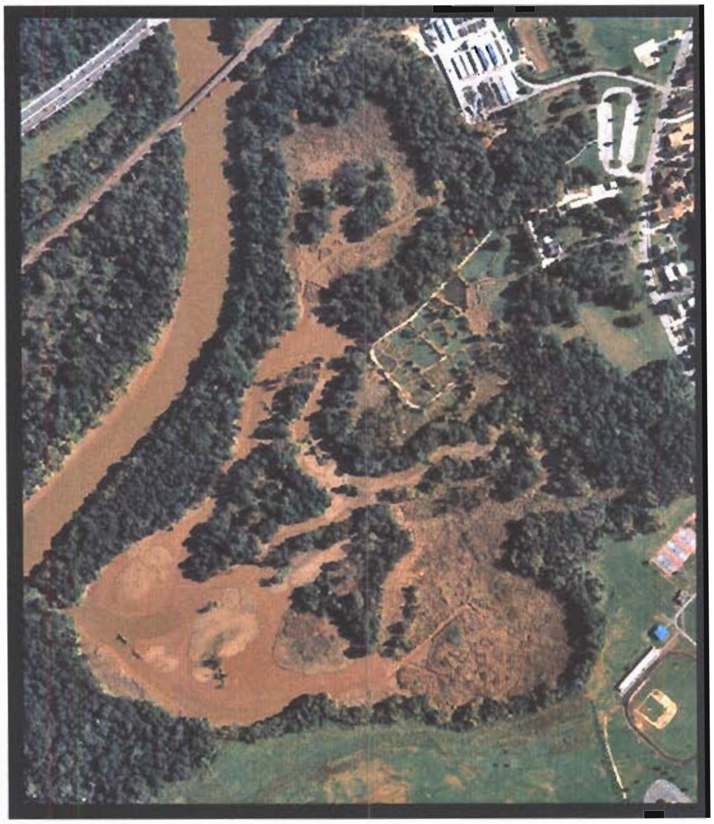
Ten Years of Anacostia Water Quality Data (1988-1997) - Five Years Pre and Post Kenilworth Marsh Reconstruction

Dr. Richard S. Hammerschlag
USGS Patuxent Wildlife Research Center

SUMMARY REPORT
FIVE YEAR POST-RECONSTRUCTION WATER QUALITY MONITORING AT KENILWORTH MARSH
(1993-1997)

Dr. Richard S. Hammerschlag
USGS Patuxent Wildlife Research Center

1988-1992
Pre-reconstruction
Kenilworth Marsh



1993-1997
Post-reconstruction
Kenilworth Marsh

SUMMARY REPORT
PRE- AND POST-RECONSTRUCTION WATER QUALITY MONITORING AT KENILWORTH MARSH (1988-1997)

Dr. Richard S. Hammerschlag
USGS Patuxent Wildlife Research Center

ABSTRACT:

Water quality at Kenilworth Marsh was measured and analyzed for differences and trends within the marsh for five years after the marsh was reconstructed (1993-97), for changes in relation to the adjacent Anacostia mainstem (as a control) for this same five-year period, and for changes in relation to the mainstem and pre-marsh (then consisting of open water tidal flats) for the five-year pre-reconstruction period (1988-92). This data set is intended to serve as a reference for the study sites and study time frame. Few trends or differences were noted throughout the ten-year study period (1988-97). Those statistically significant changes that did occur were relatively minor in that they did not reflect important contributions by the reconstructed wetlands. No significant differences or trends for these compared sites were determined for temperature, pH, conductivity and dissolved oxygen over the course of the study, or for the nutrient forms nitrate, nitrite, ammonia, orthophosphate and total phosphorus measured only during 1995-97. Dissolved oxygen data were analyzed using the *t*-test and seasonal Kendall test, and also were compared to a more intensive data set for the Anacostia compiled by the Metropolitan Washington Council of Governments. Most of the Secchi disk comparisons made were similar within a site for various time periods but yielded reduced readings for the marsh over the open river for both the pre- ($t = -2.312$, $p > 0.05$) and post- ($t = 2.758$, $p > 0.05$) reconstruction periods. Data for turbidity were also similar except for a reduction in turbidity for the marsh ($t=4.604$, $p>0.05$) and the Anacostia ($t=3.630$, $p>0.05$) in the post-reconstruction period. The suspended solids data were not different pre- and post- reconstruction, but suspended solids were elevated in the marsh relative to the river during the post-reconstruction period ($t=-3.300$, $p>0.05$). While more research is needed to determine the exact role the freshwater tidal wetland system plays in bringing about improvement in Anacostia water quality, it is evident that more wetlands are needed to help achieve a better balanced ecology.

INTRODUCTION:

Kenilworth Marsh was reconstructed as a freshwater tidal marsh (32 acres of emergent wetlands were reconstructed within the 77 acres of total marsh area) along the Anacostia River in Washington, D.C., during the winter of 1992-93. The objective of monitoring was to determine if reconstruction of the wetlands had a detectable effect or impact on the water quality of the marsh system and possibly even the nearby Anacostia during the five-year post-reconstruction period. The monitoring system was based upon and meant to be compatible with sampling in place for the five-year period preceding reconstruction. As part of the five-year post-reconstruction monitoring effort, three sites within the reconstructed marsh area (Sites 2, 3, and 4), were monitored for basic surface water quality parameters in comparison to one site in the adjacent Anacostia mainstem (Site 1), which served as a reference, and one other site about one mile downstream within the southern section of Kingman Lake (Site 7)(Maps 1 and 2). Kingman Lake was included because it is another very similar area of the tidal Anacostia also being given serious consideration for wetland reconstruction. Thus the collected data could be used as a pre-reconstruction data set for that site in the event that it becomes reconstructed. Sites 5 and 6 are historic ponds within the adjacent Kenilworth Aquatic Gardens, but are not included as part of this report since they do not share the tidal regime. The locations of the monitoring sites at Kenilworth Marsh are shown close-up on Map 2. Site 2 is located in the open water portion of Kenilworth Marsh (an important part of the 77-acre wetland that was not included in the reconstruction) about 100 yards from the inlet/outlet to the Anacostia. Sites 3 and 4 are located near the upper end of tidal guts draining separate portions of the marsh. For the purposes of this study the results from Sites 2, 3, and 4 were often combined and treated as one unit to be representative of the marsh as a whole.

Kenilworth Marsh has a tidal amplitude close to 3 ft. Mean high tide is 2.1 ft. NGVD (National Geodetic Vertical Datum) which establishes the optimum elevation for mid-marsh vegetation establishment. Post-reconstruction sampling was conducted biweekly from late March into November for the five-year period of 1993-1997 as it had been for the five-year pre-reconstruction period (1988-1992). Data were always gathered between 10:00 a.m. and 2:00 p.m. usually at high slack tide but whenever possible as the tide was beginning to ebb, to catch water coming off the emergent marsh. Sampling and analyses were managed consistently throughout the study period using standard methods. Temperature, dissolved oxygen, conductivity and Secchi were measured in the field with the first three determined using YSI meters. Water samples collected for the remaining parameters were kept on ice until return to the laboratory the day of sampling. At the laboratory samples were immediately measured for pH (using a standard pH meter), turbidity (using a turbidometer) and ammonia (using a LaMotte colorimetric determination) while a 100 ml aliquot from each site sample was filtered, weighed and then placed in a drying oven for suspended solids determination. The remaining portion of the samples was frozen until a convenient time for processing for nutrient analyses. Phosphorus forms were determined using the ascorbic acid method (1). Nitrite was measured colorimetrically using diazotized sulfanilic acid (1). Nitrate was reduced to nitrite using a cadmium reduction column (1) and then determined as with nitrite.

For purposes of this report, the parameters are plotted and measured on an annual basis, over the course of the five-year post-reconstruction period (1993-97) and to the extent possible compared with similar data collected during the five-year pre-reconstruction period (1988-92). Any change in parameters from the marsh sites (2, 3, and 4) can be measured over time, or in comparison with corresponding data from the mainstem Anacostia (Site 1 and possibly Site 7). The database from the ten years of study and the Annual Reports written for 1993-95 may be obtained from the author at the Patuxent Wildlife Research Center, Laurel, Maryland.

Most of the plots should be reasonably self-evident as to similarity, changes or trends. However, two sets of statistics were used to verify some of the interpretations. Since the sampling was not designed with replications, data were grouped for the five-year pre-reconstruction period (1988-92) and compared to data from the five-year post-reconstruction period (1993-97) using the Student's *t*-test (2). Parameters that were statistically analyzed were dissolved oxygen (DO), turbidity, suspended solids and Secchi. A synopsis of these tests is represented in Table 1. A second statistical test, the seasonal Kendall test, is based on the Mann-Kendall test for noncyclical data (2) as used by B. Hazelwood and T.J. Murphy (4) at the Metropolitan Washington Council of Governments (COG). This test was conducted to determine whether the dissolved oxygen measurements had increased or decreased at Site 1 in the Anacostia over the 10-year period of 1988-1997. Additional statistical tests were considered but not pursued on the basis they would not contribute substantially to the purposes of this report.

The following is an interpretation of the data as charted for each of the parameters measured for the given time period.

TEMPERATURE (T):

Temperature profiles were in the expected range, pattern and variation for waters in the Washington, D.C., area for the five-year post-reconstruction period (1993-97) for the marsh (Fig. 1 - Sites 2, 3, and 4) and the Anacostia River (Fig. 2 - Site 1) as well as for the five-year pre-reconstruction period (1988- 92) for the marsh (Fig. 3) and the river (Fig. 4). The water temperatures rose from ~15°C in the early spring to near 30°C peak during the summer and then declined into the fall. No significant differences were observed between data sets for the five-year pre- and post-reconstruction periods or from within the marsh as opposed to the Anacostia mainstem. The strong similarity in the temperature regime between the five-year sets for the marsh sites (2, 3, and 4) and the Anacostia (Site 1) suggests that there may not be much difference between the water quality of the two areas. The daily tides from the Anacostia essentially replace most of the water in Kenilworth Marsh so that there is almost no resident pool or body of water that might be successively enhanced or altered through repetitive tidal runoff from the wetlands. In this way components of the pollutant laden Anacostia waters tend to dominate the marsh water quality.

CONDUCTIVITY

Conductivity (measured as specific conductance) did not display any particular pattern for either of the five-year periods or the marsh versus the river (Figs. 5-8). The variation and range of the readings was wide but expected (100-500 micromhos is a common range for conductivity in the waters of the Washington, D.C., area) in context with flow/discharge events following heavy rainfall. Conductivity levels were observed to decline following rainfall events probably due to dilution despite the increased pollutant loads. Correspondingly, conductivity values tended to rise during low flow conditions. This pattern may hold true because of the relatively high base level of solutes in the heavily polluted Anacostia, but might be expected to be the inverse in a pristine stream system. Thus the tendency for conductivity values to rise during the summer may be attributed to generally lower flow rates during that period. The very close approximation of the conductivity values between the two sites (the marsh and the Anacostia) indicates the water in the two areas is similar despite the presence of the reconstructed marsh.

pH:

No particular trends or shifts in pH were noticed in either the five years of post-reconstruction data for the marsh or river (Figs. 9, 10) or the five years of pre-reconstruction data for the marsh (Figs. 11 and 12). The pH values remained (strongly buffered) between pH 6 and pH 8. The most important cause for a short-term change in pH would be from a summer algal bloom that shifted the CO_2 /carbonate balance thereby removing some of the buffering and allowing the pH to rise.

DISSOLVED OXYGEN (DO):

Dissolved oxygen is a parameter that one might expect to improve not only in response to marsh reconstruction but also in the Anacostia mainstem due to the many efforts and programs within the watershed. Figures 13 and 14, which display the block averages for the two five-year periods, suggest about a half unit (mg/L) increase in DO during the summer growing season for the five-year post-reconstruction period in the marsh but less than that in the Anacostia. Thus, at best only very minor improvement in dissolved oxygen can be attributed to the presence of the marsh. The *t*-test found no differences between Site 1 and the average of Sites 2, 3, and 4 for the pre- and post-reconstruction periods. Nor was there any change at those sites over the full ten-year time frame (Fig.14a). Looking more closely at the post-reconstruction period, there was no pattern of change either within the marsh (Fig. 15) or in the Anacostia (Fig. 16) over that five-year period. Nor did a comparison of sites during 1997 (Fig. 17) display any consistent elevated DO during the growing season for the marsh sites (Fig. 18). Thus, even dissolved oxygen levels did not reflect any obvious benefit from the reconstructed marsh; nor did they show a clear trend of improvement in the Anacostia over the past ten years when the data were pooled for the two five-year periods.

T.J. Murphy and collaborators at COG (4) analyzed a set of dissolved oxygen data collected from automatic recording meters (data received every 30 minutes during the growing season) in the Anacostia at Benning Road and the Seafarer's Marina. Both of these stations are downstream from Kenilworth Marsh with Seafarer's Marina being the farther. The data set was gathered essentially from 1988 through 1997. It revealed no real trend in DO at the Benning Road site from 1988 through 1994. However, for the Seafarer's Marina site Murphy and Hazelwood did determine an improvement in DO since 1990, which they believed could be attributed to the swirl concentrator (located upstream from Seafarer's Marina but downstream from Benning Road) coming on line at that time. While I considered the possibility of elevated DO at Seafarer's Marina being attributable to tidal mixing of Potomac waters harboring higher DO levels, our data did not show a shift in DO in the Potomac in 1990 so any influence should have been similar before or after 1990. It is possible that in years with very low summer rainfall there could be a proportionally greater contribution from the Potomac tidal influence. Based on my data using the seasonal Kendall test, the DO measurements at the reference site (Site 1 located just upstream of the inlet to Kenilworth Marsh and upstream of the Benning Road gauge) indicated no trend over the ten-year period from 1988-97 (the determined Kendall Z statistic was less than the Z threshold from a cumulative normal distribution table (4)).

SECCHI DISK READINGS:

The visibility of the Secchi disk at depth is a very simple but reliable indicator of light penetration through the water column (3, 4). The five-year averages within the marsh for the two study periods (Fig. 19) did not show consistent improvement for the post-reconstruction period. There was little influence from the wetlands as reflected by the close similarity in Secchi disk patterns for the marsh when compared to the Anacostia for the five-year periods (Figs. 20 and 20a) as well as for 1997 (Fig. 21). However, the *t*-test determined a significant difference between Secchi levels in the marsh (reduced Secchi readings) compared to Site 1 for both the pre- and post-reconstruction periods (p=0.037 and p=0.014, respectively). For undetermined reasons, the marsh waters apparently sustained a higher level of light-altering materials than the Anacostia mainstem in this area. The reconstructed marsh, then, cannot be said to have much positive influence on Secchi disk water clarity. Looking more closely at the Secchi readings for three selected intervals from the five-year post-reconstruction period (1993, 1995, 1997) there still was no pattern, just variation from year to year and according to storm events for the marsh (Fig. 22). There was no difference between the readings in the marsh when compared to the Anacostia (Fig. 23). For 1997, the last year of sampling, there was no difference among the three sampling sites in the marsh (Fig. 24), illustrating the consistency of the data.

TURBIDITY:

Turbidity displayed a significant improvement for the five-year post-reconstruction period over the pre-reconstruction period for the marsh (Fig. 25) and for the river (Fig. 26). This visual difference was corroborated with the *t*- test results producing a statistically significant difference at the α=0. 05% confidence level (p=0.007 for Site 1 and p=0.002 for the marsh). The same difference occurred whether in the marsh or in the Anacostia (Fig. 26a) so the improvement may not be attributable to improved runoff from the reconstructed wetlands but rather due to overall improvement in the Anacostia watershed. What is difficult to explain is why such a pattern showed up in turbidity but not for Secchi. Not only were the turbidity values reduced from about 50 NTUs to 20 NTUs but the variation was considerably dampened in the Anacostia estuary over the past five years. However, comparing the five-year post-reconstruction data for the marsh (Fig. 27) at the arbitrarily selected alternate years 1993, 1995, and 1997, there was no trend evident, but elevated turbidity pulses followed significant storm events. This pattern held for both the marsh (Fig. 27) and the Anacostia (Fig. 28), reflecting the commonality of water quality in the two areas. Apparently, according to the turbidity reading response, there was no major storm event during the 1993 growing season. A further insight into the consistency of data gleaned during the annual sampling can be seen from the 1997 data (Fig. 29) which showed the results from the three sites within the marsh (Sites 2, 3, and 4) as well as the similarity of results from the marsh sites combined as compared to the Anacostia near the marsh (Site 1) and the southern end of Kingman (Site 7) which may be viewed as Anacostia data further downstream (Fig. 30).

SUSPENDED SOLIDS:

The suspended solids measurements (SS) behaved more like the inverse of the Secchi readings than the turbidity, in that there was no overall improvement from pre- to post-reconstruction (Figs. 31 and 32). There was a significant difference between the two sites over the five-year post- reconstruction period (*t*-test at the $\alpha = 0.05$ confidence level), with the marsh (dark lines) containing elevated levels of SS compared to the river and the SS distinctly higher in the marsh in the earlier part of the growing season (Figs. 33a). Perhaps this is a function of slow establishment of vegetation during that time period. For the five-year time frame following reconstruction the marsh was unstable with tidal guts forming in the placed sediments. It is striking that the actual shape of the SS pattern is almost identical for the two five-year periods (Fig. 33b - dark lines vs. light lines). As has been noted previously for other parameters, this pattern reflects the similarity of the water in the two areas and overshadows any influences there might be from the reconstructed wetland. Within the 1993-1997 five-year period for the marsh (Fig. 34) and the river (Fig. 35 - Site 1), no pattern emerges. Lastly, there is close coincidence in the measurements for 1997 as an example year within the marsh (Fig. 36 - 3 sites) and the combined SS values for the marsh compared to the river sites (Fig. 37).

NUTRIENT FORMS:

The three nitrogen nutrient forms of nitrate, nitrite, and ammonia along with two phosphorus forms of soluble reactive phosphate (orthophosphate) and total phosphate were analyzed in the laboratory for 1995, 1996, and 1997 only. The following is a summary of the results.

Nitrate:

Nitrate was analyzed using the cadmium reduction column method. Sample nitrite levels were first determined. A sample aliquot was then run through the column reducing nitrates to nitrite. The original sample nitrite level was subtracted from the final to give the level of nitrate in the sample.

A representative year for these data was 1997 when nitrate levels for the three sites within the marsh were quite similar suggesting adequate analytical technique and homogeneity of water quality within the marsh (Fig. 38). The rigor of the procedure was also corroborated through the processing of standards. Nitrate was abundant in the marsh waters with a base level about 1.0 mg/ml but declined during the growing season due to increased uptake by emergents and algae as well as through more active sediment microbe transformations. When the marsh nitrate concentrations (average of Sites 2, 3, and 4) were compared with those in the river (Sites 1 and 7) there was little difference (Fig. 39). Because there is sparse emergent marsh vegetation in the estuary, little of the nitrate reduction can be attributed to the wetland vegetation. If wetland vegetation were to be an important factor, one would expect to detect some difference between the marsh area where the wetland vegetation is relatively plentiful and the vegetation-sparse river. However, any difference might be obscured if tidal river volume and associated nitrate levels were high enough to overrun the influence of limited vegetation biomass. Alternatively, it might be that only a small fraction of the river water was actually interacting with the emergent marsh. When the three sampling years were compared for the marsh (Fig. 40) and the river (Fig. 41) little difference in the nitrate levels were observed. However, the range of nitrate levels from one year to the next can be rather broad.

Nitrites:
The 1997 nitrite levels within the marsh were consistent (Fig. 42) but much lower (about one tenth) than the nitrate levels. Somewhat surprisingly, nitrite levels appeared to increase during the summer perhaps in response to increasingly anaerobic conditions. The same pattern was also displayed for the two river sites (Fig. 43). Nitrite levels remained rather stable in the marsh (Fig. 44) for the three sampling years (1995-97) but seemed more erratic during 1995 in the river (Fig. 45).

Ammonia:
Ammonia levels for 1997 in the marsh were reasonably consistent among the sites and displayed no trends (Fig. 46). The levels were around the 0.1-0.3 mg/L range. The levels for the marsh were comparable to the river sites so there seemed to be homogeneity along the Anacostia (Fig. 47). Ammonia can be released to the atmosphere, but more likely is metabolized into amino acids or further reduced to nitrogen gas. The ammonia levels seemed to fluctuate within expected limits during the years 1995-97 still lacking a describable pattern whether sampled in the marsh (Fig. 48) or in the river (Fig. 49 - Site 1).

Orthophosphate:
Orthophosphate remained stable (dynamic steady state) but at low levels in the marsh (Fig. 50) and the river (Fig. 51) during 1997, suggesting a biologically active system where most available orthophosphate is rapidly taken up by growing organisms and is almost always in demand during the growing season. Levels of orthophosphate appeared to be more dynamic in 1995 and 1996 in the marsh (Fig. 52) and Site 1 (Fig. 53) but concentrations remained relatively low. No particular pattern of change in inorganic phosphate emerged.

Total Phosphorus:
Total phosphorus ranged between 0.1 and 0.2 mg/L during 1997 both within the marsh (Fig. 54) and the river sites (Fig. 55) with the exception of a spike in late May that corresponded with a local storm event. Looking at total phosphorus over the three sampling years for the marsh (Fig. 56) and Site 1 (Fig. 57) the levels fluctuated but within a confined range possibly except for a late September 1996 spike which followed a major storm.

COMMENTARY:

It was expected that reconstruction of the 32-acre emergent wetland at Kenilworth would bring about detectable improvement to the marsh area itself. Positive trends could have been anticipated in several water quality parameters of the Anacostia over the ten-year period of 1988-97, particularly as a product of the concerted efforts to improve the watershed. However, the results of this limited monitoring study do not portray any obvious trends or shift in the water quality of the tidal Anacostia particularly in the Kenilworth Marsh reach during that period. That these data do not support an immediate (short-term) benefit to local water quality may be due in part to any or all of the following factors:

1. The 32 acres of reconstructed wetland constitute a minute percentage of the 128-square mile Anacostia watershed and cannot alone improve the water quality of the mainstem. More wetland acreage is needed to create sufficient system mass to have a chance to impact the water quality of the tidal Anacostia. However, a proportionally stronger influence was expected in the marsh locality but that was likely obscured for the reasons that follow.

2. When measuring the water quality in the marsh (even the tidal guts) at high slack tide or even ebbing tide, much of the water present was Anacostia River water that had been brought in on the rising tide. It would be prudent to conduct a study to correlate water quality including nutrient loads with hydrology (see #3).

3. Because much of the water in the Kenilworth Marsh area is exchanged during low tide and is replaced by a new volume of Anacostia water during each tide exchange (the twice daily tide cycle averages a 3 ft. amplitude) it is inappropriate to measure the marsh as if it were a pool or reservoir. To do so assumes that there might be an accumulative effect from each succeeding tidal interaction with the wetland. However, since there is no residual pool, the additive effect of any water cleansing by the wetland is lost by the flush and replacement of each tide. Thus a better way of measuring direct influence of the wetland would be to measure the marsh waters in a diurnal fashion including the collection/measurement of water coming directly off the marsh at ebb tide before it has a chance to mix with the high tide pool in the tidal guts or open water portions of the marsh.

Another, perhaps more sensitive approach would be one initiated by Dr. David Velinsky (Academy of Natural Sciences, Philadelphia). He measured the volumes of water moving in and out of Kenilworth Marsh (over two tide cycles) at the single marsh entrance from the Anacostia mainstem in a diurnal fashion and compared the concentrations/loads of nutrients, etc., entering the marsh as opposed to leaving the marsh on the tide cycles. He estimated that approximately ten million liters of Anacostia water are brought into the marsh on each rising tide (personal communication). This promising quantitative approach needs to be completed and further evaluated.

4. The volume of water and associated loads of 'pollutants' such as suspended solids and nutrients, etc., are so high in the tidal Anacostia that it would take considerable wetland acreage to affect the water quality. As the inordinately high loads in the Anacostia decrease due to multiple long-term efforts in the watershed, the Kenilworth Marsh and any additional wetlands will have an increasing opportunity to play a significant role. That is, the important but limited capacity of the wetlands to affect water quality needs to await the time when the incoming loads are low enough that the marsh influence can be detected rather than overwhelmed as appears to be the current situation. Perhaps a model or study can be constructed that compares volumes of water, pollutant loads and capacity of various acreages of wetlands needed to influence water quality.

5. Another important, but often overlooked factor, is that only a very small volume of water, if any, actually interacts with the wetland for a relatively short period of time on each tide cycle. For example, if we assume the wetland is fairly level and is at the elevation of mean high tide (as is the case for much of Kenilworth Marsh), which is optimum for mid-marsh vegetation establishment, then about 50% of the time no water interacts with the emergent marsh on those tidal cycles. Actually, during the growing season (May to October) the frequency of inundations above mean high tide is somewhat greater. However, on those higher tides that are 1, 2, or 3 inches above mean high tide (and this includes more than 60% of the tides higher than mean high tide) only a very small volume of water is covering the marsh (about 0.8-2.5 million gallons on the 32-acre site). Because those tides are only covering the marsh for a short period of time, perhaps two hours, there is limited opportunity for nutrient processing, or even sediment trapping and settling. Considering further that much of the water on tides *higher* than a few inches above mean high tide probably has little chance to interact with the marsh, then overall there is only a very small quantity of the Anacostia water that can be influenced by the reconstructed wetland. Additionally, almost no tides cover the emergent marsh during the winter (except storm events).

6. Although data are not available, it should be recognized that drag from the emergent vegetation slows the movement of any incoming tide and reduces the opportunity for volume of coverage; correspondingly, there is drag as the water ebbs off the marsh. It is likely that reduced velocity causes an increased rate of sediment deposition and contact time for microbial transformations.

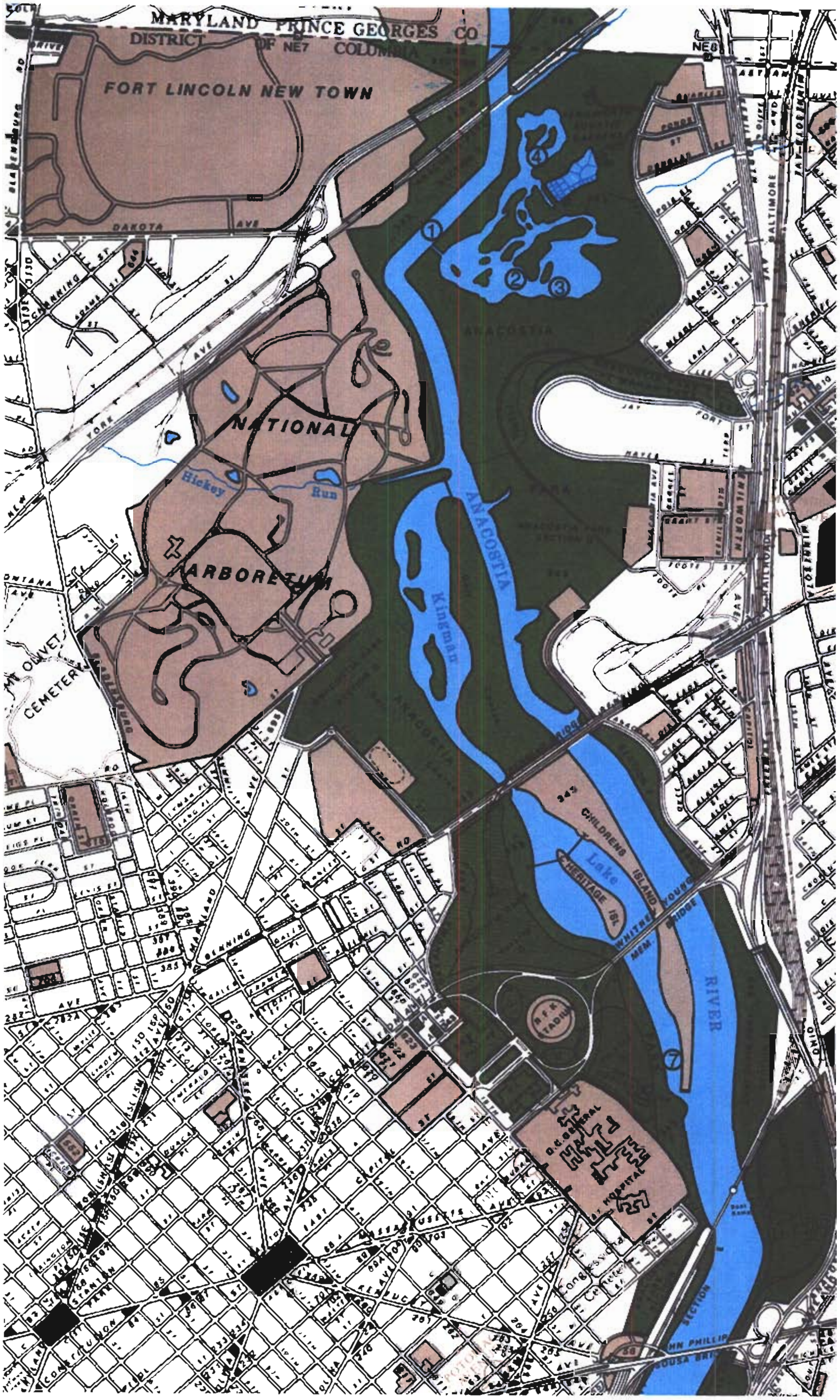
In conclusion, the force driving the processes of the wetlands is the persistent semi-diurnal tidal cycle. However, much of the potential gain from this function is negated under situations such as occur at Kenilworth Marsh where much of the water is exchanged, not pooled, on each tidal cycle thereby minimizing the possibility of accumulative local effect from the emergent wetland system. In the case of the Anacostia, any possible influence is overwhelmed at this time by the sheer volume and burden of pollutants of the mainstem. To increase the effectiveness of the freshwater tidal marshes in the Anacostia more acres of wetland are necessary, a watershed-wide reduction in sediment and nutrient loads to levels manageable by the biological/physical processes of the wetlands and reconstruction of wetlands so as to maximize the contact time of ambient waters with the wetlands.

ACKNOWLEDGEMENTS:

Considerable contribution in the gathering, assimilation and analysis of this data was provided by technical support staff (in the order of their presence) including: Dianne Ingram, Alicia Kosiorek Goddard, Lauren Glushik and Heather Mayhew. I am deeply indebted not only to their dedicated input but also to the selfless and generally cheerful manner in which it was given.

LITERATURE CITED

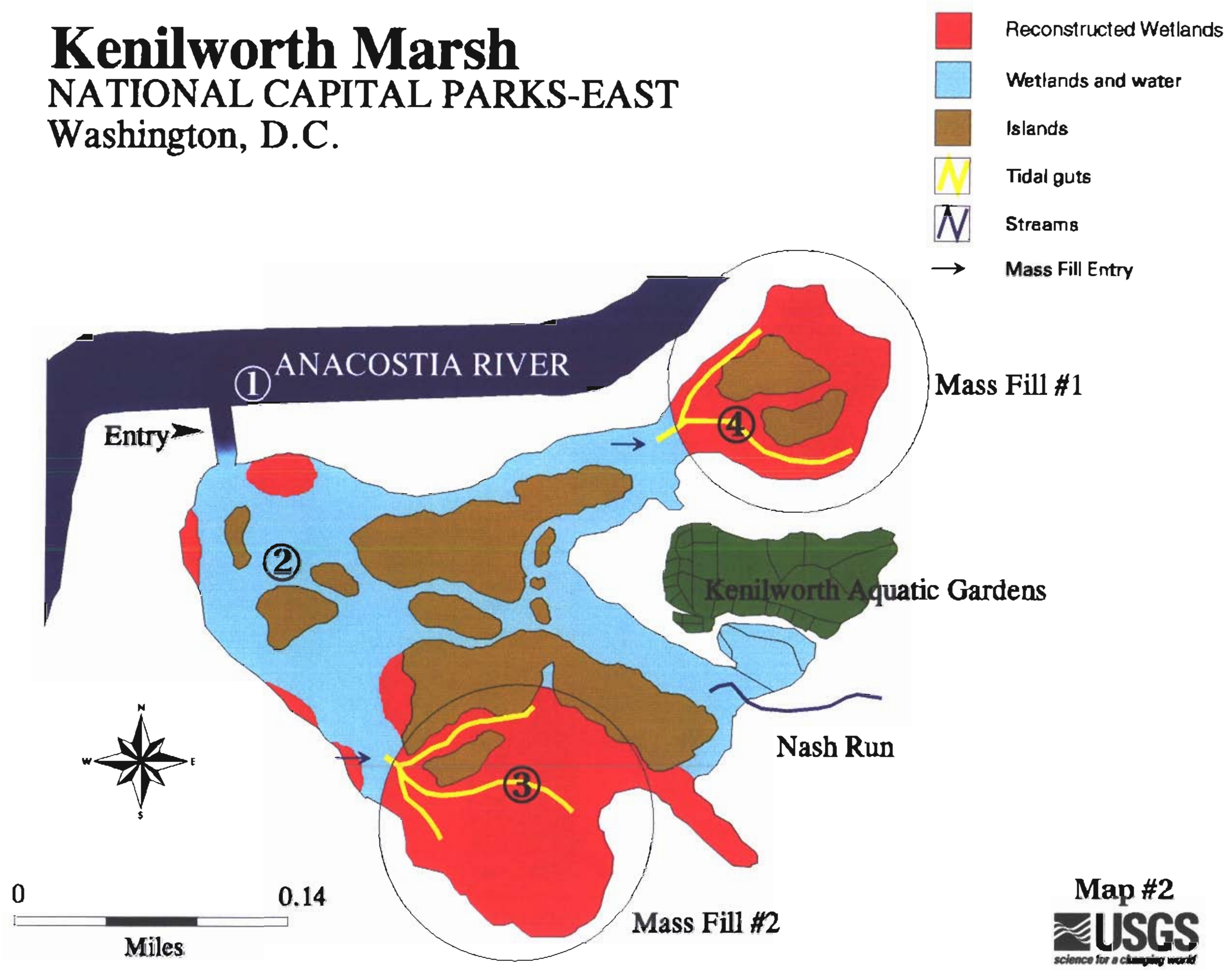
1. APHA. 1980. *Standard Methods for the Examination of Water and Wastewater*. 15th ed. Washington, DC: American Public Health Association.
2. Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. New York: Van Nostrand Reinhold.
3. Gopal, B., R. E. Turner, R.G. Wetzel and D. F. Whigham, eds. 1982. *Wetlands Ecology and Management*. Jaipur, India: International Scientific Publications.
4. Hazelwood, B., T.J. Murphy and M. Ibrahim. 1998. Anacostia River Dissolved Oxygen Conditions Technical Report: Comparative Analysis of Impacts of the Swirl Concentrator. Washington, DC: Met. Wash. Council of Govts.
5. Kirk, John T. 1986. *Light and Photosynthesis in Aquatic Systems*. Cambridge, England: Cambridge University Press.
6. Reid, George K. 1960. *Ecology of Inland Waters and Estuaries*. New York: D.Van Nostrand Co.
7. Tourbier, D. L., and R. R. Pierson, Jr., eds. *Biological Control of Water Pollution*. Philadelphia, PA: University of Pennsylvania Press.
8. Whigham, D. F., McCormick, J., Good, R. E., amd Simpson, R. L. 1978. Biomass and primary production of freshwater tidal wetlands of the Middle Atlantic Coast. In *Freshwater Wetlands: Ecological Processes and Management Potential*. R. E. Good, D. F. Whigham and R. L. Simpson, eds. New York: Academic Press.



Map #1

USGS
science for a changing world

Kenilworth Marsh
NATIONAL CAPITAL PARKS-EAST
Washington, D.C.



Map #2

Table 1. T-test Results

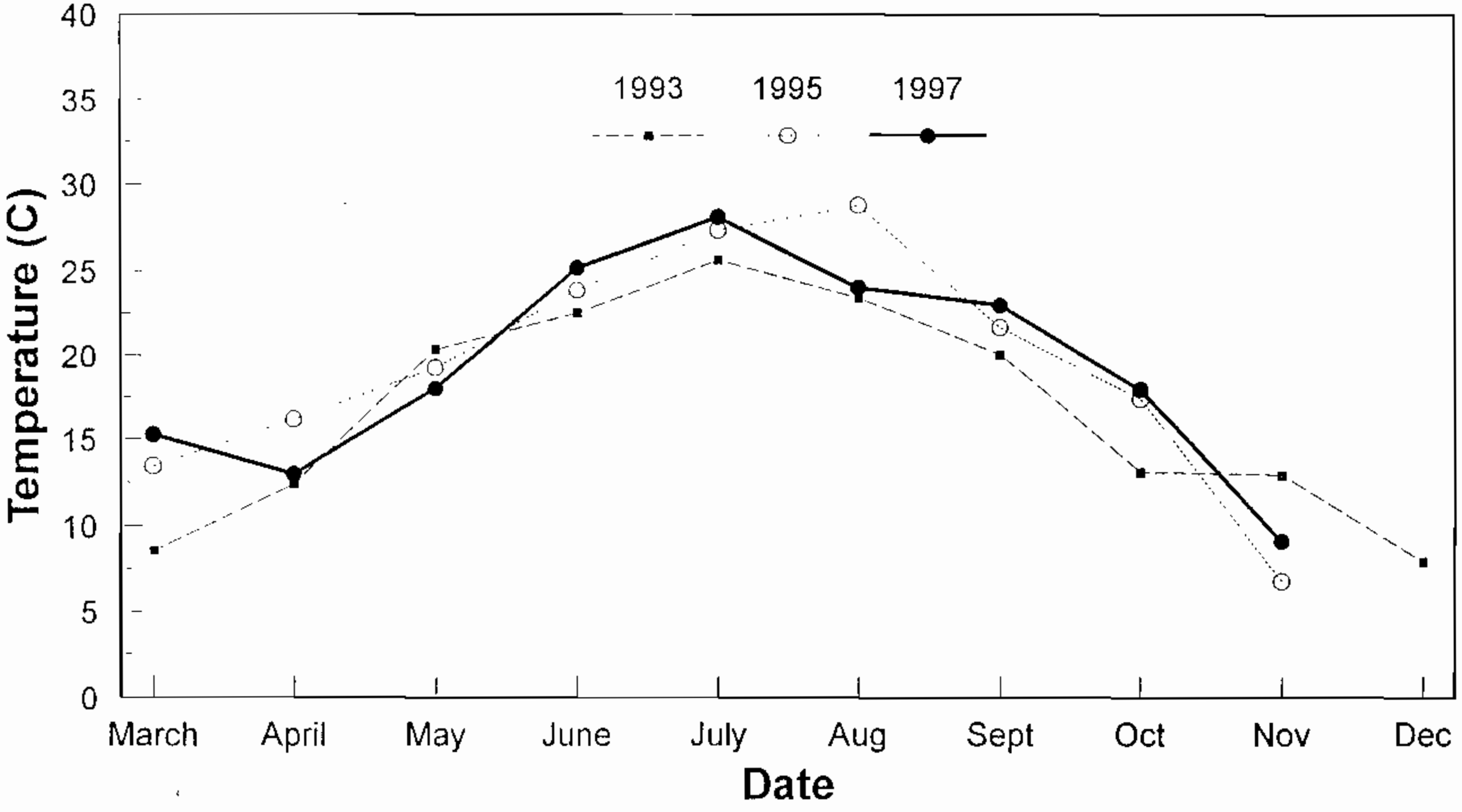
Site	N	Mean	SD	Probability (a = 0.05)
DISSOLVED OXYGEN (mg/L)				
Site 1 1988-1992	8	5.7	1.3	0.86
Site 1 1993-1997	9	5.9	2.0	
Avg. of Sites 2,3,4 1988-1992	8	5.6	1.1	0.22
Avg. of Sites 2,3,4 1993-1997	9	6.5	1.7	
Site 1 1993-1997	9	5.9	2.0	0.53
Avg. of Sites 2,3,4 1993-1997	9	6.5	1.7	
Site 1 1988-1992	8	5.6	1.1	0.78
Avg. of Sites 2,3,4 1988-1992	8	5.7	1.3	
SECCHI (cm)				
Site 1 1988-1992	8	32	4	0.80
Site 1 1993-1997	9	32	3	
Avg. of Sites 2,3,4 1988-1992	8	27	4	0.93
Avg. of Sites 2,3,4 1993-1997	9	28	4	
Site 1 1993-1997	9	32	3	0.014
Avg. of Sites 2,3,4 1993-1997	9	28	4	
Site 1 1988-1992	8	32	4	0.037
Avg. of Sites 2,3,4 1988-1992	8	27	4	
TURBIDITY (NTU)				
Site 1 1988-1992	8	45.4	18.6	0.007
Site 1 1993-1997	9	20.8	5.2	
Avg. of Sites 2,3,4 1988-1992	8	46.9	14.3	0.001
Avg. of Sites 2,3,4 1993-1997	9	21.2	4.4	
Site 1 1993-1997	9	20.8	5.2	0.86
Avg. of Sites 2,3,4 1993-1997	9	21.2	4.4	
Site 1 1988-1992	8	45.4	18.6	0.87
Avg. of Sites 2,3,4 1988-1992	8	46.9	14.3	

Table 1. T-test Results continued

Site	N	Mean	SD	Probability (a = 0.05)
<u>SUSPENDED SOLIDS(mg/L)</u>				
Site 1 1988-1992	8	28.5	8.7	0.75
Site 1 1993-1997	9	29.6	4.6	
Avg. of Sites 2,3,4 1988-1992	8	36.2	9.2	0.62
Avg. of Sites 2,3,4 1993-1997	9	38.2	6.3	
Site 1 1993-1997	9	29.6	4.6	0.005
Avg. of Sites 2,3,4 1993-1997	9	38.2	6.3	
Site 1 1988-1992	8	36.2	9.2	0.11
Avg. of Sites 2,3,4 1988-1992	8	28.5	8.7	

TEMPERATURE

SITES 2,3,4 (avg.)
1993, 1995, 1997

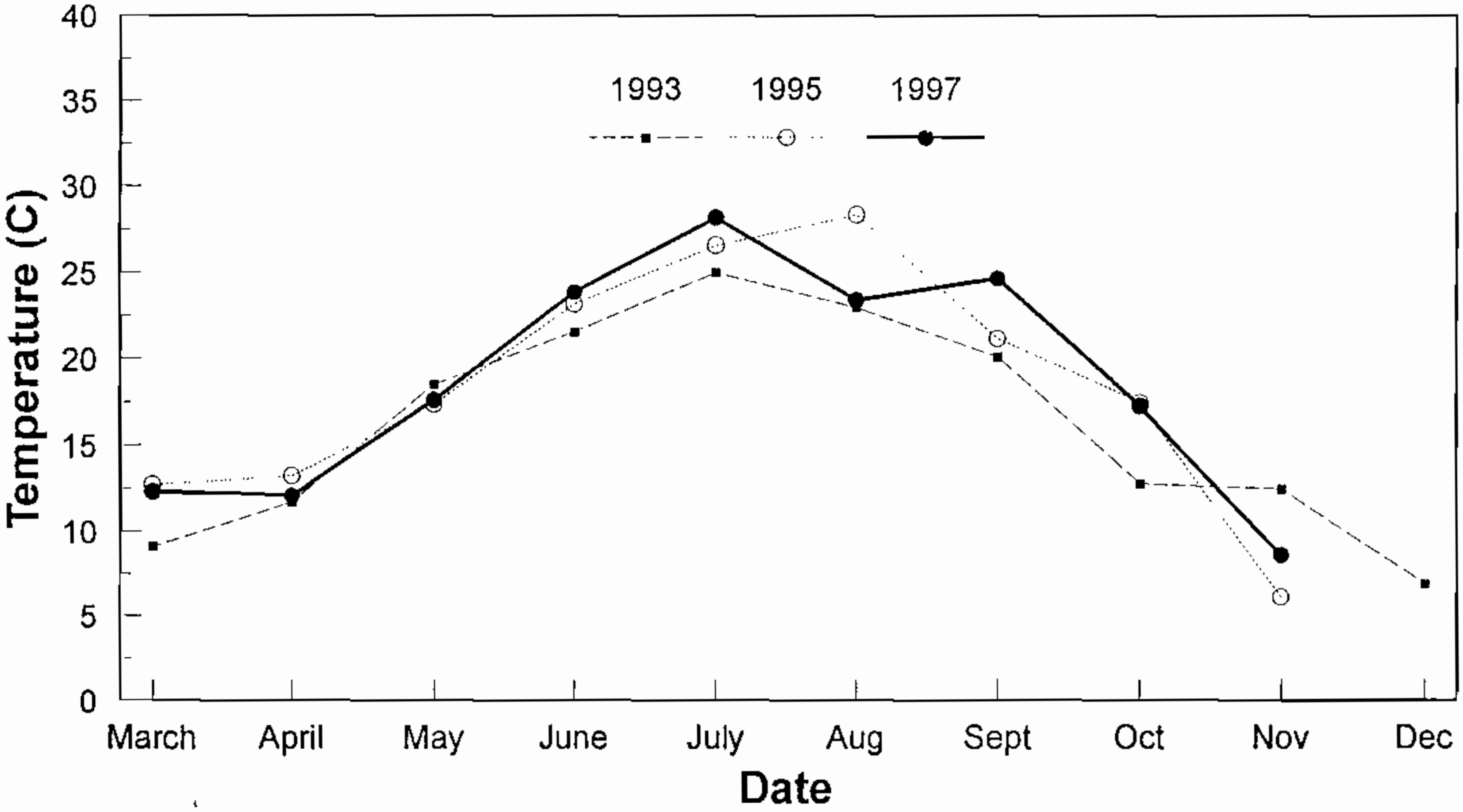


Kenilworth Marsh
Fig. 1

TEMPERATURE

SITE 1

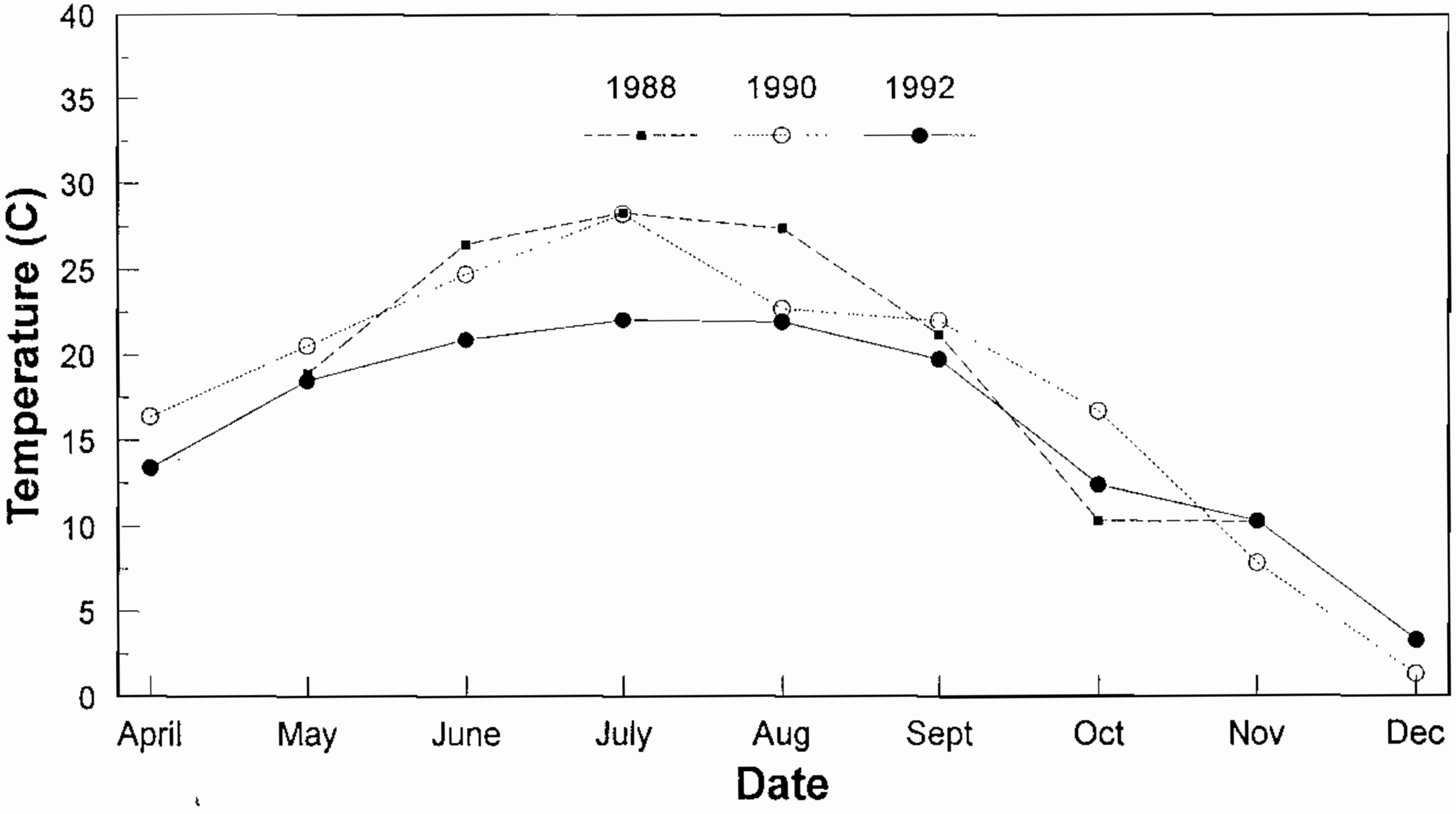
1993, 1995, 1997



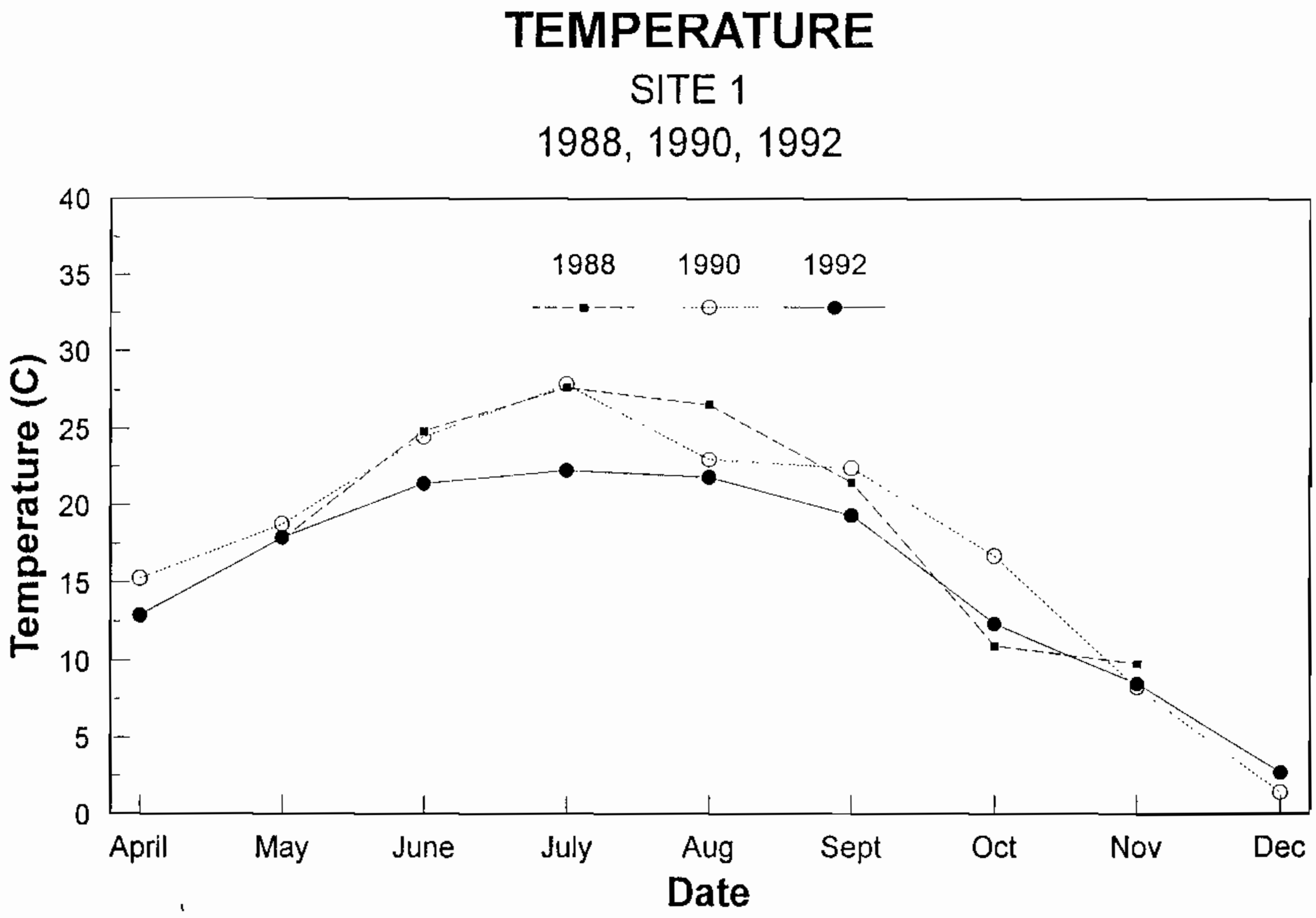
Kenilworth Marsh
Fig. 2

TEMPERATURE

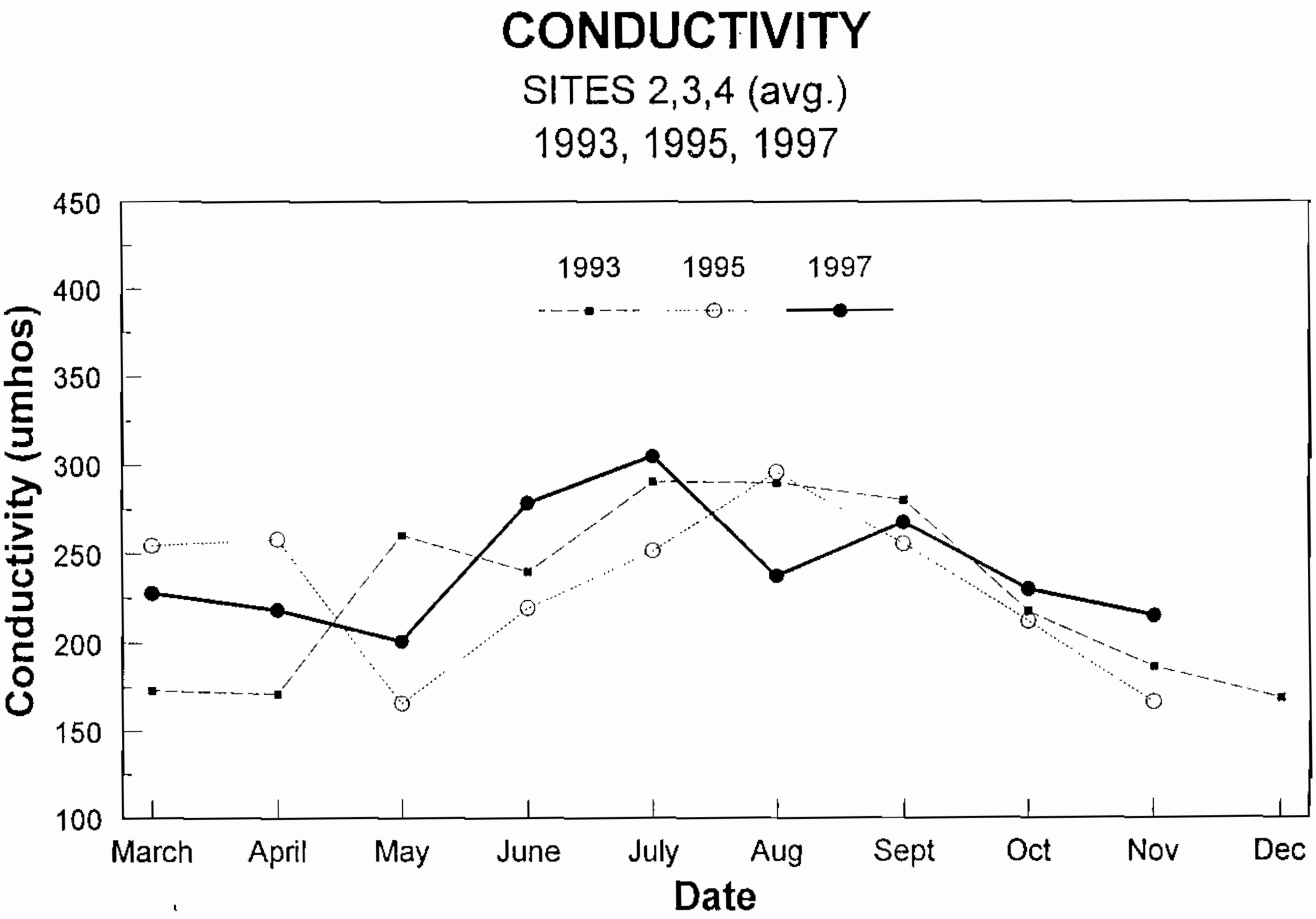
SITES 2,3,4 (avg.)
1988, 1990, 1992



Kenilworth Marsh
Fig. 3



Kenilworth Marsh
Fig. 4

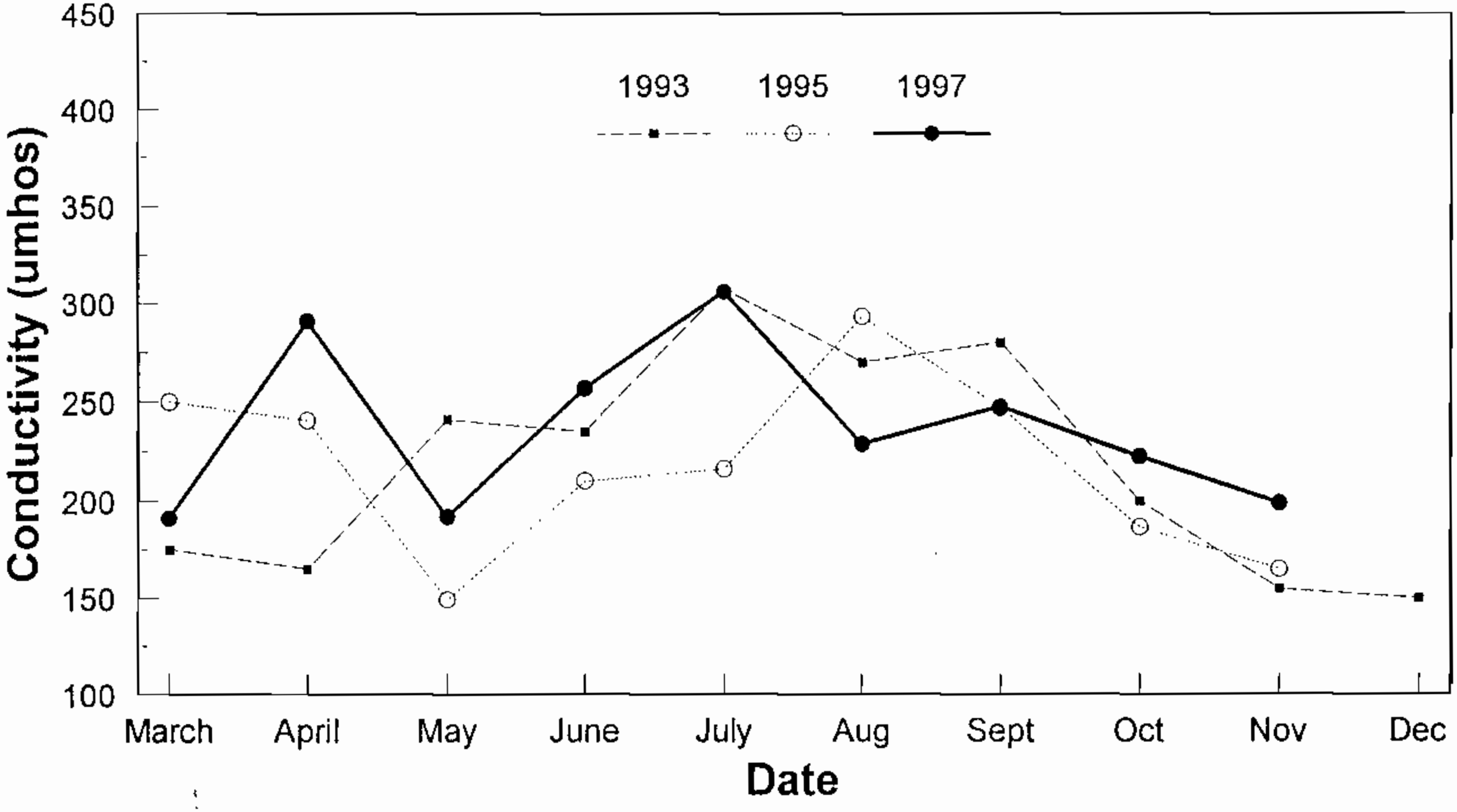


Kenilworth Marsh
Fig. 5

CONDUCTIVITY

SITE 1

1993, 1995, 1997

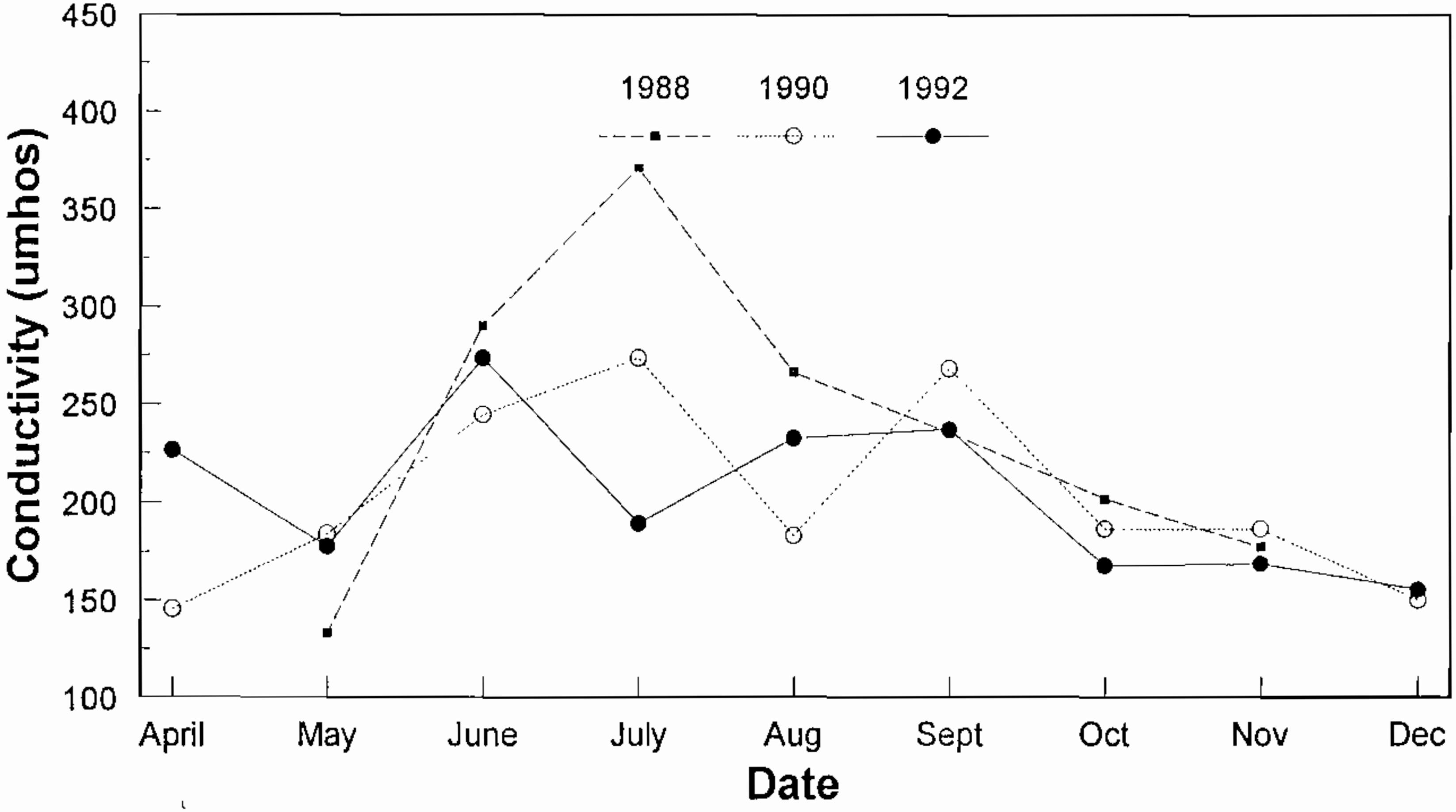


Kenilworth Marsh
Fig. 6

CONDUCTIVITY

SITES 2,3,4 (avg.)

1988, 1990, 1992

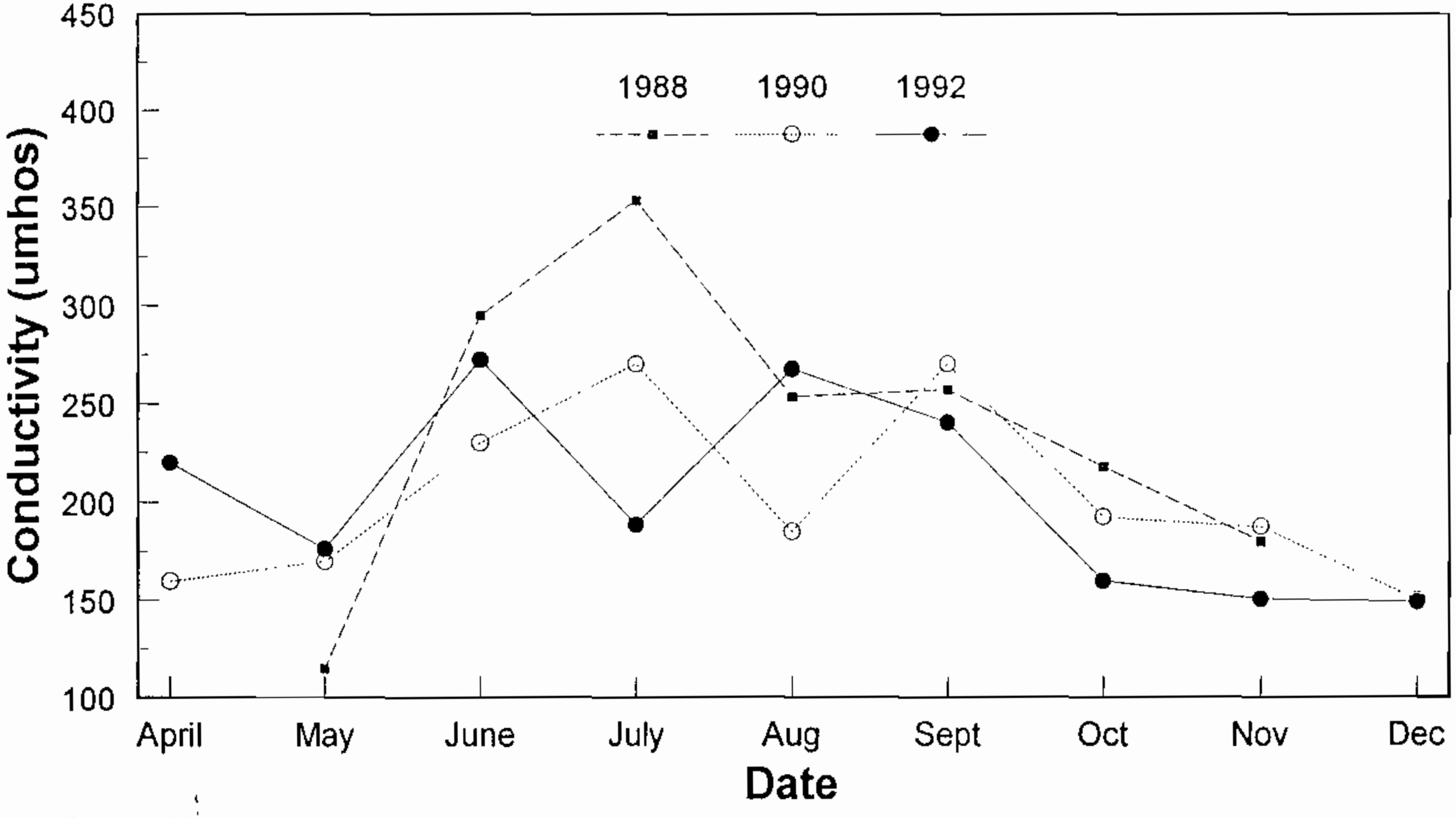


Kenilworth Marsh
Fig. 7

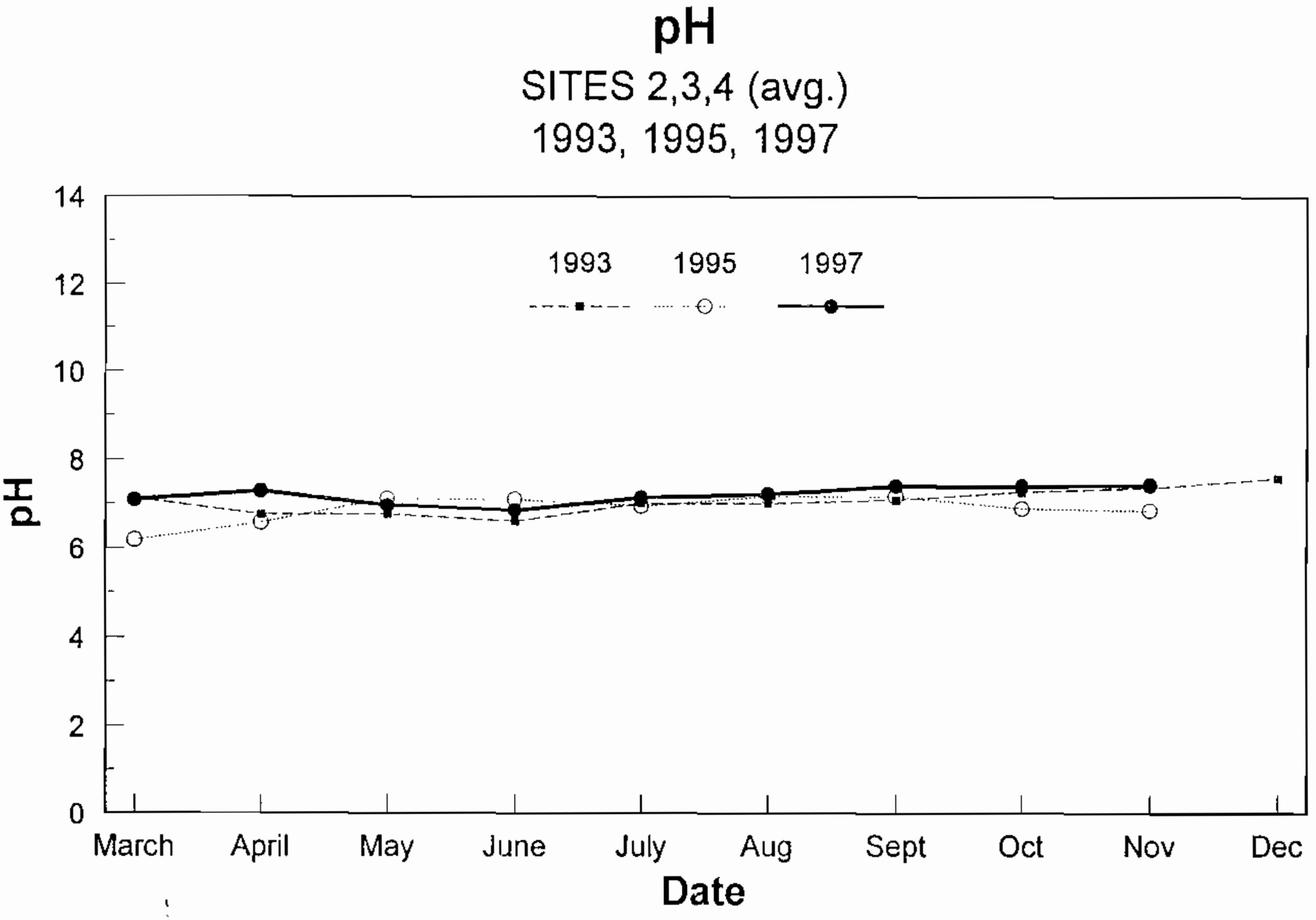
CONDUCTIVITY

SITE 1

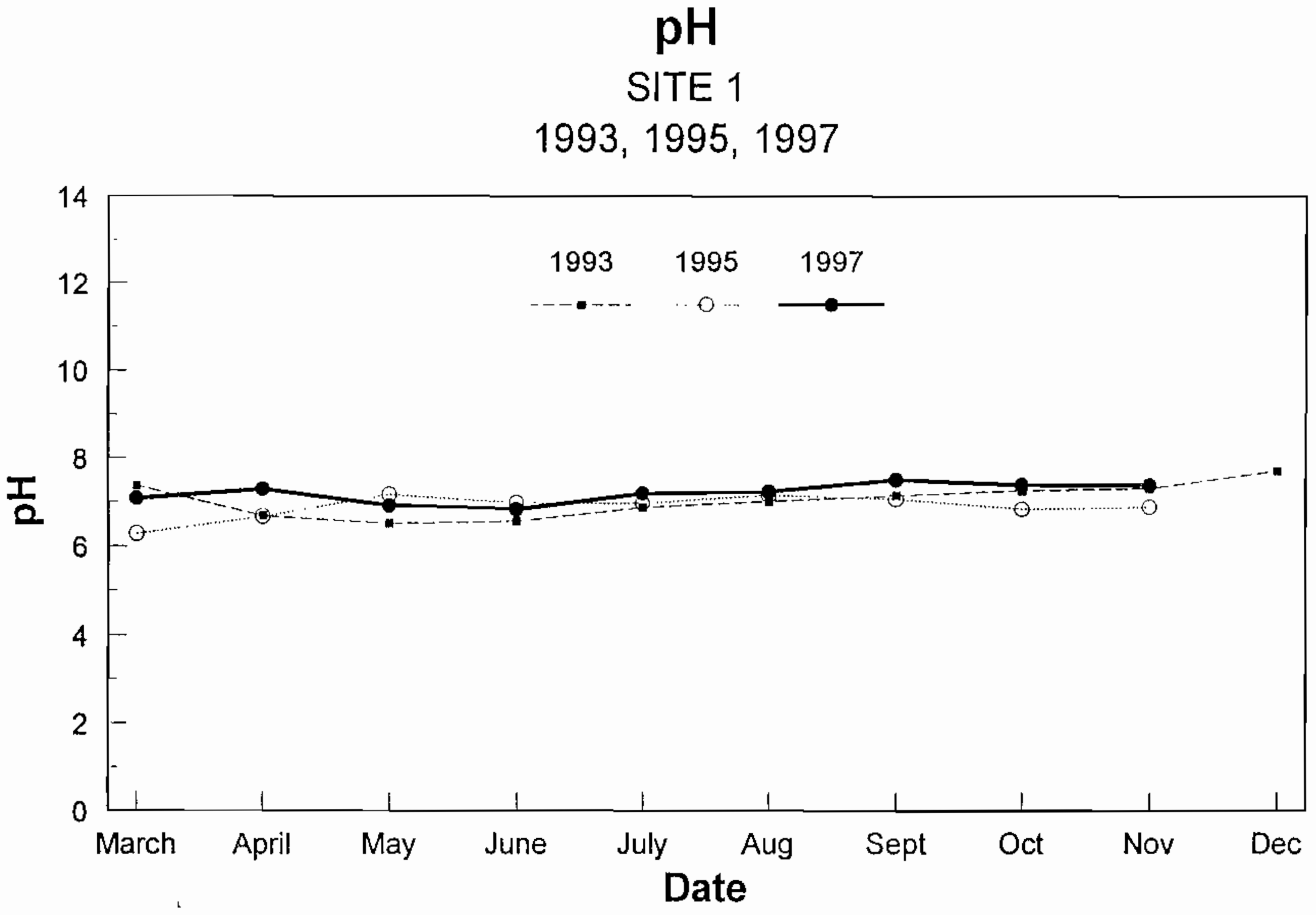
1988, 1990, 1992



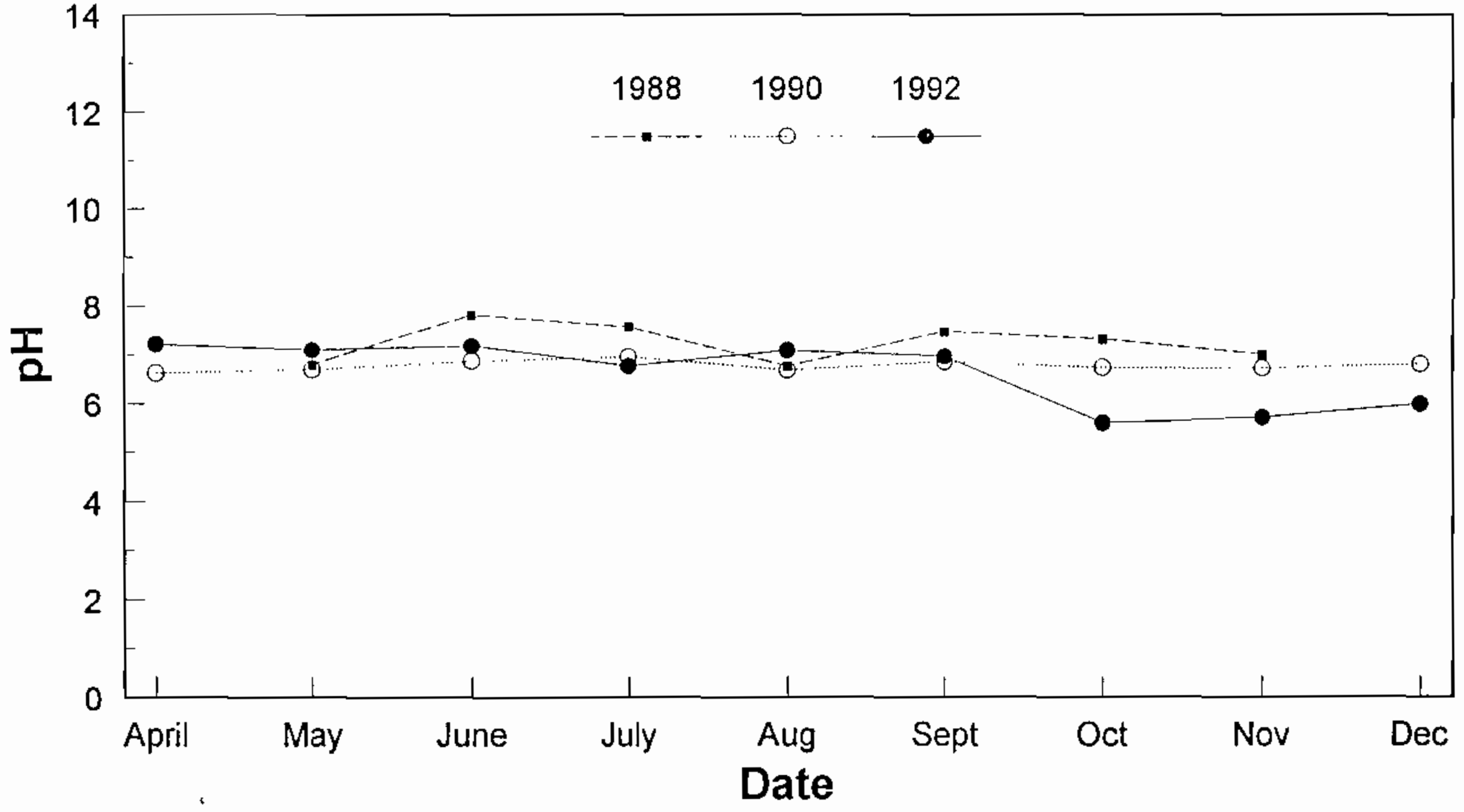
Kenilworth Marsh
Fig. 8



Kenilworth Marsh
Fig. 9



Kenilworth Marsh
Fig. 10



pH

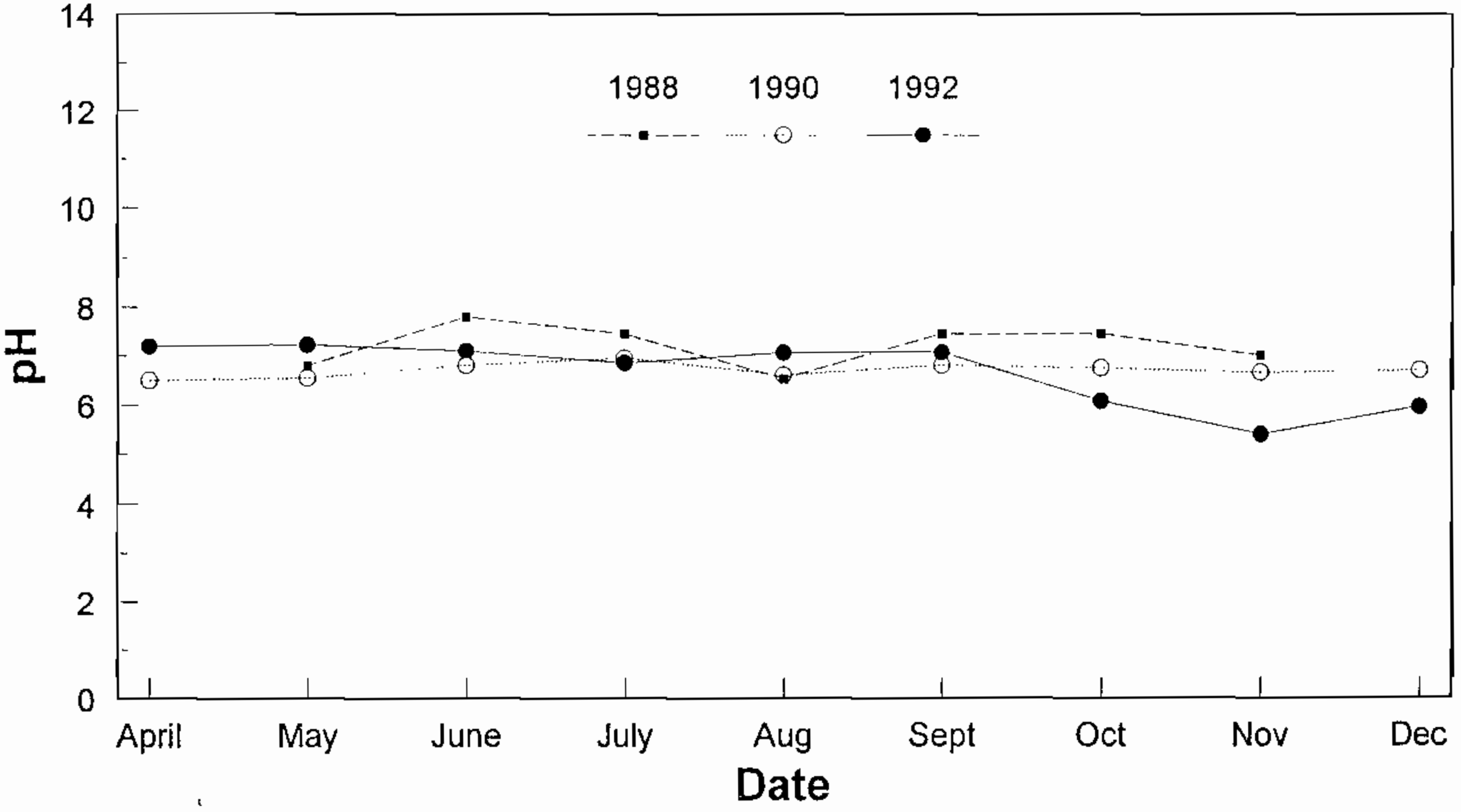
SITES 2,3,4 (avg.)
1988, 1990, 1992

Kenilworth Marsh
Fig. 11

pH

SITE 1

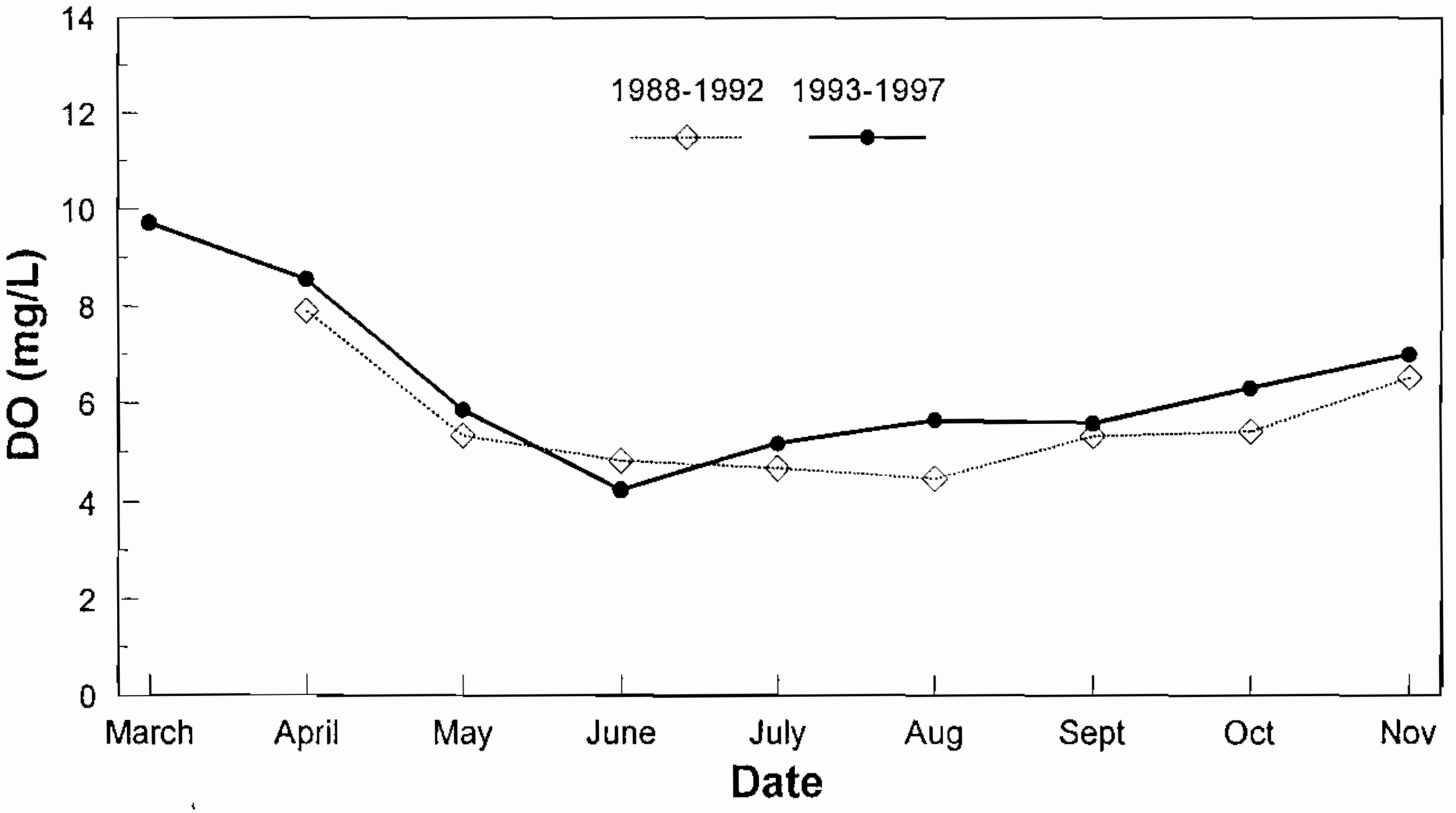
1988, 1990, 1992



Kenilworth Marsh
Fig. 12

DISSOLVED OXYGEN

SITES 2,3,4 (avg.)
5 YEAR AVERAGES

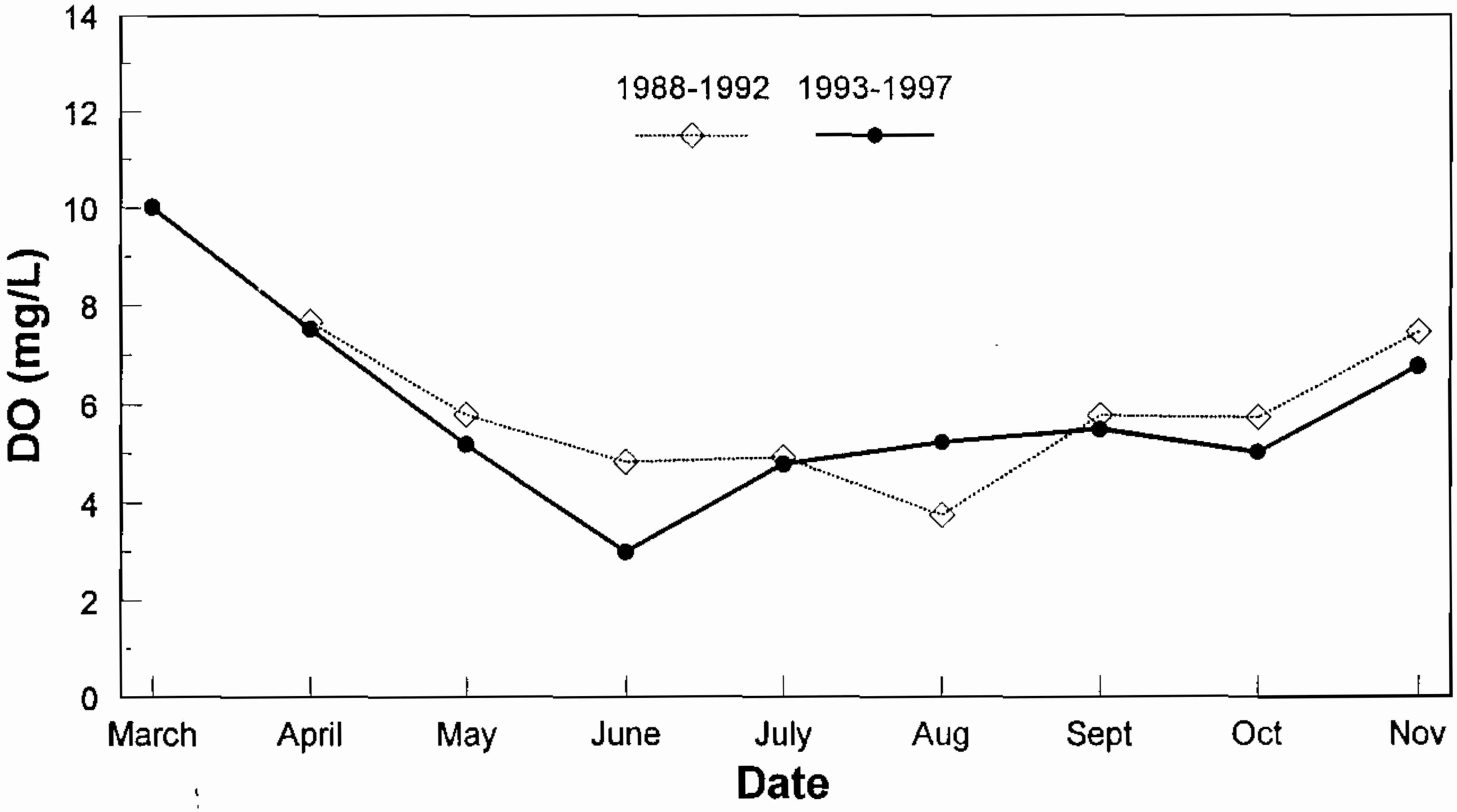


Kenilworth Marsh
Fig. 13

DISSOLVED OXYGEN

SITE 1

5 YEAR AVERAGES

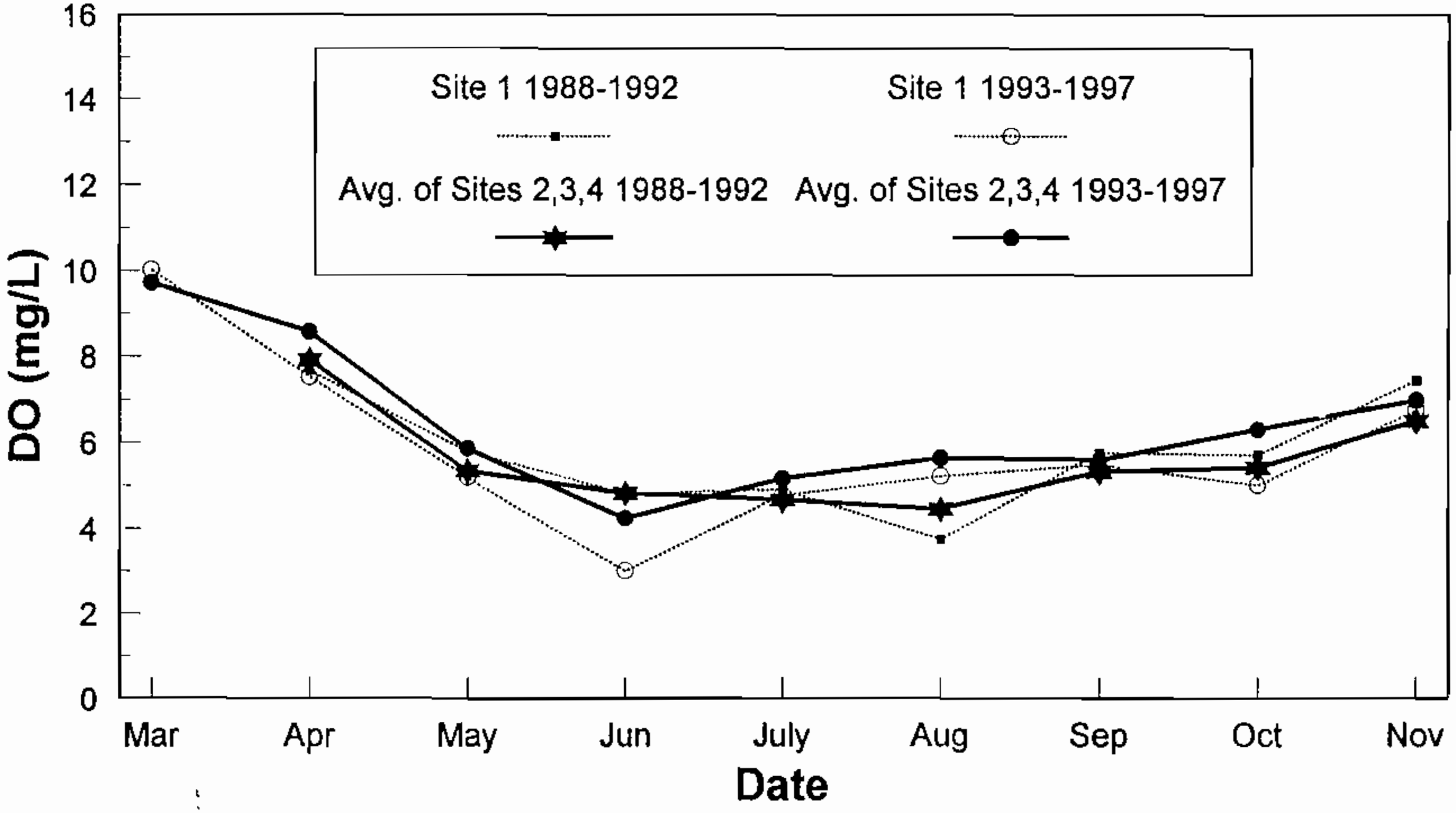


Kenilworth Marsh
Fig. 14

DISSOLVED OXYGEN

SITES 1 and 2,3,4 (avg.)

5 YEAR AVERAGES

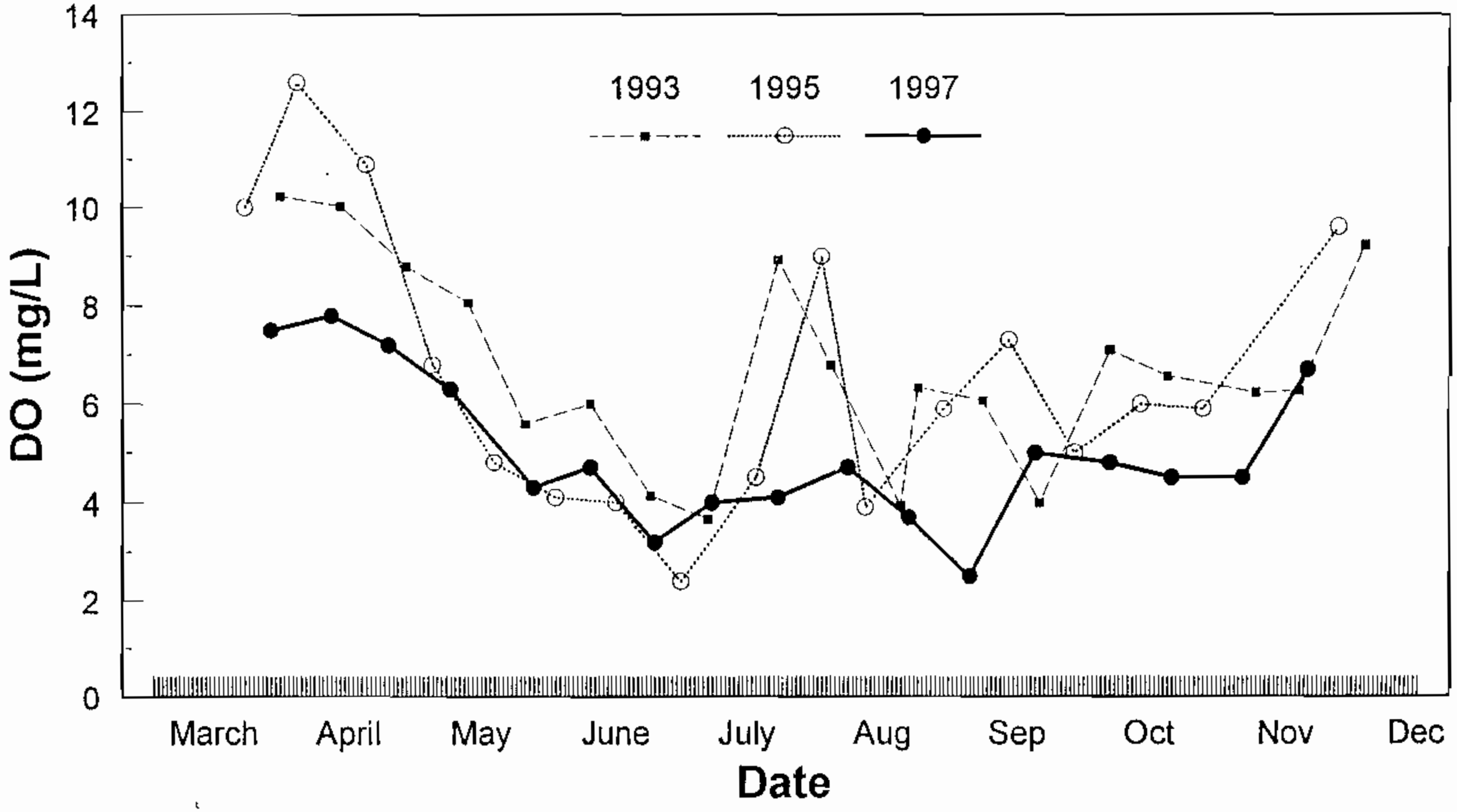


Kenilworth Marsh
Fig. 14a

DISSOLVED OXYGEN

SITES 2,3,4 (avg.)

1993, 1995, 1997

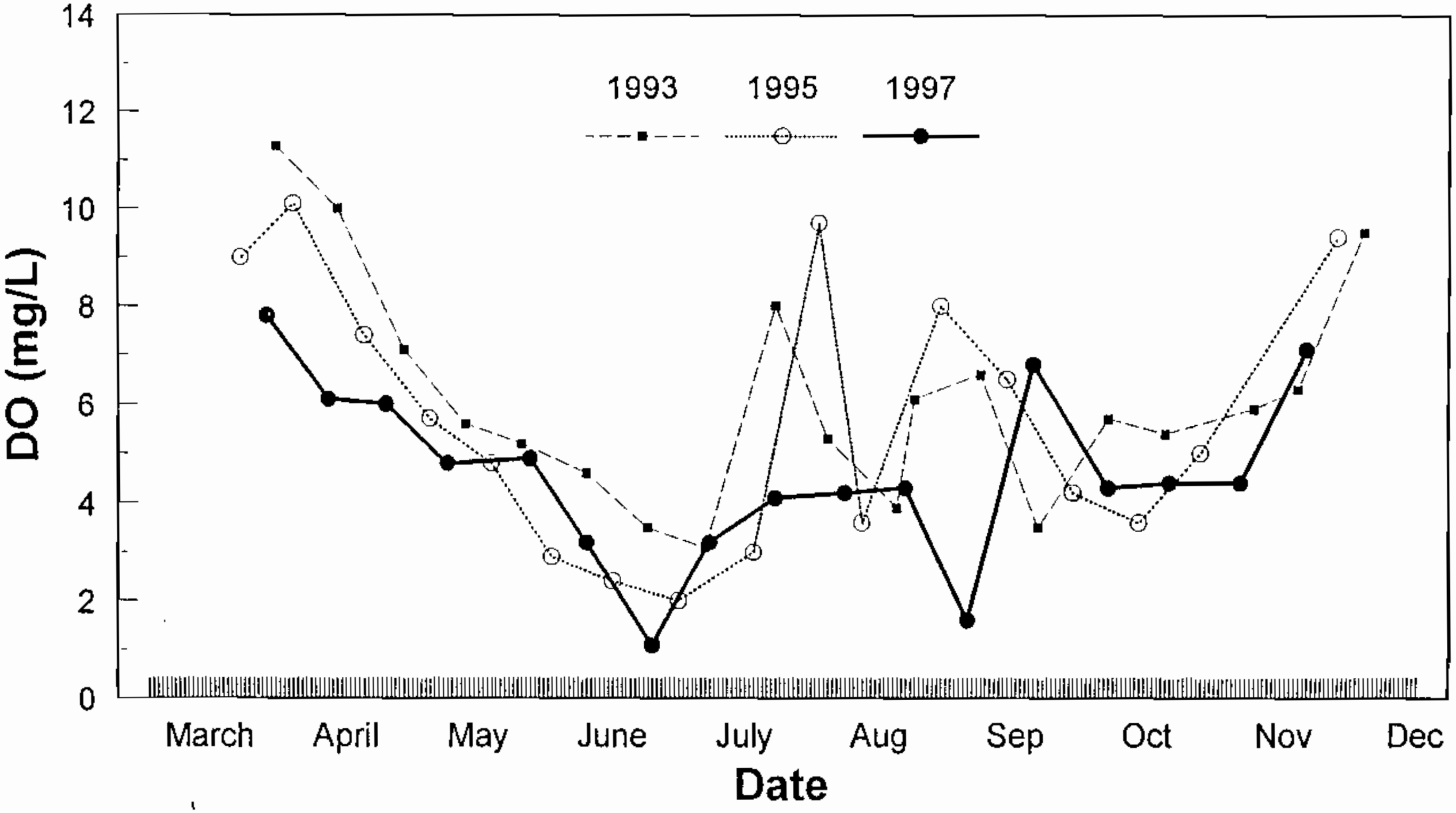


Kenilworth Marsh
Fig. 15

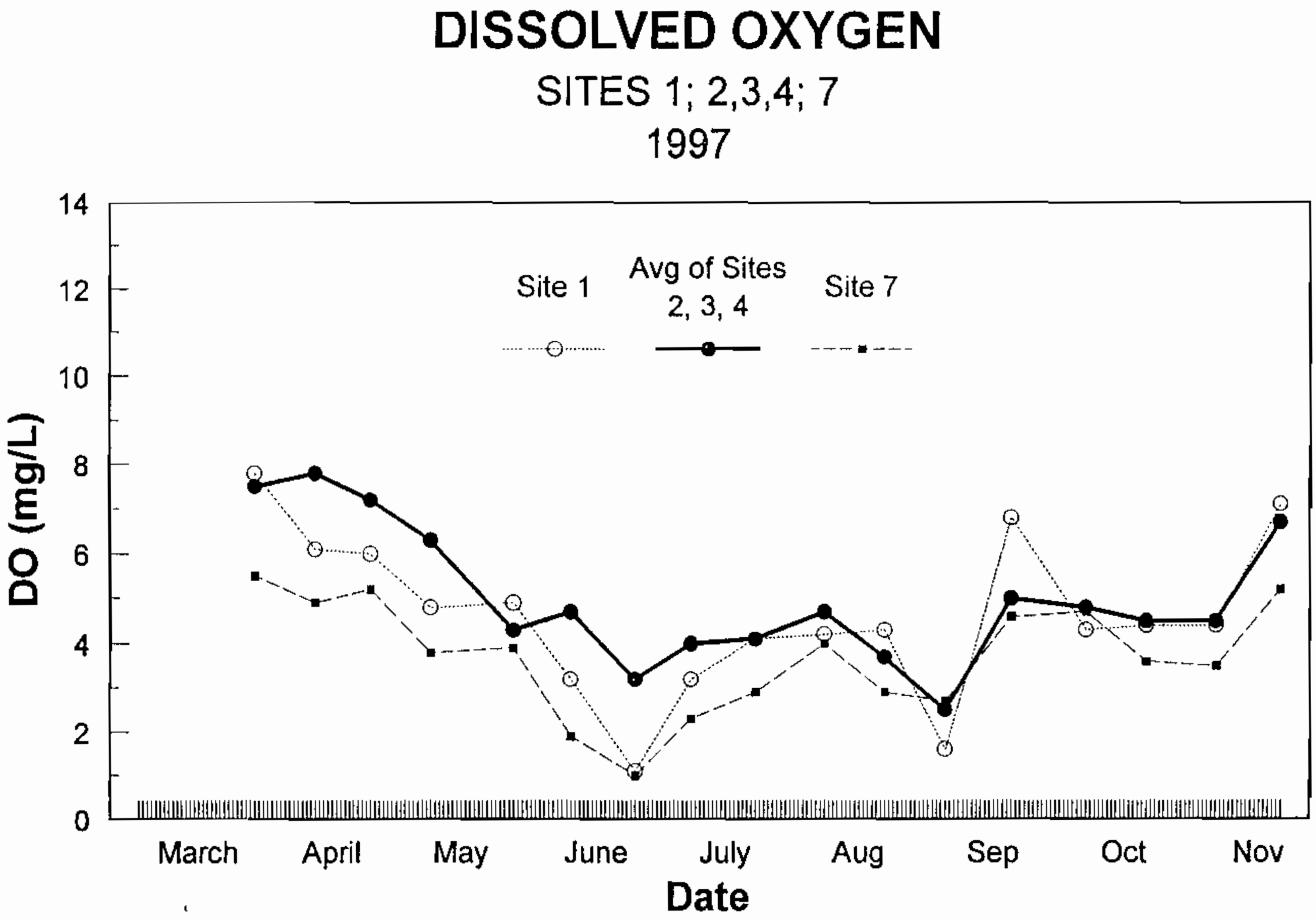
DISSOLVED OXYGEN

SITE 1

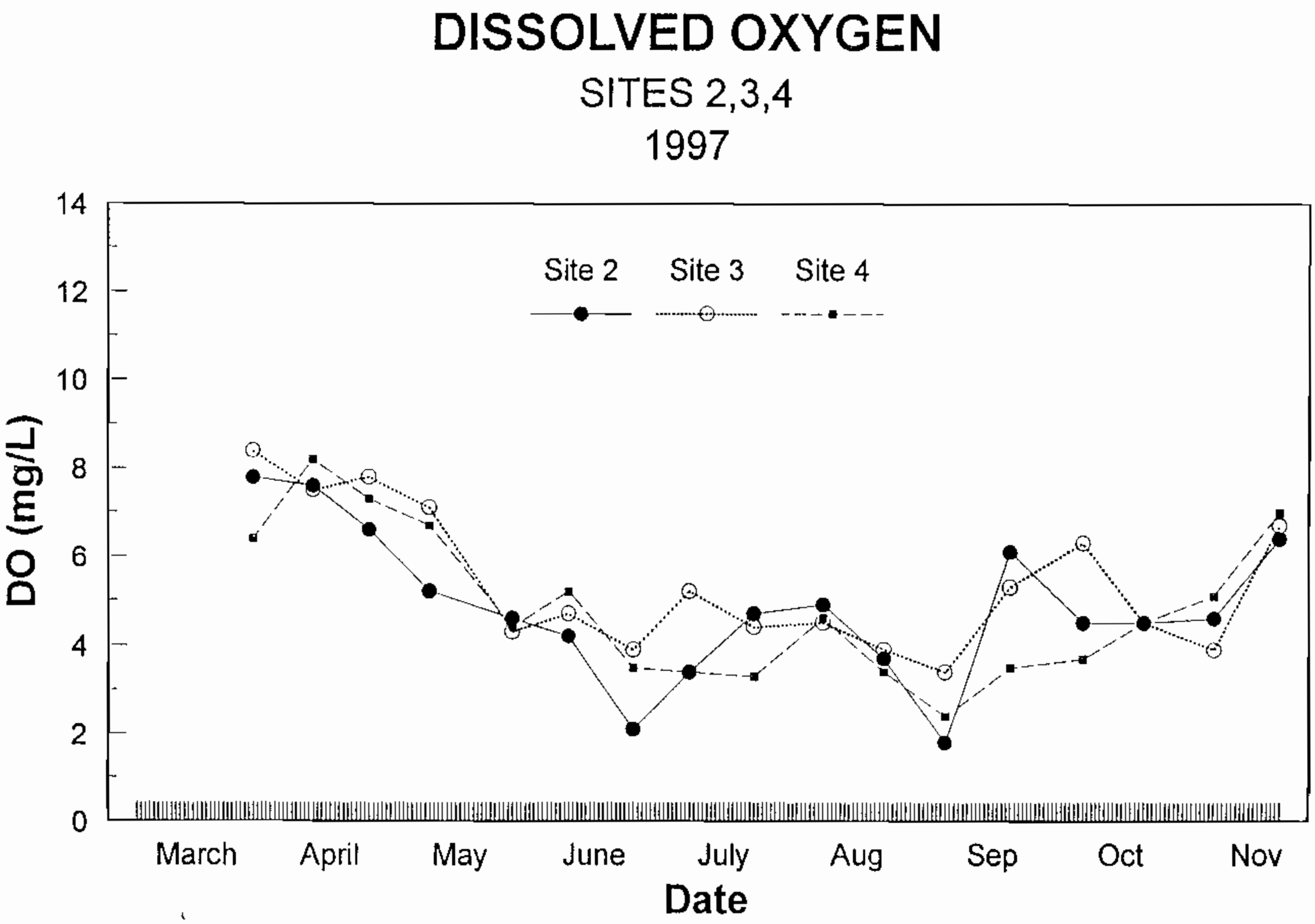
1993, 1995, 1997



Kenilworth Marsh
Fig. 16


DISSOLVED OXYGEN
SITES 1; 2,3,4; 7
1997

Kenilworth Marsh
Fig. 17

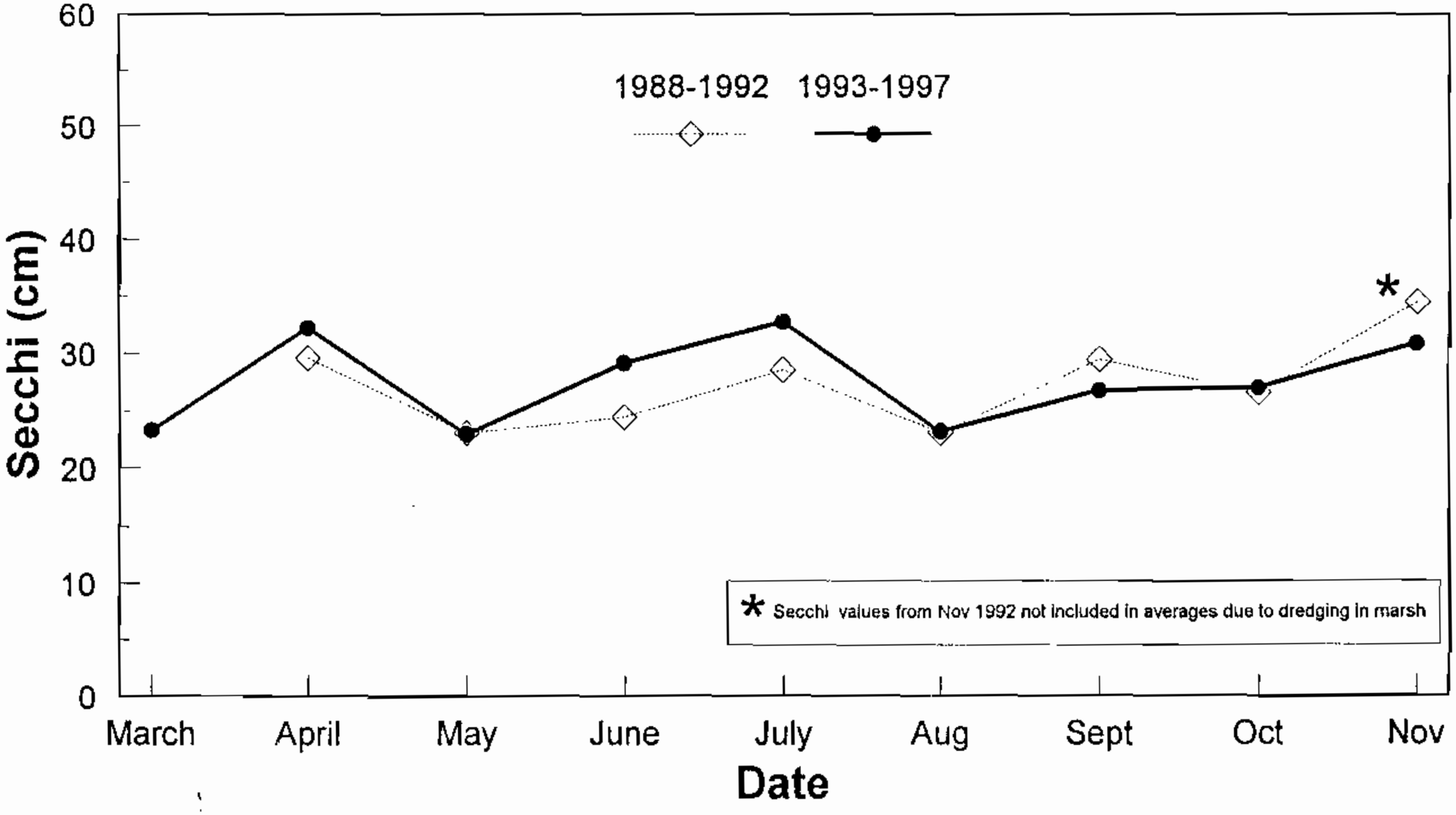


DISSOLVED OXYGEN
SITES 2,3,4
1997

Kenilworth Marsh
Fig. 18

SECCHI

SITES 2,3,4 (avg.)
5 YEAR AVERAGES

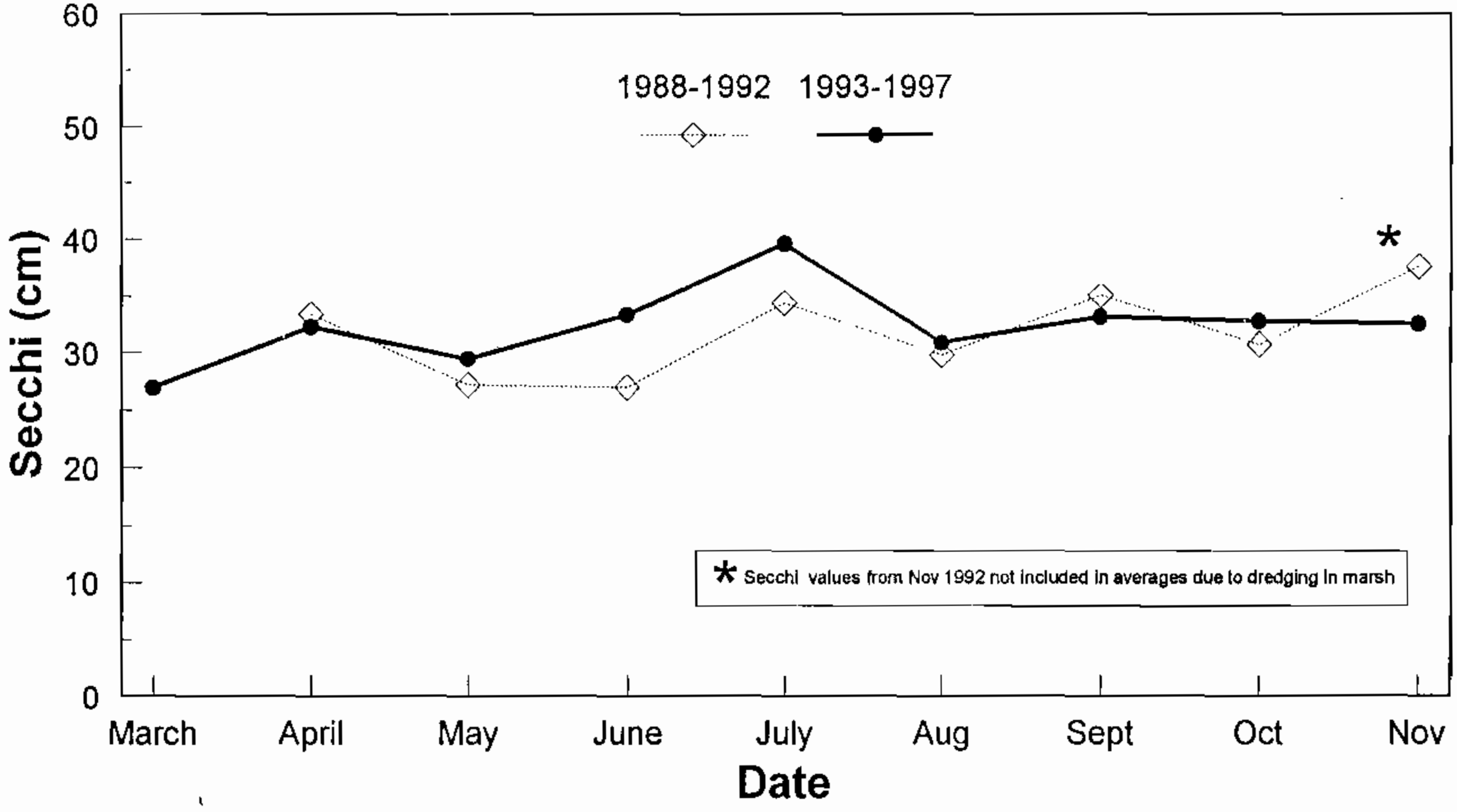


Kenilworth Marsh
Fig. 19

SECCHI

SITE 1

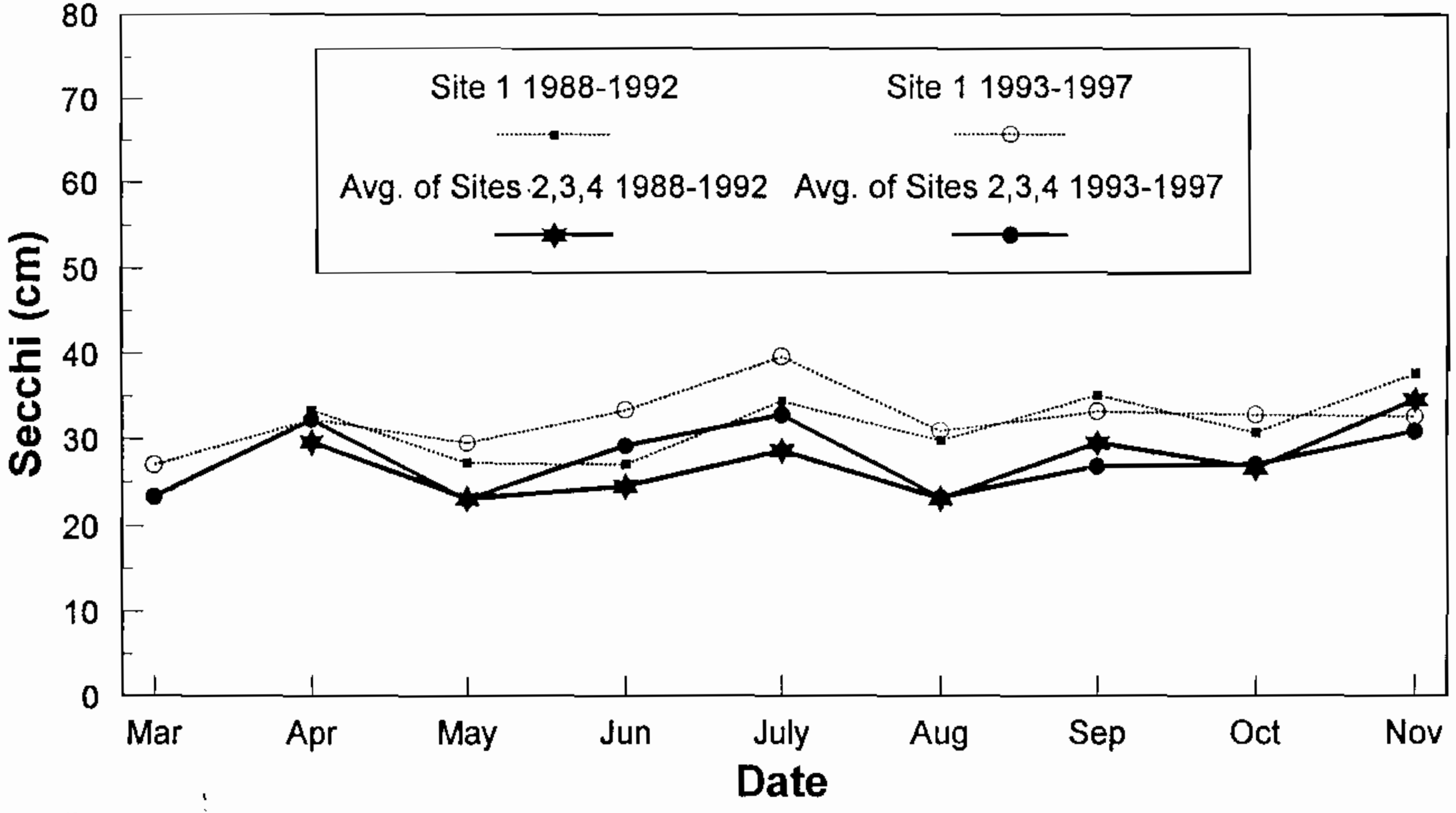
5 YEAR AVERAGES



Kenilworth Marsh
Fig. 20

SECCHI

SITE 1 and 2,3,4 (avg.)
5 YEAR AVERAGES

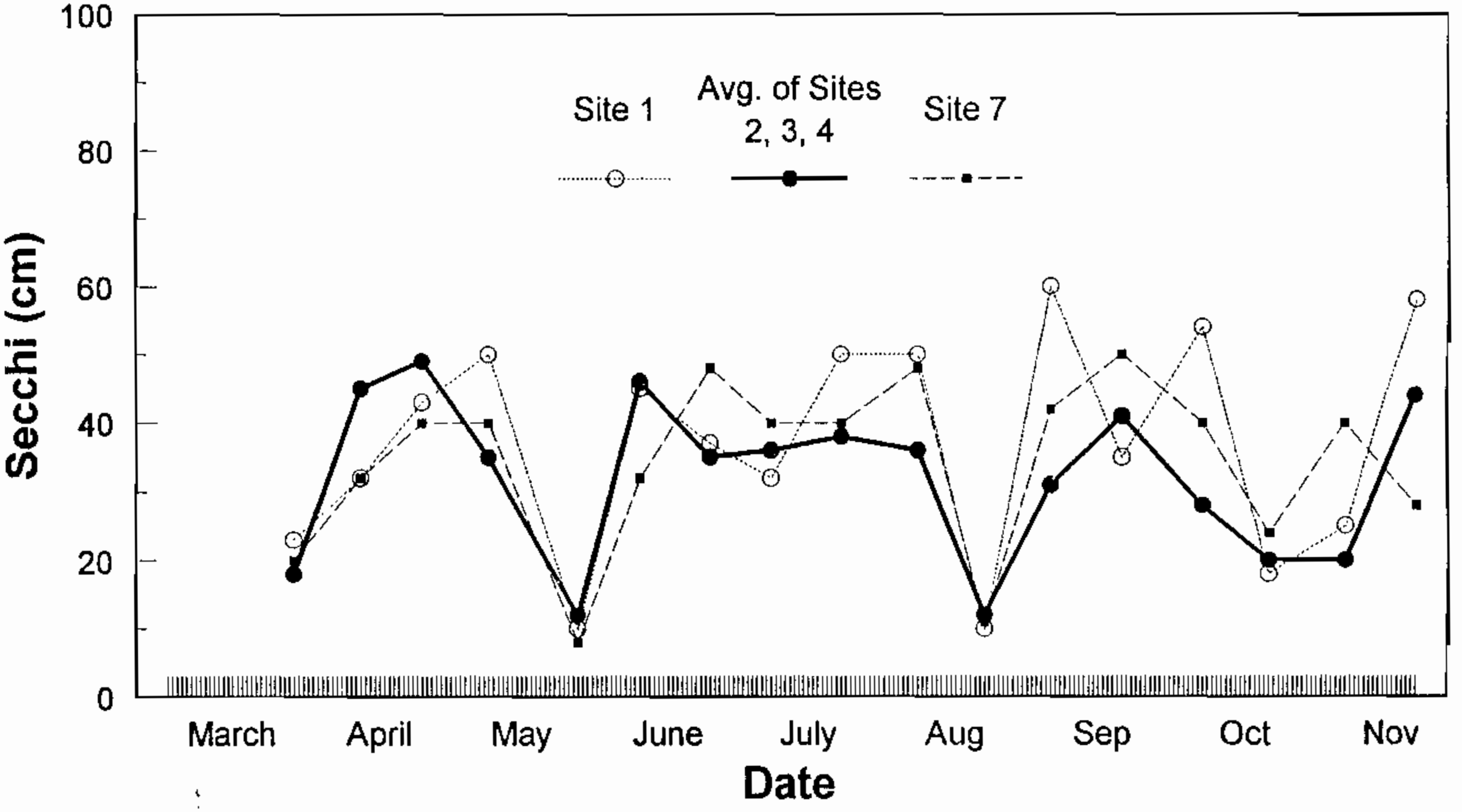


Kenilworth Marsh
Fig. 20a

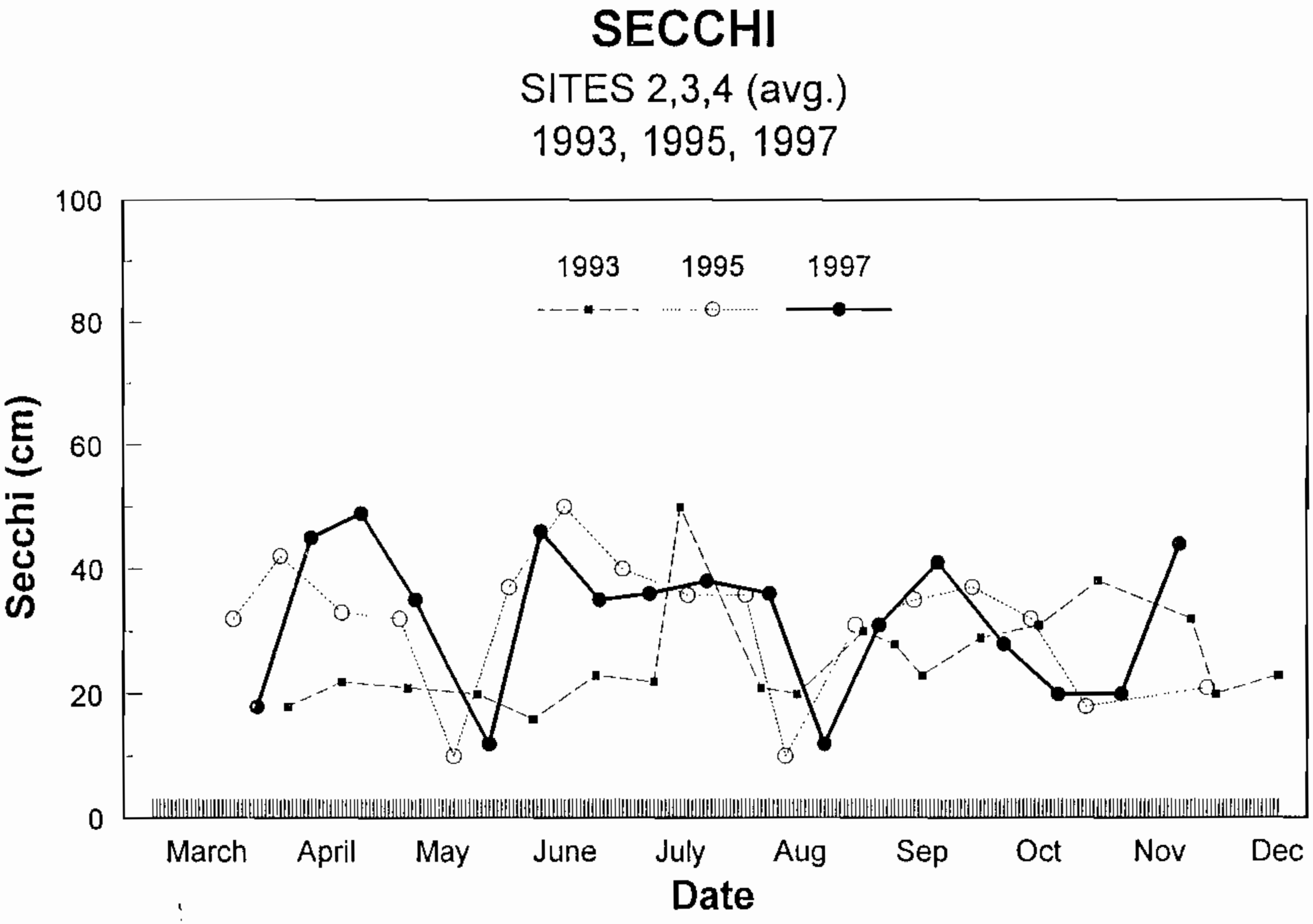
SECCHI

SITES 1; 2,3,4; 7

1997



Kenilworth Marsh
Fig. 21



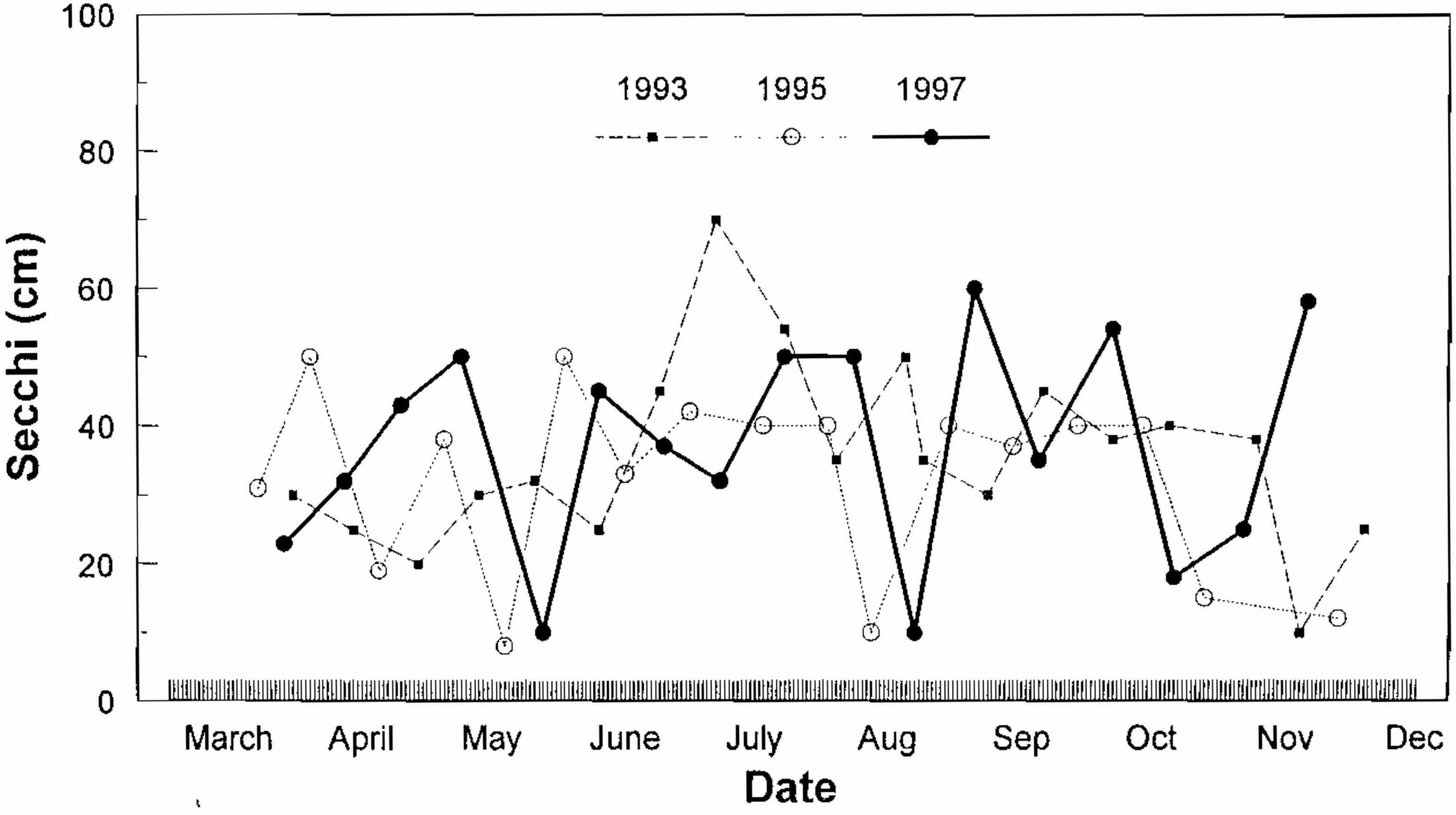
SECCHI
SITES 2,3,4 (avg.)
1993, 1995, 1997

Kenilworth Marsh
Fig. 22

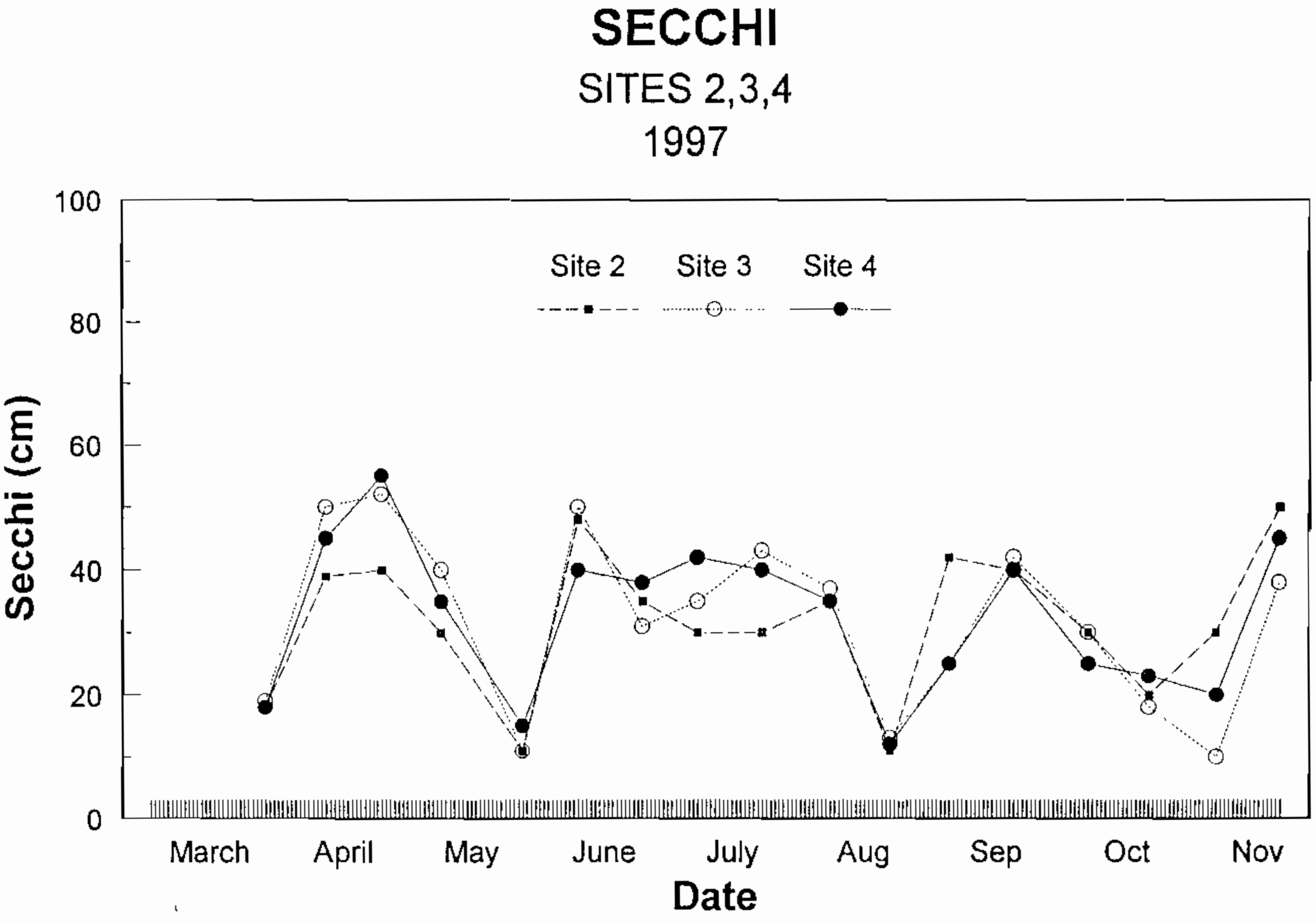
SECCHI

SITE 1

1993, 1995, 1997



Kenilworth Marsh
Fig. 23

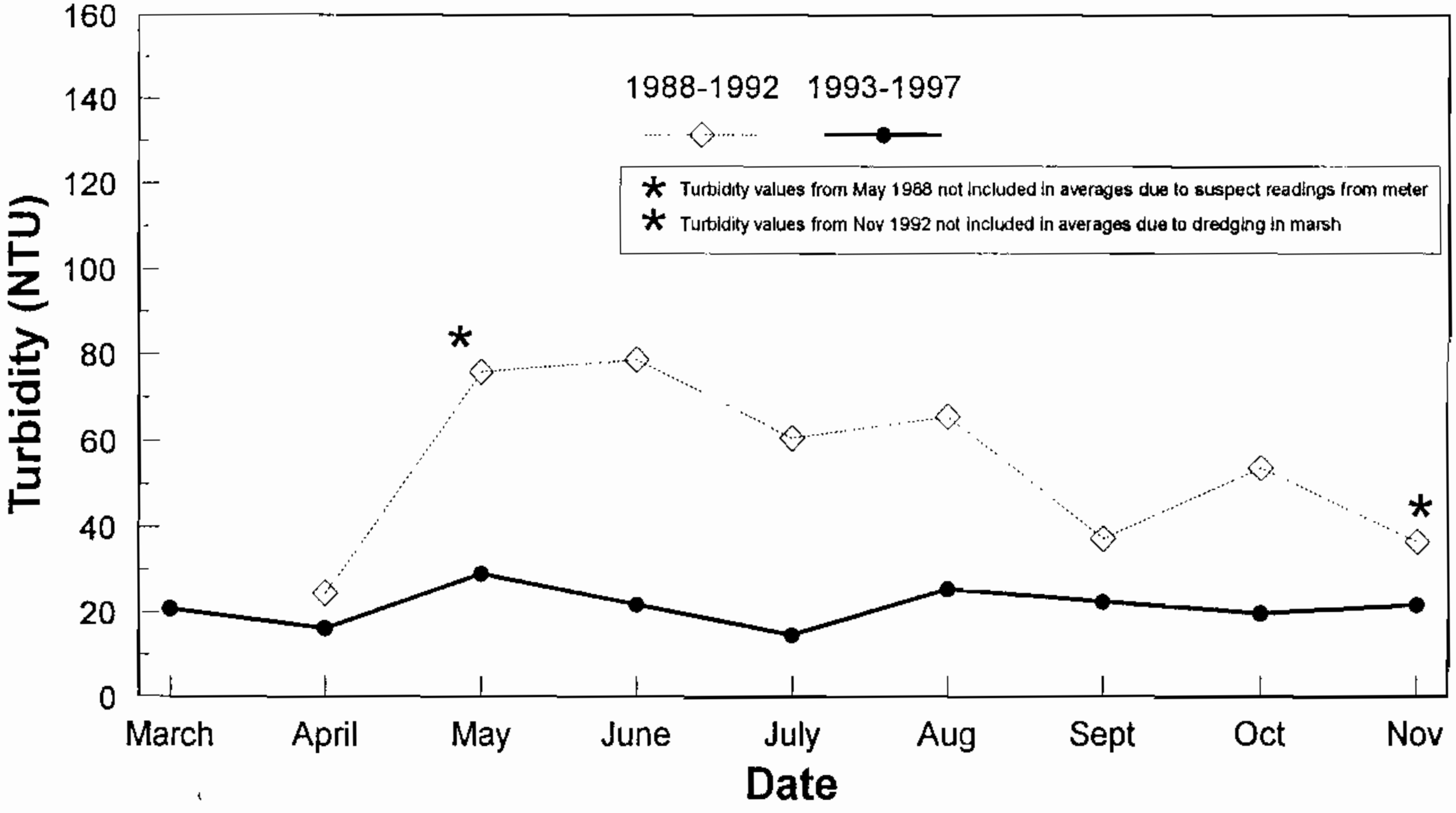


Kenilworth Marsh
Fig. 24

TURBIDITY

SITES 2,3,4 (avg.)

5 YEAR AVERAGES



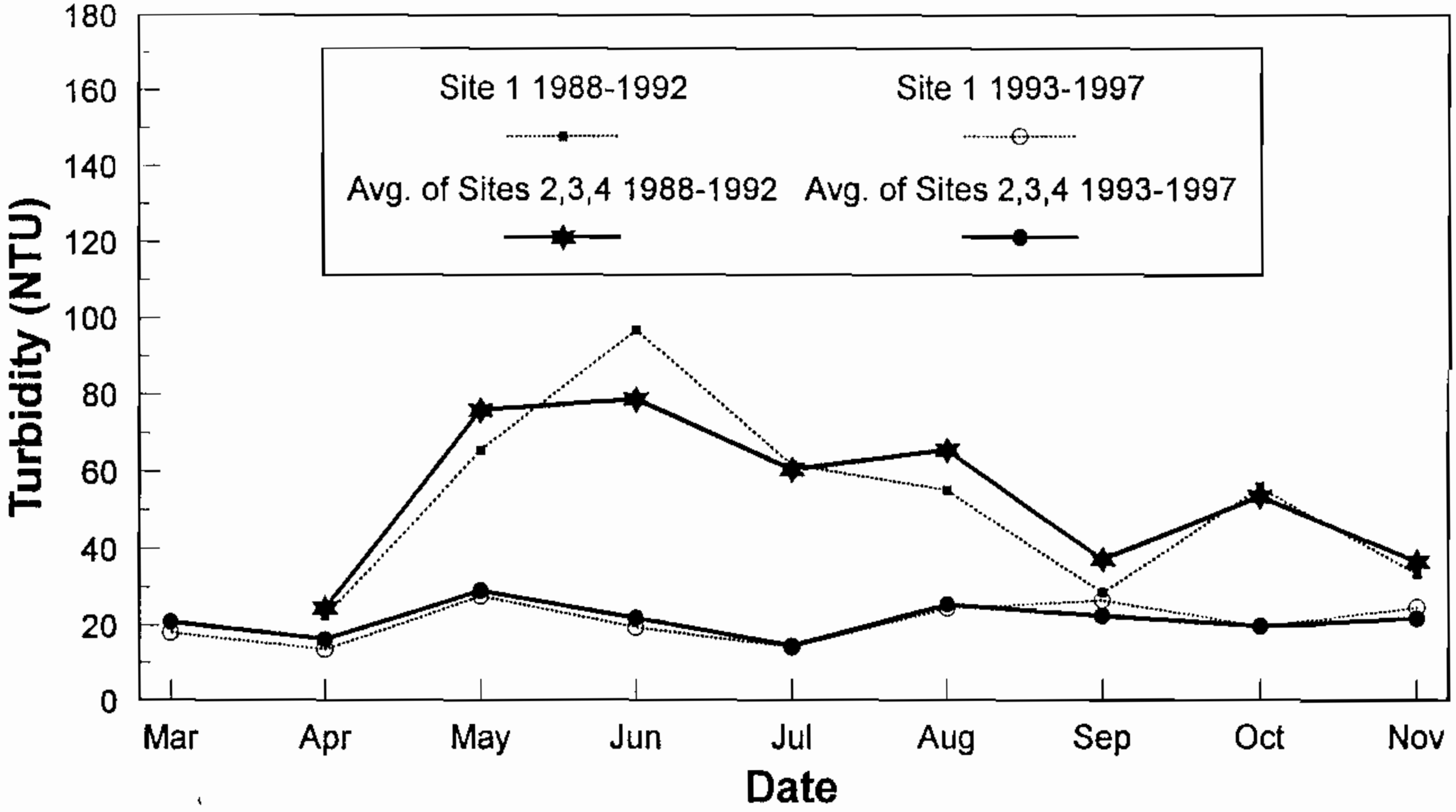
Kenilworth Marsh

Fig. 25

TURBIDITY

SITE 1 and 2,3,4 (avg.)

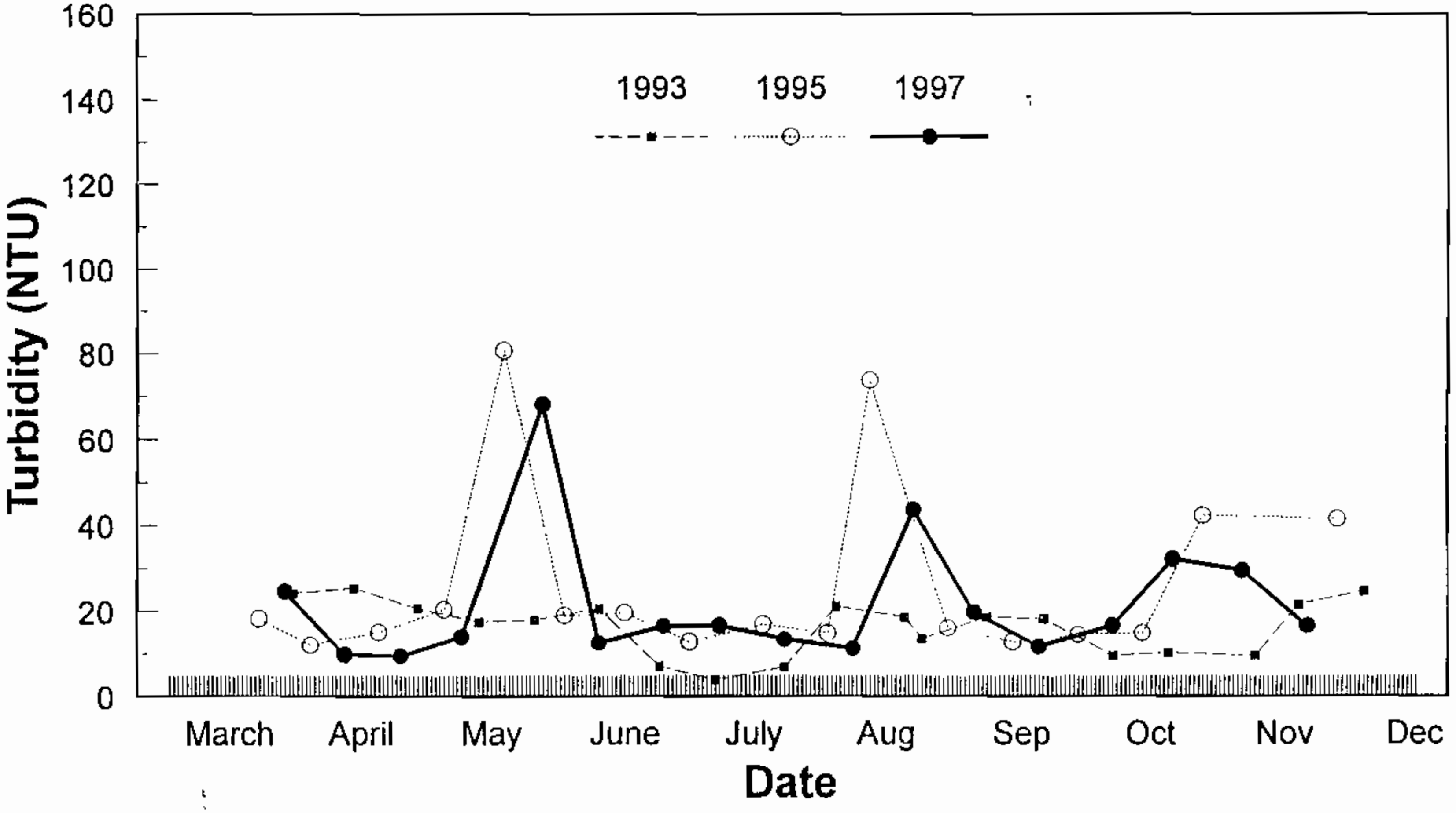
5 YEAR AVERAGES



Kenilworth Marsh
Fig. 26a

TURBIDITY

SITES 2,3,4 (avg.)
1993, 1995, 1997

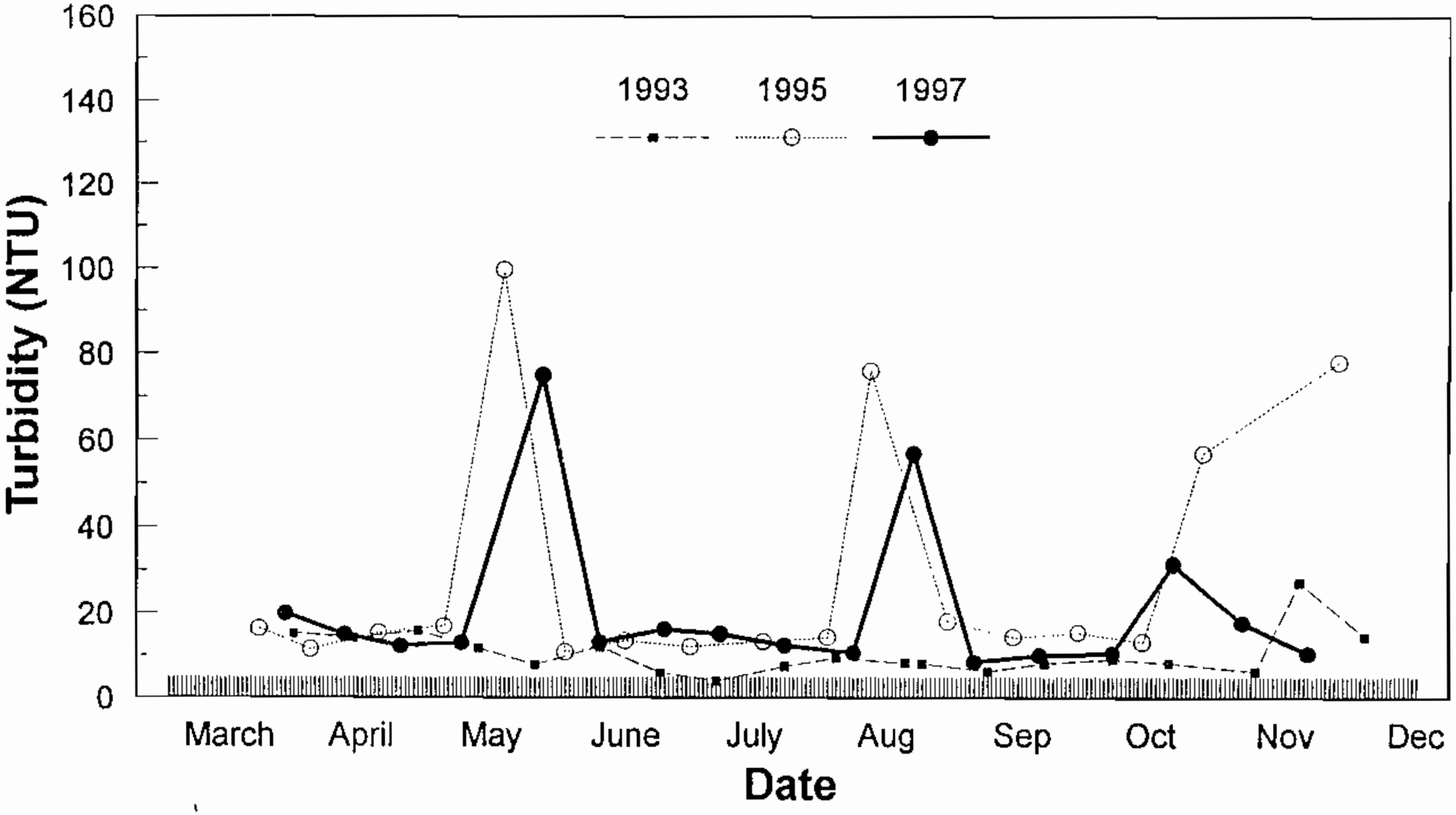


Kenilworth Marsh
Fig. 27

TURBIDITY

SITE 1

1993, 1995, 1997

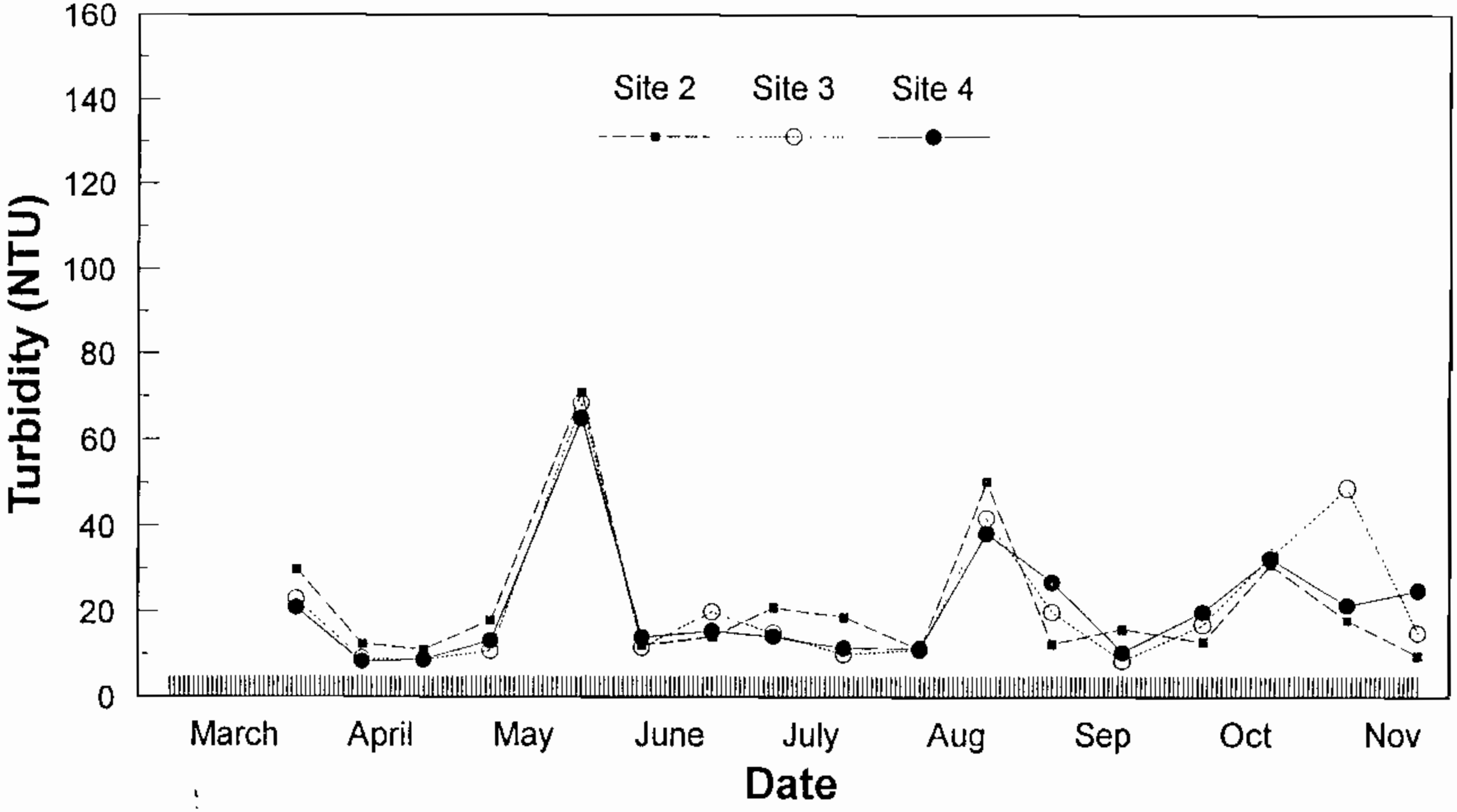


Kenilworth Marsh
Fig. 28

TURBIDITY

SITES 2,3,4

1997

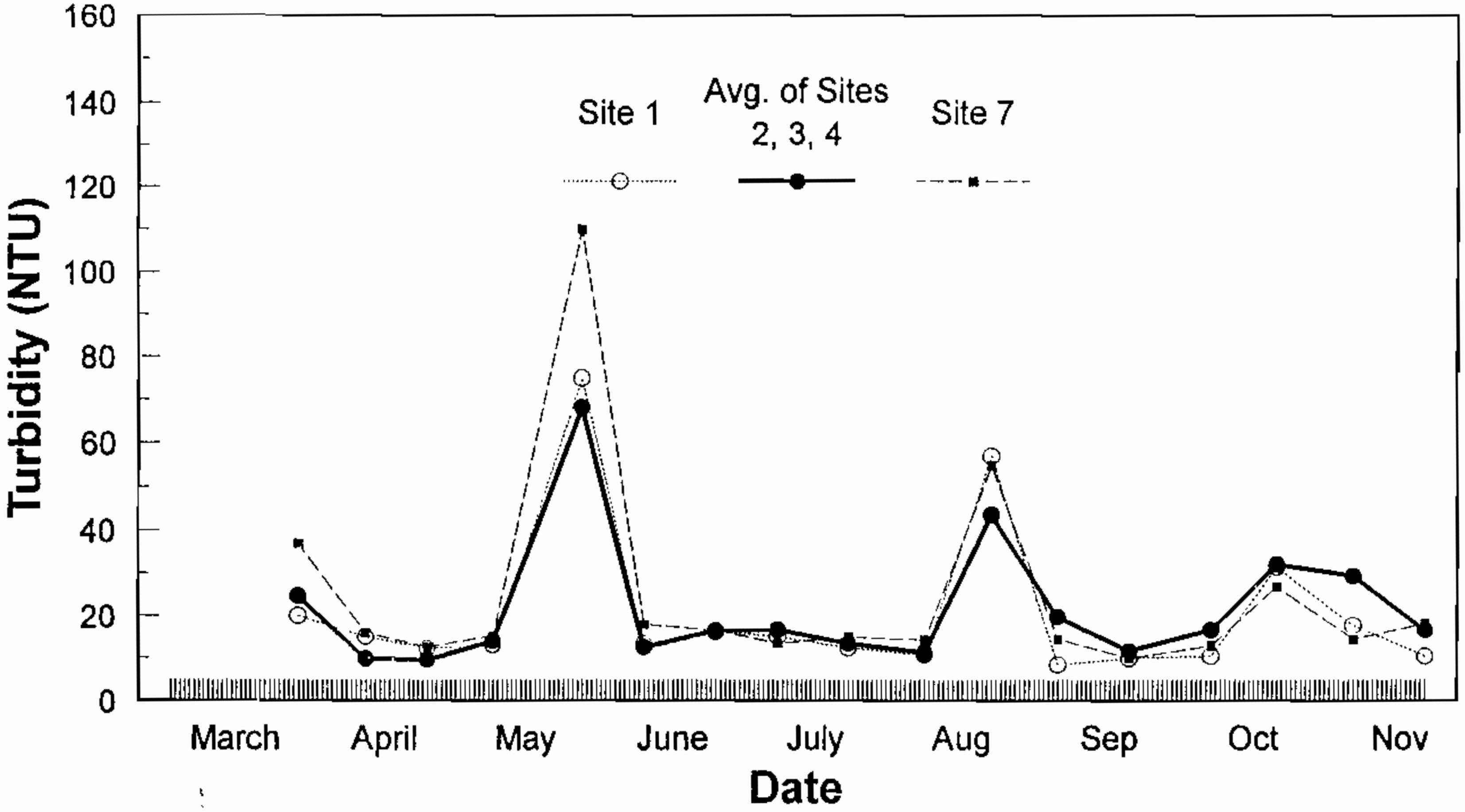


Kenilworth Marsh
Fig. 29

TURBIDITY

SITES 1; 2,3,4; 7

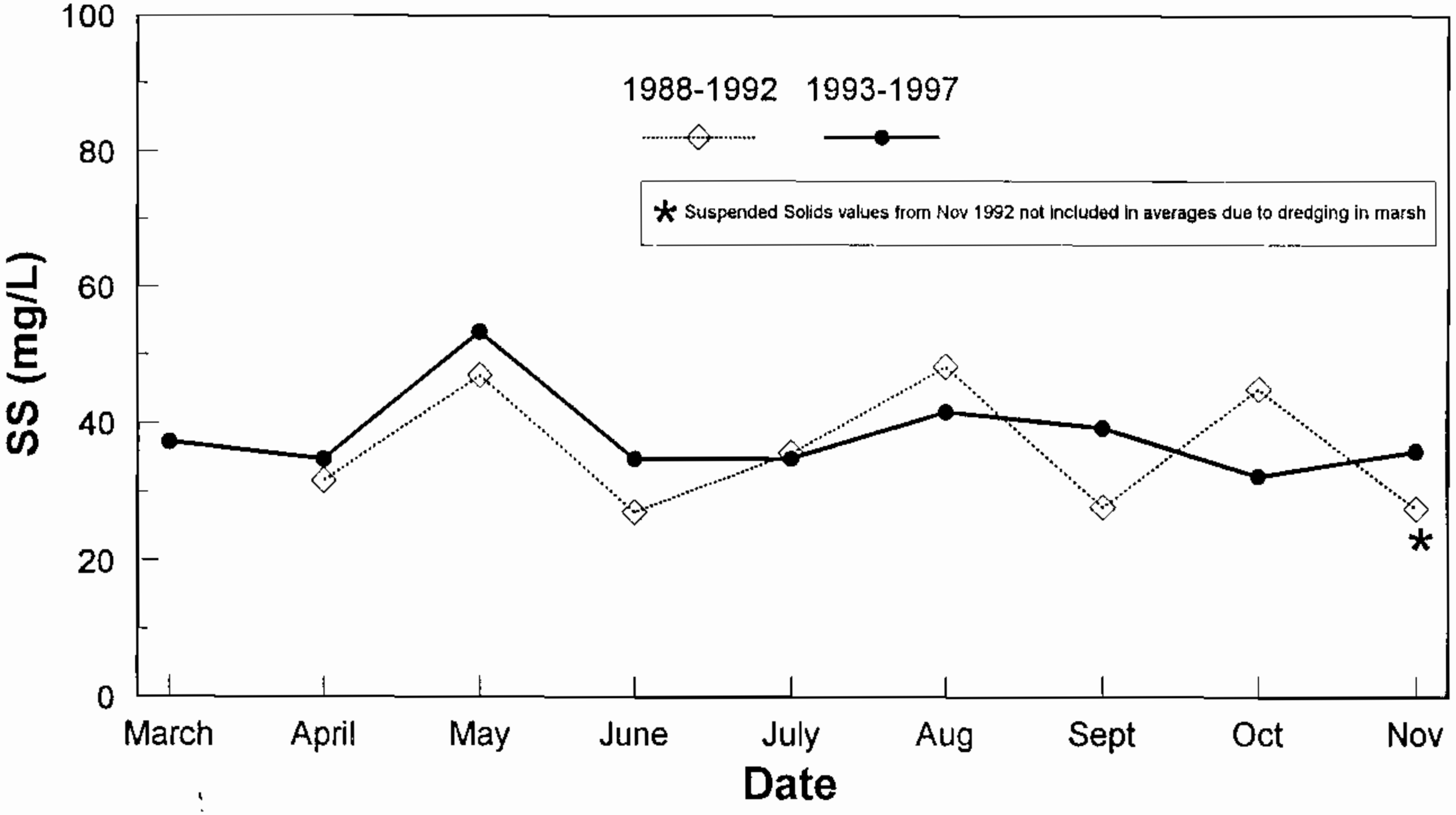
1997



Kenilworth Marsh
Fig. 30

SUSPENDED SOLIDS

SITES 2,3,4 (avg.)
5 YEAR AVERAGES

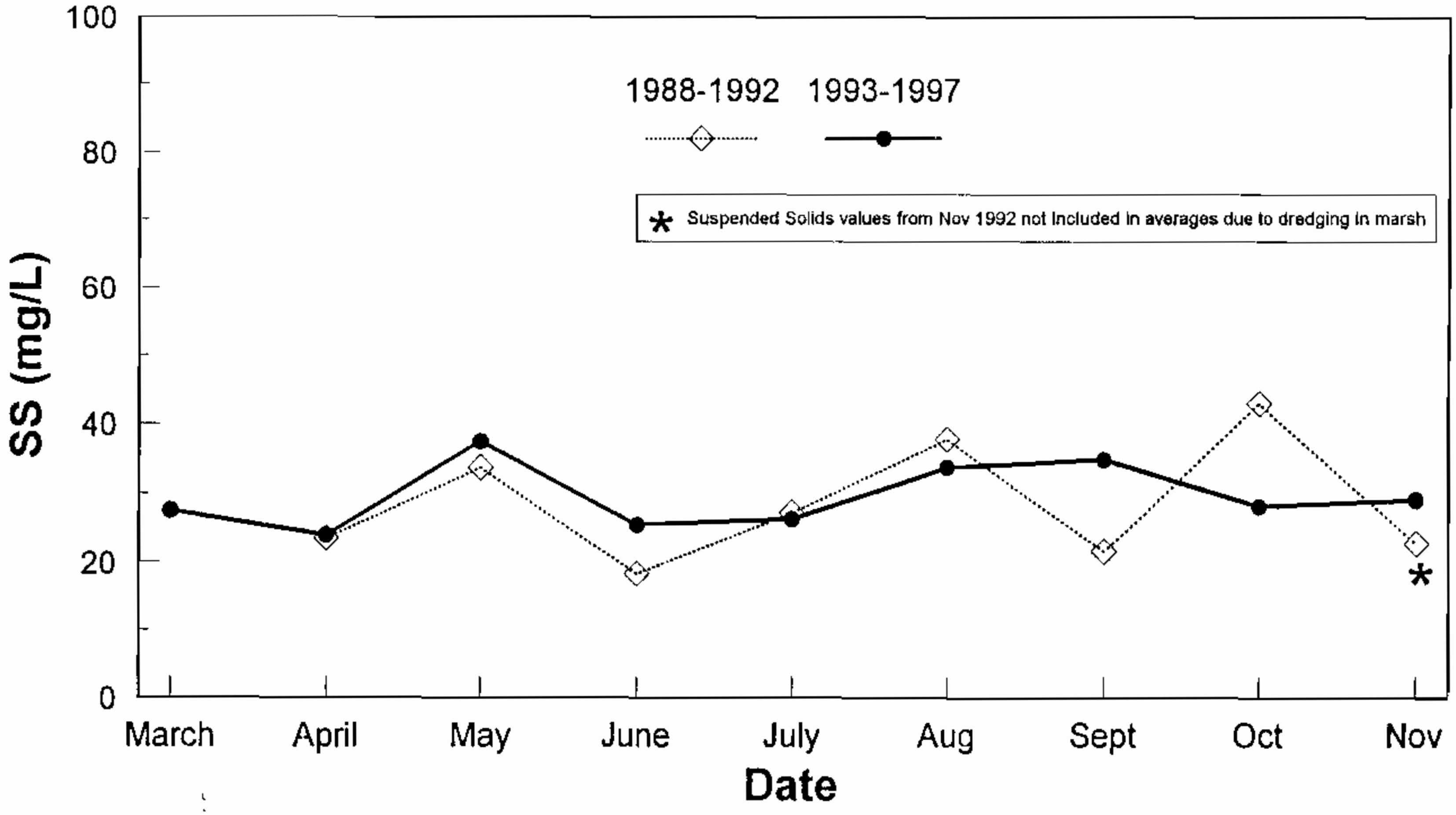


Kenilworth Marsh
Fig. 31

SUSPENDED SOLIDS

SITE 1

5 YEAR AVERAGES

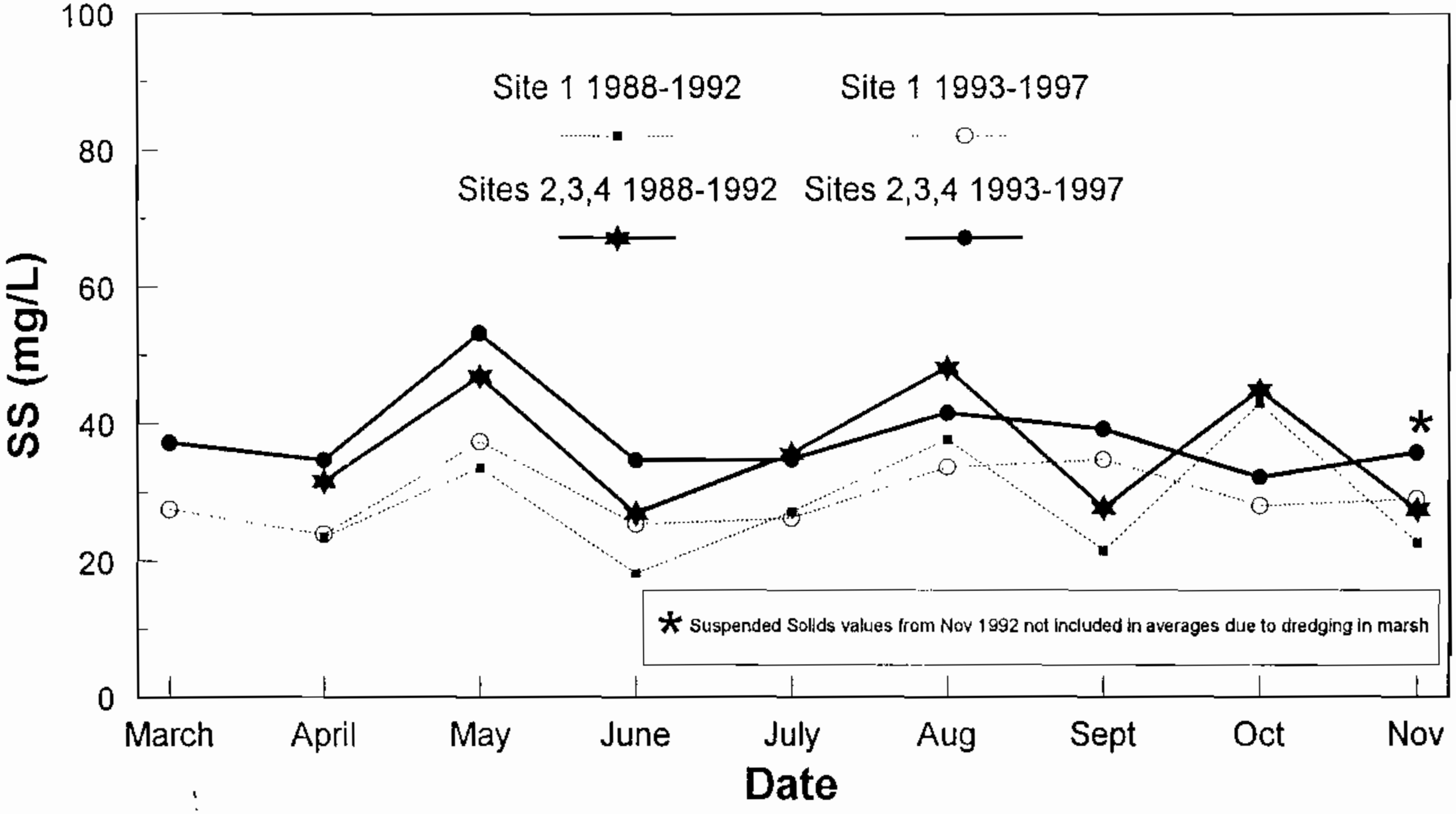


Kenilworth Marsh
Fig. 32

SUSPENDED SOLIDS

SITES 1 and 2,3,4 (avg.)

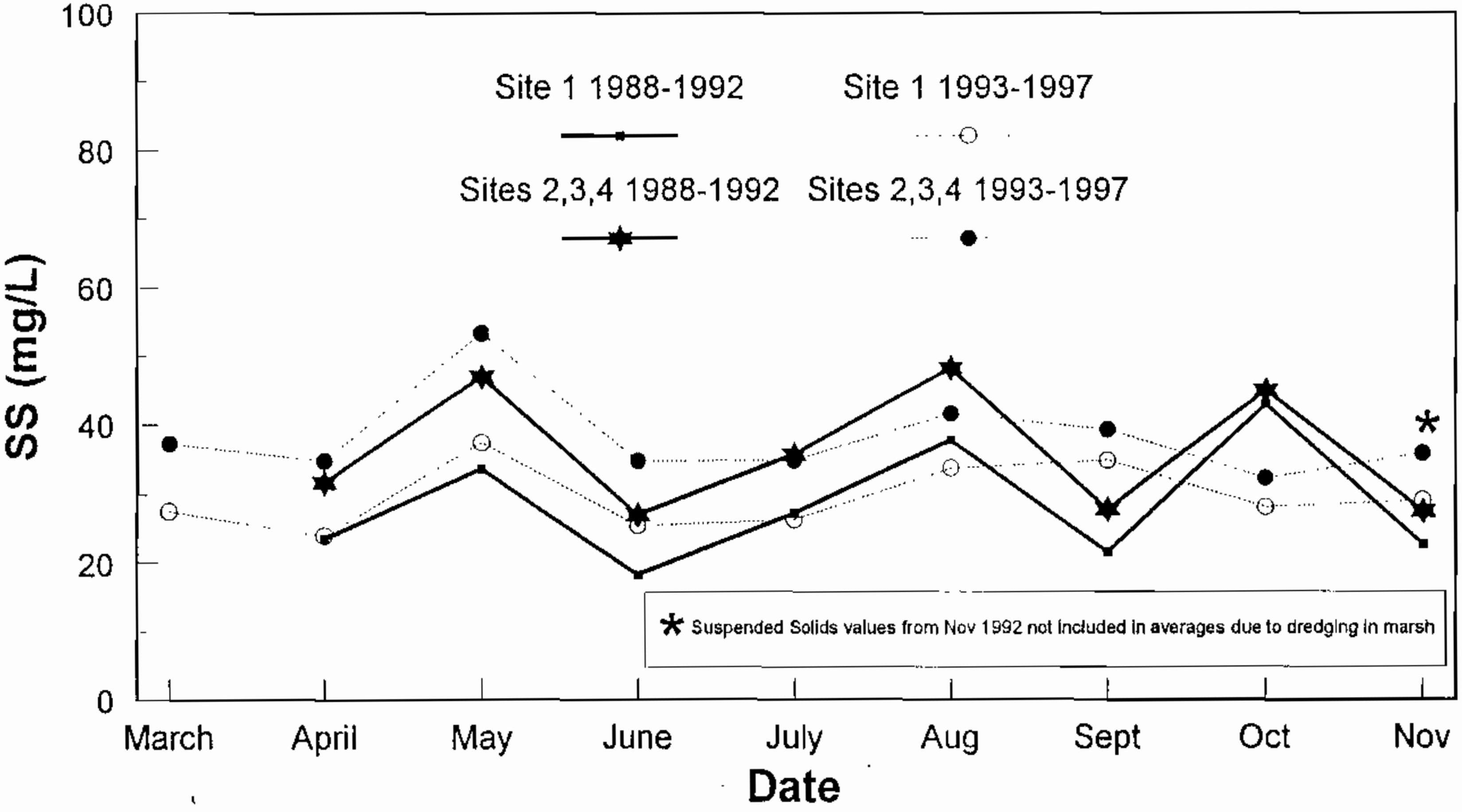
5 YEAR AVERAGES



Kenilworth Marsh
Fig. 33a

SUSPENDED SOLIDS

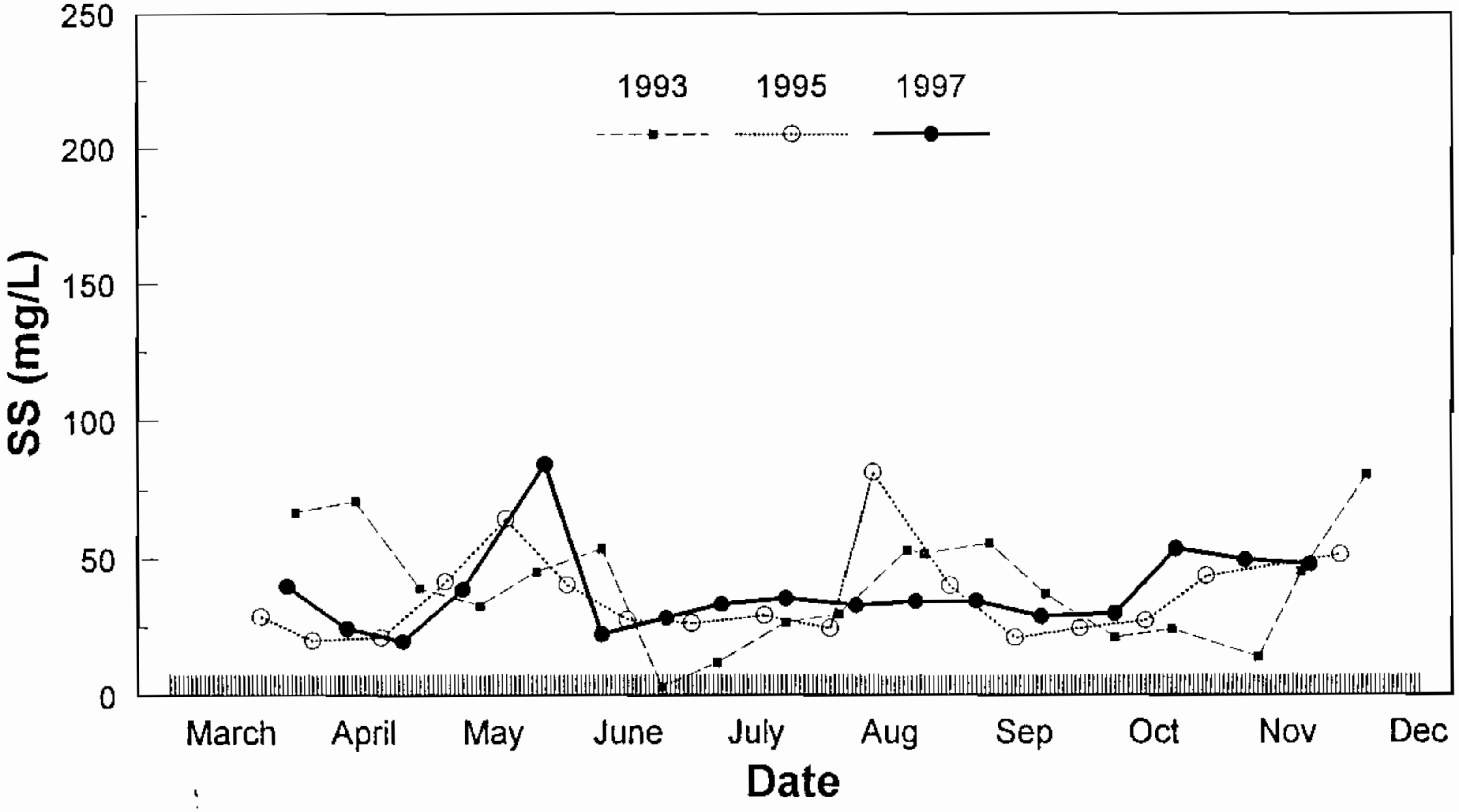
SITES 1 and 2,3,4 (avg.)
5 YEAR AVERAGES



Kenilworth Marsh
Fig. 33b

SUSPENDED SOLIDS

SITES 2,3,4 (avg.)
1993, 1995, 1997

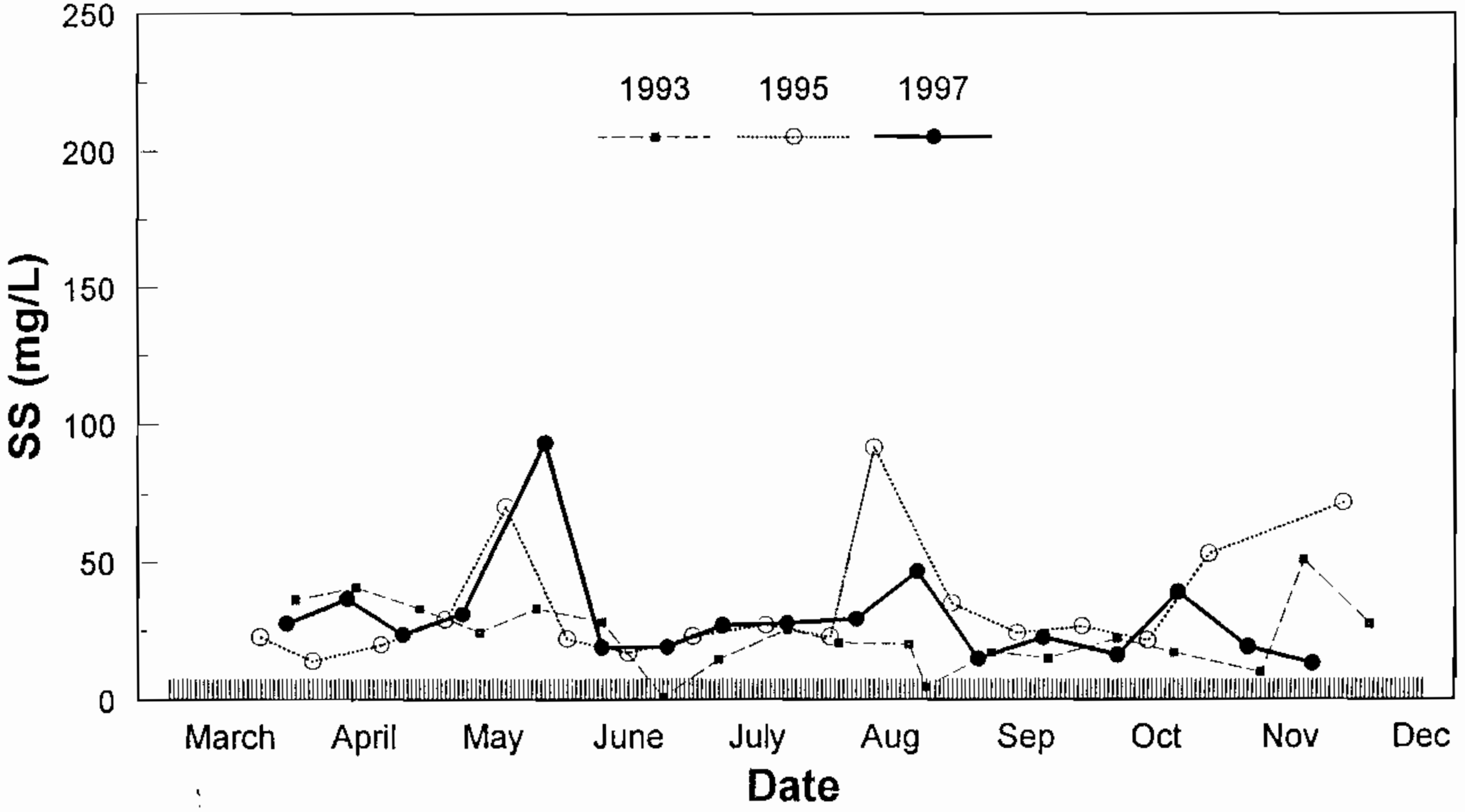


Kenilworth Marsh
Fig. 34

SUSPENDED SOLIDS

SITE 1

1993, 1995, 1997

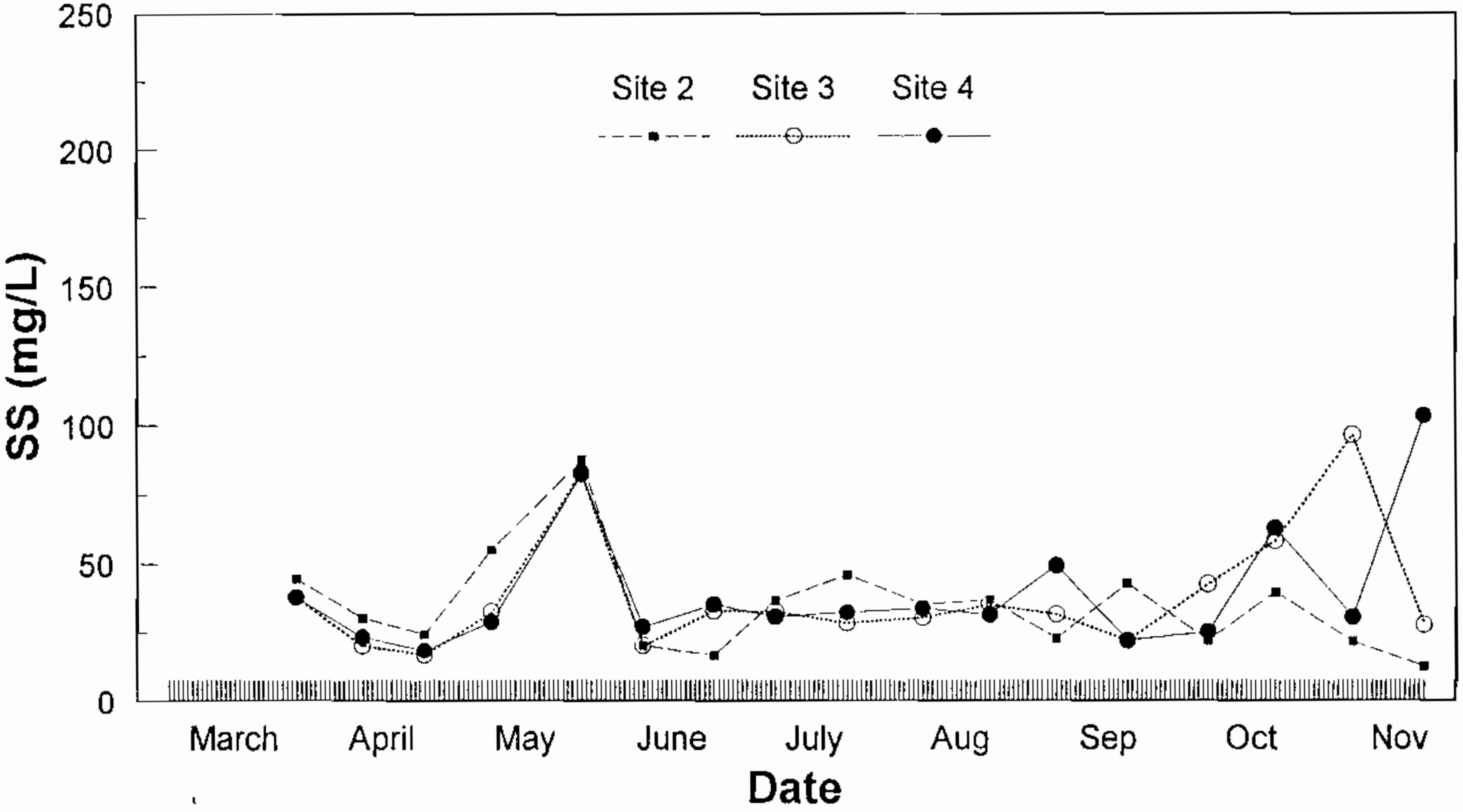


Kenilworth Marsh
Fig. 35

SUSPENDED SOLIDS

SITES 2,3,4

1997



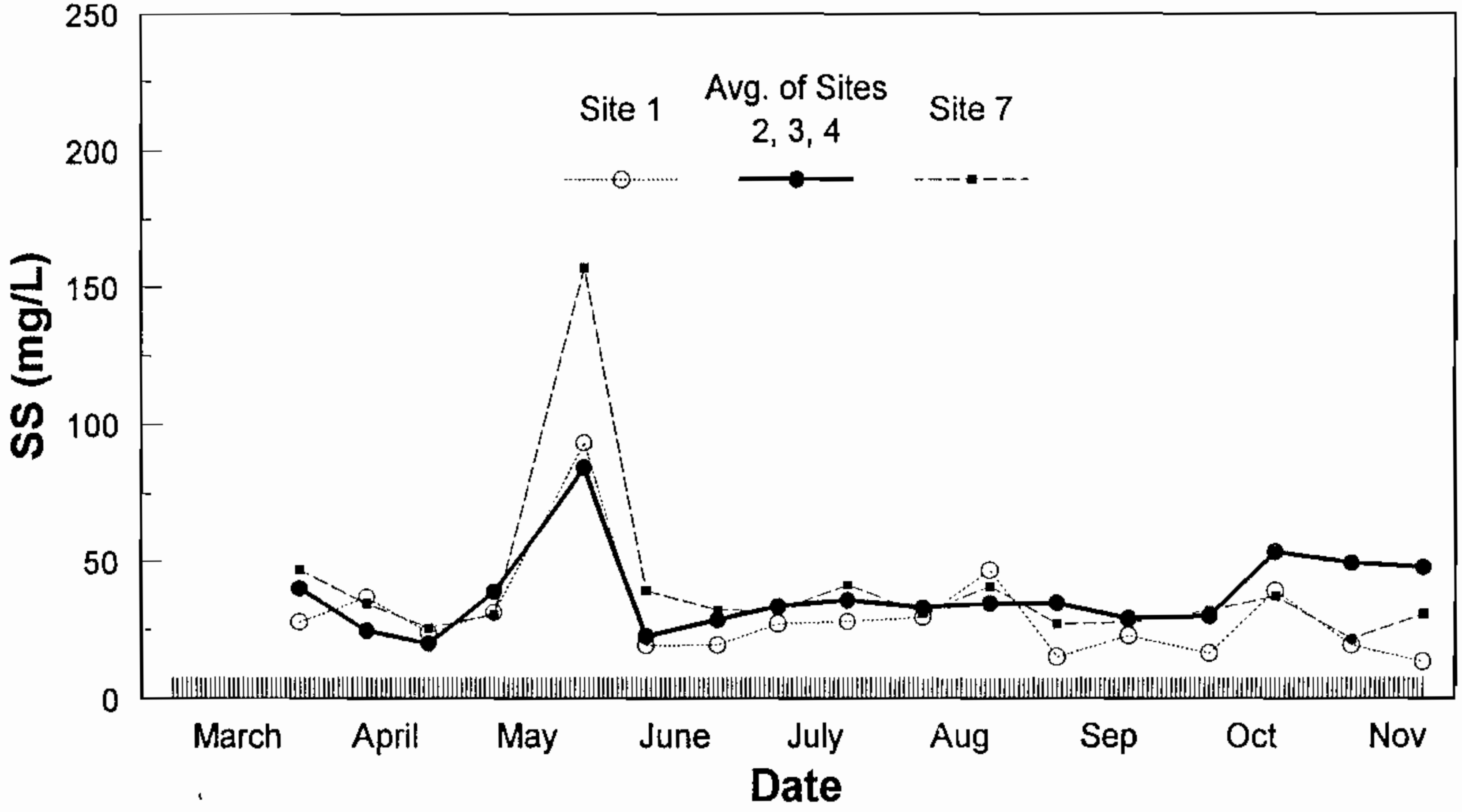
Kenilworth Marsh

Fig. 36

SUSPENDED SOLIDS

SITES 1; 2,3,4; 7

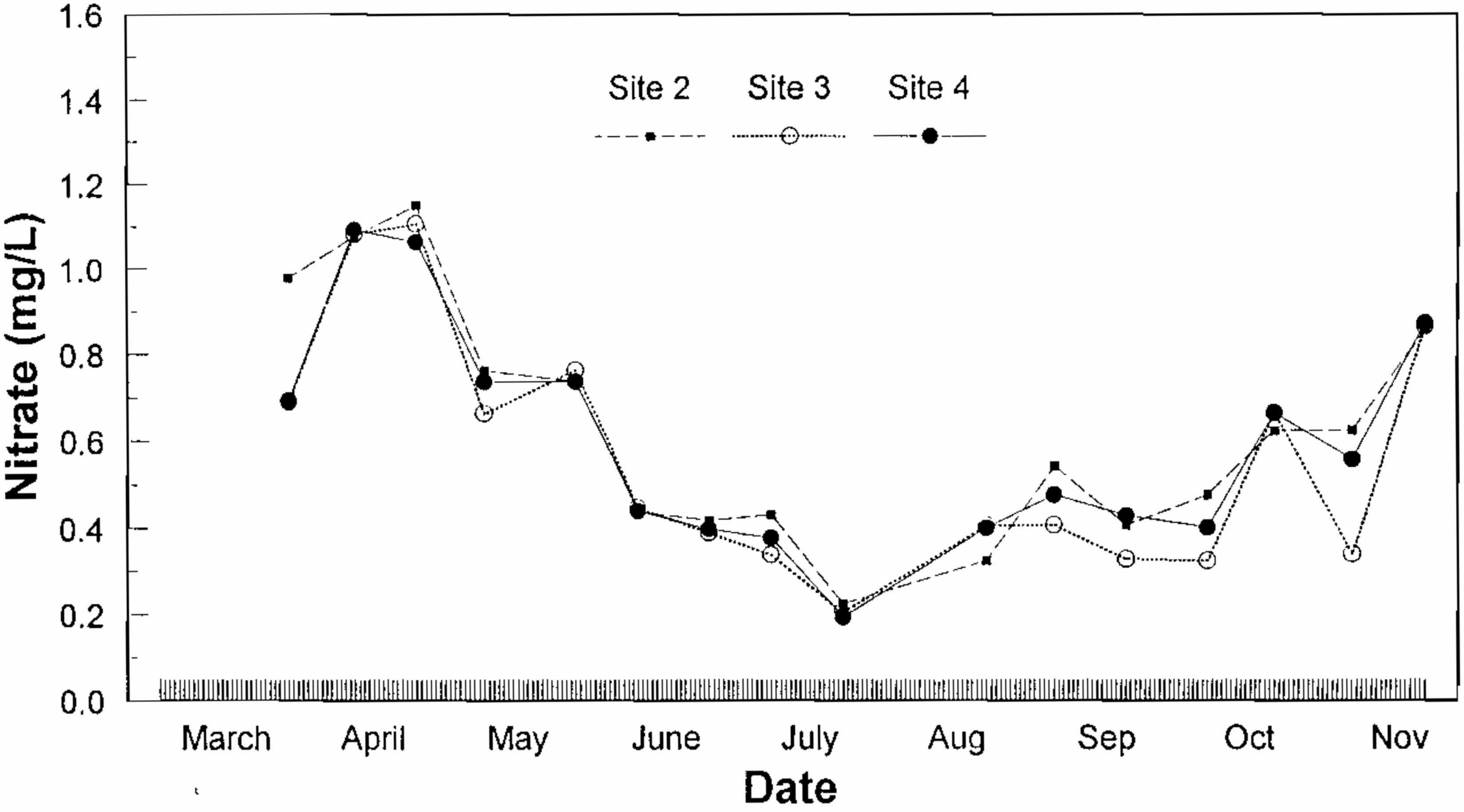
1997



Kenilworth Marsh
Fig. 37

NITRATE

SITES 2,3,4
1997

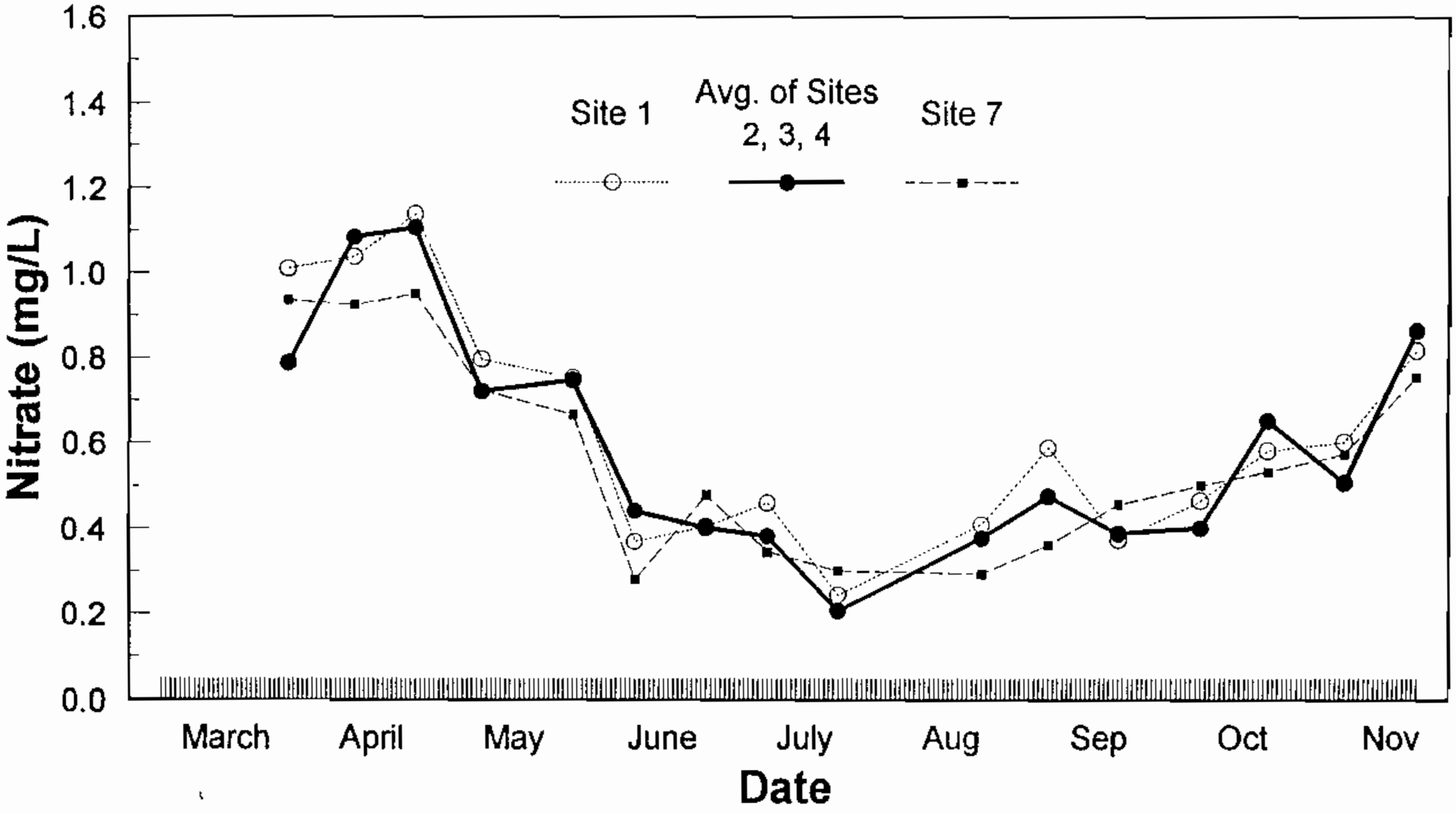


Kenilworth Marsh
Fig. 38

NITRATE

SITES 1; 2,3,4; 7

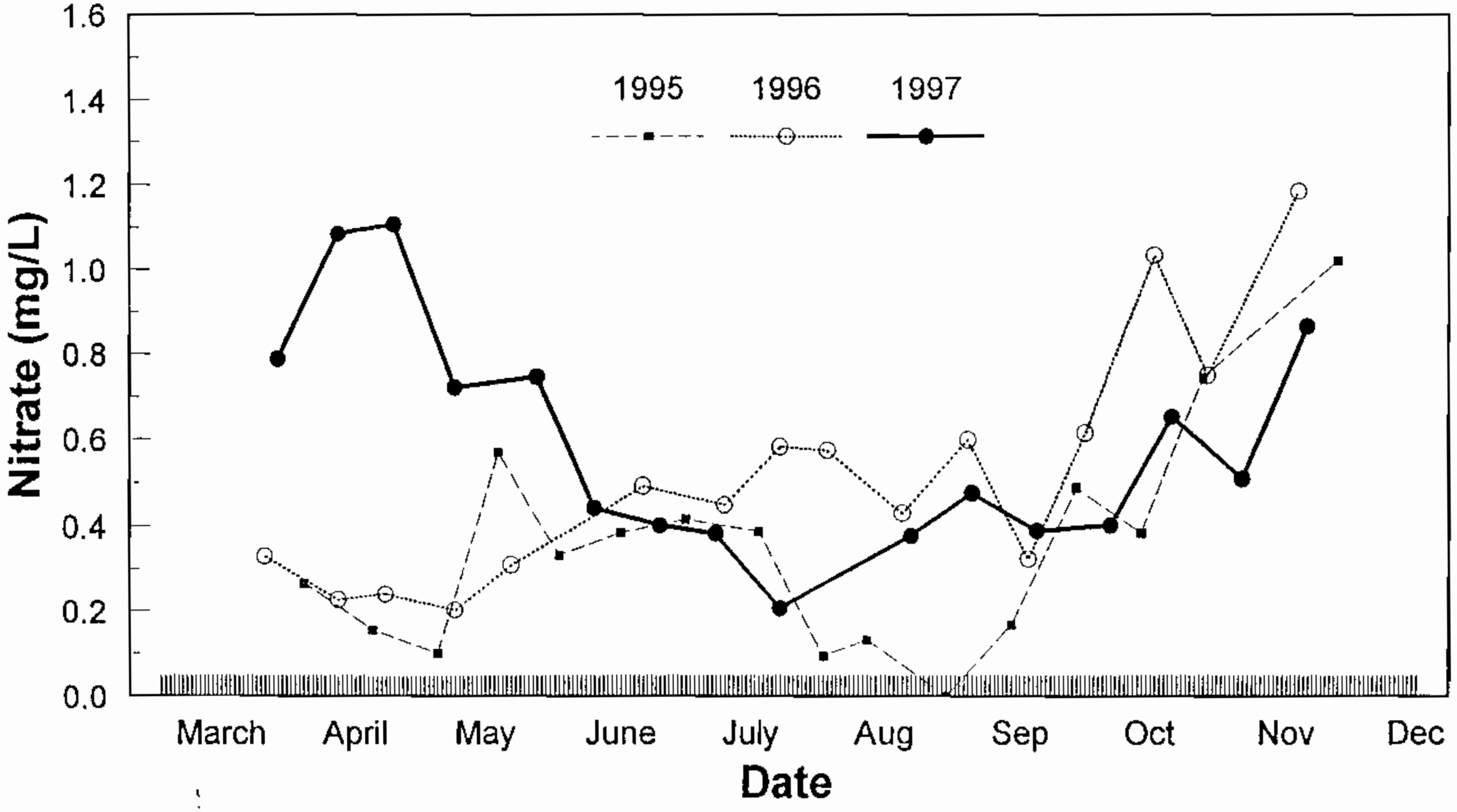
1997



Kenilworth Marsh
Fig. 39

NITRATE

SITES 2,3,4 (avg.)
1995, 1996, 1997

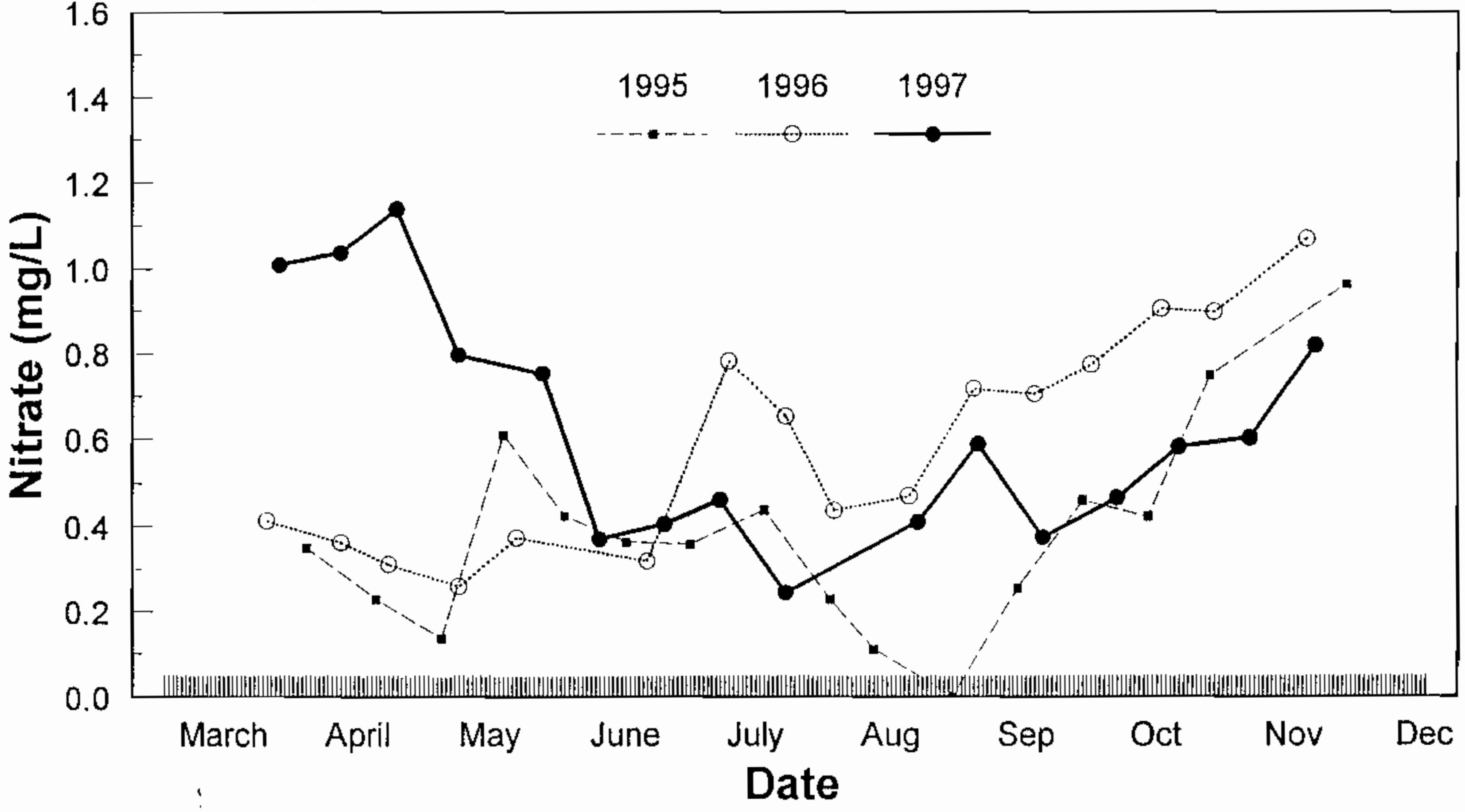


Kenilworth Marsh
Fig. 40

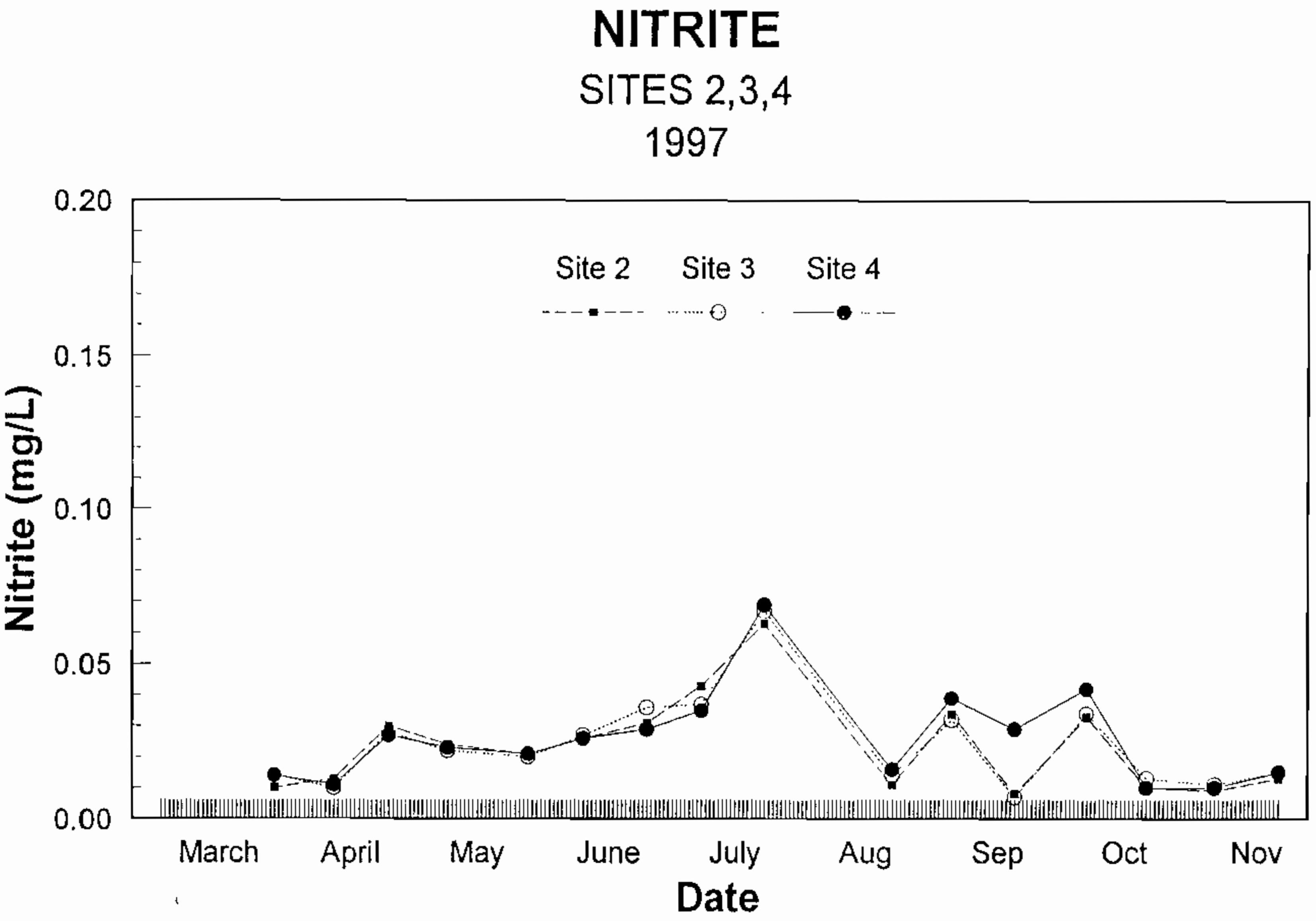
NITRATE

SITE 1

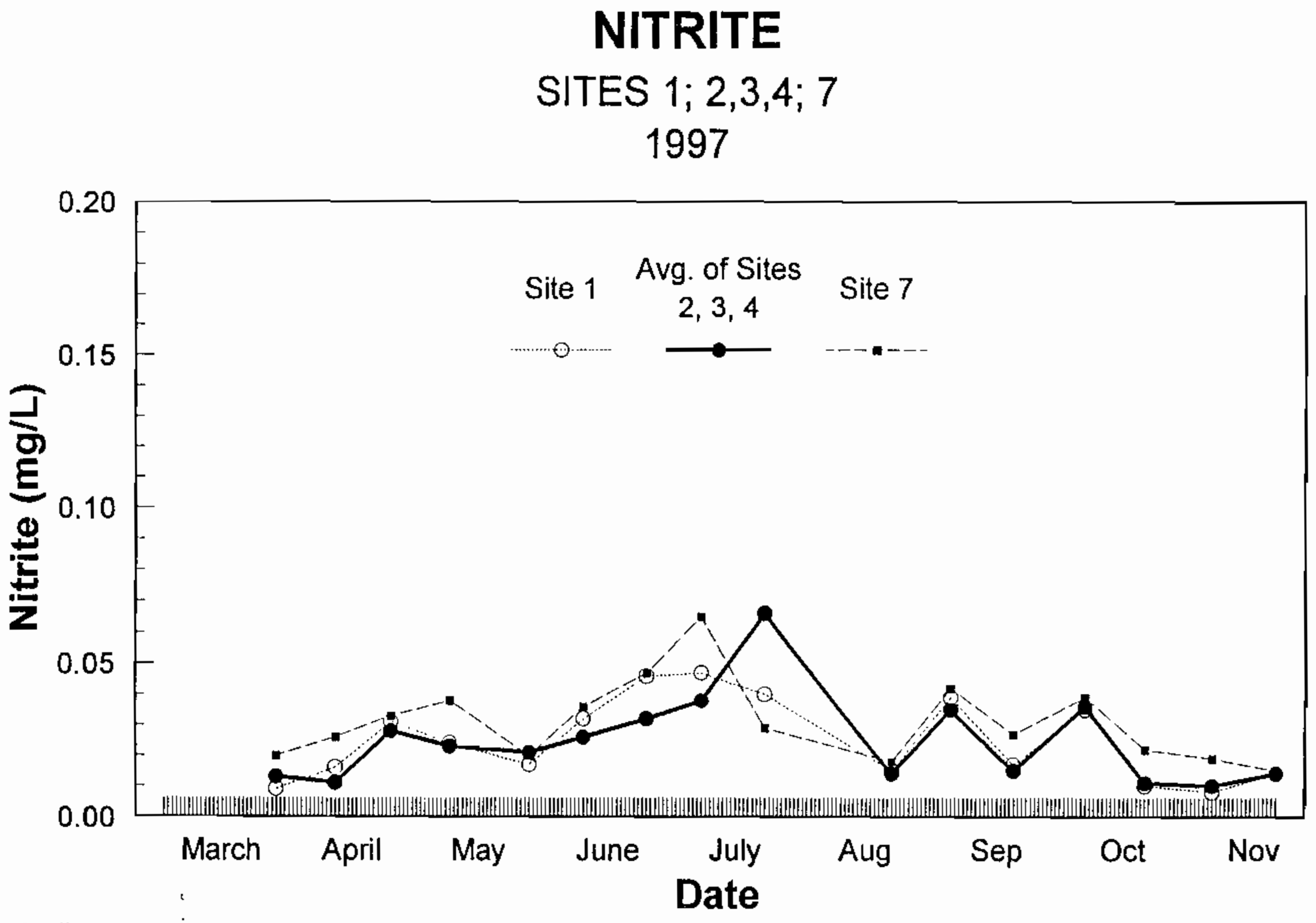
1995, 1996, 1997



Kenilworth Marsh
Fig. 41



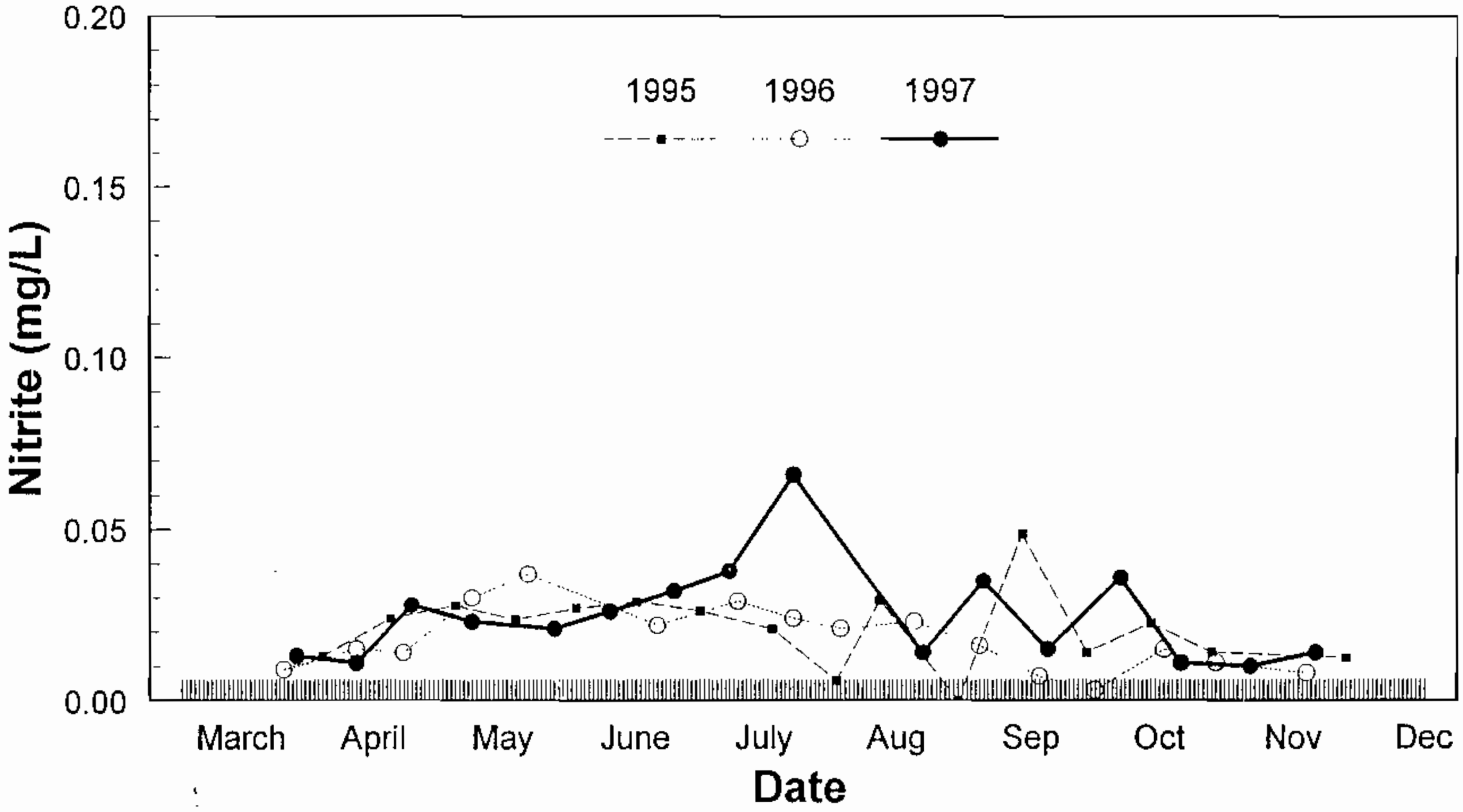
Kenilworth Marsh
Fig. 42



Kenilworth Marsh
Fig. 43

NITRITE

SITES 2,3,4 (avg.)
1995, 1996, 1997

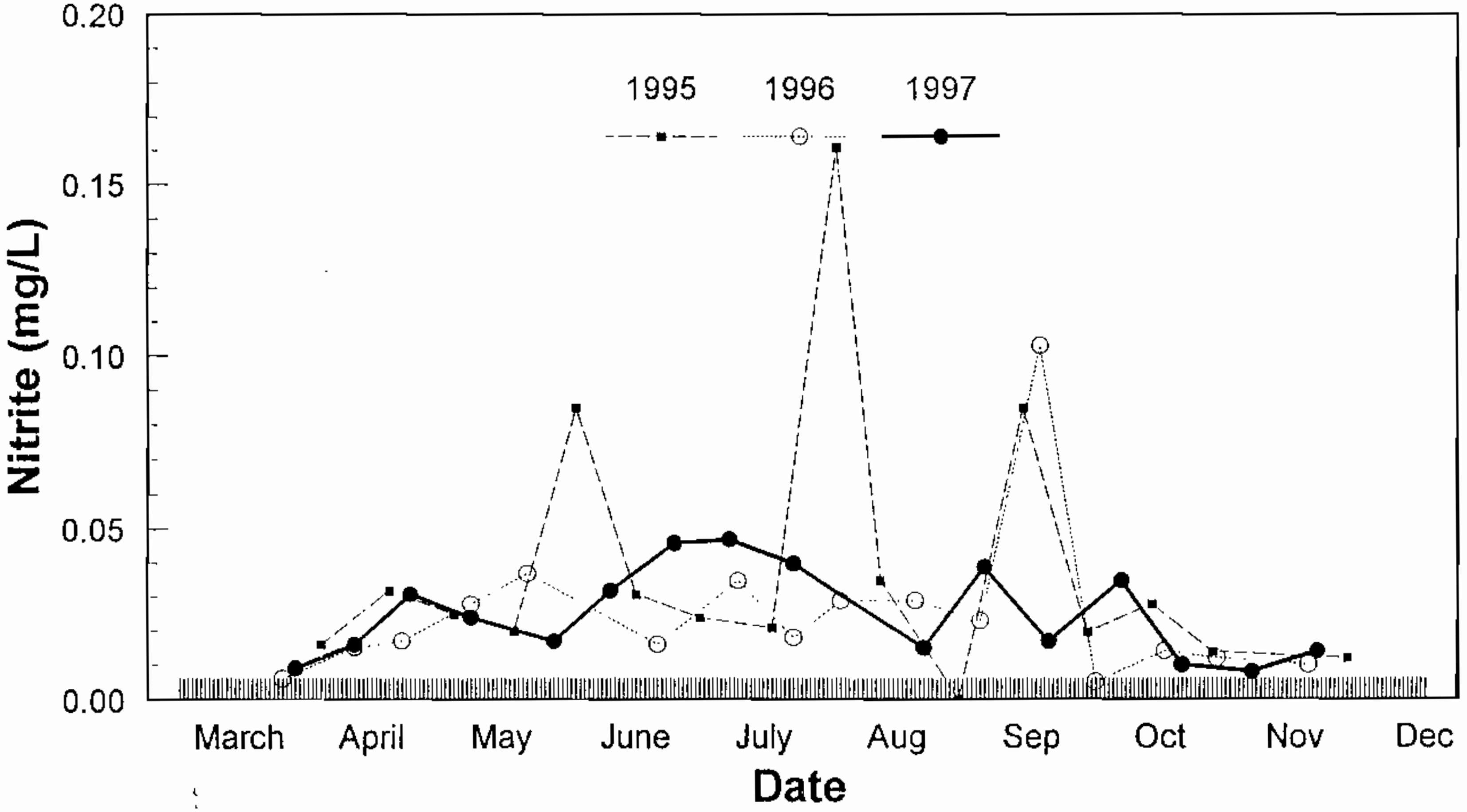


Kenilworth Marsh
Fig. 44

NITRITE

SITE 1

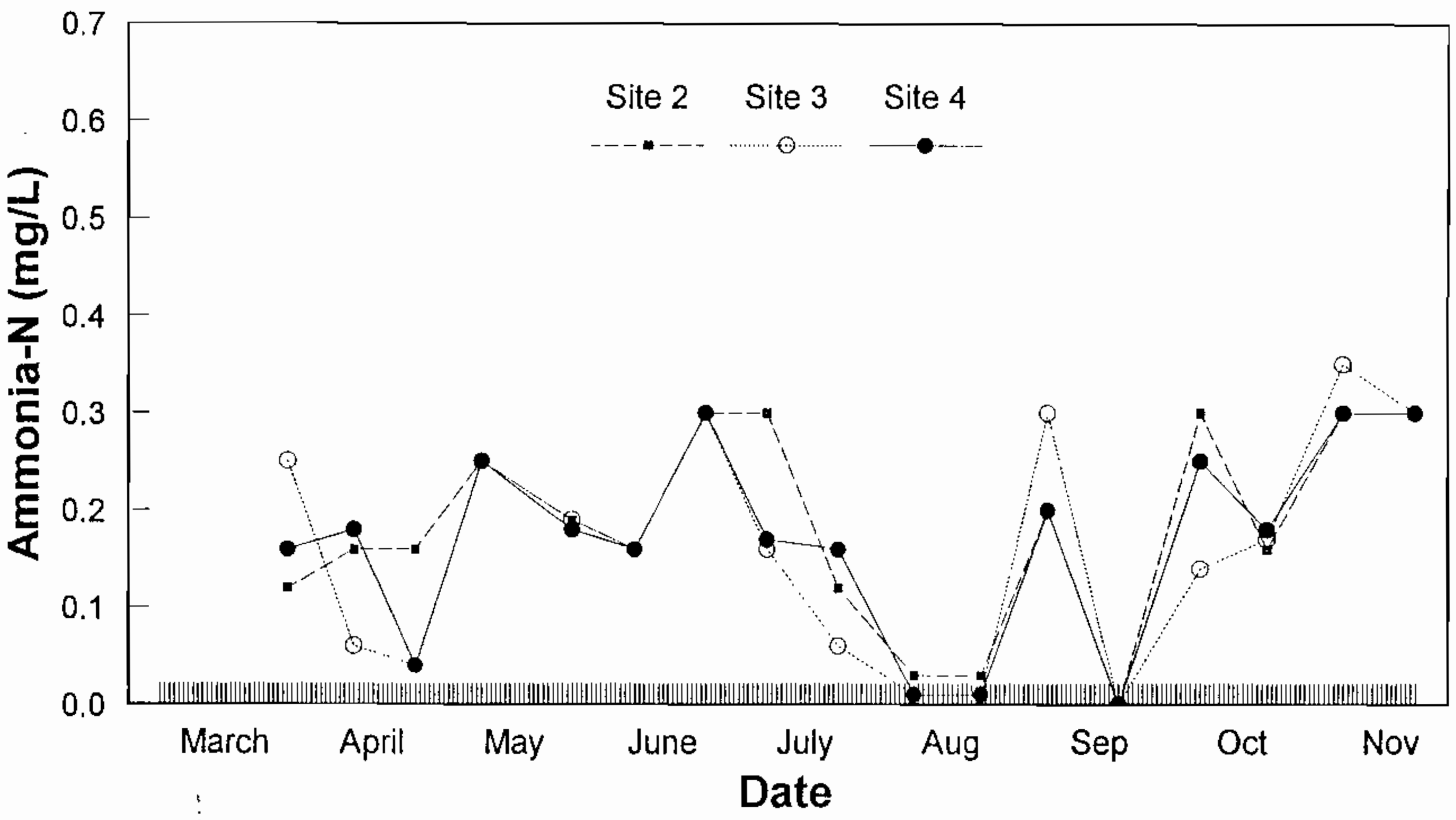
1995, 1996, 1997



Kenilworth Marsh
Fig. 45

AMMONIA-N

SITES 2,3,4
1997

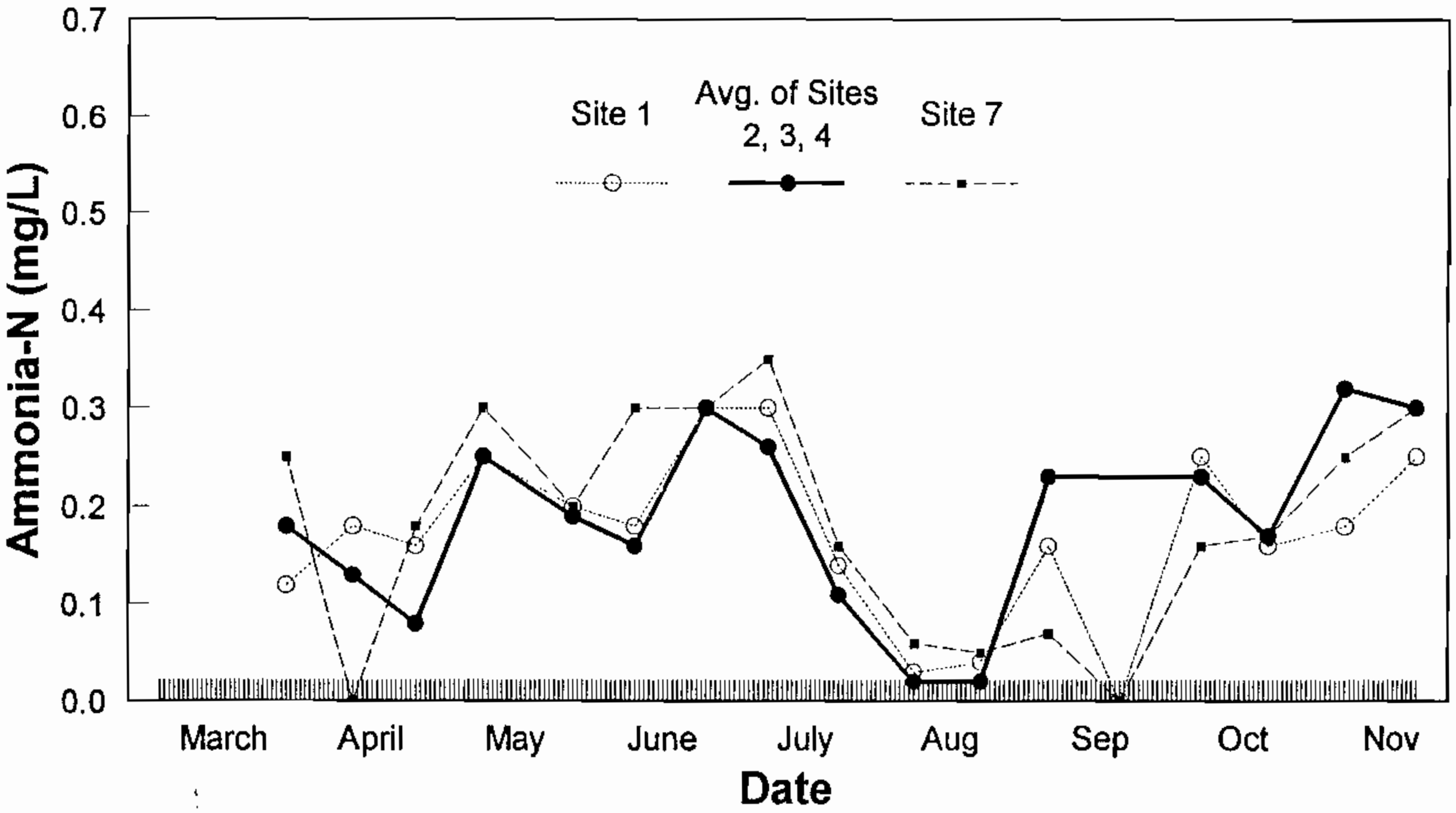


Kenilworth Marsh
Fig. 46

AMMONIA-N

SITES 1; 2,3,4; 7

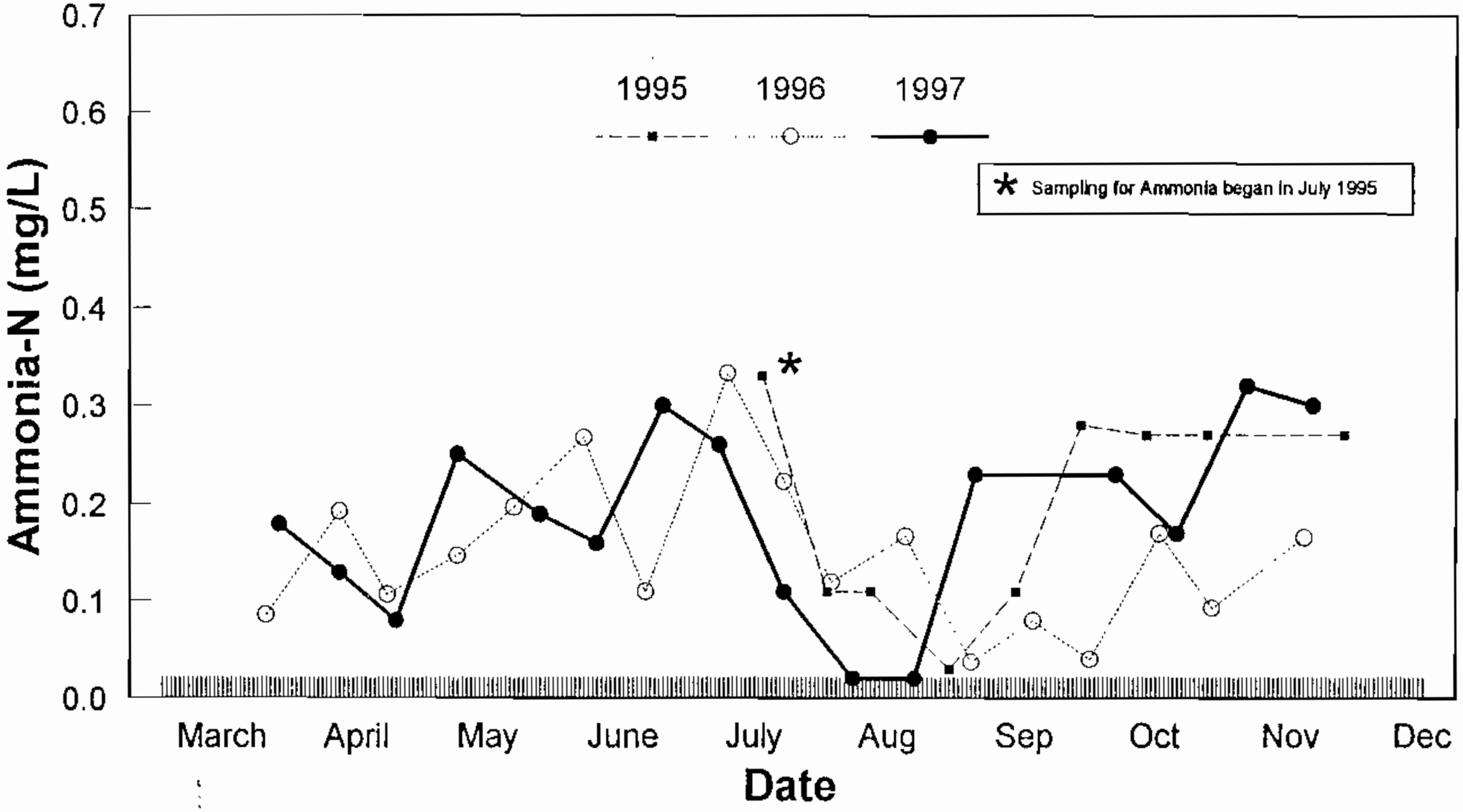
1997



Kenilworth Marsh
Fig. 47

AMMONIA-N

SITES 2,3,4 (avg.)
1995, 1996, 1997

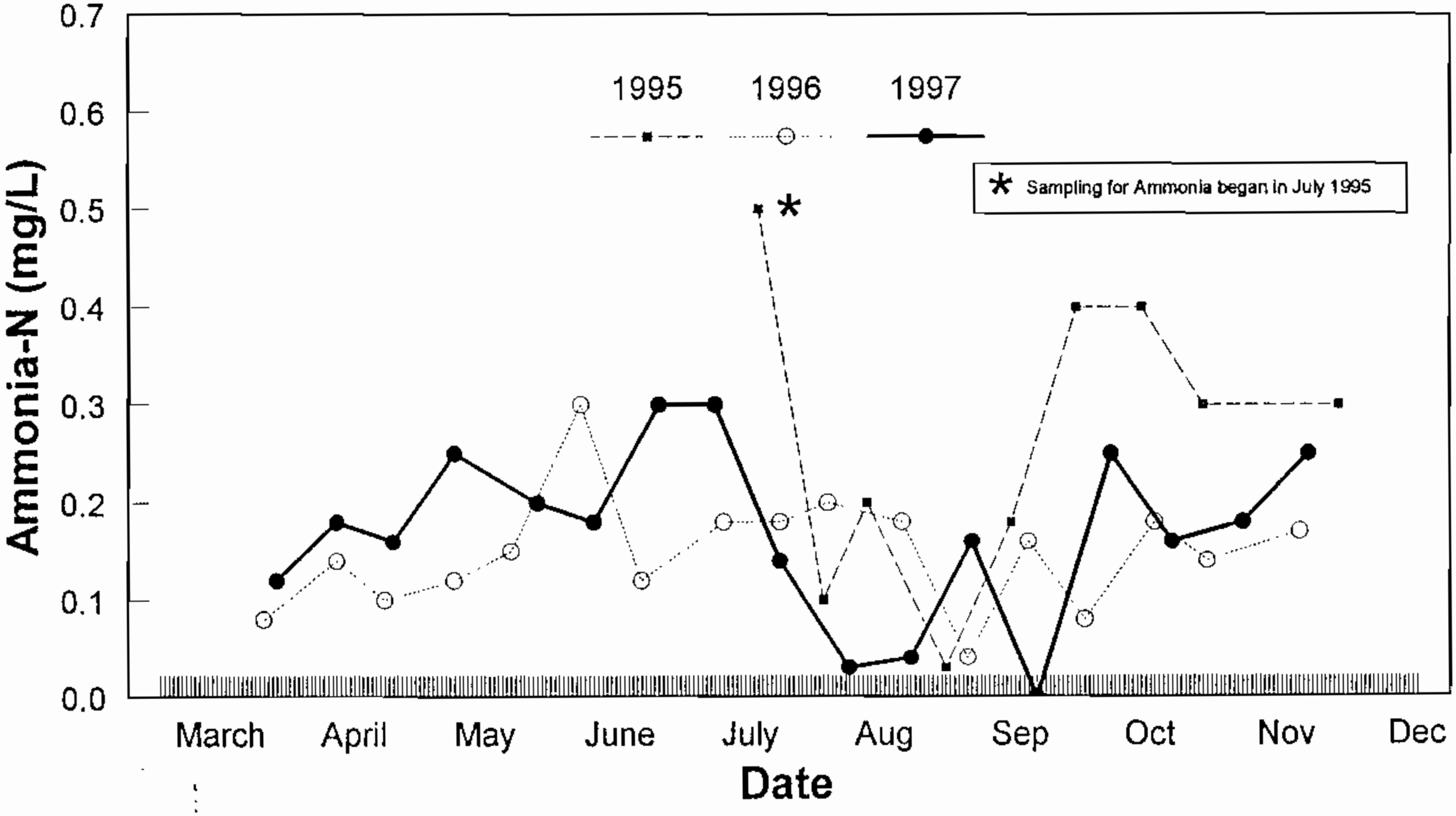


Kenilworth Marsh
Fig. 48

AMMONIA-N

SITE 1

1995, 1996, 1997

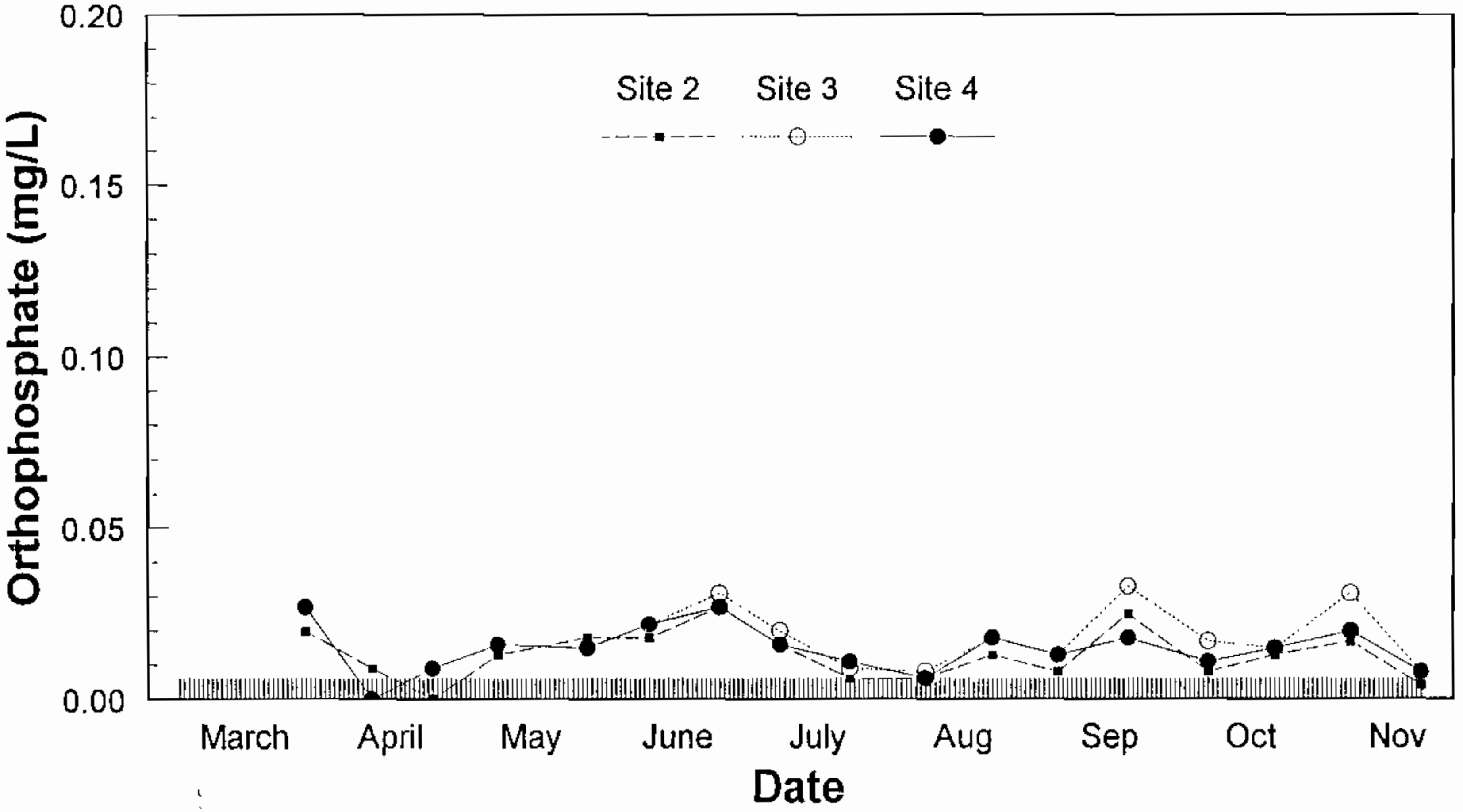


Kenilworth Marsh
Fig. 49

ORTHOPHOSPHATE

SITES 2,3,4

1997



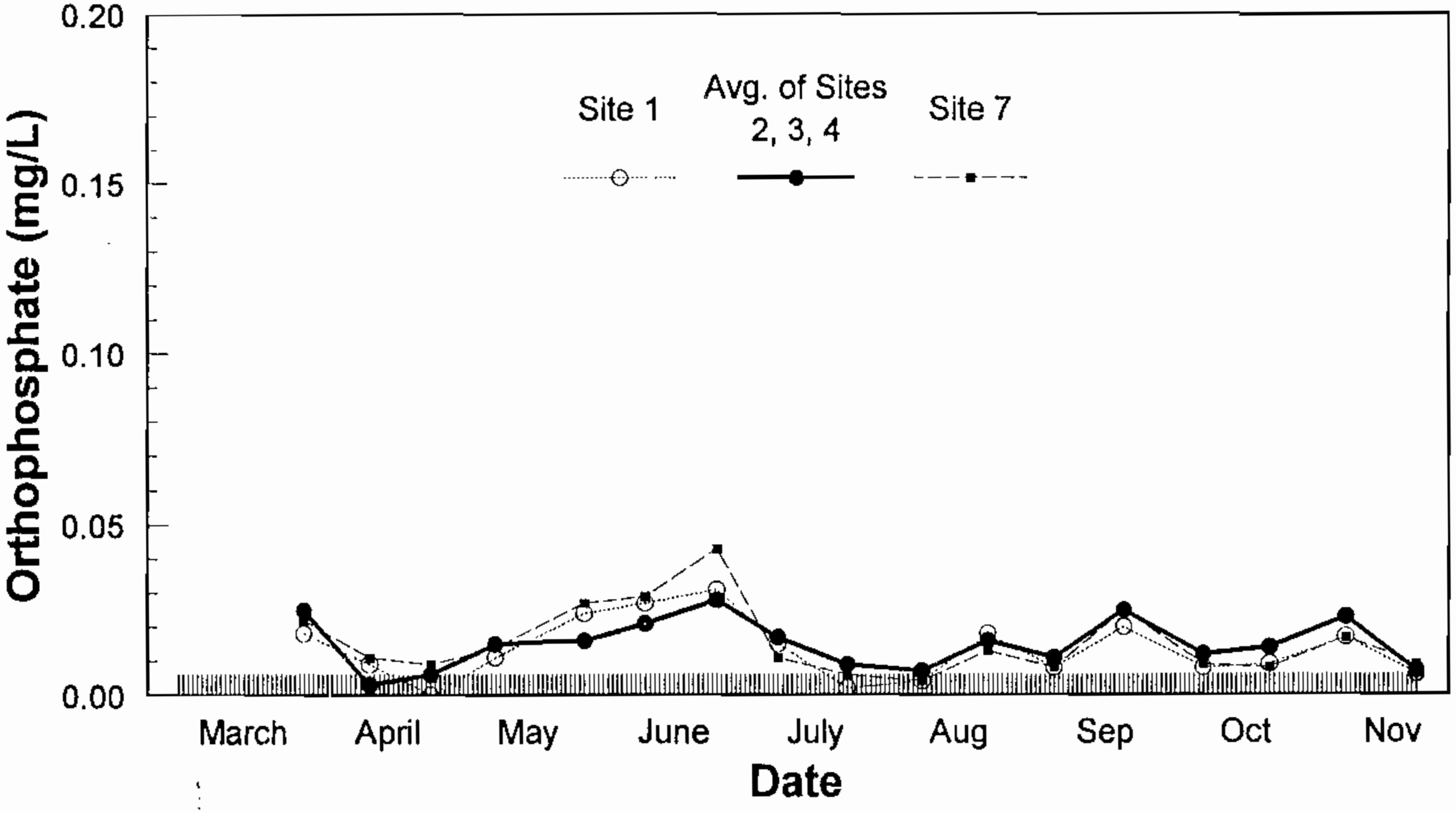
Kenilworth Marsh

Fig. 50

ORTHOPHOSPHATE

SITES 1; 2,3,4; 7

1997

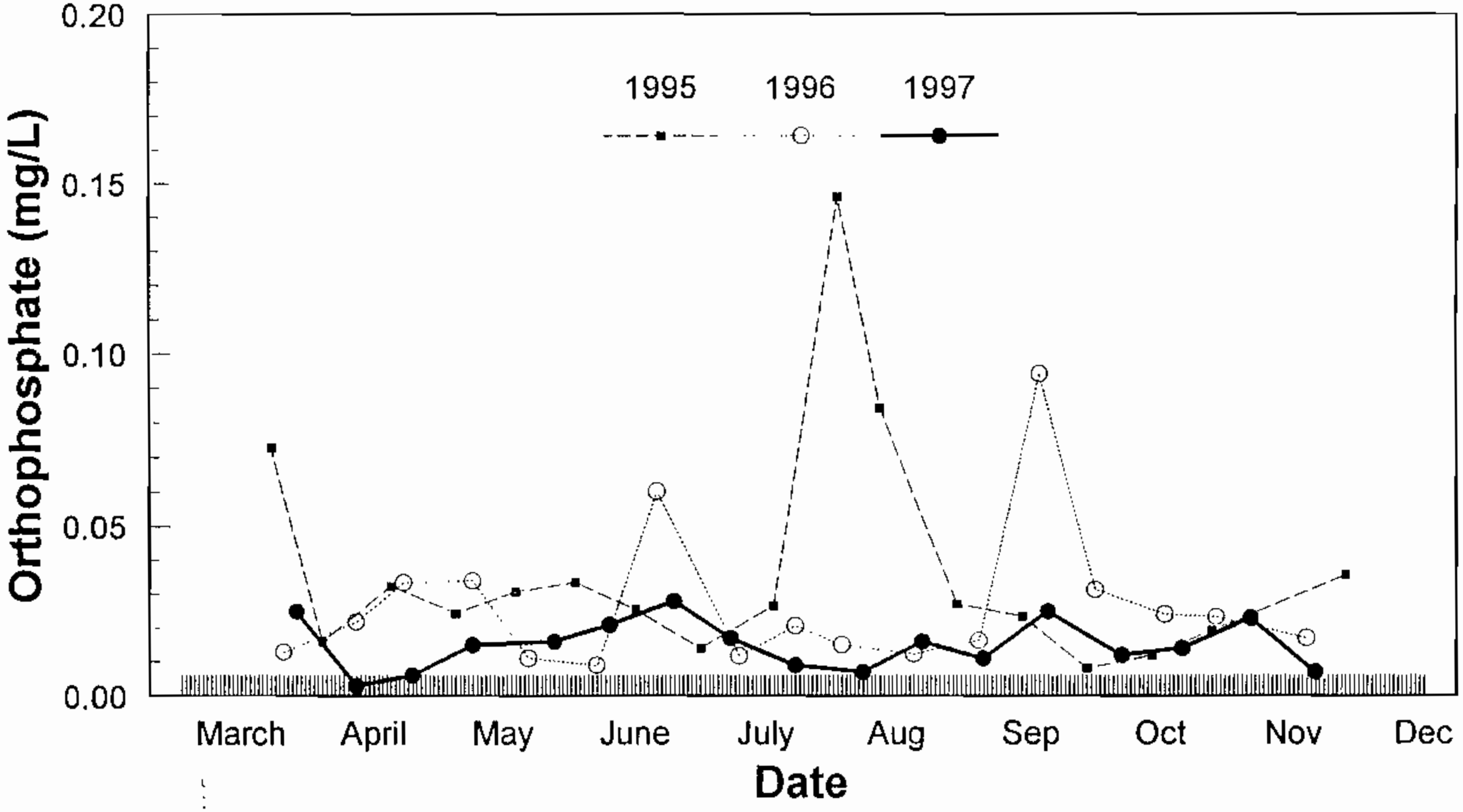


Kenilworth Marsh
Fig. 51

ORTHOPHOSPHATE

SITES 2,3,4

1995, 1996, 1997

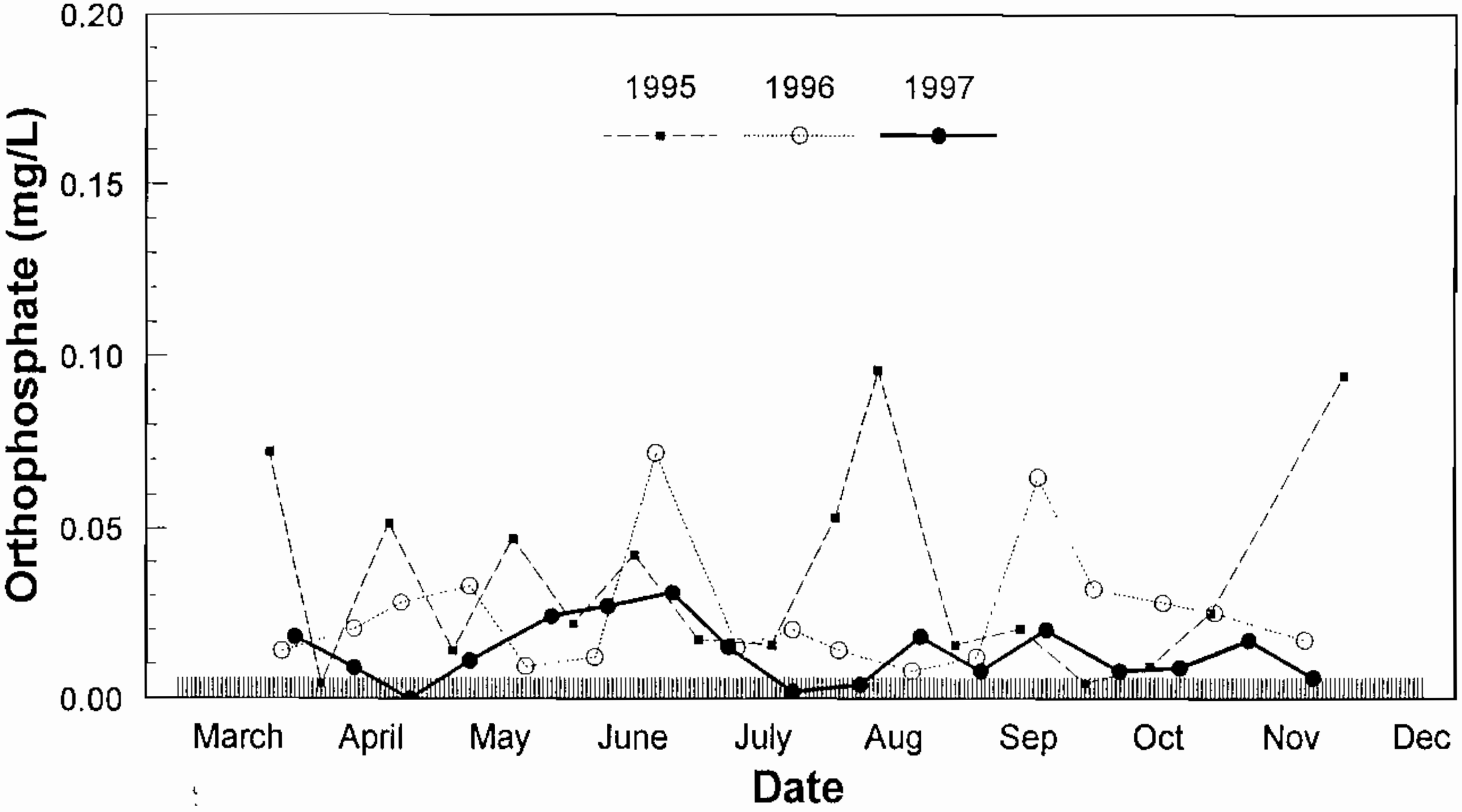


Kenilworth Marsh
Fig. 52

ORTHOPHOSPHATE

SITE 1

1995, 1996, 1997

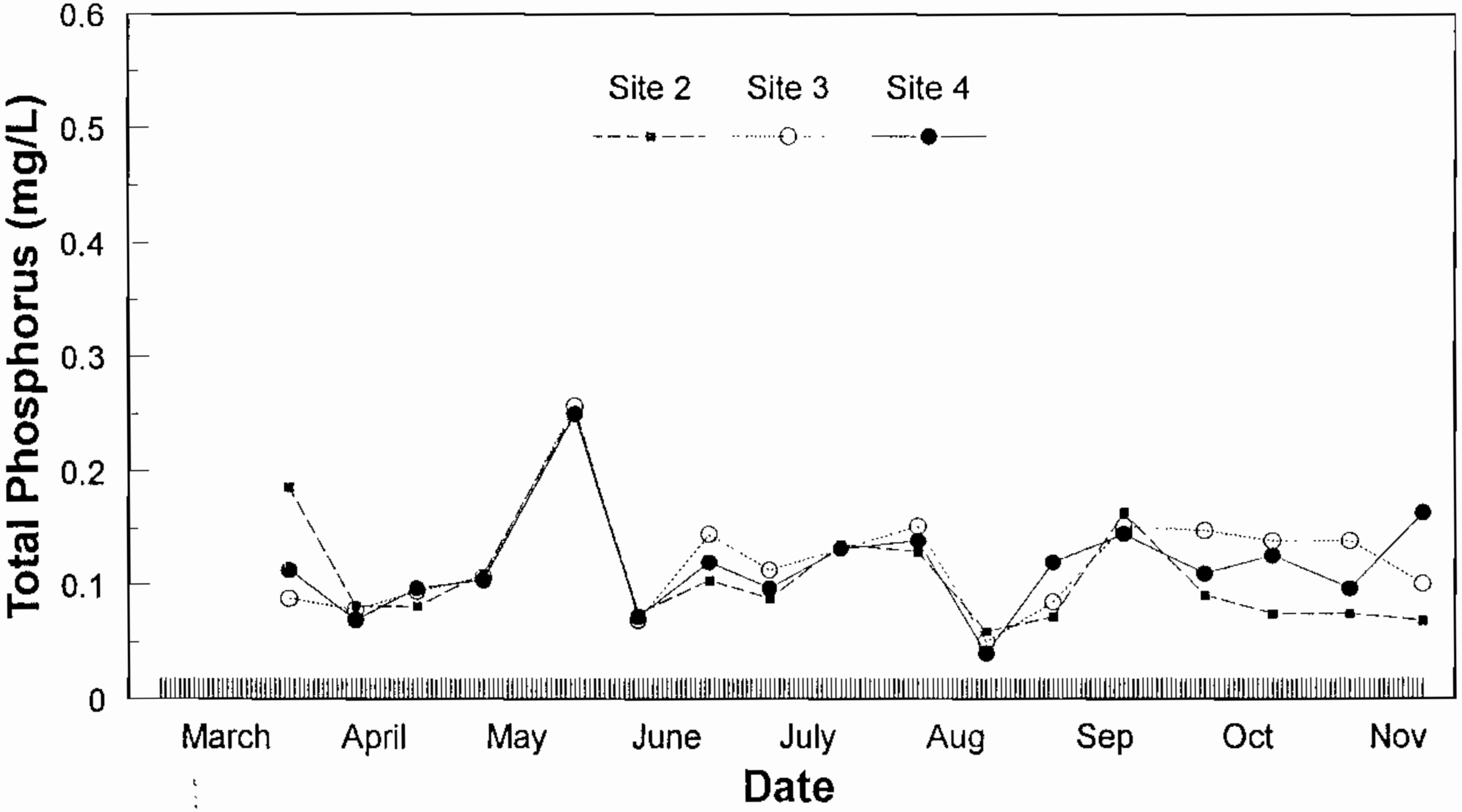


Kenilworth Marsh
Fig. 53

TOTAL PHOSPHORUS

SITES 2,3,4

1997

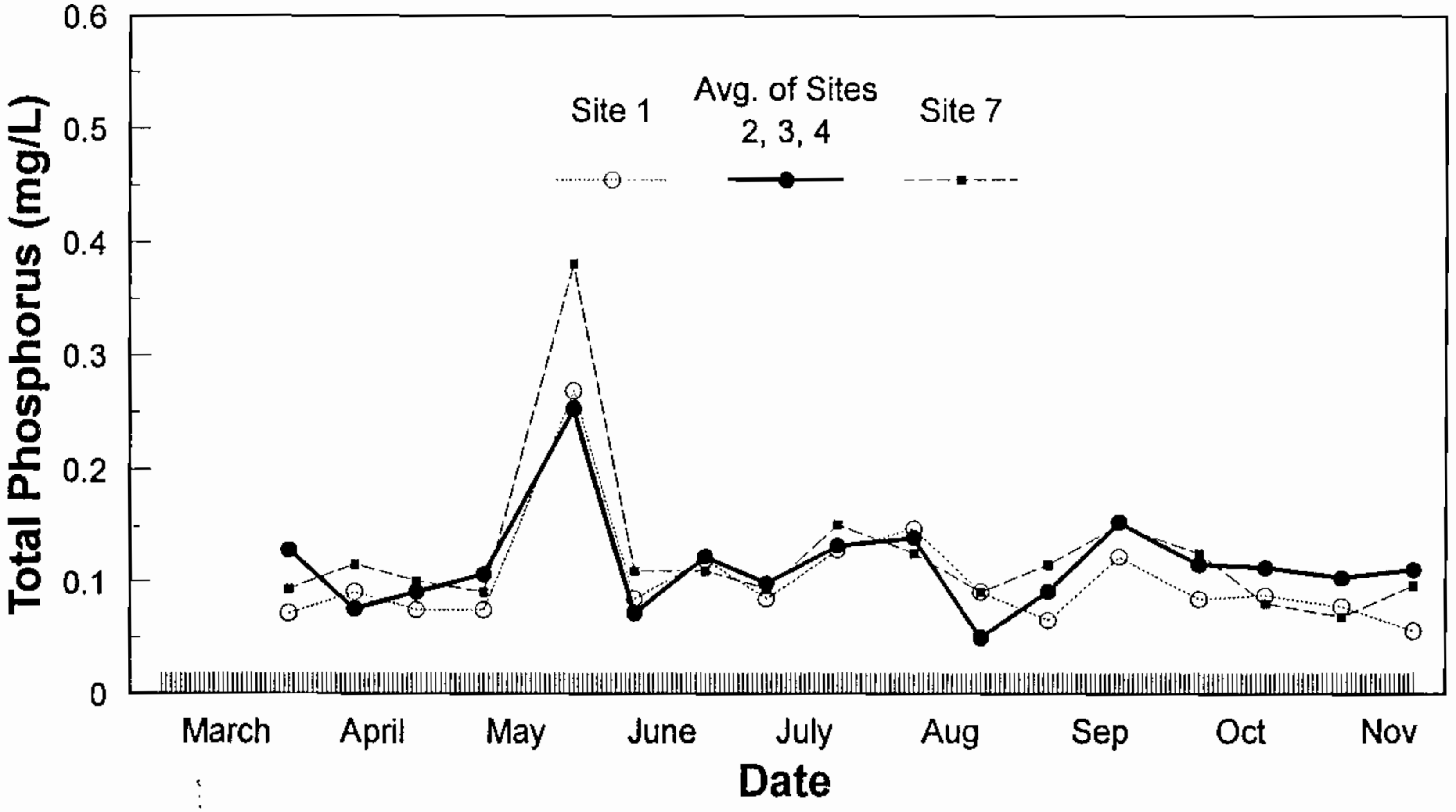


Kenilworth Marsh
Fig. 54

TOTAL PHOSPHORUS

SITES 1; 2,3,4; 7

1997

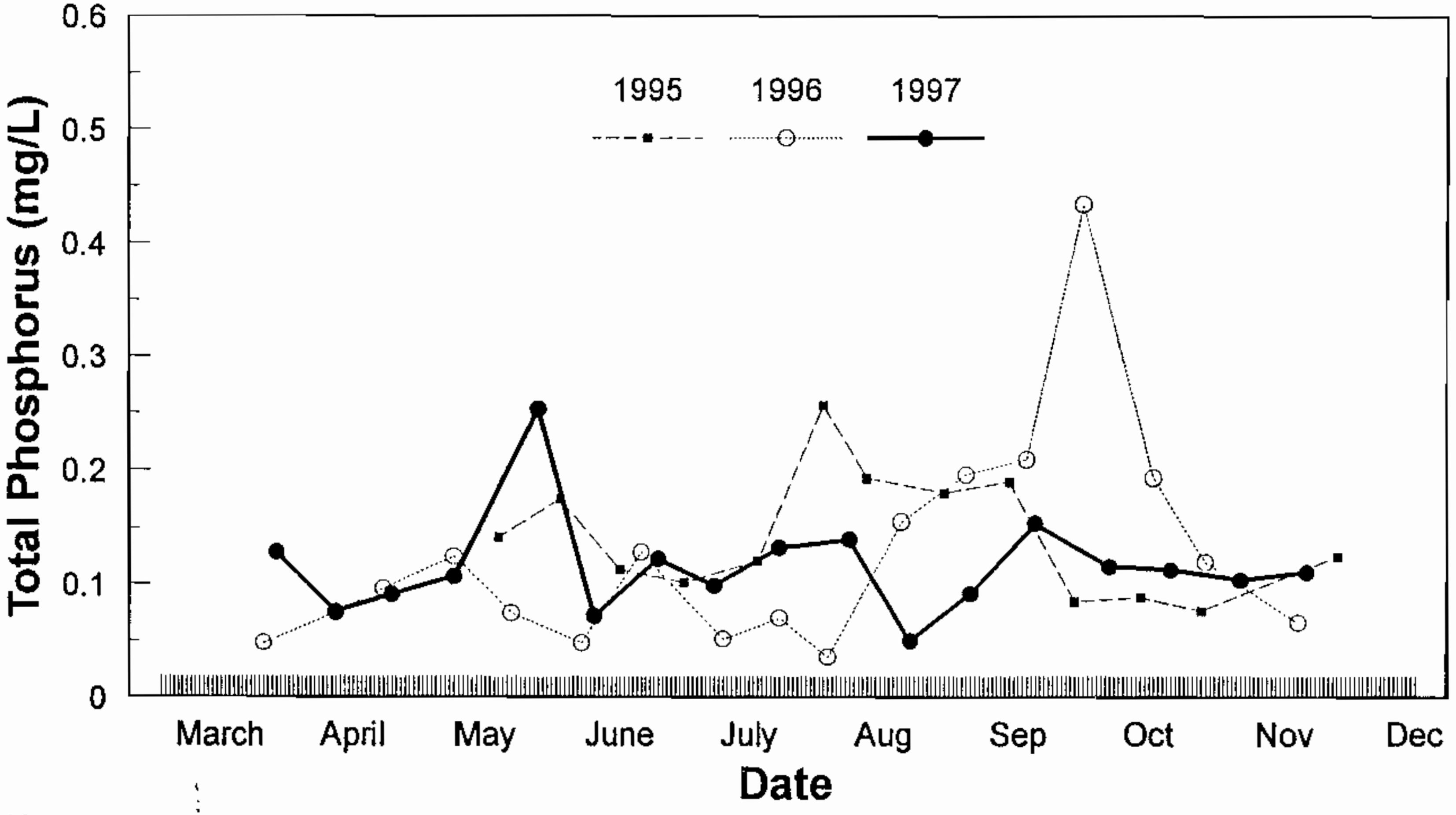


Kenilworth Marsh
Fig. 55

TOTAL PHOSPHORUS

SITES 2,3,4

1995, 1996, 1997



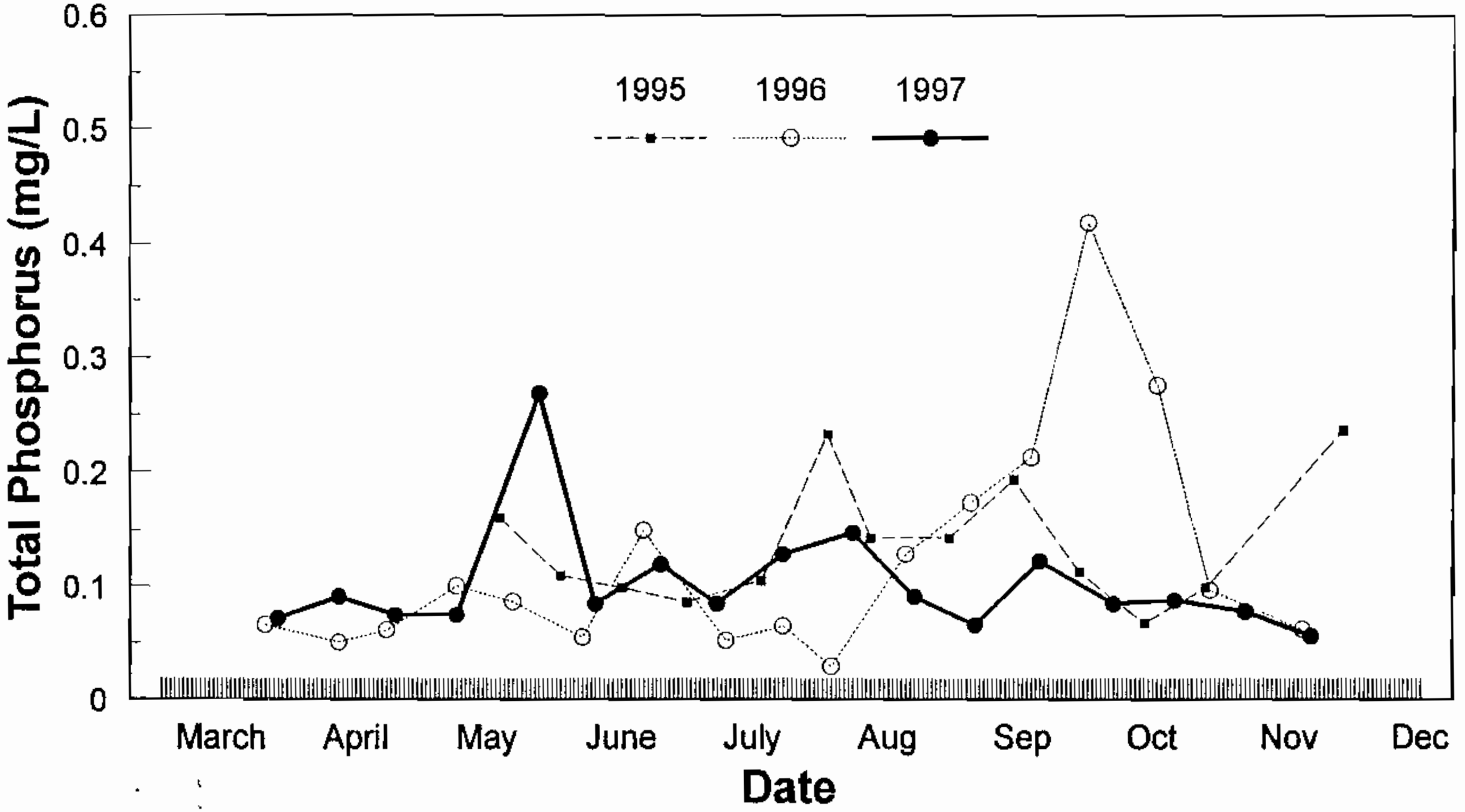
Kenilworth Marsh

Fig. 56

TOTAL PHOSPHORUS

SITE 1

1995, 1996, 1997



Kenilworth Marsh
Fig. 57