 days in the Upper Great Lakes Connecting Channels, we followed Benke (1979) in multiplying *Pw* by 365/CPI to obtain the estimate of production and Krueger & Martin (1980) in multiplying v(*Pw*) by $(365/CPI)^2$ to obtain variance for this production estimate.

To reduce the variation associated with small sample sizes in some of the size groups, we grouped the nymphs collected throughout the study into 4-mm size classes before we computed production.

3. Results and discussion

3.1. Production

Production for the April to October period varied widely throughout the study area (Table 1) and was markedly higher at stations 26, 51, and 112 in the St. Marys River and at station 177 in Lake St. Clair (3333 to 9231 mg m^{-2}) than at station 30 in the St. Marys River and the six stations in the St. Clair and Detroit rivers (359 to 980 mg m^{-2}). The values in Table 1 are valid estimates of the portion of the annual production that occurred in April to October 1986 and can be used to examine the effects of contaminated sediments on the performance of the *H. limbata* populations sampled throughout the study area.

Table 1. Production of *H. limbata* nymphs in the Upper Great Lakes Connecting Channels, April through October, 1986.

Channel and station	Production	
	Dry wt (mg m^{-2})	95% confidence interval
St. Marys River		
26	3,481	3,082–3,890
30	403	287–518
51	3,333	3,021–3,644
112	3,375	2,935–3,815
Average	2,648	
St. Clair River		
131	741	605–877
145	359	288–430
157	980	770–1,189
Average	693	
Lake St. Clair		
177	9,231	8,757–9,705
Detroit River		
217	376	264–489
225	708	558–857
243	872	708–1,035
Average	652	

3.2. Sediment contaminants

In the St. Marys River none of the measured concentrations of contaminants in sediments at stations 26, 51, and 112 (Table 2) exceeded the Ontario Ministry of Environment (OME) or U.S. Environmental Protection Agency (EPA) guidelines for the disposal of dredged materials in the Great Lakes and their connecting channels (IJC, 1982). These guidelines (Table 3) are expressed as the concentrations of various contaminants in sediments that if exceeded could cause the sediments to be classified as contaminated (OME) or polluted (EPA). In this paper, we considered sediments to be polluted if one or more of the contaminants we measured equalled or exceeded the numerical values given in Table 3.

In the St. Marys River, the measured concentrations of oil, cyanide, Cd, Cr, Cu, Ni, Pb, and Zn in one sample at station 30 exceeded the OME and EPA guidelines, and the concentrations of oil, cyanide, Cr, Cu, and Zn were the highest we measured during this study. Oil was visible in the other sample collected at station 30, indicating that the sediment was polluted according to the criterion for oil and petrochemicals in the revised Great Lakes Water Quality Agreement of 1978 (IJC, 1988).

In the St. Clair River at station 131, oil was visible in one sample and the measured concentration of oil exceeded EPA and OME guidelines in the other. Furthermore, Cu exceeded the OME and EPA guidelines in both samples and Zn

Table 2. Sediment contaminant levels (mg kg^{-1} dry wt) in the Upper Great Lakes Connecting Channels, 1986.

Channel and station	Contaminant[1]							
	Oil	Cyanide	Cd	Cr	Cu	Ni	Pb	Zn
St. Marys River								
26	–	–	0.3	7.9	9.8	7.7	12.0	33.0
		–	0.3	7.9	8.2	9.4	8.6	26.0
30	+	–	–	9.0	6.8	6.4	12.0	43.0
	3,170*	2.1*	1.1*	49.0*	44.0*	27.0*	59.0*	210.0*
51	–	–	0.3	11.0	8.6	7.2	10.0	48.0
	869	–	0.3	14.0	11.0	9.2	11.0	51.0
112	–	–	0.3	18.0	12.0	10.0	11.0	30.0
St. Clair River								
131	+	–	0.6	13.0	46.0*	15.0	34.0	93.0*
	1,670*	–	0.6	13.0	52.0*	15.0	33.0	100.0*
145	+	–	0.3	6.7	14.0	8.9	7.5	46.0
		–	0.7	7.7	18.0	14.0	9.4	63.0
157	892	–	0.4	11.0	18.0	15.0	18.0	57.0
	793	–	0.4	11.0	18.0	14.0	18.0	55.0
Lake St. Clair								
177	–	–	0.6	14.0	24.0	18.0	28.0	63.0
Detroit River								
217	+	–	1.0*	37.0*	43.0*	42.0*	71.0*	170.0*
225	–	–	0.4	32.0*	32.0*	39.0	19.0	83.0
	–	–	0.4	30.0*	33.0*	36.0	26.0	83.0
243	+, 881	–	3.2*	39.0*	48.0*	31.0	55.0*	160.0*
	1,020*	–	1.6*	30.0*	38.0*	29.0	46.0*	140.0*

[1] Dash (–) indicates no data; cross (+) indicates oil was detected by smell or as a visible sheen in sample and exceeded the pollution criterion (IJC, 1987); asterisk (*) indicates measured value exceeds U.S. Environmental Protection Agency or Ontario Ministry of Environment guideline for polluted dredged sediments (IJC, 1982).

exceeded the EPA guideline in one sample and the OME and EPA guidelines in the other. At station 145, oil was visible in one sample. At station 157 in the St. Clair River and at station 177 in Lake St. Clair, none of the contaminants exceeded the OME or EPA guidelines.

In the Detroit River, oil was visible in the single sample taken at station 217 and the concentrations of Cu, Cr, and Zn exceeded the OME and EPA guidelines; the concentrations of Ni and Pb also exceeded the guidelines and were the highest measured for those contaminants in this study. At station 225, concentrations of Cr and Cu exceeded the OME and EPA guidelines. At station 243, oil was visible in one sample and measured oil exceeded the EPA guideline in the other; concentrations of Cd, Cr, Cu, Pb, and Zn exceeded OME and EPA guidelines in both samples.

Table 3. Guidelines of the Ontario Ministry of the Environment (OME) and U.S. Environmental Protection Agency (EPA) for the disposal of dredged materials (IJC, 1982). Sediments with contaminant values equal to or larger than the tabular values are considered to be contaminated (OME) or polluted (EPA).

Contaminant (mg kg^{-1})	OME	EPA
Cadmium	1	6
Chromium	25	25
Copper	25	25
Cyanide	0.1	0.1
Lead	50	40
Nickel	25	20
Zinc	100	90
Oil	1,500	1,000

3.3. *Effect of contaminated sediments on production*

Comparison of production data (Table 1) with sediment contamination data at our 11 stations (Table 2) showed that at stations 26, 51, 112, 157, and 177, where *H. limbata* production was 980 to 9231 mg m^{-2}, sediment contaminant levels did not exceed the OME and EPA guidelines, and sediments had no oily odor or visible sheen of oil. In contrast, at the other six stations, where the sediments were polluted, the production of *H. limbata* was 359 to 872 mg m^{-2}. Although production was higher at station 157 than at the six stations where sediments were polluted, it did not differ significantly from production at two of them (stations 225 and 243) – suggesting that the April to October production of about 700 to 1000 mg m^{-2} may be typical of the boundary area between polluted and unpolluted sediments.

We believe our results indicate that contaminated sediments are adversely affecting the production of *H. limbata* in portions of these connecting channels; support for this interpretation is provided by the results of a 21-day laboratory bioassay (Henry, 1987) conducted in 1986 with *H. limbata* nymphs and sediments from the connecting channels. The bioassay showed that sediments from a portion of the Lake George Channel in the upper St. Marys River and from a portion of the Trenton Channel in the lower Detroit River (Fig. 1) were acutely toxic to the nymphs. No *H. limbata* nymphs were collected at these two

Table 4. Sediment contaminant levels (mg kg^{-1} dry wt) in the Upper Great Lakes Connecting Channels and in the Keweenaw Waterway.

	Contaminant[1]							
Location	Oil	Cyanide	Cd	Cr	Cu	Ni	Pb	Zn
St. Marys River Upper Lake George Channel[2]	4,720*	2.5*	1.0*	40*	40*	19	42*	160*
Lower Detroit River Trenton Channel[2]	16,200*	8.9*	9.3*	230*	130*	120*	330*	1,400*
Keweenaw Waterway[3]								
Torch Lake	–	–	2.5*	180*	1,800*	150*	110*	310*
North	–	–	1.0*	73*	140*	63*	17	100*
waterway	–	–	2.0*	130*	930*	120*	40*	240*
South	–	–	0.2	18	13	24*	1.9	53
waterway	–	–	0.7	51*	37*	34*	27	91*

[1] Asterisk (*) indicates measured value exceeds guidelines of the U.S. Environmental Protection Agency or Ontario Ministry of Environment for polluted dredged sediments (IJC, 1982); dash indicates no data.

[2] Henry (1987).

[3] Malueg *et al.* (1984a, 1984b); waterway is located in Michigan in the Lake Superior watershed.

locations, even though the sediment was of the 'preferred' type described by Hunt (1953) and Wright & Mattice (1981).

Sediment concentrations of oil, cyanide, Cd, Cr, Cu, Ni, Pb, and Zn were far higher in the Trenton Channel than in the upper Lake George Channel or at any of the 11 stations in the present study; they also exceeded the OME and EPA guidelines for polluted sediment by a wide margin. Sediment concentrations of oil, cyanide, Cr, Cu, and Zn in the upper Lake George Channel (Table 4) substantially exceeded OME and EPA guidelines for polluted sediments; concentrations of Cd and Pb barely exceeded the guidelines; and Ni was slightly below the EPA guideline value. Sediment concentrations of oil, cyanide, and metals other than Ni in the upper Lake George Channel substantially exceeded the values measured in the present study at stations 26, 51, 112, 157, and 177, where the production of *H. limbata* was highest (Tables 2 & 4). In the Lake George Channel, sediment concentrations of most contaminants were within the range of values we measured at our six stations where production was lower; the exception was oil, which was substantially higher in the Lake George Channel (Tables 2 & 4). The bioassay (Henry, 1987) also revealed that sediments from stations 26, 30, 51, 131, 145, 157, 225, and 243, where we measured production, were not acutely toxic to *H. limbata* nymphs. Sediment toxicity was not determined by Henry (1987) at stations 112 and 177, but the high production we measured and the low concentrations of contaminants in the sediments at those stations indicate the sediments there probably were not toxic to *H. limbata*.

Additional evidence for an impact of metals on the production of *H. limbata* in the connecting channels is provided by the results of studies in the Keweenaw Waterway (Malueg *et al.*, 1984a, 1984b), where mining activities created extensive deposits of tailings that contaminated the waterway. Concentrations of metals substantially exceeded OME and EPA guidelines, except for Cd in Torch Lake, and Cd and Pb in the north waterway. In the south waterway, on the other hand, only the concentrations of Cr, Cu, Ni, and Zn exceeded OME and EPA guidelines (Table 4). Ten-day bioassays (Malueg *et al.*, 1984a; 1984b) showed that the sediments from Torch Lake were acutely toxic to nymphs of *Hexagenia* (probably *H. limbata*), but that sediments from the north and south waterways were not. Field studies by these investigators showed nymphs present in the south waterway but none in Torch Lake and the north waterway. Although the absence of nymphs in the north waterway is not explained by the results of the bioassay by Malueg *et al.* (1984b), the absence of nymphs is perhaps not surprising, because sediment metal concentrations in the north waterway were generally within the range shown in the longer, 21-day bioassay by Henry (1987) to be acutely toxic in the Upper Great Lakes Connecting Channels (Table 4). In the south waterway, where *Hexagenia* nymphs were present, sediment concentrations of all metals were generally within the range found in the present study at locations where *H. limbata* nymphs were present (Tables 1, 2 & 4). In the south waterway, concentrations of Cd and Pb were similar to those at our productive stations 26, 51, 112, 157, and 177, whereas the concentrations of Cr, Cu, Ni, and Zn more closely resembled values we measured at our other six stations, where production was lower.

4. Conclusions

Our results strongly suggest that the considerably lower nymphal production measured in portions of the Upper Great Lakes Connecting Channels, where oil, cyanide, and metals in sediments exceeded pollution criteria, can be attributed to those contaminants operating in a manner that adversely affected the health of individual nymphs and the performance of the population. At five stations where sediments were not polluted, the production of nymphs was up to nine times higher than the highest production measured at six other stations, where sediments were polluted. Sediment bioassays and related field studies by Henry (1987) and Malueg *et al.* (1984a, 1984b) demon-

strate the lethality of sediment contaminants to *Hexagenia* nymphs and provide independent support for the interpretation that the lower production we observed at 6 of 11 stations in the study area can be attributed to sediment contamination.

No numerical criteria have been developed specifically to permit an evaluation of the effect of sediment contaminants on the performance of populations of *H. limbata* nymphs, and none were developed in the course of this study. However, our results indicate that the OME and EPA guidelines for dredged sediments, together with the Water Quality Agreement criterion for visible oil (IJC, 1988), can probably be applied to protect *H. limbata* in Great Lakes habitats. This finding is noteworthy because *H. limbata* tends to assume a major role in secondary production and trophic transfer of energy in soft-bottomed, mesotrophic habitats in shallow portions of the Great Lakes system that have not been polluted by oils, metals, and other toxic substances. Furthermore, because *H. limbata* is among the most pollution-sensitive members of the macrozoobenthos community in the Great Lakes system, the OME and EPA guidelines for disposal of dredged materials (Table 3) can probably be used as sediment pollution criteria to protect not only *H. limbata*, but also the other macrozoobenthos in these waters.

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