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Distribution of *Hexagenia* nymphs and visible oil in sediments of the Upper Great Lakes Connecting Channels[1]

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Key words: *Hexagenia*, oil, Great Lakes, channels, pollution

Abstract

As part of the study of the Upper Great Lakes Connecting Channels sponsored by the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service examined the occurrence of *Hexagenia* nymphs and visible oil in sediments at 250 stations throughout the St. Marys River and the St. Clair-Detroit River system from May 14 to June 11, 1985. The mean density of *Hexagenia* nymphs per square meter averaged 194 for the total study area, 224 in the St. Marys River, 117 in the St. Clair River, 279 in Lake St. Clair, and 94 in the Detroit River. The maximum density of nymphs ranged from 1,081 to 1,164 m^{-2} in the three rivers and was 3,099 m^{-2} in Lake St. Clair. A comparison of nymph density at 46 stations where oil was observed in sediments physically suitable for nymphs showed that densities were lower in oiled sediments (61 m^{-2}) than in sediments without oil (224 m^{-2}). Densities of nymphs were relatively high at only four stations where oil was observed in sediments. In general, oiled sediments and low densities of nymphs occurred together downstream from industrial and municipal discharges.

1. Introduction

Over the past century, industrial and urban discharges have substantially degraded sediment and water quality in connecting channels of the upper Great Lakes such that each channel is now designated as an Area of Concern (GLWQB, 1983). Degraded benthic invertebrate communities are a common feature of these areas of concern (Limno-Tech, Inc., 1985; Everitt *et al.*, 1985; EC & USEPA, 1988), and in these communities the burrowing mayfly *Hexagenia*, which is sensitive to environmental degradation (Fremling, 1964; National Academy of Sciences, 1973), is usually absent or low in abundance.

Hexagenia has been eliminated from most Great Lakes waters directly affected by industrial and urban discharges, including portions of Green Bay (Howmiller & Beeton, 1971; Mozley & Howmiller, 1977), the St. Marys River (Veal, 1968; Hamdy *et al.*, 1978; Hiltunen & Schloesser, 1983), Saginaw Bay (Schneider *et al.*, 1969), the Detroit River (Fallon & Horvath, 1985; Thornley & Hamdy, 1984), and portions of Lakes Erie, Superior, Huron, and Michigan (Britt, 1955; Veal & Osmond, 1967; Mozley & LaDronka, 1988). Hiltunen & Schloesser (1983) linked the absence or reduced abundance of *Hexagenia* nymphs in portions of the St. Marys River with the presence of visible oil in the sediments. The present study,

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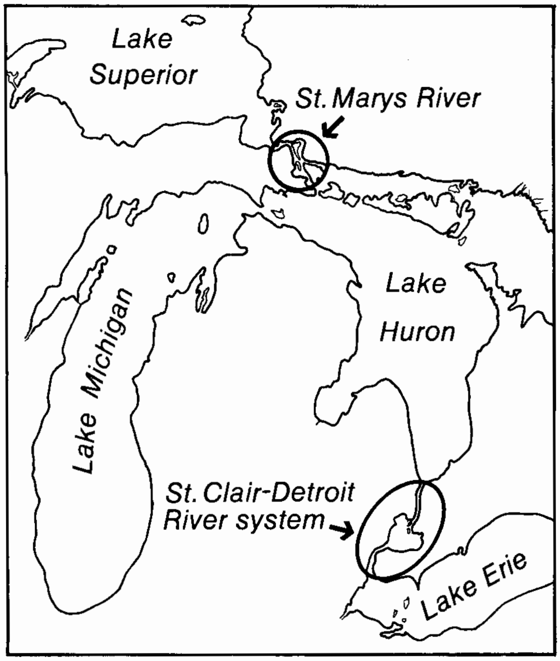

Fig. 1. The Upper Great Lakes Connecting Channels: the St. Marys River and the St. Clair-Detroit River system.

which was conducted as part of a multi-year, joint undertaking by the United States and Canada to determine the existing environmental condition of these waters (Everitt *et al.*, 1985; EC & USEPA, 1988), was designed to determine if a linkage between oiled sediments and the abundance of *Hexagenia* nymphs could be demonstrated throughout the Upper Great Lakes Connecting Channels (Fig. 1).

2. Methods

Samples of *Hexagenia* nymphs and sediment were systematically collected from May 14 to June 11, 1985 at one station in each cell of a 250-cell grid covering the Upper Great Lakes Connecting Channels (Fig. 2). Cell dimensions in each of the water bodies were (east to west and north to south); 2.2 × 2.2 km in the St. Marys River, 2.2 × 2.2 km in the St. Clair River, 6.9 × 4.8 km in Lake St. Clair, and 2.8 × 1.8 km in the Detroit River. All samples were collected before nymph emergence in July when densities of nymphs in Great Lakes waters are relatively high (Schloesser & Hiltunen, 1984).

Stations were located where *Hexagenia* nymphs had been collected previously or where the substrate was texturally suitable for them, i.e., consisted of a mixture of silt, clay, and fine sand with a sticky consistency that would support nymph burrows (Hunt, 1953; Eriksen, 1963; Wright & Mattice, 1981).

Three samples were collected at each station with a standard (0.048 m^2 jaw opening) Ponar grab. Each sample was examined for the presence of visible oil as it was transferred from the grab to a metal tub and washed through a standard U.S. No. 30 sieve (0.65 mm mesh opening). When present, oil appeared as a thin film or sheen that formed on the surface of the water surrounding the sample during washing. Oil observed during the washing process was recorded and such sediments were classified as 'oiled'. The screen residue from each sample was placed in a jar and preserved with 10 percent formalin-phloxine B, a preservative-dye (Mason & Yevich, 1967).

In the laboratory, the screen residue from each sample was divided into subsamples of a size convenient for processing (5 to 10 cm^3) and placed in white enamel pans with a concentrated sugar solution (Anderson, 1959). Subsamples were examined at 7 × magnification and nymphs were removed manually from each sample. A total of 7,045 *Hexagenia* nymphs were identified. Oil observed while examining sample residue in the laboratory was also recorded.

Data were summarized and analyzed using 18 connecting channel sections of the study area (Fig. 2). Designation of channel sections was based on knowledge of pollution sources, natural geographical features, previous studies (e.g., Hiltunen & Schloesser, 1983), and international boundaries. Differences ($P \leq 0.05$) between the mean number of nymphs m^{-2} ($\log[x + 1]$) at stations with oil and oil-free sediments were tested for significance by student's t-distribution (Snedecor & Cochran, 1973).

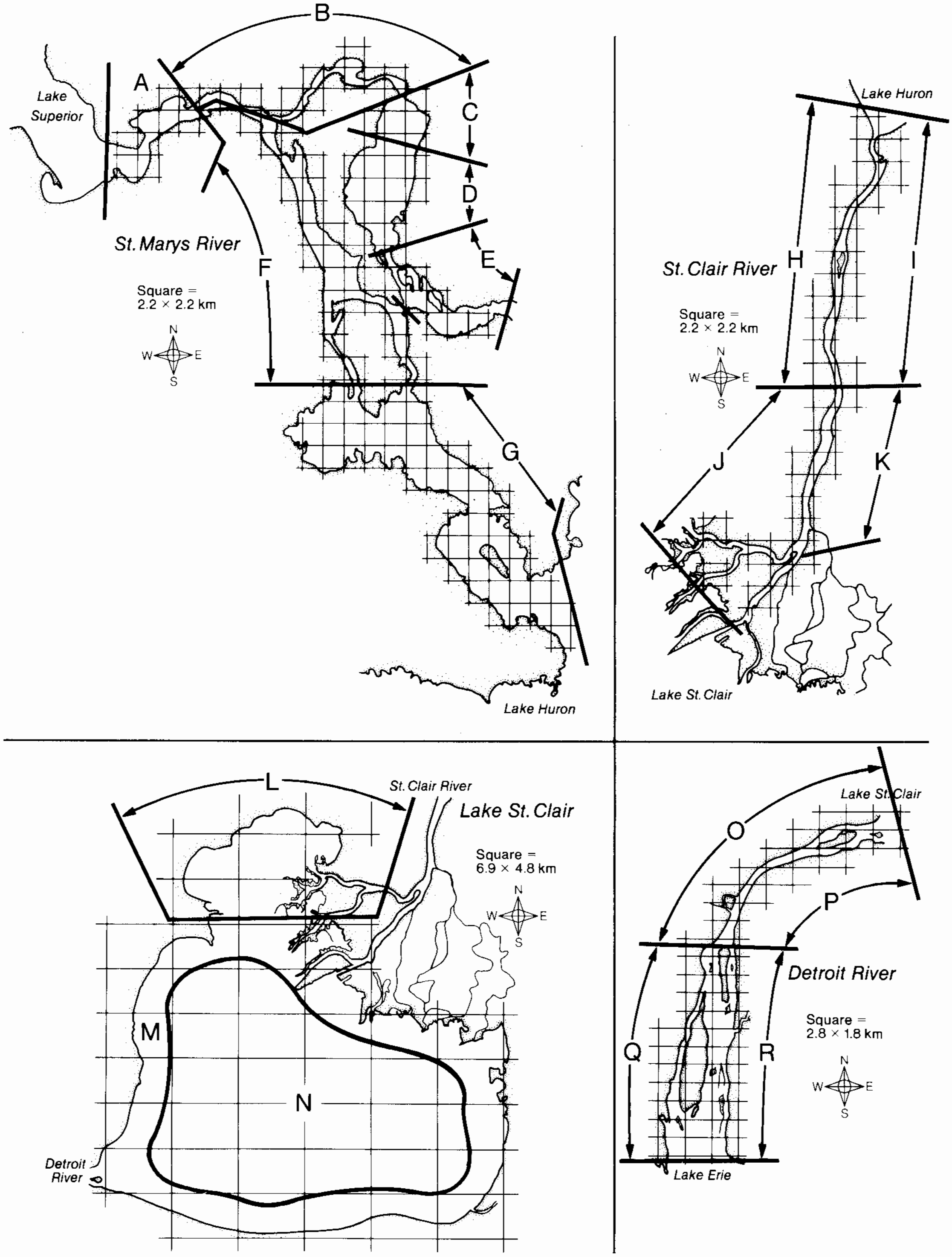

Fig. 2. Locations of 250 grid squares (in each of which one station was sampled) and 18 geographical sections (A–R) used to summarize the occurrence of *Hexagenia* nymphs and oiled sediments in the Upper Great Lakes Connecting Channels May 14–June 11, 1985.

Table 1. Mean number, standard error (SE), and range of *Hexagenia* nymphs (per square meter) at all stations and at stations with visibly oiled and oil-free sediments in 18 geographical sections of the Upper Great Lakes Connecting Channels, May 14–June 11, 1985.

Connecting channel section	All stations					Oiled sediments				Oil-free sediments			
Description	Designation[a]	Number stations	Mean	SE	Range	Number stations	Mean	SE	Range	Number stations	Mean	SE	Range
St. Marys River													
Upriver of Sault Ste. Marie	A	8	193	84.0	0–668	0				8	193	84.0	0–668
Channel above Sugar Island	B	14	11	5.6	0–69	9	12	7.5	0–69	5	11	9.3	0–48
Northern Lake George	C	6	75	34.7	0–186	2	4	3.5	0–7	4	110	41.9	34–186
Southern Lake George	D	15	129	31.7	0–461	1	0			14	138	32.5	0–461
Below Lake George	E	8	232	53.0	34–530	0				8	232	53.0	34–530
Lake Nicolet	F	24	331	63.7	0–1164	1	34			23	344	65.1	0–1164
Lake Munuscong	G	50	282	32.8	0–964	0				50	282	32.8	0–964
Total	A-G	125	224	29.3	0–1164	13	11	5.6	0–69*[b]	112	249	22.6	0–1164
St. Clair River													
Upper U.S. waters	H	10	23	7.6	0–76	3	39	22.0	0–76	7	16	5.8	0–41
Upper Canadian waters	I	9	47	30.7	0–282	7	10	6.0	0–44	2	179	103.0	76–282
Lower U.S. waters	J	9	359	121.0	7–1081	0				9	359	121.0	7–1081
Lower Canadian waters	K	7	31	7.9	0–62	2	28	13.5	14–41	5	34	10.7	0–62
Total	H-K	35	117	39.3	0–1081	12	20	7.0	0–76*[b]	23	168	57.3	0–1081
Lake St. Clair													
Anchor Bay	L	6	343	84.1	62–530	0				6	343	84.1	62–530
Perimeter of lake	M	19	22	16.1	0–310	0				19	22	16.1	0–310
Open waters of lake	N	18	528	170.9	41–3099	0				18	528	170.9	41–3099
Total	L-N	43	279	80.2	0–3099	0				43	279	80.2	0–3099
Detroit River													
Upper U.S. waters	O	7	20	7.9	0–62	3	5	4.7	0–14	4	31	11.4	14–62
Upper Canadian waters	P	9	253	115.3	41–1129	4	338	265.3	28–1129	5	184	55.0	41–310
Lower U.S. waters	Q	21	16	6.5	0–130	12	17	11.0	0–130	9	15	6.0	0–48
Lower Canadian waters	R	10	167	64.5	0–606	2	431	175.5	255–606	8	101	50.0	0–420
Total	O-R	47	94	28.8	0–1129	21	116	59.2	0–1129	26	76	21.8	0–420
All sections	A-R	250	194	19.4	0–3099	46	61	27.8	0–1129*[b]	204	224	22.4	0–3099

[a] See Figure 2.
[b] Means of oiled and oil-free sediments significantly different at $P \le 0.05$.

3. Results

Mean densities of nymphs (number m^{-2}) varied substantially in the Upper Great Lakes Connecting Channels (Table 1, Fig. 2): means of 224 were found in the St. Marys River, 117 in the St. Clair River, 279 in Lake St. Clair, and 94 in the Detroit River. Maximum densities of nymphs in the St. Marys (1,164 m^2), St. Clair (1,081 m^2), and the Detroit (1,129 m^{-2}) rivers were about one-third of that in Lake St. Clair (3,099 m^{-2}). In the St. Marys River, mean densities of nymphs were relatively high in connecting channel sections upriver from Sault Ste. Marie (193 m^{-2}), below Lake George (232 m^{-2}), and in Lakes Nicolet (331 m^{-2}) and Munuscong (282 m^{-2}). Densities were low in the channel above Sugar Island (11 m^{-2}), northern Lake George (75 m^{-2}), and southern Lake George (129 m^{-2}). In the St. Clair River, densities of nymphs were low in upper U.S. waters (23 m^{-2}) and upper and lower Canadian waters (47 and 31 m^{-2}), and high in lower U.S. waters (359 m^{-2}). Densities were high in open waters of Anchor Bay and Lake St. Clair (343 and 528 m^{-2}), but not along the perimeter of the lake (22 nymphs m^{-2}). In the Detroit River, the lowest mean densities (20 and 16 m^{-2}) occurred in U.S. waters and the highest mean densities (253 and 167 m^{-2}) were in Canadian waters.

In general, the densities of nymphs in sediments were lower at stations where oil was observed than at stations where no oil occurred in sediments (Table 1). The mean and maximum density of nymphs was significantly lower at stations where oil was present (61 and 1,129 m^{-2}). Of the total stations sampled, oiled sediments were found at 13 (10%) in the St. Marys, 12 (34%) in the St. Clair River, and 21 (45%) in the Detroit River. No oiled sediments were found in Lake St. Clair. In the St. Marys and St. Clair rivers, mean densities of nymphs were significantly lower at stations where sediments were oiled (11 and 20 m^{-2}, respectively) than at stations without oil (249 and 168 m^{-2}, respectively). In the Detroit River, mean density of nymphs was nominally higher in oiled sediments (116 m^{-2}) than in oil-free sediments (76 m^{-2}). However, this difference was not significant. Mean densities of nymphs were relatively low (< 40 m^{-2}) in oiled sediments in 9 of 11 channel sections and relatively high (> 192 m^{-2}) in 6 of 7 channel sections where no oil was observed. Densities of nymphs were high in only 2 of 11 channel sections (*P* and *R*; Fig. 2) where sediments were oiled. High densities of nymphs in these two sections are attributable to the relatively high densities of nymphs (152, 255, 606, and 1,129 m^{-2}) at four stations where oil was found in both hard clay and soft mud sediments.

4. Discussion

Densities of nymphs at stations in connecting channel sections indicated an inverse relation between visibly oiled sediment and the abundance of *Hexagenia* (Table 1). Densities of nymphs were low in oiled sediments in the St. Marys and St. Clair rivers and in the U.S. waters of the Detroit River, but not in Canadian waters of the Detroit River. However, high mean densities (338 and 431 m^{-2}) in two channel sections and maximum density at a single station (1 129 m^{-2}) where oiled sediments were found in the Detroit River indicated that oiled sediments did not prevent the occurrence of nymphs as they apparently did in the St. Marys River (Hiltunen & Schloesser, 1983). In addition, nymph densities were similar in oiled and oil-free sediments in 5 of 11 channel sections (B, H, K, O, and Q) where sediments were oiled. For example, in the channel above Sugar Island, the mean density of nymphs was 12 m^{-2} at stations with oiled sediments and 11 m^{-2} at stations with oil-free sediments.

In general, the densities of *Hexagenia* nymphs and the occurrence of oiled substrates documented in the present study were similar to those previously reported in these areas (Thornley & Hamdy, 1984; Hamdy *et al.*, 1978; Veal, 1968). Densities of nymphs and the occurrence of oiled sediments were high near urban and industrial discharges (Table 1). In the St. Marys River, industrial discharges in Sault Ste. Marie, Ontario have been identified as probable causes for degraded benthic habitat in the north channel above Sugar Island (section B, Table 1 and Fig. 2) and into Lake George (sections C and D); (Veal, 1968; Hamdy *et al.*, 1978; Hiltunen & Schloesser, 1983; Burt *et al.*, 1988). Since at least 1968, water and sediment quality have been impaired in the St. Clair River from Sarnia, Ontario, along the upper and lower Canadian shore (sections I and K) to Lake St. Clair (OME, 1979, 1986). Low densities of nymphs at ten stations in U.S. waters of the upper St. Clair River (section H) were not documented in previous studies. In the Detroit River, low densities of *Hexagenia* in U.S. waters (sections O and Q) were reported by Hiltunen and Manny (1982) and relatively high densities in Canadian waters (sections P and R) by Thornley & Hamdy (1984). The perimeter of Lake St. Clair is the only area in the present study where a low density of nymphs was not associated with the presence of industrial pollution. We observed no oil in the sediments of Lake St. Clair.

Hiltunen & Manny (1982) reported that mean and maximum nymph densities were substantially lower in Lake St. Clair in spring 1977 (183 and 654 m^{-2}, respectively) than in the present study (279 m^{-2} and 3,099 m^{-2}, respectively). The maximum density of 3,099 *Hexagenia* nymphs m^{-2} found near the middle of Lake St. Clair is among the highest *Hexagenia* densities reported in Great Lakes waters. In 1977, the benthic environment of Lake St. Clair was not severely impaired by pollution (Hiltunen & Manny, 1982). The low density of nymphs in the perimeter of Lake St. Clair has been attributed to unsuitable, natural substrates (Hiltunen & Manny, 1982; Thornley, 1985). In the present study, the substrate at 17 of 19 stations in this area consisted of loose sand, often on hard pan substrate. Empirically established criteria indicate that suitable substrates for *Hexagenia* nymphs consist of mixtures of clay, silt, and mud, and that unsuitable substrates are composed of coarse sand and larger-grained substrates (Hunt, 1953; Wright & Mattice, 1981). Laboratory studies of substrate size preference have shown that the optimal substrate for *Hexagenia limbata* nymphs consists of fine materials such as silt and clay (Eriksen, 1963).

Survival of a relatively large number of nymphs in the presence of oiled sediments at four stations in Canadian waters of the Detroit River may be attributed to relatively low oil concentrations in the upper 3 cm of sediments (Bertram *et al.*, in press). Substrates at these four stations were soft and the mean oil concentration in the top 3 cm of sediments was 366 (range 38 to 716) mg kg^{-1} of dry weight sediments. The mean oil concentration in the upper 3 cm of sediment at the other 17 stations in the Detroit River where sediments with visible oil were found was 3,695 (range 14 to 24,100) mg kg^{-1}. In addition, the four stations where densities of nymphs were high in oiled sediments were located in sediment deposition zones where water velocities were relatively low (Fallon & Horvath, 1985). We believe that high densities of *Hexagenia* nymphs can occur in the upper 3 cm layer of sediment in these deposition zones, if that layer is oxidized and oil-free, even when underlying sediments are heavily oiled. However, we are unable to demonstrate vertical stratification of oil or nymphs in sediments in the present study because each sample was a composite of sediments to a depth of about 15 cm.

The occurrence and relatively high density of *Hexagenia* in oiled sediments in the Detroit River but not in oiled sediments of the St. Marys River may reflect the greater diversity of oils spilled and discharged into the Detroit River. Most oils discharged into the St. Marys River for the past 25 years originated from three sources: 1) rolling mills in a steel plant (Veal, 1968; Anonymous, 1979); 2) machines in a paper mill (Anonymous, 1980); and 3) oil separators in a chemical plant (Hamdy *et al.*, 1978). In addition, heavy fuel or bilge oils are sometimes spilled into the St. Marys River by vessels (Anonymous, 1985a, 1985b). In contrast, hundreds of industries discharge oil of various kinds into the St. Clair and Detroit rivers (GLWQB, 1983) and large amounts of more than then ten kinds of light and heavy oils entered the St. Clair-Detroit River system from 1974 to 1985 (Edsall *et al.*, 1988; Manny *et al.*, 1988). The high density of nymphs that we observed in some visibly oiled sediments in the Detroit River suggest some of these oils may be relatively non-toxic.

Crude petroleum and most refined petroleum products are complex mixtures of organic compounds that have been used as gross indicators of hydrocarbon pollution. The visible oil reported in the present study is probably the lighter fraction of oil in sediments, because it floats easily in water and is often aromatic. In general, lighter oil fractions are more toxic than heavier fractions to aquatic organisms because the lighter fractions contain water-soluble compounds, such as benzene, toluene, and naphthalene, that in low concentration (about 1 mg l^{-1}) reduce the growth, reproduction, and survival of many aquatic plants and animals (McCauley, 1966; Emery, 1972; Anderson, 1977; Burk, 1977). However, in view of our findings that some visible oils appear to be toxic to *Hexagenia* nymphs, whereas others do not, we recommend that laboratory and field bioassays be performed to demonstrate the relative toxicity of oiled sediments from representative segments of the Great Lakes Connecting Channels.

5. Conclusion

Our study indicates that the density of *Hexagenia* nymphs in texturally suitable substrates varied substantially throughout the Upper Great Lakes Connecting Channels. In general, oiled sediments and low densities of nymphs were found in areas downstream from industrial and municipal discharges. These results indicate the objectives of 'no visible oil' and 'no impairment of benthic communities' stated in the Water Quality Agreement of 1978 (IJC, 1988) have not been met in many areas of the Upper Great Lakes Connecting Channels.

6. Acknowledgements

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References

Anderson, R. O., 1959. A modified floatation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4: 223–225.

Anderson, J. W., 1977. Responses to sublethal levels of petroleum carbons: Are they sensitive indicators and do they correlate with tissue contamination? In; D. A. Wolfe (ed). Proc. Symp. on Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, Nov. 10–12, 1976. pp. 95–114 Seattle, Washington Pergamon Press.

Anonymous, 1979. River oil pollution complaints climb. The Sault Star. Sault Ste. Marie, Ontario. August 7.

Anonymous, 1980. Abitibi faces $1.5 million order. The Sault Star. Sault Ste. Marie, Ontario. August 29.

Anonymous, 1985a. St. Marys River oil slick concentrated near Birch Point. The Evening News. Sault Ste. Marie, Mich. August 2.

Anonymous, 1985b. Coast Guard finishes off $19 000 oil slick clean-up. The Evening News. Sault Ste. Marie, Mich. August 13.

Bertram, P., T. A. Edsall, B. A. Manny, S. J. Nichols & D. W. Schloesser. Physical and chemical characteristics of sediments in the upper Great Lakes connecting channels 1985. U.S. Env. Protect. Agency Tech. Rep., Chicago, Illinois. (In press).

Britt, N. W., 1955. Stratification of western Lake Erie in summer 1953: effects on the *Hexagenia* (Ephemeroptera) population. Ecology 36: 239–244.

Burk, C. J., 1977. A four year analysis of vegetation following an oil spill in a freshwater marsh. J. Appl. Ecol. 14: 515–522.

Burt, A. J., D. R. Hart & P. M. McKee, 1988. Benthic invertebrate survey of the St. Marys River, 1985. Rep. Prep. for Ont. Min. Env. by Beak Consultants Ltd. Mississanga, Ontario.

EC & USEPA (Environment Canada & U.S. Environmental Protection Agency), 1988. Upper Great Lakes Connecting Channels Study. Draft Final Report. Vol. II. Chicago, Ill. & Toronto, Ontario. 583 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. Biol. Rep. 85(7.3). 130 pp.

Emery, A. R., 1972. A review of the literature of oil pollution with particular reference to the Canadian Great Lakes. Ont. Min. Ntrl. Resour., Res. Inform. Pap. (Fish.) No. 40. 52 pp.

Eriksen, C. H., 1963. The relation of oxygen consumption to substrate particle size in two burrowing mayflies. J. Exp. Biol. 40: 447–453.

Everitt, R. R., G. Cunningham, M. L. Jones & D. R. Marmorek, 1985. Upper Great Lakes Connecting Channel Study Planning Workshop, Final Rep., Envir. Social Sys. Anal. Ltd., Toronto, Ontario.

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., 1964. Mayfly distribution indicates water quality on the Upper Mississippi River. Science 146: 1164–1166.

GLWQB (Great Lakes Water Quality Board), 1983. Report on Great Lakes Water Quality; Appendix A: Areas of concern in the Great Lakes Basin; 1983 update of class A areas, 1984. Rep. to International Joint Commission, Windsor, Ontario. 113 pp.

Hamdy, Y., J. D. Kinkead & M. Griffiths, 1978. St. Marys River water quality investigations 1973–74. Ont. Min. Env., Toronto, Ontario. 53 pp.

Hiltunen, J. K. & B. A. Manny, 1982. Distribution and abundance of macrozoobenthos in the Detroit River and Lake St. Clair, 1977. Admin. Rpt. 82–2. Great Lakes Fish. Lab., Ann Arbor, Michigan. 87 pp.

Hiltunen, J. K. & D. W. Schloesser, 1983. The occurrence of oil and the distribution of *Hexagenia* (Ephemeroptera: Ephemeridae) nymphs in the St. Marys River, Michigan and Ontario. Freshwat. Invert. Biol. 2: 199–203.

Howmiller, R. P. & A. M. Beeton, 1971. Biological evaluation of environmental quality, Green Bay, Lake Michigan. J. Wat. Pollut. Cont. Fed. 43: 123–133.

Hunt, B. P., 1953. The life history and economic importance of a burrowing mayfly *Hexagenia limbata* in southern Michigan lakes. Mich. Dep. Conserv. Bull. Inst. Fish. Res. 4: 1–151.

IJC (International Joint Commission), 1988. Revised Great Lakes Water Quality Agreement of 1978 as amended by Protocol November 18, 1987. Annex 1, P. 40. Windsor, Ontario. 130 pp.

Limno-Tech, Inc., 1985. Summary of the existing status of the Upper Great Lakes Connecting Channels Data. Report to Upper Great Lakes Connecting Channels Study. Ann Arbor, Michigan. 156 pp.

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.

Mason, W. & P. Yevich, 1967. The use of phloxine B and rose bengal stains to facilitate sorting benthic samples. Trans. Amer. Microscop. Soc. 86: 221–223.

McCauley, R. N., 1966. The biological effects of oil pollution in a river. Limnol. Oceanogr. 11: 475–486.

Mozley, S. C. & R. P. Howmiller, 1977. Environmental status of the Lake Michigan region: zoobenthos of Lake Michigan. Argonne Ntnl. Lab. Rep. No. ANL/ES-40. Vol. 6. U.S. Energy Res. Develop. Admin. Argonne, Illinois. 148 pp.

Mozley, S. C. & R. M. LaDronka, 1988. *Ephemera* and *Hexagenia* (Ephemeridae, Ephemeroptera) in the Straits of Mackinac, 1955–56. J. Great Lakes Res. 14: 171–177.

National Academy of Sciences, 1973. Water quality criteria 1972. U.S. Env. Protect. Agency, Washington, D.C. EPA Ecol. Res. Ser. EPS-R3-73-033.

OME (Ontario Ministry of Environment), 1979. St. Clair River organics study, biological surveys, 1968 and 1977. Toronto, Ontario, 99 pp.

OME (Ontario Ministry of Environment), 1986. St. Clair River pollution investigation (Sarnia area). Toronto, Ontario. 135 pp. + appendices.

Schloesser, D. W. & J. K. Hiltunen, 1984. Life cycle of a mayfly *Hexagenia limbata* in the St. Marys River between Lakes Superior and Huron. J. Great Lakes Res. 10: 435–439.

Schneider, J. C., F. F. Hooper & A. M. Beeton, 1969. The distribution and abundance of benthic fauna in Saginaw Bay, Lake Huron. Proc. 12th Conf. Great Lakes Res. 12: 80–90.

Snedecor, G. W. & W. G. Cochran, 1973. *Statistical methods*. 6th Edition. Ames, Iowa State Univ. Press. 593 pp. ISBN 0-8138-1560-6.

Thornley, S., 1985. Macrozoobenthos of the Detroit and St. Clair Rivers with comparisons to neighboring 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. Ont. Min. Env. Toronto, Ontraio. 48 pp.

Veal, D. M., 1968. Biological survey of the St. Marys River. Ont. Wat. Resour. Commiss., Toronto, Ontario. 53 pp.

Veal, D. M. & D. S. Osmond, 1967. Bottom fauna of the western basin and nearshore Canadian waters of Lake Erie, Ontario. Ont. Wat. Resour. Commiss., Toronto, Ontario.

Wright, L. L. & J. S. Mattice, 1981. Substrate selection as a factor in *Hexagenia* distribution. Aquat. Insects 3: 13–24.