Benthic Infauna Report
Great Lakes Restoration Initiative
Template: 44 Expanded Mussel Watch
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Introduction

Benthic invertebrates have long been used to assess aquatic ecosystem health in the Great Lakes (Cook and Johnson 1976, Mozley and Howmiller 1977). These organisms inhabit bottom sediments and form stable communities that integrate conditions in both sediments and overlying waters. In general, species assemblages shift in a predictable way in response to excessive inputs of industrial and municipal discharges as well as to habitat modifications associated with these discharges; species tolerant of a degraded environment will increase in abundance, while sensitive or intolerant species will decrease. Hence, community structure provides a practical, effective tool to assess changes in ecosystem health over both space and time.

To address environmental degradation in the nearshore region of the Great Lakes, the International Joint Commission and later The Great Lakes Water Quality Agreement identified over 40 problem locations and termed them "Areas of Concern" (AOCs). These areas were targeted because of elevated levels of pollutants (nutrients, organic contaminants, metals, etc.) that limited resource use and degraded environmental quality. Specific environmental issues were categorized into 14 Beneficial Use Impairments (BUIs), and each AOC was assessed in terms of the BUIs present. While the number of BUIs per AOC varied, one of the most common BUIs was the "degradation of benthos". In a broad sense, this BUI not only included the benthic macroinvertebrate community, but also other components of the benthic region such as sediment toxicity, physic-chemical state (i.e. oxygen availability), contaminant bioaccumulation, and sediment stability (Krantzberg et al. 2000). Fundamental to this BUI is the recognition that benthic macroinvertebrate communities integrate all of these other components, and that a degraded community has implications for the entire food web.

As noted by Grapentine (2009), addressing the BUI of a degraded benthos involves: 1) defining and measuring the appropriate metrics to assess the community; 2) quantifying the extent of

"degradation"; 3) determining and remediating the likely causes of degradation; 4) identifying the extent of recovery; and 5) deciding if the beneficial use had been restored. Inherent in this process are a number of serious challenges. Among the most basic of these challenges is how to define the extent of degradation and how to track relevant response variables. Degradation can be defined as the extent the benthic community at an AOC site diverges from the community at an unimpacted or "reference" site located nearby. Ideally, the benthic community at reference sites represents the natural state where environmental conditions are similar to those found at the AOC except for human-induced stressors. Yet variation in even unstressed benthic communities can be considerable in nearshore regions as influenced by natural factors (substrate type, storms, wave action, temperature, etc.) (Barton 1989). In addition, stressors unrelated to common pollutants (such as invasive species) may complicate interpretations of differences between AOC and Reference sites. A further challenge is choosing the appropriate metric of community structure to assess degradation and track changes. Some common indices include species diversity, taxa richness, and relative proportions of tolerant to intolerant taxa. However, these indices often respond differently to different stressors and stressor interactions, making interpretations difficult.

While a number of studies have examined spatial and temporal patterns in benthic community structure at specific AOCs (Kreiger and Ross 1993, Carter et al. 2006, Dermott et al. 2012, Nelson and Steinman 2013), there has not been a comparative assessment of the benthic community over a wide range of AOCs. In this report, we present benthic data collected at nearshore sites located across the Great Lakes in 2009 and 2010. Of these sites, 29 were located in an AOC, and 12 were located at a nearby site outside an AOC, and thus considered a Reference site. Our objectives herein are to: 1) document abundances of all taxa present; 2) apply various commonly-used indices to compare benthic community structure between AOC sites and Reference sites, and 3) provide a relative comparison of perceived degradation across all sites. Our intention is to only provide the raw data and some preliminary results, hence interpretation of findings are minimal, particularly as related to potential causes of any differences between sites. Further detailed analysis and interpretation will be given in other publications.

Materials and Methods

Station Locations, Field Procedures

Samples for benthic macroinvertebrates were collected at 41 sites located throughout the Great Lakes, including the connecting channels (St. Mary's River, St. Clair River, Detroit River, and Niagara River) (Table 1, Fig. 1). As noted, 29 sites were located within an area considered to be an AOC, and 12 sites were located outside an AOC and thus considered a Reference site. All AOC sites had a degraded benthos BUI except for LOOR (Oswego River) and LMWM (Manistique River). Sites in the eastern portion of the Great Lakes region (downstream of Detroit River) were sampled September 9-22, 2009, and sites in the western portion (upstream of Detroit River) were sampled September 8-18, 2010. In addition to macroinverterbrates, sediments for organic and inorganic contaminants were collected at all sites (Kimbrough et al. 2014).

Samples were collected in triplicate at each site with a Young-modified VanVeen grab (area = 0.04 m^2). Immediately upon collection, all material was washed through a screen with 0.5-mm openings and retained material placed into a wide-mouth jar and preserved in 10 % buffered formalin containing rose bengal stain. Each jar was labeled with the station designation, replicate number (1, 2, or 3), and the sampling date. Water depth and a general description of the sediment were recorded at time of collection.

Laboratory Procedures

In the laboratory, retained material (coarse sediment, detritus, organisms) was gently rinsed through a 0.5-mm screen to remove preservative and then placed into a large, clear petri dish. All organisms were picked, counted, and sorted into major taxonomic groups (Amphipoda, Oligochaeta, Chironomidae, *Dreissena,* Sphaeriidae, and other) under a binocular microscope (10X). As per protocol, all remaining material was independently checked for any further organisms by a second party. Organisms within each major taxonomic group were placed into separate vials containing 5% buffered formalin. Each vial was clearly marked with the station, replicate number, and date of collection.

Organisms were identified to the lowest practical taxonomic level. Oligochaetes were mounted on microscope slides in CM9 before identification. CM9 is a mounting medium that clears the organisms and provides permanent mounts. If the total number of oligochaetes in a particular replicate exceeded

150, then the sample was proportionately split with a folsom plankton splitter so that at last 75-100 individuals were mounted and identified (Nalepa et al. 1998). Since oligochaetes can easily fragment during the screening process leading to inflated numbers, only oligochaetes with a protomium (head) were identified to the lowest practical taxonomic level and included in abundance estimates. The number of fragments were, however, counted and recorded. Chironomids were also mounted on slides in CM9 before identification. Heads capsules were teased from the body and then mounted on the slide mentum side up.

Determination of Indices

To define community structure and to assess relative degradation of the benthic community, the following indices were calculated at each of the sites: proportion of oligochaetes in total benthos (oligochaete density/total benthos density; Prop-O Index), oligochaete-chironomid ratio (oligochaete density/oligochaete density + chironomid density; O/C index), the oligochaete trophic index (O-TCI), Taxa Richness (R), and Shannon Diversity (H). These indices have been widely used in the Great Lakes and collectively provide a broad measure of the relative status of the benthic community. The Prop-O-Index is based on the well-documented finding that the total abundance of oligochaetes increases relative to other benthic groups with increased organic enrichment (Goodnight and Whitley 1961, Mozley and Howmiller 1977, Wiederholm 1980). Many species within this taxonomic group are detritivores that respond to organic inputs, feed at depth within the sediment, and are very tolerant of adverse conditions. The O/C Index measures the relative proportion of oligocheates and chironomids, and this proportion also increased with organic enrichment (Wiederholm 1980). Similar to oligochaetes, most species of chironomids are detrivores and very tolerant, but they feed near the sediment surface and other common species are predacious. Often, oligochaetes and chironomids are by far the dominant groups found in severely degraded environments, so the O/C index compliments the broader-based Prop-O Index. The O-TCI (Milbrink 1983) is based on the wide range of tolerances to organic enrichment for species within the oligochaete group. This index was originally developed by Howmiller and Scott (1977) and was shown

to be more sensitive to other indices such as the Pro-O Index and indices based on species diversity. Milbrink (1983) further refined the index as:

$$\mathrm{O-TCI} = \mathrm{C\ X}\ \frac{0.5\sum \mathrm{n0} + \sum \mathrm{n1} + 2\sum \mathrm{n2} + 3\sum \mathrm{n3}}{\sum \mathrm{n0} + \sum \mathrm{n1} + \sum \mathrm{n2} + \sum \mathrm{n3}}$$

where n_0, n_1, n_2, and n_3 are the number of individuals assigned to each of four categories as defined by their different tolerances to organic enrichment (n_0 = intolerant, species indicative of oligotrophic conditions; n_1 = somewhat intolerant, species indicative of mesotrophic conditions; n_2 = tolerant, species indicative of eutrophic conditions; n_3 = very tolerant, species indicative of extreme eutrophication). The species assigned to each tolerance category are given in Table 2 and follow the classifications of Lauritsen et al. (1985). At times, the assigned tolerance category of a particular species differed from that given in Milbrink (1983), but it was felt that the classifications given in Lauritsen et al. (1985) were more specific to the Great Lakes. We assigned unidentifiable immature oligochaetes to species according to the proportions of the identified adults at a particular site. Immatures without hair setae were assigned to *Limnodrilus* spp., *L. hoffmeisteri*, *L. cervix*, and *L. maumeensis*. Immatures with hair setae were assigned to *Ilyodrilus templetoni* and *Potamothrix moldavensis*. C as given in the O-TC index is a coefficient based on the total density (n = no. per m^2) of all oligochaetes in the sample: C = 0 when n < 130 m^2; C = 0.25 when 130 m^2 < n < 400 m^2; C = 0.50 when 400 m^2 < n < 1,200 m^2; C = 0.75 when 1,200 m^2 < n < 3,600 m^2 and; C = 1.0 when n > 3,600 m^2 (Milbrink 1983). The index varies from 0 to 3, with higher values indicating greater organic enrichment. As a general guideline, Milbrink (1983) noted that index values < 0.6 suggest oligotrophic conditions, values 0.6-1.0 suggest mesotrophic conditions, and values > 1.0 suggest eutrophic conditions; values approaching 3.0 suggest gross organic pollution.

While the Prop-O, O/C, and O-TCI indices mainly focus on the relative abundance and composition of oligochaetes, Taxa Richness (R) and Shannon Diversity (H) are more related to species composition of the total community. The former index is simply the total number of taxa found in the sample, while the latter index takes into account both the total number of taxa and the proportion that each taxa comprises of the total number. Shannon Diversity was calculated as:

$$H = -\sum_{i=1}^{t} (\mathrm{Pi})(\ln \mathrm{Pi})$$

where P_i is the proportion of the ith taxa within the total number of individuals found for all taxa (t).

To provide a composite assessment of benthic community structure using all 5 indices, values of each index were sorted, and then the sites were ranked based on the given order. That is, the 41 sites were ranked from 1 to 41 based on the value of the particular index. For each index, the sites were ranked such that an increasing rank would indicate increased degradation based on the index value. For Prop-O, O/C and O-TOC, there is a positive relationship between the index value, relative rank, and extent of degradation (e.g. higher value, higher ranking, higher degradation). For R and H, however, there is a negative relationship between index value and extent of degradation (lower value indicative of greater degradation), so for these indices the ranking had to be transposed (e.g. lower value, higher ranking, higher degradation). A mean ranking was assigned to all sites that had the same value of a given index. Finally, an overall ranking for each site was determined based on the mean ranking of all 5 indices.

Results

Data Presentation

Numbers of each taxa found at each of the sites and replicates is provided in an Excel file (see Appendix A). Values are given as number per grab; to convert to number per square meter (no. m^2) multiply values by 25. A list of all taxa collected is given in Table 2 along with the four-letter code assigned to each species as given in the file. Other variables in the file include year of collection (2009 or 2010), Julian Date (JD), Station (as given in Table 1), and replicate number (1, 2, or 3). While three replicates were taken at LSTL, the replicates were inadvertently combined during the laboratory-rinsing procedure so values given for this station are means of the three replicates.

A general description of sediments at each site is given in Table 3. Most sediments were fine-grained, consisting of silt with some clay and mussel shells. Often, an oily sheen/smell was noted at some of the sites.

Density and Composition of Macroinvertebrates

Over all sites, the most widespread and dominant taxa group was Oligochaeta; this group comprised 71% of all organisms collected. Mean oligochaete density at a given site was 7,355 ± 2,770, but the range of abundance at a given site was great (38 m^{-2} at LOSL to 113,259 m^{-2} at LMMR) (Table 4). A total of 32 individual oligochaete taxa were found, with the most common species being *Limnodrilus hoffmeisteri*, *Limnodrilus cervix*, and *Ilyocryptus templetoni*. The next most widespread group was Chironomidae, which also contained the most individual taxa (51). The most common taxa in this group was the genus *Chironomus*. Individuals within this genus comprised about 40 % of all chironomids collected: *C. anthracinus*-type (18.8%), *C. semireductus*-type (12.3%, and *Chironomus* sp. (8.5%). Other common chironomid taxa were *Tribelos jucundum* (10.5%), *Procladius* sp. (10.2%), and *Polypedilum halterale*-grp (8.6%). Most other chironmid taxa were uncommon or rare. For example, 30 of 51 taxa comprised < 1% of the total number found, and 15 taxa were represented by only one individual.

Invasive dreissenid mussels, *Dreissena rostroiformis bugenis* (quagga mussel) and *Dreissena polymorpha* (zebra mussel), were found at 21 of the 41sites, and maximum density at a given site was 18,242 m^{-2} (at SBPP) (Table 4). Of the two dreissenid species, *D. r. bugenisis* was by far the most abundant and widespread, comprising 97.6 % of all dreissenid individuals found. *D. polymorpha* was collected at only 6 sites: LERB, LEPB, SBPP, LOOS, LSLR, and LMWL.

Of the three taxa of amphipods, the invasive *Echinogammarus ischnus* was the dominant form, comprising 64% of all amphipods as compared to 24% for *Hyallela* and 9% for *Gammarus*. As a group, amphipods were not widespread, but tended to be highly abundant at just a few sites. For instance, *E. ischnus* was found at only 8 sites, but while mean density was 2,050 m^{-2} at LOCV, mean density was < 708 m^{-2} at all other sites. Also, *Hyallela* was found at only 6 sites, but while mean density was 1,266 m^{-2} at LSSM, all other sites had densities < 17 m^{-2}.

Comparison of AOC and Reference Sites

Mean densities of the major groups were determined for the AOC and Reference sites, and differences examined using the Mann Whitney U-Test (Table 5). Both oligochaetes and sphaeriids were

significantly more abundant at AOC sites, and *Dreissena* was significantly more abundant at the Reference sites ($P < 0.05$). For these three taxa, the difference in abundance between the two site types was at least 4-fold. Other taxa such as Ephemeroptera and Amphipoda were at least 4 times more abundant at the Reference sites, but differences were not significant ($P > 0.05$).

Values of all five indices at the sites are given in Table 6. The two indices based on the relative abundance of oligochaetes, Prop-O and O/C, were both significantly higher ($P < 0.05$) at the AOC sites than at the Reference sites (Table 5). The OTC index was also higher, although the difference was not significant (($P <0.05$). Together, these differences would indicate that AOC sites were more organically enriched than Reference sites, and that species best able to take advantage of organic inputs and/or best adapted to adverse conditions were more dominant at the AOC sites. Since dreissenids were less abundant at AOC sites and thus may have influenced the Prop-0 index, this index was re-calculated without including dreissenids. While the difference was not as pronounced, the Prop-O index was still far greater at the AOC sites (Table 5). In contrast, both species diversity (H) and taxa richnesss (R) were slightly higher at the AOC sites, indicating the benthic community was less degraded.

Figure 1 gives the relative ranking of all sites based on a composite of all five indices. As noted previously, a higher overall ranking indicates greater degradation of the benthic community based on the indices used. Overall, there was a tendency for AOC sites to have a higher ranking. Although the mean difference of the ranking was not significant (Table 5), 17 of 20 sites above the median ranking were AOCs, and 10 sites with the highest ranking were AOCs. The three Reference sites above the median ranking were LEAB, LOOC1, and LOOC2. The latter two sites were in close proximity to each other and both had a relatively high ranking mainly because of low species diversity and taxa richness. The two sites with the worst ranking were both AOCs, LMMR (Rouge River) and LECR (Cuyoga River). Despite the tendency for AOC sites to have a higher ranking, two AOC sites, LMWL (White Lake) and LCSC (St. Clair River), had the lowest ranking (least degraded) of all 41 sites. Finally, it is interesting to note that the two AOC sites without a degraded-benthos BUI, LOOR (Oswego River) and LMWM (Manistique River), both had rankings that were below the median; however, both had a relative ranking that was above 11 other AOC sites that did have a degraded-benthos BUI.

Discussion

We assessed benthic community structure at AOC and References sites by calculating common measures of community health and then evaluating differences on both an absolute and relative basis. Assessments were based on field observations, and thus degradation was defined in an ecological rather than in a physiological context. By definition, assessments based on physiological tolerances are a result of evaluating exposure impacts under controlled conditions. While an ideal assessment includes both measures of community health (Grapentine 2009), field observations provide the most realistic integration of both natural and human-induced stressors.

In terms of abundances of major taxonomic groups, the most striking difference between AOC and Reference sites was the lower abundance of *Dreissena* at the AOC sites. In the Great Lakes, the role of *Dreissena* as an indicator species has not been clearly defined, but evidence suggests that both *D. polymorpha* and *D. r. bugensis* are relatively sensitive to organic enrichment and associated low oxygen conditions (Garton et al. 2013). As evidence, in surveys of dreissenid distributions in Lake Erie, both species were rare in the deeper portion of the central basin where hypoxic conditions occur every summer (Patterson et al. 2005, Karatayev et al. in press). Further, Mouthon (1996) examined the distribution *D. polymorpha* and 47 other mollusc species relative to physico-chemical variables indicative of organic pollution in various river systems. Comparative results indicated *D. polymorpha* was among the species considered to be less tolerant of such pollution. The lower abundance of dreissenids at the AOC sites may indeed indicate greater degradation at these sites. However, the myriad of factors that can influence dreissenid distributions and abundances (fish predation, inherent patchiness, variable recruitment success, etc.) can bring much uncertainty to such an interpretation.

Notwithstanding the abundances of dreissenids, abundances of oligochaetes and indices based on the relative abundance of oligochaetes (PROP-O and O/C) indicated a strong, consistent pattern of greater degradation at the AOC sites. Of all the major groups, indices based on the absolute and relative abundance of oligochaetes have been the most widely-used metric to assess benthic community health in the Great Lakes (Mozley and Howmiller 1977, Schloesser et al. 1995). Mean oligochaete abundance was

4 times greater at AOC sites than at Reference sites, and this difference was significant despite the great range in values within each of these two site categories (38 m^{-2} to 113,000 m^{-2} at AOC sites; 258 m^{-2} to 5,125 m^{-2} at Reference sites). While oligochaete abundances are directly and positively related to organic enrichment, values must be placed into context within the entire benthic community. Indeed, an increase in oligochaete abundances can be interpreted as an indicator of improved conditions if the increase is accompanied by a decline in the relative proportion of oligochaetes (Kreiger and Ross 1993, Carter et al. 2006). Similarly, a decline in absolute abundances of oligochaetes can occur without a corresponding decline in the relative proportion. For example, site LECR in this study was located near a site sampled in 1989 as part of an assessment of the Cleveland Harbor area (site 84; Kreiger and Ross 1993). Depths at the two sites were generally similar (5.2 m and 8.8 m). In 1989, mean oligochaete abundance, PROP-O, and O/C were 56,157 m^{-2}, 0.99, and 1.00, respectively. In 2009, values were 7,088 m^{-2}, 0.99, and 1.00. In this case, absolute abundances declined dramatically between 1989 and 2009, but the two indices indicated the benthic community had not changed and was still severely degraded. Of all sites sampled, LECR had the highest overall index ranking, and thus perceived as the most degraded.

While indices based on relative abundance and composition of oligochaetes (Prop-O, O/C, O-TCI) were consistent in demonstrating greater organic enrichment at AOC sites, species diversity (H) and taxa richness (R) showed no differences, or showed perhaps a slight tendency for less degraded conditions at the AOC sites. While often used in assessments of the benthic community, these indices can give misleading results when used to assess gradients in environmental degradation. Diversity reaches a maximum in transitional environments, and can be low under conditions that are considered both polluted and unpolluted (Howmiller and Scott 1977, Milbrink 1980).

Potential confounding factors when comparing benthic community structure at AOC and Reference sites are the effects of dreissenids on other benthic groups (Higgins 2010, Ward and Ricciardi 2013). Dreissenids impact benthic community structure a number of different ways: 1) as filter feeders, dreissenids compete with other taxa that have the same feeding mode; 2) through biodeposition of feces and pseudofeces, dreissenids increase the amount of available food for some detritivores; 3) dreissenid shells provide shelter from fish predation for some benthic taxa; 4) increased light penetration resulting

from dreissenid filtering promotes growth of benthic algae and ultimately enhances food resources for some taxa. In nearshore environments, dreissenid activities tend to have a general positive effect on most major benthic groups (Higgins 2010). Based on meta-analysis, the common groups found to be most positively influenced by dreissenids were: Amphipoda > Gastropoda > Ephemeroptera > Oligochaeta > Diptera. Groups most negatively affected were: Unionidae > Sphaeriidae > Tricoptera. Hence, greater abundances of amphipods and ephemeropterans, and lower abundances of sphaeriids at Reference sites may be partly due to greater abundances of dreissenids at these sites. However, greater absolute and relative abundances of oliogchaetes at AOC sites despite lower abundances of dreissenids tends to re-enforce the conclusion that factors other than dreissenids were the cause of differences between AOC and Reference sites for the PROP-O and O/C. The influence of dreissenids on oligochaete composition and hence the O-TCI index is unknown. To determine if dreissenids indeed played a role in index outcomes, we determined Pearson correlation coefficients for dreissenid abundances and the PROP-O, O/C, and O-TCI indices. Coefficients were -0.270, -0.068, and - 0.182 for the three indices, respectively. Negative values may suggest that higher index values at AOC sites may be partly a result of lower dreissenid abundances, but the generally low coefficients indicate any influence of dreissenids on comparative differences between AOC sites and Reference sites would be minimal.

In summary, the sampling of sites across the Great Lakes gave a site-specific context to benthic community health over a wide geographical range. The ranking of sites based on commonly-used indices of benthic degradation have identified which AOC sites are, on a relative basis, the least and most degraded, and also identified the extent by which AOC sites differ from Reference sites that were perceived to be less subject to human-induced stressors. Given the difficulty of identifying an absolute endpoint in which remedial actions have been deemed successful and the BUI of a “degraded benthos” can be removed (Grapevine 2009), these data serve as a context for relative responses among a large number of AOCs. We realize that sampling on one date and at one location at each of the sites does not provide enough data to truly characterize the benthic community within a given AOC or Reference site. However, as illustrated in the example for Cleveland Harbor, presented data can provide a perspective for temporal and spatial patterns.

Future plans include examining associations between benthic community health and concentrations of organic and inorganic contaminants across all the sites (see Kimbrough et al. 2014). Based on the indices used, there was a wide range in benthic community health across sites, and linking spatial gradients to similar gradients in contaminants can be a powerful tool in defining specific stressors. At the very least, the data presented here provides a baseline to track temporal changes at individual sites, and also places any changes into a spatial context with all other sites. This spatial context would be especially valuable if a future stressor unrelated to current conditions (i.e. climate change, new invasive species, etc.) affected the benthic community over a large number of sites.

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Table 1. List of sites sampled along with sampling date, location, depth (meters), and site type (AOC = Area of Concern; REF = Reference)

Lake/Station	Year	Julian Date	Latitude	Longitude	Location	Depth	Type
Lake Superior							
LSLR	2010	257	46.74645	92.12383	St. Louis River Mouth	5.8	AOC
LSTL	2010	257	47.15777	88.41690	Torch Lake, Keewanaw	6.1	AOC
St. Marys River							
LSSM	2010	254	46.28650	84.21133	St. Marys River	3.0	AOC
Lake Michigan							
GBBS	2010	260	44.63988	87.81260	Green Bay, Bayshore Park	5.8	REF
LMGF	2010	260	44.53845	88.00558	Fox River Mouth	3.0	AOC
LMHM	2010	260	41.69862	87.50590	Hammond Marina	5.4	AOC
LMIK	2010	259	42.67461	86.20730	Kalamazoo River Mouth	1.0	AOC
LMMB	2010	261	43.04001	87.89191	Milwaukee Harbor	3.4	AOC
LMML	2010	258	43.22020	86.30467	Muskegon Lake, south side	7.0	AOC
LMMM	2010	259	45.09588	87.59098	Menominee River Mouth	6.1	AOC
LMSR	2010	261	43.75160	87.69733	Sheboygan River Mouth	3.0	AOC
LMWH	2010	261	42.36268	87.82303	Waukegan Harbor	7.0	AOC
LMWL	2010	259	43.40697	86.35371	White Lake, west end	3.0	AOC
LMWM	2010	255	45.94533	86.24638	Manistique River Mouth	3.7	AOC
Lake Huron							
SBSR	2010	255	43.67149	83.83188	Saginaw River Mouth	9.0	AOC
St. Clair River							
LCSC	2010	52	42.60827	82.53411	West shore, mid-length	1.8	AOC
Lake St. Clair							
LCCR	2010	251	42.59217	82.80069	Clinton River Mouth	2.2	AOC
LSAB	2010	252	42.64898	82.71273	Anchor Bay, nearshore	3.3	REF
Detroit River							
DRSE	2009	252	42.10642	83.13570	Just east of Grosse Isle	3.5	AOC
LMMR	2010	251	42.28032	83.11807	Mouth of Rouge River	3.0	AOC
Lake Erie							
LEAB	2009	258	41.94125	80.73175	Ashtabula, nearshore	13.6	REF
LEAR	2009	259	41.91815	80.78747	Astabula River , Mouth	5.3	AOC
LEBR	2009	256,262	41.47530	82.18122	Black River, Mouth	4.2	AOC
LECR	2009	258	41.49960	81.71770	Cuyahoga River, Mouth	5.2	AOC
LEDK	2009	260	42.53650	79.27188	Dunkirk, nearshore	17.5	REF
LEMR	2009	253	41.70276	83.45526	Maumee River, mouth	2.0	AOC
LERB	2009	253	41.67091	83.22708	Reno Beach, nearshore	5.5	REF
LERR	2009	252	41.89900	83.36200	Raisin River, Turning Basin	3.0	AOC
LEOW	2009	254	41.38142	82.51427	Old Woman Creek, nearshore	0.65	REF
LEPB	2009	259	42.13810	80.09532	Presque Isle Bay	4.7	AOC
LESP	2009	254	41.95070	83.23662	Stoney Point, nearshore	5.9	REF
SBPP	2009	255	41.66128	82.82626	Peach Orchard Point	10.1	REF
Niagara River							
NRNF	2009	261	43.07211	78.95123	Just below falls	1.0	AOC
Lake Ontario							
LOCV	2009	265	44.14778	76.32349	Cap Vincent	9.0	REF
LOEC	2009	262	43.33825	78.71902	Eight Mile Creek, Harbor	3.8	AOC
LOOC1	2009	262	43.35394	78.69032	Olcott, nearshore	11.0	REF
LOOC2	2009	262	43.35530	78.69801	Olcott, nearshore	14.9	REF
LOOR	2009	263	43.46658	76.51223	Oswego River, Harbor	5.5	AOC
LOOS	2009	264	43.46802	76.58727	Oswego, nearshore	30.0	REF
LORC	2009	263	43.26613	77.49744	Rochester Bay	19.5	AOC
LOSL	2009	265	44.98144	74.88910	St. Lawrence River	12.5	AOC

Table 2. Taxa found in benthic samples collected at all sites in 2009 and 2010. The four letter code identifies each of the taxa in the Excel spreadsheet given in Appendix A. The number in parenthesis is the tolerance classification for the calculation of the O-TCI (see Methods).

Taxa	Code	Taxa	Code
Tricoptera		Diptera	
Oecetis sp.	OCET	Chironomidae	
Phylocentropus sp.	PHYL	*Ablabesmyia annulata*	AANN
Polycentropus sp.	POLY	*Ablabesmyia* sp.	ABLA
Megaloptera		*Axarus* sp.	AXAR
Sialis sp.	SIAL	*Chironomus sp.*	CHIR
Lepidoptera	LEPI	*Chironomus anthracinus* type	CANT
Coleoptera	COLE	*Chironomus mozleyi*	CMOZ
Ephemeroptera		*Chironomus semi-reductus* type	CSEM
Hexagenia sp.	HEXA	*Cladopelma sp.*	CLAD
Amphipoda		*Clinotanypus sp.*	CLIN
Echinogammarus ischnus	ECHI	*Coelotanypus sp.*	COEL
Gammarus spp.	GAMM	*Corynocera sp.*	CORY
Hyalella sp.	HYLA	*Cricotopus sp.*	CRIC
Isopoda	ISOP	*Cricotopus bisinctus*	CBIC
Bivalvia		*Cryptochironomus sp.*	CRYP
Dreissenidae		*Cryptotendipes sp.*	CYPT
Dreissena polymorpha	DPOL	*Demicryptochironomus cuneatus*	DCUN
Dreissena rostiformis bugensis	DBUG	*Dicrotendipes sp.*	DICR
Sphaeriidae	SPHA	*Eclipidrilus sp.*	ECLI
Corbiculidae		*Epoicocladius sp.*	EPOI
Corbicula sp.	CORB	*Glyptotendipes sp.*	GLYP
Gastropoda	GAST	*Harnischia sp.*	HARN
Hirudinea	HIRU	*Monodiamesia depectinata*	MDEP
Annelida		*Microchironomus sp.*	MICR
Enchytraeidae	ENCH	*Monodiamesa sp.*	MONO
Lumbriculidae		*Microtendipes pedellus grp.*	MPED
Stylodrilus heringianus (0)	SHER	*Micropsectra cf. polita*	MPOL
Naidinae		*Monodiamesa tuberculata*	MTUB
Arcteonais lomondi	ALOM	*Pagastiella sp.*	PAGA
Dero sp.	DERO	*Parachironomus frequens*	PFRE
Dero furcata	DFUR	*Paralauterborniella nigrohalteralis*	PNIG
Dero nivea	DNIV	*Paratendipes albimanus grp.*	PALB
Nais bretcheri	NBRE	*Pentaneurini sp.*	PENT
Nais communis	NCOM	*Pentaneura inconspicua*	PINC
Nais pardalis	NPAR	*Phaenopsectra flavipes*	PFLA
Nais pseudobtusa	NPSE	*Polypedilum halterale grp.*	PHAL
Nais variabilis	NVAR	*Potthastia longimana*	PLON
Pristina acuminata	PACU	*Phaenopsectra obediens*	POBE
Pristina acuminata	PAEQ	*Procladius* sp.	PROC
Paranais litoralis	PLIT	*Polypedilum scalaenum grp.*	PSCA
Piquetiella michiganensis	PMIC	*Pseudochironomus* sp.	PSEU
Slavina appendiculata	SAPP	*Psectrocladius simulans*	PSIM
Specaria josinae	SJOS	*Polypelilum tuberosum*	PTUB
Stylaria lacustris	SLAC	*Rheotanytarsus* sp.	RHEO
Tubificinae		*Stempellina* sp.	STEM
Aulodrilus limnobius (1)	ALIM	*Strictochironomus*	STIC
Aulodrilus americanus (1)	AMER	*Tanytarsus* sp.	TANY
Aulodrilus pigueti (1)	APIG	*Thienemannimyia*	THIE
Aulodrilus pluriseta (1)	APLU	*Tanypus punctipennis*	TPUN
Branchiura sowerbyi	BSOW	*Tribelos jucundum*	TJUC
Ilyodrilus templetoni (1)	ITEM	*Tanypus neopunctipennis*	TNEO

Table 2. Continued.

Tubificinae continued		Chironomidae continued	
Limnodrilus sp. (2)	LIMN	Chironomidae pupa	PUPA
Limnodrilus cervix (3)	LCER	Ceratopogonidae	
Limnodrilus hoffmeisteri (2)	LHOF	*Mallochohelea sp.*	MALL
Limnodrilus maumeensis (3)	LMAU	*Probezzia* sp.	PROB
Limnodrilus udekemianus (2)	LUKE	*Sphaeronais* sp.	SIAS
Potamothrix moldaviensis (1)	PMOL	Chaoboridae	
Potamothrix vejdovskyi (1)	PVEJ	*Chaoborus* sp.	CHAO
Quistadrilus multisetosus (3)	QMUL	Unknown diptera	DIPT
Spirosperma ferox (1)	SFER	Hydrozoa	
Immature with hair chaetae	IMWH	*Hydra* sp.	HYDR
Immature without hair chaetae	IMWO	Malacastraca	
Oligochaete fragments	OFRA	*Mysis diluviana*	MYSI
Polychaeta			
Manayunkia speciosa	MSPE		
Turbellaria	TURB		
Nemertea			
Prostoma sp.	PROS		

Table 3. A field description of sediments found at each of the staitons sampled. (AOC = Area of Concern; REF = Reference)

Lake/Station	Site Type	Sediment Description	Sediment Color	Sediment Odor
Lake Superior				
LSLR	AOC	clay, mud, shell/rock	brown, rust	none
LSSM	AOC	-	-	-
LSTL	AOC	mud, sticky (stamp sand)	other/pink	none
Lake Michigan				
GBBS	REF	silt, mud, sand, shell/rock	brown, other/tan	none
LMGF	AOC	silt, mud, sand, shell/rock	brown, other/tan	none
LMHM	AOC	silt, sand	brown, gray	none
LMIK	AOC	silt, sand	brown, gray	none
LMMB	AOC	mud, sand, shell/rock	black, brown	none
LMML	AOC			
LMMM	AOC	mud, shell/rock	black, green	oily
LMSR	AOC	silt, mud, sand, shell/rock	gray	none
LMWH	AOC	silt, sand	brown, gray	other
LMWL	AOC	silt, mud	black	none
LMWM	AOC	silt, mud, organic debris	black	none
Lake Huron				
SBSR	AOC	silt, clay	brown, gray	none
St. Clair River				
LCSC	AOC	silt, mud, sand	brown, gray	none
Lake St. Clair				
LCCR	AOC	silt, mud	gray	oily
LSAB	REF	silt, sand	brown, gray	none
Detroit River				
DRSE	AOC	silt, clay	brown	oily sheen
LMMR	AOC	silt, clay	black, brown	oily
Lake Erie				
LEAB	REF	silt, sand, shell/rock	brown	none
LEAR	AOC	silt, clay, mud, sand, detritus	black, brown	none
LEBR	AOC	silt, clay, sticky mud, shell/rock	black, brown	other
LECR	AOC	Silt, wood chips	gray	none
LEDK	REF	silt, sand, shell/rock	brown, gray	none
LEMR	AOC	clay, sticky mud, shell/rock	Black brown	none
LERB	REF	clay, mud, sand, shell/rock	Brown	None
LERR	AOC	mud, sand	brown	oily
LEOW	REF	silt, clay, sand	brown	none
LEPB	AOC	silt, sand, mud, shell/rock, wood	black, brown, green	oily
LESP	REF	clay, mud, shell/rock	brown	none
SBPP	REF	silt, clay, mud, sand	brown	none
Niagara River				
NRNF	AOC	silt, sand	brown, gray	none
Lake Ontario				
LOCV	REF	silt, sand, shell/rock	black	none
LOEC	AOC	silt, mud, shell/rock	brown, gray	oily
LOOC1	REF	silt	brown	none
LOOC2	REF	silt	brown	none
LOOR	AOC	silt, sand shell/rock	black, gray	other
LOOS	REF	silt, clay	brown	none
LORC	AOC	silt. clay, shell hash	brown, gray	none
LOSL	AOC	silt, clay, mussel shell	gray	none

Table 4. Mean (± SE) density (per m^2) of major taxonomic groups at each of the sampled sites.

Lake/Station	Oligochaeta	Chironomidae	*Dreissena*	Amphipoda	Sphaeriidae	Gastropoda	Tricoptera	Ephemeroptera	Others	Total
Lake Superior										
LSLR	8,467 ± 3,118	1,267 ± 257	1,533 ± 659	8 ± 8	17 ± 17	75 ± 38	208 ± 51	33 ± 8	150 ± 50	11,758 ± 3,447
LSSM	5,467 ± 571	1,816 ± 643	0 ± 0	1,317 ± 694	692 ± 210	108 ± 46	17 ± 17	1292 ± 167	608 ± 79	11,283 ± 1,401
LSTL	200	8	0	0	33	0	0	0	0	242
Lake Michigan										
GBBS	5,125 ± 578	2,250 ± 250	0 ± 0	0 ± 0	75 ± 50	33 ± 33	0 ± 0	0 ± 0	8 ± 8	7,492 ± 491
LMGF	8,617 ± 2,316	708 ±83	8 ± 8	0 ± 0	92 ± 46	0 ± 0	0 ± 0	0 ± 0	58 ± 30	9,467 ± 2,362
LMHM	2,575 ± 832	158 ± 36	1,008 ± 558	8 ± 8	83 ± 44	25 ± 14	0 ± 0	0 ± 0	0 ± 0	3,858 ± 1,415
LMIK	3,900 ± 578	25 ± 14	0 ± 0	8 ± 8	583 ±242	8 ± 8	0 ± 0	0 ± 0	0 ± 0	4,525 ± 664
LMMB	15,233 ± 3,114	617 ± 239	0 ± 0	0 ± 0	8 ± 8	0 ± 0	0 ± 0	0 ± 0	0 ± 0	15,858 ± 3,332
LMML	700 ± 138	17 ± 8	8 ± 8	0 ± 0	92 ± 22	0 ± 0	0 ± 0	0 ± 0	408 ± 153	1,225 ± 58
LMMM	1,425 ± 420	342 ± 112	0 ±0	0 ± 0	33 ± 8	0 ± 0	8 8	0 ± 0	0 ± 0	1,808 ± 496
LMSR	28,017 ± 12,382	283 ± 110	8 ± 8	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	28,308 ± 12,466
LMWH	9,400 ± 1,883	392 ± 94	0 ± 0	0 ± 0	17 8	0 ± 0	0 ± 0	0 ± 0	8 ± 8	9,817 ± 1,858
LMWL	225 ± 63	267 ± 44	42 ± 8	33 ± 33	100 ± 88	0 ± 0	0 ± 0	33 ± 33	108 ± 36	767 ± 80
LMWM	12,792 ± 3,926	2,417 ± 172	0 ± 0	0 ± 0	25 ± 14	0 ± 0	167 ± 44	17 ± 8	25 ± 25	15,442 ± 4,091
Lake Huron										
SBSR	8,442 ± 2,809	158 ± 36	0 ± 0	0 ± 0	58 ± 36	0 ± 0	0 ± 0	0 ± 0	0 ± 0	8,658 ± 2,867
St. Clair River										
LCSC	1,025 ± 375	1,850 ± 664	8 ± 8	25 ± 14	8 ± 8	117 ± 22	0 ± 0	133 ± 30	92 ± 79	3,192 ± 1,032
Lake St. Clair										
LCCR	3,142 ± 571	342 ± 8	0 ± 0	8 ± 8	33 ± 17	8 ± 8	0 ± 0	0 ± 0	0 ± 0	3,853 ± 553
LSAB	1,633 ± 426	792 ± 96	83 ± 22	282 ± 94	142 ± 8	375 ± 90	8 ± 8	2,317 ± 210	275 ± 214	5,917 ± 649
Detroit River										
DRSE	2,075 ± 227	125 ± 43	0 ± 0	0 ± 0	92 ± 17	0 ± 0	0 ± 0	17 ± 17	8 ± 8	2,317 ± 254
LMMR	113,250 ± 26,180	467 ± 42	8 ± 8	8 ± 8	200 ± 151	50 ± 50	0 ± 0	0 ± 0	125 ± 52	114,108 ± 26,334
Lake Erie										
LEAB	3,958 ± 1,053	167 ± 36	6,942 ± 2,692	17 ± 8	134 ± 74	25 ± 25	0 ± 0	0 ± 0	0 ± 0	11,242 ± 3,856
LEAR	9,383 ± 2,057	467 ± 67	0 ± 0	0 ± 0	25 ± 25	0 ± 0	0 ± 0	0 ± 0	8 ± 8	9,883± 2,091
LEBR	8,988 ± 3,816	96 ± 28	0 ± 0	8 5	113 ± 60	4 ± 4	0 ± 0	0 ± 0	17 ± 5	9,225 ± 3,891
LECR	7,088 ± 1,063	25 ± 25	0 ± 0	0 ± 0	38 ± 13	13 ± 13	0 ± 0	0 ± 0	0 ± 0	7,163 ± 1,113
LEDK	517 ± 17	158 ± 33	17 ± 17	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	692 ± 67
LEMR	808 ± 112	200 ± 150	0 ± 0	0 ± 0	1,625 ± 437	0 ± 0	0 ± 0	17± 8	67 ± 44	2,708 ± 727
LERB	2,942 ± 210	350 ± 66	2,633 ± 1,020	0 ± 0	0 ± 0	17 ± 17	0 ± 0	292 ± 44	117 ± 117	6,350 ± 1,050
LERR	3,492 ± 630	75 ± 29	0 ± 0	0 ± 0	25 ± 25	0 ± 0	0 ± 0	0 ± 0	0 ± 0	3,591 ± 641
LEOW	533 ± 202	92 ± 22	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	8 ± 8	67 ± 44	700 ± 202
LEPB	2,542 ± 600	258 ± 108	5,575 ± 5179	458 ± 434	75 ±38	42 ± 30	0 ± 0	0 ± 0	133 ± 133	9,083 ± 5,312
LESP	258 ± 36	125 ± 66	25 ± 25	0 ± 0	42 ± 22	0 ± 0	0 ± 0	17± 8	8 ± 8	475 ± 132
SBPP	483 ± 220	117 ± 220	18,542 ± 16,391	708 ± 658	0 ± 0	8 ± 8	0 ± 0	25± 0	133 ± 133	20,017 ± 17,382
Niagara River										
NRNF	2,258 ± 356	125 ± 101	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	33 ± 22	2,417 ± 440
Lake Ontario										
LOCV	508 ± 73	800 ± 419	11,158 ± 4,013	2,050 ± 416	0 ± 0	33 ± 17	0 ± 0	0 ± 0	50 ± 25	14,600 ±4,075
LOEC	6,950 ± 1,485	892 ± 237	192 ± 102	8 ± 8	0 ± 0	0 ± 0	0 ± 0	0 ± 0	8 ± 8	8,050 ± 1,691
LOOC1	3,867 ± 1,571	217 ± 36	4,808 ± 654	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	8,962 ± 2,054
LOOC2	3,475 ± 1,701	200 ± 25	16,842 ± 16,418	375 ± 375	0 ± 0	0 ± 0	0 ± 0	0 ± 0	42 ± 30	20,933 ± 18,510
LOOR	3,813 ± 1,263	588 ± 363	0 ± 0	0 ± 0	13 ± 13	0 ± 0	0 ± 0	0 ± 0	0 ± 0	4,413 ± 1,638
LOOS	2,338 ± 588	1,400 ± 750	7,925 ± 1,475	38 ± 13	0 ± 0	0 ± 0	0 ± 0	0 ± 0	25 ± 25	11,712 ± 1,663
LORC	5,617 ± 2,961	408 ± 148	7,867 ± 7,867	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	13,892 ± 10,865
LOSL	38 ± 13	288 ± 13	0 ± 0	13 ± 13	200 ± 200	0 ± 0	0 ± 0	38 ± 13	25 ± 25	600 ± 225

Table 5. Mean (± SE) density (per m^2) of major taxonomic groups at AOC sites and Reference sites. Also given is the mean (± SE) of calclulated indices. Differences were tested using the Mann-Whitney U-test (P values given).

Taxonomic Group	Site Type: AOC (n=29)	Site Type: Reference (n=12)	P -Value
Oligochaeta	9,514 ± 3,859	2,137 ± 493	0.029
Chironomidae	506 ± 112	555 ± 192	0.920
Dreissena	561 ± 328	5,747 ± 1,939	< 0.001
Amhipoda	66 ± 47	290 ± 172	0.206
Sphaeriidae	148 ± 60	33 ± 16	0.026
Gastropoda	16 ± 6	41 ± 31	0.379
Tricoptera	14 ± 9	<1 ± <1	0.579
Ephemeroptera	55 ± 44	221 ± 192	0.425
Other	65 ± 25	60 ± 23	0.419
Total	10,938 ± 3,854	9,085 ± 2,017	0.667
Indices			
Prop-O	0.74 ± 0.05	0.39 ± 0.08	0.001
Prop-O[1]	0.79 ± 0.05	0.64 ± 0.08	0.022
O/C	0.86 ± 0.04	0.77 ± 0.05	0.016
R	17.27 ± 1.24	14.67± 1.75	0.206
H	1.54 ± 0.09	1.32 ± 0.16	0.316
O-TCI	1.64 ± 0.10	1.27 ± 0.14	0.055
Overall Rank	22.31 ± 1.56	17.84 ± 1.64	0.109

[1]Not including dreissenids

Table 6. Values of the five indices used to assess relative health of the benthic macroinvertebrate community at each of the sites. See Methods for an explanation of how each index was calculated.

	Index				
Lake/Station	PROP-O	O/C	O-TCI	H	R
Lake Superior					
LSLR	0.72	0.87	1.58	1.92	30
LSSM	0.48	0.75	1.71	2.47	32
LSTL	0.83	0.96	0.43	1.39	6
Lake Michigan					
GBBS	0.68	0.69	1.84	1.81	19
LMGF	0.91	0.92	1.86	1.64	22
LMHM	0.67	0.94	1.57	2.25	22
LMIK	0.86	0.99	2.28	1.38	12
LMMB	0.96	0.96	2.31	1.39	16
LMML	0.57	0.98	0.96	1.42	9
LMMM	0.79	0.81	1.35	1.63	17
LMSR	0.99	0.99	2.25	1.54	16
LMWH	0.96	0.96	1.87	1.57	22
LMWL	0.29	0.46	0.48	2.60	20
LMWM	0.83	0.84	1.73	1.68	25
Lake Huron					
SBSR	0.97	0.98	1.66	1.12	12
St. Clair River					
LCSC	0.32	0.36	0.96	1.96	30
Lake St. Clair					
LCCR	0.89	0.90	1.23	2.20	19
LSAB	0.28	0.67	1.44	2.07	27
Detroit River					
DRSE	0.90	0.94	1.47	0.92	14
LMMR	0.99	1.00	2.37	1.13	19
Lake Erie					
LEAB	0.35	0.96	1.67	1.16	16
LEAR	0.95	0.95	2.56	1.75	14
LEBR	0.97	0.99	1.95	0.99	21
LECR	0.99	1.00	1.94	0.67	11
LEDK	0.75	0.77	0.73	1.60	9
LEMR	0.30	0.80	0.91	1.30	15
LERB	0.46	0.89	1.58	1.61	15
LERR	0.97	0.98	1.75	1.24	11
LEOW	0.76	0.85	1.24	1.90	9
LEPB	0.28	0.91	1.25	1.44	22
LESP	0.54	0.67	0.47	1.87	9
SBPP	0.02	0.81	1.14	0.31	21
Niagara River					
NRNF	0.93	0.95	1.45	0.83	13
Lake Ontario					
LOCV	0.03	0.39	0.68	0.60	20
LOEC	0.86	0.89	1.88	1.04	17
LOOC1	0.43	0.95	1.92	0.99	12
LOOC2	0.17	0.95	1.68	0.82	8
LOOR	0.86	0.87	1.63	1.93	16
LOOS	0.20	0.63	0.78	1.11	11
LORC	0.40	0.93	1.53	1.20	7
LOSL	0.06	0.12	2.50	2.00	11

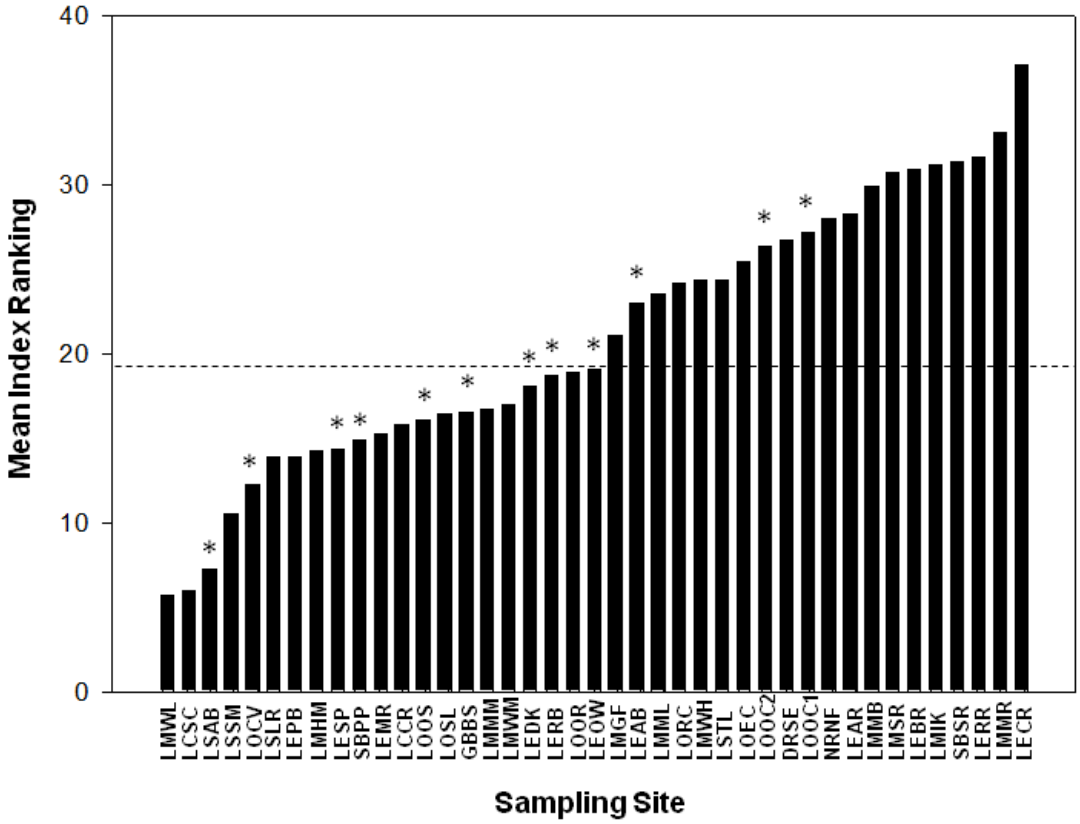

Fig. 1. Mean ranking of all sampling sites based on the five indices used to assess benthic community health. Based on the indices used, the higher the ranking the more degraded the community An asterisk (*) denotes Reference sites. The dashed line indicates the median ranking.