FINAL REPORT

LAKE ERIE PROTECTION FUND PROJECT LEPF-97-30

Ecosystem Change in Lake Erie: Recolonization by Burrowing Mayflies and their Contribution to Fish Diets

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Executive Summary

The goals of this project were to document the continued expansion of the burrowing mayflies *Hexagenia limbata* and *H. rigida* into suitable habitat in the western and central basins of Lake Erie and to measure their role in the benthic-pelagic food web. Three hypotheses were tested: (1) that the mayflies would continue to increase in abundance and distribution in the western basin during the late 1990s, (2) that they would begin to repopulate the central basin in an eastward direction during the late 1990s, and (3) that forage fishes intermediate in the food web between the benthic invertebrates and the commercial and sport fishes would feed increasingly on the mayfly nymphs as the density of nymphs increased in both basins. Therefore, we established the following objectives: (1) To survey the distribution and abundance of *Hexagenia* nymphs in sediments in the western basin in 1997 and 1998, and in the nearshore zone of the central basin in the years 1997 through 1999. (2) To document the distribution and relative abundance of *Hexagenia* subadults and adults at several onshore western basin and central basin sites in 1997, 1998 and 1999, enlisting volunteer help. (3) To determine the contribution of *Hexagenia* to the diets of several species of Lake Erie fishes.

***Hexagenia* continued to expand its distribution and density (individuals per square meter) in the western basin in 1997 but showed a sharp decline in density in 1998 while continuing to expand its range. These results indicate that these mayflies may have attained or exceeded their carrying capacity in 1997 and that their numbers will vary around that capacity in future years. In the central basin, data from the volunteer Mayfly Watch and sediment collections in nearshore waters showed that *Hexagenia* did increase in density each year from 1997 through 1999, with greater numbers west of Euclid, Ohio. Nightly collections of winged *Hexagenia* at three locations along the western basin shoreline revealed that the pattern of emergence ("swarms") varies somewhat from place to place and year to year but that most years there are one or two periods of peak emergences (very large swarms) lasting from one to several nights each that account for most of the mayflies that emerge from the lake each summer. The dates**

of peak emergence occurred between the middle of June and the second week in July. The Mayfly Watch indicated similar dates of peak emergence in the central basin.

The diets of four forage fishes were investigated in both the western and central basins. Emerald shiners (*Notropis atherinoides atherinoides*) fed almost entirely on zooplankton in both basins and none were found to have consumed *Hexagenia*. Spottail shiners (*Notropis hudsonius*) also fed largely on zooplankton but did occasionally include *Hexagenia* in their diet. Of the four species, only spottail shiners fed on the nymphs in the central basin. Trout perch (*Percopsis omiscomaycus*) had the most varied diet of the four species, feeding on both the zooplankton and the zoobenthos, and feeding heavily on *Hexagenia* in the western basin. The percentage of trout perch with *Hexagenia* in their stomachs each year, as well as the average number of *Hexagenia* per stomach, reflected the changes in the density of the nymphs in the sediments. Although the actual number of nymphs was small in comparison to the total animals consumed during the May through July period ($\leq$5%), the dry biomass of the mayflies contributed up to 82% of the diet. By contrast, trout perch from the central basin did not contain *Hexagenia*. Silver chubs (*Hybopsis storeriana*) were unique in including a large proportion of native fingernail and pill clams (Pisidiidae) and the exotic zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*) in their diet; together these clams accounted for as much as 69% of the organisms in the silver chub diet during the period May through July, while *Hexagenia* comprised up to 5% of the organisms eaten in the western basin. No silver chubs taken from the central basin contained *Hexagenia*.

This study has shown that *Hexagenia* may have reached its carrying capacity in the western basin while increasing in abundance in the central basin during the late 1990s. It has further shown that these mayflies have become an important link in the overall fisheries food web of western Lake Erie.

Introduction

The Lake Erie ecosystem has undergone major changes since Europeans began to exploit its resources in the eighteenth century. Two obvious changes have been (1) shifts in the abundant game and commercial fish species, largely in response to overharvest and changes in habitat quality, and (2) a long term degradation of water quality that threatened public health as well as the aquatic communities. Less noticeable among the changes in Lake Erie in the past 200 years has been a major alteration in the "keystone" aquatic invertebrates, those that exert a major influence on the invertebrate community structure and dynamics. Some of those changes in the invertebrate community affected the food quantity and quality available to important fishes.

Two species of burrowing mayflies, *Hexagenia limbata* (Serville) and *H. rigida* McDunnough, were keystone species in western Lake Erie and in the nearshore regions of the central and eastern basins. Photographs of an adult and a nymph of *Hexagenia* are included in an earlier report to the Ohio Lake Erie Office (Krieger 1999b). For centuries until the mid-1950s, the nymphs were abundant in the sediments of the western basin (Reynoldson and Hamilton 1993) and comprised an important food resource for many of the forage fishes upon which commercially and recreationally valuable fishes, such as walleye (*Stizostedion vitreum vitreum*), fed. Some important fishes, such as yellow perch (*Perca flavescens*), fed directly on the bottom-dwelling nymphs. Among numerous other fishes that fed on *Hexagenia* in Lake Erie were white perch (*Morone americana*), freshwater drum (*Aplodinotus grunniens*), and channel catfish (*Ictalurus punctatus*) (Boesel 1937, Daiber 1952, Price 1963). *Hexagenia* were most vulnerable to fish predation in June and July, when the nymphs swam to the surface to molt into winged subadults (subimagoes), and they were frequently the primary food in fish diets during that period. The winged, nonbiting subadults (subimagos) and adults (imagos) in the 1940s and early 1950s were widely reported in metropolitan newspapers and other media to attain nuisance swarms of millions of individuals (Teale 1960, Burns 1985).

Between 1930 and the early 1950s, densities of *Hexagenia* nymphs in the sediments of the western basin averaged around 300 m^{-2} to 500 m^{-2}, and at some locations in the island area, densities occasionally exceeded 1000 m^{-2} (Britt 1955, Wright 1955). The large populations of the two species died suddenly, however, in the late summer of 1953 as a direct result of depletion of dissolved oxygen in the bottom waters of the lake (Britt 1955). Other factors, such as increased application of insecticides in the Great Lakes basin, have been suggested as additional mechanisms in the demise of the burrowing mayfly population of Lake Erie, although there exists little evidence to support those contentions (Burns 1985). Oxygen depletion was known to be an increasing problem in much of the central basin (Burns 1985), but until the 1950s the shallowness of the polymictic western basin seemed to ensure that a sufficient supply of dissolved oxygen was maintained at the interface between the bottom sediments and the overlying water.

Under the Great Lakes Water Quality Agreement of 1972, signed by Canada and the U.S., an extensive binational effort was launched to reduce and eliminate sources of pollution

to Lake Erie. Water quality in the lake responded to those measures (Makarewicz and Bertram 1991); however, the burrowing mayflies apparently did not begin to recolonize the sediments until the late 1980s or early 1990s. Around 1991, *Hexagenia* began a rapid recolonization of the western basin sediments (Krieger *et al.* 1996). The winged subadults and adults formed onshore swarms of sufficient size in June and July 1995 that the public along the lake shores first began to notice them again. In late June 1996, swarms of millions of mayflies were attracted to lights near the lakeshore in cities from Toledo (Point Place) to Port Clinton, Ohio, and wire services and newspapers carried stories about their impact throughout Ohio and the region (e.g., Hogarth 1996; *The Ann Arbor News*, 25 June 1996; *The Plain Dealer*, 24 June 1996). The increase in the size of the onshore swarms corresponded with increases in the distribution and abundance of nymphs in the lake sediments (Krieger *et al.* 1996). The size and timing of the swarms have varied from summer to summer, and their appearance continues to draw the attention of the public and the popular press (e.g., *The Blade*, 5 June 2000; Markey 2000).

The changes that permitted the recolonization of the lake bottom by *Hexagenia* have not been determined (Krieger *et al.* 1996). Pollution abatement measures undertaken over the past two decades were resulting in an improvement in some lake quality indices, such as secchi depth (Makarewicz and Bertram 1991). Dramatic changes wrought by the invasion of the zebra mussel (*Dreissena polymorpha*), and later the quagga mussel (*D. bugensis*), such as a further increase in water clarity and the consequent re-establishment of regions of submersed aquatic plants, may have played some, as yet unresolved, role in the ability of *Hexagenia* to recolonize the sediments successfully. Interactions between *Dreissena* and early-instar *Hexagenia* nymphs were recently investigated experimentally through an Ohio Sea Grant project directed by David J. Berg (Miami Univ.) and K. Krieger. The results of that study, which were confirmed by field studies, suggested a negative response of the nymphs to large densities of *Dreissena* overlying the nymphs' native substrate (Freeman 1999). Studies regarding the possibility of a substantial decline in toxic contaminants in the sediments, within which *Hexagenia* nymphs construct their burrows, apparently have not been conducted.

The resurgence of the burrowing mayfly populations of Lake Erie is important (1) because of their impact on the benthic-pelagic food web, which extends to key commercial and recreational fishes and ultimately to humans; (2) because of their high visibility to the public while swarming; and (3) because of their very real potential economic impact on public utilities, such as causing electrical shorts at power generating plants (*The Ann Arbor News*, 25 June 1996), and on public services, such as creating slick streets and fouled beaches (*The Blade*, 1 July 1996). *Hexagenia* may be bioconcentrating toxic contaminants that remain in lake sediments and transfering them via fish to humans. This concern is being investigated by others (Corkum *et al.* 1997).

Hypotheses and Objectives

We tested three primary hypotheses in this study. (1) Although the burrowing mayflies *Hexagenia limbata* and *H. rigida* had begun recolonizing the sediments of western Lake Erie in the early 1990s, they would continue to increase in abundance and distribution in the

western basin during the late 1990s. (2) Based on the large populations of *Hexagenia* that had developed in the western basin in the early and mid-1990s, we predicted that *Hexagenia* would begin to increase in abundance in an eastward direction in the nearshore zone of the central basin in the late 1990s, demonstrable both as nymphs in the sediments and as winged stages on shore. (3) We further predicted that forage fishes would feed increasingly on the mayfly nymphs as the density of nymphs in the lake sediments increased in both the western basin and central basin.

The goals of this project were to document the continued expansion of *Hexagenia* into suitable habitat in the western and central basins and to measure its role in the benthic-pelagic food web. Therefore, we established the following objectives: (1) To survey the distribution and abundance of *Hexagenia* nymphs in sediments in the western basin in 1997 and 1998, and in the nearshore zone of the central basin in the years 1997 through 1999. (2) To document the distribution and relative abundance of *Hexagenia* subadults and adults at several onshore western basin and central basin sites in 1997, 1998 and 1999, enlisting volunteer help. (3) To determine the contribution of *Hexagenia* nymphs and winged stages to the diets of several species of Lake Erie fishes.

Methods

Objective 1. Distribution and Abundance of Nymphs

General Collection Method. The locations of the stations in the western and central basins that were sampled for nymphs in 1997, 1998, and 1999 are listed in Tables 1 and 2 and are shown in Figures 1 and 2. Because suitable sediments for *Hexagenia* are very patchily distributed in the nearshore zone of the central basin, a number of sampling sites had to be shifted or abandoned, and new ones added, from year to year (Table 2). The western basin was sampled in May of both 1997 and 1998, whereas the central basin was sampled in the first half of June all three years. Sampling was completed in each basin prior to the beginning of the seasonal emergence of the subadults.

Sampling was accomplished aboard the *R/V Pike*, operated by the U.S. Geological Survey, Lake Erie Biological Station in Sandusky, Ohio. Four replicate sediment samples were collected with an Ekman grab (23.9 cm x 23.9 cm) at each station each year and were individually rinsed onboard through a No. 30 mesh (0.60 mm openings) sieving bucket with the aid of a stream of lake water from a hose. The sample residues were preserved with formaldehyde and were returned to the Heidelberg College Water Quality Laboratory for further processing and removal of nymphs for sexing, counting, and measuring. The methodology and equipment were identical to those employed during sampling in 1995 and 1996 (Krieger 1999b).

Table 1. Locations and depths of sediment sampling stations in the western basin, showing years sampled. Refer also to Figure 1.

				Years Sampled			
Station	N Latitude	W Longitude	Depth, m*	95	96	97	98
5B	41□41.50'	82□46.00'	11.3	Ć	Ć	Ć	Ć
6B	41□52.00'	82□49.00'	13.1	Ć	Ć	Ć	Ć
3D	41□56.33'	83□12.17'	8.5	Ć	Ć	Ć	Ć
8D	41□57.33'	83□07.17'	9.1	Ć	Ć	Ć	Ć
15D	42□02.00'	83□09.17'	6.4	Ć	Ć	Ć	Ć
1K	41□45.00'	82□45.00'	12.2	Ć	Ć	Ć	Ć
2K	41□46.00'	82□52.00'	12.2	Ć	Ć	Ć	Ć
6K	41□40.00'	82□40.00'	13.1		Ć	Ć	Ć
7K	41□34.00'	82□40.00'	13.7		Ć	Ć	Ć
2L	41□47.83'	83□13.83'	9.4	Ć	Ć	Ć	Ć
6L	41□50.83'	83□07.00'	11.6	Ć	Ć	Ć	Ć
7L	41□49.00'	83□00.00'	11.9	Ć	Ć	Ć	Ć
10L	41□53.67'	82□59.17'	12.5	Ć	Ć	Ć	Ć
1M	41□42.83'	83□25.50'	3.4	Ć	Ć	Ć	Ć
7M	41□44.00'	83□17.83'	7.3	Ć	Ć	Ć	Ć
8M	41□47.33'	83□21.33'	7.0	Ć	Ć	Ć	Ć
1P	41□32.92'	82□55.00'	7.3	Ć	Ć	Ć	Ć
3P	41□39.00'	83□09.00'	6.1	Ć		Ć	
4P	41□45.00'	83□06.25'	11.0	Ć	Ć	Ć	Ć
5P	41□44.00'	82□58.25'	11.6	Ć	Ć	Ć	Ć
6P	41□38.42'	82□56.67'	9.8	Ć	Ć	Ć	Ć
7P	41□41.25'	83□02.42'	11.0	Ć	Ć	Ć	Ć
4R	41□52.83'	83□17.83'	7.3	Ć	Ć	Ć	Ć
1T	41□41.81'	83□28.13'	2.7	Ć	Ć	Ć	Ć
2T	41□44.55'	83□26.86'	2.7	Ć	Ć	Ć	Ć
3T	41□44.21'	83□27.77'	2.7			Ć	Ć

*As recorded in 1998 or last year sampled

Table 2. Locations and depths of sediment sampling stations in the central basin, showing years sampled. Refer also to Figure 2.

				Years Sampled				
Station	N Latitude	W Longitude	Depth, m*	95	96	97	98	99
BRD15	41□24.37'	82□29.52'	11.0			Ć	Ć	Ć
CP1	41¼30.01'	82¼38.07'	12.2				Ć	Ć
CP2	41¼26.60'	82¼.35.00'	11.6				Ć	Ć
CP3	41¼25.71'	82¼35.04	9.1				Ć	Ć
LV52	41□27.30'	82□24.00'	13.7			Ć		Ć
LV52s	41¼26.14'	82¼22.54'	12.2				Ć	
LV56	41□27.30'	82□21.10'	13.7			Ć		Ć
LV56b	41¼27.00'	82¼20.86'	13.1				Ć	
LV66	41□28.75'	82□11.17'	10.4				Ć	
LV66b	41¼28.84'	82¼11.44'	10.1			Ć		
BRD16	41□30.11'	82□09.74'	12.2			Ć		
BRD16b	41¼29.57'	82¼09.46'	11.6				Ć	Ć
AV1			18.3					Ć
RR1	41□29.49'	81□50.38'	4.6		Ć	Ć		
RR1b	41¼29.83'	81¼51.72'	12.2				Ć	Ć
RR2	41□30.59'	81□40.32'	ca. 12		Ć			
CW80	41□29.83'	81□45.33'	9.4			Ć	Ć	
CW81	41□30.80'	81□45.33'	14.0				Ć	Ć
CW82	41□32.87'	81□45.83'	16.8					Ć
EW1	41□29.72'	81□43.94'	3.0		Ć			
CE84	41□29.83'	81□43.50'	8.2	Ć	Ć	Ć	Ć	Ć
CE85	41□30.30'	81□42.75'	9.4	Ć			Ć	Ć
CW88	41□31.50'	81□42.70'	13.1				Ć	Ć
CW89s	41¼30.95'	81¼43.60'	13.1				Ć	
CE90	41□31.60'	81□40.50'	5.8	Ć				
CE91	41□32.25'	81□39.33'	7.9			Ć	Ć	Ć
CE92	41□32.70'	81□40.50'	14.6					Ć
CE92b	41¼32.25'	81¼40.45'	12.8				Ć	
CE97b	41¼33.20'	81¼38.03'	12.2				Ć	
CE99b	41¼36.08'	81¼34.25'	10.7				Ć	
CE100	41□36.20'	81□35.83'	14.6					Ć
BRD18	41□45.47'	81□19.22'	11.0			Ć	Ć	Ć
FP111	41□46.10'	81□18.40'	12.2			Ć	Ć	Ć
FH1	41□45.95'	81□16.91'	7.3			Ć	Ć	Ć
FP116	41□47.17'	81□16.80'	14.0			Ć		
FP116b	41¼46.92'	81¼16.87'	12.2				Ć	Ć
AS124	41□52.25'	81□00.40'	14.6			Ć		
AS124b	41¼52.35'	80¼59.25	12.2				Ć	Ć
BRD19	41□54.38'	80□49.42'	10.4			Ć		
BRD19b	41¼54.55'	80¼49.49'	12.2				Ć	Ć
AS135	41□56.39'	80□47.58'	17.1			Ć		
AS135s	41¼52.95'	80¼55.60'	12.2				Ć	Ć
AS139c	41¼54.89'	80¼48.31'	11.0				Ć	Ć
AH1	41□55.10'	80□47.65'	10.7			Ć		
AH1b	41¼55.15'	80¼47.70'	10.7				Ć	Ć
AH2	41□54.92'	80□47.30'	9.8			Ć		Ć
AH2b	41¼54.92'	80¼47.36'	9.4				Ć	
CN1	41□59.90'	80□34.00'	17.7					Ć

*As recorded in 1998 or last year sampled

***Hexagenia* Rapid Assessment Method (*H*RAM)**. A technique was proposed and attempted whereby a simple, standardized field procedure would permit the rapid assessment of the abundance of *Hexagenia* nymphs at specific locations without the need to return sample residues to the laboratory for laborious processing. The advantage of a *H*RAM was expected to be that the results would be complete when the technician returns from the field, rather than requiring weeks for sample analysis. Thus, a much larger number of sites could be sampled with limited staffing and funding than when using standard quantitative techniques. Furthermore, the method would eliminate the substantial time lag in reporting nymph densities prior to the annual mayfly emergence.

The HRAM involved standard field methods except that the sediment collected in the Ekman grab was rinsed through a screen with 3.00 mm openings prior to rinsing it through the standard No. 30 (0.60 mm openings) screen. All *Hexagenia* nymphs seen on the 3-mm screen were removed by hand. A standard time was allotted for the sample screening and searching process. We field-tested the method against the standard quantitative methodology in order to test its efficiency at recovering a consistent proportion of mayflies, because the smallest nymphs would pass through the 3-mm screen.

Biomass of Live Nymphs. As many nymphs as possible from each sample were returned alive in vials on ice to the laboratory, where they were rinsed and frozen in water within 24 hrs. Later they were thawed and their sizes were determined to the nearest 0.1 mm by measuring head width and length. Each nymph was dry weighed to obtain a size:biomass relationship. Initial samples were also ash-free dry weighed (Klemm *et al.* 1990) in order to develop a dry mass:ash-free dry mass relationship that could be applied to later samples. Comparisons of regressions of dry mass on size were intended to permit estimation of the relative health or condition of the nymphs in different parts of the lake. The data for this part of the study await detailed analysis.

Objective 2. Distribution and Relative Abundance of Winged Stages (Subadults and Adults)

Western Basin. The objectives for observing winged stages were different between the western and central basins. By the time this study was proposed (1996), *Hexagenia* had repopulated the soft sediments in most of the western basin. The question was not what the distribution of subadults and adults along the western basin shore would be, for it was known that they would be found nearly everywhere. Rather, several questions revolved around their distribution and relative abundances at different locations on individual nights. For example, even though records show that *Hexagenia* displays a peak abundance on a single night during the summer, does that peak occur on the same night everywhere around the basin? On nights when there are very few winged *Hexagenia* at one place, are there a great number elsewhere? If abundances around the shoreline are dissimilar, is there a relationship with weather patterns?

To determine changes in relative abundance of winged *Hexagenia* during the primary emergence period in the western basin, we selected three sampling sites, one on

Gibraltar Island in Put-in-Bay Harbor of South Bass Island, another on Sand Road east-northeast of Port Clinton, and the third a few hundred meters from the shore of the lower Ottawa River (drowned by Lake Erie) in Point Place, eastern Toledo (Figure 3). From 15 June 1997 through 31 July 1997, insect blacklights were operated every night for two hours beginning at sundown. Each blacklight was centered on a white sheet pulled taut over a piece of white-painted plywood on which was drawn a circle containing an area of 1.0 m^2. After two hours, all the *Hexagenia* on the blacklight and within the circle were collected and placed in a container of ethyl alcohol. A different container(s) was used each night. Weather conditions during the 2-hour time of collection and the number of sample containers were recorded on a data sheet.

Recruits for the project were compensated a small sum. However, because of the requirement that the mayflies be collected every night for over six weeks, and because one of the recruits moved, operators in the Point Place and Port Clinton areas could not be arranged in 1998. Therefore, the number of blacklights and boards used in 1998 and 1999 was reduced to two, operated by the same individual, a graduate student or research assistant residing at the Franz Theodore Stone Laboratory on Gibraltar Island. One assembly was set near the edge of a north-facing cliff about 35 feet (10.5 m) above the water in the same location as in 1997, the other facing east on a grassed area about 5 meters inland and about 3 feet (1 m) above the water (Figure 3). The purpose of this arrangement was to examine the microdistribution and abundance of winged *Hexagenia*, in this case the role of the compass orientation of the shoreline in combination with height above the lake over a short distance (approximately 100 m) in attracting mayflies to the insect lights. The mayflies thus collected each night were sexed, identified to species, and counted.

Central Basin. Repopulation of the soft sediments of the central basin had not been documented by the mid-1990s, and no reports of summer swarms of *Hexagenia* had been reported. *Hexagenia* nymphs were absent from all of hundreds of central basin samples from Huron to Conneaut, OH, examined by this investigator, collected in 1978, 1979, 1987, 1988, and 1989 (Krieger 1984, Krieger and Ross 1993, and unpublished USGS data on the 1987 samples). They were also absent in samples collected by USGS from the same sites in 1995 as in 1987 (unpublished data, Mike Bur, USGS, Sandusky, OH). It was thought that, if the mayflies were beginning to repopulate the central basin sediments, the probability of finding adults onshore was much greater than finding widely scattered nymphs in the sediments. Therefore, the objective in the central basin was to document where along the central basin shoreline, from Huron, OH, to the Pennsylvania state line, winged *Hexagenia* would appear in the summers of 1997, 1998, and 1999, and how many nights they appeared at each location. For this purpose, a program conducted by more than 20 volunteers along the lakeshore, called "Mayfly Watch", was instituted. Detailed methods are presented in the reports for the first two years of the project (Krieger 1998, 1999a), and a minor variation in the method of recording wind speed in 1999 will be described in the forthcoming report on Year Three of Mayfly Watch.

Objective 3. Contribution of **Hexagenia** *to Fish Diets*

As in our previous project funded by the Ohio Lake Erie Protection Fund (Krieger 1999b), we obtained frozen spottail shiners (*Notropis hudsonius*), emerald shiners (*Notropis atherinoides atherinoides*) , silver chubs (*Hybopsis storeriana*), and trout perch (*Percopsis omiscomaycus*) from the Ohio Department of Natural Resources, Fisheries Research Unit, Sandusky, Ohio, which they collected in May, June, and July of 1997 and 1998. The number of fish whose stomach contents were examined is shown for four years, 1995-1998, in Table 3. The analyses for 1995 and 1996 were performed under a previous grant (LEPF-94-08). Following the procedures established by the Fisheries Research Unit of the Ohio Division of Wildlife in Sandusky, Ohio, we dissected out the stomachs and analyzed the contents. We identified each organism to one of the following groups: amphipods (scuds), isopods (sow bugs), calanoid copepods, cyclopoid copepods, harpacticoid copepods, cladocerans (water fleas), ostracods (seed shrimps), water mites, *Hexagenia*, *Caenis* (mayfly), *Oecetis* (caddisfly), chironomid midge pupae, Tanypodinae midge larve, other chironomid larvae, *Dreissena* (zebra and quagga mussels), Pisidiidae (native fingernail and pill clams), snails, leeches, nematodes, other aquatic invertebrates, and terrestrial invertebrates.

The mussel and clam shells encountered in the fish stomachs were almost always fragmented into many pieces, and the soft body parts were indistinguishable. Therefore, in order to obtain accurate counts of the clams present in each stomach, it was necessary to count the fragments that contained a septum (*Dreissena*) or cardinal and lateral teeth (Pisidiidae). Unless the right and left valves of the shell were still attached, the total number of fragments containing septa or teeth was halved to calculate the total number in the stomach.

In order to determine the original biomass of zebra and quagga mussels eaten by the fish, it was necessary to develop a means to measure the size of the individual fragmented mussels present in the stomachs. For *Dreissena*, the method was similar to the one described by Morrison *et al.* (1997). In brief, the lengths of the right and left septa of previously frozen *Dreissena polymorpha* (n=20) and *D. bugensis* (n=20) obtained from two sites in western Lake Erie (5B-ZM and 8M) were measured, as were the total shell length and total body dry biomass. One hundred individuals of each species over a broad range of sizes were measured (only 30 *D. bugensis* from 8M). From these data, regression equations were calculated (Table 4). The equation for septum length:shell length permitted estimation of the length of the intact shell, and the equation for shell length:body dry biomass permitted estimation of the biomass of the intact *Dreissena* at the time it was eaten. A similar set of equations is needed for the native pisidiid clams; however, it is difficult to identify the numerous species, and lack of this information impedes development of accurate regression equations. Although this work will not be conducted under this grant, we hope to revisit this problem at a later date.

Biomass was determined directly for the remaining groups of invertebrates found in the stomachs of trout perch but not for the other species because of funding constraints. No attempt was made to correct dry biomass measurements for losses resulting from varying amounts of digestion and storage in ethyl alcohol. Following organism counts prior to biomass measurements, they were stored in vials of ethyl alcohol (85%), glycerin (5%), and water, which is established practice. However, the glycerin would have increased the dry

mass measurements, probably by various amounts dependent on each particular taxonomic group. Thus, prior to dry mass determination, the organisms were soaked twice for several hours in ethyl alcohol to extract the glycerin.

Table 3. Number of specimens of each species of fish whose stomach contents were examined, collected 1995-1998 from the western (W) and central (C) basins.

	Sample Sizes (N)					
	Emerald Shiner		Spottail Shiner		Trout Perch		Silver Chub	
	W	C	W	C	W	C	W	C
1995	0	0	52**	0	133	0	89	0
1996	92	0	43	0	140+	0	74	0
1997	39++	34	62	19**	150	105**	91	3*
1998	104	0	143	37	166	192	146	18*

* June only
\+ 25 from eastern end collected in August
** June and July only
\+\+ May and July only
May and June only

Table 4. Regression equations for conversion from total (body + shell) wet weight to dry body weight, and from septum length to body dry weight for zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*).

Species	Independent Variable	Dependent Variable	Regression Equation	r^2	N	Source of Specimens
D. polymorpha	Total wet wt.	Body dry wt.	$y = 0.410x + 0.001$	0.951	20	6 w. b. stations, 1997
D. bugensis	Total wet wt.	Body dry wt	$y = 0.023x + 0.005$	0.713	20	6 w. b. stations, 1997
D. polymorpha	Total wet wt.	Shell dry wt.	$y = 0.421x + 0.001$	0.990	20	6 w. b. stations, 1997
D. bugensis	Total wet wt.	Shell dry wt.	$y = 0.384x + 0.007$	0.983	20	6 w. b. stations, 1997
D. polymorpha	Shell length	Septum length*	$y = 0.108x + 0.206$	0.860	100	Station 5B-ZM, w. b. 1998
D. polymorpha	Shell length	Septum length*	y = 0.116x Š 0.018	0.981	100	Station 8M, w. b. 1998
D. polymorpha	Shell length	Body dry wt.	$y = 0.002x^{2.836}$	0.922	100	Station 5B-ZM, w. b. 1998
D. polymorpha	Shell length	Body dry wt.	$y = 0.011x^{2.331}$	0.899	100	Station 8M, w. b. 1998
D. bugensis	Shell length	Septum length*	$y = 0.108x + 0.073$	0.951	100	Station 5B-ZM, w. b. 1998
D. bugensis	Shell length	Septum length*	$y = 0.091x + 0.288$	0.771	30	Station 8M, w. b. 1998
D. bugensis	Shell length	Body dry wt.	$y = 0.003x^{2.827}$	0.955	100	Station 5B-ZM, w. b. 1998
D. bugensis	Shell length	Body dry wt.	$y = 0.003x^{2.870}$	0.817	30	Station 8M, w. b. 1998

* Right septum only; data for left septum are available.

Results and Discussion

Objective 1. Distribution and Abundance of Nymphs

Western Basin

General Results. The changing distribution and abundance of *Hexagenia* nymphs in the western basin from 1995 through 1998 are interpreted at length in a recently submitted manuscript (Schloesser *et al.* 2000). Briefly, *Hexagenia* expanded its distribution and density (number per square meter) in the basin from 1991 through 1997. Its density declined (mean 157/m^2) in 1998 compared to 1997 (mean 451/m^2) while remaining higher than in previous years (Figure 1). It may be that these mayflies reached or exceeded their carrying capacity in western Lake Erie in 1997 and that their numbers will vary around that capacity in the coming years. The distribution increased slightly from 91% of the stations sampled in 1997 to 95% in 1998.

***Hexagenia* Rapid Assessment Method (*H*RAM)**. The results indicated that the *H*RAM is not feasible for estimating the density of *Hexagenia* nymphs. Only 20% (437 of 2191) of the nymphs collected in 1997 were obtained from the 3-mm sieve, which was expected to capture most of them. The 0.6-mm sieve trapped the remainder of the nymphs; however, only an additional 39% of the total number in the sample were found on the sieve while in the field. The remaining 41% of the nymphs were found upon processing the sample residues in the laboratory. Thus, enumeration of nymphs while on the boat accounted for only 59% of the total. The correlation (r=0.59) between the numbers of nymphs on the 3-mm sieve and the total numbers in the samples indicated a poor association between the *H*RAM and the standard approach. However, the correlation (r=0.91) was relatively high between the total nymphs found in the field (using both the 3-mm and 0.6-mm screens) and the total in the sample.

Relative Condition Based on Size:Biomass Relations. A large body of data was gathered for comparison of size:biomass relations. The outcome of these comparisons will be submitted in a follow-up report.

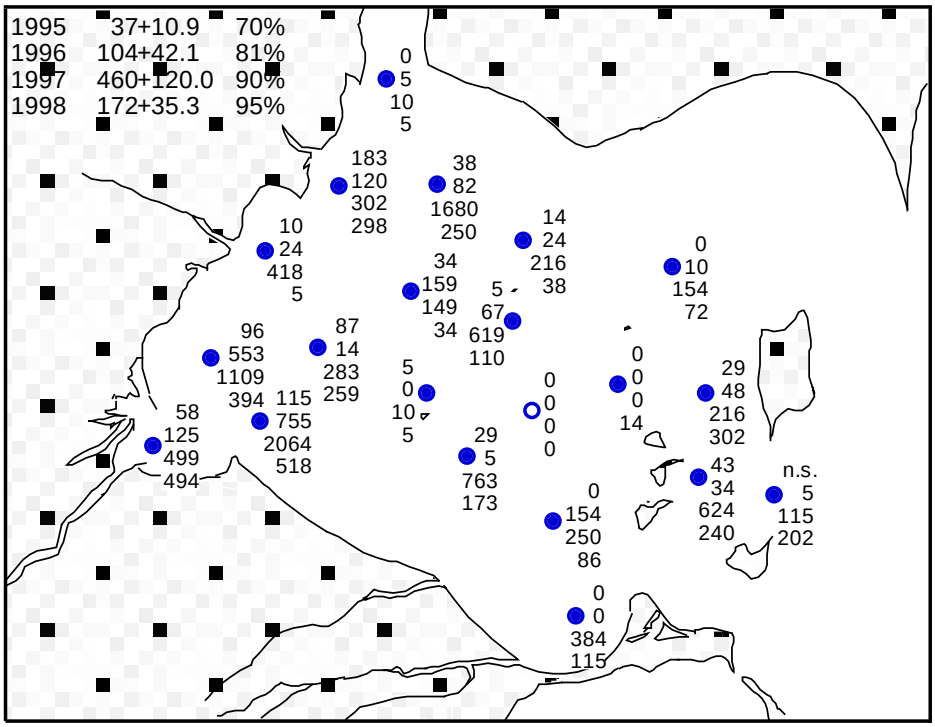
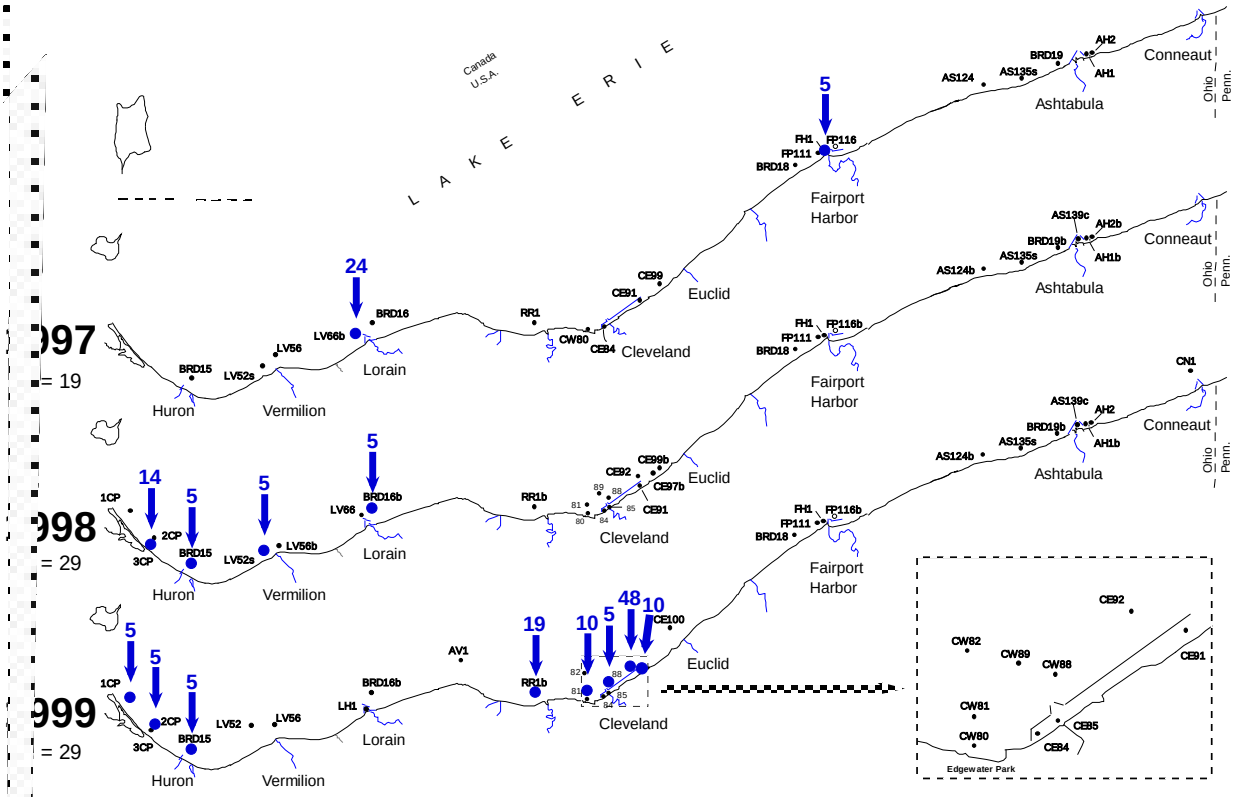


Figure 1. Basin-wide mean density + S.E. of nymphs of *Hexagenia* spp. and percent of stations with nymphs (upper left), and mean density of four replicate samples at each station in May each year, 1995 through 1998, in the western basin of Lake Erie. Adapted from Figure 2 of Schloesser *et al.* (submitted).

Central Basin

Figure 2 shows that nymphs were generally absent from the sediment samples collected from Huron to Conneaut in 1997, being found only outside of Fairport Harbor (one individual) and beyond Lorain Harbor (5 individuals). In 1998 no nymphs were found east of Lorain; however, they were found at four stations from Lorain westward almost to Cedar Point. In 1999, all the nymphs collected were from two areas: (1) from Huron west to Cedar Point and (2) from the Rocky River to the eastern end of Cleveland Harbor. Nymphs were found at 10.5% of the stations where sediments were successfully collected in 1997, at 13.8% in 1998, and at 27.6% in 1999. The mean density of nymphs at each station (including those with no nymphs) was 1.5 nymphs/m^2 in 1997, 1.0 nymphs/m^2 in 1998, and 3.7 nymphs/m^2 in 1999. It is apparent that *Hexagenia* began to repopulate sediments near shore from Sandusky to Cleveland during those years, but either was not repopulating the sediments, or was doing so more slowly, from Euclid to Conneaut. The results of the Mayfly Watch (below) indicate that *Hexagenia* has repopulated soft sediments along much of the Ohio shoreline of the central basin, but the density apparently has remained so low that the probability of finding nymphs in the samples is small. For example, where the density of nymphs is one per square meter, there is only a 5% probability of finding the nymph in a single 0.052 m^2 Ekman sample

collected from that square meter. Even by collecting four replicate samples, as was done, the probability of collecting the nymph is only 20%. Where our data show an average of 5 nymphs/m^2 (Figure 2), we collected a single nymph among four replicate samples.



igure 2. Stations sampled and distribution of *Hexagenia* nymphs near shore from Huron to Conneaut, Ohio, 1997 through 1999.

The expanse of the central basin (16,138 km^2) is much greater than that of the western basin (3,284 km^2) (Bolsenga and Herdendorf 1993); thus, if oxygenation remains above critical levels in the summer, there is the potential for these mayflies to become even more abundant there than in the western basin, even if they do not attain the same densities. Their carrying capacity (maximum sustainable density) is likely lower in the central basin because that basin has a lower overall productivity than the western basin. Furthermore, Reynoldson and Hamilton (1993) reported that *Hexagenia* nymphs apparently did not populate offshore sediments of the central basin even in prehistoric times.

Objective 2. Distribution and Relative Abundance of Winged Stages (Subadults and Adults)

Our study of *Hexagenia* emergences focused on the western and central basins separately. In the western basin, where these mayflies were already well established, we wanted to learn about the patterns of emergence, both from place to place around the basin and from night to night. In the central basin, *Hexagenia* was either not established, or it was present in low abundance. Therefore, we were interested in the presence or absence of winged mayflies from place to place along the central basin shoreline, and whether the number of places where they were present changed from day to day during the emergence period, and from year to year.

Western Basin. Three locations along the western basin shoreline separated by 10 or more kilometers were sampled in 1997 (Figure 3a). The emergence began earliest at Point Place (northeastern Toledo), where small numbers of the mayflies were seen prior to the initiation of collections on 15 June, and peaked from 27 June through 30 June. Seventy percent of all the *Hexagenia* collected at the light trap during the sampling period (15 June through 31 July) were collected on those four nights, in similar numbers each night (Figure 4). Collections were missed sporadically on eight nights after 4 July, which might have altered the results to a slight extent. However, the very small collections obtained at the other two locations on those same nights may indicate a small emergence throughout the basin on those dates.

A different pattern was observed at Sand Road (near Port Clinton) and on Gibraltar Island, both near the eastern end of the western basin. At both locations, the mayflies were found only on one night from 15 June through 22 June, after which they began to appear nightly at the light traps (Figure 4). The emergence period at Sand Road showed two large peaks of similar size, 1 July through 4 July, and 9 July through 11 July, separated by four days of low numbers (5 July through 8 July). Together these two peak periods accounted for 81% of all the mayflies collected. Afterward, only small numbers of *Hexagenia* were collected on any given night. Similarly on Gibraltar Island, two peaks were seen, from around 30 June through 3 July and again on 7-8 July, again accounting for 81% of the total collection. Forty percent of the total was obtained on 7 July, and no *Hexagenia* were attracted to the insect light after 24 July (Figure 4).

In 1998 and 1999, only two light assemblies were used, both on Gibraltar Island. This permitted evaluation of the effect of placement of the lights on the size of the collections from night to night. The lights were placed approximately 100 m apart, one facing north toward the open lake and the western end of Middle Bass Island at the edge of a cliff 10.5 m above the water, the other facing east about 1 m above the water in view of the northeastern end of South Bass Island and Put-in-Bay as well as the eastern end of Middle Bass Island.

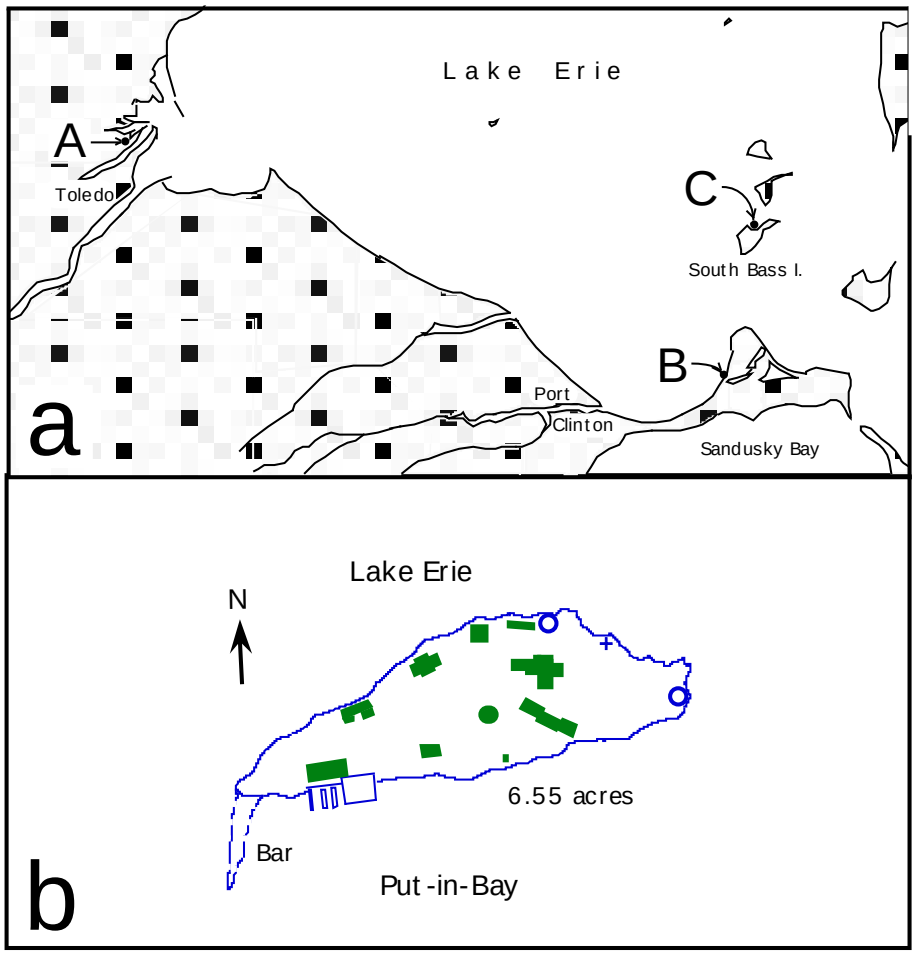


Figure 3. **a.** Locations of the three sampling sites for winged *Hexagenia* in the western basin in 1997: Holliday Road, Point Place, Toledo (A).; Sand Road, east of Port Clinton (B); Gibraltar Island, Put-in-Bay, South Bass Island (C).
b. Locations (open circles) of the sampling sites on Gibraltar Island above the north-facing cliff (1997-1999) and behind the east-facing pebble beach (1998 and 1999).

The general shapes of the graphs showing the proportions of *Hexagenia* collected each night (Figure 5) indicate that similar seasonal patterns occurred at both lights. However, the patterns differed between years. Most of the mayflies were collected early in the emergence period at both lights in 1998, whereas the emergence was more evenly distributed in 1999. The pattern in 1999 was similar to the pattern in 1997, although the entire emergence period appeared to be shorter in 1997.

Although the general patterns were similar between the two lights, the dates of the largest collections did not coincide in 1999 as they did in 1998. Furthermore, the total number of mayflies collected was 49% greater at the east-facing light than at the north-facing light in 1998, but in 1999 the collection was 235% greater at the north-facing light

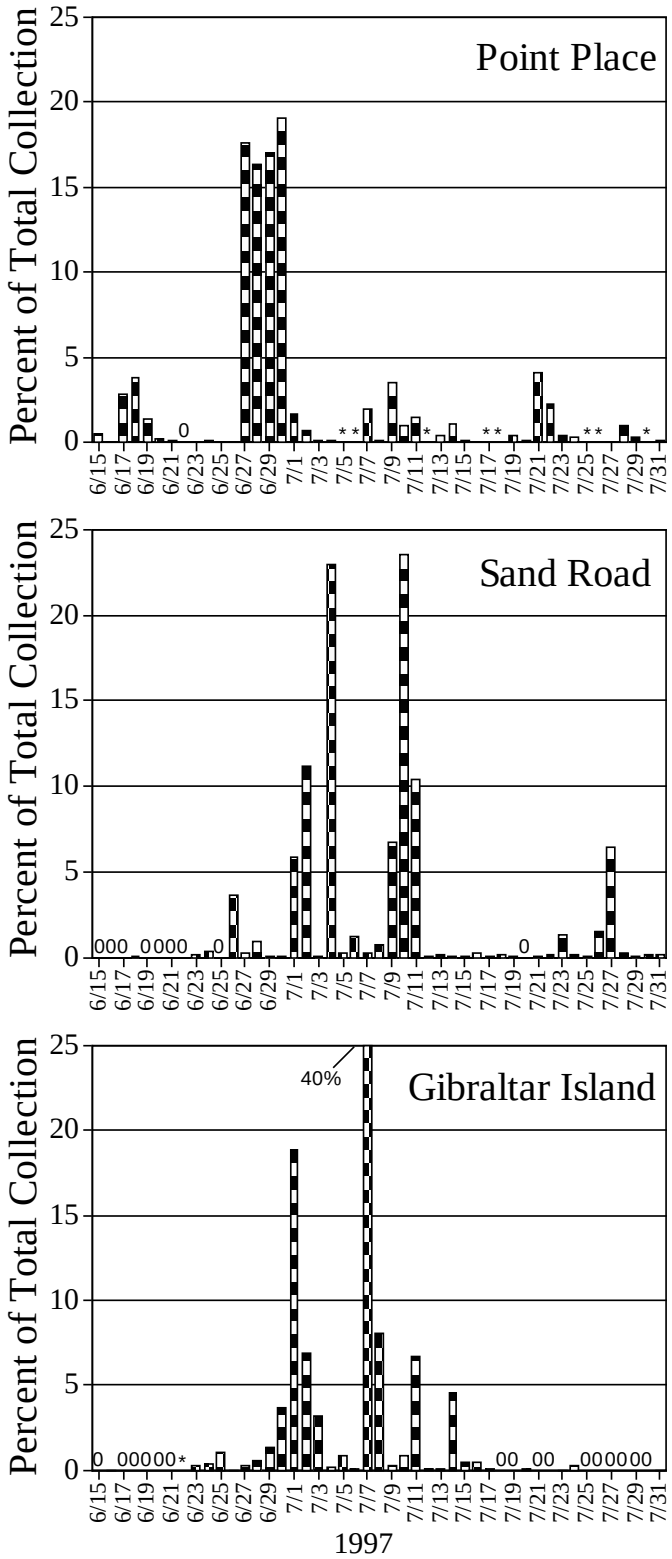
(Table 5). The collection at the north-facing light increased by 268% in 1998 compared to 1997, and increased again in 1999 by 148% over 1998, yielding a collection in 1999 that was 9.1 times that in 1997. The later starting date in 1997, and the few nights when collections were missed (Figures 4, 5), probably had little effect on the total number collected.

Table 5. Total specimens of *Hexagenia limbata* and *H. rigida* collected at light traps on Gibraltar Island.

Location	Aspect	1997	1998	1999
Cliff, 10.5 m	North	12,292	45,185	112,250
Beach, 1.0 m	East	N/A	67,278	33,539

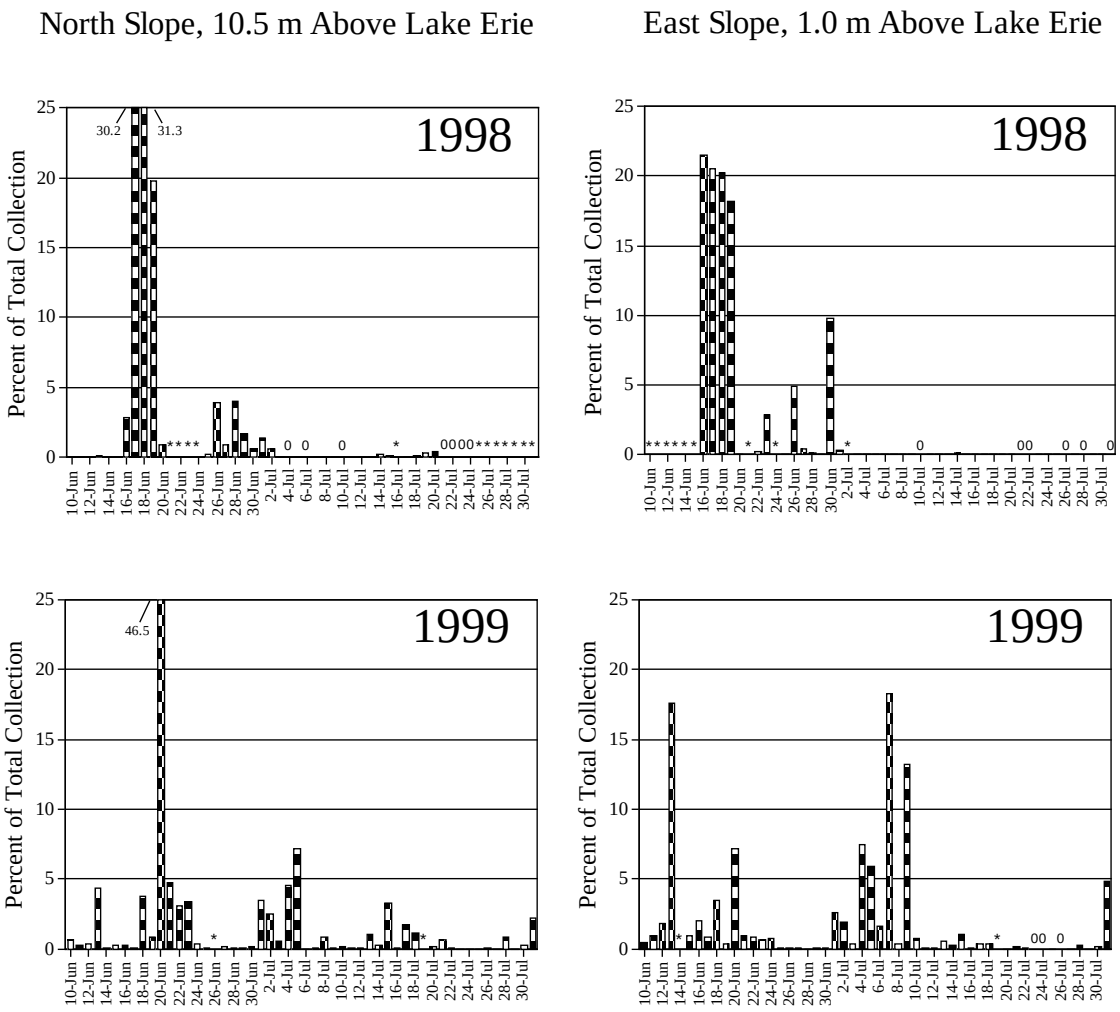
These results show that even when lights are placed in relatively close proximity (tens of meters), the aspect (direction the lights are facing) and height above the lake surface may individually or together yield quite different results on a nightly and a seasonal basis. Observations by the author revealed that the direction and force of wind at dusk may be important in determining where the majority of mayflies in the swarm will be positioned on a given night relative to the lakeshore and protective structures such as trees and buildings. The questions of what environmental cues cause the mass emergences on particular nights, and what factors determine where the large swarms will be on a given night, are of much interest to lakeshore residents and industries. Further research should be devoted to answering these questions.

Central Basin. Trends in the distribution and abundance of winged *Hexagenia* along the Ohio portion of the central basin shore between 1997 and 1998 were reported in the annual reports on the first two years of Mayfly Watch (Krieger 1998, 1999a). The data for 1999, the third and last year of Mayfly Watch, showed a further increase in the abundance of winged *Hexagenia* as revealed by sightings of greater densities and a prolonged season of emergence. The final report on the Mayfly Watch results will be forthcoming.



* No collection on this date. Zeroes show dates collections were conducted but no *Hexagenia* were found.

Figure 4. Relative numbers of *Hexagenia* spp. collected in 1997 at light traps on the western Lake Erie shore



* No collection was conducted on this date.

Zeroes show dates collections were conducted but no Hexagenia were found.

Figure 5. Relative numbers of *Hexagenia* spp. collected in 1998 and 1999 at light traps on Gibraltar Island.

Objective 3. Contribution of **Hexagenia** *to Fish Diets*

Emerald Shiner

Emerald shiners, which were added to the study in 1996 when spottail shiners were few in the collections, fed almost entirely on zooplankton in both basins (cite abstract), and fed only infrequently on invertebrates associated with the lake bottom, such as ostracods, amphipods, and clams (Table 6). None were recorded to have *Hexagenia* in their stomachs (Table 7).

Table 6. Animals found in stomachs of trout perch, silver chubs, spottail shiners, and emerald shiners, 1995-1998, in the western (W) and central (C) basins.

	TROUT PERCH		SILVER CHUB		SPOTTAIL SHINER		EMERALD SHINER	
TAXONOMIC CATEGORY	W	C	W	C	W	C	W	C
NEMATODA	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
HIRUDINEA	Ć	Ć	Ć					
CRUSTACEA								
Cladocera	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
Copepoda								
Calanoida	Ć						Ć	Ć
Cyclopoida	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
Harpacticoida	Ć							Ć
Ostracoda	Ć	Ć	Ć		Ć	Ć	Ć	
Amphipoda	Ć	Ć	Ć		Ć		Ć	Ć
Isopoda	Ć	Ć					Ć	
HYDRACHNIDIA	Ć		Ć		Ć			
INSECTA								
Ephemeroptera								
Hexagenia	Ć		Ć		Ć	Ć		
Trichoptera								
Oecetis	Ć	Ć	Ć	Ć	Ć	Ć		
Diptera								
Chironomid, other (larva)	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
Tanypodinae (larva)	Ć	Ć	Ć	Ć	Ć	Ć		
Chironomid pupa	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
GASTROPODA	Ć		Ć		Ć			
BIVALVIA								
Dreissenidae	Ć	Ć	Ć	Ć	Ć	Ć		
Pisidiidae	Ć	Ć	Ć	Ć	Ć	Ć	Ć	
FISH (unknown type)	Ć							
OTHER AQUATIC	Ć		Ć		Ć	Ć		
TERRESTRIAL	Ć	Ć	Ć	Ć	Ć	Ć	Ć	Ć
Total Taxa/Groups	21	14	16	10	16	13	11	9

Spottail Shiner

Although similar to emerald shiners in feeding largely on zooplankton, spottail shiners had a slightly more varied diet, and occasionally included both *Hexagenia* and the caddisfly *Oecetis* in their diet (Table 6). No *Hexagenia* were found in the stomachs of specimens collected in 1995 or 1996, but 4.8% and 5.6% of the stomachs contained the nymphs in 1997 and 1998, respectively, in the western basin, with similar low percentages in the central basin (Table 7). As a percentage of all animals found in the stomachs (Table 8), the nymphs comprised less than 0.1% in the western basin in both 1997 and 1998, but a considerably greater percent in the central basin.

Trout Perch

Of the four species examined, trout perch had the most varied diet (Table 6) and also fed most heavily on *Hexagenia* (Tables 7-9). It fed largely on the zoobenthos, although zooplankton (Cyclopoida, Calanoida, and Cladocera) comprised from 8% to 88% of all animals present in the stomachs each month in the western basin (Figure 6), and around half to nearly three-fourths of all animals on a yearly (May, June, July) basis (Figure 7). The

percentage of trout perch stomachs containing *Hexagenia* each year reflected the increase in the density of nymphs in the basin through 1997 and the decrease in 1998 (Table 7). The same pattern was evident in the average number of nymphs per stomach (Table 9). It is notable that no *Hexagenia* were found in trout perch stomachs from the central basin in any year (Table 7), which reflects the persistently low density of the nymphs in that basin.

Trout perch was the only fish for which biomass of the diet items was determined. The importance of reporting biomass in addition to numbers of individuals is obvious from Figures 6 and 7. Even though *Hexagenia* nymphs comprised a very small proportion (5% or less) of the total diet each year in terms of number of individuals consumed (Table 8), the mayflies contributed 50% to 82% of the dry biomass consumed during the period May through July (Figure 7). On a monthly basis, the contribution was as high as 88% of total dry biomass (Figure 6).

Silver Chub

Among the four fishes included in this study, the silver chub was unique in including a large proportion of native fingernail and pill clams (Pisidiidae) and the exotic zebra mussel and quagga mussel (Dreissenidae) in its diet. The other three fishes occasionally fed on pisidiids, and all except emerald shiners occasionally fed on dreissenids (Table 6), but these clams always comprised a very small portion of the diet in terms of numbers of individuals consumed (e.g., Figure 6). Whereas *Hexagenia* nymphs contributed as many as 5% of the individuals in the diet of silver chubs in the period May through July of a given year, zebra and quagga mussels comprised up to 43%, and native clams up to 33%. During May through July 1995, 69% of the diet consisted of dreissenid and pisidiid clams (Table 10). It is apparent that clams contributed a large (probably the major) proportion of the biomass in the diet of silver chubs; however, the extent of that contribution will have to await development of regression relations to convert measurements on broken shells of the native clams to biomass.

Benefits and Information Dissemination

This study has confirmed the importance of the native burrowing mayflies *Hexagenia limbata and H. rigida* to the present ecology of Lake Erie. Its role in coupling the benthic and pelagic food webs, as well as the aquatic and terrestrial food webs, is now well established in the western basin, as shown by the data gathered in this study. The data on both the nymphs and the winged stages show that *Hexagenia* is becoming increasingly important in the central basin of Lake Erie as well. This information should be useful to fisheries biologists and managers who are attempting to understand the changing fisheries of Lake Erie, including the resurgence of certain bottom-feeding fishes such as the lake sturgeon (*Acipenser fulvescens*) and the recently-improved status of yellow perch (*Perca flavescens*).

The early summer swarms of *Hexagenia* onshore have continued to arouse the attention of residents, workers, and visitors along western Lake Erie. The news media with which the project director conducted discussions during the project are listed in Table 11. The data presented in this report show that the swarms are likely to increase in size and duration along

the central basin shoreline as well, although the rate of increase appears to be slower than that witnessed in the 1990s in the western basin.

As part of this project, the project director wrote and later revised a fact sheet for the general public titled "Mayflies and Lake Erie, a Sign of the Times", published and distributed by the Ohio Sea Grant College Program (Krieger 1998a). This four-page brochure, which incorporated results of our studies up to early 1998, explains the ecology and life cycle of *Hexagenia* as well as the benefits and less desirable effects of their recolonization of Lake Erie. The brochure has been widely disseminated at public gatherings such as boat shows. It can also be downloaded from the Ohio Sea Grant web site: **http://www.sg.ohio-state.edu/osgrant/**.

The project results have been disseminated widely to the scientific community and the public via numerous oral and poster presentations (Table 12). To date, two peer-reviewed articles have been produced (Table 13), and more are planned.

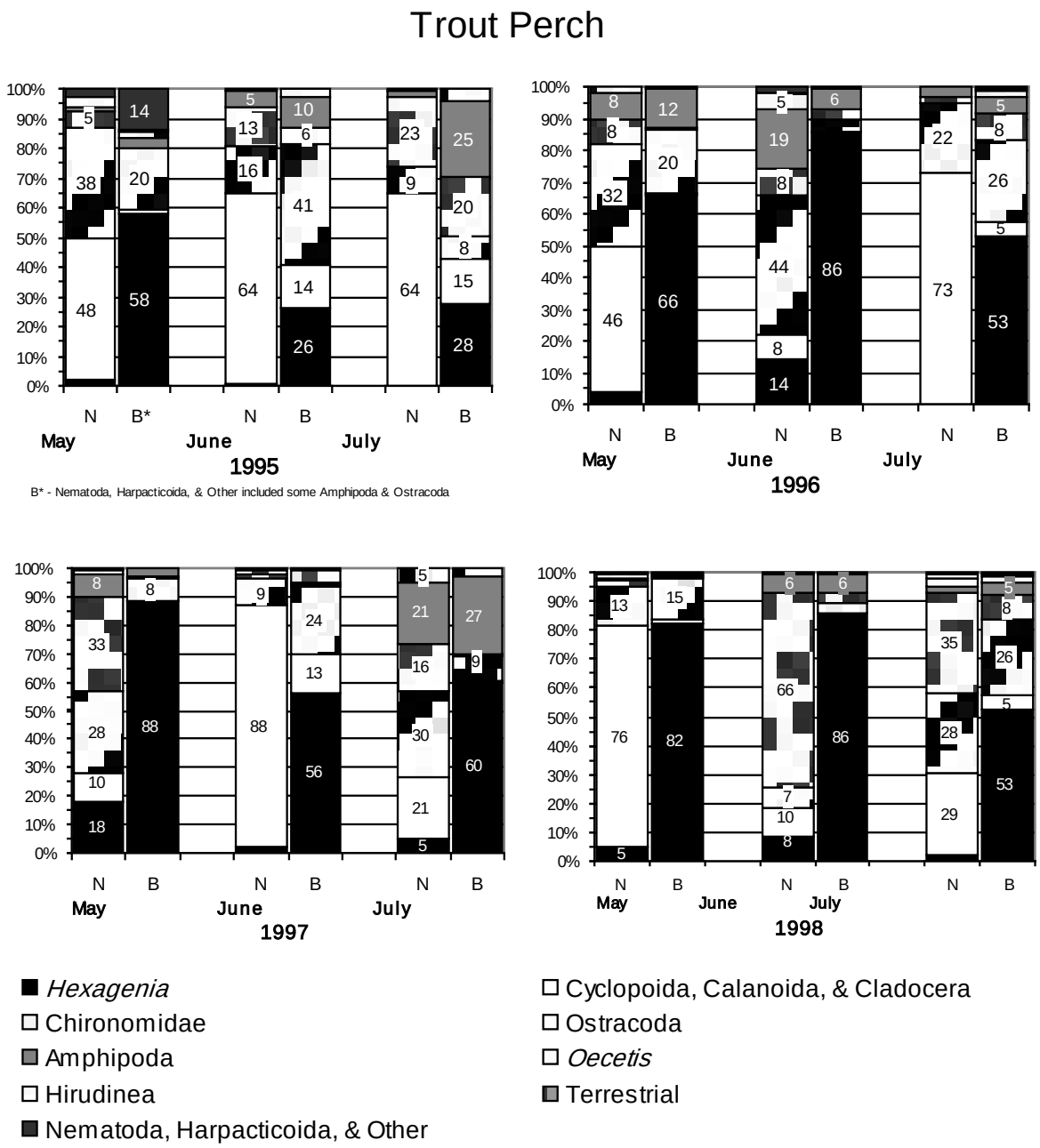


Figure 6. Contributions of invertebrates to the diet of trout perch in the western basin of Lake Erie by number of individuals (N) and dry biomass (B), May, June and July, 1995 through 1998.

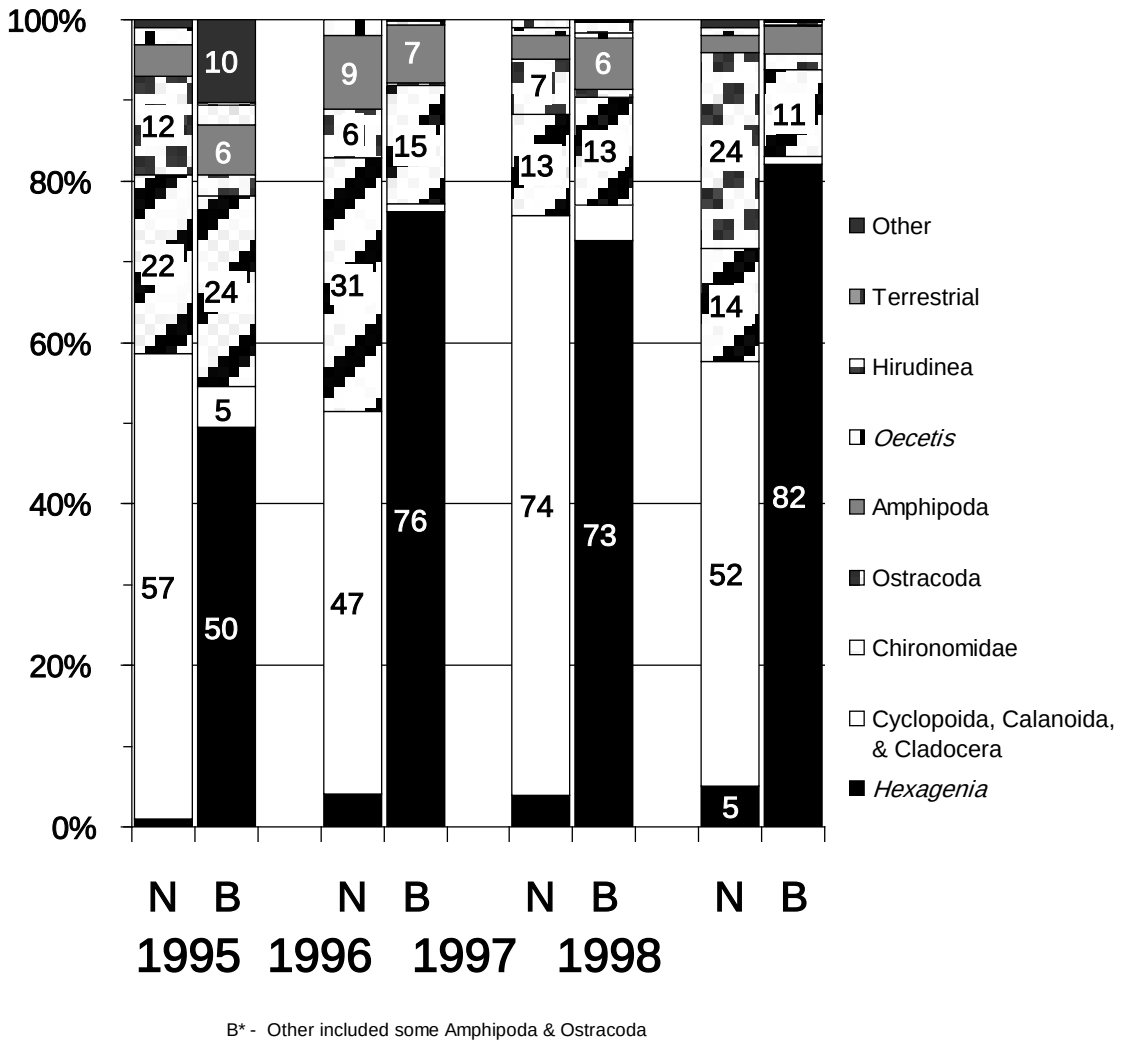


Figure 7. Contributions of invertebrates to the diet of trout perch in the western basin by number of individuals (N) and dry biomass (B) during the three-month period, May through July, 1995 through 1998.

Table 7. Percentage of fish with *Hexagenia* in stomachs in western basin (W) and central basin (C).

	Emerald Shiner		Spottail Shiner		Trout Perch		Silver Chub	
	W	C	W	C	W	C	W	C
1995	-	-	0.0%	-	22.6%	-	12.4%	-
1996	0.0%	-	0.0%	-	32.9%	-	32.4%	-
1997	0.0%	0.0%	4.8%	5.3%	55.3%	0.0%	31.9%	0.0%
1998	0.0%	-	5.6%	2.7%	43.4%	0.0%	19.9%	0.0%

Table 8. *Hexagenia* nymphs as a percentage of all animals present in the stomachs.

	Emerald Shiner		Spottail Shiner		Trout Perch		Silver Chub	
	W	C	W	C	W	C	W	C
1995	-	-	0.0%	-	1.2%	-	1.0%	-
1996	0.0%	-	0.0%	-	1.1%	-	4.9%	-
1997	0.0%	0.0%	0.03%	5.0%	4.1%	0.0%	3.8%	0.0%
1998	0.0%	-	0.05%	2.7%	5.0%	0.0%	3.0%	0.0%

Table 9. Average number of *Hexagenia* nymphs per stomach.

	Emerald Shiner		Spottail Shiner		Trout Perch		Silver Chub	
	W	C	W	C	W	C	W	C
1995	-	-	0.00	-	0.43	-	0.15	-
1996	0.00	-	0.00	-	0.77	-	0.72	-
1997	0.00	0.00	0.05	0.05	1.83	0.00	0.34	0.00
1998	0.00	-	0.06	0.03	0.94	0.00	0.26	0.00

Table 10. Contributions of *Hexagenia* nymphs, dreissenids (zebra and quagga mussels), and pisidiids (fingernail and pill clams) to the diet of silver chubs collected from the western basin, May through July, 1995 through 1998.

	Hexagenia spp.	*Dreissena* spp.	Pisidiidae
1995	1%	17%	52%
1996	5%	30%	33%
1997	4%	43%	12%
1998	3%	23%	17%

Table 11. News media that have contacted the project director regarding this project

Correspondent	Affiliation	Date(s) of Contact
Bob Gross	***Times Herald*** (Port Huron, MI)	2/26/97
Jeff Barnhill, Lou Hebert	**WTOL-TV** (Toledo)	5/16/97
Karin Messner	free-lance (Port Clinton)	5/20/97
Scott Carpenter	***Fremont News-Messenger*** & ***Port Clinton News-Herald***	5/22/97
Debbie Katterheinrich	**Ohio Lake Erie Office**	6/97
Ellen Tietjen, Kris Weiss	***Sandusky Register***	6/97
Maggie Kelch	***Lakefront News***	6/13/97
Molly Cavanaugh	***Plain Dealer*** (Cleveland)	6/25/97
Art Weber	***Milbury Press*** (Toledo)	7/18/97
Tom Henry, George Tamber	***The Blade*** (Toledo)	6/98
Ron Vidica	***Lorain Journal***	6/4/98
Michael Culp	***Advertiser Tribune*** (Tiffin) & ***Port Clinton News-Herald***	6/15/98
Frank Savukinas	***Port Clinton News-Herald***	9/16/98
Ron Truman	free-lance (Belleville, Ontario)	11/3/98
Mark Boleky	***News-Herald*** (Willoughby)	6/8/99
Joe Case	**Audio News Service** (Columbus)	6/14/99
Jenni Laidman	***The Blade*** (Toledo)	5/28/00

Table 12. Presentations of project results at professional meetings (abstracts available)

1. Ciborowski, J., L. Corkum, K. Krieger, and D.W. Schloesser. October 1997. Burrowing mayfly (*Hexagenia*) populations in Lake Erie. 24th Annual Aquatic Toxicity Workshop, Niagara Falls, Ontario.

2. Ciborowski, J. J. H., L. D. Corkum, J. Gerlofsma, D. W. Schloesser, and K. A. Krieger. May 1998. Burrowing mayfly (*Hexagenia*) populations in Lake Erie. International Association for Great Lakes Research, McMaster Univ., Hamilton, Ontario.

3. Schloesser, D.W., J.J.H. Ciborowski, K.A. Krieger, and T. Nalepa. December 1998. Abundance of burrowing mayfly nymphs in western Lake Erie: exponential increases 1991-1997 and a decline in 1998. 60th Midwest Fish & Wildlife Conference, Cincinnati, Ohio.

4. Shields, L.A. February 1999. The burrowing mayfly influences the diets of forage fish in Lake Erie. Fifth Annual Student Research Conference, Heidelberg College, Tiffin, Ohio.

5. Krieger, K.A., L.A. Shields, S.L. Wildman, J.B. Saxton, and K.G. Boggs. April 1999. Changes in the diets of four forage fishes in western Lake Erie in relation to changes in the benthic invertebrate community. Annual Meeting, Ohio Academy of Science, Cleveland, Ohio.

6. Ciborowski, J.J.H., L.D. Corkum, A. Grgicak, M.E. Chase, D.W. Schloesser, and K.A. Krieger. May 1999. Estimated flux of nutrients and contaminants associated with *Hexagenia* mayflies in western Lake Erie. Annual Meeting, International Association for Great Lakes Research, Cleveland, Ohio.

7. Krieger, K.A., S.L. Wildman, L.A. Shields, J.B. Saxton, and K.G. Boggs. May 1999. Forage fishes in Lake Erie respond to changes in benthic food resources. Annual Meeting, International Association of Great Lakes Research, Cleveland, Ohio.

Table 13. Peer-reviewed papers published or in preparation that directly resulted from this project

1. Madenjian, C.P., D.W. Schloesser, and K.A. Krieger. 1998. Population models of burrowing mayfly recolonization in western Lake Erie. *Ecological Applications* 8(4):1206-1212.

2. Schloesser, D. W., K. A. Krieger, J. J. H. Ciborowski, and L. D. Corkum. 2000. Recovery of burrowing mayflies (Ephemeroptera: Ephemeridae: *Hexagenia* spp.) in Lake Erie of the Laurentian Great Lakes. *J. Aquatic Ecosystem Stress and Recovery* 8:125-141.

Acknowledgments

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Many volunteers participated in the three-year Mayfly Watch. At some of the more than 20 locations, a primary contact was assisted by additional volunteers. As far as is known, all participants are listed in the reports on the first two years of Mayfly Watch (Krieger 1998b, 1999a) and will be included in the forthcoming report on the third year. However, numerous other individuals were doubtless involved, including employees at some of the lake-side industries, family members, and lakeshore residents. **Nancy Csider** of the Mentor Marsh Nature Center enlisted several observers. **Keith Linn** of the Northeast Ohio Regional Sewer District (NEORSD) also involved many field technicians in the project all three years. **Nancy Miller** made contact by telephone with all of the volunteers all three years to arrange for delivery of reference specimens and the pick-up of mayfly samples. Nancy also assisted in budget management and in other ways throughout the duration of this project. Heidelberg College undergraduate technicians Kevin Boggs, Matt Mapus, Chris Monsour, Jamie Saxton, Laura Shields, Beth Toot, and **Stacie (Wildman) Roby** delivered and retrieved materials from the volunteers; and Mark Blanchard, Stacie Roby, **Samantha Haught**, and **Erica Nighswander** counted the mayflies and identified their species and sex. I am especially indebted to **Frank Lichtkoppler** and **Dave Kelch** of the Ohio Sea Grant Extension Service, as well as to **Al Percival** of the Davis-Besse nuclear power plant, for suggesting names of potential volunteers. The enthusiasm and dedication of all of these people are deeply appreciated.

The nightly collection of winged *Hexagenia* with the light traps required an exceptional amount of dedication because of the late hours and restriction of activities. I am extremely grateful for the help in 1997 of **John and Bev Hoffman** of Port Clinton, who performed the collection without fail for nearly seven weeks; and the help of **Dave and Tina Harmon** and their sons **Garrett and Josh**, who made the collections at Point Place in northeastern Toledo. **Ken Freeman** performed the nightly collections in 1997 and 1998 on Gibraltar Island, and **Sean Burke** carried on those duties in 1999. Special thanks are extended to **John Hageman**, Sea Grant Extension agent and laboratory manager at the Franz Theodore Stone Laboratory of The Ohio State University, for overseeing the mayfly collections on Gibraltar Island during the three years of this project. The mayflies were identified to species, sexed, and counted by Ken Freeman in 1997 and 1998. **Lisa Kutschbach-Brohl** instructed several technicians on the methods of identifying and sexing the mayflies. The collection boards were constructed by **Dave Dariano**, who also enthusiastically accompanied the project director on several mayfly photography trips. **Dr. Jeff Reutter**, director of Ohio Sea Grant and Stone Laboratory, provided space at Stone Lab for equipment storage and sample processing.

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