The effects of shooting range lead shot on the sand-dwelling animals in the near shore waters of Lake Michigan

A Report Submitted to

City of Chicago
Department of the Environment

Submitted by

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Executive Summary:

In an attempt to determine the effects of lead shot on sand dwelling animals, Lake Michigan sands were surveyed in areas impacted by the Lincoln Park Gun Club and a control area. Lead shot accumulated over years of gun club activity in the Lincoln Park area of Chicago has been buried in the Lake Michigan sands at the clay sand interface. The effects of the presence of this lead shot on benthic meiofauna were studied by collecting surface grab sand. Community composition was determined statistically, and no significant differences were found in either total counts or composition between the two locations. Based on data from the surface sands, we failed to show that buried lead shot is having an effect on the sand-dwelling animals.

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Background/Scope:

The presence of lead contamination in aquatic ecosystems may have direct negative effects on organisms at many trophic levels (Di Giulio and Scanlon 1985,US EPA 1986, Naqvi and Howell 1993, Scheuhammer and Norris 1996). In some aquatic systems, lead pellets (shot) from shooting ranges or hunting activity are a significant source of lead (Di Giulio and Scanlon 1985, Harza 1995, Scheuhammer and Norris 1996). Studies implicate lead shot in waterfowl poisonings through ingestion (Di Giulio and Scanlon 1985, Scheuhammer and Norris 1996) and increased lead content in aquatic plants (Behan et al. 1979). While there is some information about the effect of lead in sediments on macroinvertebrates (invertebrates over 1 mm in length), there is almost no information on the effect on animals typical of the relatively clean submerged sands characteristic of the Great Lakes. The submerged sands of Lake Michigan are dominated by benthic animals called meiofauna. This group of animals primarily inhabits the interstices of the sand and is largely defined by its size range: 42 to 1000 microns (Higgins and Thiel 1988). Although the interstitial meiofauna dominate the bottom community in submerged sands (Nalepa and Quigley 1983), little is known about their occurrence and distribution. Coull and Palmer (1984) showed that both diversity and density of meiofauna, especially microcrustacea, decreased when habitats were perturbed. Little is known about the vertical distribution of meiofauna in freshwater sands. Whitman and Clark (1984) showed that meiofauna commonly occur to depths of 30 cm below the water in sandy streams, and Whitman et al. (1994) demonstrated that sand meiofauna is abundant a meter or so below the surface of exposed beach sands of southern Lake Michigan.

From 1912 to 1991, Lincoln Park Traps, Inc. operated trap and skeet shooting at a site on the shore of Lake Michigan north of the Diversey Harbor mouth in Chicago. During that time, approximately 2,700 metric tons of lead shot were discharged over the lake. Visual examination by divers in 1992 did not detect lead shot on the lake bottom. Subsequent coring revealed shot in 6.5 ha of sandy bottom sediments offshore of the Lincoln Park Gun Club site. Shot was concentrated below 0.6 to 3 m of sand at the interface between sand and clay sediment layers, and the thickest shot stratum was found approximately 73 m offshore. A study by Harza (1995) determined that nearshore sediments were polluted with total lead and lead shot, but the two parameters were not related. Lead shot could not be related to any other laboratory analysis. Supernatant lead and Toxicity Characteristic Leaching Procedure (TCLP) lead concentrations were generally low, indicating low levels of soluble lead salts in the sediment. Sediment supernatants occasionally exceeded the Lake Michigan lead water quality standard, but overlying water failed to demonstrate toxicity using *Photobacterium phosphoreum* (Microtox®). The Microtox® test measured the toxicity of the supernatant liquid on one bacteria species in a laboratory setting over limited exposure time. It is difficult to extrapolate these results to the long-term toxic effect on the natural aquatic taxa, particularly invertebrates living on and in the sediment under ambient physical and chemical conditions. Lead contamination may influence benthic invertebrates through both chronic and acute toxic effects (Naqvi and Howell 1993). Aquatic habitats with differing levels of heavy metal contamination can have significant

differences in the benthic macroinvertebrate community composition (Hart et al. 1986) and significant correlations between benthic macroinvertebrate populations and heavy metal content of the sediment (Yu et al. 1994). Benthic invertebrates are an important food web link in most aquatic habitats, and changes in the benthic invertebrate community have ramifications for the entire ecosystem. The importance of the benthic invertebrate community and its susceptibility to heavy metal toxicity make it an important study subject for evaluating the toxic impact of lead shot from the Lincoln Park Gun Club.

Objectives:

1. To examine the occurrence, distribution, and composition of benthic animals in areas containing lead shot and unimpacted nearshore areas of Lake Michigan.
2. To identify biological effects of existing lead shot on the benthic animals in the near-shore community.
3. To quantify the amount of lead and the texture and organic content in the surface sediments of the control and affected areas.
4. To relate the lead concentration in the sediments to community characteristics of benthic animals in the control and affected areas.

Approach/methods:

Statistical design

An impact-control design was used to determine if the presence of excessive lead shot in the nearshore sediments has had or is having a biological effect on the benthic fauna. This design consisted of identifying an area expected to have lead shot contamination (impact area) and an area that has not been contaminated by lead shot (control area). These areas were identified based on previous core sampling done in the area (Harza 1995). The control area was located as near as possible to the impact area because we wanted to minimize differences in community composition attributed to abiotic factors other than lead (e.g., sediment composition, hydrodynamic conditions). Benthic fauna samples were compared statistically between the control and impacted area with a Students t-test. Statistical power (i.e., the ability of the test to detect a difference based on sample variance) was calculated for quality assurance (Wilkinson 1997). Community parameters are regressed on lead concentration to examine their relationship. In all cases, assumptions of the tests were checked and data transformations applied where appropriate. Data are stored in spreadsheet form (Microsoft Excel).

Sampling

A control area and a treatment area were determined based on previous sampling in the area (Harza 1992). The treatment site was located directly offshore from the Lincoln Park Gun Club shooting range. Cores sampled by Harza (1992) indicated that this area was contaminated with lead pellets. The control area was located north of the treatment area. This site was updrift of the treatment site and thus minimized the chances that lead would be found in this area.

Each sampling area was divided into a grid system, and each compartment of the grid was assigned a Cartesian coordinate. A random number generator was used to choose which compartments would be sampled. Because an exact sampling site could not be determined randomly within the compartment, a sampling site was arbitrarily selected within the randomly selected compartment. Thus, we approximate as closely as possible a random sampling design within each sampling area.

Samples were collected on 7 December 1999. Sampling compartments were located with the use of a map, and precise location of the sampling site was determined using a GPS unit. At each

site, a ponar grab (225 cm^2) was dropped to the sediment surface. Samples were retrieved and deposited into a collecting basin. Excess water was poured through a 106-:m sieve, and the collected sediments were transferred to sterile plastic sampling bags. Animals and sediment from the sieve were also washed into the sampling bags. Samples were kept in coolers until processing in the laboratory.

In the laboratory, samples were elutriated using the protocol outlined in Whitman et al. (1983, 1994). Briefly, this method requires transferring the sediments to a large container, adding 500 ml of distilled water, hand-agitating the sediments, then carefully decanting the overlying water through a 106-:m sieve. This procedure is repeated three times, each time checking for larger organisms (e.g., mollusks and chironomid midge larvae) that would not be entrained in the water. These organisms were hand-picked from the container. The collected animals and sediments then were transferred to a petri dish, where they were preserved in Lugols solution until counting.

Identification and enumeration of the organisms was done under 25X magnification. Some organisms had to be mounted on microscope slides for identification under a compound microscope. Specialist taxonomic keys were used for identification (Fitzpatrick 1983, Balcer et al. 1984, Pennak 1989, Thorp and Covich 1991, Hudson et al. 1998). Identifications of unique organisms (e.g., benthic crustaceans) were confirmed by taxonomic experts.

Statistics

Primer (version 4.0, Carr 1996) was used to calculate community indexes for meiofauna data. Primer calculates Shannon-Wiener diversity index (H′, called Shannon diversity from here) as $-\Sigma_i\, p_i(\log p_i)$, where p_i is the proportion of the total count arising from the *i*th taxon. Margalef's index (d) is calculated as $d = (S-1)/\log N$, where S is the number of taxa and N is the total number of individuals. Margalef's index is an index of taxa richness. Evenness is Pielou's evenness index calculated as H′(observed)/ H'_{max}, where H'_{max} is the maximum possible diversity achieved if all species were equally abundant (Clarke and Warwick 1994). A two-sample t-test was used to compare means of indices between the control and treatment areas. Homogeneity of variance and normality were checked for each index, and only evenness and total individuals had to be $\log_{10}$ transformed to conform to the assumptions of the t-test (Sokal and Rohlf 1981). Because transformations were successful, we used the pooled variance $\forall$ for all tests. Because multiple t-tests were performed, we applied the Dunn-Sidak adjustment to the p-value (Wilkenson). In addition to the community indices, counts of the dominant taxa classes were tested as above. All statistics were performed using SYSTAT (version 7.0, SPSS Inc., Chicago).

Results

Community indices

No measure of the community showed a significant difference between the means of the control and treatment areas (Table 1, but see also Table 2). Looking at each measure separately, the mean number of families encountered in both the areas was just slightly greater than 6, and ranged from 3 to 9 in the treatment and 4 to 9 in the control (Figure 1). The total number of individuals ranged from 9 to 225 in the treatment area. This corresponds to densities of 400 to 10,000 individuals m^{-2}. In the control area, total individuals ranged from 11 to 448, or 488 to 19,900 individuals m^{-2} (Figure 2). Three control samples were outliers in the analysis for Margalef's index (Figure 3), which likely were the result of low total individuals and high total family since Margalef's index takes both parameters into account. Results were the same even when these outliers were removed. Shannon diversity was similar between the two areas, but it varied slightly more in the control area (Figure 4). In general, taxa were distributed evenly in samples (Figure 5). Samples that displayed rather low evenness scores tended to be dominated by a single species, often Nematoda or Dreissenidae.

Major taxonomic groups were also analyzed, but in all cases, the data were $\log_{10}+1$ transformed to correct for heteroscedasticity, which was probably caused by the high occurrences of zeros in the data set. Similar to the community indices, the taxa groups showed no significant differences between the control and treatment areas (Table 1; Figures 6-9).

Crustaceans and nematode worms comprised nearly 80% of the samples. Because of taxonomic difficulties in identification, Nematoda were not identified to family. Within the Crustacea, the copepods tended to be most numerous compared to the ostracods and amphipods. The cyclopoid copepods contained individuals that could be considered planktonic, or closely associated with near-sediment waters. Although these are not true benthic organisms, their close association with the sediments still makes them a relevant organism to include (Hudson et al. 1998). The oligochaete worms were represented by three families (see appendix) commonly encountered in the Great Lakes (Spencer 1979). The insects were represented largely by Chironomidae. When dreissenids were present in samples, they were often numerically dominant. This mollusk is often found in large druses (clumps of mussels held together with byssal threads secreted by the mussels within the clump), so when druses are encountered, many individuals often are collected together. Few gastropods were collected, but this is not unusual because these grazers tend to be found on larger substrates that are more stable than the sands observed in the study areas. However, snails were encountered, possibly using the occasional gravel that we encountered as substrate. Other organisms (e.g., tardigrads and water mites) were encountered only rarely in samples (Figure 10).

Most of the benthic animals encountered reside within or on the sediments. The possible exceptions are the gastropod and non-sphaeriid bivalves, which may move over the sediments but do not burrow into them. Among the insects, only the chironomids burrow into the sediments. The oligochaetes and nematodes will burrow throughout the sediments, feeding on the detritus among the interstices. The water mites (Acariformes) are known to move through the interstitial spaces feeding on detrital particles or capturing prey, depending on the mite species. The calanoid copepods may spend time near or on the sediments, but often they are

found in the water column, whereas the harpacticoid copepods are eubenthic and move throughout the interstitial spaces, feeding on detritus and microbes. The macrocrustaceans, amphipods, often can be a major consumer of detritus near or on the sediment surface. The animals that move through the sediments or consume detritus found within the interstices would be at the greatest risk of exposure to the lead.

In conclusion, the results of our examination of the top few centimeters of sediment revealed no significant difference between the test area and the control area. Benthic organisms were similar in the two locations.

Table 1. Results of two-sample t tests. Asterisks indicate that the data were $\log_{10}$ transformed before running the test.

Parameter	Pooled-variance t	df	Dunn-Sidak adjusted p-value
Number of families	1.031	48	0.788
Margalef's index	1.223	48	0.787
Shannon-Wiener index	0.532	48	0.996
Evenness *	0.235	48	1.000
Total individuals *	0.376	48	0.999
Total insects *	1.313	48	0.581
Total annelids *	0.060	48	1.000
Total nematodes *	0.948	48	0.819
Total crustaceans *	0.416	48	0.989

Table 2. The raw data from samples taken in control and treatment sites. T = treatment and C = control.

Site	Total families	Total individuals	Density ind./m^2	Margalef's index	Shannon-Wiener diversity index	Evenness
T1	6	19	819	1.70	1.58	0.88
T2	6	43	1853	1.33	1.27	0.71
T3	7	32	1379	1.73	1.73	0.89
T4	6	42	1810	1.34	1.35	0.75
T5	9	225	9698	1.48	0.86	0.39
T6	4	23	991	0.96	1.07	0.77
T7	5	18	776	1.38	1.19	0.74
T8	3	9	388	0.91	0.85	0.77
T9	9	65	2802	1.92	1.48	0.67
T10	8	51	2198	1.78	1.55	0.75
T11	7	39	1681	1.64	1.51	0.78
T12	7	54	2328	1.50	1.66	0.85
T13	6	62	2672	1.21	1.24	0.69
T14	6	15	647	1.85	1.58	0.88
T15	9	111	4784	1.70	1.02	0.46
T16	4	94	4052	0.66	0.64	0.46
T17	4	60	2586	0.73	0.52	0.38
T18	3	29	1250	0.59	0.82	0.74
T19	5	40	1724	1.08	1.31	0.81
T20	7	63	2716	1.45	1.54	0.79
T21	7	42	1810	1.61	1.55	0.79
T22	4	20	862	1.00	1.28	0.92
T23	7	97	4181	1.31	1.07	0.55
T24	6	31	1336	1.46	1.50	0.84
T25	6	29	1250	1.48	1.31	0.73
C1	6	52	2241	1.27	1.67	0.93
C2	5	32	1379	1.15	0.98	0.61
C3	7	95	4095	1.32	1.19	0.61
C4	6	32	1379	1.44	1.49	0.83
C5	6	47	2026	1.30	1.27	0.71
C6	5	37	1595	1.11	0.95	0.59
C7	8	135	5819	1.43	0.90	0.43
C8	6	25	1078	1.55	1.45	0.81
C9	9	60	2586	1.95	1.39	0.63
C10	6	53	2284	1.26	0.91	0.51
C11	6	32	1379	1.44	1.63	0.91
C12	5	110	4741	0.85	0.41	0.26
C13	7	58	2500	1.48	1.74	0.89
C14	5	19	819	1.36	1.13	0.70

C15	8	448	19310	1.15	0.68	0.33
C16	7	20	862	2.00	1.68	0.86
C17	4	14	603	1.14	1.24	0.89
C18	6	15	647	1.85	1.30	0.72
C19	6	42	1810	1.34	1.22	0.68
C20	7	67	2888	1.43	1.83	0.94
C21	7	138	5948	1.22	1.10	0.57
C22	6	36	1552	1.40	1.27	0.71
C23	8	79	3405	1.60	1.77	0.85
C24	8	11	474	2.92	1.97	0.95
C25	8	19	819	2.38	1.66	0.80

Figure 1. Number of families in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

Figure 2. Total number of individuals (log_{10} +1 transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

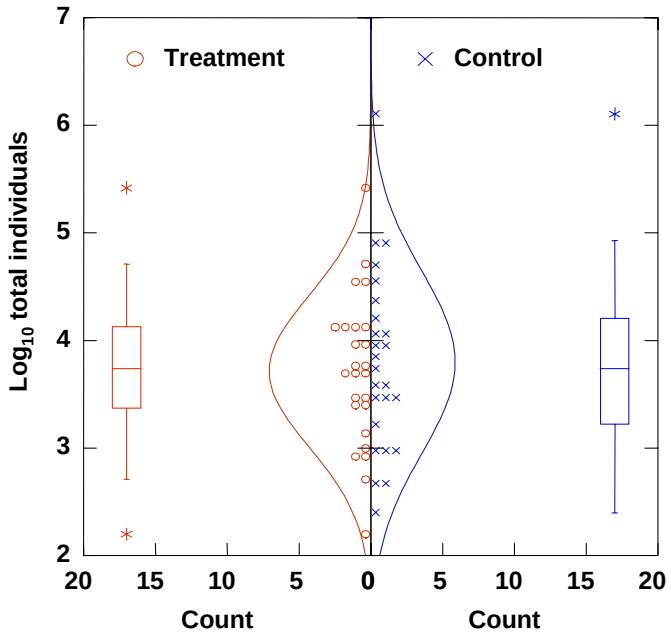


Figure 3. Margalef's index in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks, with far outside values indicated by open circles. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

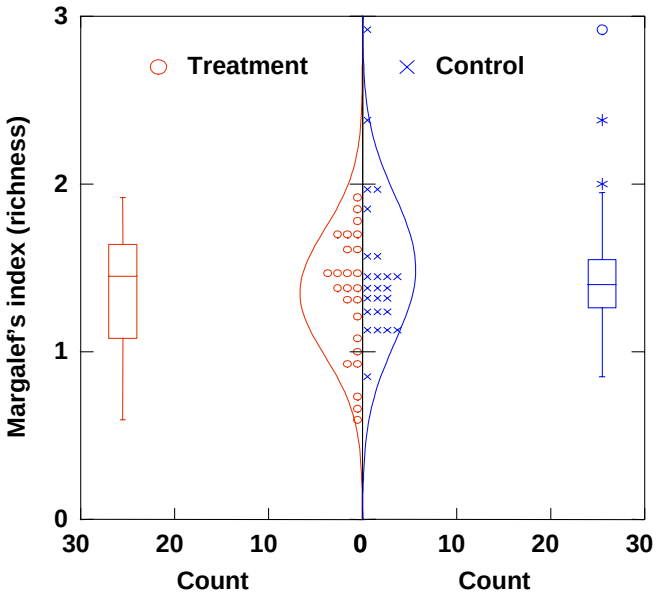


Figure 4. Shannon-Wiener diversity index in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

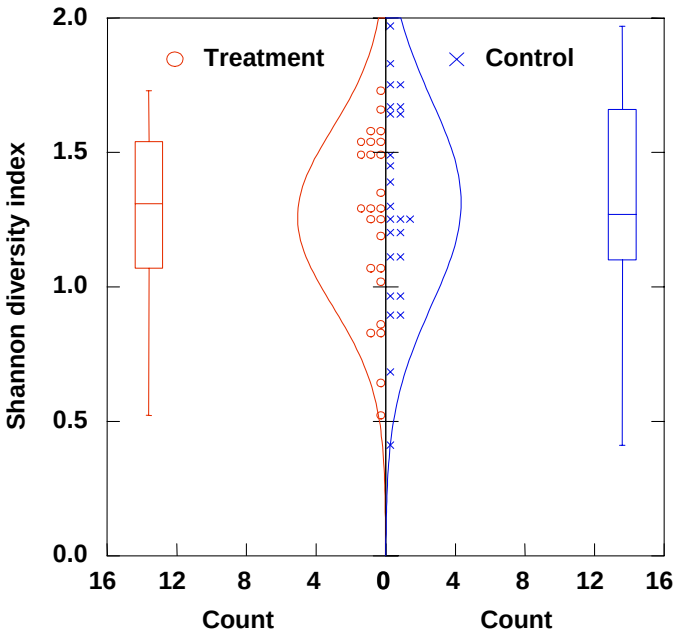


Figure 5. Evenness (log_{10} transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

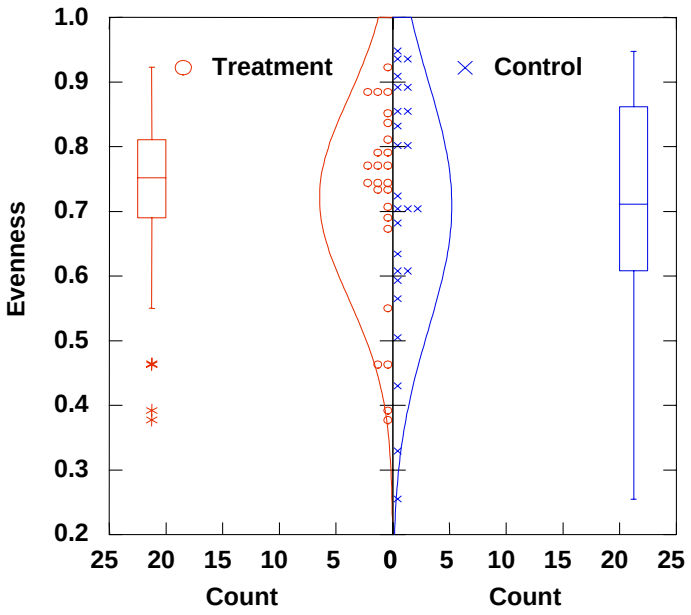


Figure 6. Total number of crustaceans (log_{10} transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

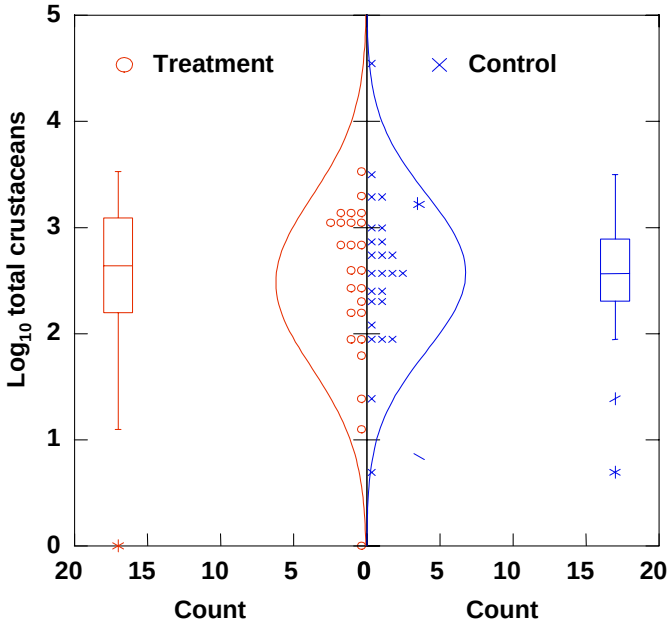


Figure 7. Total number of nematodes (log_{10} transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values, and outsider values are indicated by asterisks. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

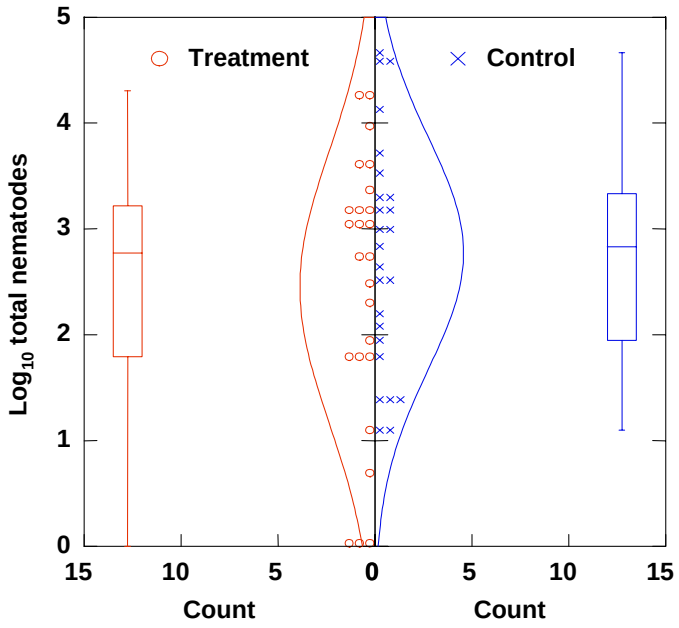


Figure 8. Total number of annelids (log_{10} transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

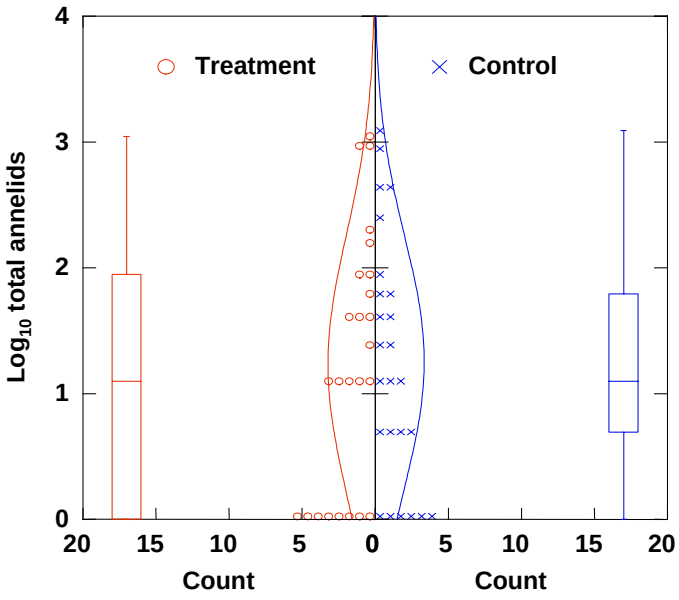


Figure 9. Total number of insects (log_{10} transformed) in the treatment versus the control site. The box plots show the sample median (central vertical line), and the range within which the central 50% of values fall (box length), with the box edges at the first and third quartiles. The whiskers show the range of values. A normal curve is displayed based on the sample mean and standard deviation, with individual observations shown as open dots (treatment) or x (control).

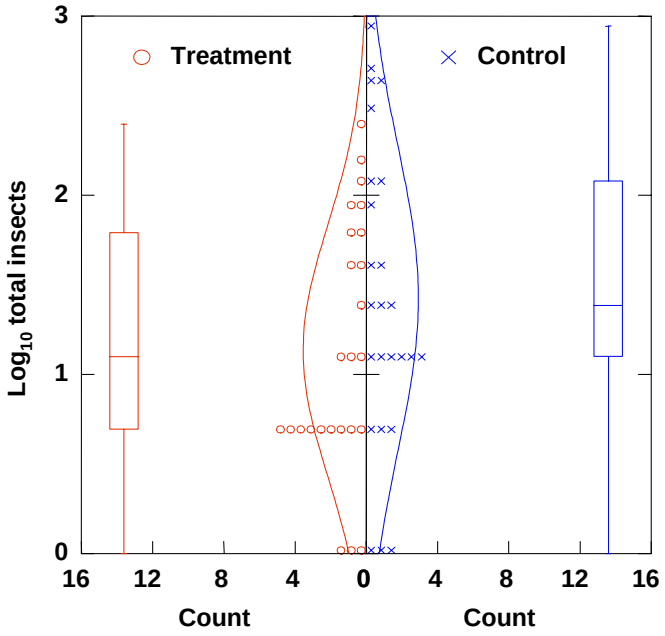
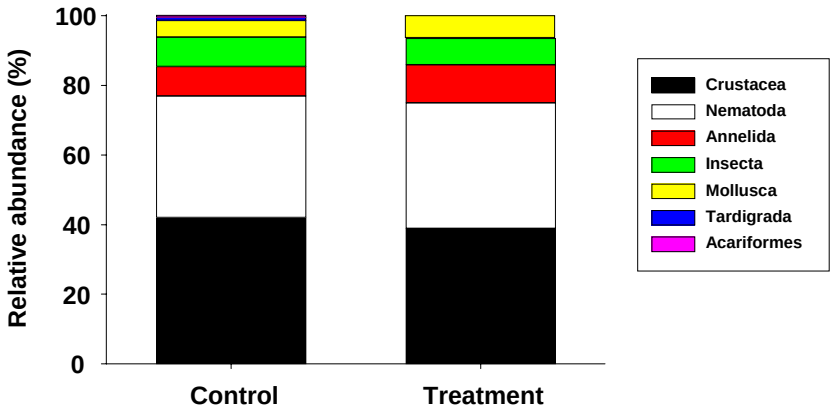


Figure 10. Relative abundance of the taxa groups collected in the control and treatment sites.



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Appendix. The abundance data of taxa from samples collected in the treatment (T) and control (C) sites. Numbers are raw counts.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25
Insecta																									
Chironomidae	1	1	2	8	0	0	1	1	2	7	2	5	10	1	0	1	3	6	1	6	1	4	4	1	4
Leptoceridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Acariformes																									
Torrenticolidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lebertidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea																									
Gammaridae	3	0	0	2	11	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Mollusca																									
Dreissenidae	0	0	0	0	29	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Sphaeriidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annelida																									
Tubificidae	0	2	3	0	2	0	0	2	4	1	1	2	2	0	2	18	1	0	16	5	3	0	0	14	0
Naididae	0	0	1	0	0	0	0	0	1	1	2	2	2	0	0	0	0	0	2	2	1	0	1	3	0
Naidid "buds"	0	0	5	0	0	0	0	0	1	0	1	2	0	0	0	0	4	0	1	1	0	0	2	1	0
Aeleosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Nematoda	2	24	5	23	0	0	9	0	37	20	20	23	36	5	1	73	52	20	14	28	11	6	68	5	15

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25
Insecta																									
Chironomidae	14	2	7	4	2	4	11	2	7	2	0	0	6	0	1	3	0	1	3	13	18	2	13	1	1
Leptoceridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acariformes																									
Torrenticolidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lebertidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Crustacea																									
Gammaridae	0	0	0	0	0	0	3	0	1	0	0	0	0	0	90	0	0	0	0	0	0	0	0	1	0
Mollusca																									
Dreissenidae	0	0	0	0	0	0	0	8	1	0	0	0	0	0	6	0	1	0	0	0	0	0	0	0	0
Sphaeriidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Annelida																									
Tubificidae	4	2	11	1	0	1	2	0	1	0	2	0	5	1	0	1	0	1	0	4	2	1	2	0	2
Naididae	3	0	4	0	3	2	0	0	1	0	3	0	0	1	0	0	0	0	0	2	4	2	3	0	0
Naidid "buds"	6	2	6	0	0	3	0	0	2	0	0	0	0	0	0	0	0	0	1	12	4	0	8	0	0
Aeleosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda	13	23	61	12	27	26	##	3	33	40	8	0	19	11	5	7	3	2	6	16	94	19	27	2	3