DEVELOPMENT OF A BENTHIC INVERTEBRATE OBJECTIVE FOR MESOTROPHIC GREAT LAKES

Trefor B. Reynoldson[1], D.W. Schloesser[2]
and B.A. Manny[2]

NWRI Contribution No. 89-02

[1] Lakes Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
L7R 4A6
Canada

[2] National Fisheries Center -
Great Lakes
U.S. Fish & Wildlife Service
1451 Green Road
Ann Arbor, MI 48105
U.S.A.

ABSTRACT

The desirable characteristics of a biological indicator of mesotrophic conditions are: that it should provide an appropriate and interpretable endpoint; that it should be achievable if corrective measure are taken, that is it should be within the environmental continuum; and that progress towards the objective can be measured. Historical data bases from the Great Lakes suggest that *Hexagenia limbata*, provides an appropriate endpoint, that the tubificid oligochaete community can be used to determine recovery, and data from other systems shows that *Hexagenia* can return to locations where it was formerly abundant.

MANGEMENT PERSPECTIVE

A requirement under the recently revised Water Quality Agreement signed by the governments of Canada and the United States is the development of ecosystem objectives for various componets of the Great Lakes system. This report proposes such an objective that can be applied to more naturally productive areas of the basin, such as western Lake Erie, Green Bay and Saginaw Bay. The objective utilises the fact that the burrowing mayfly was formerly a major portion of the biological community and as such was likely of great importance in the food chain. The demise of this species has been related to pollution of the lakes, yet refuge populations still remain and the return of this species to its former habitats would be an indicator of recovery of systems from which it has been absent for 20-30 years. The recommendations in this report if adopted would drive both remedial action plans and allow monitoring of the success of any remedial actions taken.

EXECUTIVE SUMMARY

A standard approach to managing water quality has been the development of objectives and criteria. Until recently however such criteria and objectives have been chemical only, and have established concentrations of chemicals as targets. This approach while practical in the sense that such concentrations are absolute measures and thus easy to use, in that "pass - fail" is obvious, is of less value when examined more critically. Concerns with water quality ultimately relate to "health" concerns; both human and that of the biological community. Therefore a beginning is being made in the development of objectives that more accurately represent such values. This report proposes that the abundance of a key component of the benthic invertebrate community be used as an objective for shallower more productive regions of the Great Lakes. It is suggested that if a healthy reproducing population of the burrowing mayfly, *Hexagenia limbata*, is present in such areas, that they may be considered as being of good quality.

RÉSUMÉ

Les caractéristiques souhaitables d'un indicateur biologique des conditions mésotrophiques sont les suivantes: il doit constituer un stade final approprié et interprétable; ce stade doit être réalisable, avec la mise en application de mesures correctives, c'est-à-dire qu'il doit être intégré dans le continuum environnemental; et l'évolution vers l'objectif doit être mesurable. Les bases de données chronologiques sur les Grands Lacs indiquent que *Hexagenia limbata* constitue un stade final approprié, que la communauté d'oligochètes tubicoles peut servir à indiquer le rétablissement et, enfin, que des données recueillies dans d'autres réseaux hydrographiques montrent que *Hexagenia* peut recoloniser des secteurs où il était autrefois abondant.

PERSPECTIVE GESTION

Une exigence de l'Accord relatif à la qualité de l'eau dans les Grands Lacs, signé par les gouvernements du Canada et des États-Unis, et récemment révisé, concerne l'élaboration d'objectifs pour diverses composantes de l'écosystème des Grands Lacs. Ce rapport propose un objectif qui peut s'appliquer à des régions plus naturellement productives du bassin comme la partie ouest du lac Érié, la baie Green et la baie Saginaw. L'objectif découle du fait que l'éphémère fouisseuse constituait autrefois une composante majeure de la communauté biologique et, à ce titre, avait probablement une grande importance dans la chaîne alimentaire. Cependant, bien que la régression de l'espèce soit liée à la pollution des lacs, il existe encore des populations relictes, et le retour d'*Hexagenia* dans son ancien habitat serait un indice du rétablissement des réseaux hydrographiques qu'elle a désertés depuis vingt à trente ans. Les recommandations de ce rapport, si elles sont adoptées, préconisent l'application de mesures correctives et le suivi écologique de ces interventions.

RÉSUMÉ

Une approche normalisée de gestion de la qualité de l'eau consistait à élaborer des objectifs et des critères. Cependant, jusqu'à récemment de tels critères et objectifs ne concernaient que le domaine de la chimie et les cibles étaient des concentrations établies de substances chimiques. Malgré son côté pratique dans le sens où de telles concentrations constituent des mesures absolues et sont faciles à utiliser, c'est-à-dire qu'il est clair qu'elles satisfont ou ne satisfont pas à la norme, cette approche a moins de valeur lorsqu'on l'examine d'un oeil plus critique. Les préoccupations sur la qualité de l'eau sont en définitive liées à celles sur la "santé", tant pour la communauté biologique que pour l'homme. En conséquence, on a commencé à élaborer des objectifs qui représentent ces valeurs avec une plus grande exactitude. Ce rapport propose que l'abondance d'une composante clé de la communauté d'invertébrés

benthiques soit utilisée comme objectif dans les zones moins profondes et plus productives des Grands Lacs. Ainsi, la présence d'une population saine et reproductrice de l'éphémère fouisseuse <u>Hexagenia limbata</u> dans de tels secteurs indiquerait la bonne qualité du milieu.

INTRODUCTION

The most significant impacts on the Great Lakes from human activity, have been eutrophication, toxic contaminants, and habitat loss. As part of the Great Lakes Water Quality Agreement, objectives have been established for many chemicals of concern. There has, however, been a developing awareness that chemical objectives alone are insufficient as an indication of overall health of the Great Lakes ecosystem, and that ultimately the biological integrity of the ecosystem is of prime concern. Therefore biological criteria are more appropriate. Accordingly, more broadly based, integrative, ecosystem objectives require development.

Past approaches to lake classification systems have used geological background, thermal regime and trophic level. While arguably the classification of lakes into oligotrophic, mesotrophic and eutrophic is simplistic, and in reality, lake habitats comprise a continuum of productivity, the trophic series does provide an intellectual framework and individual lakes do have a specific level of productivity determined by morphology, climate, and watershed characteristics. However this specific level of productivity can be affected by changes in any of the determining variables.

A previous initiative (Ryder and Edwards 1985) in developing biological criteria was the recommendation of an oligotrophic index. This utilizes aspects of lake trout and *Pontoporeia hoyi* populations and has been incorporated into the recently revised Great Lakes Water Quality Agreement signed by the Governments of Canada and the United States in 1987. However, this index can only be used in evaluating the larger lakes such as Superior, Michigan, Huron and Ontario. These components of the Great Lakes system have historically been less productive and may be characterized as oligotrophic. In contrast large, shallow embayments, such as Green Bay, Saginaw Bay, Hamilton Harbour, the Bay of Quinte and Lake St. Clair and the shallower west and central basins of Lake Erie, are naturally more productive regions of the basin. These historically would have been more appropriately characterized as mesotrophic. No index has been developed for these regions and therefore an ecosystem objective for these areas is required.

This paper proposes that aspects of the benthic invertebrate community are appropriate as indicators of ecosystem health, and that characteristics of this component of the lake community are suitable for objective development. The background, historical changes, and current conditions are described for selected mesotrophic systems in the Great Lakes particularly western Lake Erie and recommendations made as to possible ecosystem objectives for this and other mesotrophic systems in the Great Lakes.

A BENTHIC INDICATOR

A suitable mesotrophic indicator should have three characteristics: it should provide a suitable endpoint; it should have characteristics that allow progress to the desired endpoint to be measured and; it should be achievable if recovery actions are taken, that is it should be in the environmental continuum. It is suggested that the benthic community meet these three requirements.

1. A Suitable Endpoint

Examination of the response of the benthic invertebrate community to environmental stress provides an indication of an appropriate end point for a healthy community. Data from three mesotrophic systems in the Great Lakes basin, western Lake Erie, Saginaw Bay and Green Bay are described.

TABLE 1.

QUANTITATIVE AND SEMI-QUANTITATIVE SURVEYS OF LAKE ERIE OPEN WATER BENTHOS.

DATE	REGION SAMPLED	SAMPLER	AUTHOR(S)
1928-30	Western basin	Petersen	Wright
1937	Western basin	Petersen	Shelford & Boesel
1942-44	Western basin	Petersen	Chandler
1950	River mouths	Unknown	Brown
1951-52	Western basin	Drag/Eckman	Wood
1953	Western basin	Eckman	Britt
1954	Western basin	Eckman	Britt
1957-58	Western basin	Unknown	Beeton
1961	Western basin	Petersen	Carr & Hiltunen
1963	Whole lake	Franklin	Brinkhurst et al.
1963-64	Whole lake	Unknown	F.W.P.C.A
1967	Western basin/nrshr	Ponar	Veal & Osmond
1967-68	Whole lake	Unknown	F.W.P.C.A
1973-75	Whole lake	Ponar	Pliodzinskas
1979	Western basin/nrshr	Ponar	Thornley
1982-83	Western basin	Ponar	Schloesser et al

Most data are available for the western basin of Lake Erie and the first quantitative surveys were conducted by Wright in 1928-30 (Wright 1955). Some earlier work was done prior to this but was of a qualitative nature addressing only one or two benthic groups or, small areas (Osburn 1926a,b, Miller 1929, Cutler 1929). Since Wright's surveys, many similar community studies have been conducted (Table 1).

The changes in abundance of the four major invertebrate groups are summarized in Figure 1. Given the variation in site selection, time of sampling and differences in methodology, the results do show qualitative changes in the western basin. It is evident that in the early 1950's a major community change occurred whereby the burrowing mayfly, *Hexagenia*, declined markedly, from dominance in the early 1950's to being absent by 1960. Conversely, over the same period, the oligochaetes, chironomids and sphaeriids increased markedly. The chironomids appeared to reach a stable density, the Sphaeriidae peaked in the early 1960's and declined in numbers in the mid 1970's, and the oligochaetes which increased in numbers through the 1960's to become the most abundant benthic group. While the early 1950's appear to have been the time when community structure changed, there is evidence that the system had been destabilised prior to that time. Figure 1 shows that *Hexagenia* abundance was highly variable prior to 1950 and oscillated considerably. Chandler (1963) suggested that a catastrophic crash of *Hexagenia* had occurred between 1930 and 1940 as evidenced by a change in year class dominance. It is likely that the western basin of Lake Erie was unstable prior to the 1950's and may have been a stressed system at the time of Wright's first surveys in the late 1920's. To illustrate the spatial changes in western Lake Erie, the data from two surveys have been used, 1930 (Wright 1955) and 1961 (Carr and Hiltunen 1965). A recent survey was also conducted and these data will be reported (Manny et al, in prep). These data were collected by staff of the U.S. Fish and Wildlife Service, who sampled identical site locations and used the same or comparable sampling devices. Data from these surveys have been re-analyzed using cluster analysis to define spatial trends and develop community characteristics associated with those spatial differences. Figure 2 provides the summary synthesis of that data, using benthic community structure. Because the level of taxonomic detail varies spatial characterization was done using the major components of the community at that time. The variables used were numbers of Tubificidae, Chironomidae, Sphaeriidae and *Hexagenia*.

In 1930 the zone of impact was estimated to be off the Maumee, Raisin and Detroit rivers (Fig 2a), and the greatest effect was observed off the Maumee River. Only one station was impacted off the Raisin River and off the Detroit and Maumee Rivers a gradient was observed of declining numbers of *Hexagenia* and increasing numbers of tubificid oligochaetes (Fig 2a). By 1961 not only the zone of impact but also the degree of impact had increased markedly (Fig 2b), this is best shown by the much higher numbers of oligochaetes at the river mouth zones. An analysis of the data series together, rather than in separate years, most dramatically illustrates the extent of the impact. From Figure 2c the results show the 1930 zone 1 to include not only the one site off the Maumee River but also four sites off the Detroit River and two sites off the Raisin River. The 1930 zone 2, which only comprised one site off the Raisin river, in 1961 included 13 additional sites and had extended its boundary half way into the study area. Zone 3 in 1930 which was restricted to one site off the Maumee and the only Detroit River site to demonstrate impact in 1961 includes all the remaining sites except one, and only one station in 1961 was associated with the large lake zone of 1930, that being off the north shore of the lake well away from the Detroit River plume. This confirms the major impacts described by Carr and Hiltunen (1965) but suggests that at the least the entire western half of the basin (the entire study area) was severely affected.

Less frequent surveys have been conducted on Saginaw and Green Bays (Table 2). These systems show evidence of a similar sequence of changes in community structure that can be documented from temporal surveys or inferred from spatial patterns.

TABLE 2

DENSITY OF BENTHIC INVERTEBRATES IN SAGINAW BAY IN 1955, 1956 AND 1965

TAXA	NUMBER PER SQUARE METRE		
	1955[1]	1956[2]	1965[3]
EPHEMEROPTERA	63	9	1
AMPHIPODA	123	200	330
SPHAERIIDAE	122	tr	100
CHIRONOMIDAE	424	294	360
OLIGOCHAETA	2174	3532	3060

[1] SURBER 1955
[2] SCHNEIDER ET AL 1969
[3] SCHUYTEMA AND POWERS 1966

In Green Bay documented changes are a consequence of pollution from the Fox River. Between 1952 and 1969 the abundance of oligochaetes had increased generally over the whole bay, while amphipods, leeches, gastropods, sphaeriids and Hexagenia had disappeared or undergone drastic declines. Increased numbers of Chironomidae were observed at most stations, but had declined in relative importance, a result of the huge increases in oligochaetes. Howmiller and Scott (1977) demonstrated using an index derived from species composition of the tubificid oligochaetes a eutrophic to mesotrophic spatial series in Green Bay from the Fox River to the connection with L. Michigan. Their data ranged from the maximum of 2.0 (eutrophic) to 0.0 (oligotrophic). The eutrophic community was formed by two species of *Limnodrilus*, and the oligotrophic community by *Stylodrilus heringianus*. The mesotrophic species dominated in the range of 1.6 - 0.8.

In Saginaw Bay similar drastic changes occurred in the benthic fauna between 1959 and 1965, the results of three surveys are summarized in Table 3. *Hexagenia* declined most dramatically from 63 m^{-2} in 1955 to 9 m^{-2} in 1956 to 1 m^{-2} in 1965. Although no increase in oligochaetes was observed, as in the western basin of Lake Erie, these results only represent a brief snapshot of events occurring in the system.

In neither Saginaw nor Green Bay can a complete record of changes in the benthic fauna be established. However there is sufficient evidence to demonstrate a similar response to environmental degradation in each system. All three systems had in the early part of the record, i.e. 1950 or earlier, significant numbers of *Hexagenia*, and over a 10 year period showed a loss of *Hexagenia* to a community dominated by tubificid oligochaetes and increased numbers of Chironomidae.

Two hypotheses have been proposed to explain the disappearance of *Hexagenia* and consequent changes in benthic community structure (Burns 1985). The first attributes the losses to anoxia resulting from changes in trophic state, and the fact that *Hexagenia* cannot tolerate extended anoxia. The decline in 1953 in western Lake Erie was certainly associated with a major anoxic event (Britt 1955a,b). A second explanation ascribes the decline to increased contaminants in the sediments, notably pesticides such as DDT. Proponents of this view cite the similar disappearance of this species from several regions of the Great Lakes at the same time, however these systems were also being subject to nutrient loading stress and the associated onset of anoxia. Significantly *Hexagenia* has always been abundant in the Lake St Clair system which did not experience occurrences of low oxygen events and presumably had similar pesticide exposures. Furthermore, *Hexagenia* has been successfully raised on western basin sediment (Burns 1985). Therefore, although contaminants may be a contributing factor, the weight of evidence suggests oxygen depletion as a result of nutrient loads as the major arbiter of changes in benthic community structure.

A similar sequential response to environmental stress occurred in each of the described mesotrophic systems . This consists of the elimination of *Hexagenia* to be replaced by a community dominated by oligochaetes, and with increased numbers of chironomids. It is suggested that benthic community structure should be used as an indicator of mesotrophic conditions with a desirable objective being the presence of a benthic community dominated by *Hexagenia*.

The disadvantage of using *Hexagenia* alone is that, first there are no intermediate measures of system recovery, second that recovery may not be to a *Hexagenia* system but rather an alternate mesotrophic climax community. These two problems are discussed below.

2. Tracking Progress

Data from the western basin of Lake Erie (Fig.1), Saginaw Bay and Green Bay (Table 2), have described the decline of mesotrophic systems. However appropriate markers are required as intermediate points if system recovery is to be identified. In the last thirty years tubificid oligochaetes have been numerically the most important members of the benthic community in the western basin of L. Erie. In a recent paper (Schloesser et al, in prep) we have shown that oligochaete species can successfully be used to track spatial and temporal changes in trophic state. These results are briefly discussed below.

Using agglomerative clustering techniques 1961 results from the oligochaete species (Schloesser et al in prep) are very similar to that shown by using the complete benthic fauna (Figs 2b and 3a), zones of impact being observed off each of the three major rivers. In 1982 however an impact zone was only identifiable off the Detroit River and those sites that in 1961 formed impact zones at the Maumee and Raisin Rivers were in 1982 part of the lake zone. This demonstrates that trends can be measured before a recovery of *Hexagenia* occurs, and when the benthic community is still almost exclusively oligochaete worms.

An alternative method of using the oligochaete fauna to track change in trophic state is the use of a trophic index based on oligochaete species composition. Such indices use a scoring system for species depending on whether they are classified as mesotrophic or eutrophic. A number of such indices have been proposed (Brinkhurst et al 1968, Mozley and Howmiller 1977, Howmiller and Scott 1977, Uzunov 1979, Milbrink 1983, Lauritsen et al 1985), and all rank species into three or four categories representing conditions ranging from oligotrophy to eutrophy, or clean to polluted conditions. The relative proportions of numbers of individuals in each category producing an index value. The key to these systems is the category to which species are assigned and there are differences between authors which can efect interpretation of change in trophic state. These differences are to be the subject of a subsequent paper.

The ranking given to the species used from these data (Table 3) are those defined by Milbrink (1983). The index used here is that described by Milbrink (1983) and is a modification of that proposed by Howmiller and Scott (1977) and has been calculated for the zones defined by cluster analysis.

TABLE 3

RANKING OF OLIGOCHAETE SPECIES IN WESTERN L. ERIE

MESOTROPHIC	EUTROPHIC
Aulodrilus americanus	Limnodrilus cervix
A. limnobius	L. claparedeianus
A. pigueti	L. hoffmeisteri
A. pluriseta	L. maumeensis
Ilyodrilus templetoni	L. udekemianus
Spirosperma ferox	Tubifex tubifex
Potamothrix moldaviensis	
P. vejdovskyi	

Using this trophic index the changes observed in western L. Erie can be simply explained (Table 4). In all the zones, defined by 1961 analysis (Fig. 3a) the trophic condition has declined, indicating less eutrophic conditions. The greatest decline being at those sites which comprised the Maumee/Raisin River zone in 1961. Using this index the trophic condition in the sites in 1982 that formed the 1961 zone was similar to that in the open lake (Table 4). This general change in trophic state over the 20 year period can be attributed to both a decline in numbers of species tolerant of organic pollution (eutrophic species) and an increase in species characteristic of mesotrophic or somewhat enriched conditions (Fig. 4). There are however some other points of interest. In 1961 mesotrophic species occurred in higher numbers at sites at the mouth of the Detroit R., this may be due to the fact that the river mouth areas had higher oxygen levels or a lower frequency of anoxic events. The changes in the open lake from 1961 to 1982 were minimal and due more to an increase in numbers of mesotrophic species rather than a decline in eutrophic species. The decline in eutrophic species from 1961 to 1982 occured primarily at the river mouths, indicating that the system has responded to point source loadings and the effects of loading reductions are greatest in the vicinity of the sources.

TABLE 4

TROPHIC INDEX IN SITES IN LAKE ERIE IDENTIFIED BY CLUSTER ANALYSIS OF THE 1961 DATA SET

ZONE	REGION	1961	1982	% CHNG
Zone 1	Detroit R. 1	1.46	1.21	-17.1
Zone 3	Detroit R. 2	1.41	1.08	-23.4
Zone 4	Detroit R. 3	1.25	1.19	- 4.8
Zone 2	Maumee/Raisin	1.43	1.07	-25.2
Zone 5	Lake	1.10	1.03	- 6.4

This represents a major shift in species composition over the 20 year period, and is indicative of a major improvement at the river mouths. It is hypothesized that this is due to changes in the dissolved oxygen status of the basin, resulting from reductions in nutrient and organic loadings from point sources associated with the three major rivers (Fraser 1987, Rosa 1987). The annual loadings of phosphorus having declined from between 27-30 metric tonnes in 1967 to approximately 10 metric tonnes in 1982, with the greatest reductions being from the Detroit River (Fraser 1987).

As well as using a trophic index which simplifies the data set and makes presumptions about the distributions and representativeness of species, oligochaete assemblages have been determined for both 1961 and 1982. The species examined were those identified by cluster (complete linkage method) and principal component analyses as contributing significantly to site separation. These results have been represented in 3-dimensional space (Fig. 5), each axis representing one of the first three principal components, and represents a continuum from a more to a less eutrophic state. Ellipses have been hand drawn around what appear to form distinct species groups. In 1961 four distinct species groupings are observed, two of single species and two of multiple species (Figure 5): 1. *L. hoffmeisteri*, 2. an assemblage in which *Q. multisetosus* is the most abundant species 3. *L. varietas*, and 4. an assemblage in which *L. cervix* and *L. udekemianus* are most abundant. In 1982 similar species groupings were observed, although *L. varietas* was associated with *L. hoffmeisteri*. In 1961 the first factor (Fig. 5) explained 74% of the variance, compared to 39% in 1982. This indicates that the species groups in 1961 are being highly directed by discharges at the river mouths on factor 1 with sites closest to the river mouths (zones 1 & 2) being most eutrophic. The species groupings are therefore indicative of trophic state with *L. hoffmeisteri* tolerating the worst conditions the others of improving conditions and the *Q. multisetosus* assemblage being intermediate.

Examination of species selected from the above species assemblages from zones identified in 1961 (Fig. 3a), and based on reported information as to their trophic range, illustrates the changes that have occurred in their abundance (Table 5). *Limnodrilus hoffmeisteri* was the most abundant species in all zones in 1961 but only at sites off the Maumee and Raisin rivers (zone 2) and at a few off the Detroit R.(zones 3 & 4) in 1982. Furthermore its relative abundance declined markedly in the 20 year period. In 1961 this species formed 20 - 30% of the community at the river mouths and 15 % in the open lake. In 1982 this was reduced to 2 - 10% at the river mouths and 3.5% in the open lake. In 1982 the most abundant species at the most impacted sites, those at the mouth of the Detroit River, zones 1 and 2 in 1982 (Fig. 3b) was the *Quistodrilus* complex, this is made up of two species, *Q. multisetosus multisetosus* and *Q. multisetosus longidentus*. The three mesotrophic species shown in Table 6 are *Aulodrilus pluriseta, A. pigueti* and *Ilyodrilus templetoni*. Of these the species of *Aulodrilus* are known to be mesotrophic species with *A. pluriseta* being reported to be more tolerant of higher productivity (Brinkhurst, 1969b; Milbrink, 1973; Spencer, 1980). Both species of *Aulodrilus* have either increased in relative abundance or remained as a similar proportion of the total population. Interestingly *A. pluriseta*, the more tolerant of the two species, has increased in abundance at the sites associated with the Detroit R. mouth and *A. pigueti* at sites in the open lake and off the Maummee and Raisin Rivers, those that in 1982 formed part of the lake zone. Although *I. templetoni* is not an abundant species it is known to be sensitive to extended periods of anoxia. It has been shown that this species cannot survive longer than 4 weeks of anoxia as compared to more than 10 weeks for *L. hoffmeisteri* and up to 16 weeks for *T. tubifex* (Reynoldson, 1987). This species also increased in relative abundance in the sites in the open lake and off the Maumee and Raisin rivers.

TABLE 5

ABUNDANCE OF FIVE TUBIFICID SPECIES

IN SITES DEFINED BY 1961 ZONES

(No. m^{-2}; corrected for sampler efficiency)

	DETROIT 1		DETROIT 2		DETROIT 3		MAUMEE/ RAISIN		OPEN LAKE	
	1961	1982	1961	1982	1961	1982	1961	1982	1961	1982
SPECIES										
L. hof.	22844	1984	7182	711	2673	438	3412	583	2360	338
Q. mul.	6869	5670	1365	4310	36	33	39	0	520	480
A. plu.	62	476	506	1224	18	45	2	4	29	72
A. pig.	5	147	58	251	18	490	4	99	14	217
I. tmp.	67	157	174	129	23	133	23	104	22	95
TOTAL NO ($x10^3$)	78	18	37	28	9	10	17	6	10	7

3. Recovery - Can *Hexagenia* return?

The last requirement for an appropriate mesotrophic indicator is that it be achievable. There are two aspects to this, can conditions return to those that are appropriate for the species, and if those conditions recur can the species return. With regard to the former, it is suggested that this is primarily a question of technology, both hard and soft, in reducing loadings and whether society has the political will to take the necessary action. Once loadings are reduced however it is likely that as a result of sediment storage of contaminants and oxygen demanding materials that recovery will be delayed. However once conditions are appropriate the question has been raised as to whether the mayfly can return. For this to occur there needs to be both a source population and an ability of the species to recolonize. Both the Detroit River and Lake St Clair have resident populations of *Hexagenia* (Hiltunen and Manny 1982, OMOE 1984), and evidence from the Mississippi R. (Fremling, 19) suggests they can return to former habitats, once conditions have improved.

In summary it is suggested that even though *Hexagenia* has not returned to the west basin of Lake Erie that there has been a change towards mesotrophy in the lake as evidenced by the tubificid community structure. Furthermore that trends in the status of the benthic community can be tracked by observation of the benthic community, and finally there is evidence that *Hexagenia* can return to former habitats.

RECOMMENDATIONS

It is concluded that the benthic community has the three attributes required by a mesotrophic indicator as defined above. That a suitable end point can be defined, that is an open lake community where *Hexagenia* is the dominant benthic invertebrate. That progress toward that objective can be readily measured, by using the existing species complex of the benthic community, and that in the western basin of Lake Erie the species complex of tubificid worms shows clear evidence of recovery on spatial and temporal scales. Third that there is sufficient evidence as described above that the system can recover to a *Hexagenia* community.

Further work is required to implement this objective. Historic data bases need to be assembled to more precisely document spatial changes and confirm the exact nature of the decline in *Hexagenia*. Also more detailed information is required on the environmental requirements of *Hexagenia*.

It is recommended therefore that a mesotrophic objective should be the maintenance of densities of the mayfly Hexagenia limbata in mesotrophic regions of the Great Lakes in densities similar to those observed in the west basin of L. Erie in the period 1928 - 1930; at 180 individuals .m^{-2}.

It is further recommended that the benthic community in toto be monitored on a regular basis at key identified locations in order to track progress toward attaining the desired objective.

ACKNOWLEDGEMENTS

The authors particularly wish to express their appreciation to members of the IJC Mesotrophic Work Group, where lively discussion resulted in many of the ideas expressed in this paper: U. Borgmann, R.A.Ryder, C. Lewis, W.W.Taylor, J.H.Leach, J.Koonce, R.Hayward, W.Hartman, H.A.Regier, R.Knight and C.J.Edwards.

REFERENCES

Beeton, A.M. 1961. Environmental Changes in Lake Erie. *Trans. American Fish. Soc.* 90:153-159.

Brinkhurst, R.O. 1969. Changes in the Benthos of Lake Erie and Ontario. In *Proc. Conf. on Changes in the Biota of Lakes Erie and Ontario.* Buffalo Soc. Natur. Sci. Bull. 25(1):45-65.

Brinkhurst, R.O. 1969. *The fauna of pollution in The Great Lakes as an environment.* Great Lakes Inst. Univ Toronto No. P.R. 39.

Brinkhurst, R.O., Hamilton, A.L. and Herrington, H.B. 1968. *Components of the Bottom fauna of the St Lawrence Great Lakes.* Great Lakes Inst. Univ Toronto No. PR 33. 49pp.

Britt, N.W. 1955. Stratification in western lake Erie in summer of 1953: Effects on the *Hexagenia* (Ephemeroptera) Population. *Ecology* 36(2):239-244.

Britt, N.W. 1955. *Hexagenia* (Ephemeroptera) population recovery in western Lake Erie following the 1953 catastrophe. *Ecology* 36(3):520-522.

Brown, E.H. 1953. *Survey of the bottom fauna at the mouths of ten Lake Erie south shore rivers: its abundance, composition, and use as an index of stream pollution.* Ohio Dept. Nat. Res. Div. Water, Lake Erie Survey , Final report.

Burns, N.M. 1985. *Erie, the lake that survived.* Rowman and Allanheld, New Jersey.

Carr, J.F. and Hiltunen, J.K. 1965. Changes in the Bottom Fauna of western Lake Erie from 1930 to 1961. *Limnol. Oceanogr.* 10(4):551-569.

Chandler, D.C. 1963. Burrowing mayfly nymphs in western Lake Erie previous to 1947. Abstract In: *Proc. 6th Conf. on Great Lakes Research, 1963.* Great Lakes Res. Div., Inst. Sci. & Tech., Univ. Michigan., Publ. No. 10:267-268.

Cutler, N.L. *1929 The Biological Investigations of Pollution in the Erie-Niagara Watershed.* State of N.Y. Conservation Dept., Supp. 18th Ann. Rpt., 1928, pp. 134-139. Albany.

Federal Water Pollution Control Administration. 1968. *Lake Erie environmental summary, 1963-1964.*

Federal Water Pollution Control Administration. 1968. *Lake Erie surveillance data summary, 1967-1968.*

Fraser, A.S. 1987. Tributary and point source total phosphorus loading to lake erie. *J. Great Lakes Res.* 13(4):659-666.

Fremling, C.R.

Hiltunen, J.K. and Manny, B.A.. 1982. *Distribution and abundance of macrozoobenthos in the Detroit River and Lake St. Clair, 1977.* Administrative Report No. 82-2. Gt. Lakes Fish. Lab. U.S.F.W.S.

Howmiller, R.P. and Scott, M.A. 1977. An environmental index based on relative abundance of oligochaete species. *J. Wat. Pollut. Cont. Fed.* 49:809-815.

Keeler, G.P. 1981. *Western basin Nearshore 1978-1979, Benthic Macroinvertebrates.* CLEAR Tech. Rep. No. 204:11. Ohio St. Univ. 124pp.

Lauritsen, D.D., Mozley, S.C. and White, D.S. 1985. Distribution of oligochaetes in Lake Michigan ans comments on their use as indices of pollution. *J. Great Lakes Res.* 11(1):67-76.

Manny, B.A., Schloesser, D.W. and Reynoldson, T.B. IN PREP - NEED TITLE

Milbrink, G. 1973. On the use of indicator communities of Tubificidae and some Lumbriculidae in the assessment of water pollution in swedish lakes. *Zoon* 1:125-139.

Milbrink, G. 1983. An improved environmental index based on relative abundance of oligochaete species. *Hydrobiologia* 102:89-97.

Miller, J.A. 1929 *The Leeches of Ohio.* Ohio St. Univ., Stone Lab., Contribution No 2. 38pp. Columbus.

Mozley, S.C. and Howmiller, R.P. 1977 *Environmental status of the Lake Michigan region: Zoobenthos of Lake Michigan.* Argonne National Lab. Report No. ANL/ES-40, Vol. 6, U.S. Energy Research and Development Administration.

Thornley, S. and Hamdy, Y. 1984. *An Assessment of the Bottom Fauna and Sediments of the Detroit River.* Ontario Ministry of Environment.

Ontario Ministry of Environment. 1981. *An assessment of the bottom fauna and sediments of the western basin of Lake Erie, 1979.* Ont. Min. Env. 24pp.

Osburn, R.C. 1926. *A preliminary study of the extent and distribution of sewage pollution in the west end of Lake Erie.* Mimeographed report, 6pp. Columbus.

Osburn, R.C. 1926. *Details regarding preliminary pollution survey of Lake Erie.* Mimeographed report, 14pp. Columbus.

Pliodzinskas, A.J. 1978. *Aquatic Oligochaetes in the Open waters of western and central Lake Erie.* CLEAR Tech. Rep. No. 98. Ohio St. Univ. 160pp.

Reynoldson, T.B. 1987. The role of environmental factors in the ecology of tubificid oligochaetes - an experimental study. *Hol. Ecol.* 10:241-248.

Rosa, F. 1987. Lake Erie central basin total phosphorus trend analysis from 1968 to 1982. *J. Great Lakes Res.* 13(4):667-674.

Ryder, R.A. and Edwards, C.J. 1985. *A Conceptual Approach for the Application of Biological Indicators of Ecosystem Quality in the Great Lakes Basin.* Report to the Great Lakes Science Advisory Board. IJC. Windsor 169pp

Schloesser, D.W., Reynoldson, T.B. and Manny, B.A. in prep Oligochaete fauna of western Lake Erie, 1961 and 1982.

Schneider, J.C., Hooper, F.H. and Beeton,A.M. 1969. The distribution of benthic fauna in Saginaw Bay, Lake Huron. In *Proc. 12th Conf. on Great Lakes Res.* Pp 80-90. Internat. Assoc. Great Lakes Res.

Schuytema, G.S. and Powers, R.E. 1966. The distribution of benthic fauna in Lake Huron. In *Proc. 9th Conf. on Great lakes Res.*, Publ. No. 15, Great Lake Res. Div., Univ. Michigan: 155-163.

Shelford, V.E. and Boesel, M.W. 1942 Bottom Animal Communities of the Island Area of Western Lake Erie in the Summer of 1937. *Ohio J. Science* XLII (5):179-190.

Spencer, D.R. 1980. The aquatic oligochaetes of St. Lawrence Great Lakes region. In *Aquatic Oligochaete Biology*, ed. R.O.Brinkhurst and D.G.Cook. Plenum Press. New York.

Surber, E.W. 1955. *Results of a biological survey of Saginaw bay, June 24th, 1955.* Rep. to Mich. Water Resources Comm., 3pp.

Uzunov, Y. 1979. Aquatic Oligochaeta: a supplement to the list of limnosaprobic indicators. *Comptes rendus de l'Academie bulgare des Sciences*. 32(8):1101-1103.

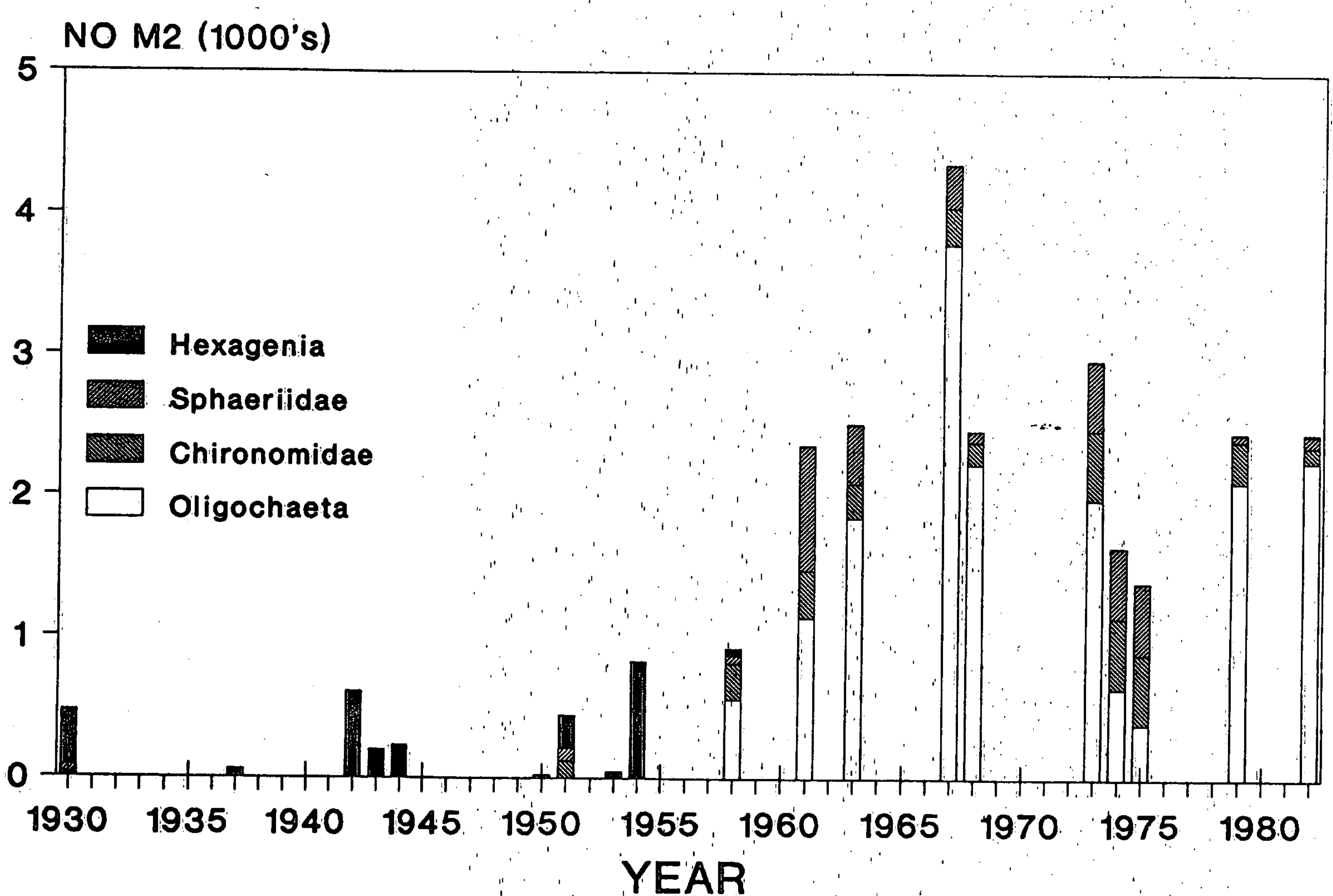
Veal. D.M. and Osmond, D.S. 1968. Bottom Fauna of the Western Basin and Nearshore Canadian waters of Lake Erie. In *Proc. 11th. Conf. Great Lakes Res*. pp.151-160. Int. Ass. Gt. Lakes Res.

Wood, K.G. 1953. Distribution and Ecology of certain Bottom Living Invertebrates of the Western Basin of Lake Erie. PhD Thesis. Ohio St. Univ. 145pp. Columbus.

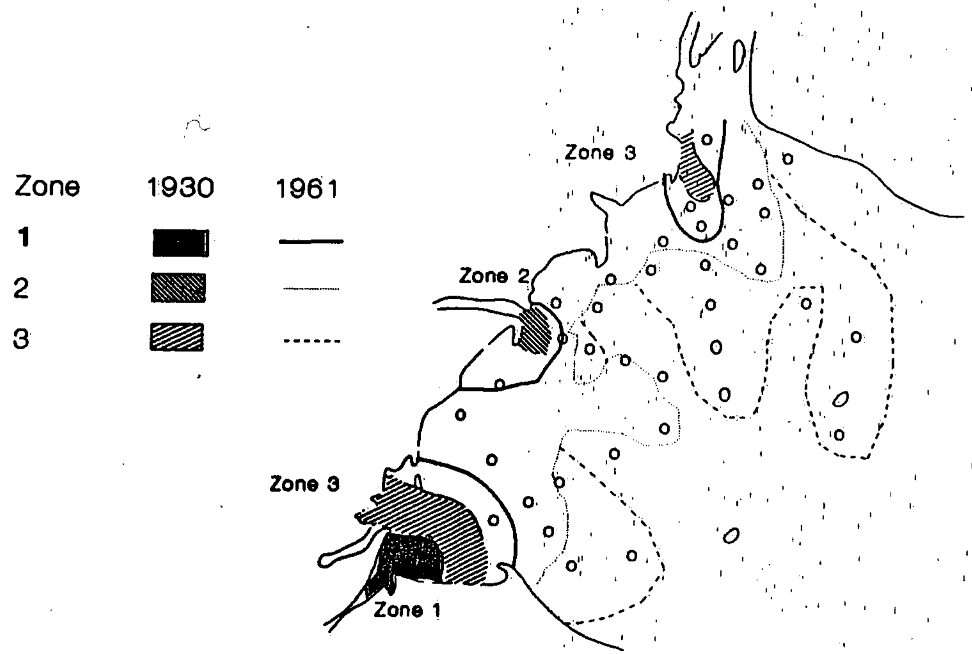
Wood, K.G. 1963. *The Bottom Fauna of Western lake Erie, 1951-52.* Pub. No. 10, Great Lakes Res. Div. Univ. Michigan pp. 258-265.

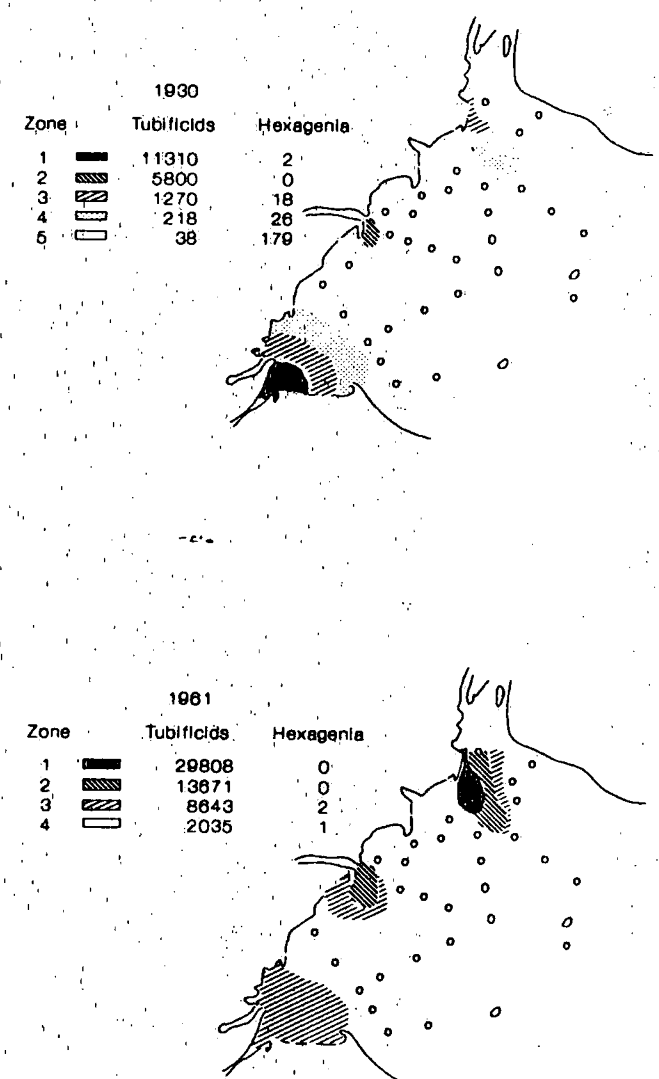
Wright, S. 1955. *Limnological survey of Western Lake Erie*. U.S. Fish and Wildlife Service. Special Scientific Report - Fisheries No. 139. 341pp.

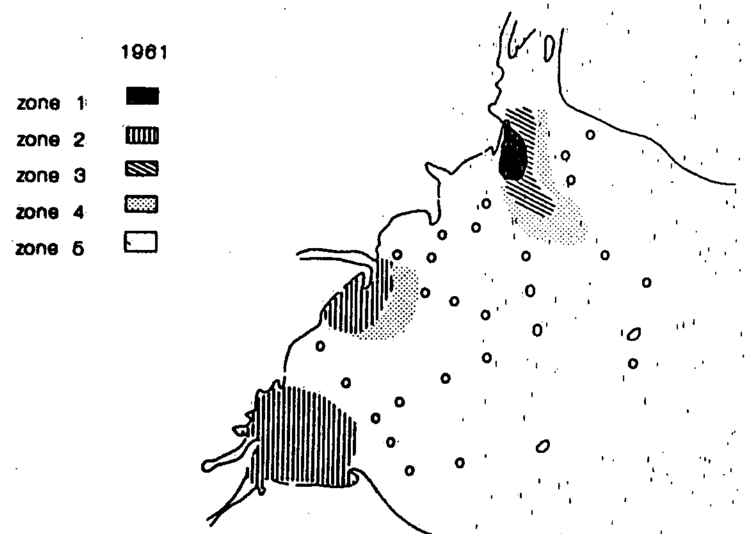
LIST OF FIGURES


NO M2 (1000's)
5
4
3
2
1
0
Hexagenia
Sphaeriidae
Chironomidae
Oligochaeta
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
YEAR

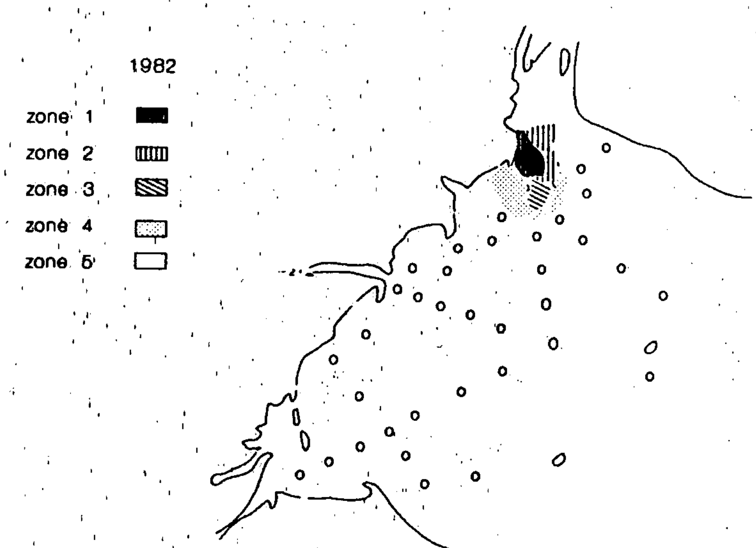
Expansion of 1930 Zones



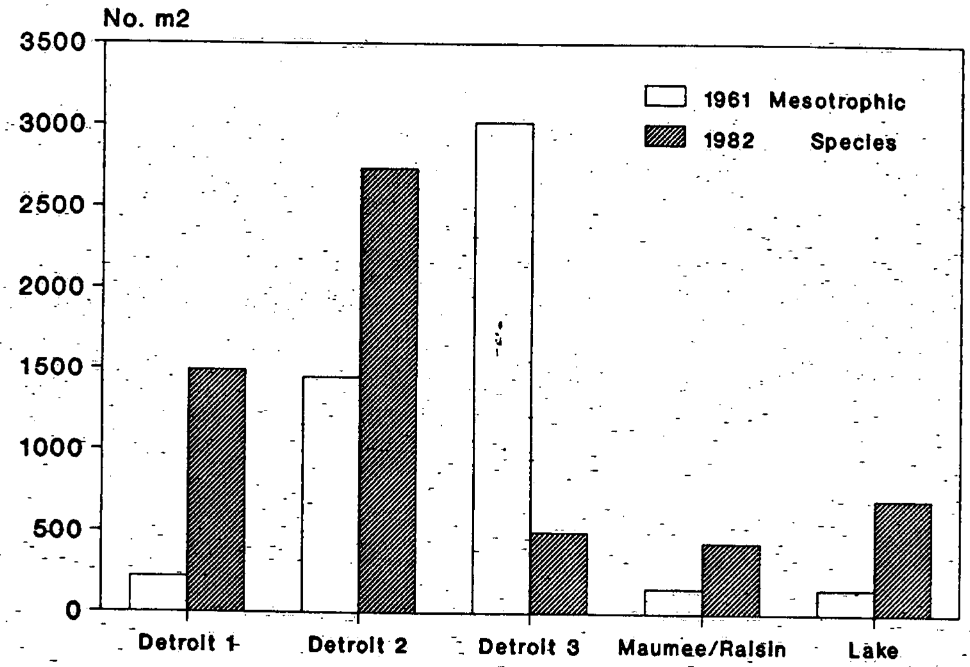


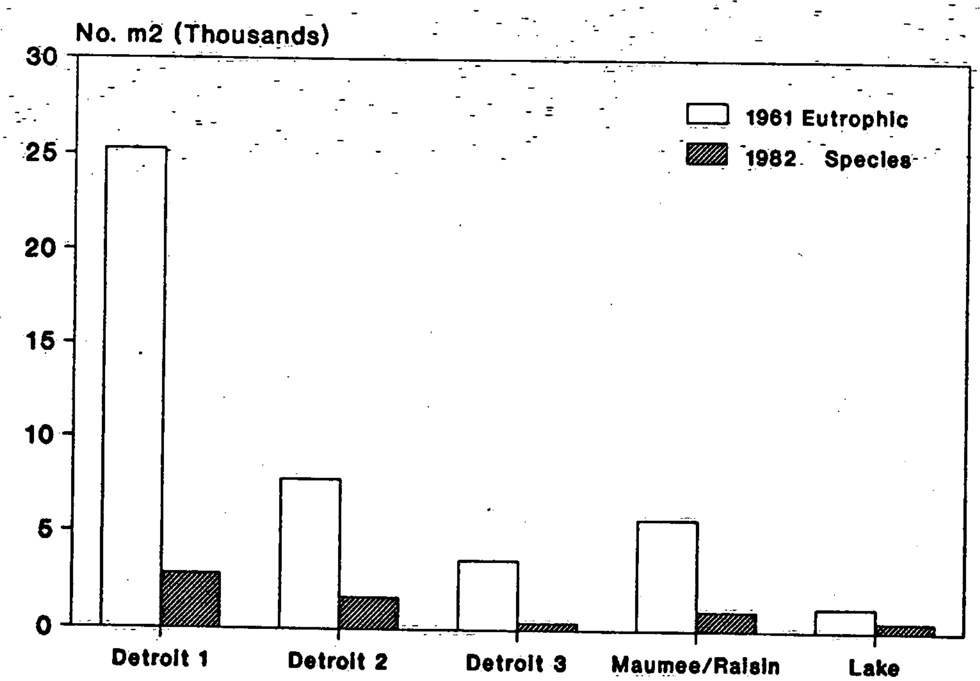


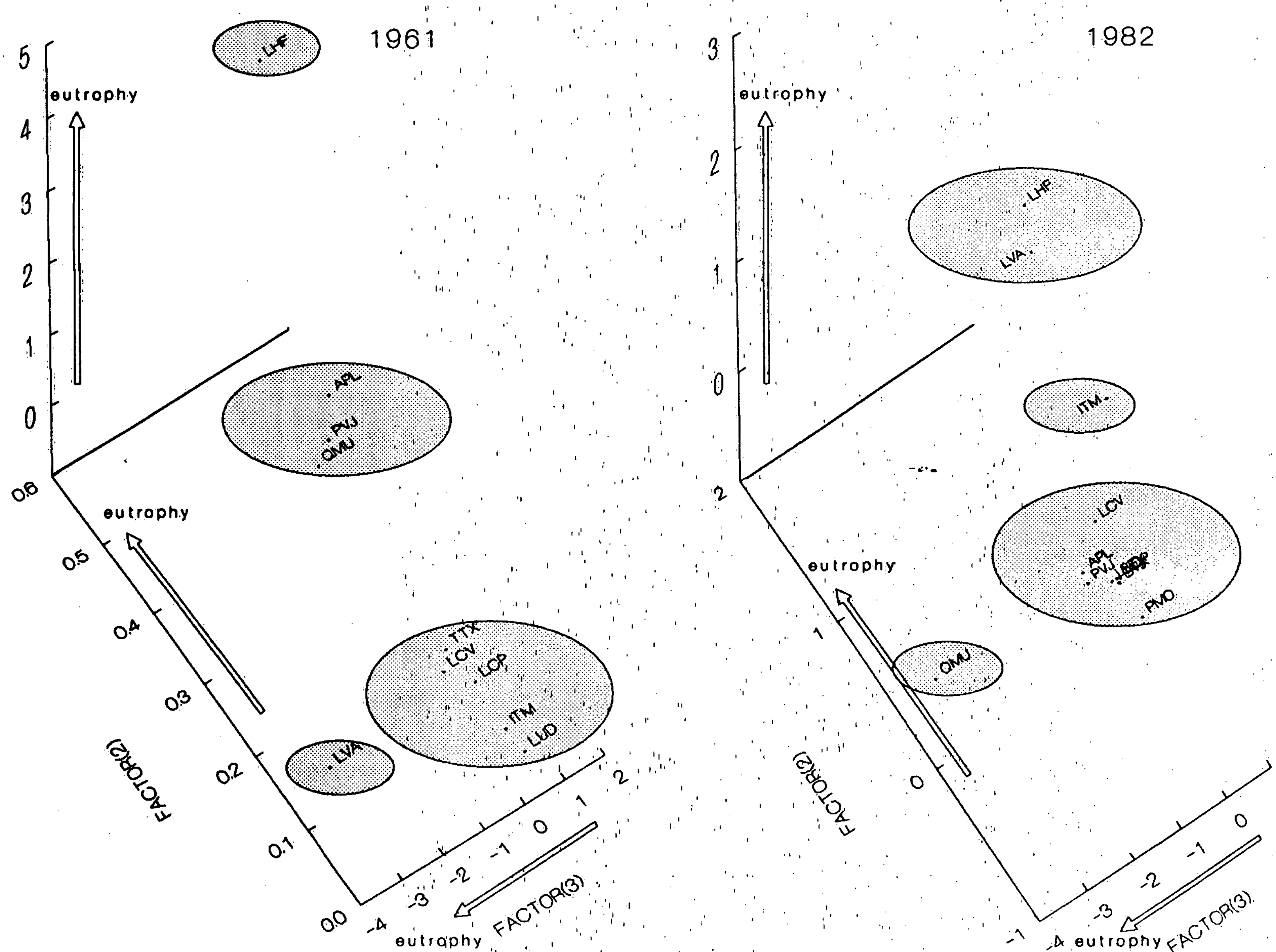
centroid clustering (10 spp)



centroid clustering (12 spp)


No. m2
3500
3000
2500
2000
1500
1000
500
0
1961 Mesotrophic
1982 Species
Detroit 1
Detroit 2
Detroit 3
Maumee/Raisin
Lake


No. m2 (Thousands)
30
25
20
15
10
5
0
1961 Eutrophic
1982 Species
Detroit 1
Detroit 2
Detroit 3
Maumee/Raisin
Lake


1961
LHF
APL
PVJ
OMJ
TTX
LCV
LCP
ITM
LUD
LVA
eutrophy
eutrophy
eutrophy
FACTOR(2)
FACTOR(3)
1982
LHF
LVA
ITM
LCV
APL
PVJ
PVO
OMJ
eutrophy
eutrophy
eutrophy
FACTOR(2)
FACTOR(3)