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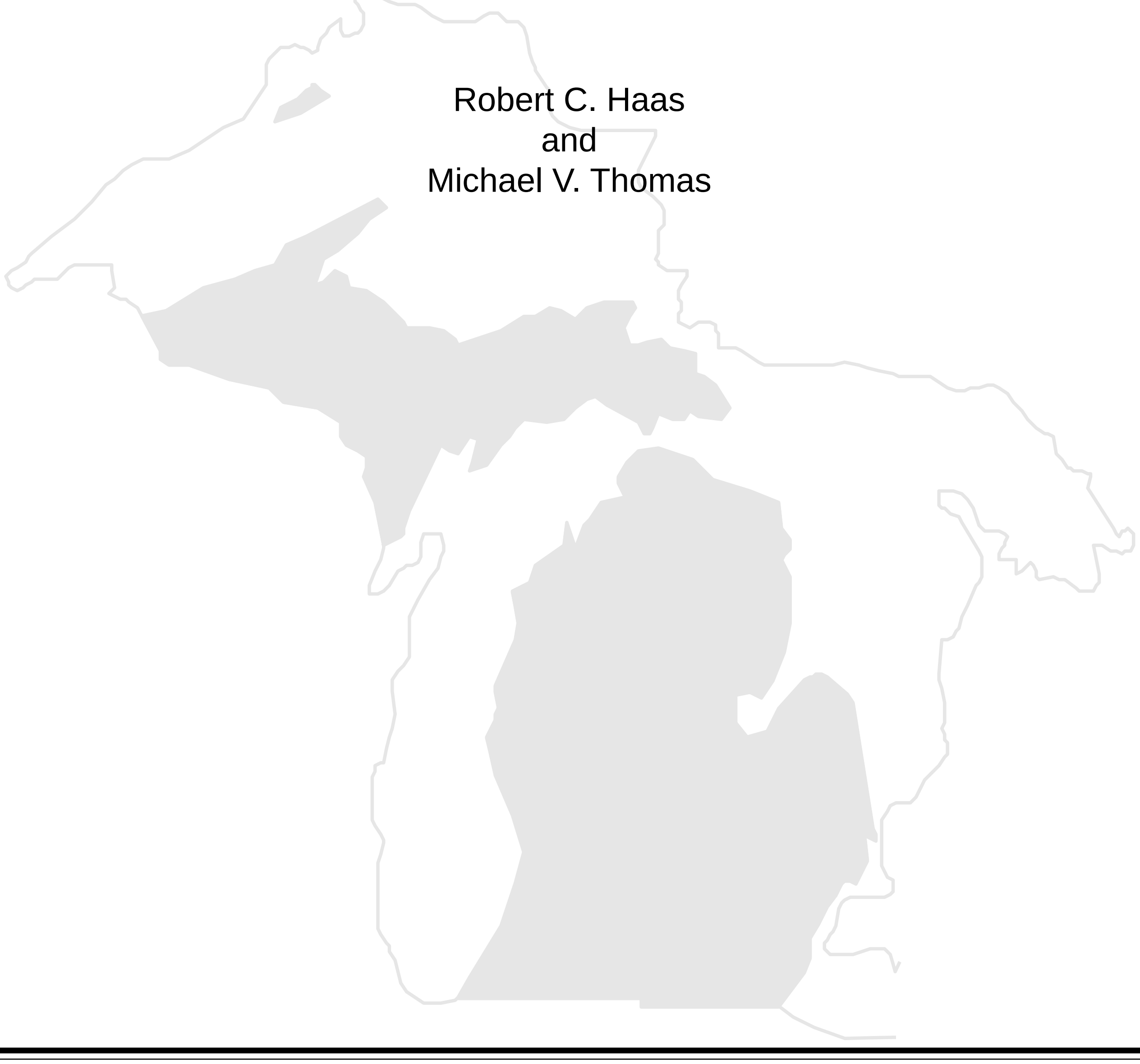

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RESEARCH REPORT

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Nutrient Levels and Plankton Populations of Five Great Lakes Tributaries and Their Relation to Walleye Year Class Strength (Spawning Success)

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Abstract.–We monitored spring environmental conditions at the mouths of five Great Lakes tributaries from 1990 to 1994 with the purpose of identifying the factors conducive to walleye *Stizostedion vitreum* fry survival. Factors monitored included: 1) nutrient levels as characterized by concentrations of nitrate/nitrite, ammonia, phosphorus, silica, and total organic carbon (TOC); 2) plankton community composition, population density, and size structure; and 3) zebra mussel *Dreissina polymorpha* growth in suspended cages as a surrogate for growth of herbivorous zooplankton. Monitoring was conducted at the mouths of three rivers considered to be productive walleye spawning rivers; the Maumee River, an Ohio tributary to Lake Erie; the Thames River, a Lake St. Clair tributary in Ontario; and the Saginaw River, a Michigan tributary to Saginaw Bay, Lake Huron. Monitoring was also conducted at two rivers that currently host very small runs of walleye; the Clinton River, a Michigan tributary to Lake St. Clair; and the Huron River, a Michigan tributary to Lake Erie. We compared growth and survival of walleye fry in cages placed in the lower Clinton River to those reared in ponds. We estimated historical walleye year-class strength, based on catch data, and tried to correlate it with weather conditions and river discharge. We found few statistically significant differences in nutrient levels and plankton populations between years. However, differences between the rivers for the five year period were significant. The Saginaw, Maumee, and Thames rivers were characterized by warm to moderate mean water temperatures (16.9, 18.2, and 17.3 C), high nitrate/nitrite concentrations (1.08, 4.25, and 1.80 mg/L), high to moderate phosphorus concentrations (0.08, 0.16, and 0.05 mg/L), high to moderate TOC concentrations (11.13, 9.02, and 3.78 mg/L), and dense zooplankton populations (12.2, 6.9, and 4.9 individuals/L). Conversely, the Clinton and Huron rivers were typified by moderate to cold mean water temperatures (14.5 and 16.7 C), low nitrate/nitrite concentrations (0.33 and 0.43 mg/L), moderate to low phosphorus concentrations (0.04 and 0.06 mg/L), moderate to low TOC concentrations (2.61 and 4.49 mg/L), and less dense zooplankton populations (1.5 and 1.7 individuals/L). The Huron River had the most variable measures of environmental conditions. Walleye fry rearing experiments in ponds and cages showed that food conditions and growth in the lower Clinton River, a poor walleye river, were inferior. Analysis of weather and river discharge data indicates that strong walleye year classes in Lake Erie and Lake St. Clair are correlated with colder winters. No significant relationships were detected between Saginaw Bay walleye year-class strength and weather or river discharge data.

Introduction

Walleye *Stizostedion vitreum* populations are typified by variable reproductive success and recruitment which ultimately leads to fluctuations in fishing success. Causes of these variations are not well understood, however, it is apparent that the early life stages from egg production through the first winter of life are critical. Fluctuations of year class strength appear to be in phase over fairly broad geographical areas suggesting that general weather related phenomena may be important causative agents. Several studies have been conducted in an attempt to correlate year class strength with physical environmental variables, such as, rate of spring warming (Busch et al. 1975, Shuter and Koonce 1977). These, and other researchers have also attempted to describe a relationship between estimates of broodstock size and eventual year class strength. Work to date has not effectively accounted for year class variation in Great Lakes walleye, and we do not have sufficient knowledge of determinants of walleye fry survival to explain why some tributary rivers support large spawning populations and others do not. Walleye fry are known to be dependent upon abundant zooplankton of relatively large size to support maximum fry growth and survival. Knowledge of critical food demands for walleye fry might allow more accurate prediction of recruitment, more effective protection of spawning grounds and nursery habitats, and more effective management of the Great Lakes walleye stocks.

River spawning is common amongst Great Lakes walleye populations in Saginaw Bay, Lake St. Clair, and Lake Erie. These fish normally run up rivers in mid to late March and spawning occurs shortly thereafter. Walleye fry typically hatch about the middle of April. Walleye fry move immediately downstream with the current so that the majority of fry have entered the river mouth by the first of May. Populations of zooplankton in most rivers are minimal and likely would not support good growth of walleye fry. Fry probably reach the river mouth within one or two days of the onset of exogenous feeding. At least some of the Great Lakes river mouths provide adequate plankton populations and survival probabilities for fry that make it downriver in good condition. This is attested to by the maintenance of large, river spawning walleye stocks with frequent successful reproduction during the past 25 years.

Foraging theory suggests that growth of planktivorous fish is affected by plankton type, density, and size (Werner and Hall 1974). Walleye fry feed primarily on zooplankton until they reach a length of about 2 cm (Smith and Pycha 1960). Critical periods for fry growth and survival certainly occur well before that length is obtained. Li and Mathias (1982) found substantially higher mortality 5-10 days after hatching, when fry switched to exogenous feeding, compared to later fry stages. They also found that fry survival in the lab increased with increasing food density, reaching maximum survival at 100-200 large cladocerans per liter. Walleye fry typically prefer planktonic organisms that are considerably larger than the average size found in samples from their habitat. Swanson and Ward (1988) found that walleye fry in two rearing ponds selected the largest zooplankton available. They also found that walleye growth was slower where average zooplankton size was smaller in a pond (which also contained fathead minnows), presumably because of reduced food size.

The main purpose of this study was to determine if Great Lakes tributaries which supported historically good walleye spawning success are characterized by "good" plankton populations in river mouths; whereas, those that have minimal spawning have "poor" plankton populations. Also, we wished to determine if strong year classes of walleye, are produced in years with larger and more abundant zooplankton communities.

Preliminary work was conducted in 1989 to develop field and lab sampling techniques. Zooplankton populations were periodically sampled near the mouths of the Thames River, a Lake St. Clair tributary in Ontario, the Saginaw River, a Michigan tributary to Saginaw Bay, Lake Huron, and the Clinton River, a Michigan tributary to Lake St. Clair and in walleye rearing ponds on Selfridge Air Base near Mt. Clemens, Michigan. Walleye fry were sampled twice weekly for growth and stomach contents in Selfridge rearing ponds and in a fry cage suspended in the mouth of the Clinton River, adjacent to Lake St. Clair. The Thames River has historically supported extensive walleye spawning, and the Saginaw River had large walleye spawning runs prior to collapse of the Saginaw Bay walleye population in the late 1940's or early 1950's. Successful production of walleye fry has not been documented in the Clinton River and we classified it as a poor spawning river.

Plankton samples collected in 1989 indicated that mean length and density of natural zooplankton near the three rivers was much lower than the plankton cultivated in Selfridge rearing ponds. Although zooplankton found near the three rivers appeared similar, there was general support for our assumptions about conditions necessary for spawning success, since the mean length and density of the major plankton food groups were highest in the Thames River and lowest in the Clinton River samples. Growth of walleye fry was much greater in the Selfridge ponds compared to the fry cages in Clinton River near the mouth (Appendix Figure 1). Statistical tests showed a highly significant difference between growth in length and weight over the 7-week period after which no fry survived in the fry cages. Possibly, caged fry could not accumulate enough energy to sustain life. Comparison of gut contents showed that caged fry ate similar numbers of planktonic organisms; however, the plankton were much smaller in size. The smaller food particles probably contributed much less energy, on a per unit basis, to the caged fry. In addition, density of plankton within the fry cages was much lower than in the Selfridge ponds; thus, caged fry may have had to search much longer per organism consumed. Cladocerans made up the bulk of the diet of fry in the Selfridge ponds during the first 7 weeks; whereas, cyclopoid copepods predominated in the guts of fry in the cages. Cladocerans are generally considered to be the most ideal food for zooplanktivorus fish. Mills et al. (1984) found in yellow perch that weight of food captured per unit time was greatest for the cladoceran, *Daphnia pulex*, and least for the calanoid copepod, *Diaptomus sicilis*. They also reported that the cladocerans weighed several times more than copepods of similar length. Zooplankton populations in mesotrophic waters of the lower Great Lakes have been shown to be dominated by Copepoda during spring and Cladocera during the rest of the growing season (Culver et al. 1985).

This study describes the plankton community during five consecutive years at five potential walleye spawning rivers to see whether walleye reproductive success correlates with the plankton populations and/or physical conditions of river discharge and local weather patterns. Three of the rivers, the Maumee, a large tributary to Lake Erie in Ohio, the Thames, and the Saginaw are widely recognized as having supported both historical and contemporary walleye populations of substantial abundance. The other two rivers, the Huron, a tributary to Michigan's waters of Lake Erie, and the Clinton, have not supported large spawning populations of walleye.

Methods

Study Rivers

The mouths of five Great Lakes tributaries were monitored in this study (Figure 1). The Maumee River mouth, located near Toledo, Ohio, on Lake Erie, was the southernmost of the five study sites. The Huron River mouth, also on Lake Erie, lies just west of Rockwood, Michigan. The Thames River mouth, found just west of Tilbury, Ontario, and Clinton River mouth, at Mt. Clemens, Michigan, are both located on Lake St. Clair. The northern most site, the Saginaw River mouth, is located on Saginaw Bay, Lake Huron, near Bay City, Michigan. The Saginaw River mouth lies about 215 km north of the Maumee River site.

Physical Conditions and Nutrients

The five river mouths were sampled semiweekly for temperature and Secchi depth, and weekly for nutrients from the end of April through June, 1990-94. River sites were sampled on about 18 occasions each year.

Nutrients, usually measured during the first semiweekly trip, included nitrate/nitrite, ammonia, phosphorus, silica, and total organic carbon (TOC). Total organic carbon measurements were not made in 1990. Nutrient samples were sent to the Michigan Department of Natural Resources (MDNR) Environmental Laboratory in Lansing for analysis.

Plankton

The Maumee, Huron, Thames, Clinton, and Saginaw rivers were sampled semiweekly for zooplankton and phytoplankton from the end of April through June. Zooplankton samples were collected with a 0.5 m diameter net made of 153 μm nylon mesh. Three vertical tows were taken, one in the river channel and one off on either side (Figures 2-6) in the lake near the river mouth. All zooplankton samples were preserved in 10% buffered formalin and phytoplankton samples were preserved in Lugol’s iodine solution. Macro-zooplankton from all sites were identified to genera, counted, and measured. Zooplankton samples were enumerated with an overhead projector and digitizing tablet attached to a microcomputer. The overhead projector was fitted with a mechanical stage allowing controlled slide movement. Standard microscope slides were fitted with a metal cell designed to contain a 1.0 ml sample which was cemented over a pattern of evenly spaced lines across the length of the chamber allowing easy tracking of the counted portion. Aliquotes of 1.0 ml volume were randomly drawn from well mixed samples and counted until at least 150 organisms had been enumerated. A computer program written for processing zooplankton samples by Mills and Confer (1986) for the Apple II computer system was modified to work on an IBM-PC. This software allowed automated counting, measuring, and analysis of samples by species.

Phytoplankton samples consisted of 0.5 L of unfiltered water collected at 1.0 m depth with a standard Kemmerer water sampler. Each plankton sample was a composite of three aliquots, one collected in the river channel and the other two off to either side (Figures 2-6) in the lake near the river mouth. Phytoplankton were identified to genera and counted with a compound microscope fitted with a 45X objective and 10X eyepiece using special counting chambers designed for this study. The counting chambers consisted of a microscope slide fitted with a thin, stainless steel cell. The metal cell was machined and cemented over a cover glass with a microfilm photograph of a fine grid pattern sandwiched between the slide and cover glass. The grid width was set to match the microscope field of view so that a grid could be followed in one direction with the mechanical stage and counted without having to move the slide in a direction at 90 degrees. The grid length and depth were set to circumscribe a volume of 0.001 ml which made expansion from numbers counted to numbers per ml a simple multiplication problem. A total of 10 grids were counted for each composite sample.

In 1990, semiweekly plankton and nutrient samples were also collected from two walleye rearing ponds and the lower reach of the Clinton River for a walleye fry rearing experiment. The ponds were located on Selfridge Air National Guard Base which is adjacent to Anchor Bay of Lake St. Clair (next to the Clinton River). Zooplankton were sampled inside and outside each cage.

The plankton data for all sampling sites were tested for significant differences between sites and years using parametric (ANOVA) and nonparametric (Kruskal-Wallis) one-way analysis of variance statistical procedures. Average density of phytoplankton was used as a criterion for comparing the food value for zooplankton populations in the river mouths. Average density and size of zooplankton was used as a criterion for comparing the food value of the plankton populations for walleye fry in the rivers.

Zebra mussel growth

Zebra mussels *Dreissena polymorpha* were placed in test cages at each river mouth site to monitor growth conditions during the spring period each year. We believed that growth of zebra mussels, a filter feeder, would represent (and correlate with) growth conditions for zooplankton, thus reflecting growth conditions for walleye fry. The design of cages followed that of Bitterman et al (1994). Animals (250) were selected with a shell length of 4-5 mm from Lake Erie stock, placed in individual compartments in five Plexiglass® cages, suspended at each of the five river sites in early May and retrieved in late June. Each cage had fifty holes measuring 13.0 mm in diameter and 6.5 mm in depth. Individual zebra mussels were measured for length, width, height, and live weight at the start and end of the sampling period.

Differences in growth between sites were tested using ANOVA statistical procedures.

Rearing walleye fry

Preliminary investigation of cage culture in the lower Clinton River and pond rearing of walleye fry in 1989 indicated that fry in the lower Clinton River would experience much poorer growth conditions compared to fry in the rearing ponds at Selfridge Air Base (Appendix Figure 1).

Walleye rearing ponds were incorporated into the study during 1990 to provide comparable plankton/nutrient data which were assumed to approximate ideal conditions for walleye fry and to allow sampling of walleye fry to learn about their feeding behavior and food preferences. In 1990, we conducted walleye fry rearing experiments in the lower Clinton River and the North and South Ponds at Selfridge. Cylindrical cages were constructed of 0.79 mm nylon mesh and were 106.7 cm deep and 152.4 cm in diameter. Approximately 1,000 newly hatched walleye fry were placed in each cage at the beginning of the experiment. Approximately 10 fry were sampled semiweekly for growth and stomach contents from four locations: inside the Clinton River cage; inside a cage with fry in the North Pond; outside the cage in the North Pond; and in the South Pond. A second cage (west) in the North Pond did not receive fry and was used as a control for zooplankton analysis. The North and South ponds were being used by MDNR personnel to rear walleye fingerlings for scheduled stocking projects.

Differences between the four sites for zooplankton populations and walleye fry growth and food habits data were analyzed using ANOVA procedures, *t* test, and the Mann-Whitney test.

Walleye year class strength

Historical walleye year class strength was estimated from catch data for Lake Erie, Lake St. Clair, and Saginaw Bay. The longest and what we believed was the most representative data set available was used in each case. For Lake Erie, the combined lakewide angler and commercial harvest estimates (Great Lakes Fishery Commission, Lake Erie Committee Walleye Task Group, unpublished data) were used. The harvest estimates spanned a period from 1975-94 which provided good representation for the 1974-91 year classes. Summer trawl catch rates for walleye young-of-year were used to extend both ends of the year class series. Trawl catch data was provided by R. Knight, Ohio Department of Natural Resources, for the period. Since the 1969-73 and 1992-94 cohorts were not adequately represented in annual harvest estimates for 1975-94, , we estimated missing annual harvest values from the summer trawl catches with a linear regression equation (F =0.009, r^2 =0.32). This resulted in a 26 year series of cohorts (1969-94) with annual harvest estimates made over their lifetime. Total lifetime harvest estimates for each cohort were produced by summing the annual harvest estimates for each cohort. These lifetime harvest estimates were used to rank spawning success. Cohorts with high lifetime harvest estimates were assumed to have experienced superior conditions for fry survival compared with cohorts with lower lifetime harvest estimates.

Walleye year class strength in Lake St. Clair was estimated from Ontario Ministry of Natural Resources fall index trap net catches (D. MacLennan, unpublished data). The Ontario trap net program has operated from 1970-94 and produced direct catch-per-effort (CPE) estimates for the 1969-84 year classes. Trap net CPE values from the 1964-68 and 1985-91 year classes were incomplete as these cohorts were not completely represented in the time series. We corrected the CPE values for those cohorts by adding a percentage of their contribution at representative years according to the average percent contribution at that age. This increased the range of useful year class estimates to 28 which spanned the period from 1964-91.

Year class strength for walleye in Saginaw Bay was estimated from age composition of electrofishing samples collected by MDNR from the spawning run in the Tittabawassee River, a major tributary of the Saginaw River. Estimated age composition of the spawning population was available for 1981-94, providing good representation for the 1977-88 cohorts (Schneider et al 1988, Johnson et al 1994). Relative cohort abundance estimates, based on age composition, were summed across years to produced lifetime cohort abundance values, representing year class strength of the 1977-88 cohorts. Catch-per-effort data were also available from MDNR fall gill net surveys for 1989-94. These data were used to adjust estimates of the 1989-91 year classes (VanAmberg et al 1994) based on a linear relationship between lifetime cohort abundance values and gill net CPE values for the 1977-88 reference cohorts. Again, we assumed that cohorts with higher lifetime abundance values experienced superior fry survival relative to those with lower lifetime abundance values.

Walleye year class data were tested for differences between sites and years using ANOVA, *t* test, and Kruskal-Wallis procedures.

Weather data

Daily weather data collected at airport weather stations in Toledo, Ohio; Mt. Clemens, Michigan; and Saginaw, Michigan was purchased from the National Oceanic and Atmospheric Administrations' Climatic Data Center. Data on minimum and maximum air temperature, precipitation, and snowfall were obtained for the period from 1968 through 1994. Data were provided in English units and will be presented in that traditional way in this paper. Heating degree days were calculated on a daily basis as the maximum plus minimum temperature divided by two minus 65 F. Heating degree days, precipitation, and snowfall were summed by month to create additional descriptive weather variables.

Weather data were tested for differences between years for each area using ANOVA statistical procedures.

River discharge

Discharge data for the Thames River at Thamesville, Ontario were purchased from the Monitoring and Systems Branch of Environment Canada for the period from 1970-94. These data were provided in cubic meters per second and converted to cubic feet per second. All flow data were maintained in standard English units.

Daily river discharge measurements in cubic feet per second were obtained for the four United States (US) study rivers. Daily data for the Maumee River at Waterville, Ohio were obtained from R. Veley of the US Geological Survey (USGS) for the period 1939-94. Daily discharge data for the three Michigan rivers, the Huron River at Ypsilanti, Tittabawassee River at Midland, and the Clinton River at Mt. Clemens, were obtained from R. LeuVoy of the USGS for the period from October, 1989 through September, 1994. Average monthly discharges were calculated for the period from October, 1989 through September, 1994 which was considered to be the most important period for walleye reproductive success during the five years from 1990 through 1994. Long-term average discharges were taken either from the 1994 USGS report (Blumer et al, 1994) in the case of the three Michigan rivers or calculated from the long-term datasets provided for the Maumee (Ohio) and Thames (Ontario) rivers.

River discharge data were tested for differences between sites and years using ANOVA statistical procedures.

Results and Discussion

Good versus poor conditions for walleye fry

We compared physical, chemical, and biological conditions spatially and temporally among the five river mouth study sites to look for patterns that might have promoted good walleye fry survival. The five study rivers were ranked from poor (1) to good (5) on a generalized scale based on nine environmental criteria potentially important to growth and survival of walleye fry. The ranking sequence from poor to good was Clinton, Thames, Huron, Saginaw, and Maumee based on mean ranks of 1.0, 2.7, 3.0, 4.0, and 4.3. The Maumee and Saginaw rivers usually ranked high on the nine environmental criteria (Figure 7) while the Clinton River always ranked low. The Huron and Thames rivers ranked intermediately with the Huron river mouth showing the largest variation among the five sites. This variation in criteria for the Huron River may have been caused by excessive nutrient loading from the City of Detroit's municipal sewage outfall which is located in the Detroit River upstream from the confluence of the Huron River. The same ranking method was used to examine temporal changes in the nine environmental criteria during the years from 1990-94 (Figure 8). There was much more variability observed between years compared to sites and no pattern emerged from these criteria that would suggest one year was better or worse than the others. It is possible, however, that temporal effects are important but operate within smaller geographic areas than that covered by this study.

Physical Conditions and Nutrients

Annual mean values for all physical conditions and nutrients monitored at the five river sites over the five year study period are presented in Table 1. Mean Secchi depth of combined river sites in 1991 was 0.72 m which was significantly lower than other years (Kruskal-Wallis test, $P=0.024$). Mean Secchi depth ranged from 0.88 m in 1990 to 0.95 m in 1992. However, Secchi depth did not show any trend through time at any of the five river sites. Apparently zebra mussels were not strongly affecting spring water transparency since all sites were colonized by them during the five year study period. The Clinton site (a poor walleye river) had a significantly higher (Tukey HSD test, $P<0.05$) mean Secchi reading (1.56 m) compared to the other rivers in all years and the Maumee site (a good walleye river) had a significantly lower Secchi depth (0.42 m). The good walleye rivers, Thames and Saginaw, were characterized by intermediate mean Secchi depths of 0.89 and 0.71 m respectively. The Huron River also had an intermediate mean Secchi depth of 0.73 m.

Mean temperature at combined river sites in 1991 was 18.7 C which was significantly higher (Tukey HSD test, $P<0.05$) than 1990 or 1993 which averaged 15.4 and 15.7 C. There were no apparent temperature trends through time at the five sites. The Maumee and Thames sites (18.2 and 17.3 C) were significantly warmer than the Clinton site (14.5 C). The Saginaw and Huron rivers were characterized by intermediate temperature regimes with means of 16.9 and 16.7 C.

Mean nitrate/nitrite level at combined river sites was highest in 1992 (2.0 mg/L) and lowest in 1993 (1.13 mg/L). Annual differences in nitrate/nitrite combined across sites were not significant. There were large differences in nitrate/nitrite concentrations between most of the sites. The Maumee River averaged 4.25 mg/L, which was significantly greater (Tukey HSD test, $P<0.05$) than each of the other four. The Thames site averaged 1.80 mg/L, which was significantly greater than the Huron and Clinton rivers. The Saginaw site averaged 1.08 mg/L which was significantly greater than the Clinton site. The Huron and Clinton rivers averaged 0.43 and 0.33 mg/L.

As with other forms of nitrogen, there were numerous significant site differences in ammonia levels. The Huron and Maumee rivers were highest at 0.24 mg/L and 0.23 mg/L, which were significantly greater (Tukey HSD test, $P<0.05$) than the other three sites. The Saginaw site had intermediate levels of ammonia, averaging 0.11 mg/L, which was significantly greater than the Clinton and Thames rivers, which averaged 0.04 and 0.02 mg/L.

Annual differences were small in phosphorus concentrations at combined sites and only ranged from a mean of 0.09 mg/L in 1991 and 1993, to 0.07 mg/L during the other three years. However, phosphorus levels were quite different between sites, with the Maumee River having the highest concentration at 0.16 mg/L, which was significantly greater (Tukey HSD test, $P<0.05$) than the other four sites. The Saginaw and Thames rivers had mean phosphorus concentrations of 0.08 and 0.05 mg/L. The Clinton River had the lowest phosphorus level (0.04 mg/L) which was significantly lower than the others. Mean phosphorus concentration in the Huron River was 0.06 mg/L.

The nitrogen-to-phosphorus ratio (N:P) was highest at the Thames River site (49.30) in 1990 and lowest at the Huron River (5.22) in 1993. When years were compared across sites, the mean N:P was significantly higher (Tukey HSD test, $P<0.05$) in 1992 (27.30), compared to the lowest in 1993 (15.74). The five river mouths differed substantially in mean N:P from a high of 42.00 at the Thames to a low of 7.66 at the Huron.

Annual silica levels for combined sites were highest in 1991 at 1.08 mg/L and lowest in 1994 at 0.52 mg/L. These two years were significantly different (Median test, $P=0.006$). The other three years showed intermediate levels of 0.84, 0.81, and 0.77 mg/L. The Maumee River had the highest mean silica concentration (1.69 mg/L) which was significantly greater than the other four sites (Tukey HSD test, $P<0.05$). The Saginaw site had the second highest concentration at 0.84 mg/L which was significantly higher than the Clinton River which had the lowest concentration of 0.43 mg/L.

Mean annual TOC at combined sites was highest in 1992 (8.03 mg/L) and lowest in 1994 (4.67 mg/L). There were no significant differences between years. The Saginaw and Maumee sites had the highest mean TOC levels at 11.13 and 9.02 mg/L, respectively, both of which were significantly greater than the other sites (Tukey HSD test, $P<0.05$). The Clinton River had the lowest TOC concentration at 2.61 mg/L. The Thames and Huron rivers had mean TOC concentrations of 3.78 and 4.49 mg/L.

Phytoplankton

Annual mean values for phytoplankton at the five river sites over the five year study period are presented in Table 2. Mean total algae density for the combined river sites in 1991, 1,247 cells/ml, was significantly lower than for other years (Kruskal-Wallis test, $P=0.000$) which ranged from 3,734 cells/ml in 1990 to 6,936 cells/ml in 1992. Mean algae density in 1990 was also significantly lower (Tukey HSD test, $P<0.05$) than in 1992, 1993, and 1994. For all years combined, the Clinton River had a significantly lower (Tukey HSD test, $P<0.05$) total algal density, 880 cells/ml, than the other four rivers. Total algal densities for the Huron River, 8,123 cells/ml, were significantly higher (Tukey HSD test, $P<0.05$) than those of the Maumee River, 5,198 cells/ml, and Thames River, 3,618 cells/ml. No trends in total algal densities through time were observed for the five rivers.

Mean green algal densities for the combined river sites in 1991, 468 cells/ml, was significantly lower (Tukey HSD test, $P<0.05$) than for 1992 (2,110 cells/ml), 1993 (2,194 cells/ml), and 1994 (1,644 cells/ml), but not significantly different from 1990 (1152 cells/ml). For all years combined, the Clinton River, 124 cells/ml, and Thames River, 601 cells/ml, had green algal densities significantly lower (Tukey HSD test, $P<0.05$) than for the other three rivers, which ranged from 2,047 cells/ml (Saginaw River) to 2,343 cells/ml (Huron River). Over the study period, no trends in green algae densities through time were observed for any of the five rivers.

Mean flagellate algal densities for the combined river sites in 1990, 363 cells/ml, and 1991, 279 cells/ml, were significantly lower (Tukey HSD test, $P<0.05$) than for 1992 (1,052 cells/ml), 1993 (1,880 cells/ml), and 1994 (1,519 cells/ml). For all years combined, the Clinton River, 106 cells/ml, had flagellate algal densities significantly lower (Tukey HSD test, $P<0.05$) than for the other four rivers, which ranged from 984 cells/ml (Huron River) to 1,528 cells/ml

(Thames River). Over the study period, no trends in flagellate algae densities through time were observed for any of the five rivers.

Mean yellow-brown algae densities for the combined river sites in 1990, 291 cells/ml, were significantly higher (Tukey HSD test, P<0.05) than for 1991 (80 cells/ml), 1993 (164 cells/ml), and 1994 (66 cells/ml). For all years combined, the Huron River, with 283 yellow-brown algae cells/ml, had densities significantly higher (Tukey HSD test, P<0.05) than those for the Maumee River (89 cells/ml), Thames River (128 cells/ml), and Saginaw River (142 cells/ml). Over the study period, no trends in yellow-brown algae densities through time were observed for any of the five rivers.

Mean diatom densities for the combined river sites in 1991, 277 cells/ml, were significantly lower (Tukey HSD test, P<0.05) than for any other year. For all years combined, the Huron River, with 3,781 diatom cells/ml, had densities significantly higher (Tukey HSD test, P<0.05) than those for the other rivers. Over the study period, no trends in diatom densities through time were observed for any of the five rivers.

Mean bluegreen algae densities for the combined river sites in 1992, 1,051 cells/ml, were significantly higher (Tukey HSD test, P<0.05) than in 1991 (142 cells/ml), 1993 (252 cells/ml), and 1994 (360 cells/ml). For all years combined, the Clinton River, with 21 bluegreen algae cells/ml, had densities significantly lower (Tukey HSD test, P<0.05) than those for the Maumee River (561 cells/ml), Saginaw River (721 cells/ml), or Huron River (723 cells/ml). Over the study period, no trends in bluegreen algae densities through time were observed for any of the five rivers.

The composition of the algal assemblage varied considerably between the rivers sampled (Tables 3 and 4). The Maumee River was the only one dominated by green algae. Diatoms were the dominant component of the algal assemblage at the Saginaw, Clinton, and Huron rivers. The Thames River was the only one dominated by flagellate algae. Bluegreen and yellow-brown algae were relatively minor components of the algal assemblage for most of the river mouths, except for the Clinton, where yellow-brown algae were the second most abundant type present.

Zebra mussels feed on planktonic algae and other suspended organic particles which raises the question of whether they might compete with zooplankton for food and, thereby, reduce zooplanktonic food reserves for walleye fry. By the beginning of this study, zebra mussels had already colonized the Maumee, Huron, and Thames rivers. The Saginaw River was colonized by 1993 and the Clinton River by 1994. We compared algal density and water transparency between the river mouths, and through time, to look for change due to zebra mussels. There were no differences in phytoplankton population structure that could be attributed to zebra mussel filtering activity even though the mussels should have been feeding actively during this spring period based on water temperatures. During 1989 in western Lake Erie, Wu and Culver (1991) found that grazing by *Daphnia* controlled algal density and water transparency even though zebra mussels were abundant.

Zooplankton - River Mouths

Annual mean zooplankton densities observed at the five river sites over the five years of the study period are shown in Table 5. Mean total zooplankton density for the combined river sites in 1990 was significantly higher (Tukey HSD test, P<0.05) than in 1993 or 1994. Mean zooplankton length also differed significantly across years (Kruskal-Wallis test, *P*=0.023) with largest mean length in 1990 (0.60 mm) and smallest mean length in 1994 (0.58 mm). For all years combined, mean zooplankton densities observed at the Saginaw River, 43.4/L, were significantly higher (Tukey HSD test, P<0.05) than for any of the other sampling sites. Mean zooplankton densities at the Maumee River, 17.0/L, were the second highest and were significantly higher than those for the Clinton River (1.3/L) or Huron River (1.5/L). No trends in mean total zooplankton densities through time were noted for any of the river mouths sampled.

Comparison across sites found no significant differences between years for mean cyclopoid copepod densities. However, across years, the Saginaw River mean cyclopoid copepod density, 16.2/L, was significantly higher (Tukey HSD test, $P<0.05$) than at any other sampling site. Across sites, the average length of cyclopoid copepods was significantly (Tukey HSD test, $P<0.05$) in 1990 (0.82 mm), than in 1992 (0.75 mm) and 1993 (0.76 mm). Average length of cyclopoid copepods was significantly less (Tukey HSD test, $P<0.05$) at the Huron River, 0.72 mm, across years, than at any other sampling site. Over the study period, no trends in cyclopoid copepod densities or mean lengths were observed at the five river sites sampled.

Mean calanoid copepod density for the combined river sites in 1991, 3.2/L, was significantly higher (Tukey HSD test, $P<0.05$) than in 1992, 1.4/L, and 1994, 1.2/L. Mean calanoid copepod length differed significantly (Kruskal-Wallis test, $P=0.037$) between years across sample sites with the largest found in 1990 (0.90 mm) and the smallest in 1992 (0.83 mm). Mean calanoid copepod density across years for the Thames River, 5.4/L, was significantly higher (Tukey HSD test, $P<0.05$) than for any other site. The Huron River site density, 0.3/L, was significantly lower than for the Maumee River, 2.1/L, and Clinton River, 2.2/L. Thames River calanoid copepods were significantly larger (Tukey HSD test, $P<0.05$) at 0.95 mm, than those at the Thames River (0.80 mm), Clinton River (0.83 mm), and Huron River (0.86). The Saginaw River calanoids were also significantly larger than those in the Thames and Clinton rivers. No trends in calanoid copepod densities or mean lengths were found at any of the sample sites.

Mean cladoceran density for the combined river sites in 1990, 23.7/L, was significantly higher (Tukey HSD test, $P<0.05$), than in 1993, 6.0/L. Mean cladoceran length was significantly higher (Tukey HSD test, $P<0.05$) in 1990, 0.68 mm, than in 1992, 0.54 mm, for the sites combined. Mean cladoceran density across years for the Saginaw River, 43.4/L, was significantly higher (Tukey HSD test, $P<0.05$), than for any of the other sampling sites. Density at the Maumee River, 17.0/L, was also significantly higher than at the Clinton River, 1.3/L, and Huron River, 1.5/L. Mean cladoceran length was significantly higher for the Maumee River, 0.80 mm, than for any of the other rivers. The Saginaw River sampling site produced particularly high numbers of *Bosmina* spp. relative to the other sampling sites (Table 5). No trends in cladoceran densities or mean lengths were found at any of the sample sites.

Mean length of zooplankton was highest at the Saginaw and Maumee rivers and lowest at the Huron and Clinton rivers (Table 6). The Maumee site was the only one that consistently showed large average size and high density of cladoceran zooplankton which are considered ideal food for walleye fry.

The composition of the zooplankton assemblage varied between the river mouths sampled (Tables 7 and 8). The Maumee River was the only river mouth sampled that was dominated by daphnids and large rotifers. The Saginaw River was the only site dominated by *Bosmina* spp. The Thames River was dominated by cyclopoid copepods, while the Clinton River was dominated by calanoid copepods. The Huron River was the only site dominated by large rotifers.

Zebra mussel growth

Live zebra mussels were placed in test cages with individual compartments at the five river mouth sites in 1991-94. Cages were lost, due to storms or vandalism, at the Huron River in 1991 and 1994, and at the Saginaw River in 1992.

Length, width, height, and weight were measured for each animal before placement and, again, upon retrieval of cages. Relative daily growth rate in length and weight were calculated for each animal. Huron River growth rate was significantly higher than all other sites, while Clinton River growth was significantly lower (Table 9). Growth at the other rivers was highest at the Saginaw, moderate at the Maumee, and lower at the Thames.

Growth rates did not vary much during years of the study except that growth in 1992 was significantly lower than the other three years (Table 9). The highest growth rate occurred in 1993.

Growth of zebra mussels appeared to be a good monitor of plankton productivity which probably relates quite well to conditions important to plankton and walleye fry populations. Low growth rate in 1992 agrees with poor 1992 walleye year class strength in Lake Erie. High zebra mussel growth rates at the Saginaw and Maumee sites is consistent with their relative dense plankton populations and historical walleye reproductive success.

Zooplankton - Ponds and Fry Cages

Sampling in the South Selfridge Pond and outside the fry cages at the North Selfridge Pond and the Clinton River cage site revealed no significant differences (Tukey HSD test, $P<0.05$) in densities for any zooplankton group (Table 10). Densities for all zooplankton groups were higher inside the North Pond cage without fry, than in the cage with fry, but the difference was not statistically significant. However, mean zooplankton density inside the cage without fry in the Selfridge North Pond was significantly higher (Tukey HSD test, $P<0.05$) than in the South Pond.

Mean length of zooplankton found in the South Selfridge Pond and outside the fry cages at the North Selfridge Pond and the Clinton River Fire Dock did not differ significantly, although mean lengths were consistently highest for the North Pond and lowest for the Clinton River Fire Dock (Table 10). Mean length of calanoid copepods and cladocerans inside the North Pond fry cage without fry was significantly higher (Tukey HSD test, $P<0.05$) than inside the cage with fry. Overall zooplankton mean length inside the North Pond fry cage without fry was significantly higher (Tukey HSD test, $P<0.05$) than for any other sampling site.

Fry rearing

Fry did not survive beyond May 8th in the Clinton River cage so that portion of the study had to be terminated after five sampling episodes. Fry in the North and South ponds, outside cages, grew at very similar rates even though South Pond fry ate fewer, but larger, items (Figure 9). Apparently, the South Pond fry were able to grow as well even though their diet was very different. However, growth of North Pond caged-fry was quite different from their uncaged cohorts (Figure 10), which grew at a significantly faster rate (Tukey HSD test, $P<0.05$) even though caged fry ate significantly more items (Mann-Whitney U, $P<0.0001$). Food items eaten by fry inside the cage were significantly smaller (Mann-Whitney U, $P<0.0001$).

Fry growth and food habits were compared between the Clinton River cage and all other conditions during the shorter time interval they survived. Growth in the Clinton cage was significantly lower than all other sites (Tukey HSD test, $P < 0.05$), including those fry inside the cage in the North Pond (Figure 11). This difference is best explained by the fact that North Pond caged-fry ate more than twice as many cladocerans, a better food source, compared to the Clinton River caged-fry.

Walleye year-class strength, weather, and river discharge

Annual harvest estimates for adult walleye produced by the various fishery management agencies on Lake Erie were used to represent year class strength as the cumulative catch of each cohort over its life span. Cohorts that were either too young or too old to have their lifetime contribution represented in the harvest were adjusted according to their rank as catch at age-0 in the Ohio DNR summer trawl index program which covered a longer time period. This resulted in a consecutive series of lifetime harvest for 26 year classes from 1969 through 1994 (Figure 12). The largest Lake Erie year classes were produced in 1982, 1986, 1993, and 1994. Most of the other year classes were apparently moderate in size, while only the 1969, 1971, 1976, and 1989 could be labeled very weak.

Fall trap net index catch rates for walleye, collected by OMNR in Lake St. Clair, were used to rank year class strength for that lake. Data were available for survey years from 1970-94. Cohorts that had ages too young or too old to actually be represented in the catch were estimated from the percentage of the mean contribution at age adjusted by their percentage for ages that were present in the catch. From this procedure, a series of catch-per-effort values was generated for year classes 1969-91. These catch rates were converted to rank and percentage and compared with the same time series from Lake Erie (Table 11). There were many consistencies between the two lakes with the exception of the 1977 and 1986 year classes. The 1977 year class made up a relatively large percentage of the Lake St. Clair catch and a much smaller percentage of the Lake Erie catch. The 1986 year class showed the opposite pattern.

Walleye year class strength for Saginaw Bay was estimated from annual age samples collected by MDNR personnel from fish during the spawning run in the Tittabawassee River. We feel that year class ranking of the Saginaw Bay population is substantially weaker than the Lake Erie (best) or the Lake St. Clair due to short sampling duration and small sample size. Cohorts that were not fully represented, had their catch rates adjusted by catches in experimental gill net surveys conducted by MDNR personnel in Saginaw Bay. This procedure produced ranking and percentage contribution of 15 consecutive year classes from 1977-91 for Saginaw Bay walleye. These percentages were compared with similar values from Lake Erie and Lake St. Clair (Figure 13). Apparent year class strength in Saginaw Bay was not highly correlated with either Lake Erie or Lake St. Clair. Relatively strong year classes were produced in 1979 and 1985, while others were moderate and of very similar proportions.

Daily weather data from Toledo, Ohio, Mt. Clemens, Michigan, and Saginaw, Michigan were summarized to look for patterns that might relate to walleye spawning success. Monthly averages of heating degree days, snowfall, and precipitation were examined over the period from 1968-95 to compare with strengths of walleye year classes. Monthly values from the Toledo Airport are shown in Appendix Figures 2-4. Data from the other two airports was summarized in similar fashion. We also thought that more specific, short term, daily weather patterns might be related to plankton populations and spawning success. Daily minimum and maximum temperature were plotted for the period from January 1st to July 1st each year and compared to the long-term daily averages (see Appendix Figures 5-9 for Toledo weather station).

Comparison of Toledo, Ohio, weather patterns with Lake Erie walleye year class strength indicators revealed several relationships. Strong year classes followed winters with significantly colder temperatures (Tukey HSD test, $P>0.05$). Strong year classes also followed winters with significantly higher mean monthly snowfall totals (Tukey HSD test, $P>0.05$). In addition, there is some indication that warmer spring temperatures promote strong walleye year classes in Lake Erie.

Mt. Clemens, Michigan, weather patterns were compared with Lake St. Clair walleye year class strength. Strong walleye year classes in Lake St. Clair followed winters with significantly lower daily mean maximum temperatures, daily mean minimum temperatures, and daily mean heating degree days (t-test, $P<0.01$). No significant difference in snowfall during winters preceding strong and weak year classes was evident.

We found no significant differences in weather patterns between years of strong walleye year class strength indicators and weak year class strength indicators for Saginaw Bay. Problems with accuracy of walleye year class strength indicators for Saginaw Bay could play a role in the lack of discernible weather influences on walleye spawning success in the bay.

In light of documented walleye movement between Lake Erie, Lake St. Clair, and Saginaw Bay, and the geographical proximity of these water bodies, we compared the walleye year class strength indicators used for each lake in the above weather pattern analyses. This evaluation revealed close significant correlation ($P=0.01$) between Lake St. Clair and Lake Erie walleye year class strength indicators. In contrast, Saginaw Bay walleye year class strength indicators did not correlate significantly with either Lake Erie or Lake St. Clair indicators. This may also be a result of weak indicators of walleye year class strength for Saginaw Bay.

River discharge

River discharge data during 1990-94 from each site were summarized by month and plotted with the long-term average monthly discharge to look for unusual patterns that might relate to walleye reproductive success (Appendix Figures 10-14). Average flow rates during the study period were highest in the Maumee (5,622 $ft^3 \cdot sec^{-1}$), moderate in the Tittabawassee (2,093 $ft^3 \cdot sec^{-1}$) and Thames (1,993 $ft^3 \cdot sec^{-1}$), and low in the Huron (831 $ft^3 \cdot sec^{-1}$) and Clinton (770 $ft^3 \cdot sec^{-1}$) rivers (Table 12). Rivers had similar monthly patterns of discharge with the highest flow in March and April and lowest in August, September, and October. The highest flow rates occur during the period of walleye spawning, egg incubation, and fry dispersal. Winter flow rates were considerably higher than summer which may also be important to walleye spawning behavior.

The Tittabawassee River had unusually high winter and spring flow during 1991-93, while 1990 and 1994 were about average (Appendix Figure 10). The Clinton River only had unusually high winter and spring flow in 1993, which was preceded by relatively high summer and fall (1992) flows (Appendix Figure 11). The Thames River did not have any spring flows greater than the long-term mean during the study period. Thames flow during the fall and winter of 1990-91 and 1992-93 were above average (Appendix Figure 12). The Huron River showed average or below average discharges during all five study years (Appendix Figure 13). The Maumee River had unusually high winter or spring flow during all study years except 1992 (Appendix Figure 14).

Future considerations

Estimates of year class strength from trawl catches or other samples of juvenile fish are tentative. Therefore, we plan to reexamine the data after adult estimates become available. Consequently, the remainder of field work will involve improving estimates of walleye reproductive success and survival for the 1990-94 cohorts from representative aged adult samples collected in the fisheries in Lake Erie or from index netting in all three lakes. By the year 2000, these cohorts should have completed their major contribution to the adult stock so that reliable estimates of year class strength can be made.

This report presents interim results since the study is little more than half completed. The field portion of the study will be finished in 1999 and the final report, a companion to this document, will be prepared in the year 2000. That report will contain a thorough discussion of the data and results presented here including a complete literature review.

Acknowledgments

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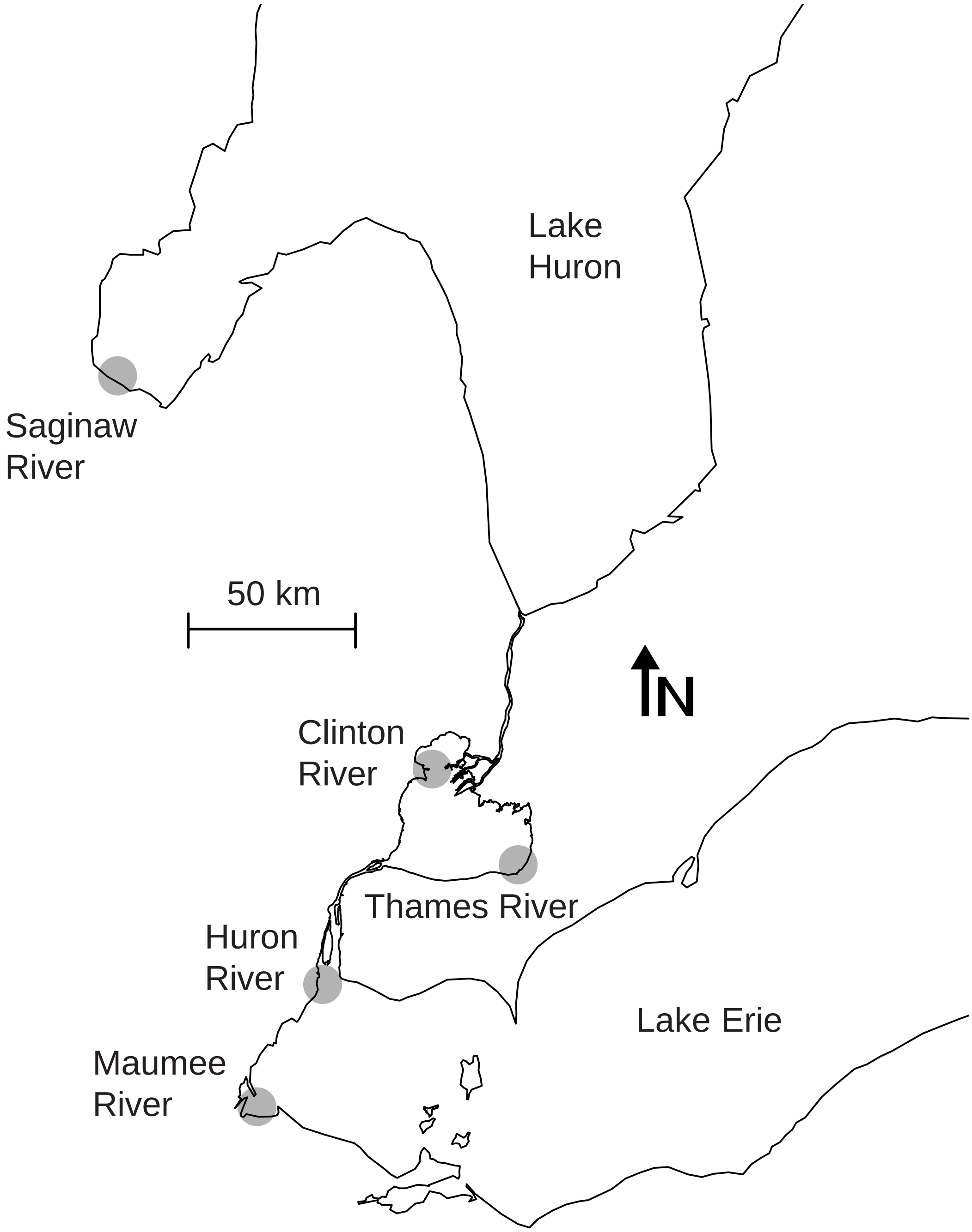

Figure 1.—Geographical location of river mouth sampling sites on Saginaw Bay, Lake Huron (Saginaw River), Lake St. Clair (Clinton and Thames rivers), and Lake Erie (Huron and Maumee rivers).

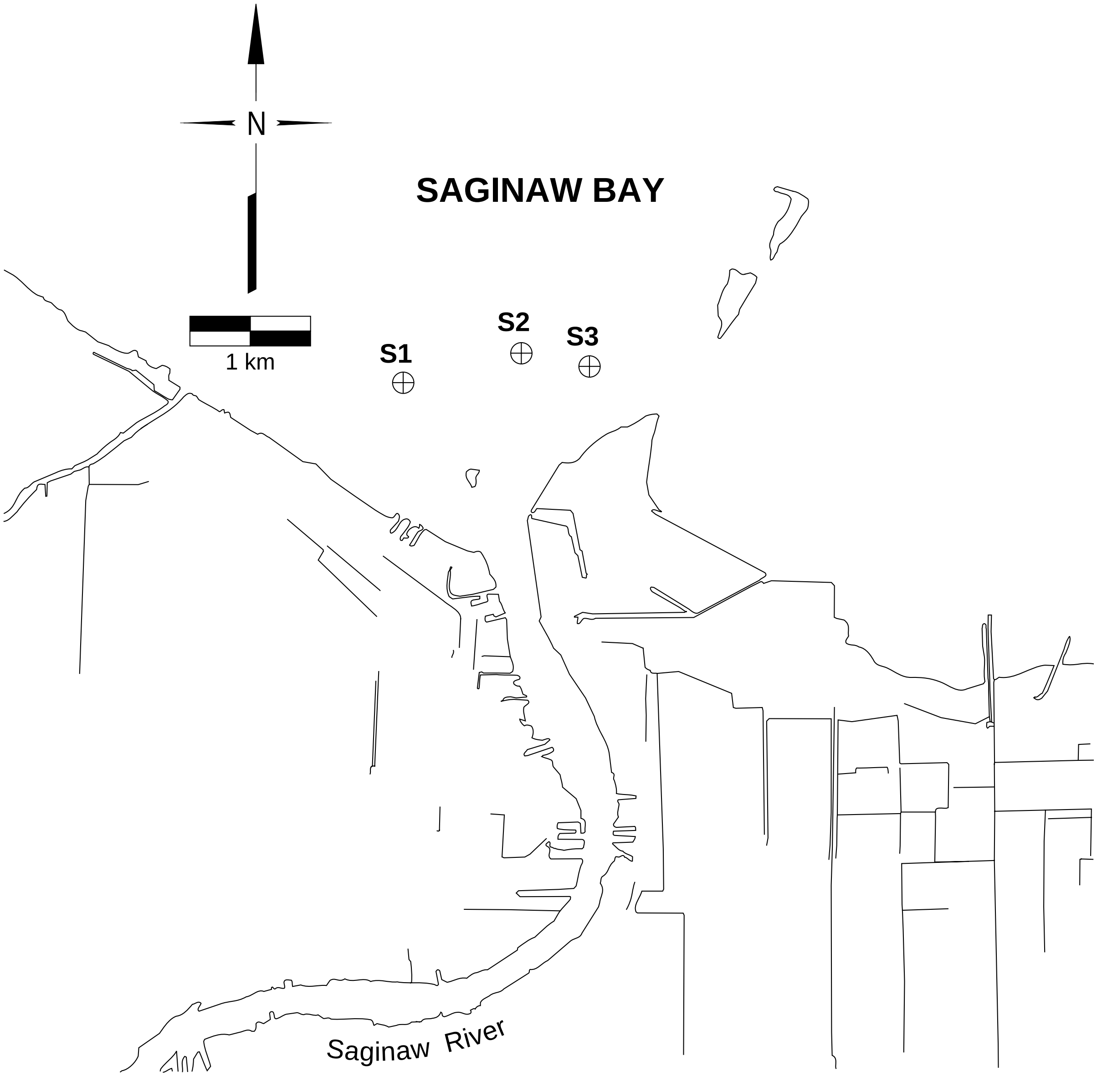

Figure 2.—Geographical location of three sampling sites at the Saginaw River estuary from which composite nutrient and plankton data were collected. Site S1 was located at 43^0 39.55’ N latitude and 83^0 51.63’ W longitude. Site S2 was located at 43^0 39.68’ N latitude and 83^0 50.90’ W longitude. Site S3 was located at 43^0 39.62’ N latitude and 83^0 50.48’ W longitude.

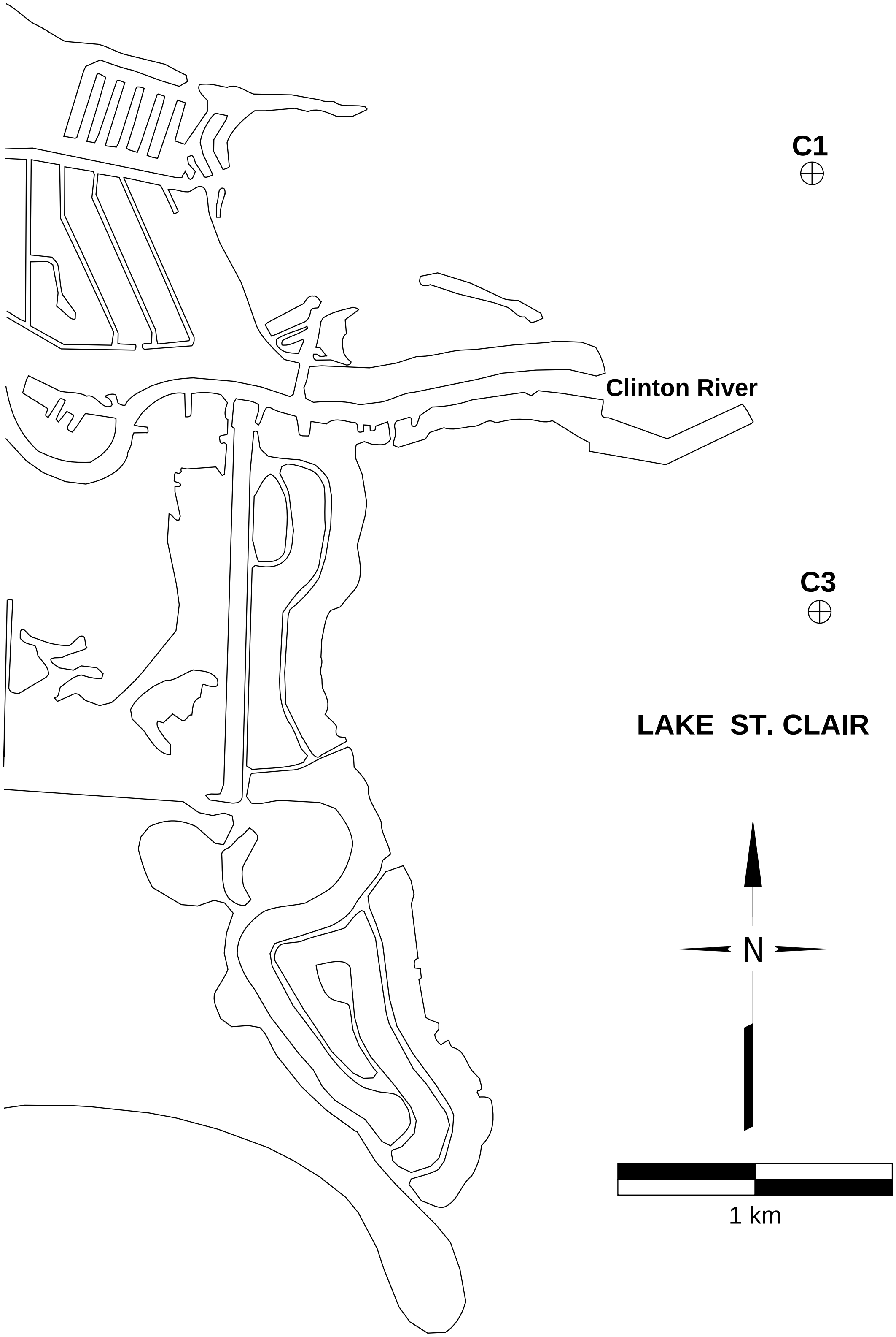

Figure 3.—Geographical location of three sampling sites at the Clinton River estuary from which composite nutrient and plankton data were collected. Site C1 was located at 42^0 36.10’ N latitude and 82^0 46.00’ W longitude. Site C2 was located at 42^0 35.62’ N latitude and 82^0 45.52’ W longitude. Site C3 was located at 42^0 35.23’ N latitude and 82^0 46.00’ W longitude.

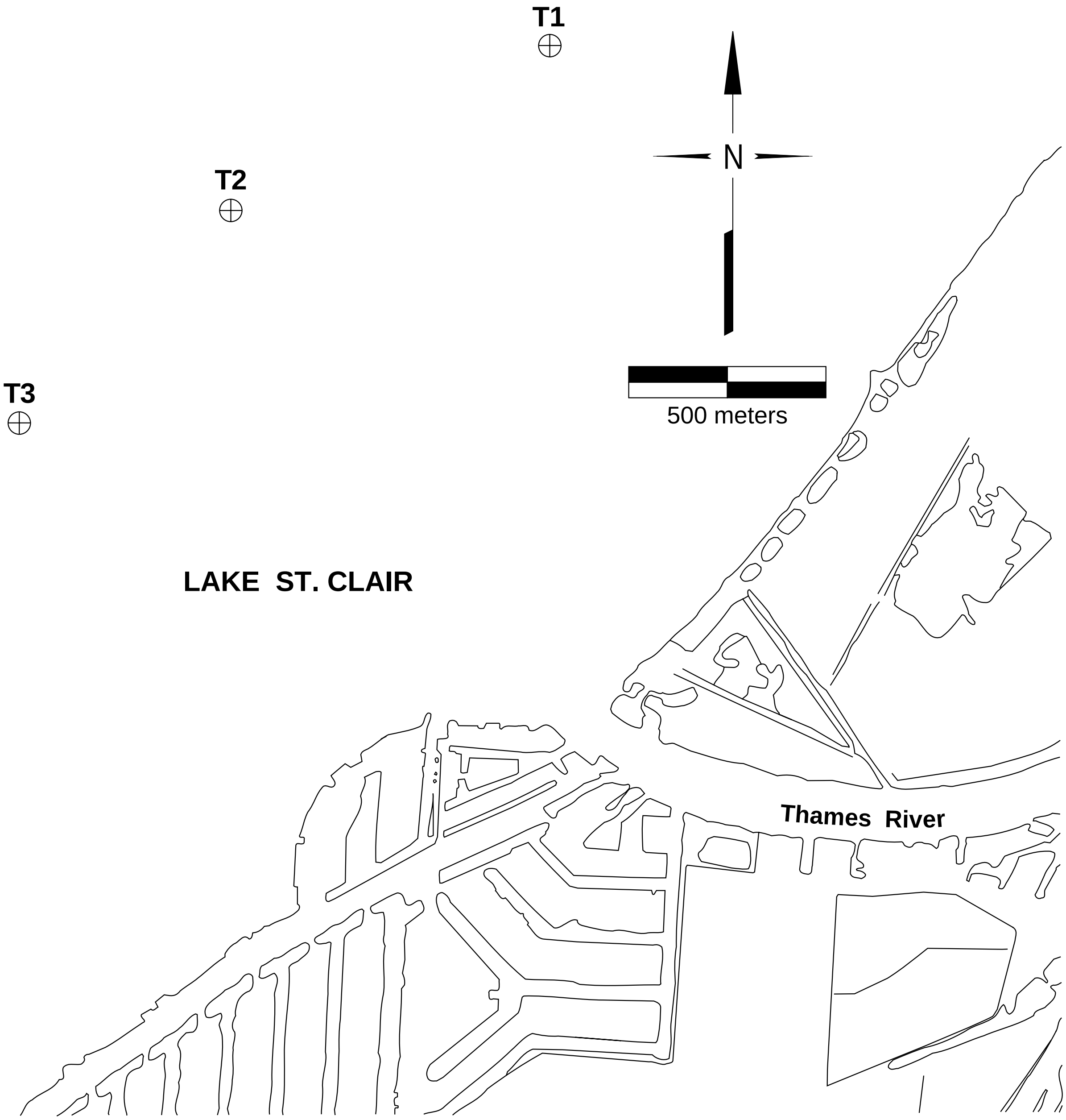

Figure 4.—Geographical location of three sampling sites at the Thames River estuary from which composite nutrient and plankton data were collected. Site T1 was located at 42^0 20.08’ N latitude and 82^0 27.33’ W longitude. Site T2 was located at 42^0 19.83’ N latitude and 82^0 27.92’ W longitude. Site T3 was located at 42^0 19.53’ N latitude and 82^0 28.30’ W longitude.

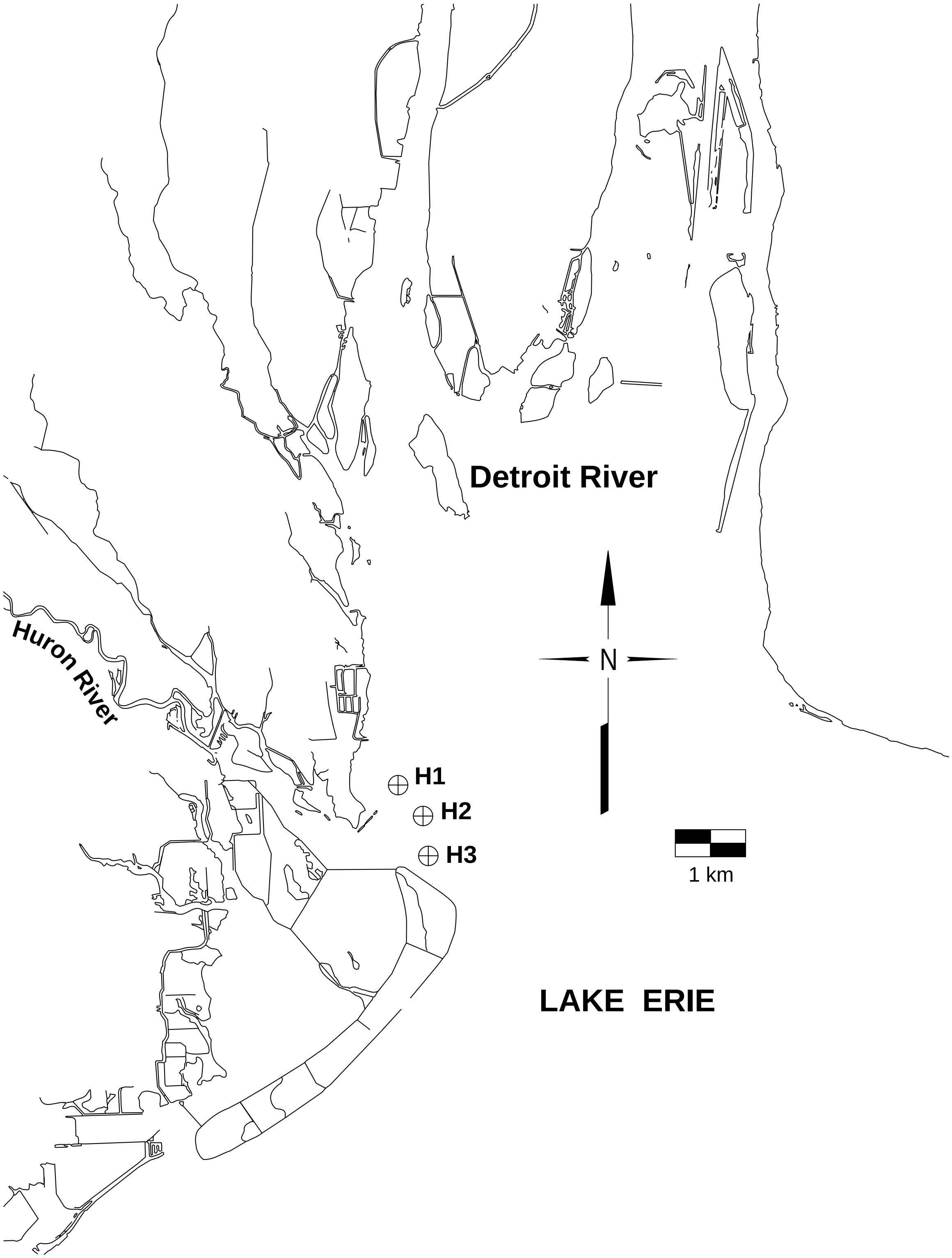

Figure 5.—Geographical location of three sampling sites at the Huron River estuary from which composite nutrient and plankton data were collected. Site H1 was located at 42^0 02.25' N latitude and 83^0 10.88' W longitude. Site H2 was located at 42^0 02.00' N latitude and 83^0 10.62' W longitude. Site H3 was located at 42^0 01.68' N latitude and 83^0 10.57' W longitude.

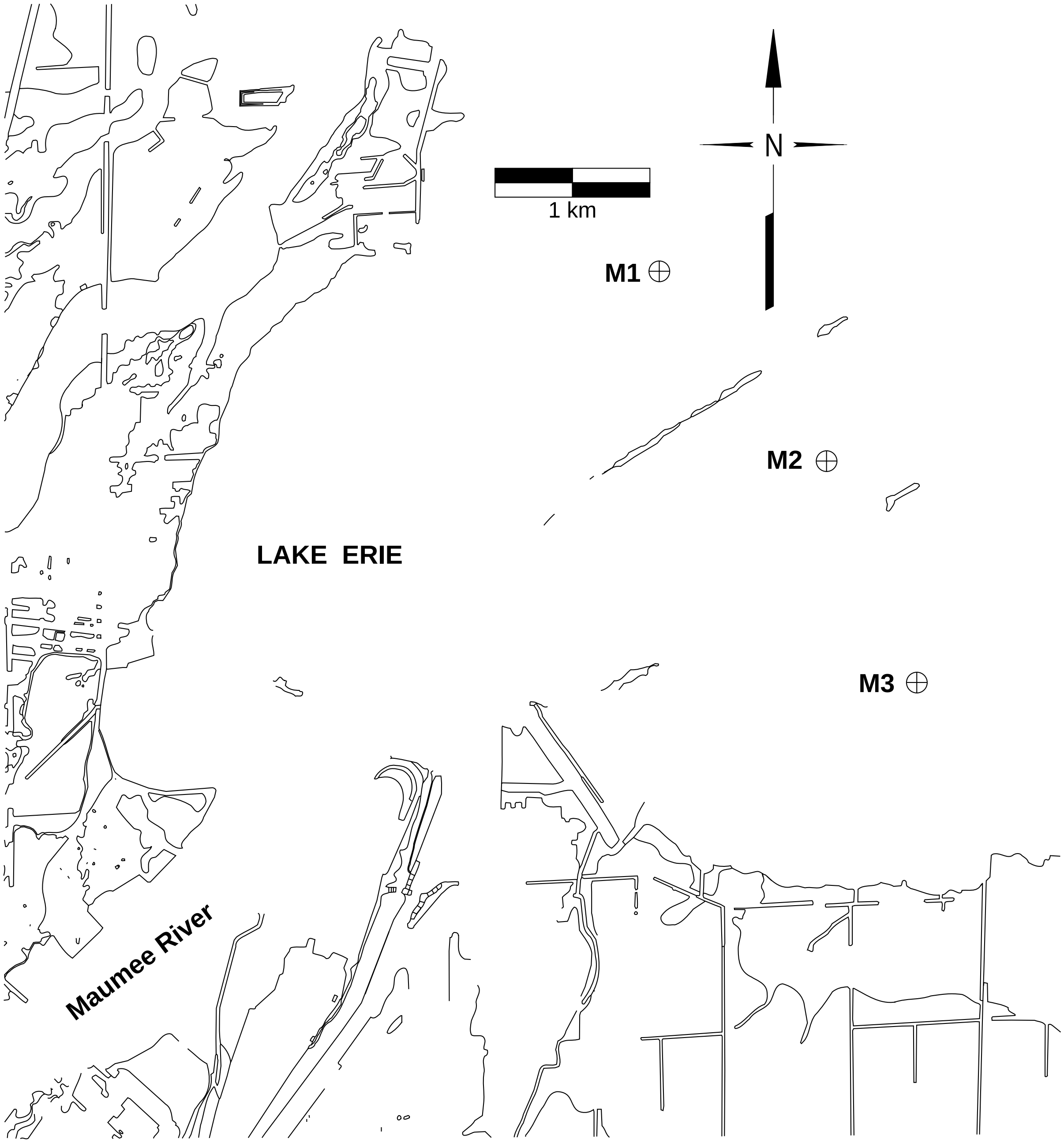

Figure 6.—Geographical location of three sampling sites at the Maumee River estuary from which composite nutrient and plankton data were collected. Site M1 was located at 41^0 43.57’ N latitude and 83^0 26.20’ W longitude. Site M2 was located at 41^0 42.92’ N latitude and 83^0 25.40’ W longitude. Site M3 was located at 41^0 42.15’ N latitude and 83^0 24.95’ W longitude.

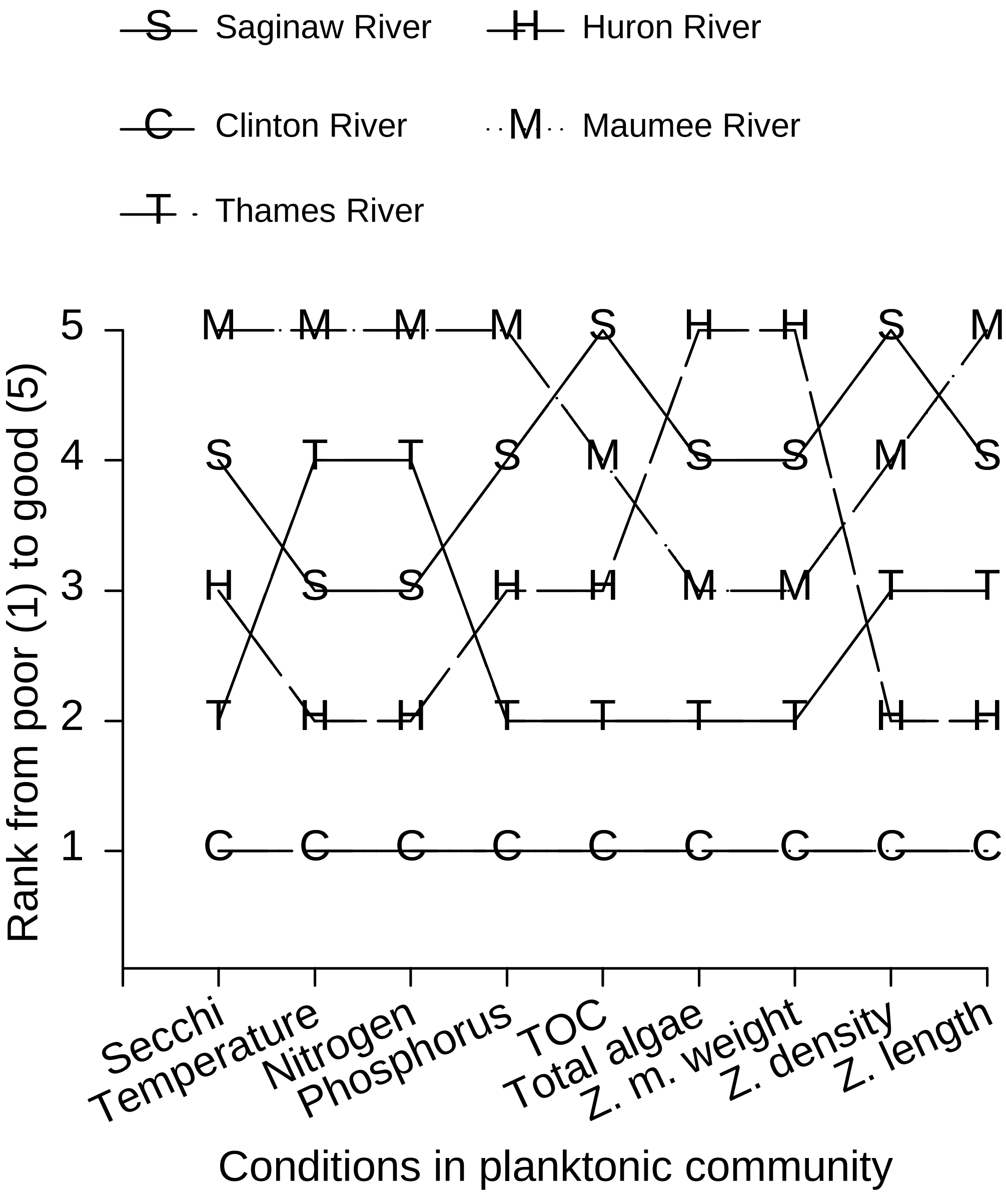

Figure 7.—Comparative ranking of five walleye spawning rivers from poor (oligotrophic) to good (eutrophic) based on Secchi depth; temperature; concentrations of nitrate/nitrite, phosphorus, and organic carbon; density of phytoplankton; growth of caged zebra mussels; and mean zooplankton density and length.

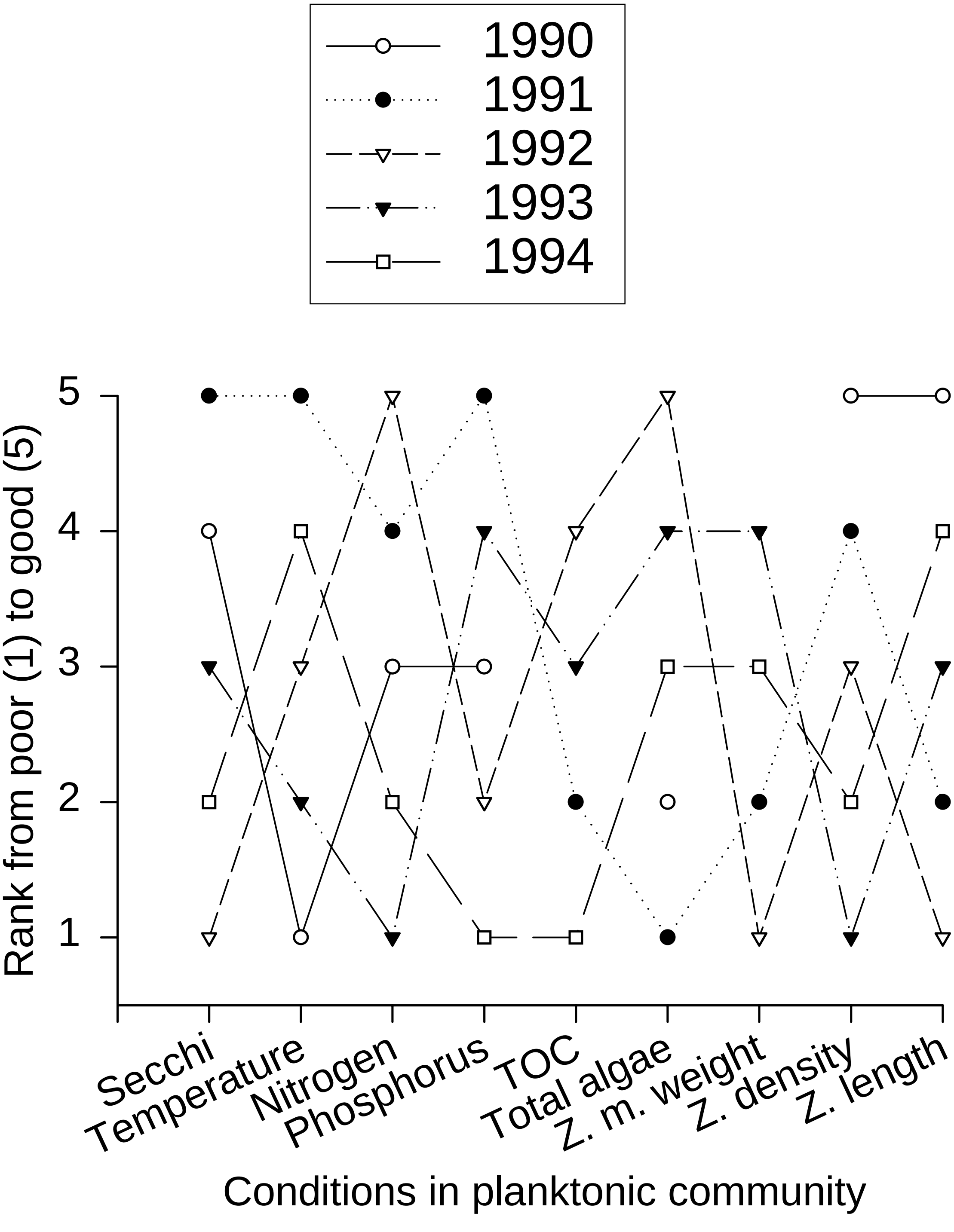

Figure 8.—Comparative ranking of five survey rivers from poor (oligotrophic) to good (eutrophic) based on Secchi depth; temperature; concentrations of nitrate/nitrite, phosphorus, and organic carbon; density of phytoplankton; growth of caged zebra mussels; and mean zooplankton density and length.

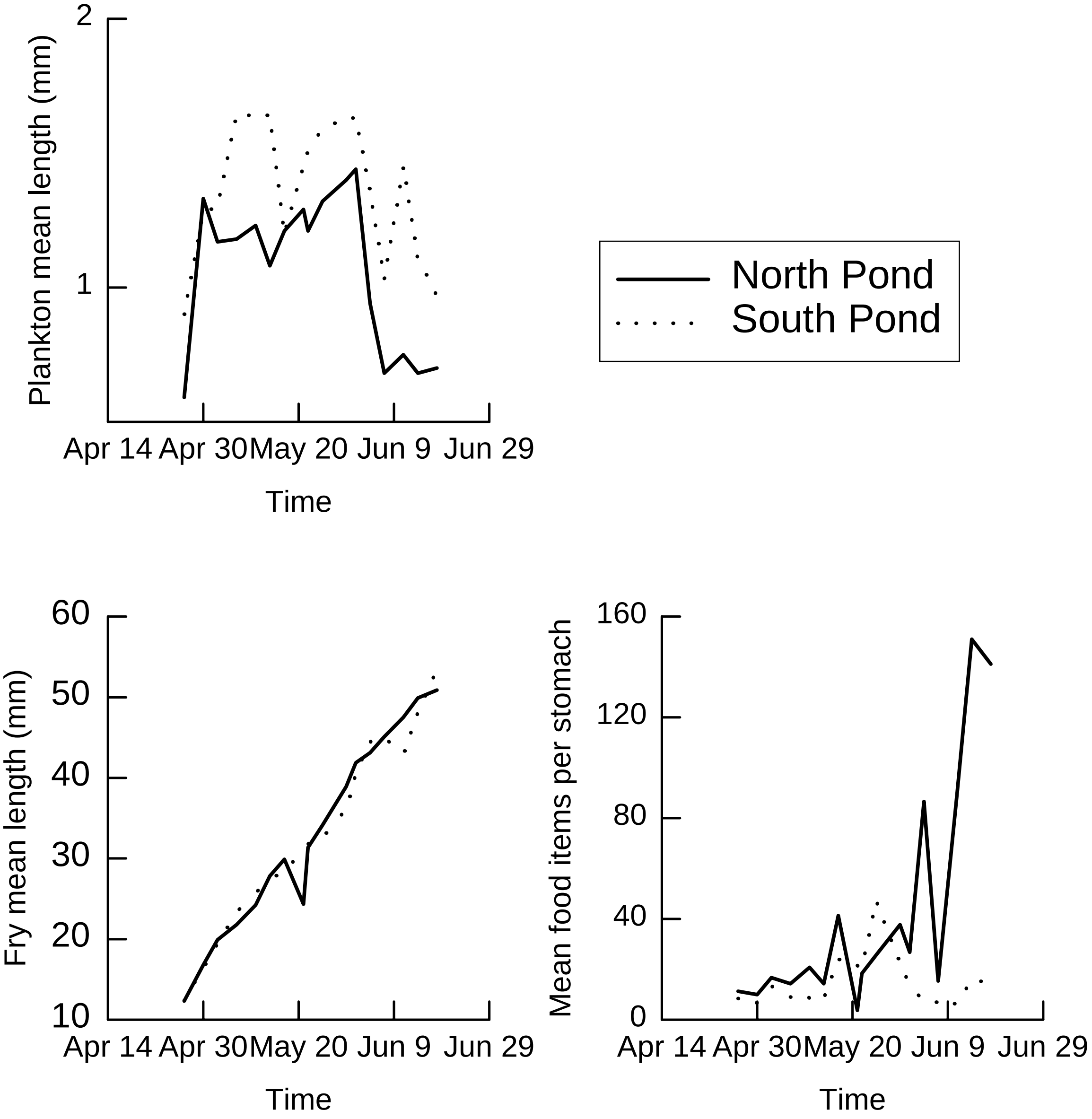

Figure 9.—Walleye fry mean length, mean number of food items per stomach, and mean size of plankton in stomachs from Selfridge Air Base during spring, 1990. Solid lines indicate data from the North Pond and dotted lines indicate data from the South Pond.

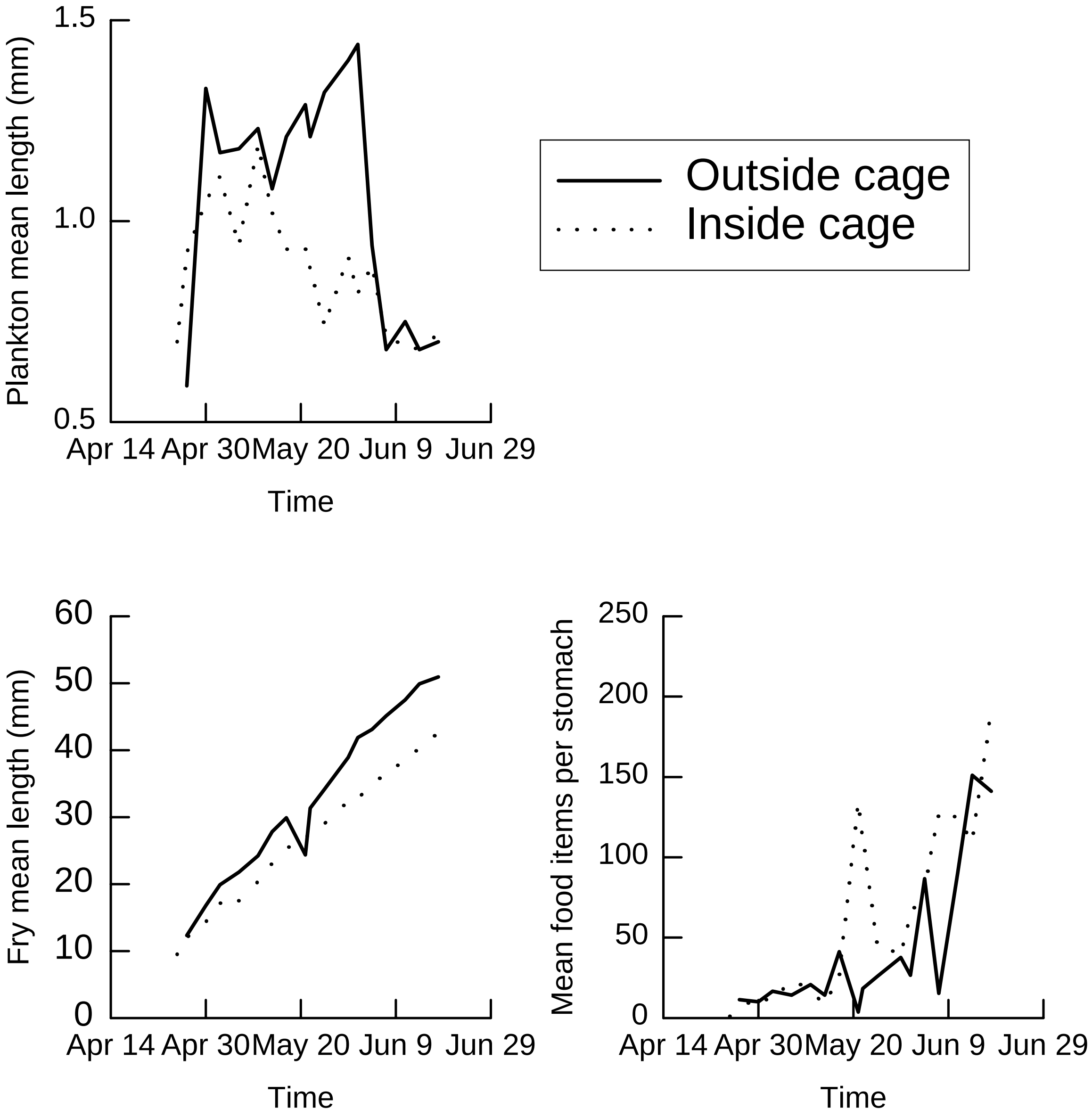

Figure 10.—Walleye fry mean length, mean number of food items per stomach, and mean size of plankton in stomachs from the North Pond at Selfridge Air Base during spring, 1990. Solid lines indicate data from fry caught outside the cage while dotted lines indicate data from fry caught inside the east cage.

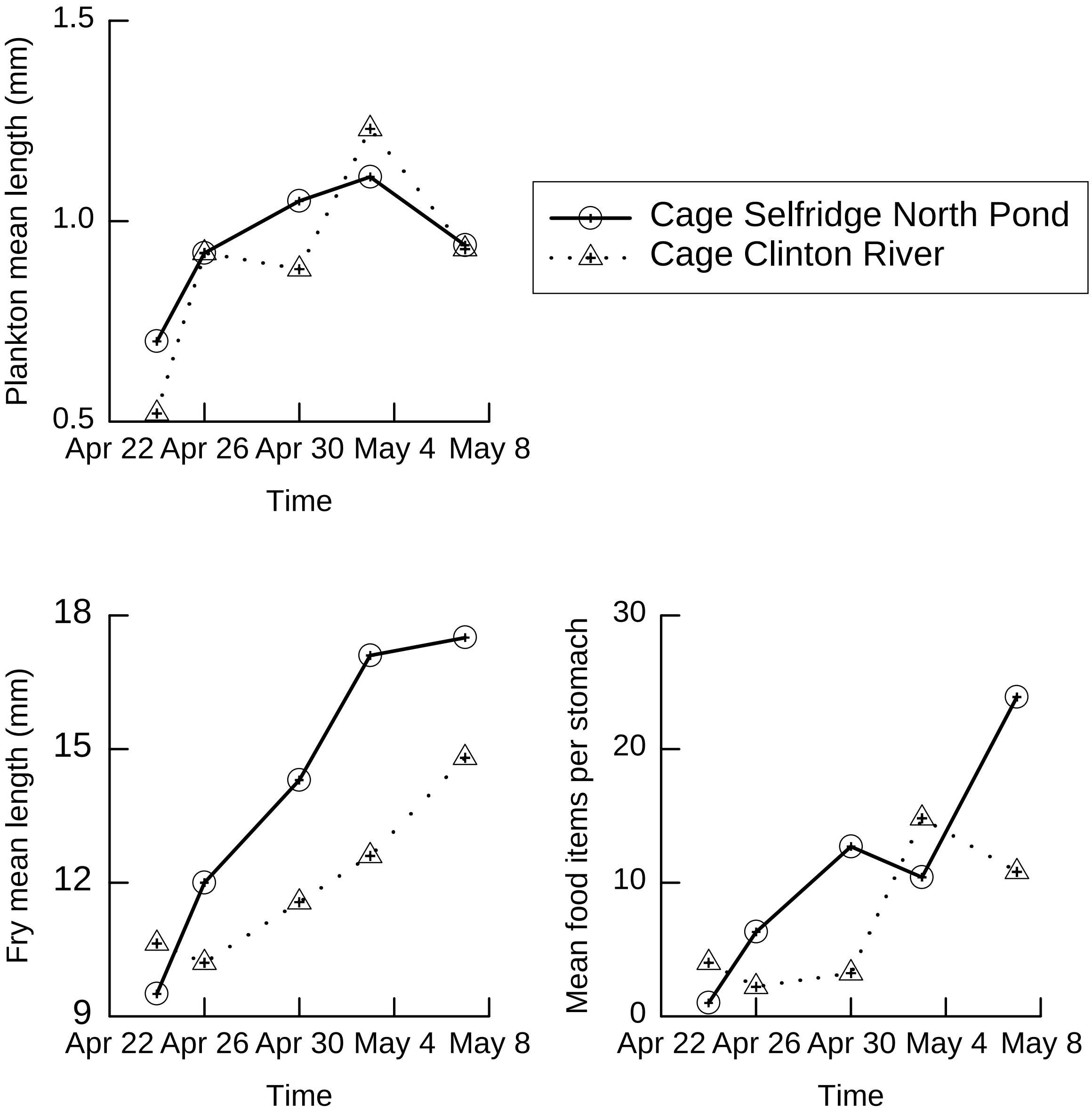

Figure 11.—Walleye fry mean length, mean number of food items per stomach, and mean size of plankton in stomachs from caged fish during spring, 1990. Solid lines indicate data from fry caught in the North Pond's east cage at Selfridge Air Base while dotted lines indicate data from fry caught in the Clinton River cage.

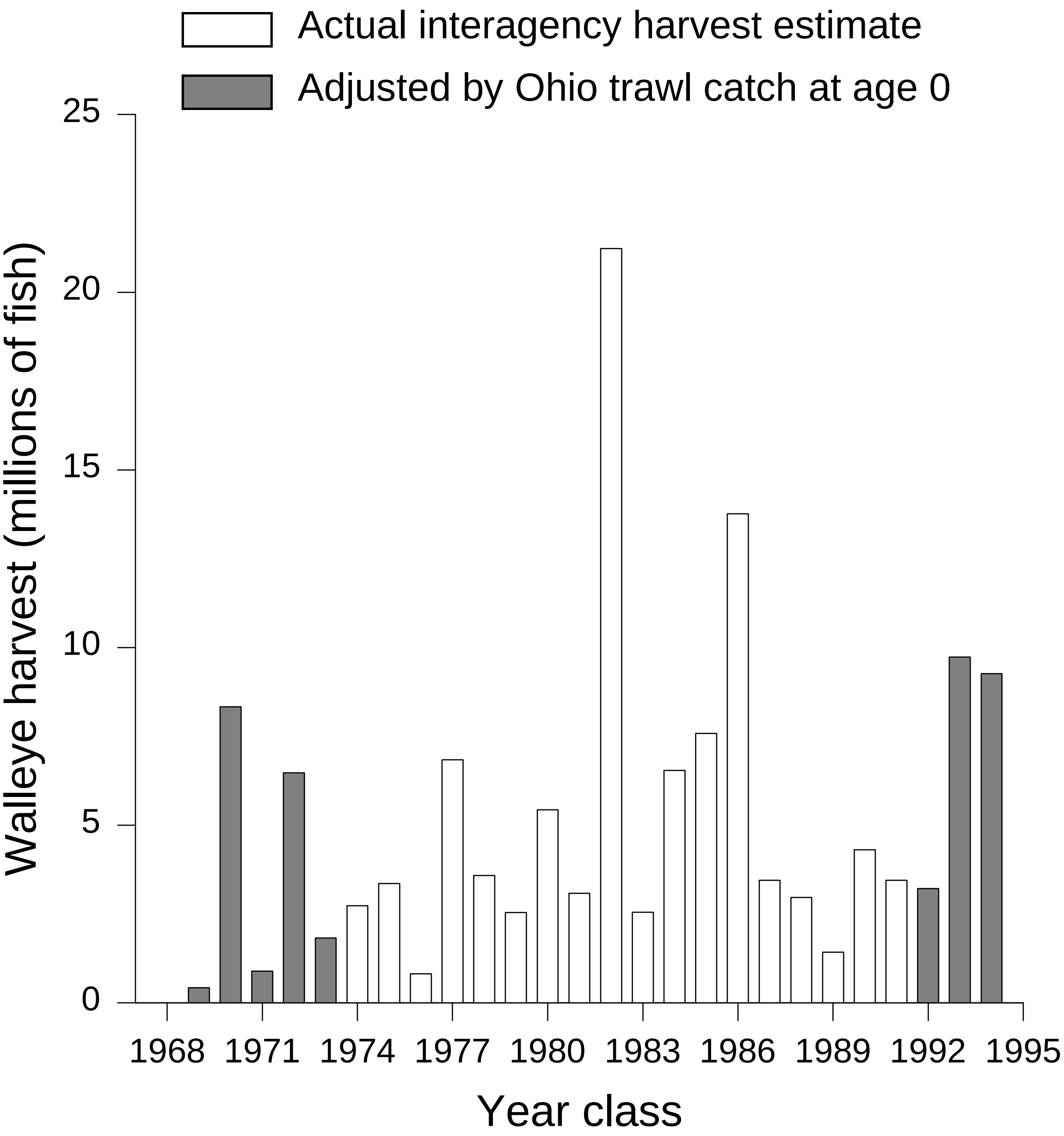

Figure 12.—Total harvest of 26 consecutive year classes of walleye from western Lake Erie. Data fro the 1974-91 cohorts were taken from the Interagency database maintained by the Lake Erie Committee of the Great Lakes Fishery Commission. Harvest of remaining cohorts was adjusted by Ohio DNR summer trawl catches of age-0 walleye.

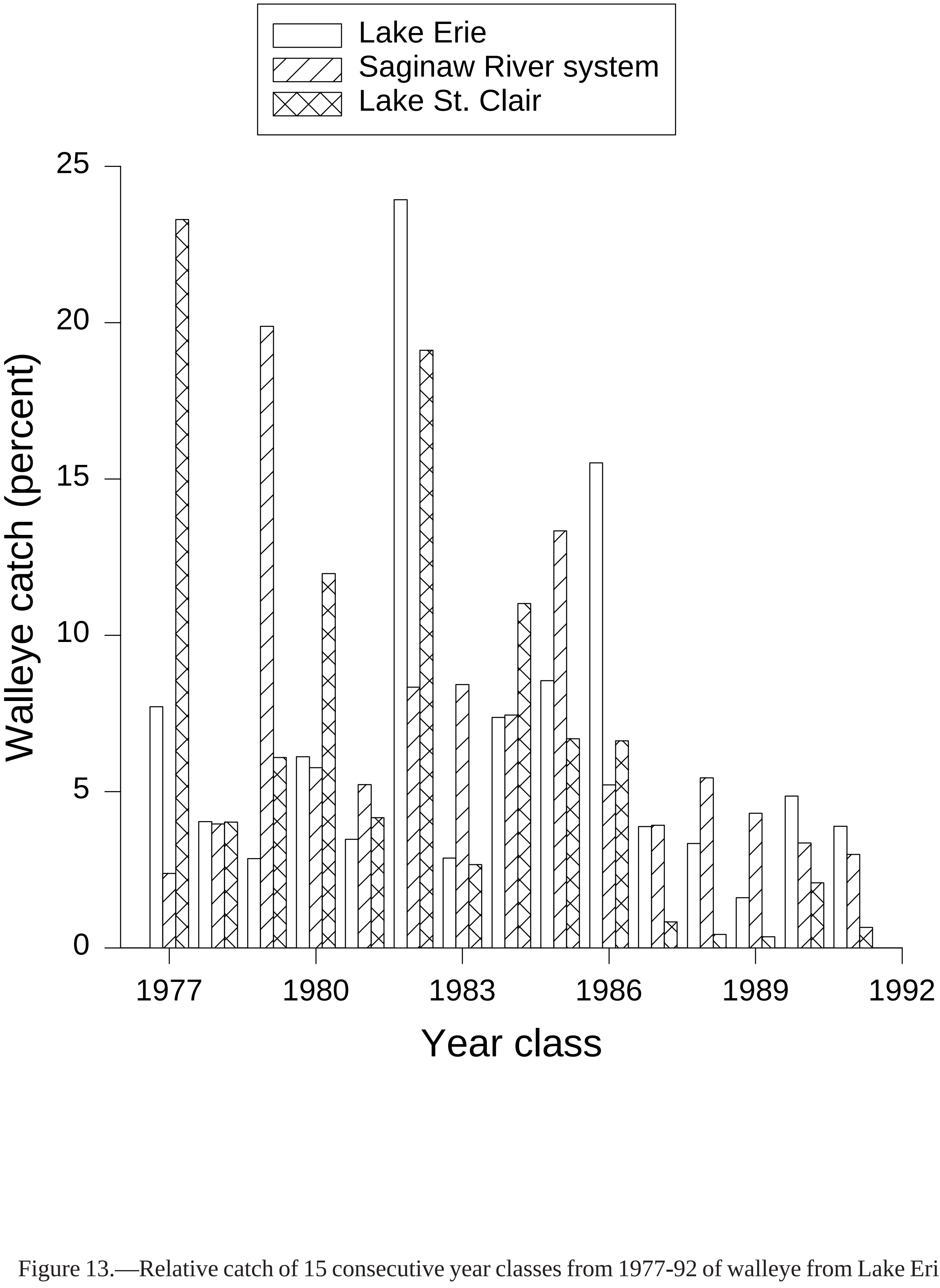

Figure 13.—Relative catch of 15 consecutive year classes from 1977-92 of walleye from Lake Erie, Lake St. Clair, and Saginaw Bay. Lake Erie data are a subset of data presented in Figure 12. Lake St. Clair and Saginaw Bay data were derived from long-term index netting programs of the Ontario Ministry of Natural Resources and MDNR.

Table 1.–Mean spring (April to June) water chemistry measurements for the five study rivers. Nutrient concentrations are given in mg/L.

		Productive walleye rivers			Unproductive walleye rivers	
	Year	Maumee River	Saginaw River	Thames River	Huron River	Clinton River
Secchi depth (m)	1990	0.42	0.50	0.66	0.88	1.69
	1991	0.34	0.46	1.07	0.53	1.20
	1992	0.42	0.87	0.95	0.83	1.60
	1993	0.36	0.73	0.94	0.72	1.76
	1994	0.59	1.07	0.84	0.73	1.61
Water temp (C)	1990	15.20	16.20	14.40	15.70	11.75
	1991	17.24	20.44	18.27	18.25	16.82
	1992	17.25	16.31	16.61	16.98	13.46
	1993	17.25	14.54	16.59	15.88	13.65
	1994	16.09	16.06	18.70	14.67	16.09
Nitrate/nitrite	1990	4.91	0.76	2.07	0.41	0.30
	1991	4.63	1.15	2.03	0.52	0.33
	1992	6.36	1.00	1.77	0.48	0.39
	1993	2.80	0.80	1.35	0.39	0.29
	1994	2.41	1.73	1.68	0.36	0.31
Ammonia	1990	0.23	0.08	0.03	0.33	0.01
	1991	0.19	0.10	0.03	0.25	0.02
	1992	0.25	0.13	0.09	0.22	0.02
	1993	0.17	0.11	0.04	0.19	0.02
	1994	0.28	0.14	0.03	0.21	0.03
Phosphorus	1990	0.16	0.08	0.05	0.05	0.02
	1991	0.20	0.11	0.05	0.07	0.02
	1992	0.15	0.07	0.04	0.06	0.02
	1993	0.19	0.08	0.07	0.08	0.01
	1994	0.12	0.08	0.05	0.06	0.02
Silica	1990	2.11	0.49	0.37	0.83	0.48
	1991	2.16	1.43	0.77	0.62	0.43
	1992	1.80	0.57	0.49	0.58	0.36
	1993	1.50	1.07	0.44	0.61	0.42
	1994	0.83	0.55	0.36	0.40	0.47
TOC	1990	–	–	–	–	–
	1991	7.63	9.66	3.70	4.01	2.43
	1992	14.48	15.04	4.13	4.77	2.94
	1993	7.88	13.57	3.91	4.99	2.53
	1994	6.13	7.00	3.44	4.31	2.50
N/P ratio	1990	35.51	9.65	49.30	8.65	19.89
	1991	23.10	10.63	42.80	7.98	17.75
	1992	41.46	15.22	44.09	8.14	23.52
	1993	14.61	10.19	20.28	5.22	21.12
	1994	20.02	14.96	35.45	6.10	17.24

Table 2.–Spring planktonic algae densities (cells/ml) for five study rivers.

		Productive walleye rivers			Unproductive walleye rivers	
Taxa	Year	Maumee River	Saginaw River	Thames River	Huron River	Clinton River
Green algae	1990	1,024	2,656	582	1,083	246
	1991	424	1,114	90	643	72
	1992	2,890	3,681	456	3,386	87
	1993	4,095	1,798	769	4,230	124
	1994	2,941	1,301	1,093	2,604	100
Flagellates	1990	422	608	283	406	44
	1991	249	689	194	217	48
	1992	1,378	2,235	1,031	621	39
	1993	1,228	1,853	4,069	2,100	153
	1994	1,682	1,940	2,030	1,574	260
Yellow-brown algae	1990	203	196	191	315	447
	1991	39	160	56	62	83
	1992	102	184	230	564	282
	1993	55	158	105	415	88
	1994	65	21	87	123	29
Diatoms	1990	645	2,871	729	1,389	554
	1991	114	559	198	378	137
	1992	1,519	2,760	866	6,616	617
	1993	1,217	2,220	1,979	5,989	456
	1994	2,349	2,045	1,582	4,962	338
Bluegreen algae	1990	284	1,880	281	320	46
	1991	42	473	29	159	7
	1992	1,540	899	614	2,168	12
	1993	144	312	121	653	22
	1994	716	225	305	493	17
Total cells/ml	1990	2,698	8,177	2,240	3,556	1,351
	1991	867	2,995	567	1,460	347
	1992	7,429	9,760	3,198	13,355	1,038
	1993	6,740	6,342	7,042	13,386	843
	1994	7,754	5,532	5,097	9,756	744

Table 3.–Mean spring phytoplankton densities (cells/ml) for five study rivers during spring, 1990-94.

	Productive walleye rivers			Unproductive walleye rivers	
	Maumee	Saginaw	Thames	Huron	Clinton
Total algae	5,198	6,409	3,618	8,123	880
Green	2,310	2,047	601	2,343	124
Diatom	1,201	2,042	1,071	3,781	430
Flagellate	1,020	1,463	1,528	984	106
Yellow-brown	89	142	128	283	196
Bluegreen	561	721	257	723	21

Table 4.–Mean spring phytoplankton densities (cells/ml) for five years at combined sites.

	1990	1991	1992	1993	1994
Total algae	3,734	1,247	6,936	6,859	5,889
Green	1,152	468	2,110	2,194	1,644
Diatom	1,290	277	2,451	2,369	2,299
Flagellate	363	279	1,052	1,880	1,519
Yellow-brown	291	80	272	164	66
Bluegreen	579	142	1,051	252	360

Table 5.–Spring zooplankton densities (individuals/L) for five study rivers.

		Productive walleye rivers			Unproductive walleye rivers	
Taxa	Year	Maumee River	Saginaw River	Thames River	Huron River	Clinton River
Rotifers	1990	2.961	10.047	2.727	3.976	1.324
	1991	4.724	4.545	1.894	2.570	2.387
	1992	7.378	18.213	1.230	3.790	2.902
	1993	12.240	10.902	2.972	6.070	0.370
	1994	7.118	5.284	1.749	7.396	0.090
Cyclopoid copepods	1990	3.113	19.629	5.872	1.177	1.150
	1991	2.376	14.067	4.759	0.799	1.747
	1992	7.251	15.279	3.154	0.674	1.384
	1993	4.124	9.302	11.720	1.023	0.936
	1994	7.955	14.750	4.558	1.801	0.435
Calanoid copepods	1990	1.136	1.287	4.866	0.866	1.830
	1991	1.340	0.979	6.844	0.319	2.756
	1992	0.406	1.473	2.486	0.246	1.653
	1993	0.764	0.835	5.710	0.141	2.112
	1994	1.804	1.133	1.509	0.273	0.565
Cladocerans	1990	4.713	68.564	3.351	1.375	0.959
	1991	5.268	27.150	4.751	1.649	2.851
	1992	8.078	44.840	1.928	0.538	4.743
	1993	5.347	7.685	4.507	0.726	0.278
	1994	16.015	19.822	3.481	1.630	0.265
Daphnids	1990	3.416	3.121	1.745	0.221	0.113
	1991	3.604	2.359	3.478	0.128	0.210
	1992	6.373	1.050	0.083	0.096	0.045
	1993	4.662	0.458	2.106	0.169	0.110
	1994	12.709	1.499	0.960	0.373	0.020
Bosmina	1991	1.311	20.462	1.039	1.272	2.432
	1992	0.878	41.375	1.757	0.253	0.511
	1993	0.241	6.302	2.209	0.363	0.136
	1994	1.376	17.563	2.364	0.801	0.213
Total zooplankton	1990	12.850	102.237	19.355	8.188	6.876
	1991	15.312	49.657	23.444	5.866	12.294
	1992	25.603	86.583	11.163	5.817	8.372
	1993	23.701	30.921	35.130	8.747	6.040
	1994	37.132	44.364	14.195	12.683	1.710

Table 6.–Spring zooplankton mean length (mm) for five study rivers.

		Productive walleye rivers			Unproductive walleye rivers	
Taxa	Year	Maumee River	Saginaw River	Thames River	Huron River	Clinton River
Rotifers	1990	0.292	0.284	0.306	0.253	0.384
	1991	0.294	0.285	0.281	0.236	0.270
	1992	0.257	0.283	0.310	0.213	0.229
	1993	0.234	0.288	0.269	0.218	0.269
	1994	0.288	0.276	0.282	0.250	0.239
Cyclopoid copepods	1990	0.753	0.692	0.669	0.659	0.729
	1991	0.777	0.737	0.687	0.672	0.669
	1992	0.691	0.605	0.614	0.663	0.649
	1993	0.647	0.662	0.667	0.577	0.646
	1994	0.697	0.642	0.618	0.618	0.671
Calanoid copepods	1990	0.898	0.863	0.795	0.797	0.854
	1991	0.899	1.008	0.829	0.912	0.841
	1992	0.998	0.896	0.753	0.836	0.821
	1993	1.044	0.839	0.867	0.834	0.746
	1994	0.958	0.913	0.825	1.003	0.858
Cladocerans	1990	0.913	0.379	0.701	0.423	0.525
	1991	0.862	0.423	0.756	0.371	0.402
	1992	0.908	0.338	0.353	0.462	0.590
	1993	0.934	0.386	0.583	0.518	0.544
	1994	0.943	0.388	0.500	0.533	0.398
Daphnids	1990	1.074	0.918	0.911	0.731	0.868
	1991	1.055	0.985	0.861	0.720	0.933
	1992	1.004	0.816	0.832	0.930	0.905
	1993	0.991	0.869	0.839	0.960	0.803
	1994	1.048	0.842	0.851	0.960	0.773
Bosminids	1991	0.366	0.370	0.367	0.329	0.342
	1992	0.369	0.330	0.335	0.348	0.351
	1993	0.356	0.359	0.348	0.337	0.348
	1994	0.374	0.343	0.335	0.355	0.347
All zooplankton	1990	0.690	0.434	0.608	0.403	0.578
	1991	0.623	0.504	0.615	0.405	0.494
	1992	0.606	0.383	0.545	0.335	0.448
	1993	0.501	0.446	0.537	0.309	0.508
	1994	0.838	0.854	0.786	0.686	0.675

Table 7.–Mean spring zooplankton densities (Number/L) and length (mm) for five study rivers during spring, 1990-94.

	Productive walleye rivers			Unproductive walleye rivers	
	Maumee	Saginaw	Thames	Huron	Clinton
			Density		
All zooplankton	6.9	12.2	4.9	1.7	1.5
Cyclopoid copepods	7.8	16.2	9.4	1.4	1.4
Calanoid copepods	2.2	1.4	5.4	0.4	2.2
Cladocerans	17.0	43.4	6.6	1.5	1.3
			Length		
All zooplankton	0.61	0.58	0.55	0.55	0.54
Cyclopoid copepods	0.80	0.78	0.79	0.72	0.81
Calanoid copepods	0.95	0.92	0.80	0.87	0.83
Cladocerans	0.80	0.57	0.63	0.49	0.54

Table 8.–Mean spring zooplankton densities (Number/L) and length (mm) for five years at combined sites.

	1990	1991	1992	1993	1994
			Density		
All zooplankton	7.8	5.6	4.9	4.6	4.7
Cyclopoid copepods	8.1	6.5	5.7	7.9	7.9
Calanoid copepods	2.6	3.3	1.4	3.0	1.3
Cladocerans	23.8	13.3	15.6	6.0	12.3
			Length		
All zooplankton	0.60	0.56	0.55	0.56	0.58
Cyclopoid copepods	0.49	0.50	0.52	0.46	0.52
Calanoid copepods	0.90	0.87	0.83	0.87	0.90
Cladocerans	0.68	0.60	0.54	0.58	0.62

Table 9.–Zebra mussel mean relative weight (g) gain per day for five study rivers.

	Productive walleye rivers			Unproductive walleye rivers		
Year	Maumee River	Saginaw River	Thames River	Huron River	Clinton River	Total
1991	0.260	0.594	0.170	–[1]	0.160	0.291[3]
1992	0.221	–[1]	0.134	0.321	0.140	0.204
1993	0.357	0.227	0.266	0.612	0.120	0.313[3]
1994	0.339	0.235	0.189	–[1]	0.066	0.297[3]
Mean	0.297[2]	0.341[2]	0.195[2]	0.465[2]	0.134[2]	0.272

[1] Cages lost due to storms or vandalism.
[2] River sites significantly different from all others ($P < 0.05$); Tukey HSD test.
[3] Years of growth significantly greater than 1992 ($P < 0.05$); Tukey HSD test.

Table 10.–Mean spring zooplankton densities (Number/L) and lengths (mm) for Clinton River, Selfridge ponds, and fry cages in spring 1990.

	North pond	South pond	North pond east cage[2]	North pond west cage[3]	Clinton River cage[2]	Clinton River[1]
			Density			
Total zooplankton	20.9	15.3	77.2	137.8	10.2	7.3
Cyclopoid copepods	16.4	23.9	67.5	102.0	10.5	6.5
Calanoid copepods	20.6	4.4	54.0	75.2	19.4	3.2
Cladocerans	24.9	15.8	116.1	196.7	11.7	5.7
Daphnids	3.6	6.9	12.6	48.5	1.5	1.5
			Length			
Total zooplankton	0.65	0.59	0.62	0.75	0.56	0.53
Cyclopoid copepods	0.83	0.81	0.79	0.86	0.66	0.78
Calanoid copepods	0.89	0.77	0.80	0.96	0.84	0.77
Cladocerans	0.58	0.52	0.55	0.76	0.59	0.44
Daphnids	0.72	0.65	0.75	0.91	0.83	0.58

[1] Outside cages
[2] Cage containing walleye fry
[3] Cage without walleye fry

Table 11.–Comparison of walleye year classes in Lake Erie[1] and Lake St. Clair[2].

Year class	Rank[3]		Percent	
	Erie	St. Clair	Erie	St. Clair
1969	23	12	0.37	3.20
1970	3	9	7.34	4.14
1971	21	11	0.78	3.70
1972	7	10	5.70	4.06
1973	19	13	1.60	3.09
1974	16	5	2.40	5.67
1975	13	17	2.96	1.79
1976	22	19	0.72	0.66
1977	5	1	6.02	17.17
1978	10	15	3.15	2.97
1979	18	8	2.23	4.49
1980	8	3	4.78	8.83
1981	14	14	2.71	3.07
1982	1	2	18.70	14.08
1983	17	16	2.24	1.96
1984	6	4	5.76	8.11
1985	4	6	6.68	4.93
1986	2	7	12.12	4.88
1987	12	20	3.03	0.61
1988	15	22	2.61	0.32
1989	20	23	1.25	0.26
1990	9	18	3.79	1.53
1991	11	21	3.04	0.48

[1] From annual Interagency walleye harvest estimates for Lake Erie (see methods).

[2] From Ontario Ministry of Natural Resources index trap nets for Lake St. Clair (see methods).

[3] Rank of 1 corresponds to strongest year class.

Table 12.–Average monthly discharge (cubic feet per second) of five study rivers.

	Productive walleye rivers			Unproductive walleye rivers	
Month	Maumee	Saginaw[1]	Thames	Huron	Clinton
Oct	1,899	1,089	1,200	448	311
Nov	4,443	1,468	1,963	620	411
Dec	6,670	1,538	2,398	645	530
Jan	6,452	1,370	2,082	615	545
Feb	9,026	1,697	2,475	719	738
Mar	11,942	3,949	5,280	1,126	1,144
Apr	10,456	3,768	4,106	1,112	1,058
May	5,393	2,124	1,378	786	675
Jun	4,964	1,361	870	510	465
Jul	3,258	737	675	339	290
Aug	1,270	587	583	286	241
Sep	1,818	936	953	380	267
Annual mean	5,622	2,093	1,993	831	770

[1] Discharge data from the Tittabawassee River at Midland, Michigan; a major tributary of the Saginaw River system comprising the major walleye spawning habitat.

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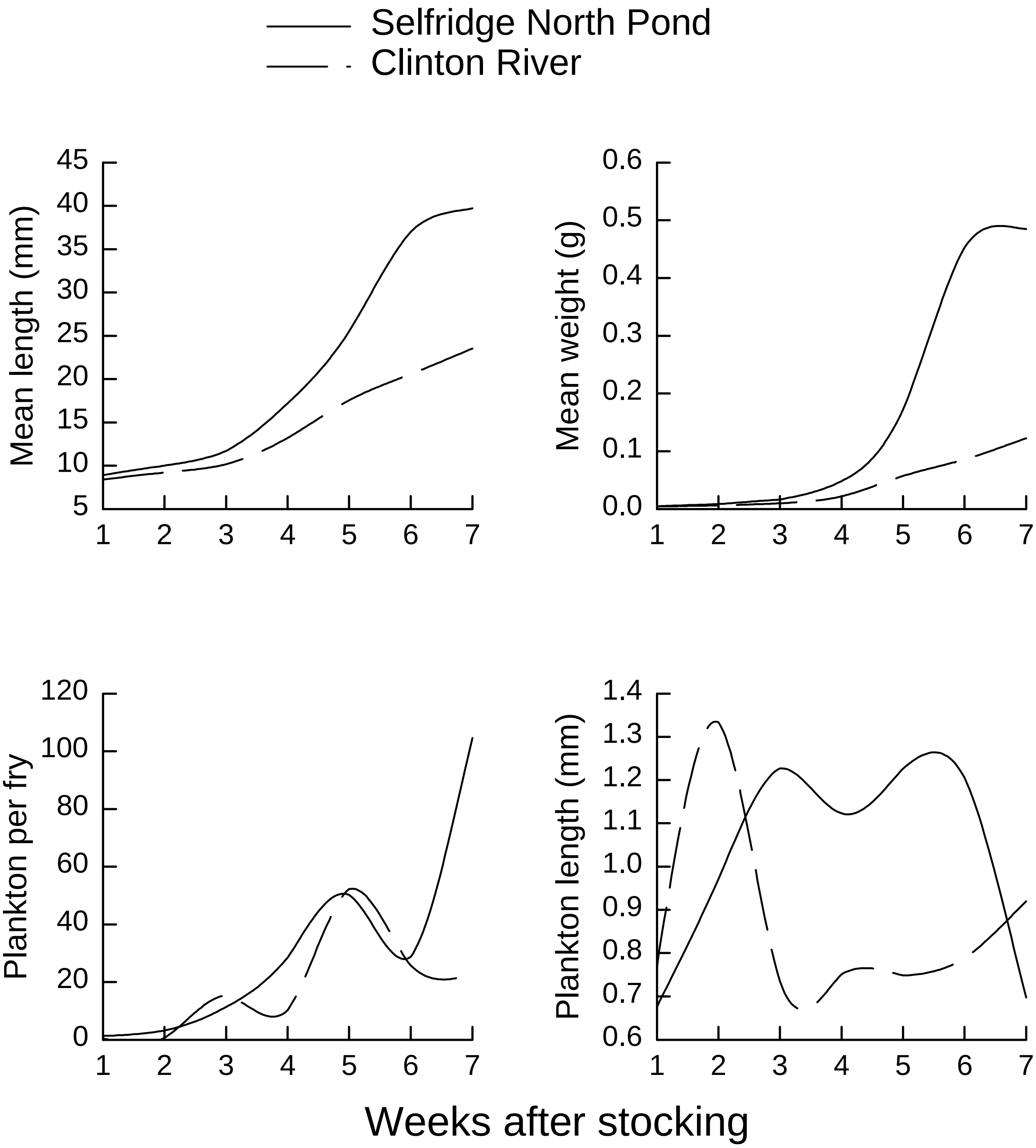
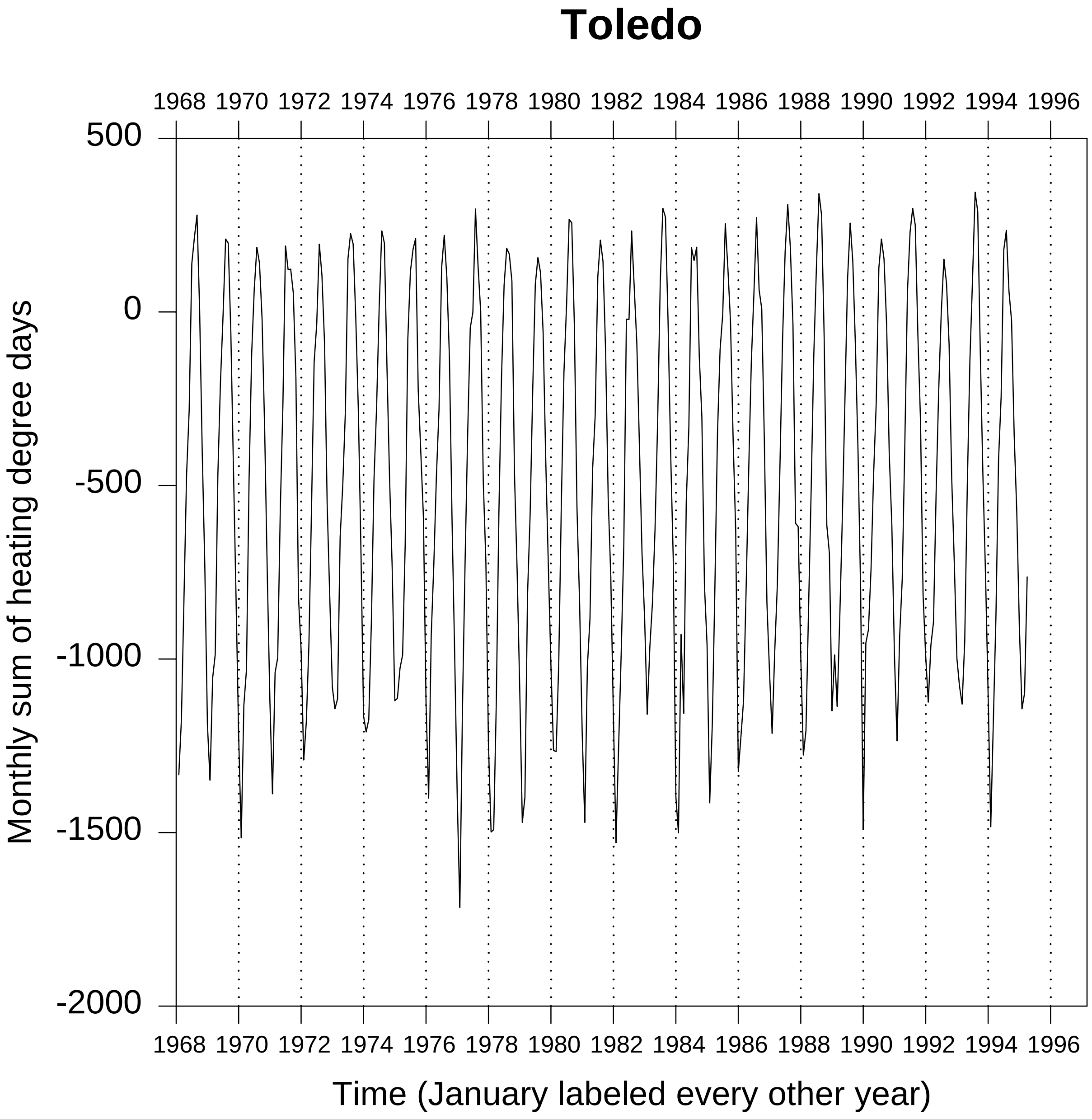
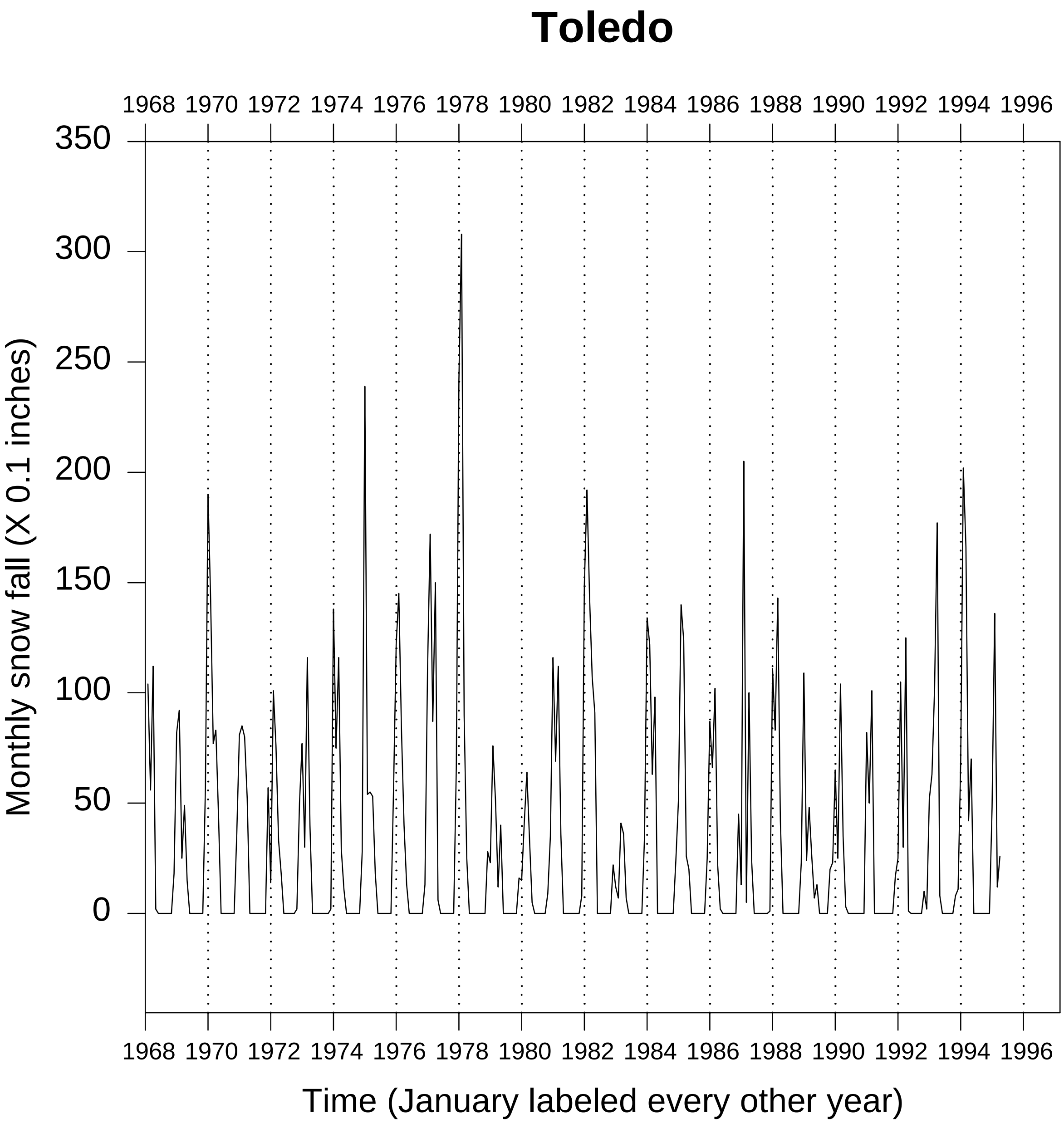


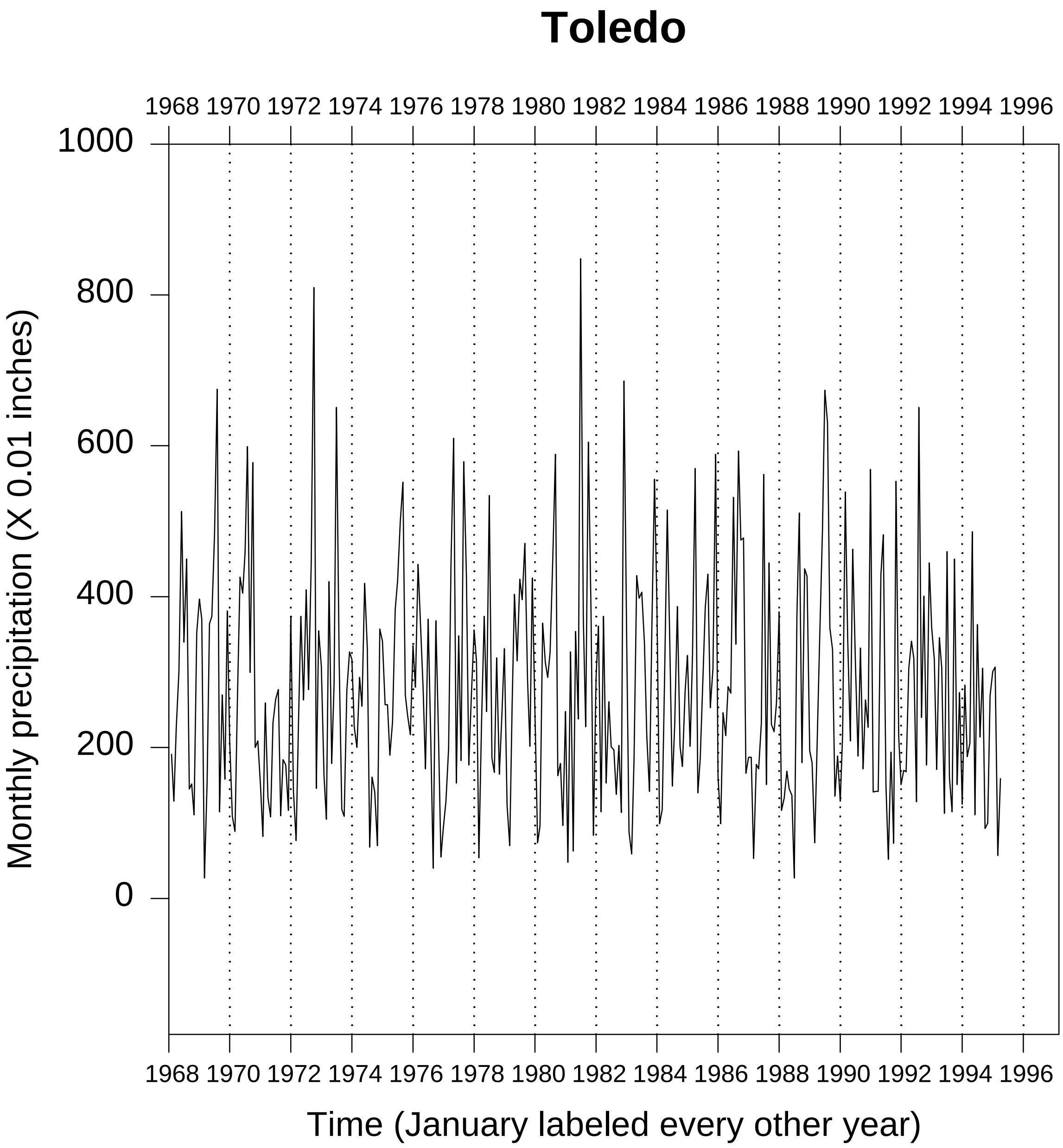
Appendix Figure 1.—Walleye fry mean length and weight, mean number of plankton prey items per fry stomach, and mean length of plankton found in fry stomachs taken from the North Pond at Selfridge Air Base and the fry cage in the Clinton River during spring, 1989.



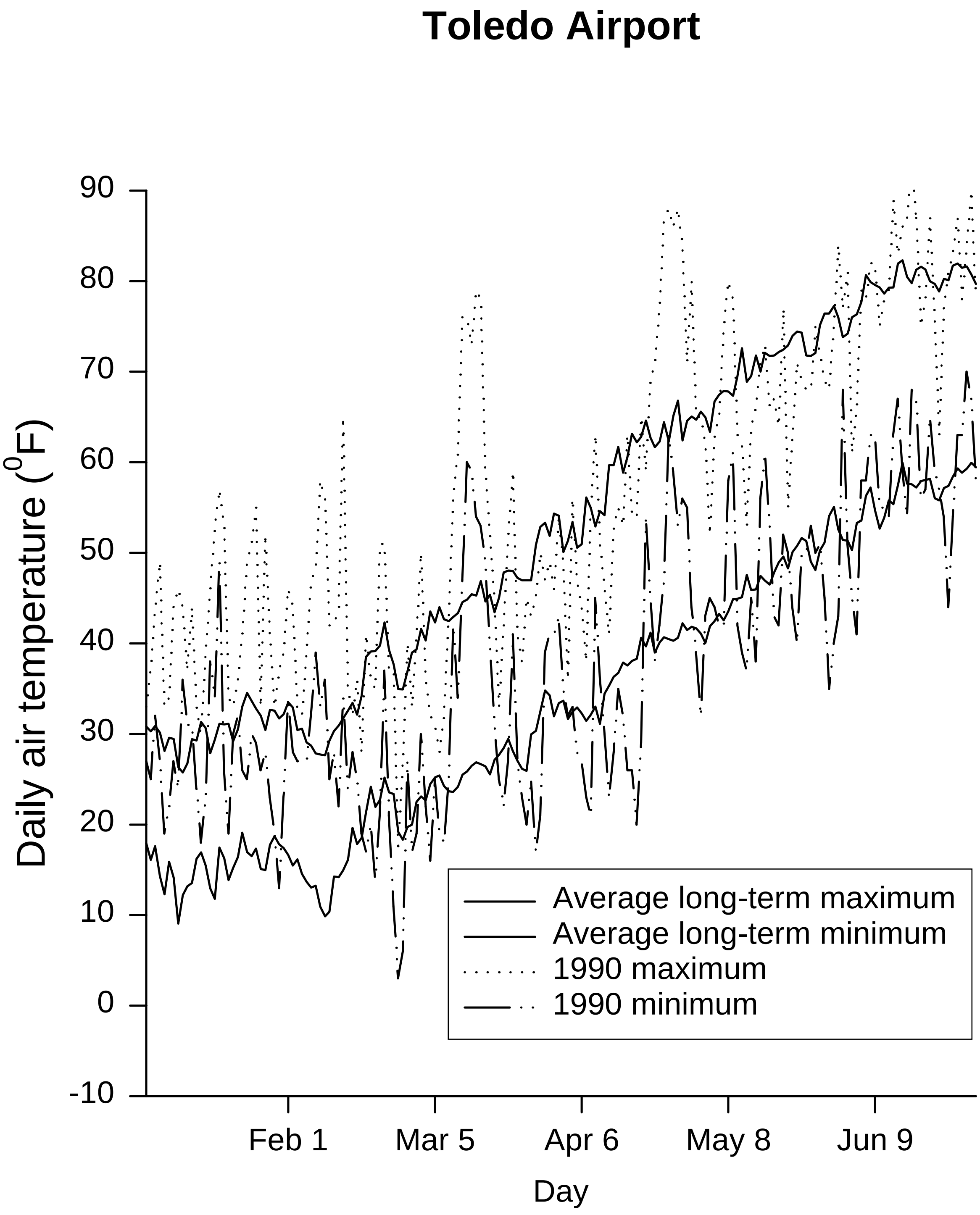
Appendix Figure 2.—Average monthly sum of heating degree days measured at the Airport near Toledo, Ohio from March, 1968 through May, 1995. Heating degree days were calculated as 65^0F subtracted from the average of the minimum and maximum temperature readings on a daily basis.



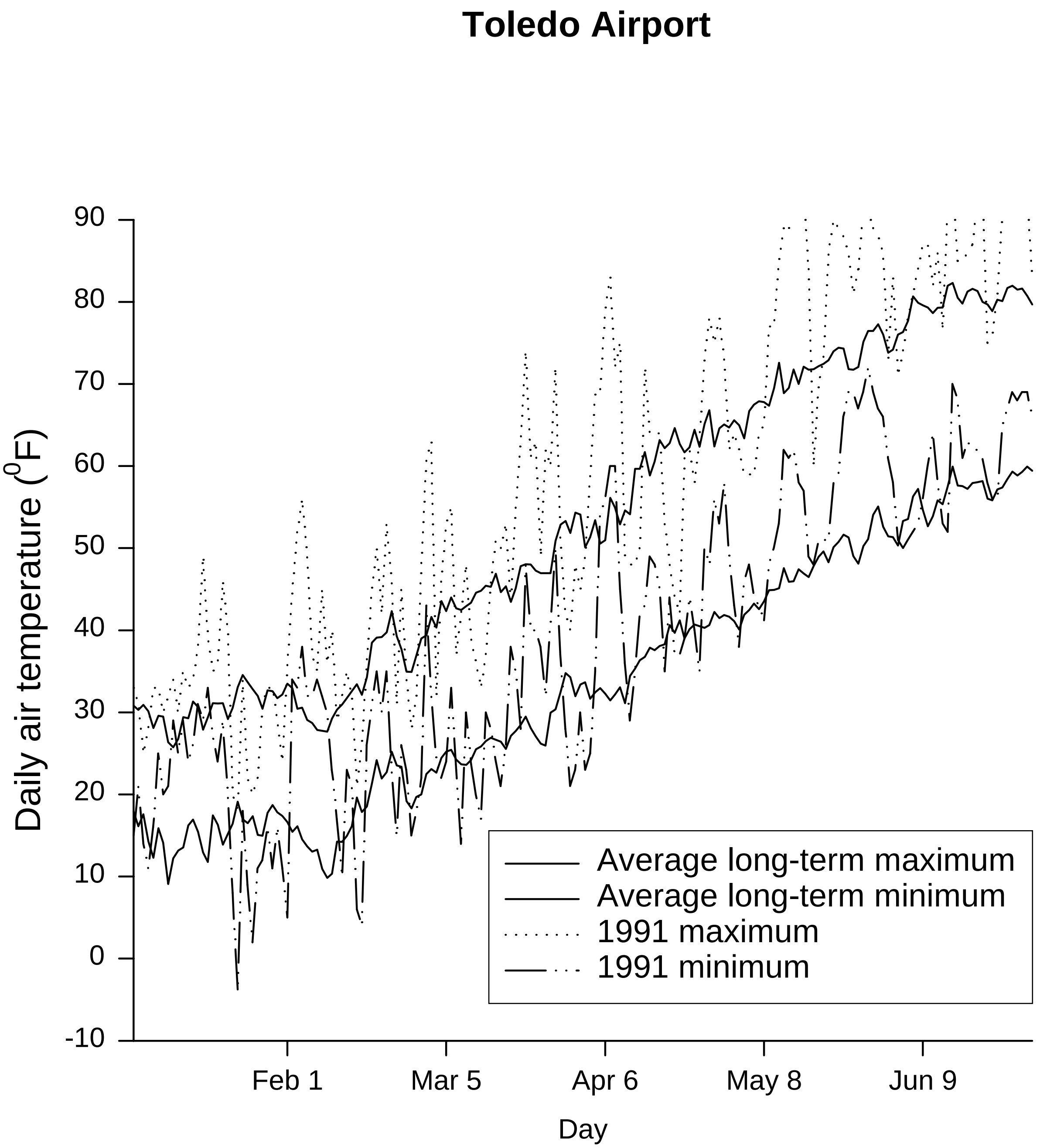
Appendix Figure 3.—Average monthly snowfall measured at the Airport near Toledo, Ohio from March, 1968 through May, 1995.



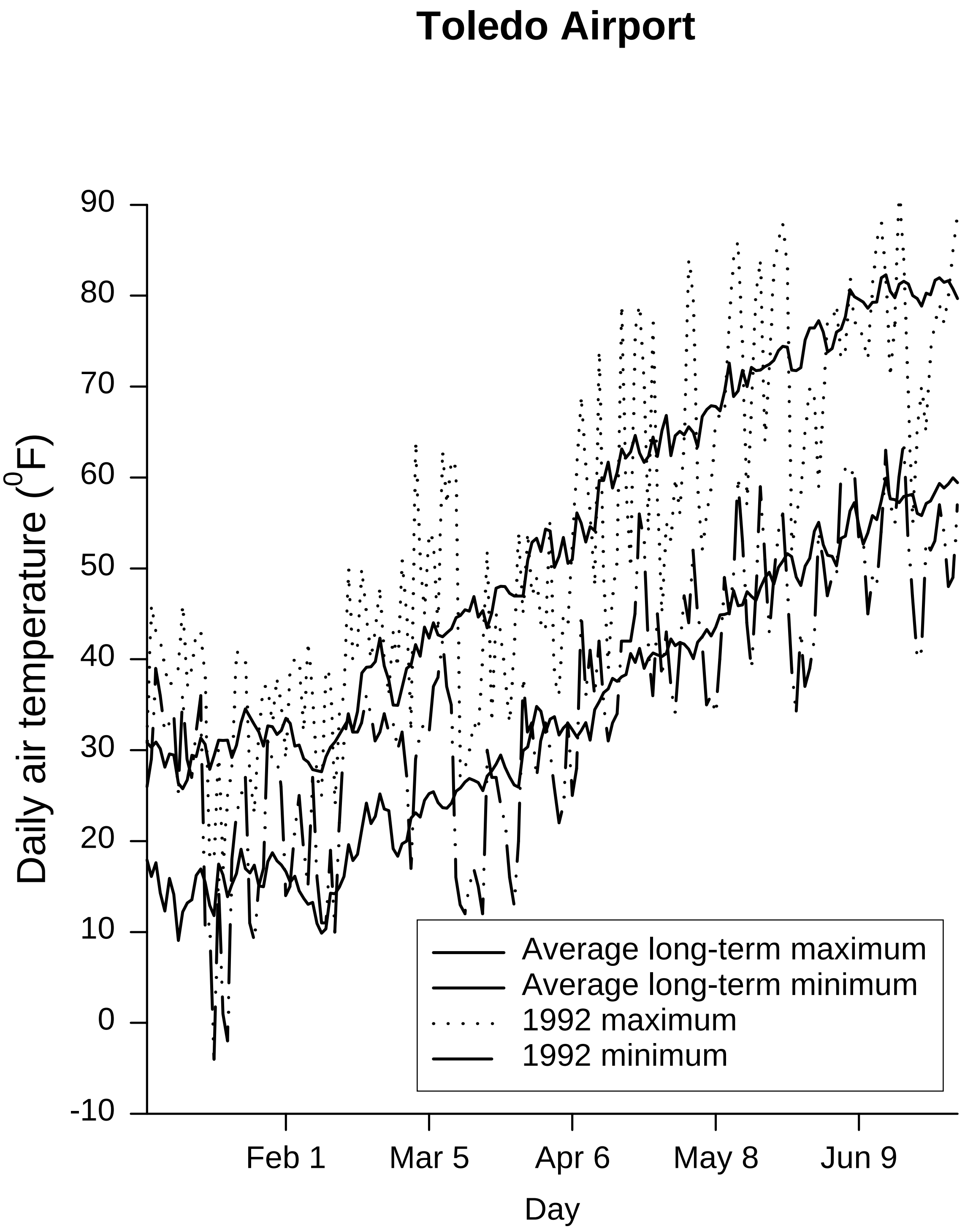
Appendix Figure 4.—Average monthly precipitation measured at the Airport near Toledo, Ohio from March, 1968 through May, 1995.



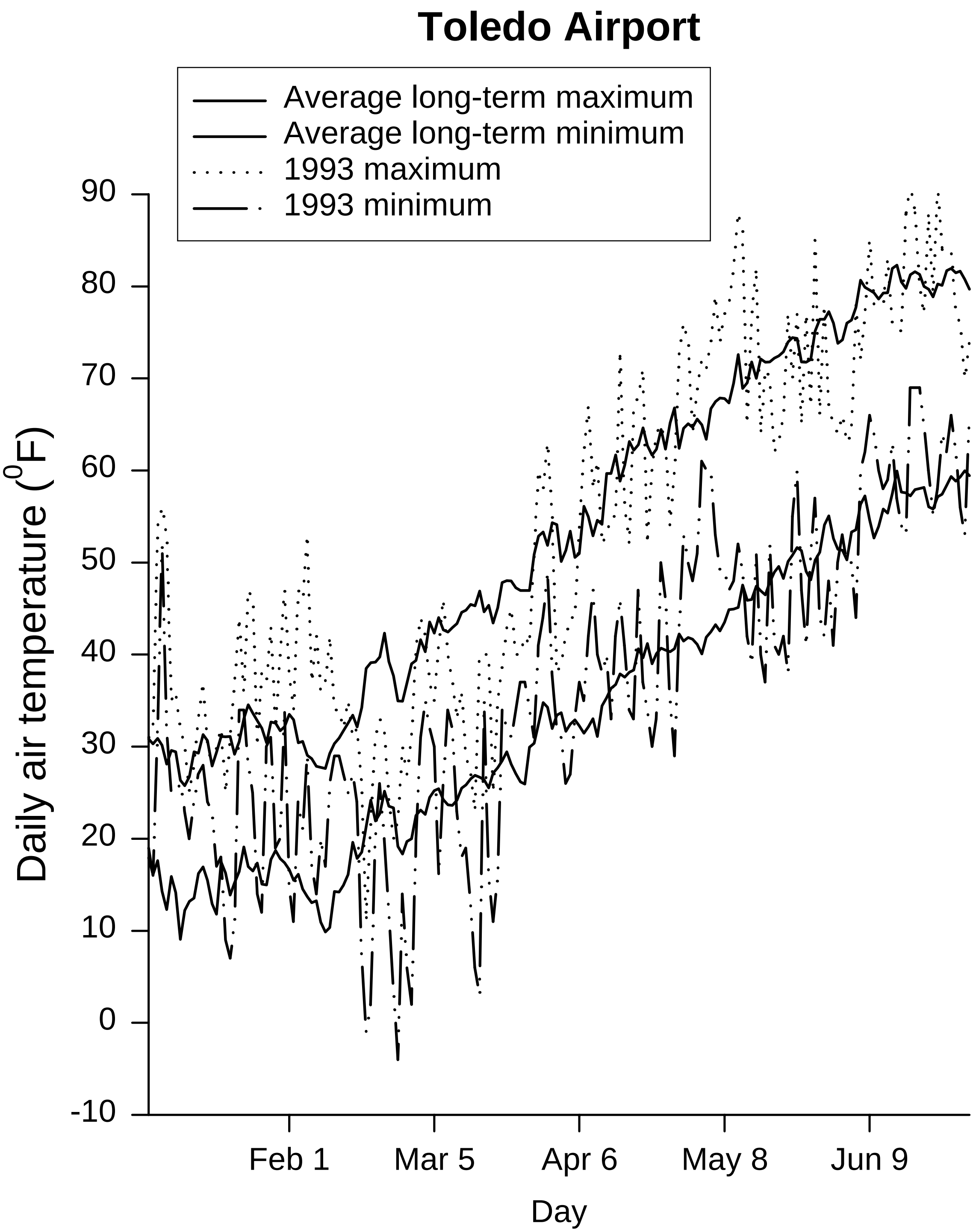
Appendix Figure 5.—Daily minimum and maximum air temperature measured at the Airport near Toledo, Ohio from January 1, 1990 through July 1, 1990 compared to the long-term daily mean.



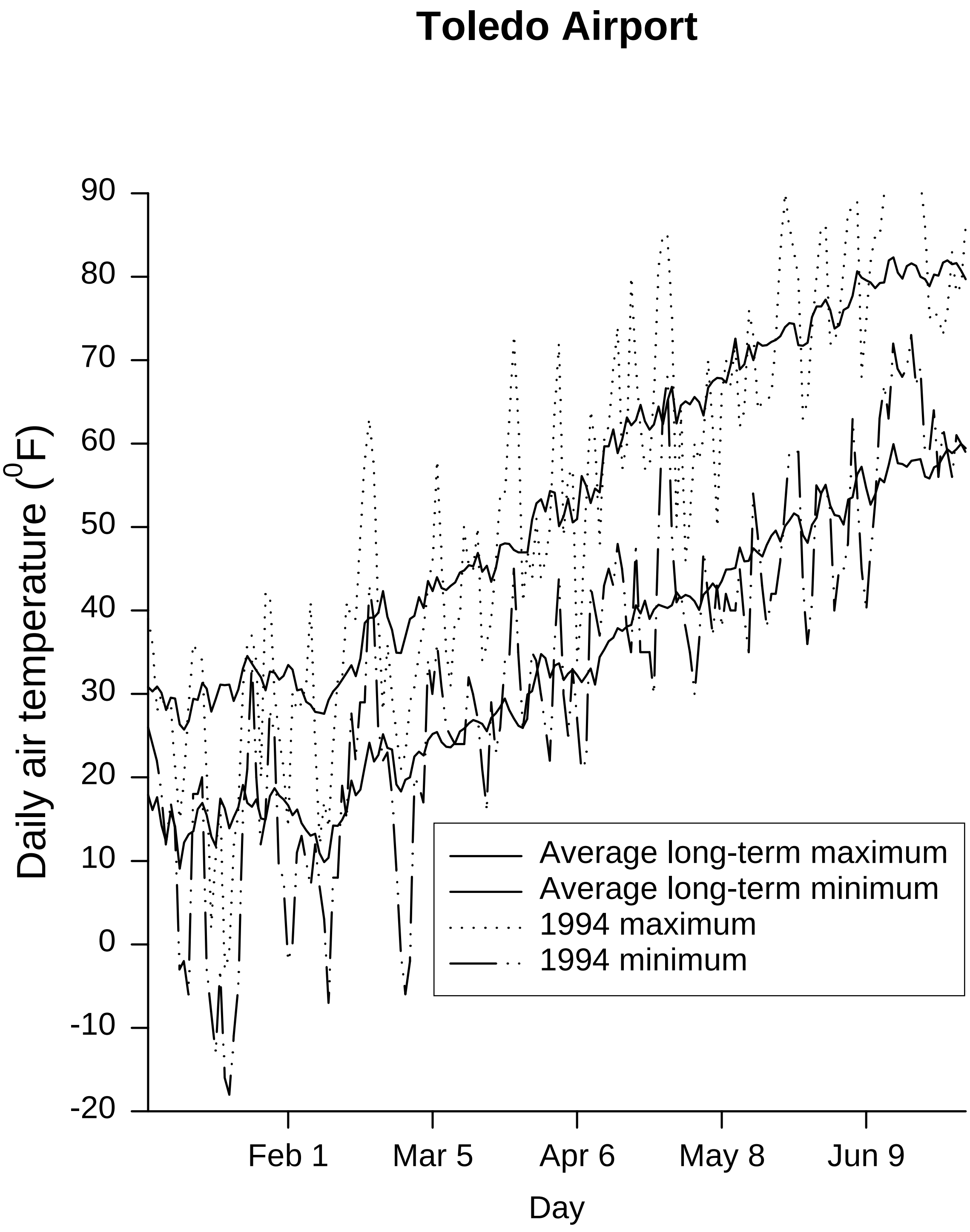
Appendix Figure 6.—Daily minimum and maximum air temperature measured at the Airport near Toledo, Ohio from January 1, 1991 compared to the long-term daily mean.



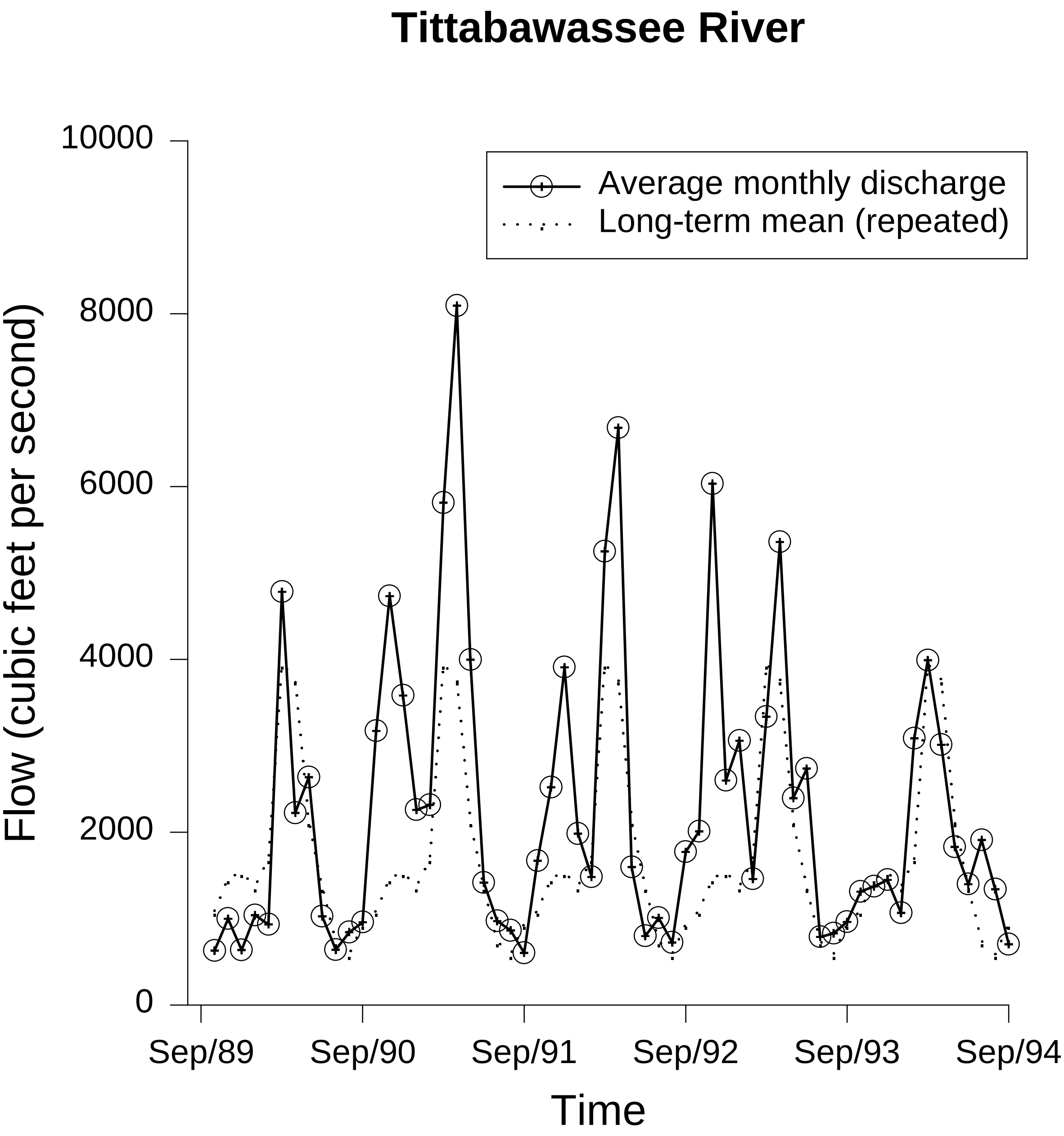
Appendix Figure 7.—Daily minimum and maximum air temperature measured at the Airport near Toledo, Ohio from January 1, 1992 compared to the long-term daily mean.



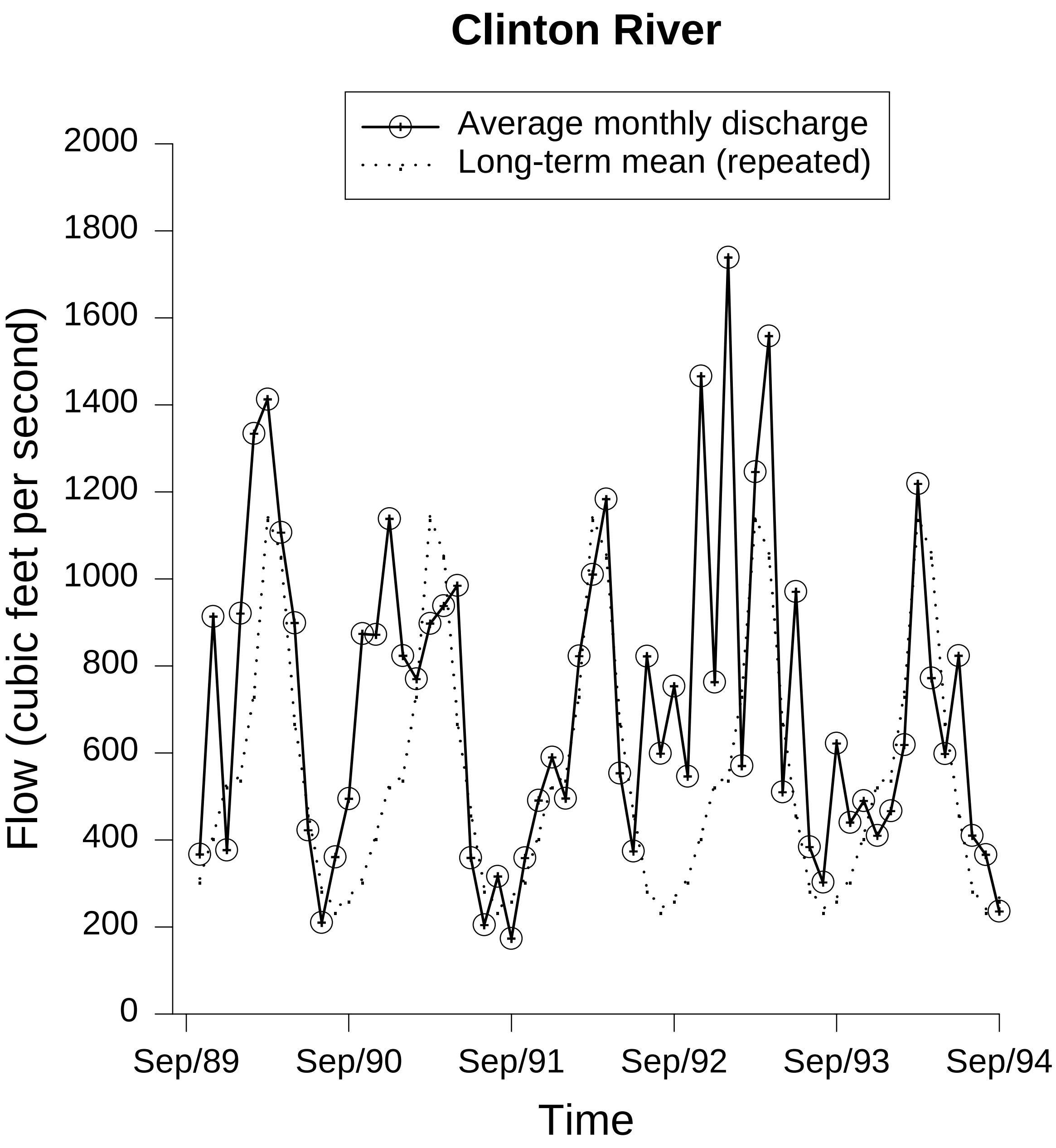
Appendix Figure 8.—Daily minimum and maximum air temperature measured at the Airport near Toledo, Ohio from January 1, 1993 through July 1, 1993 compared to the long-term daily mean.



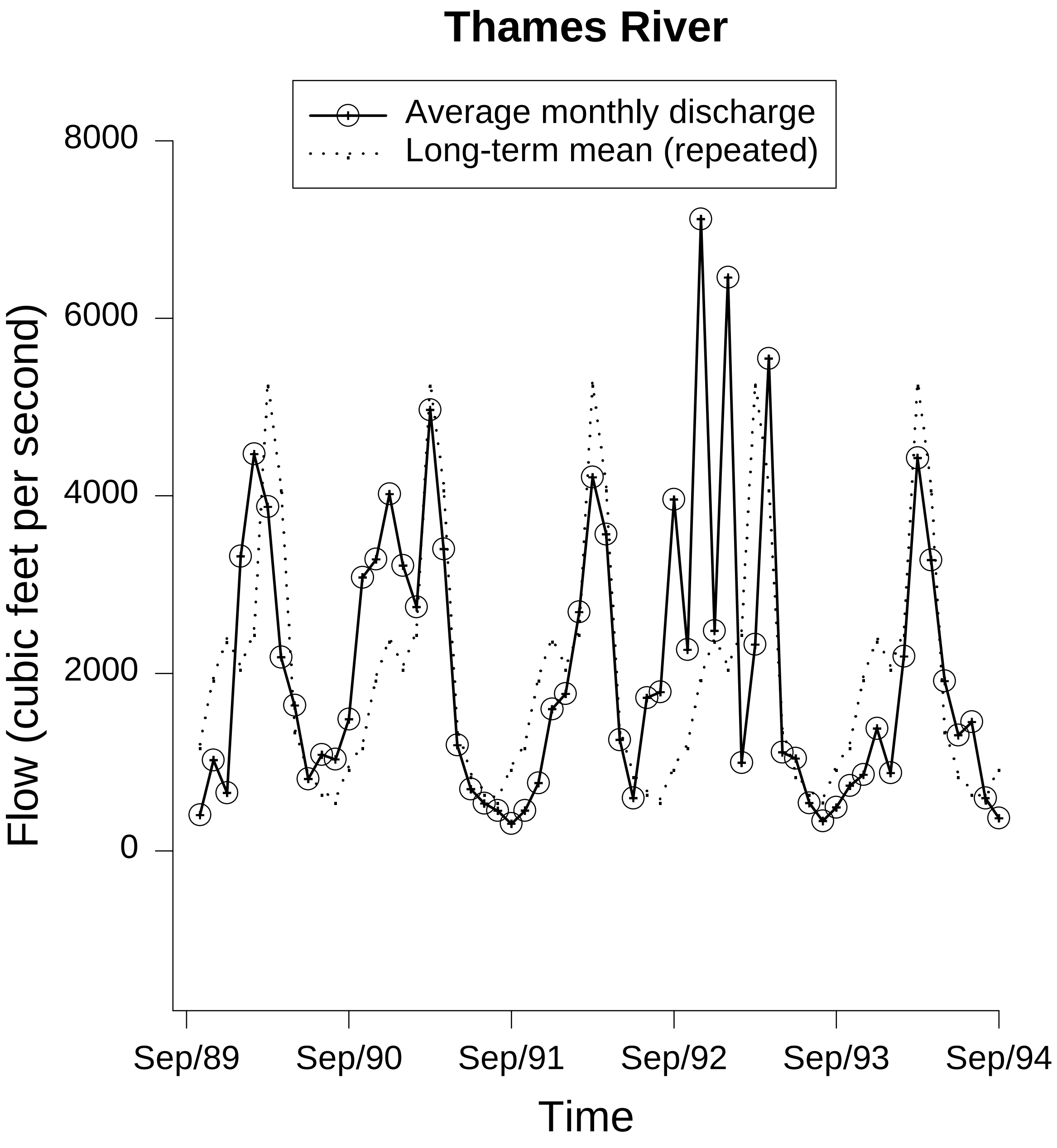
Appendix Figure 9.—Daily minimum and maximum air temperature measured at the Airport near Toledo, Ohio from January 1, 1994 through July 1, 1994 compared to the long-term daily mean.



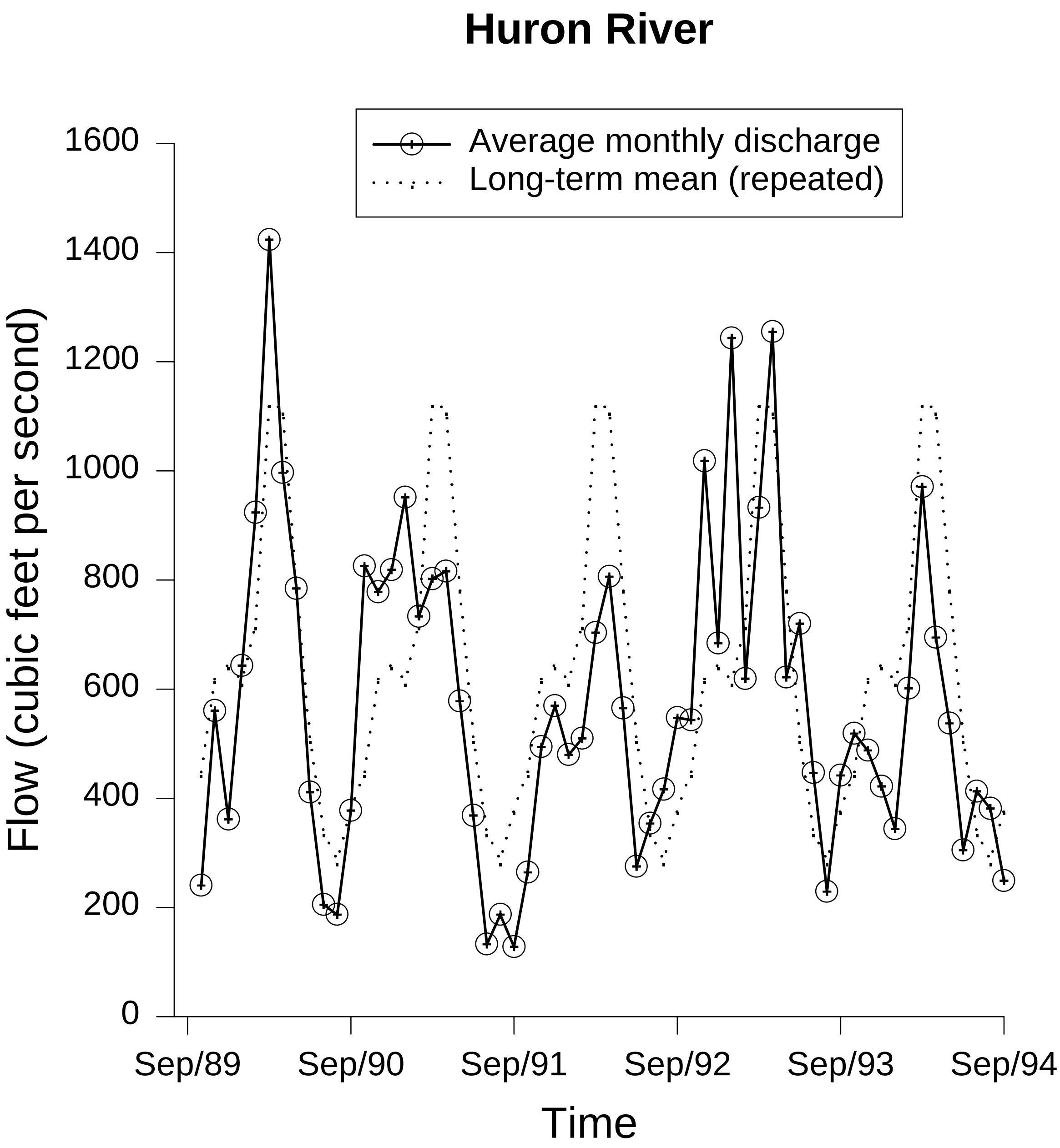
Appendix Figure 10.—Average monthly discharge of the Tittabawassee River at Midland, Michigan from October, 1989 through September, 1994 compared to the long-term mean monthly discharge for the period from 1936-94.



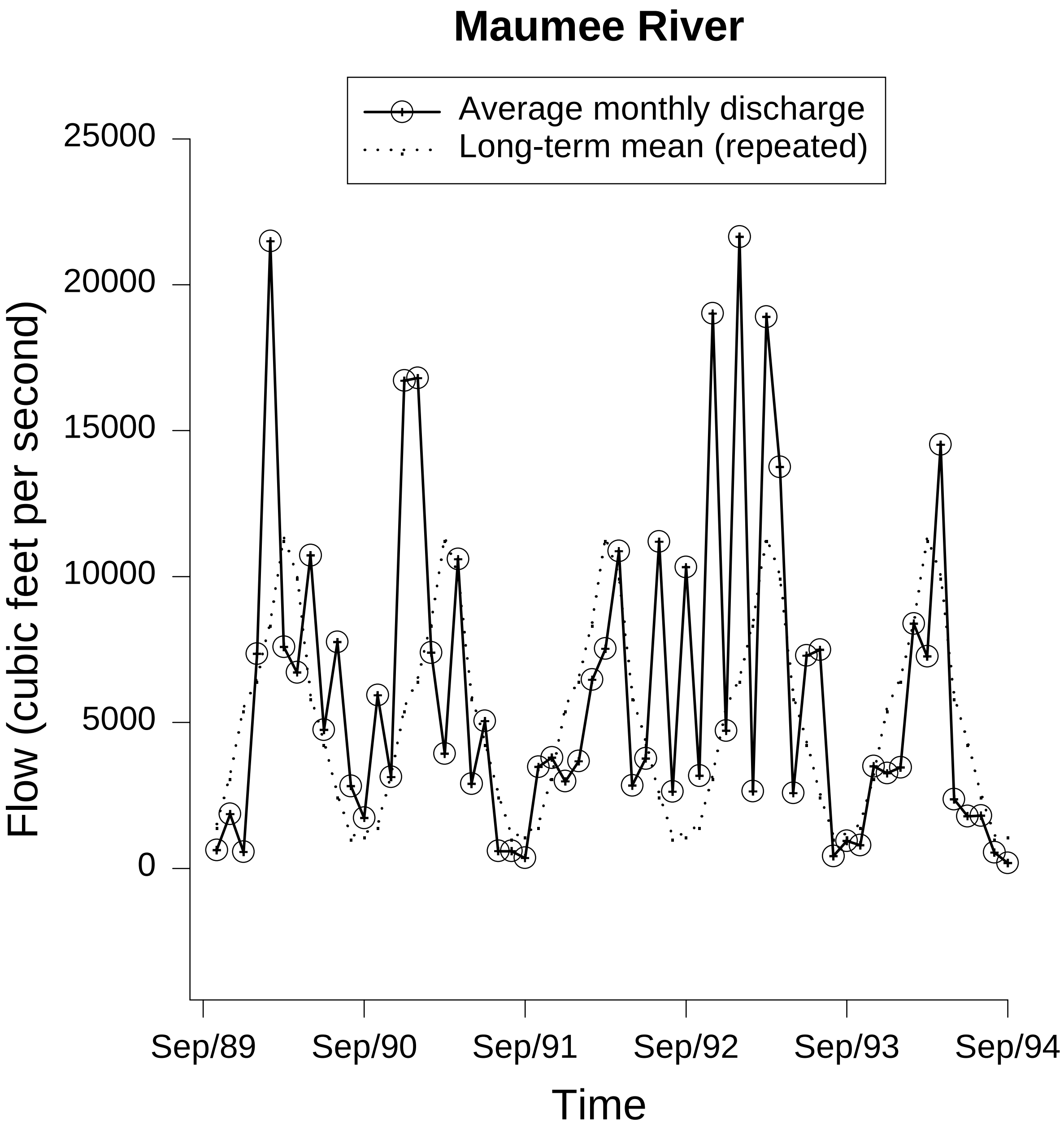
Appendix Figure 11.—Average monthly discharge of the Clinton River at Mount Clemens, Michigan from October, 1989 through September, 1994 compared to the long-term mean monthly discharge for the period from 1936-94.



Appendix Figure 12.—Average monthly discharge of the Thames River at Thamesville, Ontario, Canada from October, 1989 through September, 1994 compared to the long-term mean monthly discharge for the period from 1936-94.



Appendix Figure 13.—Average monthly discharge of the Huron River at Ypsilanti, Michigan from October, 1989 through September, 1994 compared to the long-term mean monthly discharge for the period from 1936-94.



Appendix Figure 14.—Average monthly discharge of the Maumee River at Waterville, Ohio from October, 1989 through September, 1994 compared to the long-term mean monthly discharge for the period from 1936-94.