Mayflies and Zebra/Quagga Mussels in Lake Erie's Central Basin Surveyed with a Remotely Operated Vehicle

FINAL REPORT

LAKE ERIE PROTECTION FUND PROJECT SG 232-04

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Executive Summary

*Nymphs (larvae) of burrowing mayflies (*Hexagenia *spp.) are sensitive to oxygen depletion in the bottom water and sediments of Lake Erie. For that reason, and because a historical record exists of their decline and subsequent resurgence in the western basin in apparent response to changing lake quality, their abundance in the western basin comprises one of the metrics of the Biological Indicator of the Lake Erie Quality Index developed by the Ohio Lake Erie Commission. Predictions in the 1990s that the mayflies would expand their distribution and abundance in the central basin, at least in the relatively shallow nearshore regions, have not materialized. This project continued a series of investigations into changes in* Hexagenia *distribution and abundance in the central basin and potential mechanisms impeding their population growth. The primary objectives were to survey* Hexagenia *nymphs and zebra and quagga mussels (*Dreissena *spp.) in the western part of the central basin using a remotely operated vehicle (ROV) and sediment grab samples, and to relate the distribution of the nymphs and mussels indirectly to oxygen depletion in the basin.*

This project builds directly on past projects funded by the Lake Erie Protection Fund and the Ohio Sea Grant College Program and shares with those projects the objective of attempting to understand the interrelations among groups within the biota of Lake Erie, the responses of major invertebrate species to changes in the chemical and biological quality of the lake, and their own role in bringing about some of those changes. This work is particularly pertinent to questions regarding the expansion of the "dead zone" and concomitant changes noted in various chemical characteristics of the central basin in the past few years. Furthermore, this particular project extends the monitoring efforts called for in the 2004 versions of the Lake Erie Quality Index and the Lake Erie Protection and Restoration Plan produced by the Ohio Lake Erie Commission.

The abundance or absence of oxygen-dependent animals such as burrowing mayflies and dreissenid mussels should provide important clues to the severity of oxygen depletion near the sediment surface in summer. Their populations serve as indicators of conditions throughout their life stages at the lake bottom. At the only station sampled both in spring and fall 2004, at a depth of 14.9 m (49 ft) in spring and 15.1 m (50 ft) in fall, young mayfly nymphs were present in low abundance in May but were not found again in October. Furthermore, dreissenid mussels were relatively abundant at the station in the spring but were rare in October.

At stations sampled along an east-west transect in October, nymphs were found only at the most-western and shallowest station (13.9 m, 46 ft) and not at two deeper stations (14.6 and 15.1 m). Similarly, dreissenid mussels were relatively abundant at the shallowest station but were rare at the two deeper stations. Midge (Chironomidae) larvae, which are generally more tolerant of oxygen depletion than either mayflies or mussels, were most abundant at the deepest station in October. The absence of Hexagenia *and near absence of* Dreissena *but an abundance of midges at the two deeper stations in October 2004, coupled with the findings in May 2004, indicates that hypoxia there during part of the summer most likely prevented the survival of the mayflies and most of the dreissenids that were present in May. Additional investigations should be carried out that will lead to a more complete understanding of the*

short-term dynamics of oxygen depletion of the central basin, especially in areas near the margin of the "dead zone", or hypoxic hypolimnion, and the relationship of those dynamics to benthic invertebrate community structure and function.

This project and a preceding Ohio Sea Grant project revealed several advantages and disadvantages of using a ROV for surveys of Hexagenia *and* Dreissena *at low abundance. Advantages include: (1) a ROV surveys many square meters of lake bottom in a few minutes, (2) video recordings make a permanent record of the undisturbed lake bottom and associated organisms that can be viewed and analyzed at a later time, and (3) a ROV is superior to grab sampling for finding burrow holes where their density is sparse. Disadvantages include: (1) deployment and retrieval of the ROV add 20 to 30 minutes to on-station time; (2) low water clarity at the lake bottom is difficult to predict and can be a major factor limiting the visible details and resolution; (3) because interpretation of* Hexagenia *density based on the sizes and number of holes present in video frames may be inaccurate, at least at this stage of development of the technique, more accurate estimates of mayfly density can be obtained where they are relatively abundant by means of sediment grab sampler; and (4) small holes may be those of midge larvae rather than small* Hexagenia *nymphs and at present the two types of burrows cannot be distinguished visually. It is possible that further study will provide clues to permit their visual separation.*

Introduction

The abundance of burrowing mayflies (*Hexagenia limbata* and *H. rigida*) in the western basin of Lake Erie comprises one of the metrics of the Biological Indicator of Ohio's Lake Erie Quality Index (OLEC 2004a). In the central basin of Lake Erie and areas of the other Great Lakes such as Saginaw Bay (Lake Huron) and Green Bay (Lake Michigan), the distribution and abundance of these mayflies can also serve as valuable indicators of water and sediment quality. Zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*) are also of special interest because these invasive exotic species have altered food webs in Lake Erie by modifying energy and nutrient pathways and fluxes.

Through this project we investigated the use of a potentially more effective approach to surveying both mayflies and zebra/quagga mussels in the central basin and other areas possessing sparse populations of these species. Our objectives were to (1) visually survey *Hexagenia* (mayfly) nymphs and dreissenid (zebra and quagga) mussels along several transects in the western part of the central basin via video camera mounted on a remotely operated vehicle (ROV), and to verify the video results with sediment grab samples; (2) examine the relationship between depth (potential oxygen depletion) and the observed distribution of nymphs and mussels on soft sediments, drawing on oxygen and temperature data from several sources; and (3) relate our findings to our earlier annual observations on changes in mayfly distributions in the central basin since 1997.

One Strategic Objective of Ohio's Lake Erie Protection and Restoration Plan (OLEC 2004b, p. 16) requires long-term monitoring adequate to detect trends in Lake Erie water quality. Our annual sampling program in the central basin conducted from 1997 through

2003 was a means to accomplish that objective for the benthic (bottom dwelling) invertebrate community, which is important in the diets of many fishes. In 2004, rather than look for mayflies in sediment samples at 30+ stations from Sandusky to Conneaut as done for the past seven years, we selected several transects with depth gradients ranging from shallow to deep water near Lorain, Ohio, and east of the Bass islands. The Lorain area is important because mayfly nymphs began colonizing those sediments but disappeared after 2000, as documented in a recent report to the Lake Erie Commission (Krieger 2004). The region east of the island area provides not only a depth gradient but also a gradient from abundant mayflies to few/no mayflies. We expected that the information obtained would aid interpretation of our observations in earlier years throughout the entire nearshore region of the central basin. Addition of a ROV to the sampling design was expected to demonstrate a means to dramatically enhance the efficiency of collection of data on rare individuals, in particular two of the major genera (*Dreissena* and *Hexagenia*) of benthic invertebrates of Lake Erie. We also expected that the information on *Dreissena* and *Hexagenia* obtained from this study would be valuable in advancing understanding of the mechanisms that promote or impede the successful colonization of the lake bottom by these and other animals dependent on healthy bottom conditions. The Lake Erie Trophic Study sponsored by the USEPA Great Lakes National Program Office in the early 2000s (e.g., www.epa.gov/glnpo/active/2002/jul02.html#Lake%20Erie%20Checkup) revealed the need to know the distribution and biomass of *Dreissena* in order to quantify its relationship to phosphorus regeneration. Further, *Dreissena* as well as *Hexagenia* can serve as a bioindicator of oxygen depletion in the central basin.

Methods

We surveyed for *Hexagenia* burrow holes and *Dreissena* druses (clumps of shells) by viewing and videotaping areas of lake bottom with a Deep Ocean Engineering Phantom series XTL ROV coupled with an OSD-379 monitor and video system. Stations were selected from among those where we had used a sediment grab sampler in the past. The surveys were accomplished prior to the season of mayfly emergence on 27 May 2004 in the western central basin east of the island area and 15 June 2004 in the southern central basin north of Lorain in order to maximize the agreement of numbers of burrow holes with resident nymphs (rather than recently vacated burrows). Several stations east of the island area were surveyed again on 13 October 2004 for the purpose of observing the presence of the 2004 cohort of mayfly nymphs that would have hatched from eggs deposited in the summer.

Following techniques developed in the summer of 2003 through an Ohio Sea Grant Project (R/ER-66PD, http://www.sg.ohio-state.edu/OSGRANT/FUNDING/INDEX.HTM), we videotaped areas of the lake bottom at stations along several transects representing a depth gradient from 10 m near shore to 15 m off shore (Figure 1). The location, depth, date visited, and samples collected at each station are listed in Table 1. At most stations, we videotaped the lake bottom with the ROV and collected three or four replicate sediment samples with a Ponar grab (0.054 m^2 sample area) in order to validate the number of mayfly nymphs that we estimated from the videotape.

We sieved the grab samples onboard the boat through a U.S. Standard No. 30 (0.60 mm mesh) sieve and preserved the residue in approximately 5% aqueous formalin. In the laboratory, the sample residues were stained with Phloxine B to enhance sorting efficiency and all *Hexagenia* nymphs, dreissenid mussels, and midges were removed from the residues, counted, and preserved in >50% ethanol.

A horizontal 55 cm x 55 cm grid containing 5 cm squares was videotaped with the ROV camera positioned at the same angle used for viewing the lake bottom. In the laboratory, a still videotape frame of the grid was viewed on the video monitor, and an area of the grid near the center of the image was demarcated with masking tape on the monitor screen to enclose an area of 400 cm^2 (Figure 2). Our objective had been to count all apparent *Hexagenia* burrow holes within the 400 cm^2 area of selected frames and convert them to number of burrow holes/m^2. Because each mayfly burrow has at least two holes (often more; Charbonneau and Hare 1998), the number of holes divided by 2 was expected to provide an

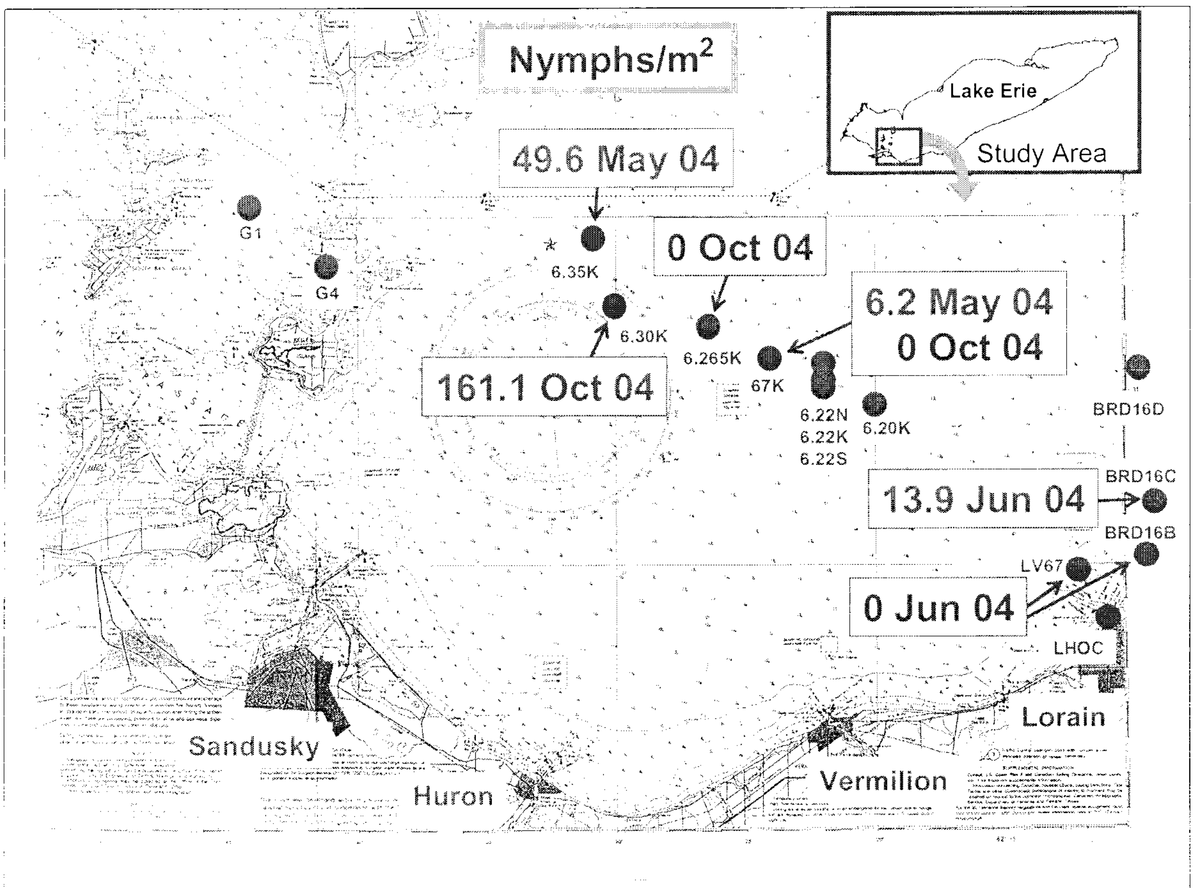

Figure 1. Stations included in this study. See Table 1 for coordinates, depths, and dates sampled, and Appendix A for type of sampling and field observations. Boxes show mean numbers of *Hexagenia* nymphs/m^2 in May, June or October 2004 where sediment samples were processed.

Table 1. Stations visited for this study. Both video and grab samples were taken at all stations except where noted. Numbers of nymphs, midges and dreissenid mussels present in each grab sample (0.054 m^2) are shown.

Station	coordinates	Date	Depth, m (ft)	Grab #	Nymphs seen while field processing?	Number of nymphs	Number of midges	Number of dreissenids
G1	41°40.31'N 82°43.98'W	27-May-04	10.2 (33)	no samples				
G4	41°38.50'N 82°41.01'W	27-May-04	15.4 (51)	no samples				
6.20K	41°34.5'N 82°19.9'W	13-Oct-04	14.6 (48)	no samples				
6.22K	41°35.2'N 83°22.0'W	13-Oct-04	14.6 (48)	no samples				
6.22N	~41°35.7'N 83°22.0'W	13-Oct-04	not recorded	no samples				
6.22S	41°35.0'N 83°22.0'W	13-Oct-04	14.6 (48)	no samples				
6.35K	41°39.14'N 82°30.92'W	27-May-04	13.7 (45)	1	Yes	0	35	2
				2		4	44	0
				3		4	30	4
67K	41°36.01'N 82°22.98'W	27-May-04	14.9 (49)	1	No	1	56	0
				2		0	2	22
				3		0	3	18
BRD16B	41°30.11'N 82°09.73'W	15-Jun-04	12.3 (40)	1	No	0	0	40
				2		0	0	3
				3		0	1	181
				4		0	2	0
BRD16C	41°31.61'N 82°09.31'W	15-Jun-04	14.9 (49)	1	No	0	35	1
				2		0	29	1
				3		2	39	0
				4		1	46	0
BRD16D	41°35.66'N 82°10.11'W	15-Jun-04	16.5 (54)	no samples				
LV67	41°29.77'N 82°11.18'W	15-Jun-04	11.6 (38)	1	No	0	0	17
				2		0	2	10
				3		0	0	9
				4		0	4	19
LHOC (Lorain Harbor Outside	41°28.54'N 82°11.03'W Channel)	15-Jun-04	not recorded	1	No	0	8	0
				2		0	0	0
				3		0	0	0
				4		0	2	0
67K	41°36.04'N 82°23.01'W	13-Oct-04 no video	15.1 (50)	1	No	0	99	0
				2		0	44	0
				3		0	125	1
6.265K	41°36.8'N 82°26.5'W	13-Oct-04	14.6 (48)	1	No	0	53	0
				2		0	39	0
				3		0	45	1
6.30K	41°37.5'N 82°30.0'W	13-Oct-04 no video	13.9 (46)	1	Yes	4	29	46
				2		17	50	3
				3		5	5	14

Table 2. Temperature and dissolved oxygen values recorded during this study

Station	Date	Time	Depth m	Temp. °C	D.O. mg/L	D.O. % sat.
G1	27 May 2004	10:45	0.5	17.5	9.7	102
			9.8	17.1	11.2	120
G4	27 May 2004	12:00	0.5	17.8	9.3	99
			13.0	16.4	9.8	103
BRD16B	15 June 2004	9:30	0.5	20.7	8.4	95
			1.5	20.3	8.3	93
			11.8	19.3	7.8	85
			12.1	19.2	7.4	81
6.265K	13 October 2004	14:15	0.5	17.5	9.4	98*
			5.0	17.4	9.4	98*
			10.0	17.4	9.4	98*
			13.0	17.3	9.3	97*
			14.0	17.3	9.3	97*

*Percent saturation calculated from Wetzel (2001, Table 9-1, p. 152)

approximate estimate of the density of nymphs in the videotaped sediments. That estimate could be compared with the estimate of nymph density derived by counting the nymphs obtained in the grab samples from the same station. This was accomplished as part of an Ohio Sea Grant project the previous year. For this LEPF grant, we reallocated the resources to a second survey of the transect east of the islands in October because of the potential to provide important information regarding recruitment of young nymphs.

Temperature and dissolved oxygen concentration were measured with a Model 550A YSI dissolved oxygen meter at four stations in May and June 2004 while conducting the survey of the lake bottom. Measurements were made at 0.5 m below the water surface and approximately 1 m above the lake bottom, with additional measurements at intermediate depths at two stations.

Results and Discussion

Dissolved oxygen and temperature in May, June, and October were nearly uniform from top to bottom at the four stations measured (Table 2). All oxygen readings near the bottom were above 80% saturation and 7.4 mg/L, indicating that adequate oxygen was probably present even at the sediment-water interface for survival and growth of *Hexagenia* nymphs. The nymphs can survive, at least for short periods of time, at oxygen concentrations down to about 1.2 mg/L (Eriksen 1963). It should be stressed that all of the readings were taken either before or after the period of summer stratification; thus, these data do not provide evidence for the extent and severity of oxygen depletion between June and October 2004.

We recorded video and/or collected samples on 27 May 2004 aboard the *R/V Erie Monitor* (Stone Lab) along two transects located near the margin of the western and central basins (four stations total) at depths ranging from 10.2 m west of Gull Island Shoal to 15.4 m at a depression north of Kelleys Island. The two more-eastward stations (6.35K, 67K) had intermediate depths (13.7 m and 14.9 m). Small (young) nymphs were found in grab samples from the latter two stations, but time did not permit collecting samples at the two westward stations. ROV video revealed small holes at the surface of the sediment at all four stations, but we could not ascertain that the holes were those of young mayflies rather than chironomid midges, which were also present in the grab samples (Table 3). Water clarity at the bottom, and therefore the quality of the video, ranged from excellent to poor, depending on the station.

On 15 June 2004, four additional stations were visited aboard the *R/V Bowfin* (USGS) north of Lorain at depths ranging from 11.6 m to 16.5 m, and one station was sampled in Lorain Harbor (Table 1). Video was recorded at all four stations in the lake, and grab samples were taken at three of those stations plus in Lorain Harbor. Video showed small burrow holes, and small numbers of midge larvae but no nymphs were found in the grab samples (Table 3). Therefore, it is assumed that the holes represented midge burrows.

On 13 October 2004, a second visit (aboard Stone Lab's *R/V Gibraltar III*) was made to one of the transects sampled in May 2004 in order to determine if the new cohort of nymphs from the past summer's eggs was present. Small holes seen at the surface of the sediment apparently were midge, and not nymph, burrows (Table 3). Examples of midge and *Hexagenia* burrow holes can be viewed on video clips within a PowerPoint presentation entitled "*Underwater Video as a Method for Detecting and Quantifying Rare Individuals, Applied to Zebra/Quagga Mussels (Dreissena spp.) and Burrowing Mayflies (*Hexagenia *spp.) in Lake Erie*". That presentation can be downloaded at www.heidelberg.edu/offices/wql/krieger/index.html. An example of a frame from one of the

Table 3. Mean number/m^2 ($\pm$ 1 standard error) of nymphs, midges, and dreissenid mussels at stations where sediment grab samples were collected.

Station	Month	*Hexagenia* nymphs	midge larvae	*Dreissena* spp.
6.35K	May 2004	49.6 (24.8)	675.4 (76.1)	37.2 (21.5)
67K	May 2004	6.2 (6.2)	378.0 (331.6)	247.9 (125.8)
BRD16B	June 2004	0.0 (0.0)	13.9 (8.9)	1041.0 (792.8)
BRD16C	June 2004	13.9 (8.9)	692.5 (66.3)	9.3 (5.4)
LV67	June 2004	0.0 (0.0)	27.9 (17.8)	255.6 (46.4)
LHOC	June 2004	0.0 (0.0)	46.5 (35.2)	0.0 (0.0)
67K	October 2004	0.0 (0.0)	1660.7 (443.9)	6.2 (6.2)
6.265K	October 2004	0.0 (0.0)	848.9 (75.4)	6.2 (6.2)
6.30K	October 2004	161.1 (77.6)	520.5 (241.7)	390.4 (239.8)

clips is shown in Figure 2, which also shows the method used for counting the number of burrow holes per unit area.

Zebra/quagga mussels generally were scattered in low abundance or entirely absent at most of the stations. Examples of their distribution can be viewed in the above PowerPoint presentation.

One of our hypotheses was that the distributions of *Hexagenia* and *Dreissena* can provide clues to the extent and severity of seasonal oxygen depletion in parts of Lake Erie, especially in relation to the so-called "dead zone" that develops in the central basin in summer. That hypothesis seems to be supported by our results, though indirectly. As is typical when sampling the central basin of Lake Erie prior to establishment of the thermocline, the temperature and dissolved oxygen (DO) concentrations in May and June 2004 were high and nearly uniform from the top to the bottom of the water column (Table 2), and the same was true in October 2004, after the thermocline may have dissipated, if it was present during summer at our stations. Therefore, as noted above, the DO readings do not provide any indication of stressful oxygen conditions that may have been present between our sampling cruises. We did not analyze the sediments for harmful or lethal concentrations of pollutants (e.g., DDT, PCBs, PAHs) that may be a factor in the absence of mayflies, though a number of studies (e.g., Burns 1985, Schloesser *et al.* 1991) have indicated that *Hexagenia* can tolerate elevated concentrations of some contaminants.

In the general area where our study was conducted, dissolved oxygen near the sediments has been shown to decline to concentrations that are near or below the tolerance range of *Hexagenia* nymphs (Krieger *et al.* 1996, Bridgeman *et al.* in press). Bartish (1987) described incursions of hypoxic (low-oxygen) water from the central basin into the western basin, and it is suspected (Krieger, in a Sea Grant proposal pending) that the hypoxic hypolimnion of the central basin episodically moves into shallower regions of the central basin that usually are well oxygenated. Data on dissolved oxygen are lacking that might show the extent of hypoxia during the time that the hypolimnion exists in summer and fall. On the other hand, the macroinvertebrate populations of the basin serve as indicators of environmental conditions throughout their life stages at the lake bottom, which include summer. Therefore, the abundance or absence of oxygen-dependent animals such as burrowing mayflies and dreissenid mussels should provide important clues to the severity of oxygen depletion at the sediment-water interface in summer.

Because we found *Hexagenia* at a relatively low density (49.6 nymphs/m^2) in May 2004 at Station 6.35K (13.7 m deep) in the central basin and also found small nymphs (6.2/m^2) in May further east in the basin at Station 67K (14.9 m), we sampled Station 67K again in October in order to determine whether the young nymphs found in May had survived the summer. No nymphs were collected (Figure 1). Dreissenids were relatively abundant at 67K in May (248 mussels/m^2) but rare in October (6.2 mussels/m^2, only one individual in three replicate samples) (Table 3).

No other stations were sampled both in the spring and fall to enable a similar comparison, but in October, nymphs were found along the western transect only at the most-western and shallowest (13.9 m) Station 6.30K and not at the two deeper stations (14.6 and 15.1 m) (Table 1). Likewise, only a single specimen of *Dreissena* was found from three replicate samples at each of the two deeper stations (6.265K and 67K) in October, while over 70 specimens (390 mussels/m^2) were found at the shallowest and most western station 6.30K (Tables 1, 3). To the contrary, the midges (Chironomidae) declined in abundance from the deepest to the shallowest station but were relatively abundant (>500 larvae/m^2) at all three. Cursory observation reveals that most of the midges in the samples are *Chironomus*, often known as "bloodworms" because of their bright red color imparted by hemoglobin in their hemolymph ("blood"). The hemoglobin in association with physiological adaptations (Irving *et al.* 2004) enables *Chironomus* to survive extended periods in oxygen-depleted sediments in Lake Erie. The absence of *Hexagenia* and near-absence of *Dreissena* but an abundance of midges at the two deeper stations in October 2004 strongly indicates that hypoxia there during part of the summer prevented the survival of the mayflies and most of the dreissenids that were present in May.

The present study results agree with the results of our earlier projects funded by the Lake Erie Protection Fund and Ohio Sea Grant (see www.heidelberg.edu/offices/wql/mayflies-in-erie.html for a complete list of reports) in that, with one exception, neither video nor grab samples taken in the central basin in 2004 near Lorain at depths between 11.6 m and 16.5 m (38 ft and 54 ft) revealed the presence of *Hexagenia* nymphs, and grab samples in 2001, 2002, and 2003 also failed to show that nymphs were present in that area (Krieger 2004). The one exception was the presence of three nymphs in two samples of four collected at Station BRD16C (14.9 m). Two dreissenid specimens were collected at the station and numerous midges (Table 1).

An important consideration in attempting to interpret the distribution and abundance of *Hexagenia* nymphs, dreissenid mussels, and other invertebrates in the bottom of Lake Erie is the composition of the sediments. Ideal sediment, that supports the greatest numbers of *Hexagenia* nymphs, is a soft, firm clay or clay-silt, as exemplified in Figures 2 and 3. Although Station 67K and Stations 6.22K, N, and S (Figure 1) are in a broad area that overall has a sediment that appears ideal for *Hexagenia*, local areas possess sediments that are not good habitat for them. For example, the sediment at Station 67K (Figure 4) consists largely of coarse sand that has been shaped by strong water currents into ripples (ridges and valleys). Not only is sand a relatively poor habitat for the nymphs, the ripples indicate that physical activity may be frequently disturbing and mixing the uppermost sediments and thereby making maintenance of burrows difficult. Therefore, factors that create suboptimal habitat confound efforts to interpret invertebrate distributions on the basis of water and sediment quality.

Conclusions

The distributions of *Hexagenia* mayfly nymphs, dreissenid mussels, and chironomid midge larvae among our study sites indicate that hypoxia in some areas of the southwestern central basin during summer prevents the survival of the mayflies and most dreissenids.

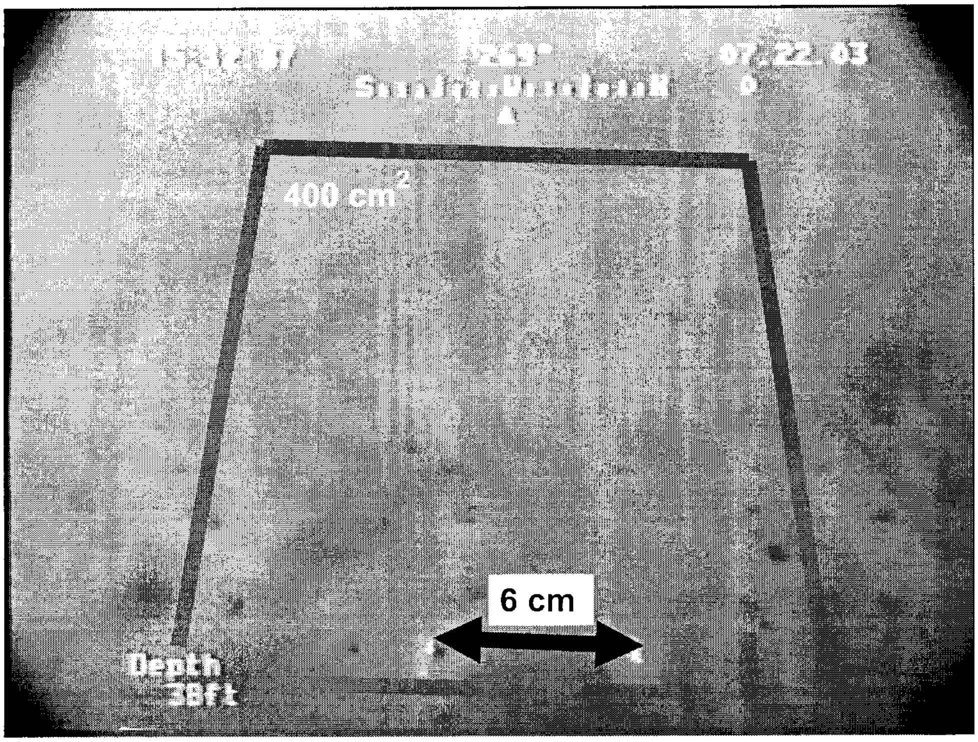

Figure 2. Hexagenia burrow holes within trapezoidal area of 400 cm^2 derived from outline of videotaped grid.

Figure 3. *Hexagenia* burrow holes at top of sediment inside an Ekman grab.

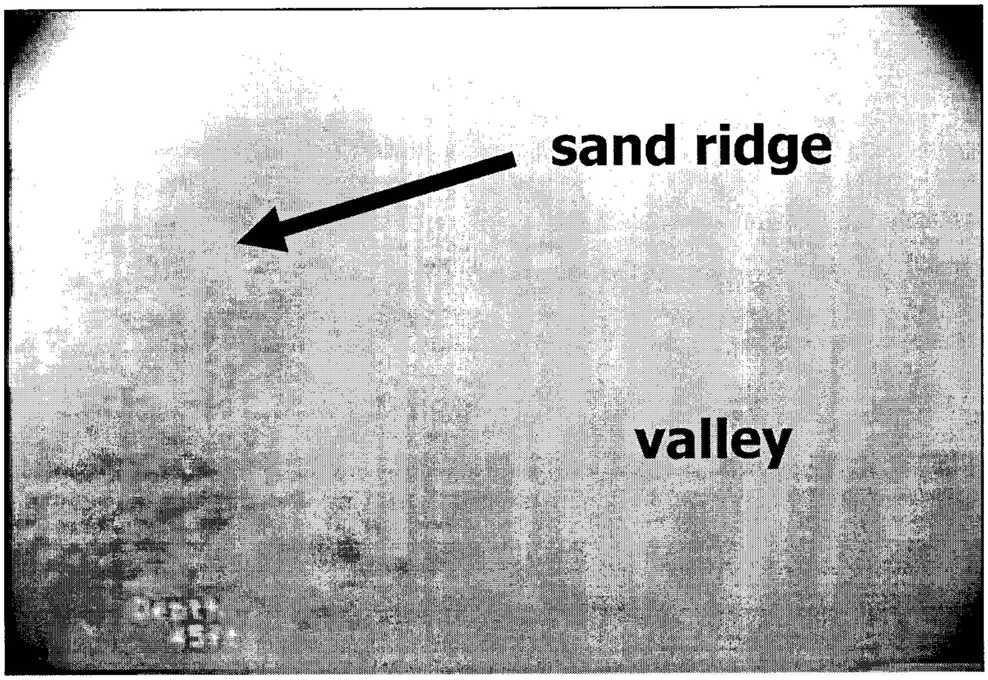

Figure 4. Sand ridge and valley comprising one of many ripples in the sediment surface at Station 67K at a depth of 13.7 m (45 ft) as viewed in natural light by ROV camera.

One of our hypotheses was that an ROV is useful in determining the distribution (presence/absence) of *Hexagenia* nymphs and *Dreissena* mussels in or on the bottom sediments of Lake Erie. That hypothesis is supported. However, use of the ROV was found to have both advantages and disadvantages:

Advantages:

1. The ROV surveys many square meters of lake bottom in a few minutes.
2. Video recordings make a permanent record of the undisturbed lake bottom and associated organisms that can be viewed and analyzed at a later time.
3. A ROV is superior to grab sampling for finding burrow holes where their density is sparse.

Disadvantages:

1. Deployment and retrieval of the ROV add 20 to 30 minutes to on-station time.
2. Low water clarity at the lake bottom is difficult to predict and can be a major factor limiting the visible details and resolution.
3. Because interpretation of *Hexagenia* density based on the sizes and number of holes present in video frames may be inaccurate, at least at this stage of development of the technique, more accurate estimates of mayfly density can be obtained where they are relatively abundant by means of sediment grab samplers.
4. Small holes may be those of midge larvae rather than small *Hexagenia* nymphs and at present the two types of burrows cannot be distinguished visually. It is possible that further study will provide clues to permit their visual separation.

Benefits and Information Dissemination

Findings of this project have been presented at the events listed in Table 4. The abstract of our poster presentation at the meeting of the International Association for Great Lakes Research in May 2005 is included as Appendix B and the poster is shown as Appendix C (available in pdf at www.heidelberg.edu/offices/wql/publish.html#reports). The results will also be incorporated into a multi-author manuscript on changes in *Hexagenia* population distribution and density in Lake Erie that is presently in the outline stage.

Table 4. Presentations that have included the project results.

08 October 2005: Krieger, K. A. *The Ecology of Mayflies in Lake Erie and Their Role in the Lake Erie Quality Index*. The Kirtlandia Society, Cleveland Museum of Natural History, Cleveland, Ohio.

23 August 2005: Krieger, K. A., M. A. Thomas, N. J. Johnson, and M. T. Bur. *Underwater Video as a Method for Detecting and Quantifying Rare Individuals, Applied to Zebra/Quagga Mussels (*Dreissena *spp.) and Burrowing Mayflies (*Hexagenia *spp.) in Lake Erie.* Sea Grant review panel at Old Woman Creek National Estuarine Research Reserve, Huron, Ohio.

16 June 2005: Krieger, K. A. *Burrowing Mayflies and Lake Erie: Connecting Biology to Policy.* Sandusky Rotary Club, Sandusky, Ohio. (included presentation of the Lake Erie Quality Index)

24 May 2005: Krieger, K. A., Bur, M. T., Thomas, M. A., and N. J. Johnson. *Distribution of burrowing mayflies (Ephemeridae:* Hexagenia *spp.) in the central basin of Lake Erie, 1997-2004: potential relationship to hypoxia.* 48th Conference of International Association for Great Lakes Research, Ann Arbor, Michigan. (poster)

09 December 2004: Krieger, K. A. *Canadian soldiers (burrowing mayflies) and the Lake Erie Quality Index: connecting biology to policy.* Evening seminar series, Biology Dept., Heidelberg College.

10 September 2004: Krieger, K. A. *The misfortunes and successes of mayflies: What they tell us about the health of Lake Erie.* Invited talk, second annual Conservation Symposium, Cleveland Museum of Natural History, Cleveland, Ohio.

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Appendices

Appendix A. Field observations recorded while using ROV and processing sediment grab samples, and laboratory observations of sediment composition.

Appendix B. Abstract of poster presented at the 47th conference of the International Association for Great Lakes Research, Ann Arbor, Michigan, May 2005.

Appendix C. Poster presented at the 47th conference of the International Association for Great Lakes Research, Ann Arbor, Michigan, May 2005.

Appendix A

Field observations recorded while using ROV and processing sediment grab samples, and laboratory observations of sediment residues.

East of the Bass Islands

Station	Date	ROV Observations	Grab Samples	Sediment Residues
G1	27 May 2004	Very murky – could not see lasers	No samples were collected.	N/A
G4	27 May 2004	May have been some burrows, but very murky. Poor visibility.	No samples were collected.	N/A
6.20K	13 Oct 2004	No ROV run.	Sandy – no Ponars kept.	N/A
6.22K	13 Oct 2004	No ROV run.	All sand – not processed.	N/A
6.22N	13 Oct 2004	No ROV run.	All fine sand – not processed. (north of transect)	N/A
6.22S	13 Oct 2004	No ROV run.	Coarse sand – not processed. (south of transect)	N/A
6.265K	13 Oct 2004	No ROV run.	Light brown veneer over dark slate gray. Cohesive mud, very little clay. A few small possibly live *Dreissena*.	Filamentous bacteria/algae, oligochaetes, detritus.
6.30K	13 Oct 2004	No ROV run.	Dark slate gray beneath brown veneer. Very firm, cohesive.	Shells, pebbles, filamentous bacteria/algae, scuds, leeches.
6.35K	27 May 2004	Very clear bottom. Saw many small holes & tracks; a few larger holes that may be *Hexagenia*. No *Dreissena*.	Light brown surface veneer over gray. A few small fragments – cinders? Soft, cohesive mud.	Clay and filamentous bacteria/algae.
67K	27 May 2004	No field notes.	Layers not apparent. Much coarse sand. No *Dreissena*.	Coarse sand, pebbles; a few small *Dreissena*.
67K	13 Oct 2004	Due west – constant ridges & valleys – "dunes", then followed a valley ~ south.	Dark slate gray beneath brown veneer. Cohesive but about half sand.	Coarse sand, shells, filamentous bacteria/algae, pebbles, oligochaetes, leeches

[Continues on next page]

Appendix A. Continued.

North of Lorain, Ohio

Station	Date	ROV Observations	Grab Samples	Sediment Residues
BRD16B	15 June 2004	Several possible burrow holes. Excellent weather: 0-5 knots, waves <0.1 m, Beaufort #2.	Can't see veneer or layers because samples loose and watery. Mostly coarse sand with pea gravel. Lots of live and dead *Dreissena*.	Pea gravel, small stones, shells, some worms (first of four replicates was shells and coarse sand).
BRD16C	15 June 2004	Some paired, small burrow holes seen. Weather as at BRD16B; water clearer; easier to see bottom than at BRD16B.	Thick light brown flocculent layer mashed through Ponar screen. Very dark gray below. No live/dead *Dreissena* or bloodworms (midges) seen.	Detritus, filamentous bacteria/ algae, many fingernail clams and leeches.
BRD16D	15 June 2004	Very monotonous terrain; a few holes seen. Numerous midge pupal skins on surface, not as numerous as the nymph skins seen at BRD16C. Secchi 6.5 m from sunny side.	No samples were collected.	N/A
LV67	15 June 2004	Many *Dreissena* but mostly not clumped. Some very small paired holes, none apparently *Hexagenia*. No midge or *Hexagenia* exuviae.	Mostly coarse sand & small pebbles. *Dreissena* half live, half dead. No midges seen in samples.	Coarse sand, shells, pea gravel, small stones, some oligochaetes.
LHOC	15 June 2004	No ROV run – water too cloudy.	Light brown on top, dark clay below. Considerable fine detritus after rinse. No *Dreissena* but one empty *Corbicula* shell. Oily smell and oil sheen developed during rinse.	Detritus, many oligochaetes, some leeches.

Appendix B

Abstract of Poster Presented at the Annual Conference of the International Association for Great Lakes Research, Ann Arbor, Michigan, May 2005

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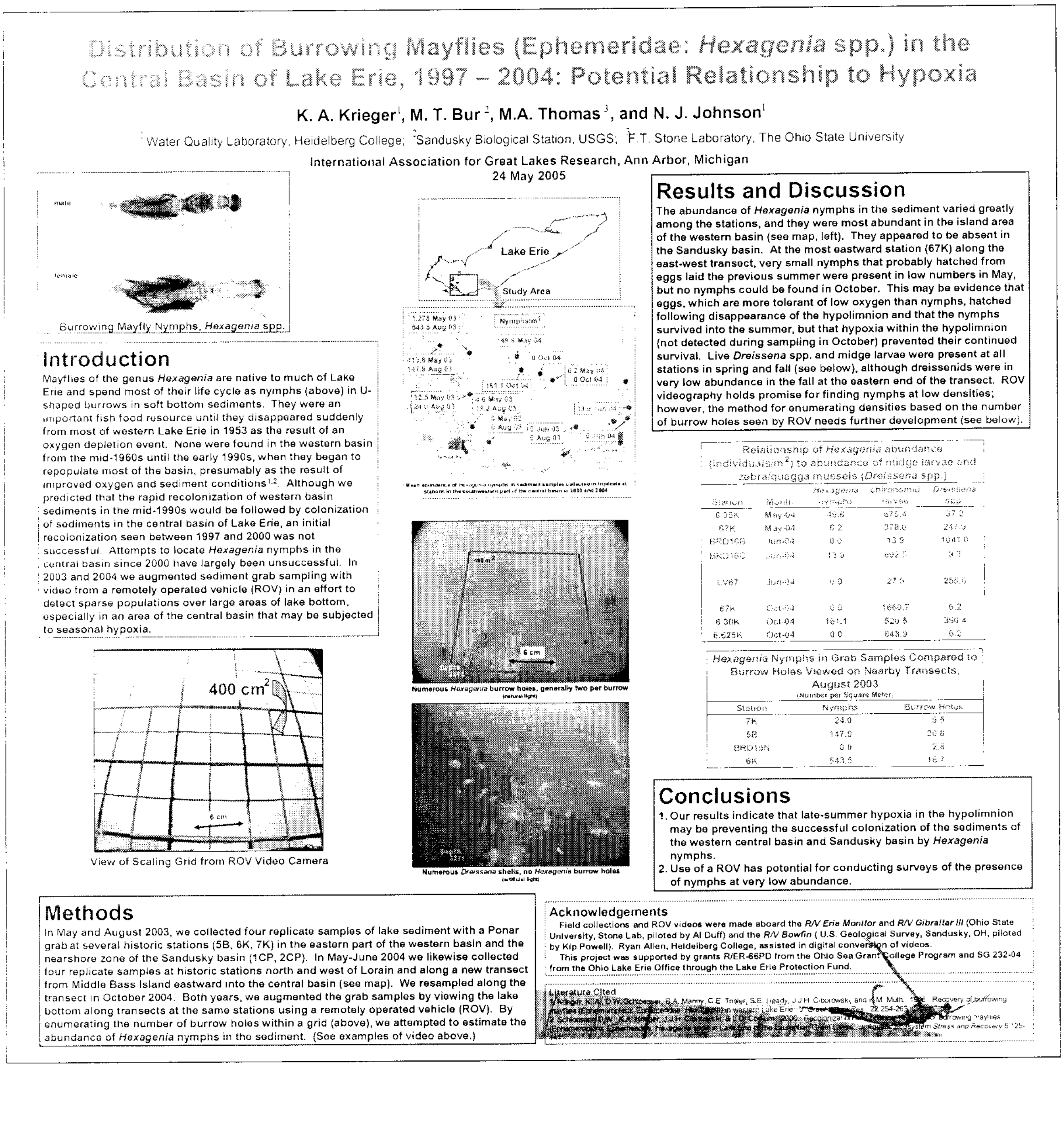
Distribution of Burrowing Mayflies (Ephemeridae: *Hexagenia* spp.) in the Central Basin of Lake Erie, 1997 – 2004: Potential Relationship to Hypoxia

Burrowing mayflies are native to shallow regions of Lake Erie and the other Laurentian Great Lakes. Extensive pollution eliminated most of these important fish food insects from Lake Erie by the middle of the twentieth century, but they recolonized most of the western basin in the 1990s following pollution abatement. Sediment grab samples collected from the nearshore central basin revealed an increase in the distribution and abundance of burrowing nymphs from 1997 through 2000 followed by a return to 1997 conditions from 2001 through 2003. Grab samples were augmented with video from a remotely operated vehicle (ROV) in 2003 and 2004 as a means of detecting sparse populations over large areas of lake bottom by viewing burrow holes. Video and grab samples in the western central basin showed an absence of mayfly burrows and nymphs in sediments of open waters in summer and fall. The presence of small nymphs during spring in the western edge of the central basin indicated that eggs are dispersed into the basin each summer and probably hatch following dissipation of the thermocline, but the young nymphs do not complete their life cycle in deeper waters. This implicates hypoxia in the hypolimnion as a factor limiting successful colonization of central basin sediments.

Appendix C

Poster Presented at the 47th Conference of the International Association for Great Lakes Research, Ann Arbor, Michigan, May 2005



Distribution of Burrowing Mayflies (Ephemeridae: *Hexagenia* spp.) in the Central Basin of Lake Erie, 1997 – 2004: Potential Relationship to Hypoxia

K. A. Krieger[1], M. T. Bur[2], M.A. Thomas[3], and N. J. Johnson[1]

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International Association for Great Lakes Research, Ann Arbor, Michigan
24 May 2005

Burrowing Mayfly Nymphs, *Hexagenia* spp.

Introduction

Mayflies of the genus *Hexagenia* are native to much of Lake Erie and spend most of their life cycle as nymphs (above) in U-shaped burrows in soft bottom sediments. They were an important fish food resource until they disappeared suddenly from most of western Lake Erie in 1953 as the result of an oxygen depletion event. None were found in the western basin from the mid-1960s until the early 1990s, when they began to repopulate most of the basin, presumably as the result of improved oxygen and sediment conditions[1,2]. Although we predicted that the rapid recolonization of western basin sediments in the mid-1990s would be followed by colonization of sediments in the central basin of Lake Erie, an initial recolonization seen between 1997 and 2000 was not successful. Attempts to locate *Hexagenia* nymphs in the central basin since 2000 have largely been unsuccessful. In 2003 and 2004 we augmented sediment grab sampling with video from a remotely operated vehicle (ROV) in an effort to detect sparse populations over large areas of lake bottom, especially in an area of the central basin that may be subjected to seasonal hypoxia.

Mean abundance of *Hexagenia* nymphs in sediment samples collected in triplicate at stations in the southwestern part of the central basin in 2003 and 2004

View of Scaling Grid from ROV Video Camera

Numerous *Hexagenia* burrow holes, generally two per burrow (natural light)

Numerous *Dreissena* shells, no *Hexagenia* burrow holes (artificial light)

Results and Discussion

The abundance of *Hexagenia* nymphs in the sediment varied greatly among the stations, and they were most abundant in the island area of the western basin (see map, left). They appeared to be absent in the Sandusky basin. At the most eastward station (67K) along the east-west transect, very small nymphs that probably hatched from eggs laid the previous summer were present in low numbers in May, but no nymphs could be found in October. This may be evidence that eggs, which are more tolerant of low oxygen than nymphs, hatched following disappearance of the hypolimnion and that the nymphs survived into the summer, but that hypoxia within the hypolimnion (not detected during sampling in October) prevented their continued survival. Live *Dreissena* spp. and midge larvae were present at all stations in spring and fall (see below), although dreissenids were in very low abundance in the fall at the eastern end of the transect. ROV videography holds promise for finding nymphs at low densities; however, the method for enumerating densities based on the number of burrow holes seen by ROV needs further development (see below).

Relationship of *Hexagenia* abundance (individuals/m²) to abundance of midge larvae and zebra/quagga mussels (*Dreissena* spp.)

Station	Month	*Hexagenia* nymphs	chironomid larvae	*Dreissena* spp.
6.35K	May-04	49.6	675.4	37.2
67K	May-04	6.2	378.0	247.[illegible]
BRD16S	Jun-04	0.0	13.9	1041.0
BRD16C	Jun-04	13.9	692.5	3.3
LV67	Jun-04	0.0	27.9	255.5
67K	Oct-04	0.0	1660.7	6.2
6.30K	Oct-04	161.1	529.6	390.4
6.625K	Oct-04	0.0	848.9	6.2

Hexagenia Nymphs in Grab Samples Compared to Burrow Holes Viewed on Nearby Transects, August 2003 (Number per Square Meter)

Station	Nymphs	Burrow Holes
7K	24.0	9.5
5B	147.9	20.6
BRD15N	0.0	2.8
6K	543.5	16.7

Conclusions

1. Our results indicate that late-summer hypoxia in the hypolimnion may be preventing the successful colonization of the sediments of the western central basin and Sandusky basin by *Hexagenia* nymphs.
2. Use of a ROV has potential for conducting surveys of the presence of nymphs at very low abundance.

Methods

In May and August 2003, we collected four replicate samples of lake sediment with a Ponar grab at several historic stations (5B, 6K, 7K) in the eastern part of the western basin and the nearshore zone of the Sandusky basin (1CP, 2CP). In May-June 2004 we likewise collected four replicate samples at historic stations north and west of Lorain and along a new transect from Middle Bass Island eastward into the central basin (see map). We resampled along the transect in October 2004. Both years, we augmented the grab samples by viewing the lake bottom along transects at the same stations using a remotely operated vehicle (ROV). By enumerating the number of burrow holes within a grid (above), we attempted to estimate the abundance of *Hexagenia* nymphs in the sediment. (See examples of video above.)

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Field collections and ROV videos were made aboard the *R/V Erie Monitor* and *R/V Gibraltar III* (Ohio State University, Stone Lab, piloted by Al Duff) and the *R/V Bowfin* (U.S. Geological Survey, Sandusky, OH, piloted by Kip Powell). Ryan Allen, Heidelberg College, assisted in digital conversion of videos.

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