# The Nearshore Benthic Invertebrate Community of Southern Lake Michigan and its Response to Beach Nourishment.

Nearshore L. Michigan benthic invertebrate community

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**ABSTRACT.** The nearshore benthic environment of Lake Michigan represents a dynamic and little studied habitat. To explore the biology and response of this community to beach nourishment, Ponar samples were taken at 1.5, 3, and 6 m depths at 10 transects along the southern shore of Lake Michigan. Forty taxa were identified, and two of these, *Chaetogaster diastrophus* and Nematoda, made up over 81% of all organisms collected. Shallow sites ($\leq$ 3 m) were generally dominated by *C. diastrophus* and Nematoda, and these sites represent communities adapted to constant wave induced sediment disturbance. Deep (6 m) sites were generally dominated by Nematoda, but fair numbers of *C. diastrophus*, *Amphichaeta leydigi*, *Paracladopelma* spp., and other less abundant taxa were identified. Greater diversity at deeper sites may be related to the stability resulting from reduced wave disturbance. A notable decrease in mean invertebrate density ($P < 0.01$) from 2001 to 2002 downdrift from the site of beach nourishment suggests that sand placement affected invertebrate populations, although a more thorough understanding of this community's response to environmental variables is required to further support this conclusion.

**INDEX WORDS:** Lake Michigan, sand, beach nourishment, macrobenthos, meiobenthos, Mt. Baldy.

# INTRODUCTION

The present day coast of the southern tip of Lake Michigan represents a dynamic aquatic ecosystem. Sediment, which consists primarily of sand, is pushed predominantly south along the eastern and western shores by wind and waves, converging along the Indiana shoreline (Chrzastowski and Thompson 1994). While the lake basin serves as a sink for some of these sediments, roughly half are deposited on the beaches and dunes of southern Lake Michigan (Colman and Foster 1994). Along the southern shore, weather influences the movement, sorting, and deposition of aquatic sediments (Thompson 1989), and severe weather may impact the nearshore area to depths of 25 m (Booth 1994).

Construction of breakwaters in Michigan City Harbor, Indiana, has trapped or diverted much of the sand that would otherwise move west along the shoreline (Shabica and Pranschke 1994). This interruption of the sediment transport cycle has caused the beaches of Indiana Dunes National Lakeshore, which lie west of Michigan City Harbor, to become sediment starved and to suffer erosion. Nourishment with sediments transported from other areas is a common solution to beach erosion (Peterson et al. 2000), and sand has been deposited on the beaches of the Indiana Dunes for more than two decades (Felicia Kirksey, U.S. Army Corps of Engineers, personal communication on 2 Jan, 2003). Most recently, in mid-August of 2001, the Corps of Engineers deposited roughly 33,000 $m^3$ of sand at Mt. Baldy, a popular tourist destination at the east end of the Indiana Dunes.

The habitat in the study area is fairly homogenous, being composed chiefly of shifting sand with little organic matter, although in some areas sediment starvation has caused the exposure of underlying clay. These nearshore sand communities have received little attention (Whitman et al. 1994, Horvath et al. 2001), but work has been done on benthos in deeper offshore waters of southern Lake Michigan (Nalepa and Quigley 1983, Nalepa et al. 1998). The effects of beach nourishment on benthos has also received little attention (Peterson et al. 2000), and no references to research on the effects of beach nourishment on freshwater invertebrates were found. The 2001 beach nourishment site at Mt. Baldy, Indiana Dunes National Lakeshore was used to survey the biology of the wave-impacted, nearshore benthic community and to investigate its response to beach nourishment.

# METHODOLOGY

Ten transects extending approximately perpendicular to the shoreline were selected, each with sampling sites at the 1.5, 3, and 6 m depth contours (Fig. 1). All were within 400 m of shore. One sample was collected from each of the 30 sites using a petite Ponar sampler (225 $cm^2$) on 31 July 2001 and 9 Aug 2002. A Garmin GPS III Plus was used to relocate transects and sites the second year of the study. Most samples contained only sand, although a few contained sand mixed with fine silt or clay. Samples were stored in lake water in plastic sample jars for roughly two hours before further processing was done in the laboratory. To separate invertebrates from sediments, samples were swirled rigorously to suspend invertebrates in the sample water and this water was poured through a 106 µm mesh sieve (Horvath et al. 2001). Tap water was added to samples, the above procedure was repeated two more times, and organisms retained by the sieve were preserved with 90 % ethanol.

Final separation of invertebrates from remaining sediment was done in gridded counting dishes. Due to their abundance, nematodes and oligochaetes were sometimes subsampled prior to enumeration. For nematodes, a random number table was used to select ten squares from which they were picked and enumerated. For oligochaetes, random squares were chosen and picked until at least 50 intact organisms were found, and these organisms were identified. Invertebrates were separated from remaining sediment under magnification using an Olympus SZ60 stereo-microscope and were identified using an Olympus BH2 compound microscope. Glycerine jelly was used as a general-purpose mounting medium, and when more permanent mounts were desired, CMCP-10 was used. When necessary, chironomid heads were cleared using a 50% solution of lactic acid.

Although plankton was occasionally collected, only benthic animals were included in the analysis. Nematodes (phylum Nematoda), flatworms (order Microturbellaria), leeches (class Hirudinea), water bears (phylum Tardigrada), aelosomatids (family Aelosomatidae), clams (family Sphaeriidae), ostracods (class Ostracoda), and mites (order Acariformes) were left at these taxonomic levels for analysis. Oligochaetes were identified to species using Kathman and Brinkhurst (1999), copepods were identified to species using Hudson and Lesko (2002), and chironomids were identified to genus according to Coffman and Ferrington (1996). An unidentified species of harpacticoid copepod resembling the marine *Heteropsyllus nunni* was found (Horvath et al. 2001, Hudson and Lesko 2002) and this taxon will be referred to as *Heteropsyllus* sp. hereafter. Number of individuals $sample^{-1}$ was converted to number of individuals $m^{-2}$ and is hereafter reported as mean $m^{-2}$ ± SE.

The outflow of Kintzele Ditch lies within the study area (Fig. 1), so it was deemed important to gauge its flow relative to the sampling years. Because no monitoring station exists on this stream, the flow of Trail Creek, which flows into Lake Michigan only 1.5 km further east, was used for comparisons under the assumption that discharge from the two streams would be roughly proportional due to the proximity of their watersheds. Analysis of the variation in offshore wind speed and wave intensity between the two years was also undertaken using data collected from Station 45007 of the National Data Buoy Center, National Oceanic and Atmospheric Administration.

SPSS v. 11.5 was used for comparative statistics (SPSS 1999), and data were $\text{Log}_{10}$ (x + 1) transformed to meet the assumption of normality. ANOVA with Tukey's b as a post hoc test and independent samples T-tests were used when data met assumptions of normality and equal variance; when either of these were violated, non-parametric equivalents were used. Spearman's rho or Pearson's correlation coefficient were used when correlations were investigated depending on whether data could be normalized. Primer v. 5 was used to compute Shannon-Wiener diversity and Pielou's evenness values (Clarke and Warwick 1994, Clarke and Gorley 2001).

## RESULTS AND DISCUSSION

### Community characterization

Booth (1994) noted that depths to 5 m are influenced by wave action during normal weather conditions, and depths up to 25 m can be influenced during severe weather. Much of the present study area, particularly the 1.5 and 3 m sites, lies within the depth range that would be continually disturbed by wave action, thus allowing only the most disturbance-tolerant organisms to persist. In other wave-impacted areas of the Great Lakes, benthic communities relate to exposed rock or macrophytes (Barton and Carter 1982). The constantly shifting sands of southern Lake Michigan, however, provide little natural, permanent structure to which benthic organisms can attach or relate, thus limiting species diversity.

Forty taxa were identified in this study, and their densities, maximum occurrence, and relative abundances are presented along with total invertebrate density (Table 1). Total invertebrate densities ranged from a minimum of 356 individuals $m^{-2}$ in 2002 to a maximum of 79, 360 invertebrates $m^{-2}$ in 2001, although most measurements were above 15, 000 individuals $m^{-2}$. These densities are low compared to some studies that sampled further offshore (Nalepa and Quigley 1983) but within the range commonly reported for the nearshore zone of the Great Lakes (Barton and Carter 1982, Barton and Griffiths 1984). Two taxa, *Chaetogaster diastrophus* and Nematoda, dominated the nearshore benthic environment, with relative abundances of most other taxa less than 1%. Whitman et al. (1994) noted the occurrence of only nematodes and oligochaetes in the swash zone of a beach at the southern tip of Lake Michigan, and these taxa represented over 90% of the organisms collected at ≤ 3 m in this study.

Mean density, diversity, number of taxa, and taxa evenness at 1.5, 3, and 6 m depths were calculated for both 2001 and 2002 (Table 2). In 2001 positive correlations between depth and diversity ($P < 0.01$), number of taxa ($P < 0.01$), and taxa evenness ($P < 0.05$) were significant, and while 2002 densities appeared to decrease with increased depth, this correlation was not significant. Many taxa exhibited either statistically significant or apparent depth preferences (Table 3). Relative abundance of nematodes increased from 21.4% at shallow sites to 51.5% at the 6 m site, while that of *C. diastrophus* decreased to 15.3% as depth increased. Another oligochaete, *Amphichaeta leydigi*, increased in relative abundance from less than 1% at shallow sites to 12.2% at 6 m sites. The oligochaetes *Piguetiella blanci*, *P. michiganensis*, *Paranais frici*, *Vejdovskyella intermedia*, *Uncinais uncinata,* and tubificids were only collected at 6 m depths. The increase with depth seen among oligochaetes and other benthic invertebrates suggests that the wave-induced disturbance of the shallows constrains the number of taxa that can persist in this environment, and this relationship has been observed in other studies (DeFelice and Parrish 2001).

The shift from a shallow community dominated by *C. diastrophus* and Nematoda to a deeper (6 m) community in which dominance is shared among a greater number of taxa is noteworthy. Considering that many taxa identified in this study are part of the detrital food web (Thorp and Covich 1991, Coffman and Ferrington 1996), the increased stability afforded by deeper water may indirectly bring about this community shift by permitting a slightly greater accumulation of organic matter. Significant correlations between amount of detritus and abundance of copepods, oligochaetes and chironomids have been observed in deeper waters (11 – 17 m) of southern Lake Michigan (Nalepa and Quigley 1983), offering further support to the idea that lack of organic matter may influence nearshore community composition.

### ***Exotic species***

Among the copepods identified in this study, *Nitocra hibernica*, *Heteropsyllus* sp., and *Schizopera borutzkyi* are non-native taxa that have invaded the Laurentian Great Lakes (Horvath et al. 2001, Hudson and Lesko 2002), and *Heteropsyllus* sp. has maintained its dominance of the copepod community at this study site. *Schizopera borutzkyi*, which was nearly as numerous as *Heteropsyllus* sp. in 2001, declined in 2002 samples, while *N. hibernica* was not identified in 2002. Whether this indicates a shift from a community co-dominated by *Heteropsyllus* sp. and *S. borutzkyi* to one dominated solely by *Heteropsyllus* sp. is unknown at this time. Horvath et al. (2001) noted that *Heteropsyllus* sp. was more abundant in shallower sites (< 9m) than *S. borutzkyi*, and year-to-year population variation may play a role in the shift in dominance noted in 2002. Hudson and Lesko (2002) label the *Heteropsyllus* sp. found in the Great Lakes as *Heteropsyllus nunni*, but due to pronounced differences in body shape and fifth leg morphology, this is likely incorrect (Judith Williams, University of Southern Mississippi, personal communication, 25 Jan, 2003). To prevent confusion, the authors suggest that the species be hereafter referred to as *Heteropsyllus* sp. until it is either positively identified or, if new to science, described.

## Nourishment effects

Mean invertebrate density in 2001 prior to beach nourishment was 27, 360 ± 2547 m$^{-2}$, and this was significantly higher ($P < 0.01$) than the mean density of 10, 556 ± 2354 m$^{-2}$ seen the following year. Additionally, the 11.4 ± 0.7 taxa identified per site in 2001 were significantly more ($P < 0.01$) than the 7.6 ± 0.6 identified in 2002. Differences in Shannon-Weiner diversity and taxa evenness between years were not significant. There were no significant differences in density between transects in 2001 (ANOVA; $P > 0.05$), although differences between transects in 2002 were significant (ANOVA; $P < 0.05$). When log transformed density at each transect was compared between years, significant differences ($P = 0.05$) were seen at transects 2 and 5-9, and a bar graph comparing densities at individual transects in both years illustrates these decreases (Fig. 2). Densities of most taxa were lower in 2002, and these differences were significant for nematodes ($P = 0.05$ at transects 1,2,5,6,7,8, and 9), *C. diastrophus* ($P = 0.05$ at 5 and 8), Sphaeriidae ($P \leq 0.05$ at 4, 6, 7, and 9), *S. borutzkyi* ($P < 0.05$ at 5), *Acanthocyclops brevispinosus* ($P < 0.05$ at 5 and 6), Microturbellaria ($P < 0.05$ at 3 and 7), *Paracladopelma* spp. ($P = 0.05$ at 6 and 9) and *Chironomus* spp. ($P < 0.05$ at 7 and 9). Significantly fewer taxa were identified in 2002 at transects 1, 8, 9 ($P = 0.05$), and 7 ($P < 0.05$).

The nearly threefold decline in mean density between 2001 and 2002 suggests substantial changes in the benthic community between the two years. Greatest year-to-year declines were noted at transects 5-9, and while densities of many taxa decreased, nematodes, *C. diastrophus*, and *Paracladopelma* spp. declined the most. Transects 5-9 in 2002 had a significantly higher evenness measure ($P < 0.01$) compared to other transects for that same year and also a higher evenness measure compared to the previous year, and this was likely due to decreases in dominant taxa in 2002 that allowed Pielou's evenness metric to reflect less numerous taxa.

The observed decrease at transects 5-9 in 2002 may signify the negative influence of beach nourishment. Wind and wave action generally push sand toward the southwest along our study area (Chrzastowski and Thompson 1994), so sediments deposited on the beach would be pushed across transects 2-10 (Fig. 1). Sand deposited in Aug and Sept of 2001 may have migrated west across the study area, with significant impact measured from transects 5 through 9. The lowest density in 2002 was measured at transect 6, and disturbance by moving sand may have decreased further west as deposited sands mixed with native sands or moved further offshore. It is possible that transect 3 or 4 may have been impacted earlier during the year as deposited sands migrated across them, but recolonization may have occurred prior to sampling in Aug 2002. Interestingly, while densities at 1.5 and 3 m sites decreased by roughly 50 % in 2002, densities at 6 m sites decreased by nearly 75 % (Table 2). The disproportional decrease in density at deeper sites from 2001 to 2002 is not presently understood.

If beach nourishment is the cause of the decreases in invertebrate density noted at transects 2 and 5-9, the precise mode of influence remains unclear. Considering that the substrate is the most important factor governing the composition of benthos, differences in grain size may have altered the substrate characteristics enough to limit the ability of some taxa to persist (Thorup 1964). Sand used to nourish Mt. Baldy was sourced from Aggregate Industries in Kalamazoo, MI, and although the grain size distribution of sands used for nourishment was not available, the acceptable grain size range allows for nourishment sediments that are considerably coarser than native sands (Fig. 3). Data on movement of deposited sediments in the study years and changes in mean grain size of nearshore sands were not available, and these data may provide the background necessary to understand better the impact of beach nourishment on the benthic invertebrate community.

Three potentially confounding factors were identified during the course of analysis, including the presence of subsurface clay formations in the area of sampling, the potentially differing effects of wind and waves against the shoreline between the two years, and the effects of a stream that empties into Lake Michigan in the study area. Just offshore of the beach, underlying clay mounds and trenches are sometimes exposed, and these formations have a benthic community distinct from that found in surrounding sands (R. L. Whitman, unpublished data). The clay formations are at their greatest level of exposure and complexity between transects 3 and 8, which conforms fairly well to the pattern of disturbance noted in 2002. Clay was only encountered in one sample in each year however, so it is unlikely that these clay formations caused the observed changes in the invertebrate community. Further, a permanent feature of the shoreline such as this would be expected to impact invertebrate samples equally in both years.

The action of wind and waves against the shoreline maintains the instability of bottom sediments, and differences between years in wind or wave action could confound this analysis. Based on data from Station 45007, a weather buoy in Lake Michigan, shoreward wind speed, wind direction, wave height, and wave direction were averaged by month and compared between years, and no significant differences were seen between 2001 and 2002 ($P > 0.05$). It is thus unlikely that meteorological variation alone caused the decrease in invertebrate density observed in 2002.

Recent water analysis by the U.S. Environmental Protection Agency found elevated levels of boron and molybdenum in a tributary of Kintzele Ditch (Kenneth Theisen, U.S. EPA, personal communication, 3 Feb 2003). While contaminated water being discharged into the study area by the stream is not a likely cause of the observed decreases in density, excessive siltation associated with increased stream discharge may contribute. Data including sediment loading and chemistry were not available for the Kintzele Ditch watershed, although discharge rates of Trail Creek, a neighboring stream whose watershed borders that of Kintzele Ditch, were acquired. Mean daily discharge rates for Trail Creek are presented (Fig. 4), and mean monthly discharge rates compared between years. February and August discharge rates showed no significant difference between years ($P > 0.05$), while discharge rates were significantly higher in 2002 in April and May ($P < 0.01$) and lower in 2002 in June and July ($P < 0.01$). Our lack of data on contaminant and sediment loading within the study area makes it impossible to assess the influence of Kintzele Ditch on the nearshore invertebrate community.

## Conclusions

Two main communities within the nearshore area were apparent in this study. The shallow water benthic community, seen at the 1.5 and 3 m sites, endures nearly constant disturbance by wave action and is dominated by *C. diastrophus* and to a lesser extent Nematoda, and *Paracladopelma* spp. with other less common taxa identified. The deeper community, seen at 6 m sites, is dominated by Nematoda with *C. diastrophus*, *A. leydigi*, and *Paracladopelma* spp. being subdominant and many other taxa identified, and the increased diversity is likely due to an increase in the habitat's stability. A negative impact on invertebrate densities in the nearshore sand community was noted in 2002, and the present analysis suggests that beach nourishment, stream outflow, or a combination of the two may have contributed to this effect. Many gaps remain in the understanding of the nearshore benthic community, however, and perhaps this study will prompt further investigation of this dynamic, yet poorly understood ecosystem.

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***TABLE 1. Mean and maximum densities and relative abundances (%) of taxa collected from the nearshore zone in 2001 and 2002. Densities of bolded taxa differed significantly between years at the P < 0.05 level.***

| | 2001 | | | 2002 | | |
|---|---|---|---|---|---|---|
| Taxa | Mean ± SE | Maximum | Rel. abund. | Mean ± SE | Maximum | Rel. abund. |
| **Nematoda** | **9519.9 ± 1171.2** | 21511.1 | 34.8 | **1798.5 ± 463.8** | 13066.7 | 17.04 |
| **Tardigrada** | **13.3 ± 7.1** | 177.8 | 0.05 | | **0** | |
| Hirudinea | 17.8 ± 10.9 | 311.1 | 0.06 | 56.3 ± 22.9 | 577.8 | 0.53 |
| Aelosomatidae | 294.8 ± 124.3 | 2666.7 | 1.08 | 42.9 ± 27.2 | 800 | 0.41 |
| *Amphichaeta leydigi* | 842.9 ± 294.2 | 5511.1 | 3.08 | 499.3 ± 228.4 | 5155.5 | 4.73 |
| ***Chaetogaster diastrophus*** | **12902.2 ± 2457.9** | 60666.6 | 47.16 | **7066.7 ± 2352.8** | 60799.9 | 66.95 |
| *Nais variabilis* | 102.2 ± 44.5 | 888.9 | 0.37 | 65.2 ± 30.9 | 800 | 0.62 |
| *Paranais frici* | 77.0 ± 40.9 | 1022.2 | 0.28 | 1.5 ± 1.5 | 44.4 | 0.01 |
| *Piguetiella blanci* | 4.4 ± 4.4 | 133.3 | 0.02 | 1.5 ± 1.5 | 44.4 | 0.01 |
| *Piguetiella michiganensis* | 26.7 ± 26.7 | 800 | 0.1 | | 0 | |
| ***Uncinais uncinata*** | | **0** | | **69.6 ± 36.9** | 800 | 0.66 |
| *Vejdovskyella intermedia* | 31.1 ± 21.6 | 488.9 | 0.11 | | 0 | |
| Tubificidae | 14.8 ± 11.1 | 311.1 | 0.05 | 8.9 ± 7.5 | 222.2 | 0.08 |
| **Microturbellaria** | **600.0 ± 146.2** | 3555.6 | 2.19 | **71.1 ± 31.4** | 666.7 | 0.67 |
| **Sphaeriidae** | **585.2 ± 140.9** | 3777.8 | 2.14 | **74.1 ± 25.6** | 533.3 | 0.7 |
| Ostracoda | 5.9 ± 3.5 | 88.9 | 0.02 | | 0 | |
| ***Acanthocyclops brevispinosus*** | **53.3 ± 11.4** | 222.2 | 0.19 | **65.2 ± 53.2** | 1600 | 0.62 |
| *Diacyclops nanus* | | 0 | | 2.9 ± 2.1 | 44.4 | 0.03 |
| *Eucyclops agilis* | 4.4 ± 3.3 | 88.9 | 0.02 | 1.5 ± 1.5 | 44.4 | 0.01 |
| *Paracyclops chiltoni* | 1.5 ± 1.5 | 44.4 | 0.01 | | 0 | |
| ***Nitocra hibernica*** | **50.4 ± 29.5** | 844.4 | 0.18 | | **0** | |
| *Canthocamptus robertcokeri* | 11.9 ± 4.2 | 88.9 | 0.04 | 11.9 ± 7.4 | 177.8 | 0.11 |
| ***Heteropsyllus nunni*** | **293.3 ± 118.5** | 3244.4 | 1.07 | **56.3 ± 23.6** | 577.8 | 0.53 |
| *Schizopera borutzkyi* | 204.4 ± 125.6 | 3777.8 | 0.75 | 2.9 ± 2.1 | 44.4 | 0.03 |
| Acari | 2.9 ± 2.1 | 44.4 | 0.01 | 4.4 ± 2.5 | 44.4 | 0.04 |
| *Apedilium* spp. | 2.9 ± 2.9 | 88.9 | 0.01 | | 0 | |
| *Axarus* spp. | 4.4 ± 3.3 | 88.9 | 0.02 | 1.45± 1.5 | 44.4 | 0.01 |
| ***Chironomus* spp.** | **189.6 ± 41.2** | 755.6 | 0.69 | **14.8 ± 5.8** | 133.3 | 0.14 |
| ***Cladotanytarsus* spp.** | **69.6 ± 21.7** | 400 | 0.25 | | **0** | |
| *Cryptochironomus* spp. | 31.1 ± 10.3 | 177.8 | 0.11 | 23.7 ± 7.9 | 133.3 | 0.22 |
| *Heterotrissocladius* spp. | 16.3 ± 6.6 | 133.3 | 0.06 | 14.8 ± 6.2 | 133.3 | 0.14 |
| *Monodiamesa* spp. | 7.4 ± 6.1 | 177.8 | 0.03 | 7.4 ± 3.7 | 88.9 | 0.07 |
| *Orthocladius/Cricotopus* spp. | | 0 | | 1.5 ± 1.5 | 44.4 | 0.01 |
| *Parachironomus* spp. | | 0 | | 1.5 ± 1.5 | 44.4 | 0.01 |
| ***Paracladopelma* spp.** | **968.9 ± 161.6** | 3911.1 | 3.54 | **487.4 ± 73.7** | 1733.3 | 4.62 |
| *Polypedilum* spp. | 75.6 ± 30.5 | 755.5 | 0.28 | 63.7 ± 23.4 | 622.2 | 0.6 |
| *Psectrocladius* spp. | 317.0 ± 144.6 | 3288.9 | 1.16 | 32.6 ± 8.8 | 177.8 | 0.31 |
| *Robackia* spp. | 0 | 0 | | 4.4 ± 3.3 | 88.9 | 0.04 |
| *Tanypus* spp. | 0 | 0 | | 1.5 ± 1.5 | 44.4 | 0.01 |
| ***Tanytarsus* spp.** | **16.3 ± 8.4** | 222.2 | 0.06 | | **0** | |
| **Total** | **27,360 ± 2547** | 79,911 | | **10,556 ± 2354** | 63,510 | |

***TABLE 2. Mean ± SE invertebrate density, Shannon diversity, number of taxa, and Pielou's evenness in 2001 and 2002 by depth. Bolded values differed significantly (P < 0.05) between years.***

| | **2001** | | | **2002** | | |
|---|---|---|---|---|---|---|
| | **1.5 m** | **3 m** | **6 m** | **1.5 m** | **3 m** | **6 m** |
| **Density** | **25164 ± 4439** | **31387 ± 5706** | **25529 ± 2782** | **12884 ± 5892** | **12258 ± 3515** | **6524 ± 1945** |
| **Diversity** | 0.99 ± 0.09 | **1.10 ± 0.10** | 1.44 ± 0.13 | 0.94 ± 0.14 | **0.72 ± 0.10** | 1.33 ± 0.09 |
| **Number of taxa** | 8 ± 1 | **11 ± 1** | **15 ± 1** | 7 ± 1 | **6 ± 1** | **10 ± 1** |
| **Species evenness** | 0.47 ± 0.03 | 0.46 ± 0.03 | 0.54 ± 0.03 | 0.48 ± 0.06 | 0.44 ± 0.08 | 0.61 ± 0.03 |

***TABLE 3. Mean densities m$^{-2}$ ± SE by depth of taxa with relative abundances > 0.05%. Bolded taxa exhibited depth preferences that were statistically significant at the $P < 0.05$ level.***

| | 1.5 m | 3 m | 6 m |
|---|---|---|---|
| **Nematoda** | **2464.4 ± 524.1** | **6264.4 ± 1484.4** | **8248.9 ± 1612.2** |
| Aelosomatidae | 377.8 ± 180.9 | 100.0 ± 51.4 | 28.9 ± 24.6 |
| **Hirudinea** | **62.2 ± 21.7** | **44.4 ± 31.1** | **4.4 ± 3.1** |
| ***Amphichaeta leydigi*** | **13.3 ± 13.3** | **37.8 ± 27.6** | **1962.2 ± 435.6** |
| ***Chaetogaster diastrophus*** | **14191.1 ± 3502.2** | **13317.8 ± 3157.4** | **2444.4 ± 1052.2** |
| ***Nais variabilis*** | **60.0 ± 43.8** | **8.9 ± 6.1** | **182.2 ± 63.0** |
| ***Paranais frici*** | **0** | **0** | **117.8 ± 59.8** |
| *Piguetiella michiganensis* | 0 | 0 | 40.0 ± 40.0 |
| ***Uncinais uncinata*** | **0** | **0** | **104.4 ± 54.2** |
| *Vejdovskyella intermedia* | 0 | 0 | 46.7 ± 32.2 |
| **Tubificidae** | **0** | **0** | **35.6 ± 19.2** |
| Microturbellaria | 642.2 ± 212.3 | 251.1 ± 85.9 | 113.3 ± 42.8 |
| Sphaeriidae | 266.7 ± 86.2 | 380.0 ± 120.7 | 342.2 ± 186.9 |
| *Acanthocyclops brevispinosus* | 111.1 ± 79.2 | 40.0 ± 12.9 | 26.7 ± 10.9 |
| *Nitocra hibernica* | 2.2 ± 2.2 | 13.3 ± 6.5 | 60.0 ± 44.1 |
| *Canthocamptus robertcokeri* | 2.2 ± 2.2 | 6.7 ± 3.6 | 26.7 ± 11.4 |
| ***Heteropsyllus* spp.** | **8.9 ± 5.2** | **46.7 ± 19.5** | **468.9 ± 168.5** |
| ***Schizopera borutzkyi*** | **11.1 ± 7.1** | **37.8 ± 11.3** | **262.2 ± 188.6** |
| *Chironomus* spp. | 26.7 ± 11.8 | 148.9 ± 47.9 | 131.1 ± 47.7 |
| ***Cladotanytarsus* spp.** | **0** | **22.2 ± 13.9** | **82.2 ± 29.8** |
| *Cryptochironomus* spp. | 6.7 ± 3.6 | 33.3 ± 13.6 | 42.2 ± 12.3 |
| *Heterotrissocladius* spp. | 8.9 ± 6.9 | 13.3 ± 7.9 | 24.4 ± 8.2 |
| *Paracladopelma* spp. | 580.0 ± 70.6 | 977.8 ± 219.2 | 626.7 ± 152.9 |
| ***Polypedilum* spp.** | **22.2 ± 11.4** | **15.6 ± 7.4** | **171.1 ± 48.8** |
| ***Psectrocladius* spp.** | **142.2 ± 123.8** | **40 ± 18.2** | **342.2 ± 182.0** |

## List of Figures

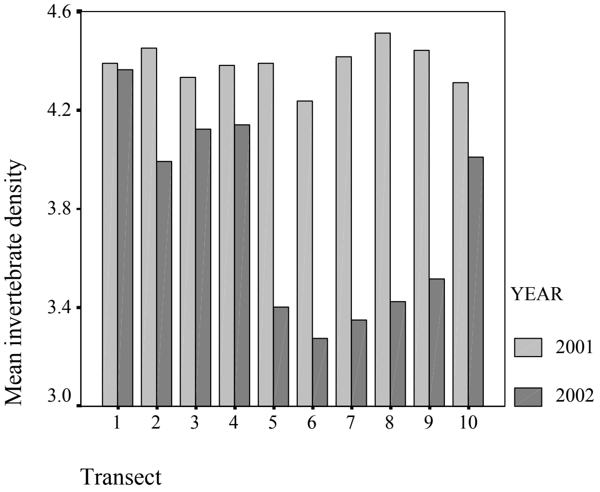
***FIG. 1. Samples were collected along labeled transects at the 1.5, 3, and 6 m depth contours, and beach nourishment occurred in the crosshatched area.***

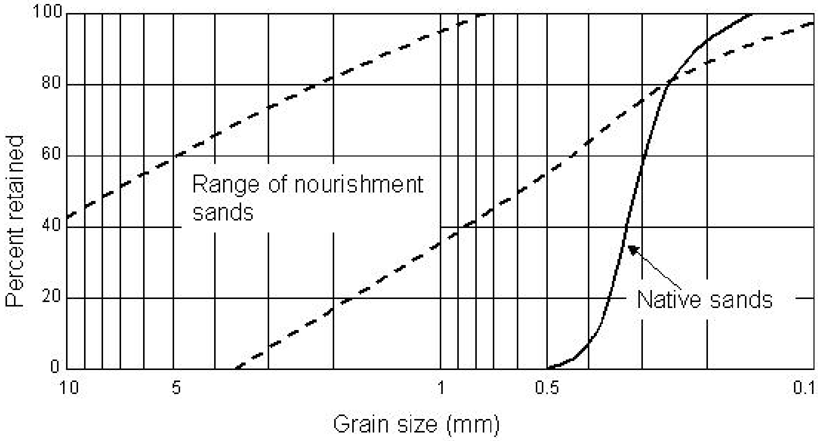
***FIG. 2. Log*** $_{10}$***(x+1) transformed mean invertebrate densities at each transect in 2001 and 2002. Differences in density were significant (P = 0.05) at transects 2 and 5-9.***

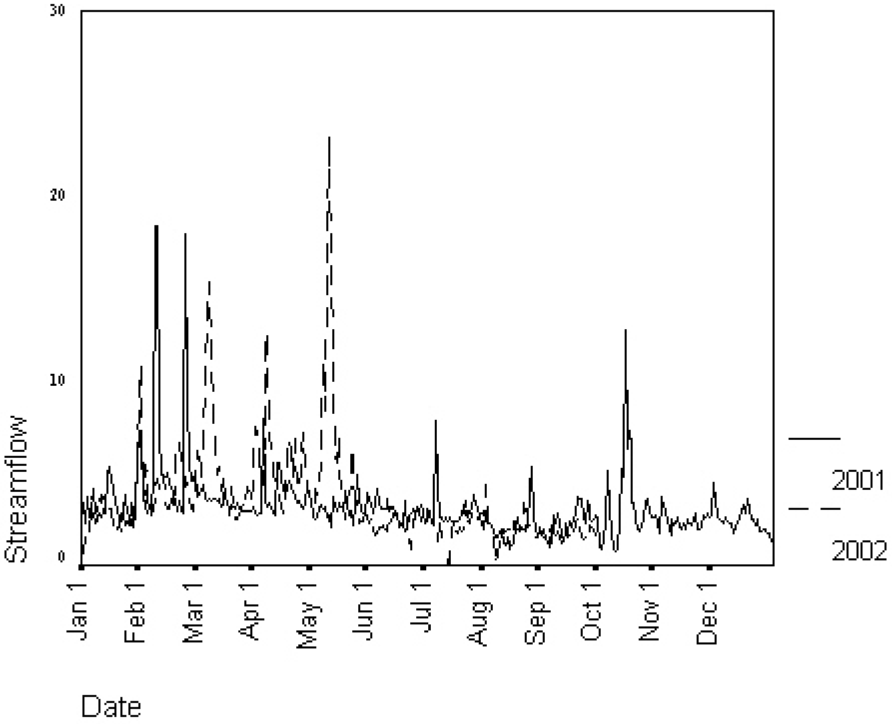
***Fig. 3. Grain size distribution of native beach sands (Wood 1983) plotted over the range of grain sizes used for beach nourishment (area between dotted lines).***

***FIG. 4. Discharge rates (*** $m^3\ sec^{-1}$***) at Trail Creek, a stream that discharges into Lake Michigan roughly 1.5 km east of Kintzele Ditch.***


Lake Michigan
Michigan City, IN
N
1
2
3
4
5
6
7
8
9
10
Trail Cr.
Michigan City Harbor
Michigan City
Kintzele D.
0
1
2
kilometers


4.6
4.2
3.8
3.4
3.0
Mean invertebrate density
1
2
3
4
5
6
7
8
9
10
Transect
YEAR
2001
2002


100
80
60
40
20
0
Percent retained
10
5
1
0.5
0.1
Grain size (mm)
Range of nourishment sands
Native sands


30
20
10
0
Streamflow
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Date
2001
2002