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# The Distribution and Contaminant Burdens of Adults of the Burrowing Mayfly, *Hexagenia*, in Lake Erie

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***ABSTRACT.*** Hexagenia *populations, eradicated in the 1950s by anoxia, are recovering in the western basin of Lake Erie. Water from the Detroit River, which provides the largest contaminant load into the lake, flows west-to-east through the center of the western basin. We hypothesized that body burdens of* Hexagenia *would reflect a gradient of decreasing contamination from west to east across the basin, and from the central axis toward shorelines. In summer 1994, we used light traps or made use of lakeside dock lights to collect subimagos (females and males) and imagos (females) for 2 h at sunset at three locations on the Detroit River and at 22 locations throughout Lake Erie. Imagos were found throughout the western basin, but at only three locations in other areas of Lake Erie. Mayflies were analyzed for 59 organochlorine compounds including 42 congeners of PCBs by electron-capture detector gas chromatography. Results were analyzed using principal component analysis to reduce autocorrelations among contaminants. There was a 1:1 correspondence for PCB concentrations between subimago and imago stages, indicating no change in body burdens between moults. The highest contaminant burdens of adults at Monroe, Michigan (an Area of Concern) reflects local sources of contaminated sediments. There are high concentrations in mayfly body burdens at Middle Sister and East Sister islands and lower concentrations near both northern and southern shorelines of the basin.* Hexagenia *are confirmed as effective and efficient monitors of organochlorines.*

***INDEX WORDS:*** Hexagenia, *contaminants, adults, Lake Erie.*

## INTRODUCTION

In mayflies (Ephemeroptera), all growth occurs in the nymphal stage. Subimagos (subadults) and imagos (sexually mature adults) do not feed and seldom live for more than 3 days, during which time they may disperse, mate, and the females oviposit (Edmunds *et al.* 1976, Corkum 1987). The burrowing mayfly, *Hexagenia limbata* Serville (Ephemeridae), is abundant throughout North America in lakes and large rivers where the substrate is composed of soft mud and clay (Edmunds *et al.* 1976). In the Great Lakes basin, *Hexagenia limbata* co-occurs with *H. rigida* McDunnough.

Although nymphs were not reported from the open waters of the western basin of Lake Erie from 1965–1992 (Krieger *et al.* 1996), imagos have been collected from shoreline areas (Ciborowski and Corkum, personal observation). We have documented the reappearance of *Hexagenia* by collecting adults annually from Colchester since 1990 and from Middle Sister Island in 1993 (Ciborowski *et al.* 1994). The extent of the recovery in western Lake Erie has been summarized by others (Krieger and Heady 1994, Schloesser *et al.* 1994). On the basis of zoobenthos collections in 1993 and 1995, Krieger *et al.* (1996) reported populations of *Hexagenia* nymphs in the western, eastern, and southern shores of western Lake Erie, suggesting that nearshore areas were recolonized before open waters.

Phosphorus abatement programs and filtering habits of zebra mussels changed Lake Erie from a mesotrophic to an oligotrophic system (Haffner 1994), facilitating recovery of *Hexagenia* populations. With a decrease in productivity, there may be a corresponding increase in susceptibility of biota

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to contaminants as chemicals become concentrated in specific components of the food web (Haffner 1994). Surveillance of body burdens in short-lived adult aquatic insects that neither feed, drink, nor defecate reflects the life-long (up to 2 years) exposure of immatures to contaminants in the sediment in which they dwell (Corkum *et al.* 1995).

Several studies have shown that adult insects are excellent indicators of overall local contaminant levels in aquatic habitats (Mauck and Olson 1977, Ciborowski and Corkum 1988, Dukerschein *et al.* 1992, Kovats and Ciborowski 1993, Corkum *et al.* 1995). Kovats and Ciborowski (1989) developed standard protocols for collecting adult insects (*Hexagenia* and caddisflies (Trichoptera)) using light traps, and showed a close correspondence between reported levels of organic contaminants in sediments and body burdens of adult insects.

Since the Detroit River provides the largest contaminant load, particularly of PCBs, entering the western basin of Lake Erie (Kelly *et al.* 1991), we hypothesized that body burdens of *Hexagenia* adults would reflect a gradient of decreasing contamination from west to east across the basin. Detroit River water flows through the center of the western basin, producing a current that oscillates irregularly to the north and south of Middle Sister and East Sister islands (McCorquodale, personal communication). Thus, differences between shoreline and mid-basin sites also may exist.

In this study, we analyzed and evaluated contaminant burdens of adult *Hexagenia* by collecting subimagos and imagos attracted to light traps in open water and shoreline areas of the lake. Because of the potential for loss of contaminants between moults of the subimago and imago stages, body burdens of these different winged stages are compared.

## METHODS

In summer 1994, we used light traps (Kovats and Ciborowski 1989) or made use of lakeside dock lights to collect subimagos (females and males) and imagos (females) for 2 h at sunset at three reference locations on the Detroit River (sites selected for their known occurrence of *Hexagenia* and absence of point source contaminants—Ciborowski and Corkum 1988, Kovats and Ciborowski 1989), and at 22 locations throughout the three basins of Lake Erie (Fig. 1, Table 1). The collection period corresponded to the time of greatest flight activity of adult *Hexagenia*. We sampled accessible shoreline areas around the entire lake and island locations in the western basin. Open water sampling was conducted aboard the Environment Canada ship, the *R.V. Limnos*. One site (Sterling State Park), was

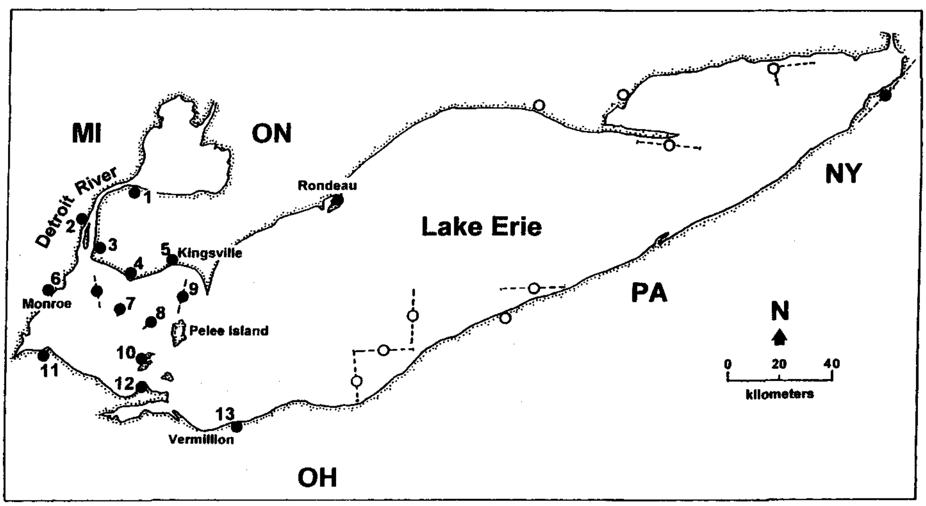


*FIG. 1. Sampling locations where* **Hexagenia** *were present (closed circle) or absent (open circle). Dashed lines extending beyond circles reflect distance travelled by ship during sampling period. Numbered sites (1–13) were those with sufficient mass of* **Hexagenia** *(≥ 3 g) for contaminant analysis. See Table 1 for site descriptions.*

***TABLE 1. Sampling dates and locations of collection sites for* Hexagenia *used in contaminant analysis. Developmental stage analysed for contaminants: SI, subimago; I, imago.***

| Site | Date (1994) | Stage | Location | Latitude (North) | Longitude (West) |
|---|---|---|---|---|---|
| 1 | 28 June | SI, I | Windsor | 42°19′ | 82°56′ |
| 2 | 19 July | SI, I | Wyandotte | 42°12′ | 83°11′ |
| 3 | 16 June | SI, I | Amherstburg | 42°05′ | 83°06′ |
| 4 | 15 June | SI, I | Colchester | 41°59′ | 82°55′ |
| 5 | 22 June | SI, I | Kingsville | 42°02′ | 82°43′ |
| 6 | 16 June | SI, I | Monroe | 41°55′ | 83°19′ |
| 7 | 21 June | SI, I | Middle Sister Isl. | 41°51′ | 83°00′ |
| 8 | 6 July | SI | East Sister Isl. | 41°49′ | 82°52′ |
| 9 | 6 July | I | N. of Pelee Isl. | 41°56′ | 82°38′ |
| 10 | 5 July | SI | South Bass Isl. | 41°40′ | 82°49′ |
| 11 | 20 June | SI | Maumee State Pk | 41°41′ | 83°21′ |
| 12 | 20 June | SI, I | Catawba Isl. | 41°35′ | 82°51′ |
| 13 | 6 July | SI | Vermillion | 41°26′ | 82°21′ |

near the River Raisin in the city of Monroe. The River Raisin was identified as an Area of Concern (AOC) (United States and Canada 1987) because of oils and grease, heavy metals, PCBs, contaminated sediments, a fish consumption advisory, impacted biota, and aesthetics.

Hexane-rinsed light traps were used with dry ice as the killing agent to minimize sample contamination. Light traps were placed on a white sheet about 2–5 m from the water. The sheet served as a reflector. *Hexagenia* tended to land on the sheet rather than enter the funnel of the light trap. Mayflies were grasped by their wings and placed in sample jars. Samples were transported in a cooler containing dry ice.

All samples were stored at –20°C prior to processing and contaminant analysis. Samples (3 g; i.e., ≈30 imagos) were sorted from the collections and analyzed for 59 organochlorine compounds including 42 congeners of PCBs by electron-capture detector gas chromatography (Kovats and Ciborowski 1989, Lazar *et al.* 1992).

Concentrations of individual contaminants were not independent. High correlations were noted among classes of contaminants (e.g., PCBs, pesticides). Accordingly, results were analyzed using principal component analysis (PCA) on ln- transformed data (lipid corrected) to reduce autocorrelations among contaminants. The relationship of PCA factor scores between subimagos and imagos was examined to determine if PCB concentrations were consistent between the two life stages.

To summarize spatial patterns of *Hexagenia* body burdens throughout western Lake Erie, factor scores of the first principal component were mapped using IDRISI (1990), a raster based geographic analysis and image processing system. The latitude and longitude of each sampling site was entered into a grid map of Lake Erie. Factor scores from the first principal component analysis, representing PCB congeners, were then associated with each site. A polynomial regression was then performed relating contaminant concentration to latitude, longitude, and their second order (squared) values. Contours were determined using the IDRISI program from the interpolated values of the best fit polynomial function.

## RESULTS AND DISCUSSION

### Spatial Distribution

Since adult *Hexagenia* are attracted to light traps, an estimate of distance travelled by the insects to the collection site is needed so that body burdens may be associated with a particular source area. Kovats *et al.* (1996) examined inland dispersal of *Hexagenia* to estimate mean dispersal distances and sizes of source areas of single-evening light traps operated for 2 h. Most (56.5 ± 11.14%) *Hexagenia* were collected in traps within 100 m from the water's edge. Ninety per cent of the *Hexagenia* captured at light traps travelled less than 2.8 km. Thus, samples collected at the sample sites are representative of local populations.

*Hexagenia* adults were found at all sites (on- and offshore) sampled in the western basin of Lake Erie

(Fig. 1). Elsewhere in the lake, only three of twelve sites sampled had adult *Hexagenia* and these sites occurred in shoreline areas. Adults of *Hexagenia* were collected from Rondeau and Vermillion in the central basin and along the shore between Dunkirk and Buffalo in the eastern basin (Fig. 1).

Krieger *et al.* (1996) documented the recovery of *Hexagenia* throughout most of the western basin of Lake Erie, but not in the northeast corner of the basin. In contrast, we were able to collect adult *Hexagenia* in this region. Nymphs present may reflect the patchy distribution of oxygenated sediments. Anoxic hypolimnetic water may flow from the central basin between Pelee Island and Point Pelee, accounting for reduced nymphal densities.

The restriction of *Hexagenia* to only two shoreline areas in the central basin of Lake Erie suggests that either suitable substrate is lacking or that anoxic conditions occur offshore. Reynoldson and Hamilton (1993) inferred historical changes in Lake Erie *Hexagenia* populations from enumeration of mandibular tusks obtained from sediment cores. Although *Hexagenia* nymphs have been recorded in deep waters of Lake Simcoe (Rawson 1930), the absence of *Hexagenia* from the deep waters of the central basin is apparently due to periodic anoxia (Reynoldson and Hamilton 1993, Winter *et al.* 1996). Thus, the current restriction of *Hexagenia* to shorelines reflects historical spatial patterns. With increased water clarity and associated oxygen conditions at the substrate level, we anticipate that *Hexagenia* will be found in shoreline areas between Vermillion and Buffalo with time.

## Contaminant Analysis

Sufficient mass of *Hexagenia* was collected at nine sites in Lake Erie and three sites along the Detroit River (Fig. 1, Table 1) for contaminant analysis. Most *Hexagenia* were collected from the western basin of Lake Erie. A sample of sufficient mass also was obtained from Vermillion, along the southwestern shoreline of the central basin. Adult *Hexagenia* were in flight at Rondeau (north shore, central basin), but there were too few specimens for analysis. *Hexagenia* males were collected from sites along the southeast shoreline of Lake Erie from Dunkirk to Buffalo, but numbers were low.

Concentrations of representative contaminants (pesticides and PCBs) in the Detroit River and in shoreline and open water areas of western Lake Erie are presented in Table 2. Of the suite of PCB congeners measured, data are presented for those with maximum concentrations in *Hexagenia* adults and potential toxicity (McFarland and Clarke 1989) including penta- (PCB 101), hexa- (PCB 138, PCB 153), and hepta- (PCB 180) chlorobiphenyls (Table 2). Coplanar (non-ortho substituted) PCBs, which are highly toxic to biota (Metcalfe and Haffner 1995), were not detected in any of the *Hexagenia* samples.

*TABLE 2. Concentrations of representative compounds (µg/kg lipid) in* **Hexagenia** *adults for sample sites.*

| Site | PCB 101 | PCB 138 | PCB 153 | PCB 180 | ppDDE | Dieldrin | Trans na |
|---|---|---|---|---|---|---|---|
| **Detroit River** | | | | | | | |
| Windsor | 38.35 | 54.78 | 69.60 | 56.17 | 129.78 | 52.62 | 21.60 |
| Wyandotte | 73.22 | 102.88 | 115.76 | 78.47 | 135.42 | 39.37 | 14.75 |
| Amherstburg | 123.28 | 171.26 | 192.11 | 147.17 | 203.24 | 87.45 | 24.49 |
| **Lake Erie Shore** | | | | | | | |
| Monroe | 765.78 | 1303.92 | 1078.25 | 1023.71 | 587.70 | 105.70 | 68.63 |
| Maumee | 114.64 | 298.26 | 269.73 | 278.91 | 315.88 | 150.87 | 78.16 |
| Catawba | 121.84 | 161.55 | 185.38 | 115.52 | 150.72 | 84.84 | 22.74 |
| Vermillion | 366.37 | 528.76 | 560.84 | 427.21 | 312.83 | 109.73 | 50.66 |
| Colchester | 136.72 | 205.35 | 213.19 | 184.14 | 199.82 | 67.91 | 27.81 |
| Kingsville | 192.73 | 506.97 | 426.21 | 353.94 | 201.52 | 82.12 | 31.67 |
| **Lake Erie Open** | | | | | | | |
| Middle Sister Is. | 300.38 | 513.96 | 507.65 | 507.84 | 318.36 | 50.48 | 25.24 |
| East Sister Is. | 333.72 | 539.37 | 549.67 | 443.19 | 282.23 | 78.74 | 39.87 |
| South Bass Is. | 210.79 | 272.25 | 308.59 | 209.91 | 213.22 | 74.89 | 30.62 |
| North of Pelee | 275.42 | 427.80 | 425.61 | 35.39 | 309.65 | 68.21 | 38.61 |

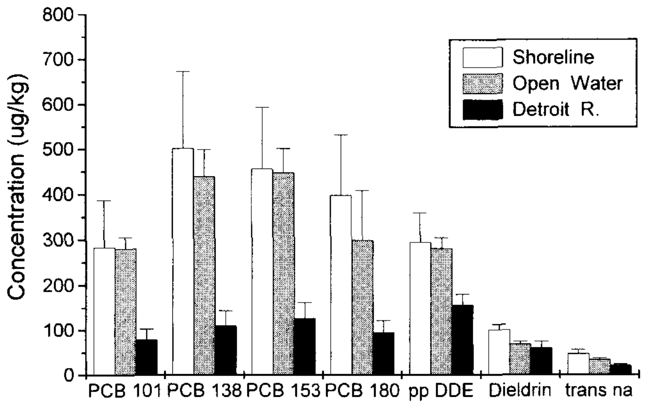


***FIG. 2. Mean (± S.E.) concentrations of representative compounds in* Hexagenia *adults for sites on the Detroit River and in shoreline and open water areas of western Lake Erie.***

Concentrations of contaminants were compared among open and shoreline areas of the western basin and the Detroit River. Mean (± S.E.) concentrations of contaminants indicated that no significant differences occurred among samples collected from shoreline (n = 6) and open water (n = 4) areas (Fig. 2). Body burdens in *Hexagenia* were significantly lower for selected PCBs and DDE at Detroit River sites (n = 3) than at Lake Erie sites ($P < 0.05$) (Fig. 2). The high degree of variability among shoreline sites was due to the unusually high body burdens from samples collected at Monroe compared to samples obtained from other shoreline stations (Table 2). High PCB levels (40,000 mg/kg) were discovered in sediments near an industrial wastewater discharge pipe in the River Raisin AOC (Hartig and Law 1994). The elevated body burdens in *Hexagenia* at Monroe reflect this local source of contamination. High concentrations of PCBs also were noted at Middle Sister and East Sister islands (Table 2).

Because concentrations of individual contaminants in the insect samples were not independent of one another, we used principal component analysis (PCA) to identify groups of associated compounds from all sample sites. The first principal component (PC-1) accounted for 64% of the overall variation in the data and was highly positively correlated with PCB congeners. PC-2 contributed 9.2% of the overall variation and was correlated with pesticides; PC-3 contributed 6.8% of the variation and was correlated with organochlorines representing industrial by-products (e.g., pentachlorobenzene (QCB)) (Table 3).

Regression analysis using PC-1 factor scores revealed a 1:1 correspondence for PCB concentrations between subimagos and imagos (the slope was not significantly different from 1, $P > 0.05$; $R^2 = 0.76$, n = 8), indicating no change in body burden between moults at those sites where both subimagos and imagos were collected. Thus, either life history stage may be used in biomonitoring studies since there appears to be no significant loss (or metabolism) of contaminants between subimago and imago for PCBs.

To explore the spatial distributions of contaminants throughout the study region, site-specific factor scores from the first principal component (representing PCB congeners) were overlaid on a grid map of Lake Erie using an image processing system (IDRISI 1990). A surface contour map of *Hexagenia* body burdens was created using factor scores from the first principal components associated with each sample site (Fig. 3). Map contours revealed decreasing contaminant concentrations

***TABLE 3. Identification of the contaminants most highly correlated with the first three principal components and the proportion of variance explained by each component.***

| Factor | Contaminant | Correlation between contaminant and factor | Proportion of variation explained |
|---|---|---|---|
| PC1 | PCB 195 | 0.972 | 0.64 |
| | PCB 97 | 0.971 | |
| | PCB 129 | 0.969 | |
| | PCB 183 | 0.961 | |
| PC2 | Dieldrin | 0.819 | 0.09 |
| PC3 | QCB | 0.904 | 0.07 |
| | | Total: | 0.80 |

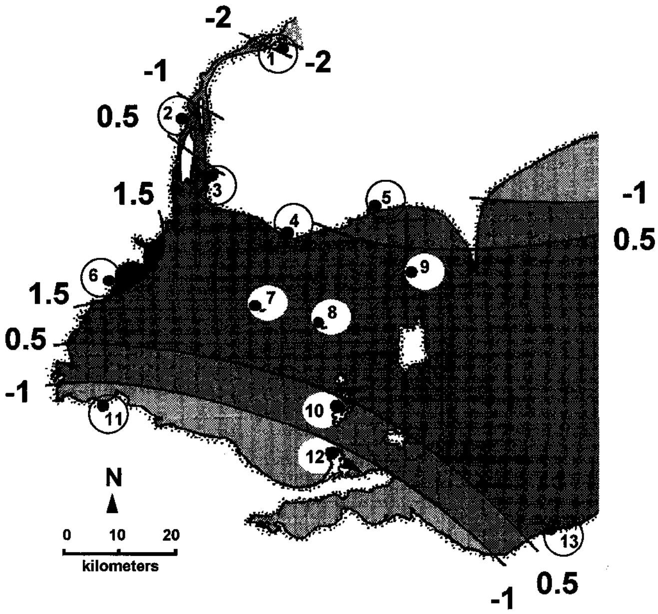


***FIG. 3. Map of contaminant contours derived from site-specific factor scores (F.S. = –2 to 1.5) of the first principal component. The decrease in shading from black (≥1.5) to light gray (F.S. ≤ –2) represents a decrease in contaminant body burden of* Hexagenia *adults from most to least contaminated areas with respect to PCB concentrations. See Table 1 for site descriptions.***

from the western shore (Monroe), to the lower Detroit River and eastward to Middle Sister and East Sister islands. Contaminant concentrations of PCB body burdens in *Hexagenia* adults declined from the center of the western basin toward both the northern and southern shores of the lake (Fig. 3).

Body burdens of *Hexagenia* in the Detroit River were low. Values obtained for the Windsor site in 1994 (this study) were similar to values obtained by Kovats and Ciborowski (1989) for the Detroit River in 1987. For example, values in µg/kg of lipid for representative PCBs (this study; Kovats and Ciborowski 1989) were PCB 101 (38.35; 61.94), PCB 138 (54.78; 86.96), PCB 153 (69.60; 104.51), and PCB 180 (56.17; 49.95).

No *Hexagenia* were found in the most contaminated area of the Detroit River, the Trenton Channel (Corkum *et al.* 1995). Ali *et al.* (1993) reported significant loads of PCBs and PAHs entering Lake Erie from the Trenton Channel. Laboratory bioassays have indicated that Trenton Channel sediment is about four times too toxic for *Hexagenia* to complete their life cycle (Corkum *et al.* 1995). In the present study, *Hexagenia* were collected upstream of the Trenton Channel and from the less contaminated eastern shoreline at Amherstburg. These data are representative of an earlier study of adult aquatic insects (Trichoptera and Ephemeroptera) in which highly chlorinated PCBs (hexa-, hepta-, and octachlorobiphenyls) were recorded from the Detroit River (Ciborowski and Corkum 1988).

The high concentrations of contaminants in insects obtained from islands located in the center of the western basin, away from obvious point sources, are consistent with previous studies (Ciborowski unpublished). Water currents from the Detroit River and within western Lake Erie move from west to east across the basin (Bolsenga and Herdendorf 1993, McCorquodale personal communication). These flow patterns from areas of high contamination may account for the elevated PCB concentrations at Middle Sister and East Sister islands.

The concentration of contaminants in body burdens of adult *Hexagenia* may be a function of sedimentation rates on the lake bottom in which immatures burrow. Thus, differences in sedimentation rates could affect the contaminant exposure of *Hexagenia* nymphs that dwell in soft sediments and ultimately the body burdens of adults. Because of resuspension events, sedimentation rates are difficult to determine in western Lake Erie (Reynoldson and Hamilton 1993). Sediment accumulation rates of up to 7 mm/y may occur (Kemp *et al.* 1977); average sedimentation rates in the western basin vary from 3.1 mm/y (Burns 1985) to 3.9 mm/y (Carter and Hites 1992).

## CONCLUSIONS

*Hexagenia* populations have reappeared in western Lake Erie. Our 1996 and 1997 collections in the same study area indicate that the recovery has continued to improve. Highest PCB concentrations occurred at Monroe, reflecting local sources of contaminated sediments. The empirically derived contour map of *Hexagenia* body burdens in the western basin reflects high contaminant concentrations near source areas along the western shoreline with lower concentrations toward the east and toward both northern and southern shorelines of the lake. Because of the 1:1 correspondence of PCB concentrations between subimagos and imagos, either life history stage could be used in biomonitoring programs.

Although the historical extent of *Hexagenia* populations in Lake Erie has been well documented, data on temporal variation in contaminant burdens are limited. The historically high productivity levels of Lake Erie have declined dramatically. In eutrophic systems, trophic dilution is thought to occur (Swackhamer and Skoglund 1993). The high levels of productivity protect the biota since an organism's growth rate exceeds its chemical uptake. With the decline in productivity in Lake Erie, the benthic community may no longer be "protected" from chemical loadings.

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