 0030-0950/85/0005-0230 $2.00/0

SNAIL DISTRIBUTIONS IN LAKE ERIE: THE INFLUENCE OF ANOXIA IN THE SOUTHERN CENTRAL BASIN NEARSHORE ZONE[1]

KENNETH A. KRIEGER, Water Quality Laboratory, Heidelberg College, Tiffin, OH 44883

ABSTRACT. The distributions and abundances of gastropods collected in sediment grab samples in 1978 and 1979 in the southern nearshore zone of the central basin of Lake Erie were compared with earlier gastropod records from throughout the lake. Since the 1920s, 34 species in eight families have been reported for the lake proper. Sixteen species have been reported only once, 13 of them in three reports prior to 1950. All but three of the species collected by two or more authors prior to the mid-1950s have also been collected in the past decade. The most frequently reported species are *Valvata tricarinata, Bithynia tentaculata, Elimia (=Goniobasis) livescens, Physella* "sp.", *Amnicola limosa, Pleurocera acuta* and *V. sincera*. Only six of 19 studies reported species densities, and most did not record sample locations, depths or substrates. Thus, only a limited comparison of the gastropod fauna between studies was possible, with the exception of several well documented studies in the western basin up to the early 1960s. Of four introduced species in Lake Erie, only two were found in the present study, and these appear to have no influence on the present distributions of the native species. The absence of snails in the southwestern part of the study area and at the mouths of the Cuyahoga and Black rivers appears to be the result of prolonged anoxia during one or more summers preceding the study.

OHIO J. SCI. 85 (5): 230-244, 1985

INTRODUCTION

Lake quality in the southern nearshore zone of the central basin of Lake Erie in 1978 and 1979 was recently interpreted from the composition of the oligochaete (worm), sphaeriid (clam) and chironomid (midge) communities, which comprised the most abundant benthic macroinvertebrate groups inhabiting soft substrates (Krieger 1984). The fourth most widely distributed and abundant group, the Gas-

[1]Manuscript received 12 February 1985 and in revised form 7 August 1985 (#85-4).

tropoda, also has been used to discern conditions of pollution and environmental change (Harman 1974). Detailed records of the gastropods in the southern nearshore zone of the central basin have never been reported. The purposes of this report are to describe the distributions and abundances of the gastropods collected in the 1978 and 1979 samples and to relate this information to previous gastropod records for Lake Erie, with discussion of some ecological factors which may influence snail distributions.

STUDY AREA

Lake Erie contains three primary basins, the shallowest being the western basin and the deepest the eastern basin (fig. 1). Because of their different morphometries and pollution sources, each basin has responded differently and in different degrees to various types of pollution (e.g., Britt 1955, Internat. Joint Comm. 1981).

Researchers have somewhat arbitrarily divided the lake into the wave zone (<2 m deep) (Barton and Hynes 1978), the nearshore zone (generally < 8 km from shore)

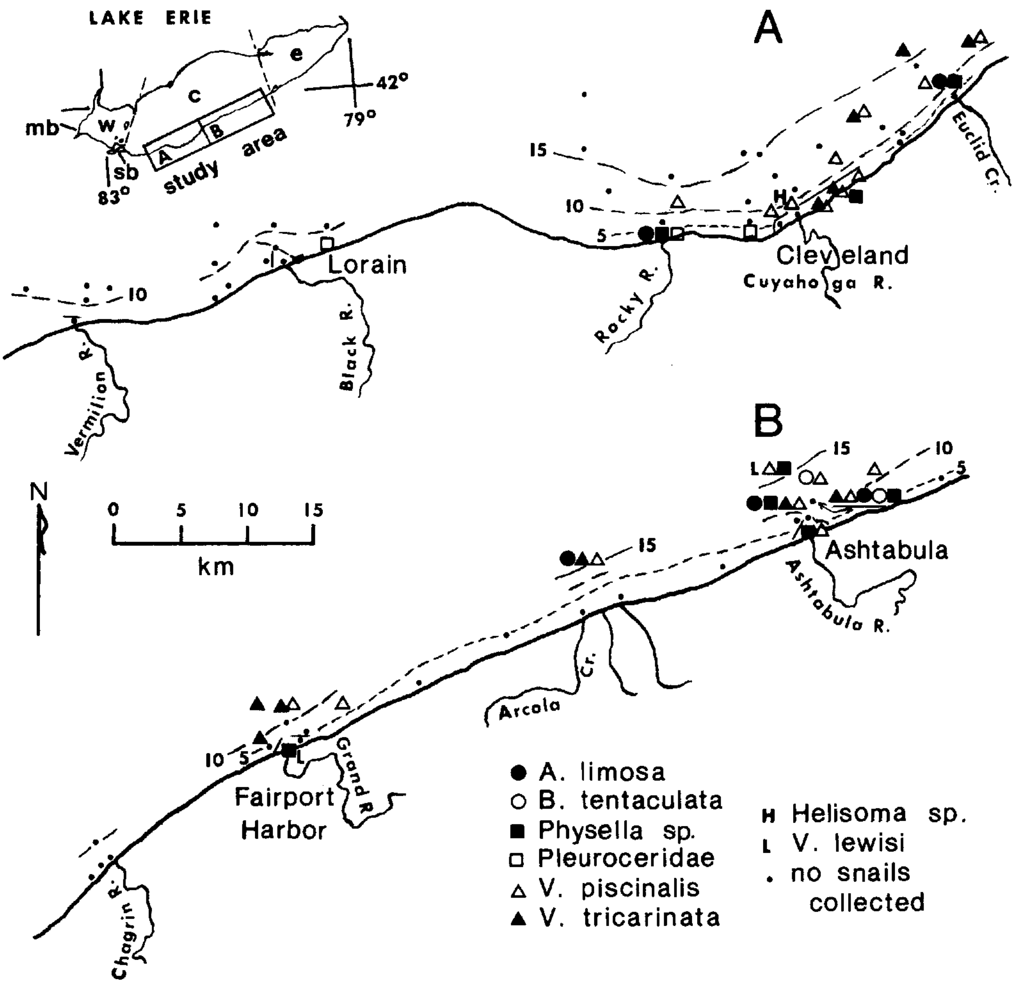

FIGURE 1. The study area, showing the 5, 10 and 15-m contours and the distribution of gastropod species in 1978 and 1979. Predominant substrate types are mapped in Krieger (1984). The dashed lines through the inset of Lake Erie mark the approximate boundaries of the western (w), central (c) and eastern (e) basins. Also shown are Maumee Bay (mb) and Sandusky Bay (sb).

(Krieger 1984), and the open lake. In the present study, samples were collected in a 155-km reach of the southern nearshore zone of the central basin (fig. 1). This region possesses numerous foci of pollution. During the study period the Black, Cuyahoga and Ashtabula rivers and their harbors were among the 18 areas in the Great Lakes Basin demonstrating the worst environmental degradation, receiving such diverse pollutants as volatile solids, oil and grease, metals, nutrients, polychlorinated organics, cyanide and fecal bacteria (Internat. Joint Comm. 1981).

The major substrate types encountered at each of the sampling stations were mapped by Krieger (1984). Sampling depths ranged from <2 m to 17 m (fig. 1).

METHODS AND MATERIALS

Quantitative and qualitative samples of the macrobenthos were collected with a Ponar grab (0.053 m^2 area) at 75 stations (fig. 1) between 16-28 June 1978 or 1-9 September 1978, and between 12-23 July 1979. Stations were located to within a 16-m radius using a LORAN-C navigational system or, at very nearshore stations, by visually aligning landmarks. Most of the stations were successfully sampled both years. Six stations were sampled in duplicate each year, and the macrobenthos densities at those stations were averaged for comparison with the densities at the remaining stations, where only a single sample was collected. Where only a partial grab sample could be obtained, the sample was treated qualitatively, and at several stations with a hard substrate, such as bedrock and gravel (see Krieger 1984), samples were not obtained. The latter substrates provide optimal habitat for some snail species (Shelford and Boesel 1942), and thus the described distributions, and probably the maximum densities reported, are conservative.

Each fresh sample was sieved through a 0.52-mm mesh screen by spraying with a stream of water from a hose. The remaining sample was preserved in an aqueous solution of 85% ethanol and 5% glycerin and was stained with Phloxine B prior to sorting.

Because the survey was designed to provide a general understanding of the benthic macroinvertebrate community throughout the southern central basin nearshore zone, the sampling design was not adequate to provide an estimate of the abundance of individual species or the entire macrobenthic community at individual stations. Furthermore, snails, as a minor component of the fauna, were sparse with only one or two specimens being collected in most of the samples in which snails were present. Thus, the samples from all stations within subdivisions of the study area were treated statistically as a group. The open lake subdivisions were the Vermilion-Lorain vicinity, the Rocky River-Cleveland-Euclid Creek vicinity, and the region from the Chagrin River to east of Ashtabula (fig. 1). The four harbors (at Lorain, Cleveland, Fairport Harbor and Ashtabula) comprised a final subdivision.

Means and standard errors were computed for each species and for total snails. Most samples contained no snails; thus the mean was strongly influenced by the sample size (the number of zero values). For this reason, median and maximum total snail densities are also presented for each subdivision of the study area. The median values for individual species were all zero. Statistical analyses were performed with the Minitab statistical package (Ryan et al. 1982).

The first major benthic surveys of the open waters of Lake Erie were conducted in the western basin during the 1920s, and reports of these surveys as well as published and unpublished technical reports and theses of later studies provided the historical record for comparison with the present data. Although several museums in the Great Lakes region have extensive collections of snails from Lake Erie, many of the records and identifications are incomplete and unverified (G. L. Mackie, C. B. Stein, 1984, pers. comm.). Hence, I have not relied on these sources for historical information.

Several early reports (e.g., Dennis 1928, Ahlstrom 1930) included river-mouth marshes and isolated ponds as some of their Lake Erie stations. Because the ecological and hydrological characteristics of these shallow water bodies differ greatly from those of the open lake in the wavezone and lakeward, those stations have been excluded from the record discussed here.

The freshwater snail nomenclature has been modified greatly since the 1920s. In order to compare distributions among reports, it was necessary to reduce the various names applied at different times to a single list, where possible, of currently accepted names. This list (table 1) reveals continuing disagreement regarding several species, genera and even one family (Mackie et al. 1980, Clarke 1981, Burch 1982). Throughout this report I refer to the names assigned by Burch (1982) in preference to others because he has provided detailed historical and systematic documentation.

RESULTS

1978-1979 COLLECTIONS. Nine snail taxa were collected in 1978-1979 in the study area (fig. 1, table 2). Snails generally accounted for $<2\%$ of the macrobenthos, although they were the most abundant group in a few samples. Snails were almost completely absent from the samples collected west of the Rocky River but were widely distributed to the east (fig. 1).

Within the study area from the Rocky River eastward, mean snail densities outside of harbors were six to 13 times greater in the subdivision from Fairport Harbor to east of Ashtabula (fig. 1B) than in the subdivision from the Rocky River to Euclid Creek (fig. 1A). The median density both years was zero in the latter area while in the more eastern subdivision the median was 19 snails m^{-2} in 1978 and 30 snails m^{-2} in 1979 (table 2). Furthermore, the maximum density encountered in a single sample was 10 times higher in the eastern subdivision both years (table 2).

The samples from the Lorain, Cleveland, Fairport Harbor and Ashtabula harbors revealed a mean density of six snails m^{-2} in 1978, but in 1979 the harbors as a group possessed a higher mean and median density of snails than the open lake (table 2). This resulted because in 1979 a locally dense population was sampled at two Cleveland Harbor stations which was not detected in 1978. Whereas no snails were found at any of the Cleveland Harbor stations in 1978, four of the six stations (excluding the westernmost and Cuyahoga River mouth stations) yielded snails in 1979. The variation in the data between the two years most likely reflects a large spatial heterogeneity in snail populations, as it was impossible to sample at precisely the same point each year.

Individual species were found at from one to 24% of the stations during the two summers (table 3). Their low occurrence precludes presenting meaningful summary data within subdivisions of the study area. Within the entire area, *Valvata piscinalis* (Müller) was the most widespread and abundant species, being collected on mud, clay or sand at 10 stations each year at all depths eastward from the Rocky River for a total of 18 stations. Its maximum densities were 340 m^{-2} in 1978 north of Ashtabula and 1,257 m^{-2} in 1979 in Cleveland Harbor, with only two other stations, near Cleveland, revealing over 100 m^{-2}.

Valvata tricarinata (Say) was also found frequently, being collected at 12 stations during the study (eight in 1978 and six in 1979). Maximum densities were 170 m^{-2} midway between Fairport Harbor and Ashtabula in 1978 and 216 m^{-2} in Cleveland Harbor in 1979. It occurred at all depths on mud, clay and sand substrates and was often sympatric with *V. piscinalis*.

The only other frequently encountered snail was the genus *Physella*. It was recovered from eight stations (six in 1978 and five in 1979), all with <50 m^{-2} except for 170 m^{-2} at one station in 1978 near Ashtabula which also possessed unusually high densities of *V. piscinalis* (340 m^{-2}), *Amnicola limosa* (Say) (284 m^{-2}), *B. tentaculata* L. (208 m^{-2}), and *V. tricarinata* (151 m^{-2}). *Physella* sp. occurred over the entire depth range and on sand, silt, and clay.

Amnicola limosa (Say) was sparsely distributed over the entire range of depths and substrates eastward from the mouth of the Rocky River. Only one specimen was collected per sample ($=20$ m^{-2}) except north of Ashtabula, where two samples revealed 236 and 284 individuals m^{-2}.

Bythinia tentaculata (L.) was found only at two eastern stations, which were >10 m deep and had a sandy substrate. It was, however, abundant at both stations, with numbers up to 452 m^{-2}. A single, small specimen of *Helisoma* sp. was collected at the entrance to Cleveland Harbor. Only two individuals of *Valvata lewisi* Currier were collected during the study, both in the eastern part of the study area. The pleurocerid snails *Elimia* (=*Goniobasis*) *livescens* (Menke) and *Pleurocera acuta* Raf. were found at only three stations, which had gravel or sandstone bottoms and depths of <5 m.

HISTORICAL RECORDS. Since the 1920s, 34 species have been reported for Lake Erie, including its bays but excluding its contiguous marshes, wetlands and flooded tributary mouths (tables 1 and 4). Except for the Valvatidae the eight families have undergone major taxonomic revision. Several early references were to Old World genera (*Ancylus, Planorbis, Segmentina*) which do not occur in North America and

TABLE 1

Lake Erie gastropod taxa as originally referenced, and their present nomenclatural status.

Original reference	Present nomenclature, where different
ANCYLIDAE	
Ancylus Müller 1774	Old World genus; probably *Ferrissia* Walker 1903[1]
Ferrissia rivularis (Say 1817)	
HYDROBIIDAE	
Amnicola binneyana Hannibal 1912	*Fontigens binneyana* (Hannibal 1912)[1]; *Probythinella lacustris* (F. C. Baker 1928)[2,3]
Amnicola integra (Say 1821)	*Cincinnatia cincinnatiensis* (Anthony 1840)[1,2,3]
Amnicola limosa (Say 1817)	
Amnicola limosa porata	*Amnicola limosa* (Say 1817)[1]
Amnicola lustrica Pilsbry 1890	*Marstonia lustrica* (Pilsbry 1890)[1], *Marstonia decepta* (Baker 1928)[2,3]
Bulimus tentaculatus L. 1758	*Bithynia tentaculata* (L. 1758)[1,2,3]; Family Bithyniidae[1,3]
Pyrgulopsis letsoni (Walker 1901)	
Somatogyrus subglobosus (Say 1825)	Same[2,3] or *Birgella subglobosa* (Say 1825)[1]
LYMNAEIDAE	
Fossaria modicella (Say 1825)	
Fossaria obrussa (Say 1825)	
Fossaria parva (Lea 1841)	
Limnea woodruffi F. C. Baker 1901	*Stagnicola woodruffi* (F. C. Baker 1901)[1] or *Stagnicola catascopium nasoni* (Baker 1906)[2]
Lymnaea auricularia (L. 1758)	*Radix auricularia* (L. 1758)[1,2,3]
Lymnaea caperata (Say 1829)	*Stagnicola caperata* (Say 1829)[1,2,3]
Lymnaea (=*Limnea*) *humilis* (Say 1822)	*Fossaria humilis* (Say 1822)[1,2]
Stagnicola catascopium niagarensis (Baker)	*Stagnicola catascopium* (Say 1817)[1]
Stagnicola emarginata ontariensis (Kuster)	*Stagnicola emarginata* (Say 1821)[1,2]
Stagnicola reflexa (Say 1821)	Same[2,3] or *Stagnicola elodes* (Say 1821) morph *reflexa*[1]
PHYSIDAE	
Physa Draparnaud 1801	*Physella* Haldeman 1843[1,2] or *Physa*[1,3]
Physa ancillaria magnalacustris Walker	?*Physella magnalacustris* (Walker 1901)[1] or ?*Physella ancillaria* (Say 1825)[1]
Physa sayii oneida (Baker)	?*Physella gyrina sayi* (Tappen 1838)[1,2]
Physella magnalacustris (Walker 1901)	
PLANORBIDAE	
Gyraulus parvus (Say 1817)	
Helisoma anceps (Menke 1830)	
Helisoma trivolvis (Say 1817)	Same[2,3] or *Planorbella trivolvis* (Say 1817)[1]
Planorbis Müller 1774	Old World genus[1]
Planorbula crissilabris Walker	Not listed[1,2,3]; see text
Planorbula jenksii (Carpenter 1871)	*Planorbula armigera armigera* (Say 1821)[1,3]
Segmentina Fleming 1817	Palaearctic genus; probably *Planorbula* Haldman 1840[1]
PLEUROCERIDAE	
Goniobasis haldemani Tryon 1865	*Elimia livescens haldemani* (Tryon 1865)[1]
Goniobasis livescens (Menke 1830)	Same[2,3], or *Elimia livescens* (Menke 1830)[1]
Pleurocera acuta Rafinesque 1831	
VALVATIDAE	
Valvata bicarinata Lea 1841	
Valvata lewisi Currier 1868	
Valvata perconfusa Walker 1917	*Valvata tricarinata* (Say 1817) morph *perconfusa* Walker 1917[1,2]
Valvata piscinalis (Müller 1774)	
Valvata sincera Say 1824	
Valvata tricarinata (Say 1817)	

TABLE 1 (Continued)

Original reference	Present nomenclature, where different
VIVIPARIDAE	
Campeloma decisum (Say 1817)	
Viviparus japonicus Martens 1861	Same[2], or *Cipangopaludina japonica* (Martens 1861)[1] or *C. chinensis* (Gray 1834)[3]

[1]Burch (1982)
[2]Mackie et al. (1980)
[3]Clarke (1981)

which cannot now be related to a specific genus or species (Burch 1982). *Planorbula crissilabris* Walker, reported originally by Shelford and Boesel (1942), has not since been reported and is not referenced in any of the recent systematic treatises (Robertson and Blakeslee 1948, Mackie et al. 1980, Clarke 1981, Burch 1982). Therefore, the identity of these specimens remains speculative.

Of the 34 species, 16 have been reported by only one author, 13 of them prior to 1950 (Dennis 1928, Ahlstrom 1930, Robertson and Blakeslee 1948). Dennis (1928) and Ahlstrom (1930) restricted their studies to the Island Region of the western basin, and Robertson and Blakeslee (1948) reported on the Niagara Frontier Region, which includes much of the eastern basin. Because of these three studies, which account for the only records of 38% of the species reported in Lake Erie, the western and eastern basins appear to possess a much richer gastropod fauna, with 22 and 20 species, respectively, than the central basin, with 11 species (table 4).

The western basin has been sampled more intensively than the central and eastern basins, increasing the probability of discovering rare species. Of the 18 citations in table 4, 12 report on the western basin, six on the central basin and five on the eastern basin. One (Barton and Hynes 1978) does not specify the basins in which the species were collected.

Most of the species which were collected by two or more authors prior to the mid-1950s have also been collected in the past decade. The three exceptions are *Birgella subglobosa* (Say), which was only found in

TABLE 2

Snail densities (mean No. m^{-2} ± one standard error, median, and maximum encountered) in 1978 and 1979 in subdivisions of the Ohio nearshore zone of the central basin of Lake Erie, from the Rocky River eastward. The 18 stations west of the Rocky River, where only one specimen was found, are not included.

	1978				1979			
Area	N*	$\bar{x}$ ± S.E.	Median	Maximum	N*	$\bar{x}$ ± S.E.	Median	Maximum
Rocky River to Euclid Creek**	15	23 ± 10	0	114	8	8 ± 5	0	40
Fairport Harbor to Ashtabula**	11	148 ± 103	19	1,153	10	104 ± 52	30	492
Harbors	10	6 ± 4	0	38	9	247 ± 161	40	1,473
Open Lake***	26	76 ± 44	19		18	61 ± 31	10	
Total	36	56 ± 32	0		27	123 ± 58	20	

*Number of stations sampled quantitatively
**Excluding stations within harbors
***The first two areas combined (Rocky River to Ashtabula)

TABLE 3

Species densities (mean ± one standard error with maximum density in parentheses) estimated from samples collected in 1978 and 1979 in the Ohio nearshore zone of the central basin of Lake Erie, from the Rocky River eastward. The median density for every species was zero. Also shown for each species is the percent of the 75 stations sampled (qualitatively or quantitatively) in the entire study area during both years at which it was encountered, and the substrate types on which it was found.

Species	Substrates*	No. m^{-2} ± 1 S.E. (maximum) 1978	1979	Percent of stations
Number of stations**		36	27	
Amnicola limosa (Say)	MSG	9 ± 8 (284)	10 ± 9 (236)	7
Bithynia tentaculata (L.)	MS	9 ± 9 (208)	18 ± 17 (452)	3
Physella sp.	MS	8 ± 5 (170)	3 ± 1 (20)***	11
Helisoma sp.	MSG	0 ± 0 (0)	1 ± 1 (20)†	1
Elimia livescens (Menke)	S	††	0 ± 0 (0)	3
Pleurocera acuta (Raf.)	R	††	0 ± 0 (0)	1
Valvata lewisi Currier	M	0.5 ± 0.5 (19)†	1 ± 1 (20)†	3
Valvata piscinalis (Müller)	MS	17 ± 10 (340)	72 ± 48 (1,257)	24
Valvata tricarinata (Say)	MS	14 ± 7 (170)	18 ± 9 (216)	16

*Mud (M), sand (S), gravel (G), rocks or boulders (R)
**Number of stations sampled quantitatively
***Maximum number represents only one specimen in a sample
†Only one specimen collected this year
††Not collected quantitatively

the western basin in 1961 and earlier (also in the central and western basins in 1973-1974? (Britt et al. 1980)); *Planorbella trivolvis* (Say), reported once from the western and eastern basins before 1953; and *Campeloma decisum* (Say), reported rarely from all three basins prior to 1962 (table 4). The three species had densities (where reported) of ≤ 1 m^{-2} with the exception of up to 23 m^{-2} *C. decisum* in the western basin in 1961.

The most frequently reported species have been *Valvata tricarinata* (12 studies), *Bithynia tentaculata* and *Elimia livescens* (11 studies), *Physella* "sp." (nine studies), *Amnicola limosa* and *Pleurocera acuta* (eight studies), and *Valvata sincera* (seven studies). These and perhaps other species have probably been encountered more frequently than reported, because numerous authors have listed only the genera.

DISCUSSION

ABUNDANCE RECORDS. The absolute or relative densities of many invertebrate species are valuable for interpreting environmental conditions (Krieger 1984). It is unfortunate, then, that of the 19 studies (including the present results), only six reported species densities. Furthermore, those six studies revealed very heterogeneous distributions and generally very low average densities with large ranges (table 4). Thus, a meaningful comparison of densities between basins and over time is not possible. The limited data indicate that *Fossaria humilis* (Say), *Physella magnalacustris* (Walker), *Valvata piscinalis* and *B. tentaculata* have occasionally exceeded 1,000 individuals m^{-2}; and *E. livescens, P. acuta, V. sincera, V. tricarinata* and *Amnicola limosa* have exceeded 250 m^{-2}. *Physella* sp. and *Valvata lewisi* have exceeded 50 m^{-2}.

Surveys to date have not been designed to quantify adequately the abundances of the less common macroinvertebrate species. Low snail densities and heterogeneous dispersions require that an intensive sampling effort throughout the chosen study area must be made in order to map the species densities and distributions accurately. The various investigators of Lake Erie benthos have employed different sampling strategies with large differences in total numbers of samples and replicates, collection methods, spatial resolution and geographical areas (see table 4). Each of these sampling considerations affects the success realized by the investigators in obtaining species which are present at low densities but which may be widely distributed. Future zoobenthic studies should be undertaken in a manner that will ensure the comparability of new data with preceding data by including (in addition to improved sampling designs and methods) previously sampled sites and similar collection methods, and by reporting detailed distributions and densities of the species as well as the substrates on (in) which they are found. Verification of identifications by specialists and the deposition of voucher specimens in a curated collection are essential and should be reported.

FACTORS INFLUENCING DISTRIBUTIONS. Snail distributions are dependent on such interacting environmental factors as substrate type, depth, food supply, interspecies competition, and physicochemical quality of the water and substrate, including the amount and types of pollutants present (Harman 1974). The limited records available (table 4) indicate that each of the more frequently encountered species in Lake Erie occurs on a variety of different substrates, although it may be most abundant on a particular one.

Snail distributions in the Great Lakes are restricted by depth. In Lake Ontario, snails were encountered only at depths ≤40 m (Nalepa and Thomas 1976), and in Lake Michigan they were limited to depths <35 m (Mozley and Garcia 1972). Snails are widespread throughout the shallow western basin of Lake Erie (Carr and Hiltunen 1965), which possesses a maximum depth of 19 m (Herdendorf 1983). Zoobenthic collections in the open lake of the central and eastern basins, with maximum depths of 26 m and 64 m, respectively, are few and largely unreported except for the most abundant groups (Brinkhurst et al. 1968, Britt et al. 1980). However, Flint and Merckel (1978) indicated that snails were characteristic only of (and perhaps were found only in) areas of the eastern basin <30 m deep. Britt et al. (1980) found *V. sincera* throughout the western basin and in all of the open lake portion of the central basin except the most central reaches, where they attributed its absence to seasonal anoxia.

Interspecific competition between snail species in moderately organically enriched habitats may also affect densities and distributions (Harman 1968). Four introduced species have been reported in Lake Erie. *Radix auricularia* and *V. piscinalis*, from Eurasia, and *C. chinensis*, from Asia, are widely but sporadically distributed in the Great Lakes basin (Clarke 1981, Burch 1982), and apparently have not become abundant, except *C. chinensis* in Sandusky Bay (Wolfert and Hiltunen 1968). One sample collected in this study did reveal over 1,000 *V. piscinalis* m^{-2} along with over 200 *V. tricarinata* m^{-2}. *Bithynia tentaculata*, from Europe, is now widespread in the Great Lakes (Clarke 1981, Burch 1982). It has attained large densities at certain localities in Lake Ontario tributaries, where it may be eliminating native species (Harman 1968). In western Lake Erie in 1961 it may also have been competing with native species, but at most stations where it exceeded 100 m^{-2}, two or more native species were also present in similar abundances (Carr and Hiltunen 1965).

In the present study only two of the four introduced species were collected, both generally at densities below 20 m^{-2}. *Bithynia* was collected at only 3% of the stations but *V. piscinalis*, found at 24% of the stations, was the most frequently encountered and most abundant species. Where both of these species were abundant, native species were also relatively abundant. Thus, it appears that neither species was influencing native species distributions in the study area in the late 1970s.

Food quality and quantity appear to influence the densities of several macro-

TABLE 4

Records published since 1926 of gastropod species, their densities, substrates and methods of collection in the three main basins of Lake Erie.

Species	Basin* western	central	eastern	not stated	Year of Collection	Method of Collection**	Substrate***	No. m^{-2}†	Reference††
ANCYLIDAE									
Ferrissia sp.	USwz				1930	Y	R		4
			Cns		1981	AG			18
Ferrisia rivularis (Say)	I				1928-29				3
HYDROBIIDAE									
Amnicola sp.	USwz				1930	GHSY	RS		4
	O				1950				8
	O, MB				1961	G	MSCGSh	0-148	10
	Cns	Cns	Cns		1967	G			12
	?O	?O			1973-74	G			17
		USns			1975	G		0-50	16
Amnicola limosa (Say)	I				1928-29				3
	I				1937	GHTY	GR	0-<1	6
	O				1951-52	GT		<1	9
	O		Cns, O, USns		1973-76	G			15
				Cwz	1974	AH			14
		Usns			1975	G		0-33	16
			Cns		1981	AG			18
Birgella sp.	?O	?O			1973-74	G			17
Birgella subglobosa (Say)	O				1928-29				3
	I				1937	GHTY	S	0-<1	6
	O				1951-52	GT		1	9
	O				1961	G	M	0-<1	10
Bithynia tentaculata (L.)			USns						7
	MB, O				1950				8
	O				1951-52	GT		46	9
	O				1961	G	MSCGSh	0-1,026	10
	SB				1963	T			13
	Cns, O	Cns	Cns		1967	G			12
			Cns, O, USns		1973-76	G			15
	?O	?O			1973-74	G			17
				Cwz	1974	AH			14
			Cns		1981	AG			18
Cincinnatia cincinnatiensis (Anthony)	O				1951-52	GT		1	9
				Cwz	1974	AH			14
			Cns		1981	AG			18
Fontigens binneyana (Hannibal)			USns						7
	O				1951-52	GT		<1	9

Marstonia lustrica (Pilsbry)			USns						7
	O				1951-52	GT		1	9
			Cns		1981	AG			18
Pyrgulopsis letsoni (Walker)			USns						7
LYMNAEIDAE									
Lymnaea sp. (See table 1)	USwz				1930	HY	CR		4
			Cns		1967	G			12
Fossaria humilis (Say)	I				1927	H	R	0-1,320	2
				Cwz	1974	AH			14
Fossaria modicella (Say)			USns						7
Fossaria obrussa (Say)	I				1928-29				3
Fossaria parva (Lea)	I				1928-29				3
Radix auricularia (L.)	I				1928-29				3
			Cns		1981	AG			18
Stagnicola caperata (Say)				Cwz	1974	AH			14
Stagnicola catascopium (Say)			Cns						7
Stagnicola elodes (Say) form *reflexa*	I				1928-29				3
Stagnicola emarginata (Say)			Cns						7
Stagnicola woodruffi (Baker)	I				1927	H	R	0-22	2
PHYSIDAE									
Physella sp.	USwz				1930	GHSY	CSGR		4
	I				1937	GHTY	GR	0-13	6
	O				1951-52	GT		2	9
	O				1961	G	M	0-<1	10
	Cns, O	Cns	Cns		1967	G			12
	?O	?O			1973-74	G			17
				Cwz	1974	AH			14
			Cns		1981	AG			18
Physella gyrina sayi (Tappan)			USns						7
Physella magnalacustris (Walker)	I				1927	H	R	0-1,645	2
	I				1928-29				3
PLANORBIDAE									
"*Planorbis*" sp. (See table 1)	USwz				1930	H	R		4
Gyraulus parvus (Say)				Cwz	1974	AH			14
			Cns		1981	AG			18
Helisoma (=*Planorbella?*) sp.	O				1961	G	MSSh	0-2	10
	Csn, O		Cns		1967	G			12
	?O				1973-74	G			17
Helisoma anceps (Menke)	O				1951-52	GT		<1	9
Planorbella trivolvis (Say)			Cns						7
	O				1951-52	GT		1	9
Planorbula sp.	USwz				1930	Y	R		4
Planorbula armigera armigera (Say)			Cns						7
Planorbula crissilabris Walker	I				1937	GHTY	GR	0-2	6
PLEUROCERIDAE									
Elimia sp.	USwz				1930	GHSY	CSGR		4

TABLE 4 (Continued)

Species	Basin* western	Basin* central	Basin* eastern	Basin* not stated	Year of Collection	Method of Collection**	Substrate***	No. m^{-2}†	Reference††
	?O	?O			1973-74	G			17
				Cns	1967	G			12
Elimia livescens (Menke)	I				1927	H	SR	0-552	2
		USns, Cns							7
	I				1926		R		1
	I				1928-29				3
	I				1937	GHTY	MSGR	<1-12	6
	O				1951-52	GT		<1	9
	I				1960	HS	GR		11
				Cwz	1974	AH			14
			Cns		1981	AG			18
Elimia livescens haldemani			USns						7
(Tryon)		SB		O	<1939				5
Pleurocera sp.	USwz				1930	GHSY	SR		4
	USns				1950				8
Pleurocera acuta Rafinesque	I				1927	H	S	0-238	2
	USwz				1928-29				3
			USns						7
	I				<1939				5
	I				1937	GHTY	MS	0-7	6
	O				1951-52	GT		2	9
		SB			1963	T			13
VALVATIDAE									
Valvata bicarinata Lea	O				1951-52	GT		1	9
Valvata lewisi Currier	O				1951-52	GT		<1	9
		USns			1975	G		0-85	16
Valvata piscinalis (Müller)			USns						7
Valvata sincera Say	O				1951-52	GT		<1	9
	O				1961	G	MSSh	0-608	10
	Cns, O	Cns	Cns		1967	G			12
			Cns, O, USns		1973-76	G			15
	?O	?O			1973-74	G			17
		USns			1975	G		0-20	16
			Cns		1981	AG			18
Valvata tricarinata (Say)	I				1927	H	S	0-11	2
	I				1928-29				3
	I				1937	GHTY	M	0-<1	6
	O				1950				8
	O				1951-52	GT		21	9
	O				1961	G	CMSGSh	0-378	10

	Cns, O	Cns	Cns		1967	G			12
	?O	?O			1973-74	G			17
				Cwz	1974	AH			14
		USns			1975	G		0-40	16
			Cns		1981	AG			18
VIVIPARIDAE									
Campeloma sp.	USwz				1930	GHS	SR		4
	?O				1973-74	G			17
									7
Campeloma decisum (Say)	I		Cns		1928-29				3
	O				1951-52	GT		<1	9
	O				1961	G	MCSG	0-23	10
Cipangopaludina japonica		SB			1963	T			13
(Martens)		SB			1963	GT	MSGSh		13

*Areas: Canadian nearshore zone (Cns), United States nearshore zone (USns), Canadian wave zone (Cwz), United States wave zone (USwz), Island Region (I), Maumee Bay (MB), Sandusky Bay (SB), open lake (O)
**Collection Methods: airlift (A), grab sampler (G), hand (H), shovel (S), trawl (T), grappling tongs (Y)
***Substrates: hard clay (C), gravel (G), mud or soft clay (M), bedrock or boulders (R), sand (S), shells (Sh)
†Densities: Reported as a mean value for all samples or as the range of means for individual sampling sites
††References: (1) Wiebe 1926, (2) Dennis 1928, (3) Ahlstrom 1930, (4) Krecker and Lancaster 1933, (5) Goodrich 1939, (6) Shelford and Boesel (1942), (7) Robertson and Blakeslee 1948, (8) Brown 1953, (9) Wood 1963, (10) Carr and Hiltunen 1965, (11) Dazo 1965, (12) Veal and Osmond 1968, (13) Wolfert and Hiltunen 1968, (14) Barton and Hynes 1978, (15) Flint and Merckel 1978, (16) Flint 1979, (17) Britt et al. 1980, (18) Barton 1981

invertebrates in the Great Lakes (Nalepa and Thomas 1976). Comparison of snail densities to oligochaete worm densities may indirectly reveal a dependency of snail densities on food availability. Both groups of organisms in soft substrates ingest sediments, and oligochaete densities in the Great Lakes appear to be dependent to a large extent on the quantity of bacteria present in the sediments (Nalepa and Thomas 1976). However, when treated by linear regression analysis, the present data from the southern central basin nearshore zone revealed no relationship between total or individual species densities and total worm densities. As many as 373 *V. piscinalis* m^{-2} and 79 *V. tricarinata* m^{-2} were found in samples containing over 18,000 worms m^{-2}. The maxima of both species (table 3) occurred in the same sample, in which worm densities were only 2,300 m^{-2}. Yet low snail densities (and no snails) occurred in samples with both very high and very low worm counts. These results indicate that conditions supporting intermediate numbers of oligochaetes may be optimal for snails. Carr and Hiltunen (1965), however, reported a direct relationship between numbers of *V. sincera* and oligochaetes.

In this study *V. piscinalis* was the most frequently encountered and abundant species, but in the western basin *B. tentaculata* was the most widely distributed and most abundant species (Carr and Hiltunen 1965), and in the eastern basin *Valvata* spp. were the most widely distributed (Flint and Merckel 1978). In Lake Ontario, *V. sincera* comprised 63% of all snails collected and was the only species in the eastern end of that lake (Nalepa and Thomas 1976). The particular environmental conditions which favor certain species over others in different regions within each of the Great Lakes deserves study.

Harman (1974), in reviewing the pollution ecology of freshwater gastropods, noted that representatives of every widespread family of freshwater snails have been considered by various authors to be tolerant of at least moderate organic pollution. He suggested that observation of changes in gastropod faunas over time is a more valuable tool for assessing changing water quality than the mere presence or absence of species. In Lake Erie, Carr and Hiltunen (1965) found that snails, mostly *B. tentaculata,* had increased sixfold in the western basin between 1930 and 1961, which they interpreted to be a response to increasing organic enrichment; and Howmiller and Beeton (1971) found that in Green Bay, Lake Michigan, between 1952 and 1969 snail diversity was reduced to a single species (*Amnicola* sp.) and maximum abundance declined from >250 m^{-2} to <25 m^{-2} as a result of severe degradation of the bay. No historical data are available for comparison in the central basin of Lake Erie.

The data in the present study, in which unreplicated samples were collected at most stations during each of two summers, indicate the need for caution in interpreting results obtained from single-year collections (e.g., Carr and Hiltunen 1965), because the apparent densities and distributions can vary markedly from one year to the next. For example, in this study gastropods comprised 0.6% of the total fauna collected in 1978, but 1.4% in 1979 (a 233% increase), while two species were collected the first year only and one species the second year only. The collection of replicate samples at each station (e.g., triplicates by Carr and Hiltunen 1965) would, however, provide a much more precise picture of species distributions and densities during a single year than unreplicated samples. Undoubtedly, consecutive-year collections with replication, while more expensive, permit the most reliable interpretation.

All aquatic snails are killed by extended periods of anoxia (Harman 1974). Although severe dissolved oxygen depletion rarely develops in the shallow western basin of Lake Erie, a four-day period with near-bottom temperatures above 24°C and dissolved oxygen at <2 ppm in 1953 eliminated the mayfly (*Hexagenia* spp.) population from most of the basin (Britt 1955). This short-term event apparently did not severely affect the gastropods, for in the 1961 collections of Carr and Hiltunen (1965) gastropods of several species were numerous (average 209 m^{-2}) but *Hexagenia,* which had formerly been abundant (300 m^{-2} in early summer 1953: Britt 1955), averaged only 2 m^{-2} (Carr and Hiltunen 1965).

Oxygen depletion has never been recorded in the thick hypolimnion of the eastern basin (Herdendorf 1983, Rathke and Edwards 1985). However, in the central basin, parts of the shallow hypolimnion become anoxic annually. The hypolimnion usually forms below 15 m (Herdendorf 1983), which is deeper than most of the collecting stations in this study, although numerous hypolimnetic intrusions into the shallower nearshore zone have been recorded (Rathke and Edwards 1985). Data collected on seven cruises of the open lake between late May and early October 1978 revealed the gradual depletion of oxygen to <2 mg L^{-1} in the hypolimnion beginning in the southwestern area of the central basin in early July and extending to the northeast and west as the summer progressed (Rathke and Edwards 1985). From early September into early October most of the central basin hypolimnion was anoxic (<1 mg L^{-1}) (Rathke and Edwards 1985). Rathke and Edwards (1985) note that the Sandusky sub-basin in the southwest corner of the central basin historically was probably the first area to develop anoxia because it usually has a hypolimnion depth of <2 m and receives high organic loading from the western basin and Sandusky Bay.

During the 1978-1979 Lake Erie Intensive Study, only 5% of the nearshore dissolved oxygen values recorded were below 6 mg L^{-1}, but most of those values, some as low as 0.1 mg L^{-1}, occurred in the Huron, Ohio, area, about 10 km southwest of the present study area. Oxygen depletion was also detected at the mouth of the Cuyahoga River (Rathke and Edwards 1985).

Oxygen concentrations below 1 mg L^{-1} were also reported near the lake bottom in late summer 1975 in a broad region from offshore of Huron and Vermilion, Ohio, extending northeastward into the near-shore zone, and ending in the open lake off the Rocky River (Herdendorf 1980, Zapotosky and Herdendorf 1980). This anoxic zone includes the part of the study area devoid of snails in 1978 and 1979 (fig. 1). This extensive region of anoxia would have required weeks to develop and would probably have proved lethal to any gastropods present at that time. Although oligochaetes, sphaeriid clams and midges were present in that area (Krieger 1984), the representatives of those groups are generally more tolerant of oxygen depletion than the gastropods, and the oligochaetes and midges can more readily repopulate areas of the lake than can the heavy-bodied snails. Thus, the recurrent pattern of seasonal oxygen depletion in the central basin appears to account for the absence of gastropods from the samples collected in the southwestern part of the study area in 1978 and 1979.

CONCLUSIONS

The historical data show that few zoobenthic studies in Lake Erie have documented gastropod distributions and densities in sufficient detail to permit comparison of the gastropod fauna between studies. Thus, with the exception of the western basin up to the early 1960s, changes in the gastropod fauna cannot be determined. Within the southern central basin nearshore zone in the late 1970s, a diverse but generally sparse snail fauna was present east of the Rocky River. Snails were present also in three of the four harbors, but their absence from Lorain Harbor and the vicinity of the Cuyahoga River mouth indicates that these two areas were severely degraded, probably experiencing occasional anoxia. The absence of snails from the samples taken west of the Rocky River appears to be related to prolonged anoxia during one or more summers in that part of the nearshore zone.

ACKNOWLEDGMENTS. I am indebted to C. B. Stein for her assistance in species identifications and to J. B. Burch for reviewing portions of the manuscript. Two anonymous reviewers were very helpful in directing the emphasis of this report. I also appreciate the services of N. Rubenstein in procuring technical reports, and of J. Huss and D. Whitmer in typing the tables. The crew of the R/V *Roger R. Simons* assisted in sample collection, and members of the Water Quality Laboratory assisted in sample processing and data management. The initial portions of the study were funded by USEPA grant No. R005350012 and USEPA contract No. 68-01-5857. Voucher specimens are deposited in the Museum of Zoology of The Ohio State University.

LITERATURE CITED

Ahlstrom, E. H. 1930 Mullusks [sic] collected in Bass Island region, Lake Erie. Nautilus 44: 44-48.

Barton, D. R. 1981 A survey of benthic macroinvertebrates near the mouth of the Grand River, Ontario, 1981. Rpt. to Ontario Ministry of the Environ. 18 p.

——— and H. B. N. Hynes 1978 Wave-zone macrobenthos of the exposed Canadian shores of the St. Lawrence Great Lakes. J. Great Lakes Res. 4: 27-45.

Brinkhurst, R. O., A. L. Hamilton and H. B. Herrington 1968 Components of the bottom fauna of the St. Lawrence Great Lakes. Toronto: Great Lakes Institute, Univ. Toronto. 32 p.

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

———, A. J. Pliodzinskas and E. M. Hair 1980 Benthic macroinvertebrate distribution in the central and western basins of Lake Erie. p. 294-330. *In*: Herdendorf, C. E., (ed.) Lake Erie nutrient control program, an assessment of its effectiveness in controlling lake eutrophication. U.S. Environ. Protection Agency. EPA-600/3-80-062.

Brown, E. H., Jr. 1953 Survey of the bottom fauna at the mouths of ten Lake Erie, south shore rivers: Its abundance, composition, and use as index of stream pollution. *In*: Lake Erie pollution survey, final report, p. 156-188. Ohio Dept. Natur. Res., Div. of Water.

Burch, J. B. 1982 Freshwater snails (Mollusca: Gastropoda) of North America. U.S. Environ. Protection Agency. EPA-600/3-82-026. 294 p.

Carr, J. F. and J. K. Hiltunen 1965 Changes in the bottom fauna of western Lake Erie from 1930 to 1961. Limnol. Oceanogr. 10: 551-569.

Clarke, A. H. 1981 The freshwater molluscs of Canada. National Mus. Natural Sci., National Mus. Canada, Ottawa. 446 p.

Dazo, B. C. 1965 The morphology and natural history of *Pleurocera acuta* and *Goniobasis livescens* (Gastropoda: Cerithiacea: Pleuroceridae). Malacologia 3: 1-80.

Dennis, C. A. 1928 Aquatic gastropods of the Bass Island Region of Lake Erie. Franz Theodore Stone Lab. Contrib. No. 8. Ohio State Univ., Columbus. 34 p.

Flint, R. W. 1979 Responses of freshwater benthos to open-lake dredged spoils disposal in Lake Erie. J. Great Lakes Res. 5: 264-275.

——— and C. N. Merckel 1978 Distribution of benthic macroinvertebrate communities in Lake Erie's eastern basin. Verh. Internat. Verein. Limnol. 20: 240-251.

Goodrich, C. 1939 Pleuroceridae of the St. Lawrence River basin. Occas. Pap. Mus. Zoology, Univ. Michigan. 404: 1-4.

Harman, W. N. 1968 Replacement of pleurocerids by *Bithynia* in polluted waters of central New York. Nautilus 81: 77-83.

——— 1974 Ch. 9. Snails (Mollusca: Gastropoda). 275-312. *In*: Hart, C. W., Jr. and S. L. H. Fuller. (eds.) Pollution ecology of freshwater invertebrates. Academic Press, NY.

——— and C. O. Berg 1971 The freshwater snails of central New York, with illustrated keys to the genera and species. Search: Cornell Univ. Agr. Exp. Sta. Entomol. Ithaca, NY. 1: 1-68.

Herdendorf, C. E. 1980 Lake Erie nutrient control assessment: An overview of the study. p. 1-63. *In*: Herdendorf, C. E., (ed.) Lake Erie nutrient control program, an assessment of its effectiveness in controlling lake eutrophication. U.S. Environ. Protection Agency. EPA-600/3-80-062.

——— 1983 Lake Erie water quality 1970-1982: A management assessment. U.S. Environ. Protection Agency. EPA-905/4-84-007. 144 p.

Howmiller, R. P. and A. M. Beeton 1971 Biological evaluation of environmental quality, Green Bay, Lake Michigan. J. WPCF. 43: 123-133.

International Joint Commission 1981 1981 report on Great Lakes water quality, appendices. Great Lakes Regional Office, Windsor, Ontario, Canada.

Krecker, F. H. and L. Y. Lancaster 1933 Bottom shore fauna of western Lake Erie: A population study to a depth of six feet. Ecology 14: 79-93.

Krieger, K. A. 1984 Benthic macroinvertebrates as indicators of environmental degradation in the southern nearshore zone of the central basin of Lake Erie. J. Great Lakes Res. 10: 197-209.

Mackie, G. L., D. S. White and T. W. Zdeba 1980 A guide to freshwater mollusks of the Laurentian Great Lakes with special emphasis on the genus *Pisidium*. U.S. Environ. Protection Agency. EPA-600/3-80-068. 144 p.

Mozley, S. C. and L. C. Garcia 1972 Benthic macrofauna in the coastal zone of southeastern Lake Michigan. *In*: Proc. 15th Conf. Great Lakes Res., p. 102-116. Internat. Assoc. Great Lakes Res.

Nalepa, T. F. and N. A. Thomas 1976 Distribution of macrobenthic species in Lake Ontario in relation to sources of pollution and sediment parameters. J. Great Lakes Res. 2: 150-163.

Rathke, D. E. and C. J. Edwards 1985 A review of trends in Lake Erie water quality with emphasis on the 1978-1979 intensive survey. Internat. Joint Comm., Windsor, Ontario, Canada. 129 p.

Robertson, I. C. S. and C. L. Blakeslee 1948 The Mollusca of the Niagara Frontier Region. Bull. Buffalo Soc. Nat. Sci. 19: 1-191.

Ryan, T. A., Jr., B. L. Joiner and B. F. Ryan 1982 Minitab Reference Manual. Pennsylvania State Univ., University Park, PA. 154 p.

Shelford, V. E. and M. W. Boesel 1942 Bottom animal communities of the island area of western Lake Erie in the summer of 1937. Ohio J. Sci. 42: 179-190.

Veal, D. M. and D. S. Osmond 1968 Bottom fauna of the western basin and near-shore Canadian waters of Lake Erie. *In:* Proc. 11th Conf. Great Lakes Res., p. 151-160. Internat. Assoc. Great Lakes Res.

Wiebe, A. H. 1926 Variations in the freshwater snail, *Goniobasis livescens*. Ohio J. Sci. 26: 49-68.

Wolfert, D. R. and J. K. Hiltunen 1968 Distribution and abundance of the Japanese snail, *Viviparus japonicus*, and associated macrobenthos in Sandusky Bay, Ohio. Ohio J. Sci. 68: 32-40.

Wood, K. G. 1963 The bottom fauna of western Lake Erie, 1951-1952. Univ. Michigan Great Lakes Res. Div. Publ. No. 10. p. 258-265.

Zapotosky, J. E. and C. E. Herdendorf 1980 Oxygen depletion and anoxia in the central and western basins of Lake Erie, 1973-1975. p. 71-102. *In:* Herdendorf, C. E., (ed.) Lake Erie nutrient control program, an assessment of its effectiveness in controlling lake entrophication. U.S. Environ. Protection Agency. EPA-600/3-80-062.