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Lake Superior Benthos: Cooperative Science and Monitoring Initiative

Final Report

U.S. Geological Survey
Cooperative Agreement USGS-GLRI G16AC00242

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MAJOR FINDINGS FROM THE CSMI BENTHIC MACROINVERTEBRATE SURVEY IN LAKE SUPERIOR IN 2016 WITH AN EMPHASIS ON TEMPORAL TRENDS

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INTRODUCTION

As part of the Coordinated Science and Monitoring Initiative (CSMI) in Lake Superior in 2016, a lake-wide benthic survey was conducted to assess the status of the benthic macroinvertebrate community with primary focus on the native amphipod *Diporeia*, Oligochaeta, Chironomidae, and Sphaeriidae.

Benthic surveys in Lake Superior were conducted in 1973 (lake-wide survey, Cook 1975), 1994, 2000, and 2003 (U.S. nearshore region, Scharold et al. 2004, Scharold et al. 2009). A dramatic increase in all major taxonomic groups was found in surveys conducted in 1994, 2000, and 2003 compared to the 1973 survey (Bronte et al. 2003, Scharold et al. 2009). The abundance of *Diporeia* in 2003 was five to eight times higher, and the abundance of Oligochaeta, Sphaeriidae (now Pisidiidae), and Chironomidae was two to three times higher than in 1973 (Scharold et al. 2009). The decline in benthivorous fish and the reduction of heavy metal loadings and siltation at the beginning of the 1980s were identified as possible reasons for the higher abundance of benthos found in later surveys (Cook et al. 1975, Bronte et al. 2003, Scharold et al. 2009).

In general, the U.S. nearshore benthic community was relatively stable in terms of abundance and composition between 1994 and 2003 (Scharold et al. 2009). The amphipod *Diporeia* was the dominant taxon of the benthic macroinvertebrate community in terms of density and biomass and was present at 99% of stations occupying the entire depth range sampled (18 to 139 meters). In 1994, nearshore *Diporeia* abundance ranged from 370 to 5507 m^{-2} with a mean **(**± SE**)** of 1,937 ± 224 m^{-2} and exceeded the ecosystem objective of at 220 to320 individuals m^{-2} for nearshore waters established by the Great Lakes Water Quality Agreement (GLWQA) of 1978 (IJC 1978, Scharold et al. 2004). In 2000, mean *Diporeia* abundance dropped by 35% and ranged from 7 to 2,782 m^{-2} with a mean (± SE) of 1,301 ± 141m^{-2}. Due to the drop in abundance, 11% of the stations did not meet the GLWQA requirements. Although the decline in *Diporeia* between 1994 and 2000 was statistically significant, in 2003 *Diporeia* abundance returned to levels similar to those in 1994 (Scharold et al 2009). Thus the *Diporeia* population in Lake Superior did not exhibit a progressive decline like those observed in other Great Lakes within the same time period (Dermott 2001, Nalepa et al. 2006, Watkins et al. 2007, Nalepa et al. 2009).

Between 1994 and 2003, Oligochaeta accounted for 22 to 27% of all organisms with *Stylodrilus heringianus* being the dominant oligochaete species (Scharold et al. 2009). Based on its trophic status *Stylodrilus heringianus* is indicative of oligotrophic conditions (Milbrink 1983). Clams accounted for 14 to 16% of total abundance between 1994 and 2003 with *Pisidium* being the only genus identified in the family Sphaeriidae (Scharold et al. 2009). Chironomidae accounted for 3 to 5% of total organisms with *Heterotrissocladius* being the dominant chironomid. Although *Dreissena* spp. had been confirmed in 2005 in the Duluth-Superior Harbor (Grigorovich et al. 2008) its abundance has remained very low and it apparently remains restricted to Duluth Harbor and the St. Louis River.

In 2016 a survey was conducted to examine the entire benthic community at randomly chosen nearshore stations, as well as at stations that were sampled previously in 1994-2003, which allowed a comparison with previous studies to assess changes of the nearshore benthic community in Lake Superior since 2003. Lake-wide trends in the entire benthic community have recently been examined in Lake Michigan (Nalepa et al. 2009), Lake Huron (Nalepa et al. 2007), Lake Ontario (Birkett and Lozano 2015), and Lake Erie (Burlakova et al. 2014). This report provides a summary of recent trends of major taxonomic groups (i.e. Oligochaeta, Sphaeriidae, and Chironomidae) with particular emphasis on *Diporeia*. More detailed analyses and discussion of trends, spatial patterns, and community composition, including comparisons to lake-wide surveys in the other Great Lakes, will be provided in other publications.

METHODS

Benthic samples were collected at 59 mostly nearshore (for this study identified as ≤ 100 m) stations in Lake Superior from August 31 through September 14, 2016 ranging from 18 to 143 m in depth (Table 1). Fourteen of these stations were located at ≤ 30 m depth, 40 stations at 31 - 100 m depth, and 5 stations were located at > 100 m depths. Of the 59 stations, 22 stations were located in the western part, 32 in the eastern part, and 5 in the northern part of the lake including Thunder Bay (Fig. 1).

Twenty-seven stations in the US nearshore waters of southern Lake Superior (LS94-76401 through LS94-111640) were previously sampled in 1994, 2000, and 2003 (Scharold et al. 2009). Selection of these 27 stations (referred in this report as "historical") followed a randomized, probability-based sampling design used in the Great Lakes Environmental Monitoring and Assessment Program (EMAP-GL) (Scharold et al. 2009). The remaining 34 stations (BE-01 through BE-56) were selected using a Generalized Random

Tesselation Stratified (GRTS) sampling design in 2016 and were not previously sampled. Some sites were outside this range due to depths being different than what was the bathymetry predicted, as well as deviations in ship positioning, and topography. The depth range of these sites was targeted based on results of previous studies which reported high *Diporeia* densities within the 30 to 100 m depth interval (Auer et al. 2013). Additionally, two stations (HN40 and HN50, Table 1) in the south central region near Houghton, MI characterized by previously high *Diporeia* densities (Auer et al. 2013) were sampled in 2016.

Sample procedures in 1994, 2000, 2003, and 2016 followed those of Nalepa (1987). In brief, benthic samples were taken in triplicate at each site with a Ponar grab (area in 2016 = 0.0523 m^2). Collected sediment s were washed through an elutriation device fitted with a 0.5-mm mesh net, and retained residue was preserved with neutral buffered formaldehyde with Rose Bengal stain to a final formalin concentration of 5-10%. Sample jars were labeled with the station designation, replicate number and date. Sampling depth and a general description of the sediments at each station were recorded on field data sheets. Methods are described in the EPA GLNPO Standard Operating Procedure for Benthic Invertebrate Field Sampling (SOP LG406, Revision 11, June 2016). In the lab, all organisms were picked and sorted into major taxa using a dissecting microscope following SOP for Benthic Invertebrate Laboratory Analysis (SOP LG407, Revision 09, April 2015). Amphipoda, Oligochaeta, Sphaeriidae (currently Pisidiidae), and Chironomidae constituted most of the benthos (98%). Occasional invertebrates such as leeches, mysids, gastropods, and flatworms were combined into a single category: other. Oligochaeta and Chironomidae were mounted on glass slides and identified to the lowest taxonomic level possible under a compound microscope. Amphipoda, Bivalvia, Gastropoda, and other organisms were identified using a dissecting microscope. Density per m^2 for each sampling station was determined by averaging counts from the three replicates and multiplied by the factor of 19.12. To determine biomass (wet weight) per m^2 for each sampling station organisms were blotted dry and weighed to the nearest 0.01 mg and the average of the 3 replicates was multiplied by the factor of 19.12. Density and biomass of the 2016 benthic community were compared among major taxa using same depth intervals as in surveys conducted in other Great Lakes: $\leq$ 30 m, 31-50 m, 51-90 m, and > 90 m. These depth intervals define distinct physical habitats that result in distinguishable benthic communities (Alley and Mozley 1975, Nalepa 1989).

For the analysis of temporal trends, our 2016 data (average density and biomass of major groups) were compared with results from the 27 stations sampled in 1994, 2000, and 2003 (Scharold et al. 2009). In 2016, no samples were taken at two of those stations (LS94-106330, LS94-109840). Station LS94-106330 was not sampled because it was unsafe for navigation due to bad weather, while station LS94-109840 was not sampled due to inability of Ponar to collect samples from hard substrate; hence only 25 stations were included in the analysis. A station-by-station comparison was done between 1994 and 2016 because only mean density values for the 2000 and 2003 sampling were provided. We used the old division of Oligochaeta by Enchytraeidae, Lumbriculidae, Naididae and Tubificidae, comparable with historical data, despite the fact that former families of Naididae and Tubificidae in the order Tubificida are now combined in one family, Naididae (Erseus et al. 2008). For consistency with historical data we also used the old division of *Pisidium* and *Sphaerium* within the family Sphaeriidae (now combined in one family Pisidiidae).

RESULTS AND DISCUSSION

In 2016, 67 taxa of benthic macroinvertebrates were identified during the CSMI study (Table 2). These included: six families of Clitellata; four families each of Malacostraca, Insecta and Gastropoda, one family each of Bivalvia, Hydridae, and Plagostomidae and one taxon in the phylum Nemertea. Density and biomass of major groups (*Diporeia*, Oligochaeta, Sphaeriidae, and Chironomidae) exhibited considerable variation among the 59 sampling stations with no consistent spatial trend (Fig. 2). The 2016 lake-wide total mean density (± standard error here and elsewhere unless noted) was 2176 ± 155 m^{-2} and total mean biomass was 3.65 ± 0.28 g m^{-2}. The total mean density and biomass changed significantly with depth, reaching its maximum at around 50 m and then declining (density: $P = 0.002$, biomass: $P = 0.001$, one-way ANOVA on log-transformed values, Fig. 3). The total mean density was significantly higher in the 31 to 50 m interval compared to the ≤ 30 m depth interval ($P = 0.02$, Tukey HSD post-hoc test) and higher than in the > 90 m interval ($P = 0.004$). Likewise, the total mean biomass was significantly higher in 31 to 50 m ($P = 0.003$, Tukey HSD test) compared to the ≤ 30 m depth interval. *Diporeia* was the dominant taxon in terms of density and biomass in all but the shallowest depths (≤ 30 m). Here, immature Oligochaeta were the most abundant taxa, and immature Lumbriculidae accounted for most of the biomass. As a glacio-marine relict *Diporeia* requires constant and colder temperatures below the thermocline and is therefore less abundant in shallow areas (Mozley and Howmiller 1977, Nalepa 1989). On the other hand, Oligochaeta can reach higher densities and biomass in the warmer and more productive nearshore zone (≤ 30 m depth interval). The spatial distribution pattern is comparable with previous studies in Lake Superior and other Great Lakes (Nalepa 1989, Scharold et al. 2009) and corresponds with depth-related changes in physical habitat characteristics (substrate, wave action) and food availability (Nalepa et al. 1989). Total benthos density and biomass were not significantly different between the eastern and western part of the lake ($P > 0.10$, one-way ANOVA).

In 2016, the amphipod *Diporeia* dominated the benthic community and was present at 54 out of 59 sampling stations (92%) ranging from 20 to 143 m in depth. Mean *Diporeia* density at all sampled stations was 1035

± 96 m^{-2} (range: 6 to 3518 m^{-2}), and mean biomass was 1.93 ± 0.21 g m^{-2}. Ninety four percent (57 out of 59) of the CSMI 2016 sampling stations had *Diporeia* densities exceeding GLWQA recommendations of 220 to 320 m^{-2} in nearshore areas of less than 100 m (IJC 1978). The GLWQA recommendations of 30 to 160 *Diporeia* m^{-2} were met for 100% of the five offshore stations (depths > 100 m), stations sampled in 2016. The two additional stations in the south central region near Houghton, MI were characterized by previously elevated *Diporeia* densities (simple mean average density (± standard deviation): 1143 ± 1311 between 2000 and 2009, Auer et al. 2013). At these two stations mean (± standard deviation) *Diporeia* densities were still high: 4,017 ± 196 m^{-2} at HN40 and 2059 ± 287 m^{-2} at HN50.

However, at the 25 historical nearshore stations resampled in 2016, *Diporeia* density declined by 59% compared to 2003 and was the lowest of all four previous surveys (837 ± 132 m^{-2}, Fig. 4). The proportion of those 25 stations that fell below GLWQA standards increased from 0% in 1994, to 10-15% in 2000 and 2003 (Scharold et al. 2009), and to 20% in 2016. *Diporeia* decline was statistically significant between 1994 and 2016 (paired t-test, $P < 0.001$). When *Diporeia* densities were compared at historical stations between 1994 and 2016, *Diporeia* declined at 95% of stations and it was not found at three stations (Fig. 5). At only one station, *Diporeia* densities were higher in 2016 than in 1994. In contrast to other Great Lakes, where significant *Diporeia* declines correlated well with the occurrence and spread of the invasive zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis*), dreissenids have not established in Lake Superior. According to previous studies, predation pressure of benthivorous fish may be a strong factor in Lake Superior affecting *Diporeia* abundance (Bronte et al. 2003, Scharold et al. 2009). In addition, results from previous surveys indicate that *Diporeia* can exhibit substantial inter-annual variability (Scharold et al. 2004, Scharold et al. 2009, Barbiero et al. 2011).

In 2016, Oligochaeta accounted for > 30% of the benthic macroinvertebrate assemblage of both density and biomass and were found at all 59 sampling stations. The dominant taxa among Oligochaeta were Lumbriculidae (average density: 151 ± 38 m^{-2}, biomass: 0.29 ± 0.07 gm^{-2}), followed by the tubificids *Spirosperma nikolskyi* (101 ± 32 m^{-2}, 0.17 ± 0.06 gm^{-2}) and *Spirosperma ferox* (94 ± 88 m^{-2}, 0.07 ± 0.06 gm^{-2}), and Enchytraeidae (70 ± 13 m^{-2}, 0.09 ± 0.02 gm^{-2}). Among Naididae, the most dominant was *Bothrineurum vejdovskyanum* (29 ± 22 m^{-2}, 0.03 ± 0.03 gm^{-2}). Lake-wide mean Oligochaeta density was 691 ± 78 m^{-2} (range: 6 to 2619 m^{-2}). At the 25 historical stations, mean Oligochaeta density declined by 25% in 2016 compared to 2003 (Scharold et al. 2009) and was the lowest of all four surveys (558 ± 91m^{-2}, Fig. 4). However, the decline between 1994 and 2016 was not significant (paired *t*-test, $p = 0.14$). When Oligochaeta densities were compared among the U.S. nearshore stations between 1994 and 2016, Oligochaeta declined at 68% of stations and increased in abundance at 32% of the stations (Figure 6). Most stations where Oligochaeta densities increased are located in shallow areas (≤ 30m) and these positive changes in abundance compared to 1994 may be indicative of trophic changes in the U.S. nearshore zone of Lake Superior.

In 2016, Sphaeriidae accounted for 16% of total density and 10% of total biomass. Sphaeriidae were present at 57 out of 59 (97%) of the sampling stations ranging from 18 to 143 m in depth. Lake-wide mean Sphaeriidae density was 357 ± 43 m^{-2} (range: 0 to 2039.5 m^{-2}). *Pisidium* sp. was the dominant genus (89%); *Sphaerium* sp. was less abundant (11%). At the 25 historical stations, the mean Sphaeriidae density in 2016 had declined by 40% compared to 2003 and was the lowest of all four surveys (309 ± 47 m^{-2}, Fig. 4).The decline in Sphaeriidae between 1994 and 2016 was marginally significant (paired *t*-test, p = 0.06). When Sphaeriidae densities were compared among the U.S. nearshore stations between 1994 and 2016, Sphaeriidae were absent at two stations during both surveys, and declined at 18 stations (78%) of the remaining 23 stations (Fig. 7). At 5 (22%) of the 23 stations Sphaeriidae density increased, however, in contrast to Oligochaeta, this increase was inconsistent with depth.

In 2016, Chironomidae accounted for 5% of total density and 2% of total biomass. Chironomidae were present at all 59 sampling stations ranging from 18 to 143 m in depth. Lake-wide mean Chironomidae density was 73 ± 11 m^{-2} (range: 6 to 223 m^{-2}). The dominant genus was *Heterotrissocladius* (22.5%) followed by *Paracladoplema* (19%), *Cryptochironomus* (12%), and *Micropsectra* (8%). At the 25 U.S. nearshore stations the 2016 mean Chironomidae density declined by 33% compared to 2003 and was the second lowest of the four surveys (86 ± 110 m^{-2}, Fig. 4). The change in Chironomidae density between 1994 and 2016, however, was not significant (paired *t*-test, p = 0.48), since they declined at 52% of the 25 US nearshore stations and increased in abundance at the rest (48%) of the stations. These changes, however, were inconsistent with depth (Fig. 8).

Lake-wide major taxonomic group composition in terms of density and biomass (Table 3) in 2016 were within the range of studies from the 1960s and 1970s which reported 22 to 80% *Diporeia* from total benthos density, 19 to 41% Oligochaeta, 0 to 24% Sphaeriidae, and 1 to 7% Chironomidae (Adams and Kreagear 1969, Hiltunen 1969, Cook 1975). The composition of the 2016 benthic community was similar to those at the historical stations (Table 4) in 1994, 2000 and 2003 (Scharold et al. 2009) when densities of *Diporeia* comprised from 50 to 61% of total benthos density, Oligochaeta comprised 22 to 27%, Sphaeriidae comprised 14 to 16%, and Chironomidae comprised 3 to 5%. This indicates that the benthic community composition in Lake Superior is relatively stable over time. However, high inter-annual variability of benthos abundance (and *Diporeia* in particular) and the lack of constant sampling intervals at historical stations in nearshore Lake Superior emphasizes the importance of maintaining long-term monitoring to better understand temporal trends in the benthic community. The decline in *Diporeia* abundance in 2016 compared to previous studies can potentially be an artefact of its high inter-annual variation, but calls for further investigations since the decreases in *Diporeia* in other Great Lakes have initially started from the nearshore areas (Nalepa et al., 2009). Although the GLNPO Biology Monitoring Program has been effective at detecting negative trends in *Diporeia* abundance in the past (Barbiero et al., 2011), only two of the 11 permanent GLNPO benthic stations in Lake Superior are at depths between 50 and 70 m known for its high *Diporeia* densities. Frequent monitoring of historical stations is essential to determine whether the 2016 change in *Diporeia* in Lake Superior is due to the high inter-annual variation or is a sign of decline as seen in the rest of Great Lakes.

SUMMARY

A lake-wide nearshore benthic survey was conducted in Lake Superior in 2016 as part of the Cooperative Science and Monitoring Initiative to assess the status of the macroinvertebrate community with particular focus on temporal trends. Benthic samples were collected at 59 nearshore stations, 25 of which were previously sampled in 1994, 2000, and 2003 (Scharold et al. 2009), and the rest were selected using a GRTS sampling design and were not sampled before. The most common benthic taxon by density in 2016 was *Diporeia* (48%), followed by Oligochaeta (32%), Sphaeriidae (16%), and Chironomidae (2%), which is comparable to the structure found in previous studies. Lake-wide, 94% of the 59 sampling stations in 2016 had *Diporeia* densities exceeding GLWQA recommendations. However we found a significant decline of *Diporeia* densities in 2016 compared to 1994 at 95% of the 25 previously sampled stations, and *Diporeia* were not collected at three of these stations. The proportion of the 25 historical stations that fell below GLWQA standards for *Diporeia* density increased from 0% in 1994 to 10-15% in 2000 and 2003 (Scharold et al. 2009), and to 20% in 2016. In contrast to other Great Lakes, *Dreissena* spp. have not established in Lake Superior and therefore cannot account for the decline in *Diporeia* abundance, suggesting that benthivorous fish predation or other environmental factors might have caused the changes. This apparent decline in nearshore *Diporeia* density could be an indication of a long-term trend of decreasing *Diporea* densities or could be a result of inter-annual variation, reinforcing the importance of frequent monitoring of historical stations to detect statistically significant temporal trends. Oligochaeta, Sphaeriidae and Chironomidae declined at some of the stations in 2016 compared to 1994, but the changes were not significant.

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Table 1. Depth and location of sampling stations in Lake Superior in 2016.

Station	Depth (m)	LAT	LONG	Substrate
BE-01	48.0	46.952667	-87.999281	90% fine sand, 10% clay
BE-02	35.5	48.322944	-88.945500	90% clay, 10% fine sand
BE-03	64.7	46.905420	-84.709037	33% mud, 33% clay, 33% fine sand
BE-04	47.0	46.929611	-90.268872	90% coarse sand, 10% clay
BE-05	18.0	46.510890	-86.942894	100% fine sand
BE-06	39.0	47.043518	-88.284370	80% sand, 20% clay
BE-07	27.0	46.800784	-85.273422	100% very fine sand
BE-08	45.5	46.872137	-89.587290	90% fine sand, 10% clay
BE-09	143.0	47.753774	-85.978797	95% clay, 5% fine sand
BE-10	40.0	47.154875	-88.868874	70% fine sand, 30% clay
BE-11	28.8	46.963498	-89.240443	98% sand, 2% clay
BE-14	19.7	46.804986	-84.581181	100% fine sand
BE-15	32.0	47.071060	-90.795157	65% fine sand, 35% clay
BE-16	46.9	48.888345	-87.877597	100% ooze
BE-17	27.0	46.525813	-87.170175	100% coarse sand
BE-18	53.9	47.289412	-87.948881	50% clay, 50% sand
BE-19	53.0	46.896655	-85.145020	90% sand, 5% clay, 5% organic matter
BE-20	54.0	46.771760	-90.549550	50% fine sand 50% clay
BE-21	64.3	47.903514	-85.401298	25% sand, 75% clay
BE-22	48.2	46.714582	-86.613108	50% pebbles/gravel, 50% coarse sand
BE-23	38.5	48.435049	-89.084576	100% clay
BE-24	52.0	46.816441	-91.776015	100% clay
BE-25	52.0	47.226638	-84.769170	30% clay, 70% sand
BE-26	63.3	46.729724	-84.952389	80% clay, 20% fine sand
BE-27	36.7	46.961177	-90.774563	100% ooze
BE-30	40.0	47.382791	-87.850361	98% clay, 2% coarse sand
BE-31	67.4	46.632070	-84.602476	100% ooze
BE-33	77.2	47.176770	-85.989647	50% pebbles, 20% clay, 30% fine sand
BE-34	31.8	46.990479	-88.097818	100% sand
BE-35	28.2	46.775790	-91.999989	Silt over clay
BE-36	43.7	46.688354	-90.421035	90% sand, 10% clay
BE-44	27.0	48.483547	-88.975228	98% clay, 2% gravel
BE-49	75.0	47.368246	-85.954070	90% clay, 10% gravel
BE-56	103.0	48.689583	-86.426680	100% ooze
LS94-104572	64.4	47.156000	-90.391533	15% clay, 5% gravel, 80% sand
LS94-104580	47.0	47.020467	-90.339733	80% sand, 20% clay
LS94-104581	106.0	46.884933	-90.287933	70% sand, 30% clay
LS94-104592	22.2	46.684333	-90.584333	905 fine sand, 10% clay
LS94-106311	96.1	47.291533	-90.450000	70% sand, 10% gravel
LS94-106322	32.8	47.090933	-90.740933	98% sand, 2% clay

Station	Depth (m)	LAT	LONG	Substrate
LS94-109860	27.6	46.823467	-91.384333	60% sand, 40% clay
LS94-111621	91.2	47.101200	-91.490933	45% clay, 55% woody debris
LS94-111640	26.0	46.756600	-91.725267	80% sand, 20% clay
LS94-76401	89.0	46.884333	-84.750600	98% ooze, 2% clay
LS94-77980	116.0	46.972267	-85.139733	30% fine sand, 70% clay,
LS94-77981	35.0	46.838553	-85.103000	90% fine sand, 10% clay
LS94-81171	27.0	46.736733	-85.806000	100% sand
LS94-82781	18.0	46.686133	-86.157200	70% coarse sand, 30% gravel
LS94-84412	40.2	46.492950	-86.842467	100% fine sand
LS94-87670	98.0	46.667467	-87.254200	30% sand over 70% clay
LS94-87671	30.0	46.524667	-87.207200	95% sand, 5% clay
LS94-90952	114.0	47.159600	-87.787933	95% sand, 5% clay
LS94-90961	44.4	46.886733	-87.692133	100% sand
LS94-92611	63.8	47.302400	-87.835533	90% coarse sand, 10% clay
LS94-92622	65.5	47.105400	-88.139133	50% sand, 50% clay
LS94-92630	51.0	46.969267	-88.090933	60% sand, 40% clay
LS94-97681	27.0	47.125267	-88.889733	100% gravel and sand
LS94-99391	84.0	47.069267	-89.239733	30% sand, 70% clay
LS94-99402	37.0	46.870467	-89.539133	85% sand, 15% clay
HN40	65.0	47.280462	-88.608810	No data
HN50	107.0	47.287765	-88.616547	No data

Table 2: Taxa found in benthic samples at 59 stations in 2016 CSMI Lake Superior

Class	Order	Family	Genus and Species
Bivalvia	Veneroida	Sphaeriidae	*Pisidium* sp.
			Sphaerium sp.
Malacostraca	Amphipoda	Pontoporeiidae	*Diporeia* sp.
		Hyalellidae	*Hyalella azteca*
	Mysida	Mysidae	*Mysis relicta*
	Isopoda	Asselidae	*Caecidotea* sp.
Clitellata	Lumbriculida	Lumbriculidae	*Stylodrilus heringianus*
	Haplotaxida	Enchytraeidae	*Enchytraeus* sp.
			Mesenchytraeus sp.
	Rhynchobdellida	Glossiphoniidae	*Helobdella elongata*
		Piscicolidae	*Piscicola geometra*
		Naididae	*Arcteonais lomondi*
			Isochaetides freyi
			Nais simplex
			Slavina appendiculata
			Stylaria lacustris
			Uncinais uncinata
			Bothrineurum vejdovskyanum
			Amphichaeta leydigi
		Tubificidae	*Limnodrilus hoffmeisteri*
			Limnodrilus profundicola
			Rhyacodrilus sp.
			Rhyacodrilus montana
			Rhyacodrilus sodalis
			Spirosperma ferox
			Spirosperma nikolskyi
			Thalassodrilus hallae
			Tubifex tubifex
Insecta	Diptera	Chironomidae	*Ablabesmyia* sp.
			Acalcarella sp.
			Chironomus sp.
			Corynocera sp.
			Cricotopus sp.
			Cryptochironomus sp.
			Dicrotendipes sp.
			Heterotrissocladius marcidus group
			Heterotrissocladius sp.
			Heterotrissocladius subpilosus group
			Micropsectra sp.

			Monodiamesa sp.
			Pagastia sp.
			Paracladopelma undine
			Paracladopelma winnelli
			Paratanytarsus sp.
			Polypedilum sp.
			Potthastia sp.
			Procladius sp.
			Protanypus sp.
			Pseudochironomus sp.
			Pseudodiamesa sp.
			Stempellinella sp.
			Stictochironomus sp.
			Tanytarsus sp.
			Virgatanytarsus sp.
		Diamesinae	*Diamesinae*
		Ceratopogonidae	*Ceratopogonidae*
	Trichoptera	Leptoceridae	*Oecetis* sp.
Gastropoda	Littorinimorpha	Amnicolidae	*Amnicola limosa*
	Hygrophila	Planorbidae	*Gyraulus parvus*
	Basommatophora	Physidae	*Physella* sp.
	Allogastropoda	Valvatidae	*Valvata lewisi*
			Valvata perdepressa
			Valvata tricarinata
Hydrazoa	Hydroida	Hydridae	*Hydra* sp.
Trepaxonemata	Neoophora	Plagostomidae	*Hydrolimax grisea*
Arachnida	Hydrachnidida		
Phylum: Nemertea			

Table 3. Lake-wide mean density (m^{-2}, ± standard error of the mean), biomass (g m^{-2}) and percent density and per cent biomass for major taxa collected at 59 sampling stations of Lake Superior in 2016

Major taxon	Density (m^{-2})	Biomass (g m^{-2})	% Density	% Biomass
Diporeia	1035±96	1.93±0.21	48	53
Oligochaeta	691±78	0.97±0.09	32	33
Sphaeriidae	357±43	0.35±0.05	16	10
Chironomidae	73±11	0.07±0.01	3	2
Other	21±4	0.10±0.02	1	3
Total	2176±155	3.65±0.28	100	100

Table 4. Mean density (No $m^{-2} \pm$ SE) and contribution to total density (%) of major taxonomic groups from 25 historical nearshore stations of Lake Superior sampled in 1994, 2000, 2003, and CSMI 2016. Data from 1994-2003 are from Scharold et al. (2009).

Taxon	1994 Density	1994 % Density	2000 Density	2000 % Density	2003 Density	2003 % Density	2016 Density	2016 % Density
Diporeia	1937±224	59	1300±250	51	2050±260	56	837±132	47
Oligochaeta	740±96	23	730±50	29	985±200	27	558±91	31
Sphaeriidae	500±95	15	400±80	16	510±90	14	309±47	17
Chironomidae	80±20	2	130±30	5	125±20	3	86±22	5
Total	3257±645	100	2560±276	100	3670±853	100	1812±207	100

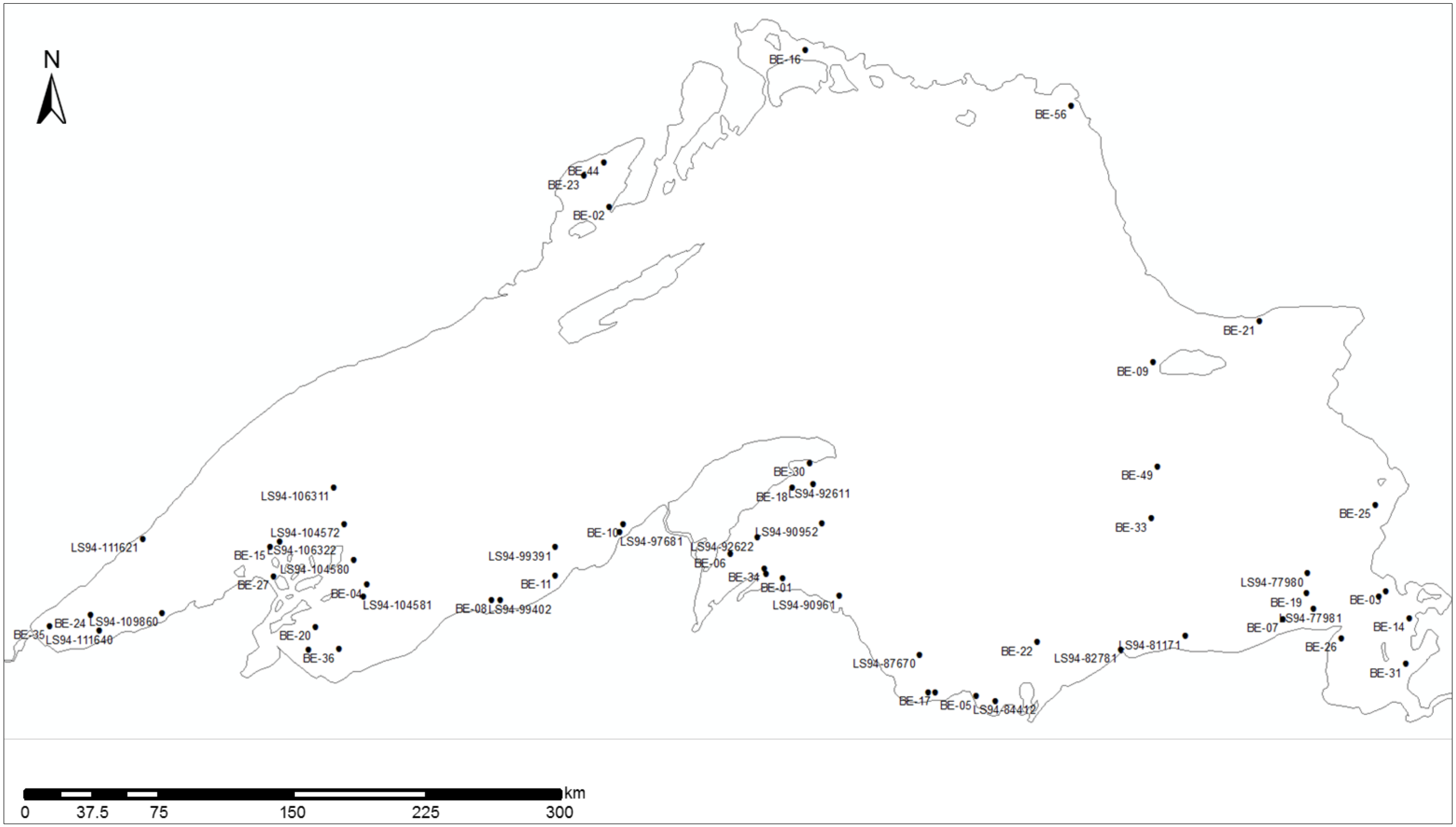
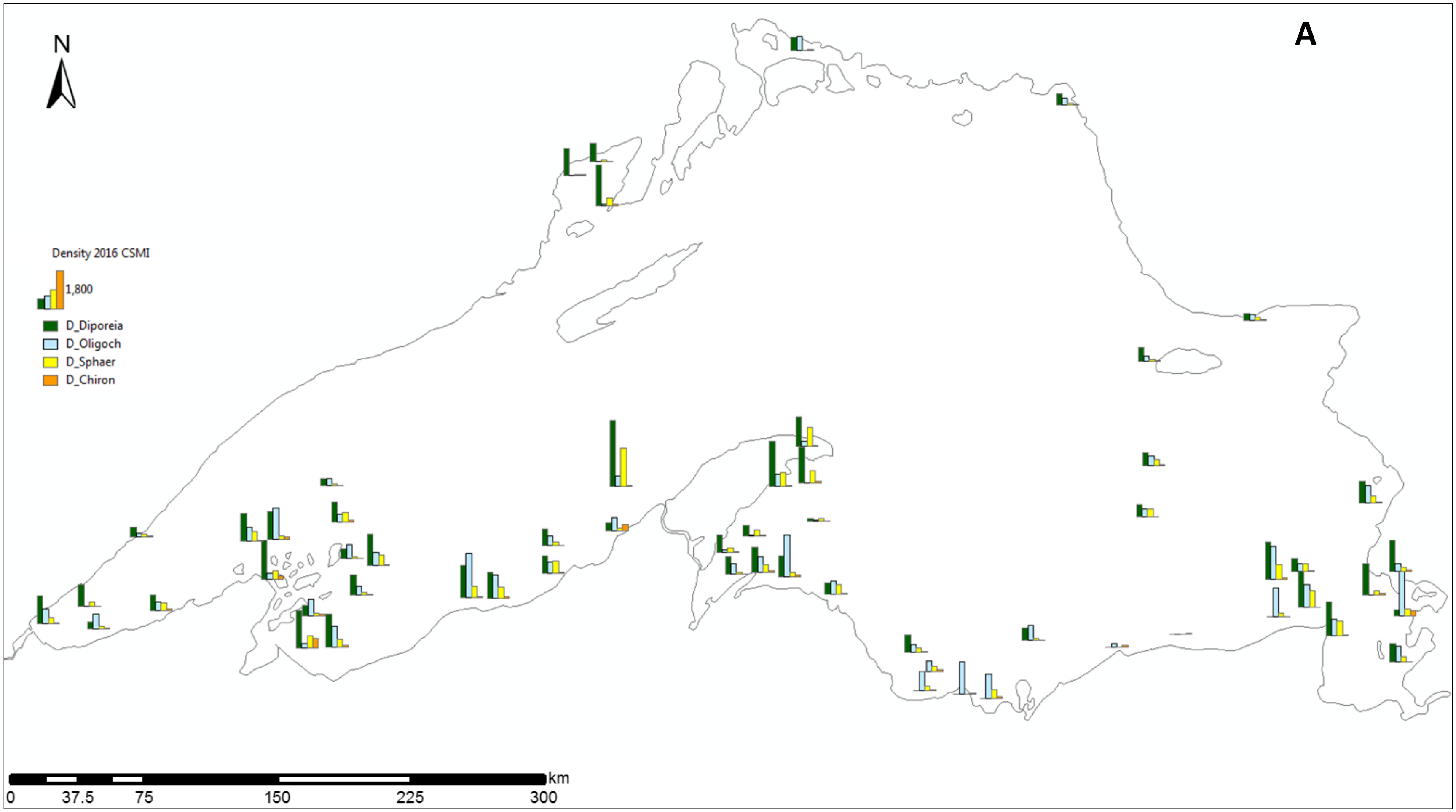


Figure 1. Location of sampling stations in Lake Superior in 2016. BE stations were chosen randomly, and LS94 stations were sampled previously in 1994, 2000 and 2003 (Scharold et al., 2009).


A
N
Density 2016 CSMI
1,800
D_Diporeia
D_Oligoch
D_Sphaer
D_Chiron
km
0
37.5
75
150
225
300

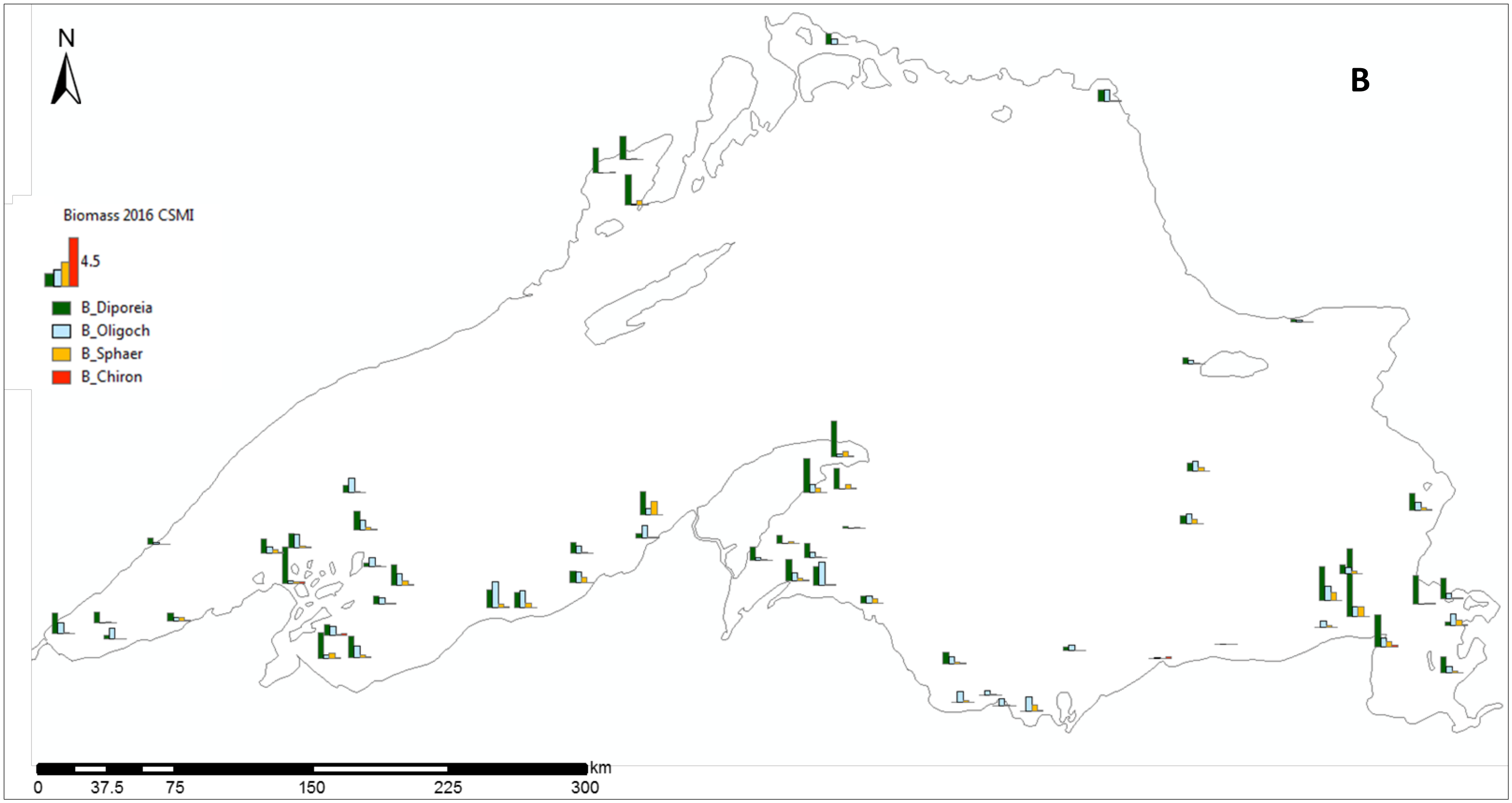
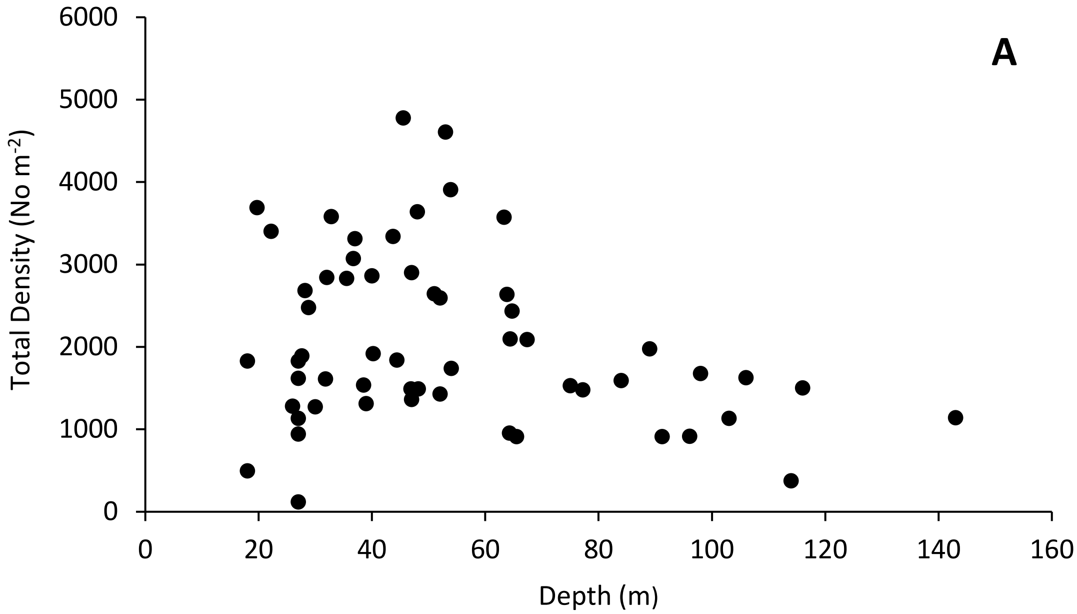


Figure 2: Density (A) and biomass (B) of major taxa (*Diporeia*, Oligochaeta, Sphaeriidae, and Chironomidae) sampled at 59 stations in 2016 in Lake Superior.



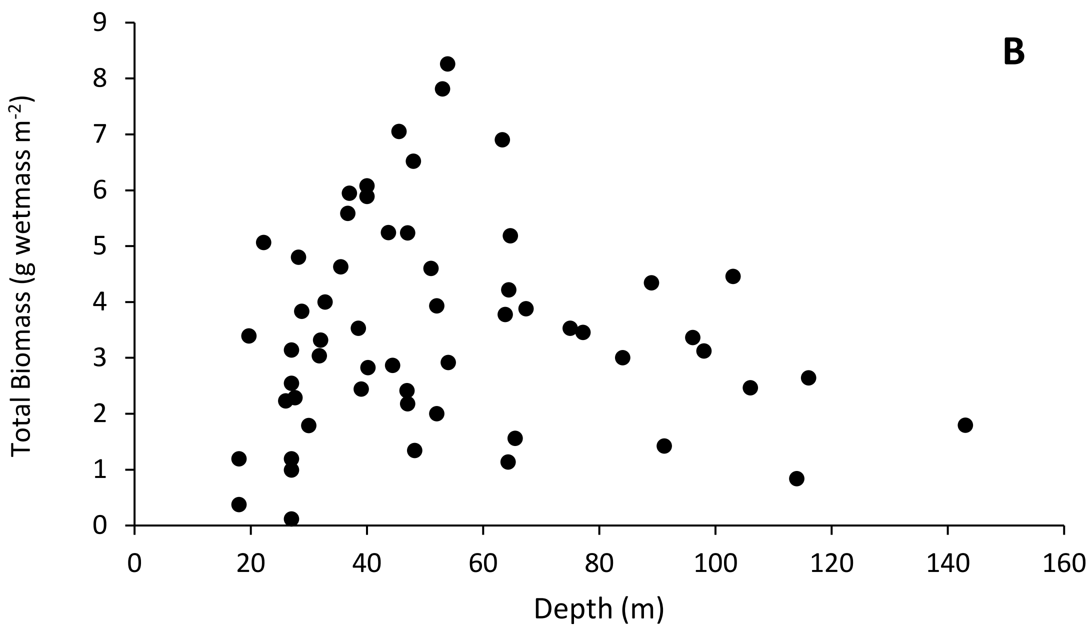


Figure 3. Depth distribution of total benthic invertebrate density (A) and biomass (B) in 2016. Symbols are the average for each sampling station (n = 59).

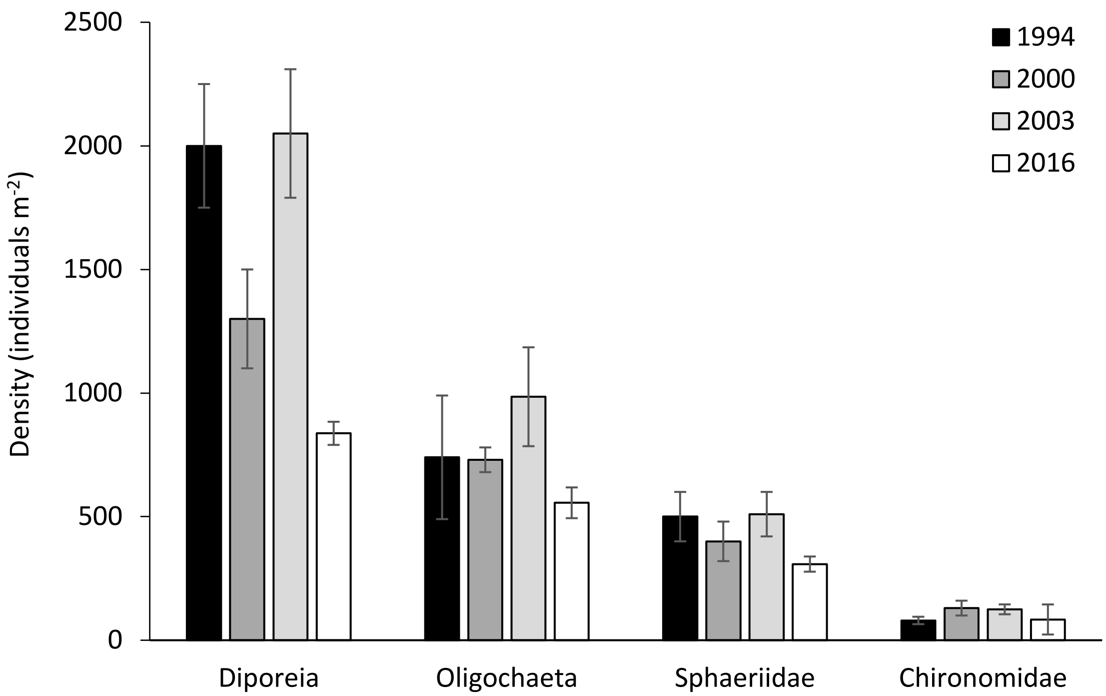


Figure 4. Abundance of major taxa from 25 stations in the U.S. nearshore waters of southern Lake Superior during 1994, 2000, 2003 (Scharold et al. 2009), and 2016. Error bars are standard error of the mean.

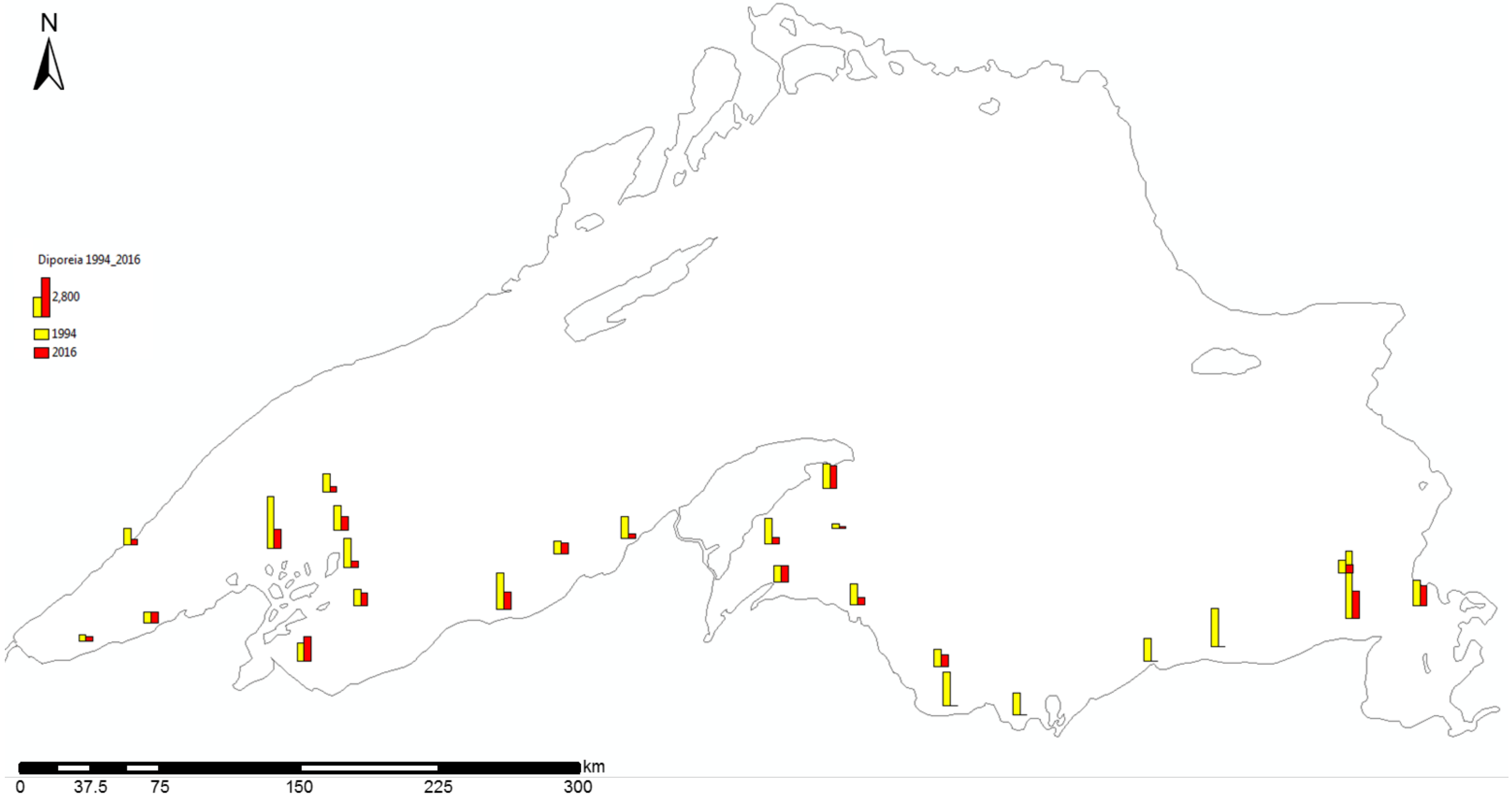


Figure 5. Changes in *Diporeia* density (No m^{-2}) between 1994 (yellow bars) and 2016 (red bars).

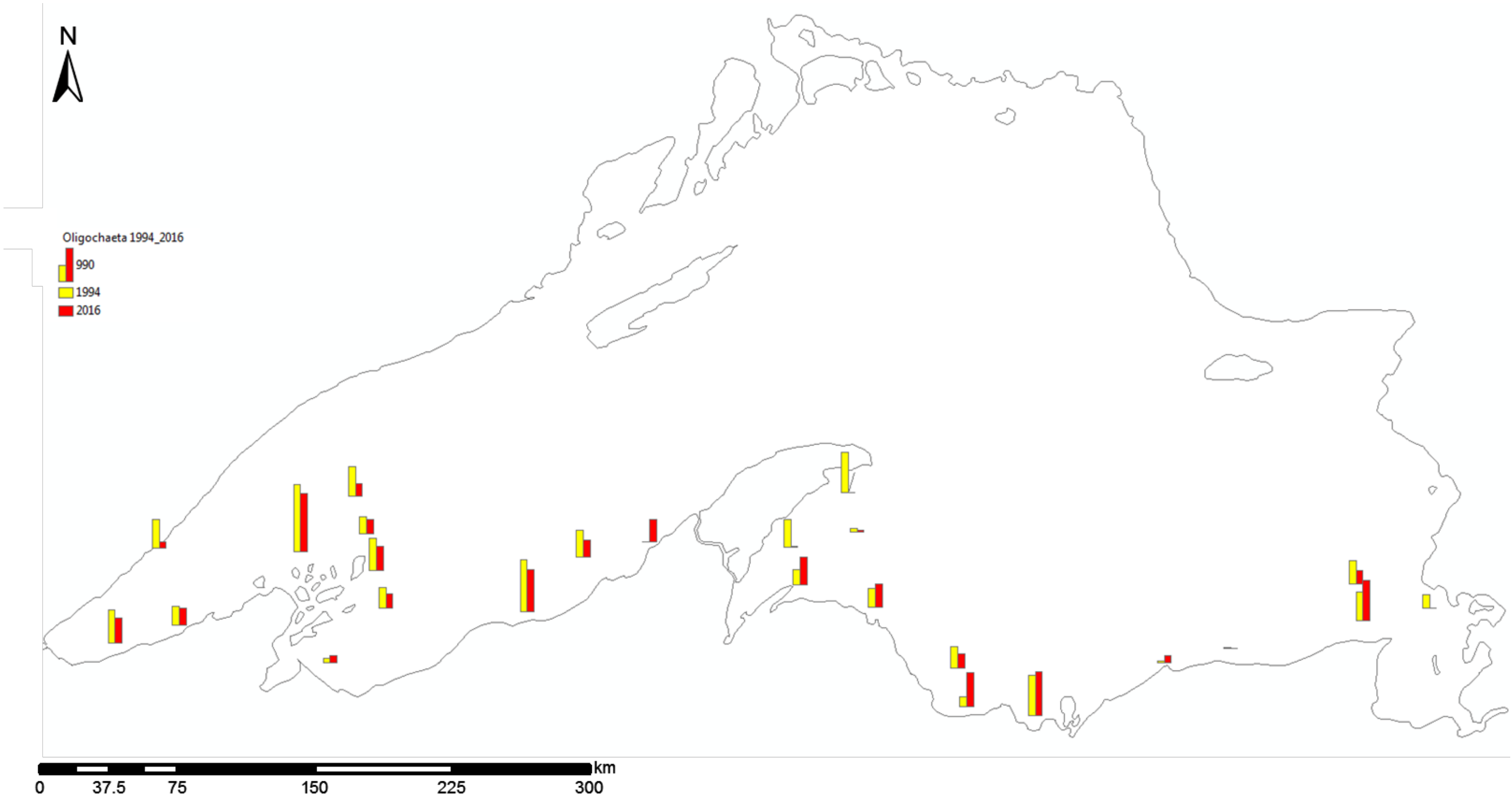


Figure 6. Changes in Oligochaeta density (No m^{-2}) between 1994 (yellow bars) and 2016 (red bars).

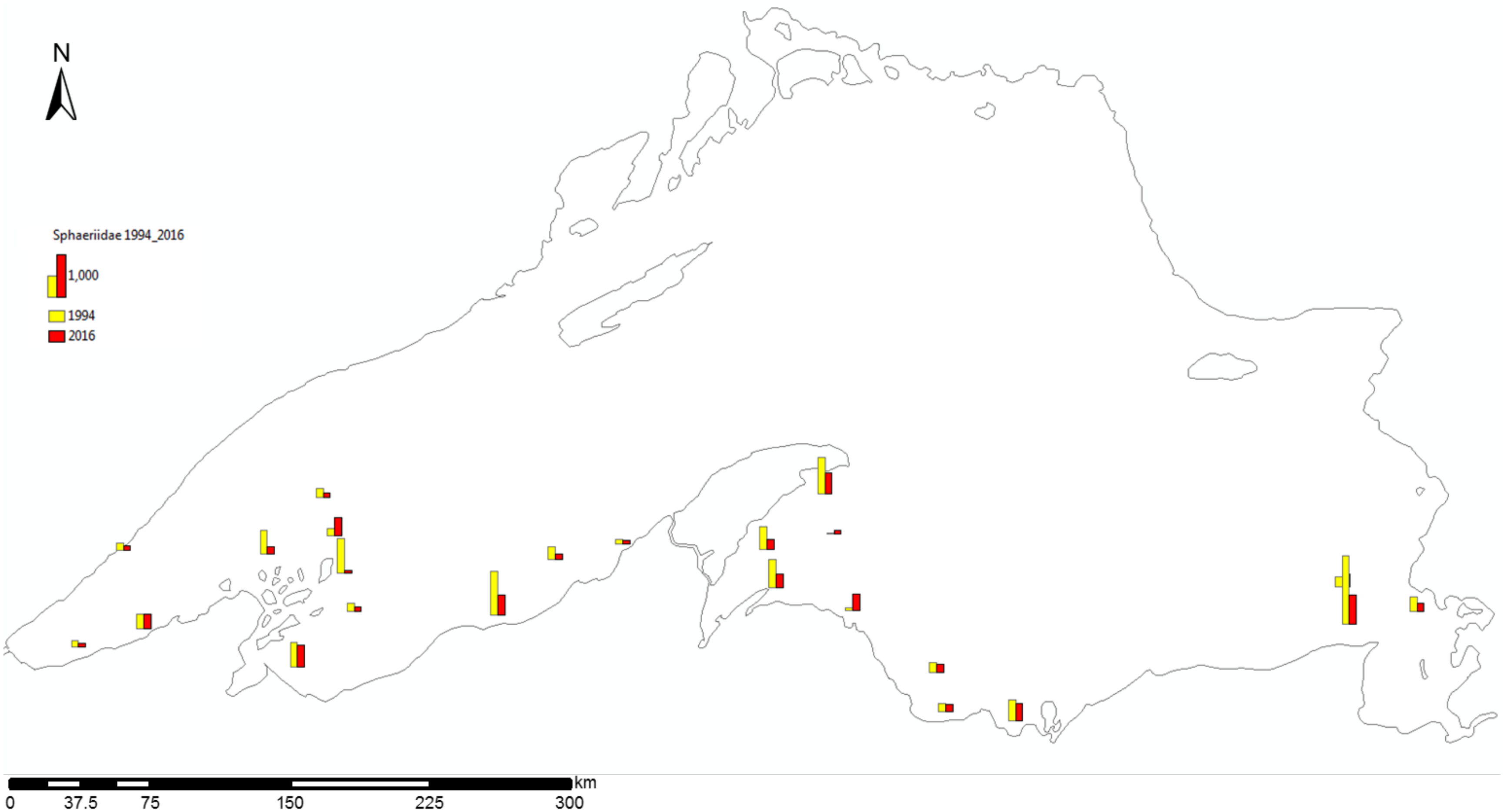


Figure 7. Changes in Sphaeriidae density (No m^{-2}) between 1994 (yellow bars) and 2016 (red bars).

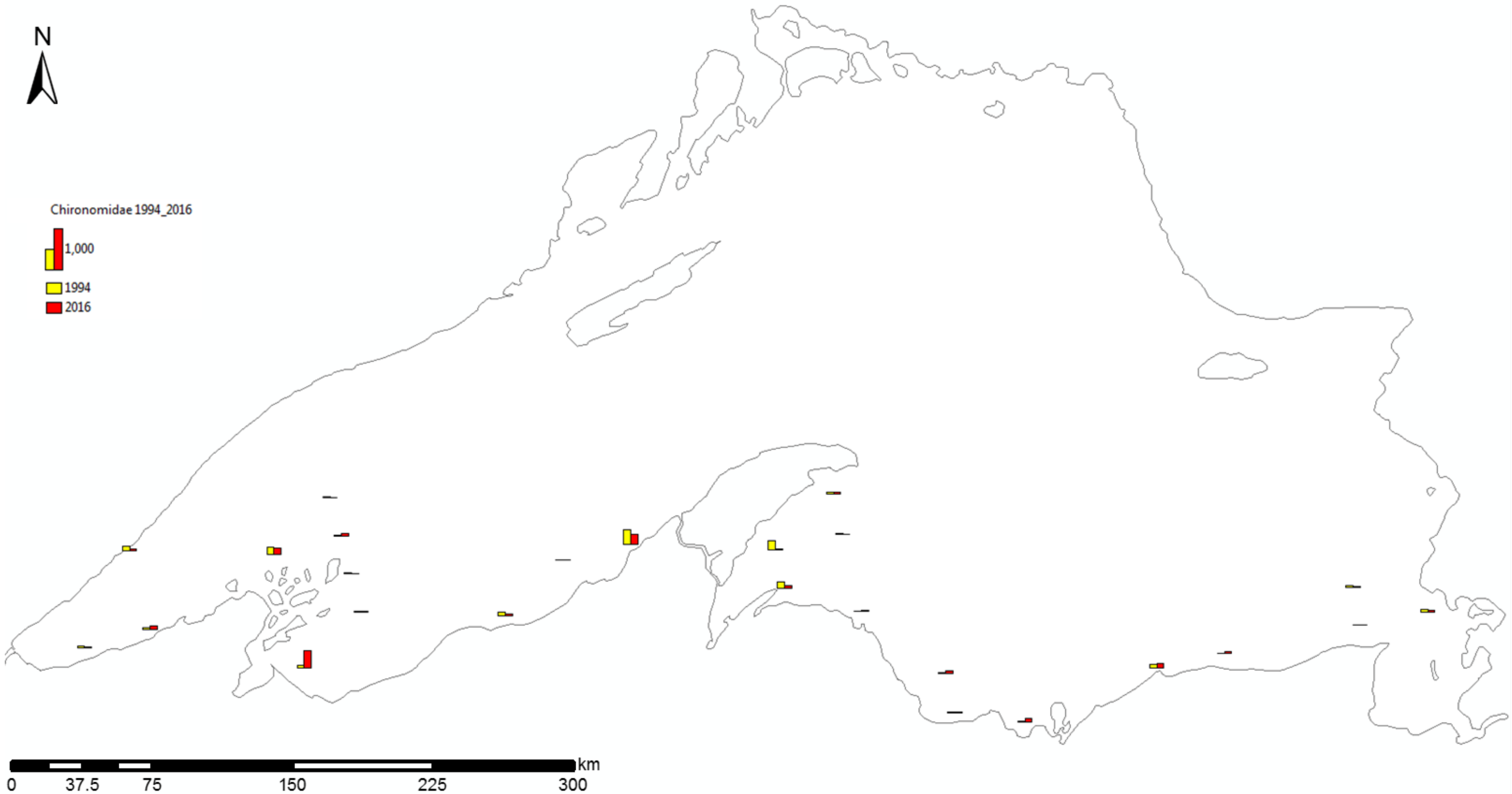


Figure 8. Changes in Chironomidae density (No m^{-2}) between 1994 (yellow bars) and 2016 (red bars).