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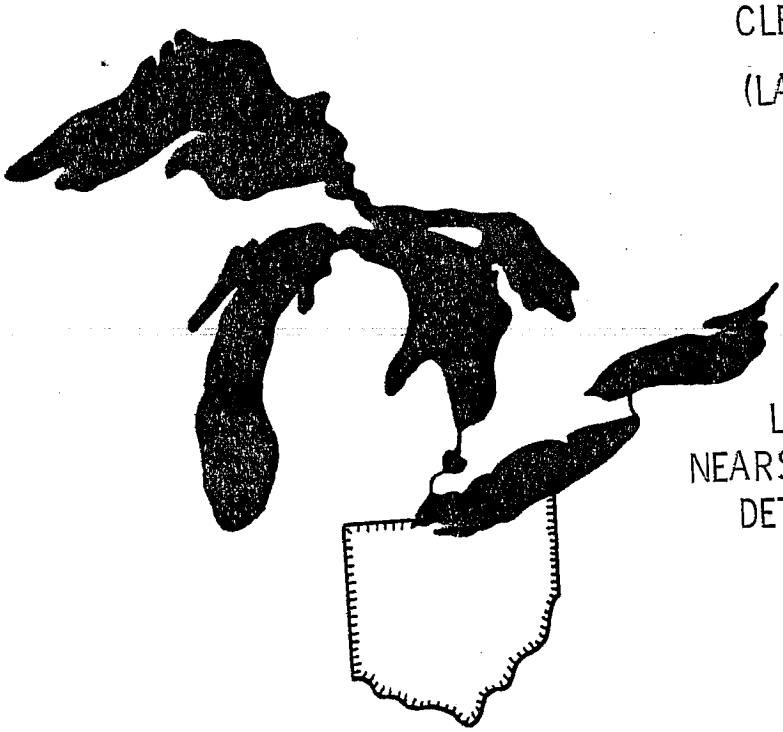

LAKE ERIE INTENSIVE STUDY: NEARSHORE NUTRIENT DISTRIBUTION-- DETROIT RIVER TO HURON, OHIO

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NUTRIENT DISTRIBUTION DURING THE 1978-1979 LAKE ERIE WESTERN BASIN NEARSHORE STUDY

RATIONALE

The nearshore zone represents an area of transition between loading from land use and the trophic state of open lake waters, and the immediate effects of high nutrient concentrations are most visible here. The nearshore waters are intensively used for industrial and municipal water supplies as well as being prime sites for waste disposal. High nutrient loadings promote undesirable growth of attached algae and phytoplankton blooms which, in turn, increase oxygen demand within the system, cause taste, odor and clogging problems for water supplies and reduce the aesthetic appeal of the area. The aesthetic appeal is an important factor as the nearshore waters are heavily used for recreational activities, and consequently the economy of many shoreline communities depends on the state of the lake.

The purpose of this study is to identify problem areas which repeatedly exceed IJC objectives and OEPA standards as presented in Chapter 6, Water Quality Violations and Problem Areas and to establish an extensive data base of the nearshore for future reference. Phosphorus has been accepted as a primary variable in determining trophic conditions and, in the case of western Lake Erie, in establishing the level of eutrophication. Nitrate + nitrite and ammonia are also important algae-enriching nutrients, with high ammonia concentrations demonstrating sites of localized input and fairly recent pollution. Silica is an important nutrient for diatom production, and fluctuations in silica can be linked with fluctuations in diatom populations. High levels are of concern in industrial situations because problems can be caused by coating boilers and heating apparatus with scale. The seasonal and annual distribution of these nutrients will be discussed in relation to inshore/offshore variations and according to specific geographic areas. Methods and quality control are presented in Chapter 2.

RESULTS

Seasonal Variation

Seasonal distribution patterns show very high nutrient values occurring in the spring, with a dramatic drop in the interval between the spring and early summer cruises. This drop is attributed to a decrease in runoff, less sediment resuspension and a sharp rise in the blue-green algae population. In 1978 concentrations continued to drop through the fall, but on a much more gradual scale. Total phosphorus concentrations in 1979 increased in the cruise interval from the early summer to the late summer cruise, corresponding with an extraordinary blue-green algae bloom. Seasonal nutrient concentrations means are presented in Table 1.

Nutrient values measured in 1978 and 1979 were very close comparatively, except for phosphorus. A significant difference in TP concentrations was noted as seen in Table 2. Concentrations at inshore/offshore stations in 1978 were 41 and 60 percent higher, respectively, than 1979 values. The late summer cruise showed the least amount of difference between the two years and was also the closest time-wise. The same trend was measured for SRP with 1978 values averaging twice as high as 1979 values. Soluble reactive phosphorus inshore/offshore concentrations in 1978 were 16.7 and 14.2 ppb, respectively, compared with 8.5 and 6.0 ppb measured in 1979. Phosphorus loading estimates for 1978 were significantly higher (approximately 35 percent) than those for 1979.

Geographic Variation

Inshore nutrient concentrations averaged higher than offshore values and exhibited a greater range (Table 3). The increased loading at river mouths largely accounted for the greater variation and higher concentrations in the nearshore zone. Figures 1-20 indicate the annual mean, range and standard error at each station in the inshore/offshore couplet design. Graphs of seasonal distribution for each parameter are presented in Appendix . . The location of river mouths is apparent on the inshore graphs, particularly for the Huron River (MI), Maumee River, Sandusky River and Huron River (OH). Station M16 consistently had higher nutrient concentrations than the surrounding area as this station is located at the effluent of the Monroe Power Plant, which draws its cooling waters from farther up the Raisin River where nutrient levels were higher.

Highest nutrient levels and spatial variations for inshore and offshore stations were observed during the spring cruises (April) each year. This is attributed to increased loading from spring runoff and maximum resuspension of sediments due to strong winds.

Ammonia values ran high throughout the year at Maumee Bay, Huron River (MI) and Huron River (OH) in comparison to adjacent inshore stations. After the first cruise each year, ammonia levels at inshore stations not located at river mouths equalled levels measured at offshore stations. Spatial fluctuations for inshore stations continued in decreasing magnitudes throughout the year, but the same pattern was exhibited for every cruise.

Nitrate + nitrite levels inshore showed considerable variation in comparison with values measured at offshore stations. Offshore concentrations showed little variation spatially except during the spring cruises each year. Nitrate + nitrite concentrations inshore averaged twice as high as offshore concentrations with the difference being very high in spring and decreasing to almost zero by October. Inshore concentrations in the Maumee Bay area were consistently five times higher than concentrations at the remaining inshore stations.

Soluble reactive phosphorus concentrations at offshore stations exhibited little variation both spatially and seasonally except for the April cruise in 1978. During this cruise SRP values fluctuated from 1 ppb to 84 ppb with all stations east of Locust Point averaging 40 ppb. Inshore values during the April 1978 cruise also held the pattern of remaining high (~ 65 ppb) east of Maumee Bay. Inshore concentrations continued to fluctuate throughout the sampling season, particularly at river mouths, with peaks becoming lower in magnitude as the year progressed. In 1979, SRP concentrations showed an increase in October over the steady decline measured over the rest of the year. Maumee Bay was always the area of highest concentrations.

Total phosphorus values at both inshore and offshore stations continued to vary spatially from April to October. Maumee Bay again harbored the highest levels with Sandusky Bay taking the lead in the summer. A gradual decrease occurred seasonally. In 1979 an increase was noted in the interval between the late July and September cruises. This increase coincided with a tremendous blue-green algal bloom.

Silica values were highest during the spring cruises (April) of each year. Sites of highest concentrations were located at Maumee Bay, Sandusky Bay, M16 (River Raisin water) and Huron River (OH). Offshore values in the spring of 1978 were 4.5 times higher off Locust Point than in waters farther east and 2.5 times higher than those to the west. In the spring of 1979, peak silica concentrations were also observed offshore Locust Point but the increase was only 1.5 times higher than the surrounding values. A lot of variation was still noted during the early summer cruises at inshore stations. Offshore stations often had higher concentrations than inshore stations not located at river mouths. By late summer silica levels had decreased from 3.00 ppm to less than .60 ppm with only Maumee Bay (1.20 ppm) and Sandusky Bay (8.20 ppm) having high concentrations. The fall cruise of 1978 showed a decline in both inshore and offshore stations, while in 1979 the decrease was observed for offshore stations, but inshore station concentrations increased.

Annual reach averages are presented in Table 4. All nutrients show the same pattern of increasing along the Michigan shoreline to Maumee Bay and then decreasing from west to east. The lowest concentrations are found along the Michigan shoreline and at the easternmost stations of the study area. Higher ammonia and silica values observed in Reach 1 are attributed to loading from the Huron River (MI). Station M16 consistently had higher concentrations than the surrounding waters due to the effluent cooling waters of the Monroe Power Plant which are drawn from the River Raisin. All nutrient concentrations show a dramatic rise upon reaching the inshore zone of Maumee Bay.

The largest contributor of nutrients appeared to be the Maumee River. Maumee Bay always had poor quality water and high suspended sediments. To show the influence of the Maumee River on the surrounding lake waters, two sets of stations were selected to show distribution in a transect from the river mouth to the Toledo lighthouse (14 km) and along the bay shoreline. Figures 21 and 22 depict nutrient distribution in the transect. The Maumee River drainage basin is largely agricultural, and as the river flows through Toledo it also picks up industrial wastes and sewage treatment plant effluent. Station 02 is located directly downriver from the sewage treatment plant for Toledo. Past station 02 there are no other major sources of loading, and as the river water mixes with higher quality lake water nutrient concentrations decrease.

Figures 23 and 24 show nutrient distribution along the shoreline from northwest to southeast. Station M23 has elevated concentrations because it is located at the outfall of the Consumer Power Plant which draws its cooling waters from the poorer quality water on the west side of Woodtick Peninsula. Station M27 is located at the mouth of the Ottawa River, 02 at the mouth of the Maumee River and station 08 at the outfall from the Bayshore Power Plant accounting for peaks at these locations. East of Maumee Bay values continue a gradual decreasing trend.

Sandusky Bay represents an area essentially separate from the lake. The Sandusky River drainage basin is mostly agricultural and nutrient concentrations are expected to be high. Soluble reactive silica concentrations are higher here than anywhere else in the western basin nearshore, and TP values are often higher than those measured in Maumee Bay. Soluble reactive phosphorus, NH_3 and $NO_2 + NO_3$ are low by comparison, but throughout this study a large standing crop of phytoplankton, particularly blue-green algae, was noted.

The high degree of fluctuation for nutrient concentrations in the nearshore zone of Lake Erie's western basin is due to a variety of factors, but all factors are related to the very nature and location of the nearshore zone. The shallowness of the area, averaging 5.2 m, makes it particularly susceptible to even slight changes in weather or runoff. Strong winds quickly stir up the water column, resuspending sediments and nutrients which had settled to the bottom. Excessive precipitation increases loading from land use and overflows treatment plants unable to handle increased storm runoff. Heavy recreational boat traffic and the freighter traffic in Toledo channel also contribute to mixing of the water column and sediment resuspension. Current patterns and tributary flow rates influence formation of areas of high concentration.

Problem Areas

Although the majority (97 percent) of water entering the western basin comes from the Detroit River (Harlow, 1966), the combined effect of volume, velocity and direction of flow prevents the formation of distinct areas of high nutrient concentrations along the Michigan shoreline. The majority of the flow heads out into the open lake and runs east along the Canadian shoreline. The velocity of the Detroit River flow is so much greater than that of the Maumee or any of the smaller tributaries along the Michigan shoreline that it actually forces the flow from these rivers back toward the shore (Simons, 1976). By contrast, the Maumee River contributes less than three percent of the water to the western basin, but nutrient concentrations in Maumee Bay are the highest in the western basin. The Maumee River has a low gradient of 1.3 feet per mile and a correspondingly sluggish flow (Horowitz et al., 1975). Maumee Bay has a flat bottom and is very shallow. The low flow, in combination with the high agricultural, industrial and municipal loadings and the physical characteristics of the area, make the Maumee Bay a problem area.

In 1978, 18 samples exceeded IJC objectives for TP, and 17 of these occurred in Maumee Bay. This was also the site of violations for ammonia. Only one station measured TP concentrations in excess of the IJC objectives in 1979.

Upper Sandusky Bay also proved to be an area of high nutrient concentrations with values up to three times higher than those measured in the lower bay. The highest silica values in the nearshore study were consistently observed in the upper bay, and TP concentrations were also higher there. Upper Sandusky Bay is separated from the lower bay by a natural indentation, two highway bridges and a railroad bridge, inhibiting free exchange of water between the two basins. Currents flowing into the bay mix lake waters with bay waters, but these currents generally circulate only in the lower bay (Ohio Geological Survey, 1966) accounting in part for the lower concentrations found there. The Sandusky River basin drains almost exclusively agricultural land with several large municipalities situated on the river (Baker, 1975). Low clay banks surrounding the bay area are easily eroded and contribute a significant amount of sediment to the bay every year. The characteristics of the bay suggest it may be a potential problem area.

Historical Trends

Nutrient concentrations at the mouth of the Maumee River have shown a decrease within the last decade. Enough data was available from the nearshore station 02 between 1968 and 1979 to establish significant trends for TP, NO_2 + NO_3 and NH_3. Data was obtained from the following studies on Maumee Bay: FWPCA (1968), Fraleigh et al. (1975),

Fraleigh et al. (1979), Herdendorf and Cooper (1975), Waybrant and Siler (1976), Horowitz et al. (1975) and from unpublished records at the Department of Public Utilities for the City of Toledo. Although year-round data was available for certain years, only concentrations measured from April to October were used to correspond with the sampling period for the nearshore study. Total phosphorus values show a decrease not only in average annual mean, but also in range (Figure 25). An increase of 200 ppb was observed from 1973 to 1974, but by 1975 the mean returned to 1973 levels and the decreasing trend continued. The average value in 1968 was 915 ppb compared to 196 ppb in 1979.

Ammonia also showed a decreasing trend from 1968 to 1979, as appears in Figure 26. After a significant rise in 1969 of 1000 ppb, concentrations returned to 1968 levels, rose 300 ppb in 1971 and then followed a decreasing trend to 1979. The annual mean in 1968 was 1610 ppb, gradually dropping to 600 ppb by 1979. Nitrite + nitrate also displays a general decreasing trend, although it is not as pronounced as for TP and NH_3 (Figure 27). More yearly variation is seen here without the steady decline from year to year. In 1968 the average concentration was 5.25 ppm and in 1979 it was 2.55 ppm.

CONCLUSIONS

1. The nearshore zone has higher nutrient concentrations and variance than does the open lake of the western basin. This difference also applies to comparison between inshore and offshore stations with concentrations and variance decreasing with distance from shore.

2. The higher concentrations and variability of the inshore stations are due mostly to the input from rivers and industrial effluents, because concentrations at inshore stations not located at sources of loading run fairly close to offshore concentrations.

3. A definite seasonal trend exists for all nutrients with spring values being much higher due to increased loading and maximum resuspension of sediments. Concentrations drop rapidly in the spring to summer cruise interval and then show a gradual decline through the fall. Biologically active nutrient levels reflect pulses in phytoplankton populations.

4. Maumee Bay consistently had the highest nutrient concentrations and the poorest quality water. Violations for ammonia and total phosphorus were measured here repeatedly.

5. Upper Sandusky Bay also had high nutrient concentrations, particularly for silica and total phosphorus. Silica values were highest here for the whole western basin nearshore.

6. Phosphorus concentrations in 1978 averaged 50 percent higher than those in 1979. Only one violation occurred in 1979 as opposed to 18 in 1978. Phosphorus loading estimates in 1978 were approximately 30 percent higher than those in 1979.

7. Surface and bottom concentrations show little difference. On several occasions in the late summer, oxygen levels at some of the deeper stations at the eastern end of the study area dropped to anoxic levels and substantial regeneration was reflected in nutrient concentrations. Surface concentrations at river mouths and outfalls were often higher than bottom values due to the fact that concentrated runoff entered at the surface and was not yet mixed through the water column.

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TABLES

TABLE 1

SEASONAL CHANGES IN NUTRIENT CONCENTRATION MEANS

1978	NH_3 (ppb)	$NO_3 + NO_2$ (ppm)	Si (ppm)	SRP (ppb)	TP (ppb)
Cruise 1	180.9 (6.6)*	2.347 (.122)	3.11 (.12)	36.2 (1.9)	185.1 (8.7)
Cruise 2	89.4 (7.5)	.565 (.058)	1.46 (.06)	12.7 (0.8)	129.9 (5.7)
Cruise 3	50.1 (5.3)	.107 (.011)	.64 (.06)	7.1 (0.6)	104.5 (3.9)
Cruise 4	24.2 (2.6)	.118 (.012)	.34 (.04)	6.8 (0.4)	103.7 (3.3)
1979	**NH_3 (ppb)**	**$NO_3 + NO_2$ (ppm)**	**Si (ppm)**	**SRP (ppb)**	**TP (ppb)**
Cruise 1	191.5 (10.5)	3.226 (.173)	2.38 (.10)	18.5 (1.2)	119.2 (3.9)
Cruise 2	41.6 (4.5)	.923 (.062)	.92 (.05)	4.4 (0.4)	68.8 (3.0)
Cruise 3	36.1 (7.3)	.206 (.023)	.60 (.06)	5.7 (0.8)	89.8 (2.2)
Cruise 4	55.5 (5.0)	.200 (.014)	.64 (.03)	5.5 (0.3)	73.5 (3.5)

*() Indicates standard error

TABLE 2

COMPARISON OF 1978 AND 1979 TOTAL PHOSPHORUS

Cruise		1978 Mean	1978 S	1979 Mean	1979 S	% Higher '78 Values Are
1	Inshore	211.8	133.2	139.2	57.8	34
	Offshore	137.4	45.3	77.3	30.5	44
2	Inshore	184.7	120.1	99.1	60.7	46
	Offshore	102.7	41.0	45.1	22.4	56
3	Inshore	131.2	60.1	110.5	44.1	16
	Offshore	64.8	23.3	64.2	11.2	1
4	Inshore	125.7	57.5	95.0	37.5	24
	Offshore	72.1	34.6	46.8	11.1	35

TABLE 3

ANNUAL INSHORE/OFFSHORE RANGES

1978	NH_3 (ppb)	SRP (ppb)	TP (ppb)	$NO_3 + NO_2$ (ppm)	SRS (ppm)
INSHORE					
Range	1.0 - 1231.0	1.0 - 111.7	16.3 - 874.0	.005 - 6.750	.03 - 9.65
Mean	88.9	16.7	143.3	.930	1.51
Std. Error	12.6	3.1	18.0	.194	.18
OFFSHORE					
Range	1.0 - 395.5	1.0 - 91.1	24.9 -451.0	.005 - 9.650	.04 - 8.90
Mean	73.5	14.2	108.2	.676	1.29
Std. Error	7.5	2.5	5.5	.139	.22

1979	NH_3 (ppb)	SRP (ppb)	TP (ppb)	$NO_3 + NO_2$ (ppm)	SRS (ppm)
INSHORE					
Range	1.0 - 1523.6	1.0 - 126.4	11.5 - 976.5	.005 - 11.280	.03 - 9.50
Mean	80.3	8.5	101.2	1.315	1.25
Std. Error	20.5	1.6	6.3	.329	.21
OFFSHORE					
Range	1.0 - 288.8	1.0 - 55.1	14.0 - 331.4	.005 - 7.180	.03 - 5.86
Mean	61.9	6.0	67.3	.666	1.01
Std. Error	13.1	1.0	5.7	.191	.12

TABLE 4

ANNUAL REACH AVERAGES--1978 AND 1979

Reach No.	SRP (ppb)	NH_3 (ppb)	$NO_3 + NO_2$ (ppm)	TP (ppb)	SRS (ppb)
			1978		
1	5.5	105.4	.214	128.5	894
2	8.4	77.6	.271	131.0	745
3*	21.8	50.8	.510	158.3	794
	53.3	254.2	1.774	291.0	1967
4	24.5	54.4	1.196	105.7	1677
5	22.0	87.8	.725	103.7	1526
6 Upper	21.4	36.0	.668	216.2	5006
Lower	6.5	8.8	.663	140.0	2286
Lake	16.3	59.4	.590	90.4	1287
7	12.3	61.1	.598	96.4	1053
			1979		
1	3.6	103.8	.490	75.2	890
2	4.2	57.9	1.124	79.2	915
3*	8.3	75.5	2.306	120.3	1136
	47.1	282.7	-	-	2271
4	7.3	54.3	1.181	82.4	1164
5	4.8	36.7	.867	76.1	583
6 Upper	18.7	41.8	1.153	174.7	3751
Lower	7.4	35.0	.800	145.2	1577
Lake	4.5	27.7	.409	65.3	718
7	4.9	33.9	.429	58.9	752

*When two values appear it indicates inshore concentrations much higher than offshore, and averages are calculated separately. First value is offshore, second value is inshore.

FIGURES

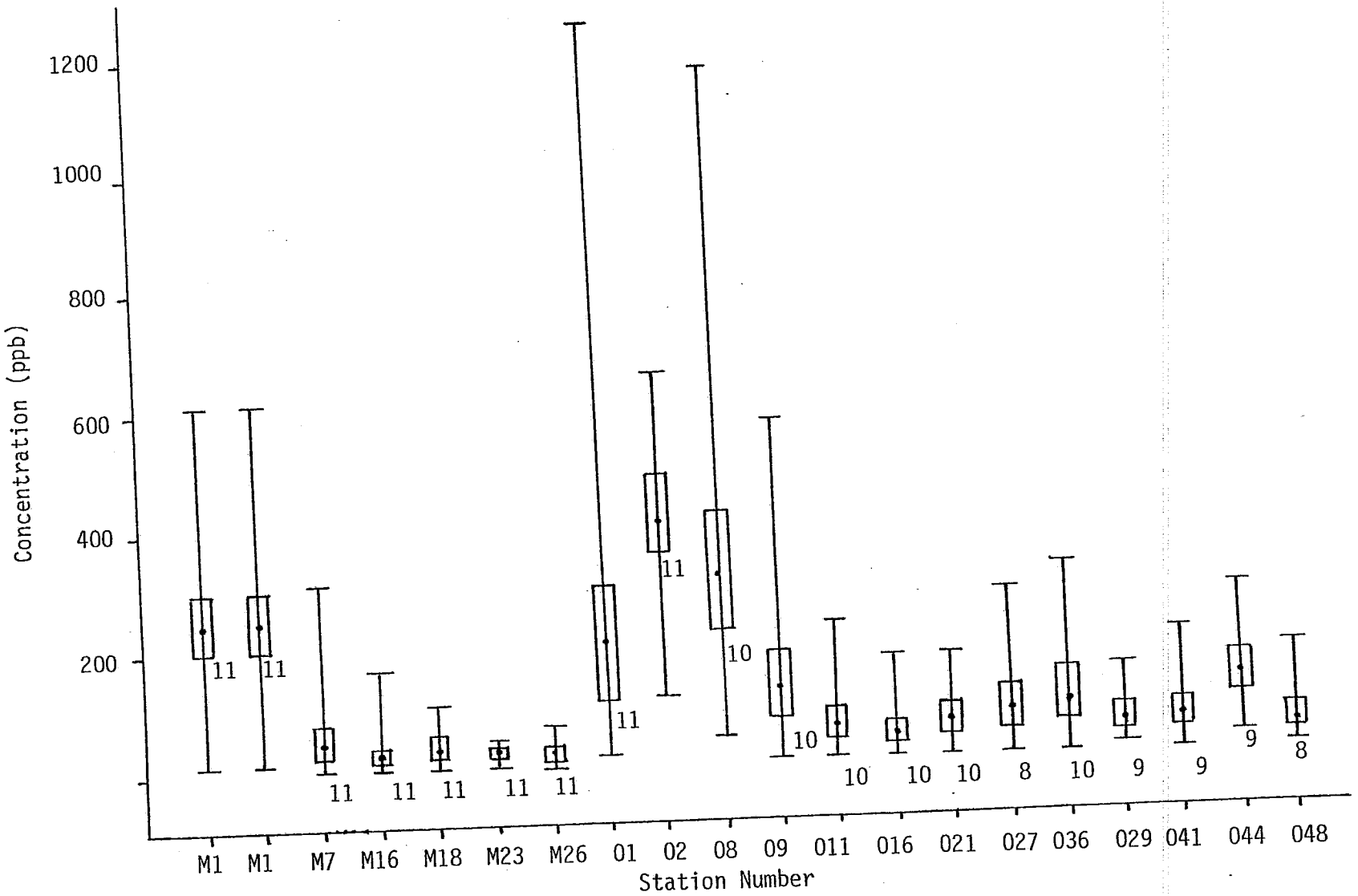


Figure 1. Annual Average Concentrations of Ammonia at Inshore Stations in 1978.

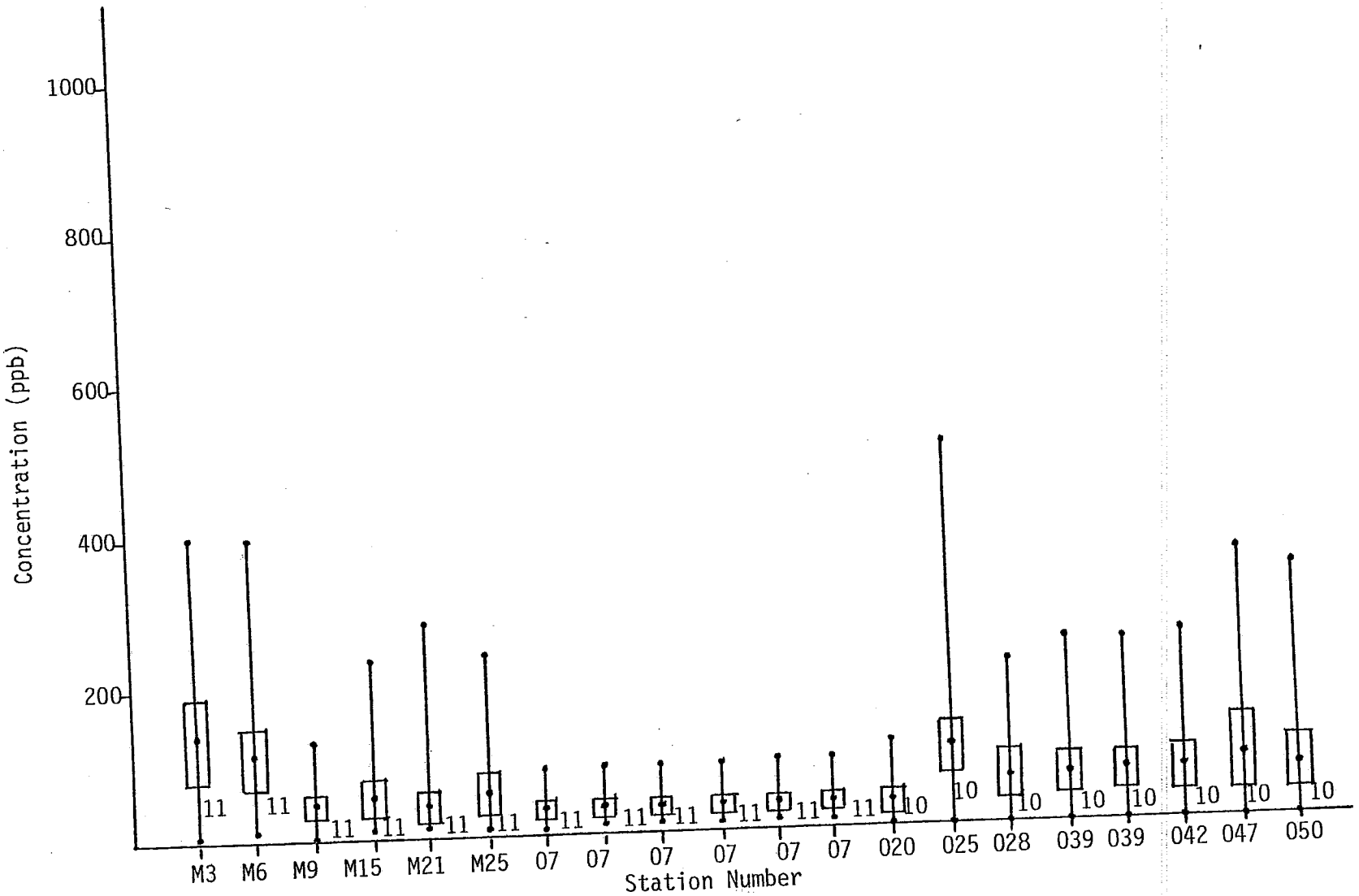


Figure 2. Annual Average Concentrations of Ammonia at Offshore Stations in 1978.

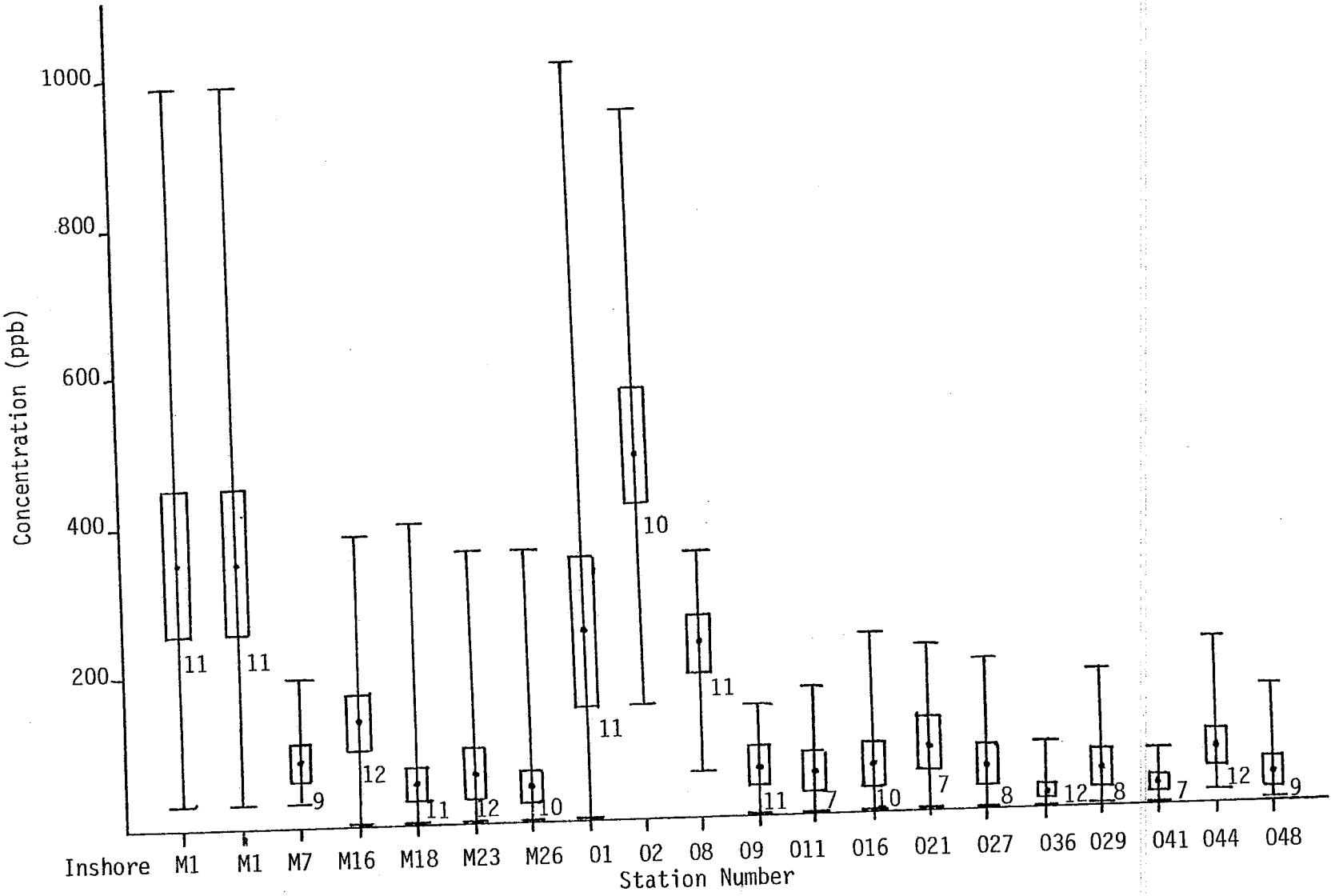


Figure 3. Annual Average Concentrations of Ammonia at Inshore Stations in 1979.

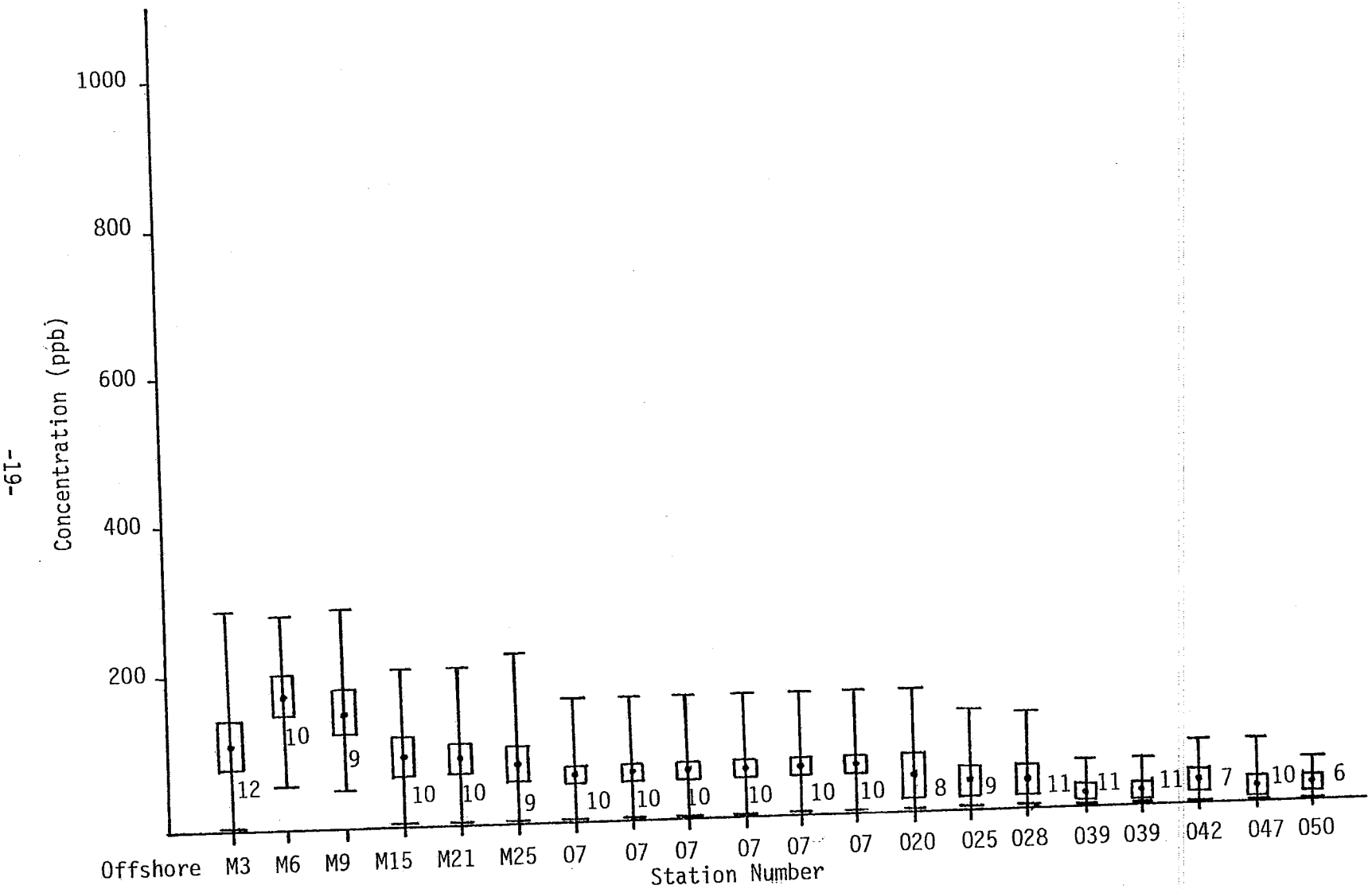


Figure 4. Annual Average Concentrations of Ammonia at Offshore Stations in 1979.

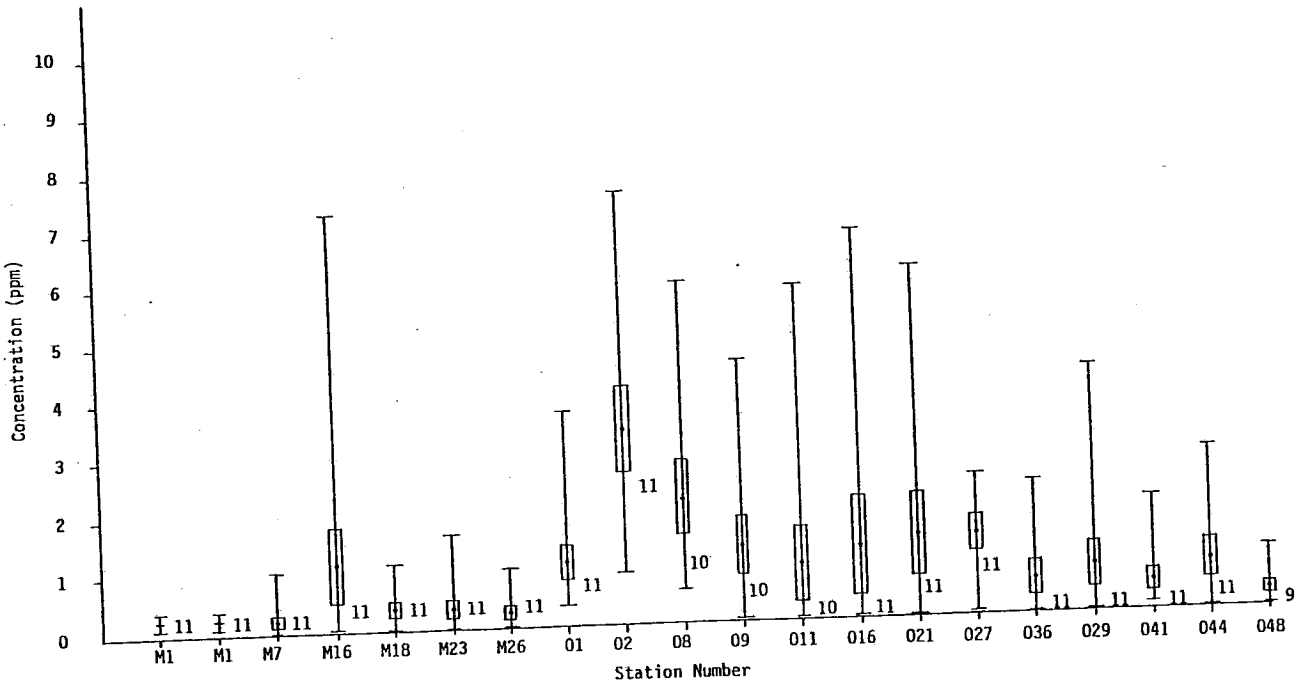


Figure 5. Annual Average Concentration of Nitrate and Nitrite at Inshore Stations in 1978.

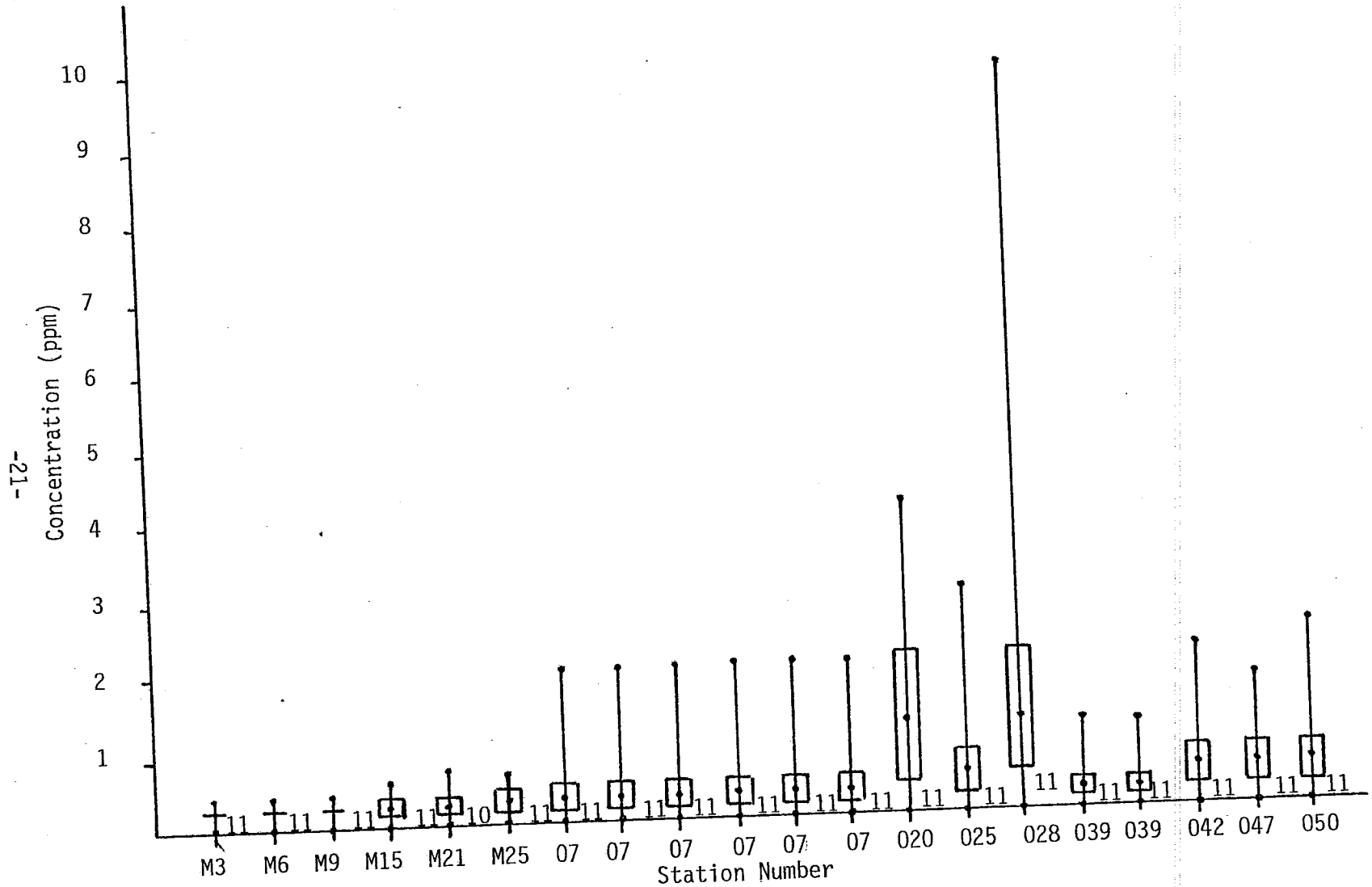


Figure 6. Annual Average Concentrations of Nitrate plus Nitrite at Offshore Stations in 1978.

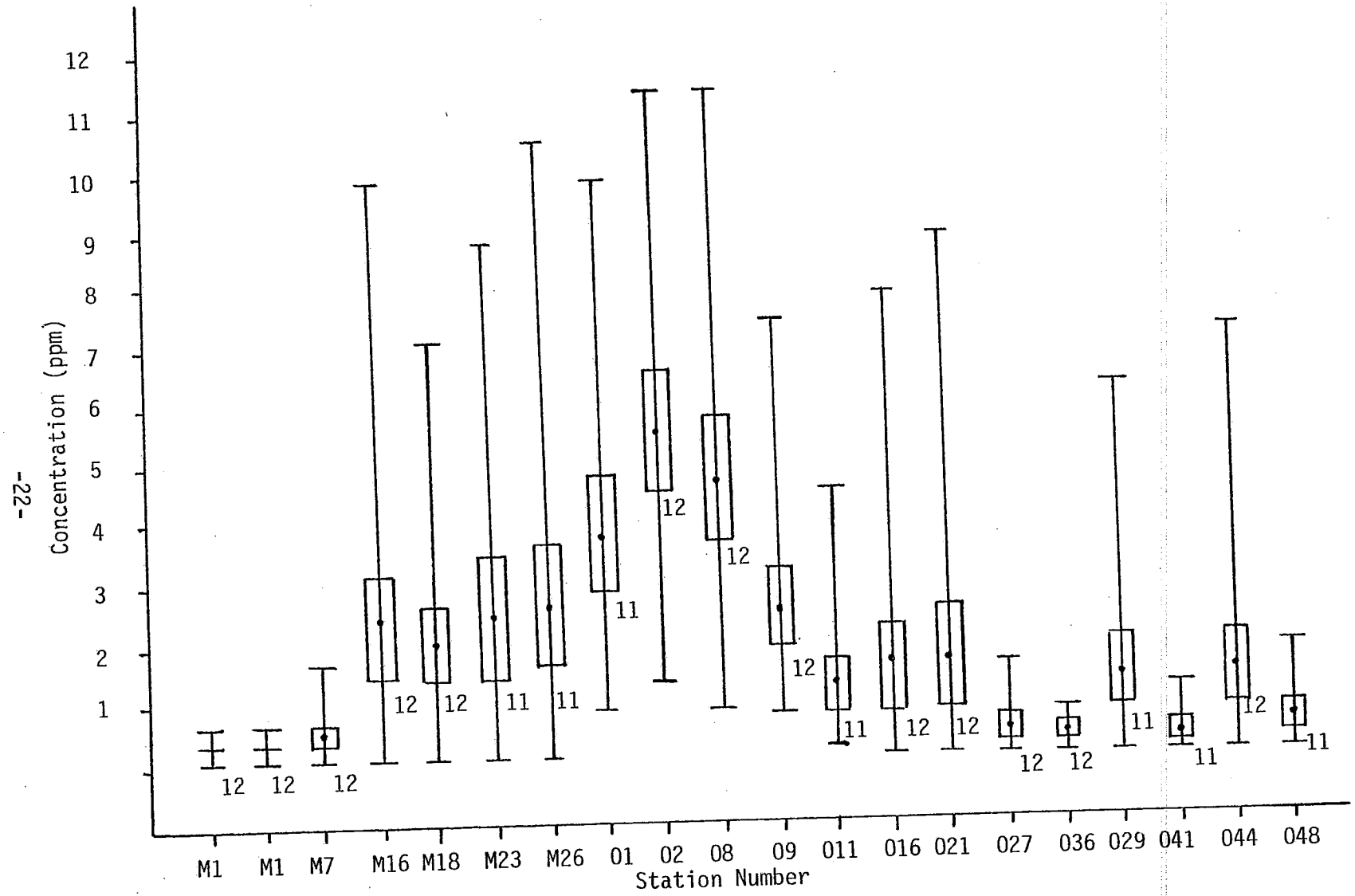


Figure 7. Annual Average Concentrations of Nitrate and Nitrite at Inshore Stations in 1979.

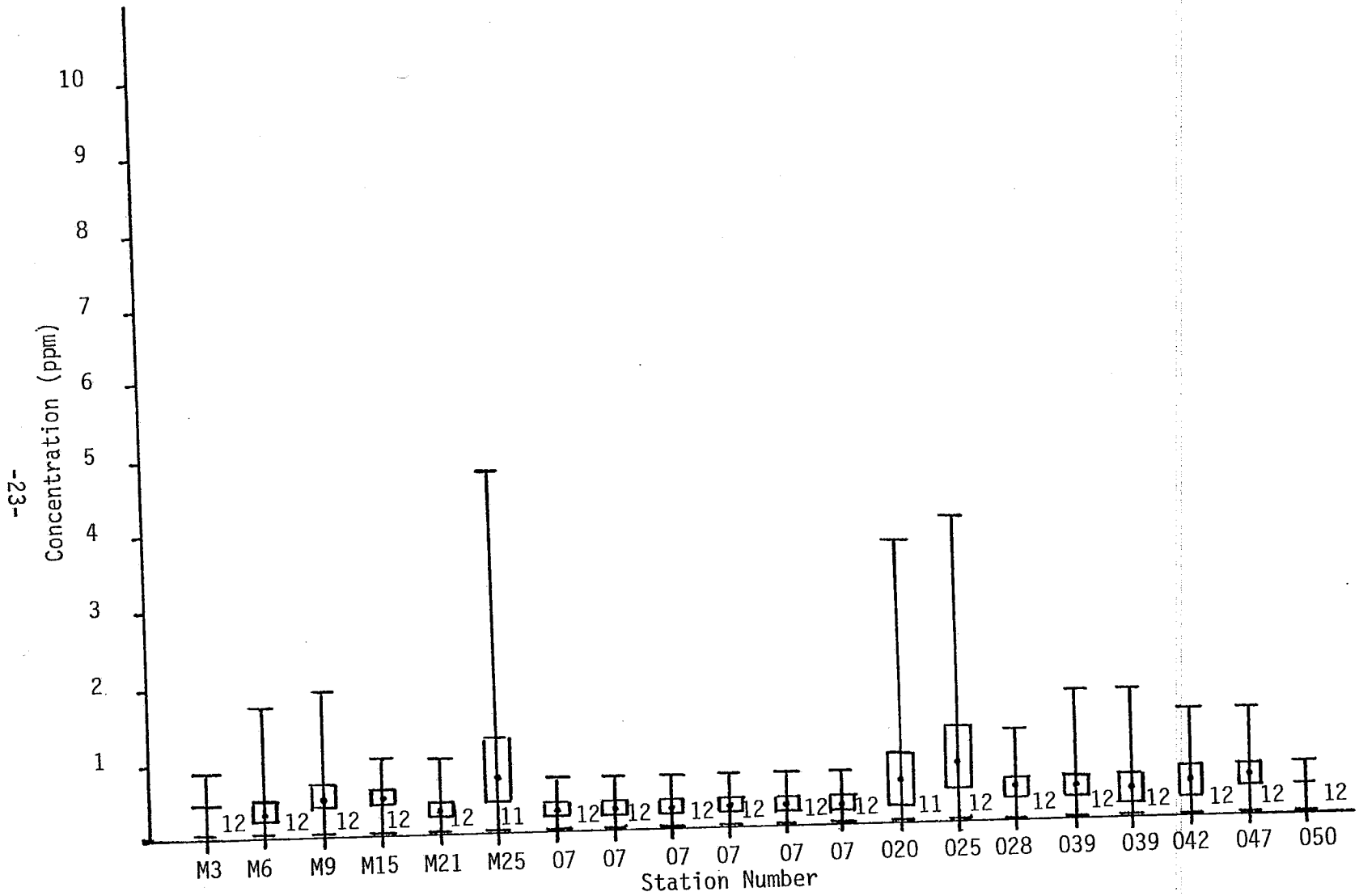


Figure 8. Annual Average Concentrations of Nitrate plus Nitrite at Offshore Stations in 1979.

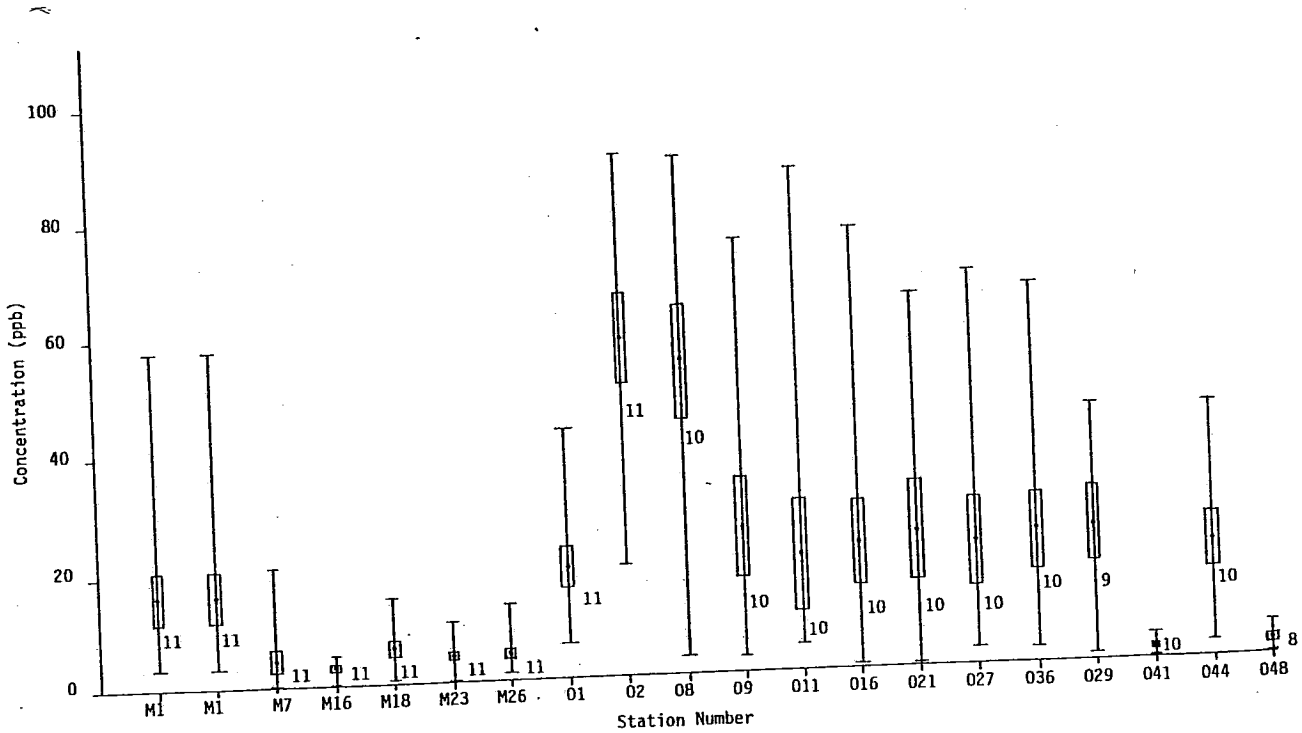


Figure 9. Annual Average Concentration of Soluble Reactive Phosphorus at Inshore Stations in 1978.

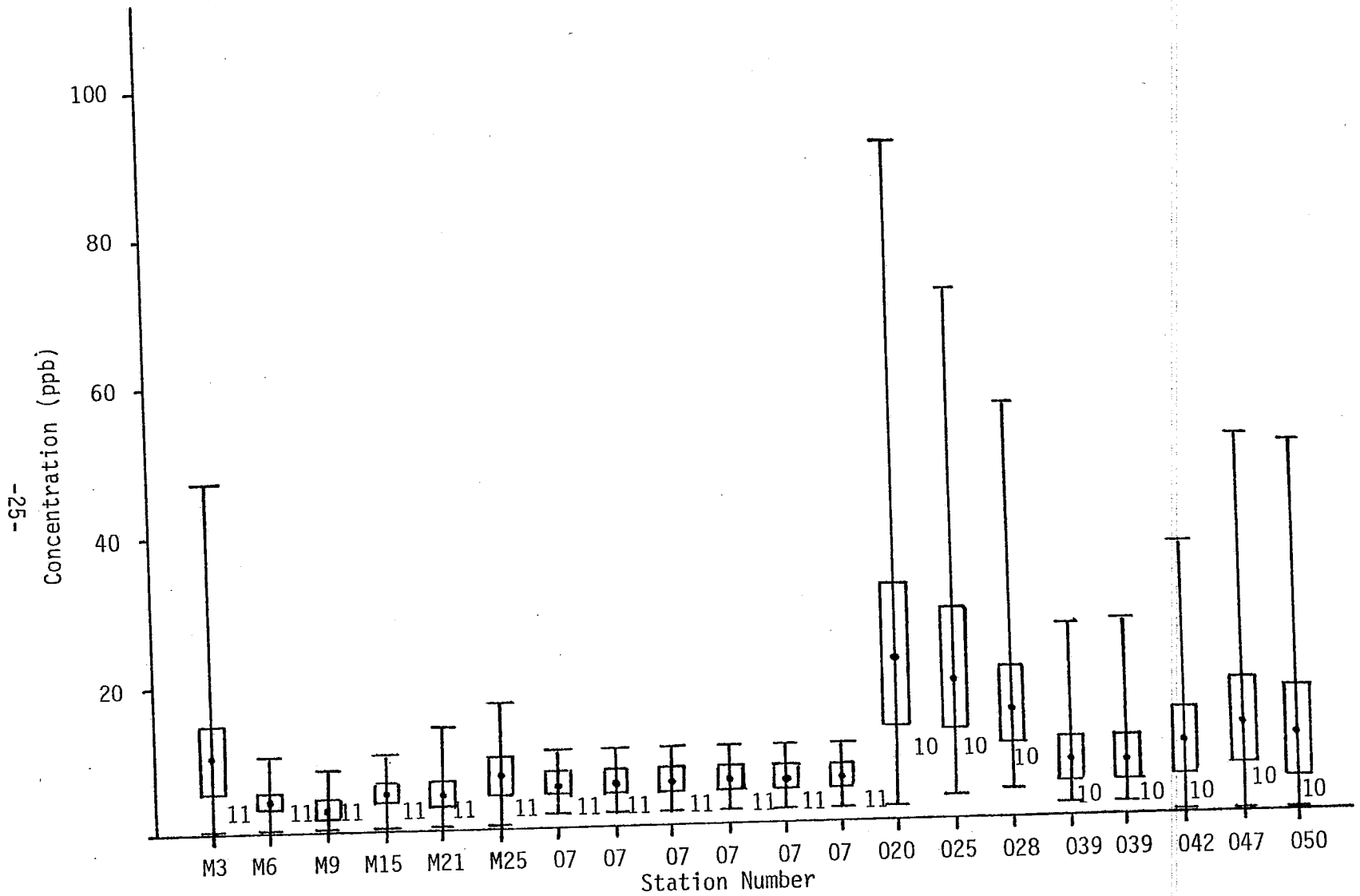


Figure 10. Annual Average Concentrations of Soluble Reactive Phosphorus at Offshore Stations in 1978.

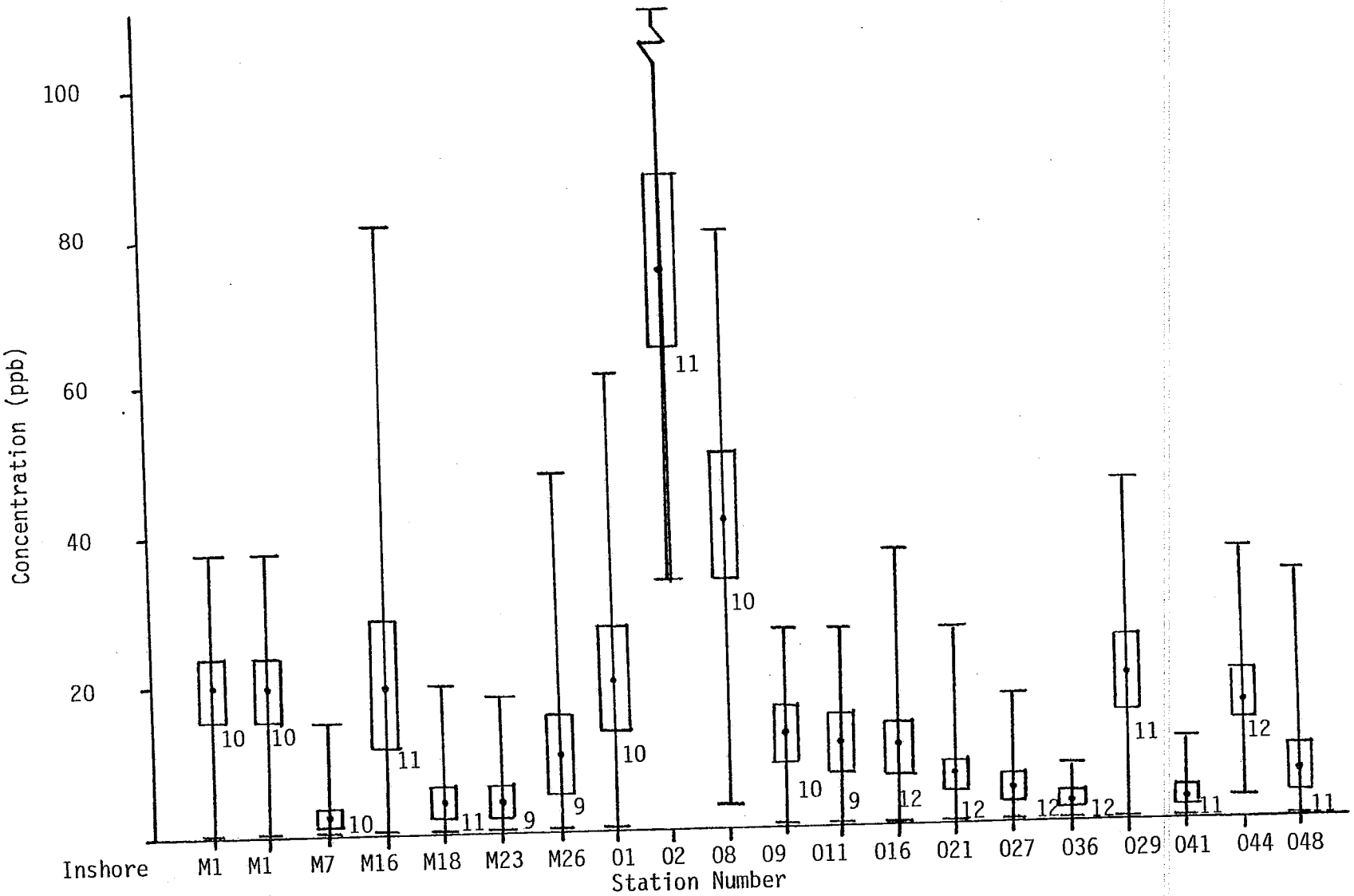


Figure 11. Annual Average Concentrations of Soluble Reactive Phosphorus at Inshore Stations in 1979.

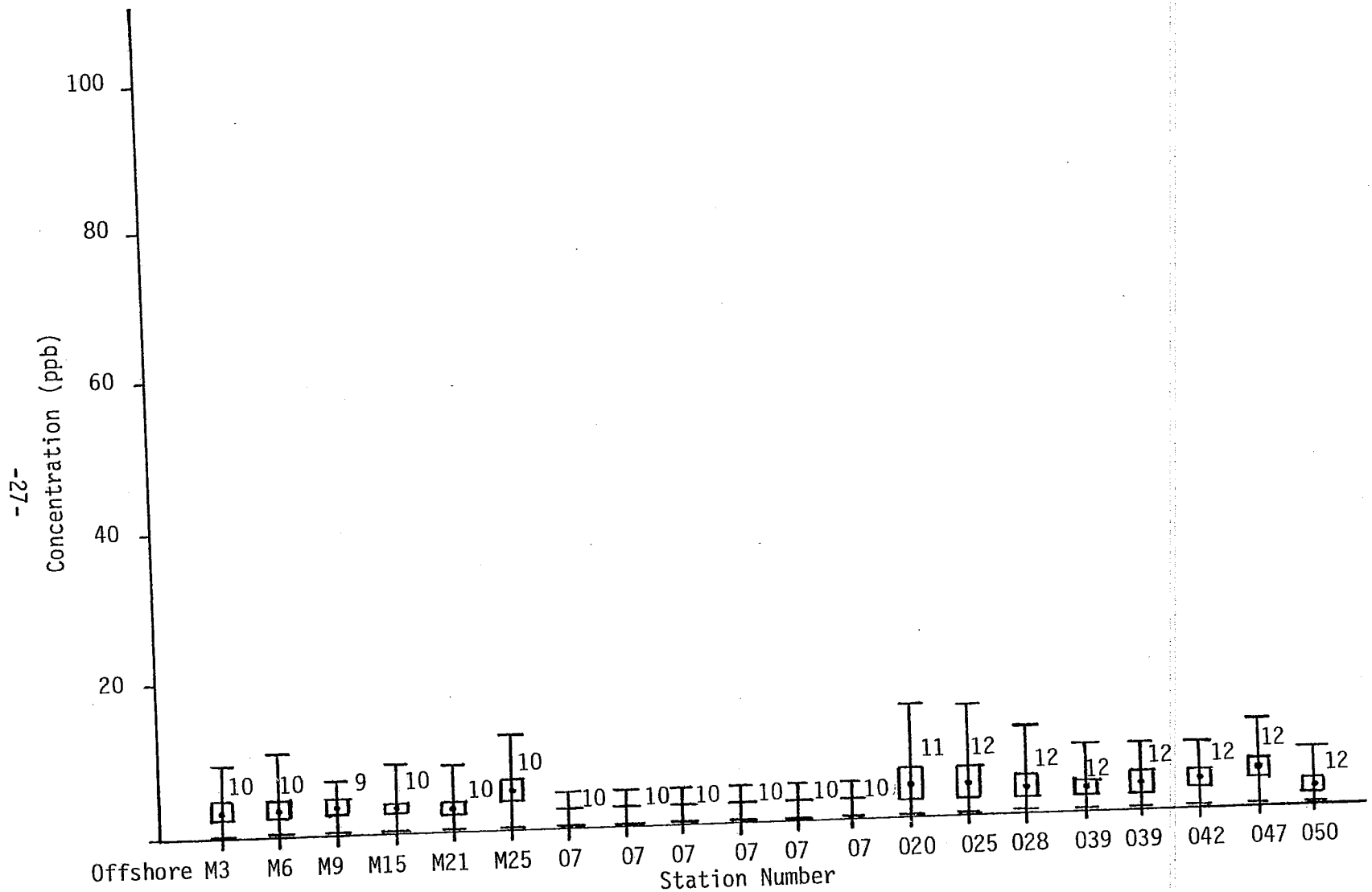


Figure 12. Annual Average Concentrations of Soluble Reactive Phosphorus at Offshore Stations in 1979.

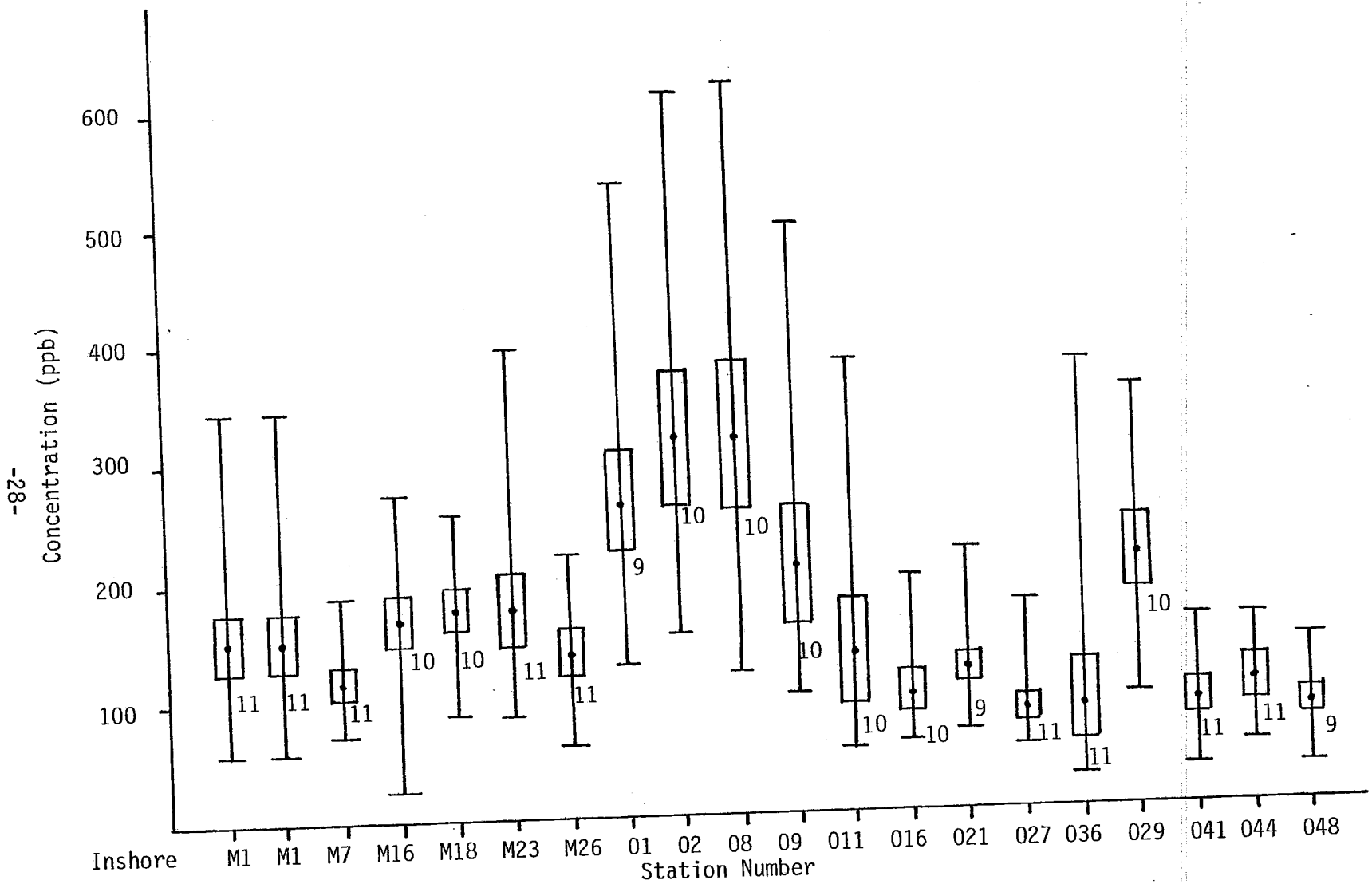


Figure 13. Annual Average Concentrations of Total Phosphorus at Inshore Stations in 1978.

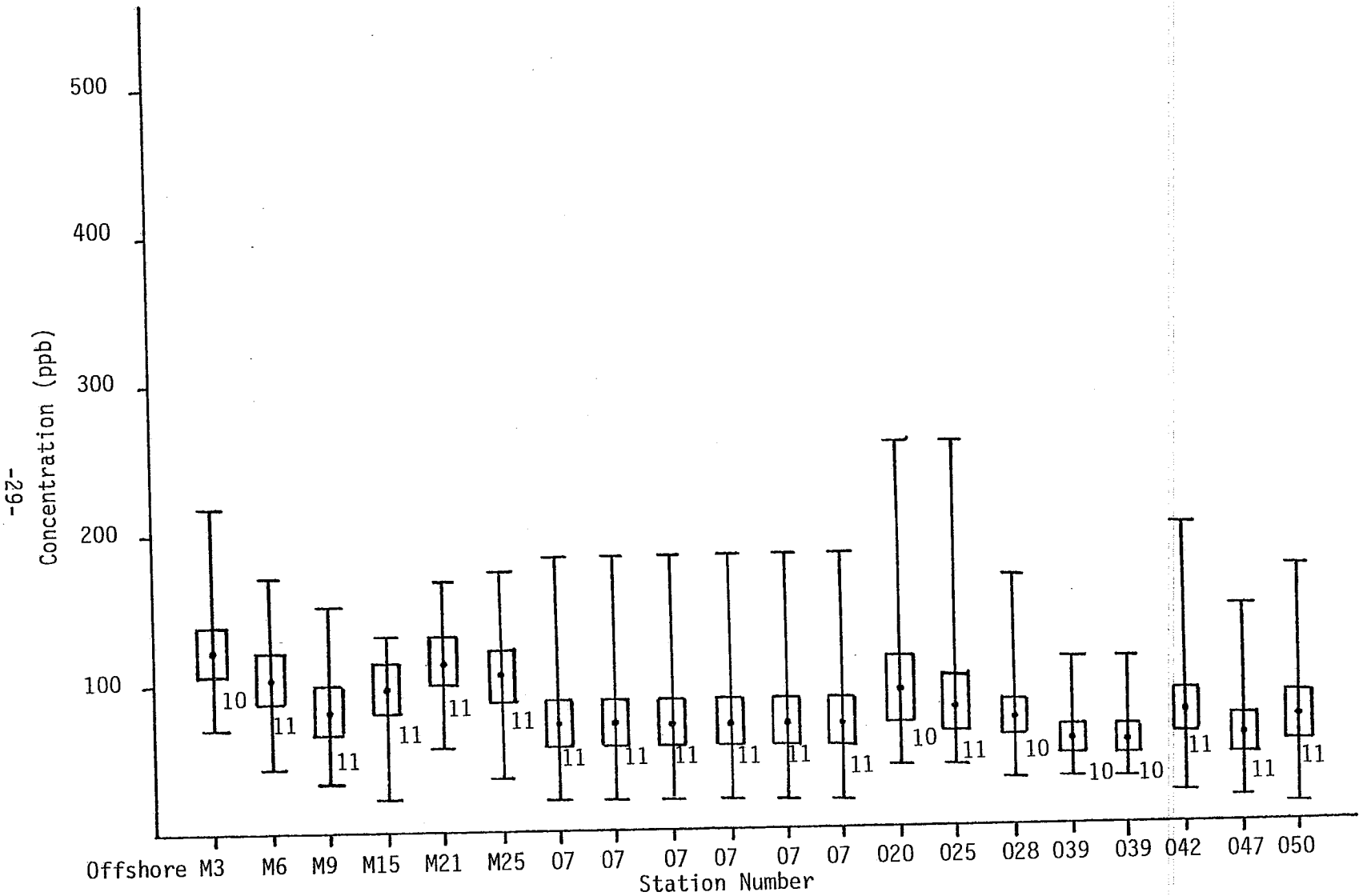


Figure 14. Annual Average Concentrations of Total Phosphorus at Offshore Stations in 1978.

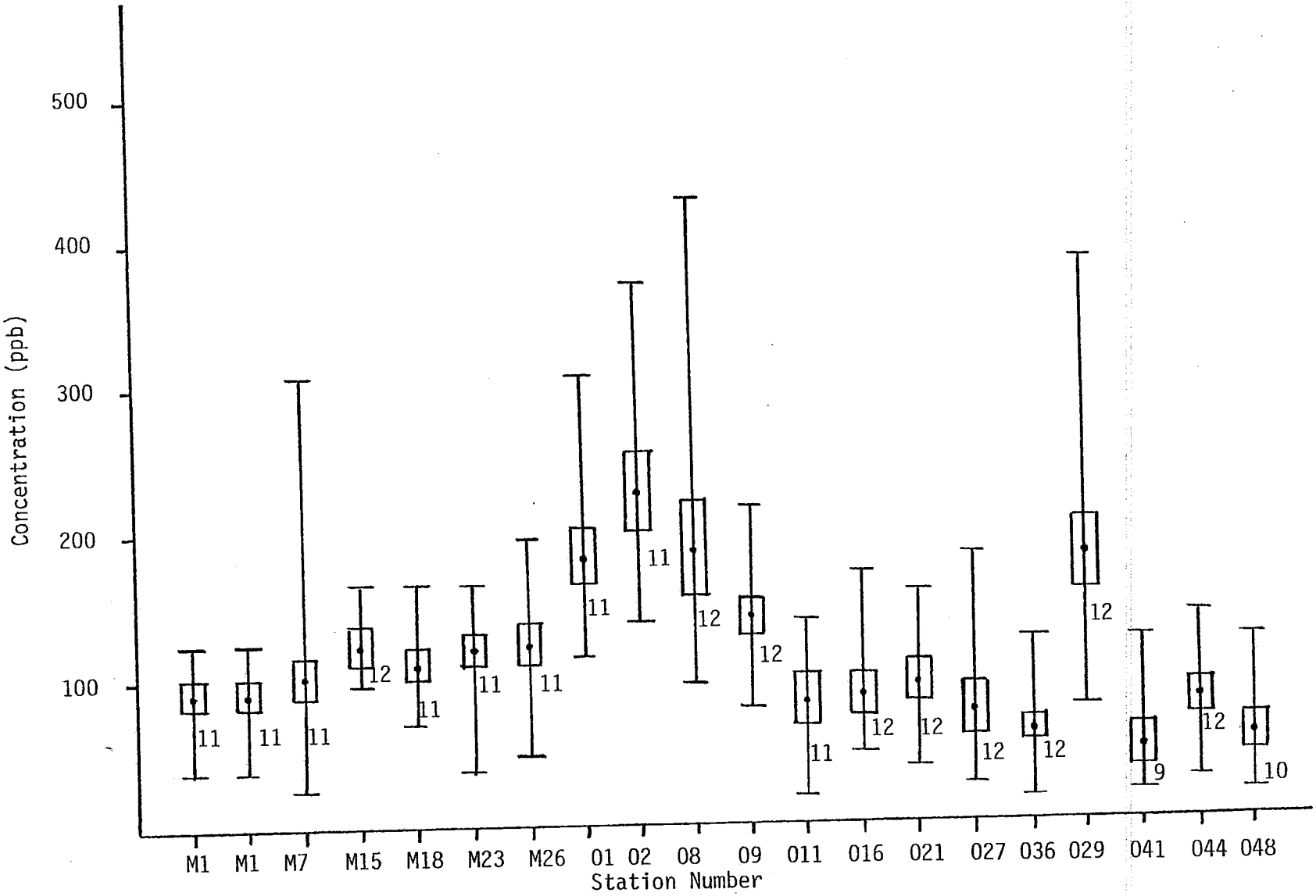


Figure 15. Annual Average Concentrations of Total Phosphorus at Inshore Stations in 1979.

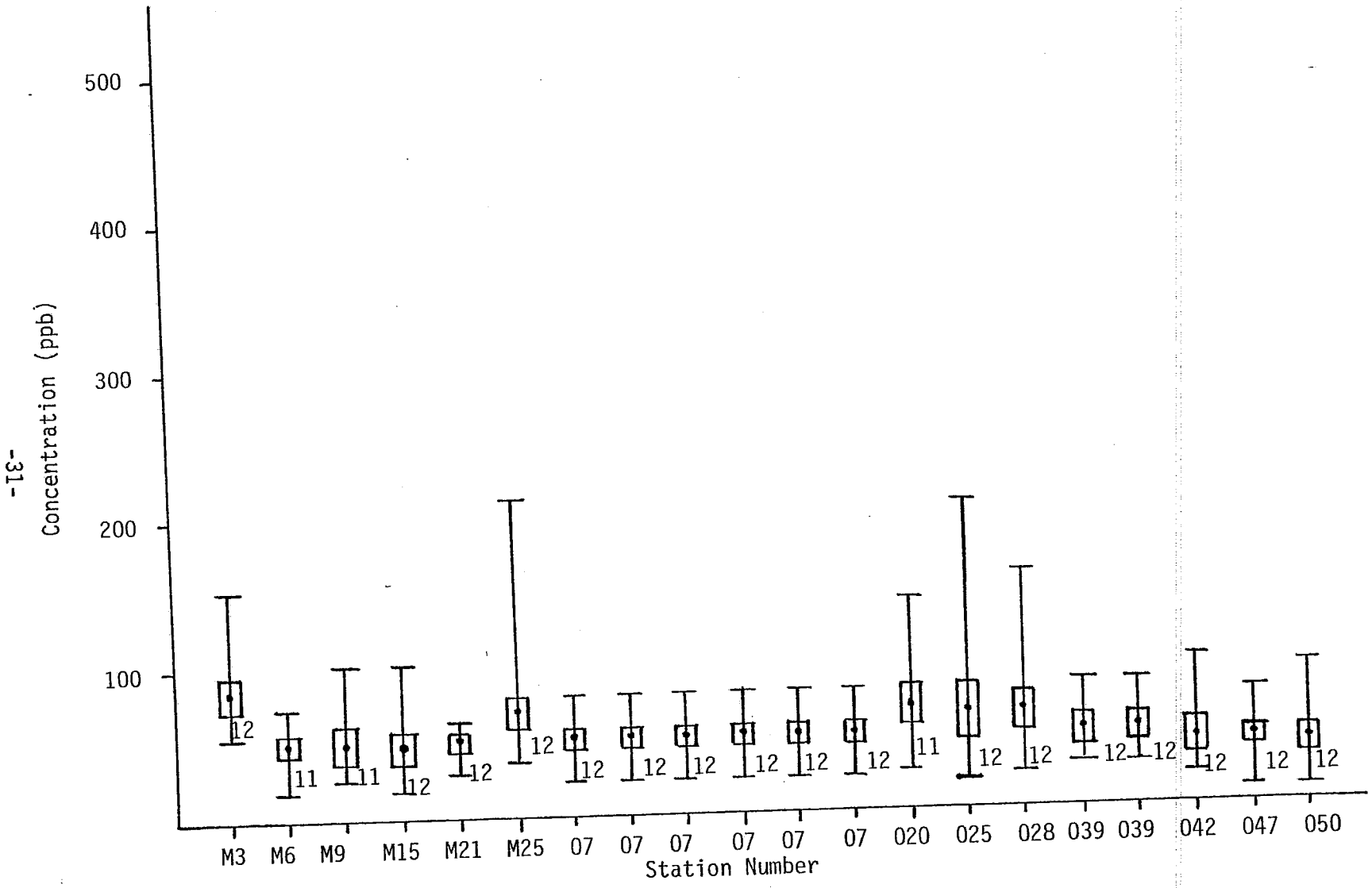


Figure 16. Annual Average Concentrations of Total Phosphorus at Offshore Stations in 1979.

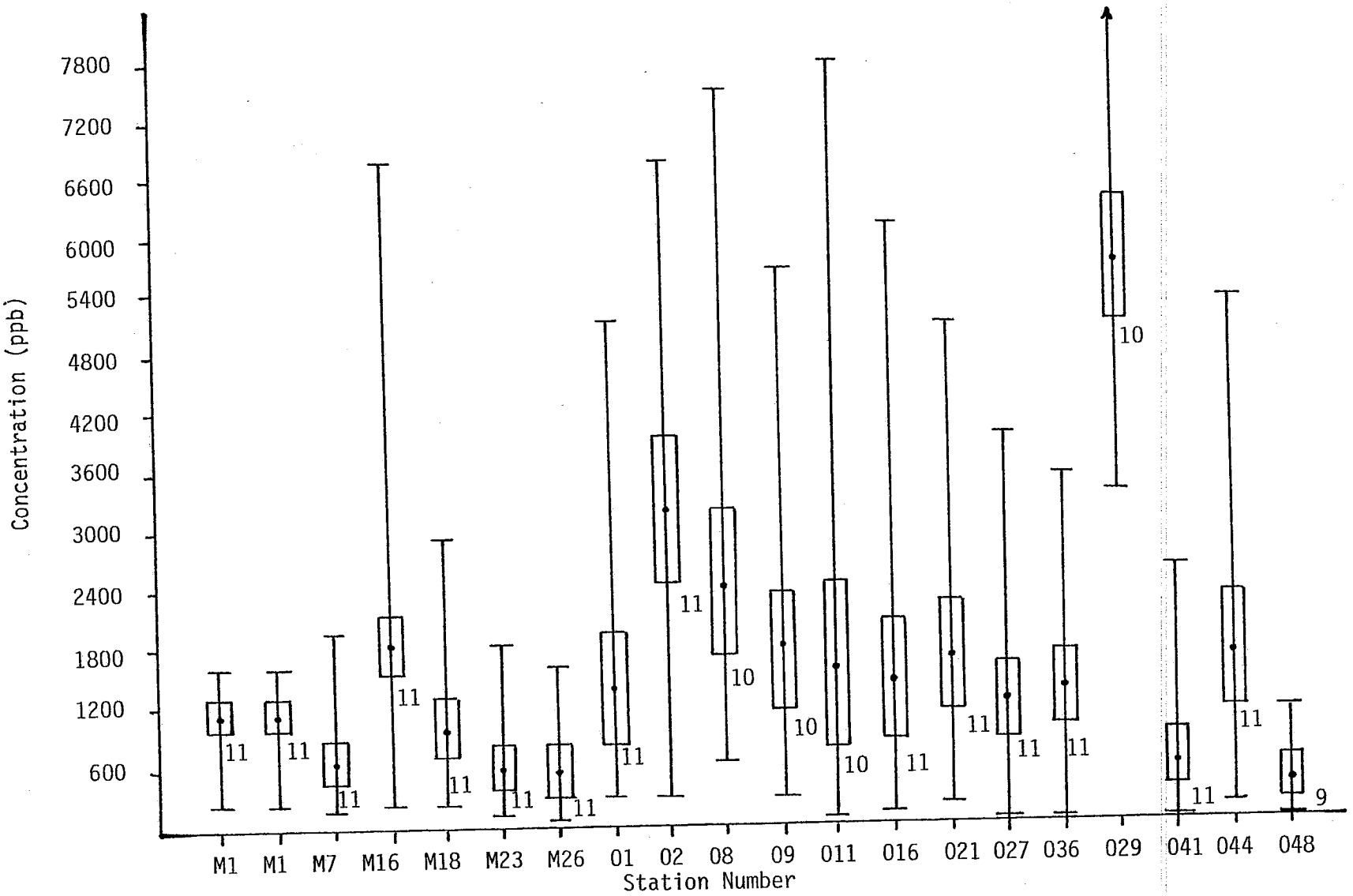


Figure 17. Annual Average Concentrations of Soluble Reactive Silica at Inshore Stations in 1978.

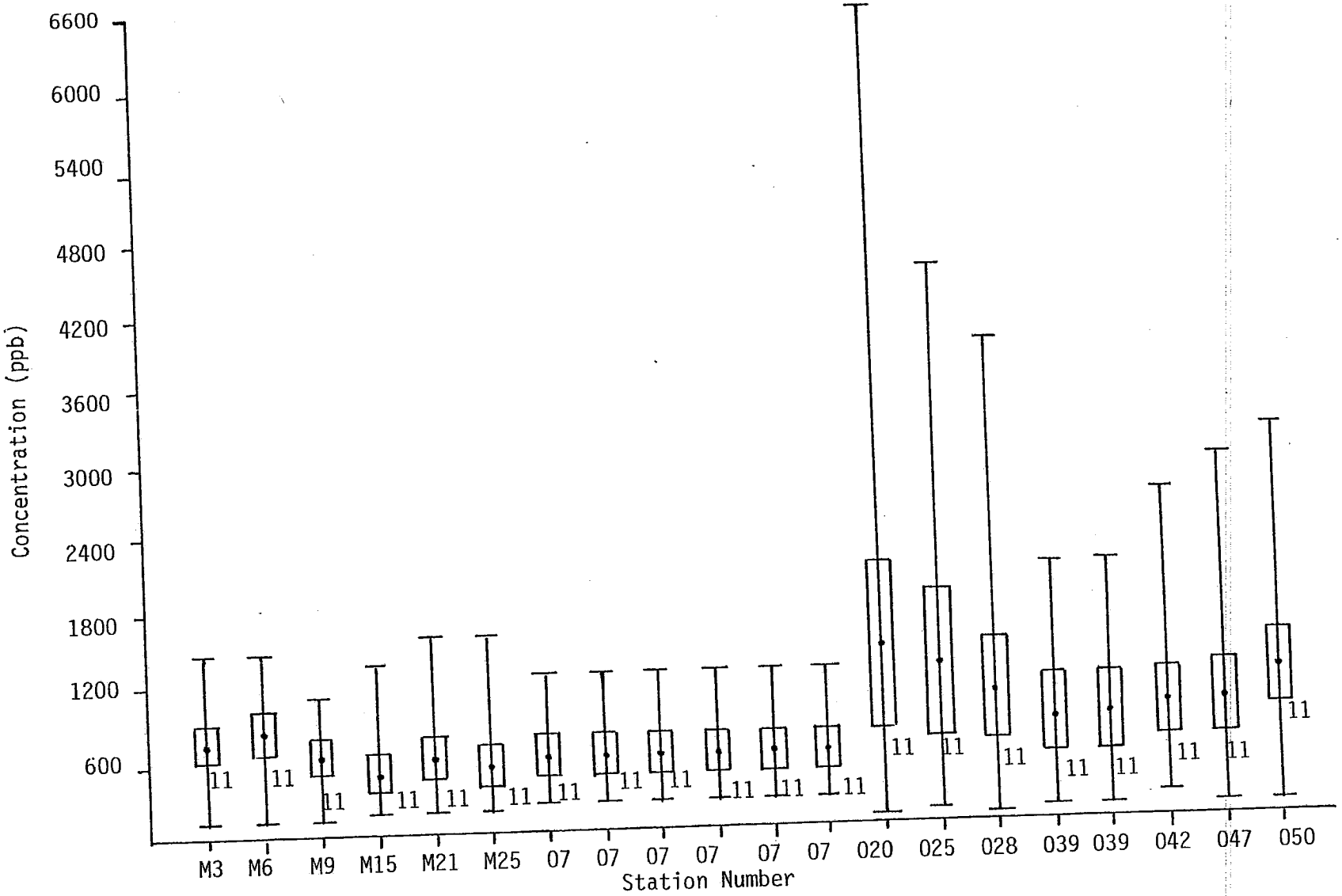


Figure 18. Annual Average Concentrations of Soluble Reactive Silica at Offshore Stations in 1978.

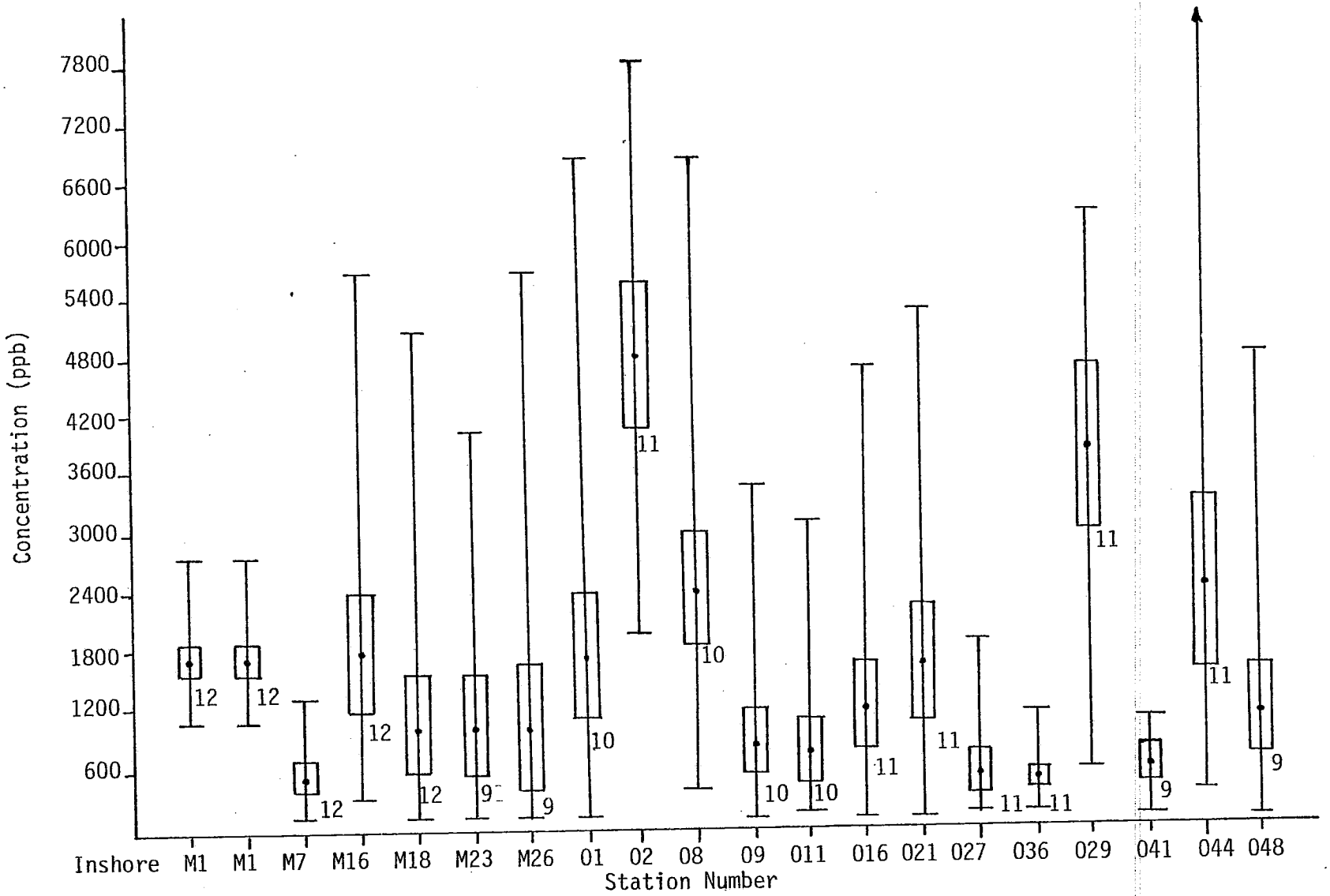


Figure 19. Annual Average Concentrations of Soluble Reactive Silica at Inshore Stations in 1979.

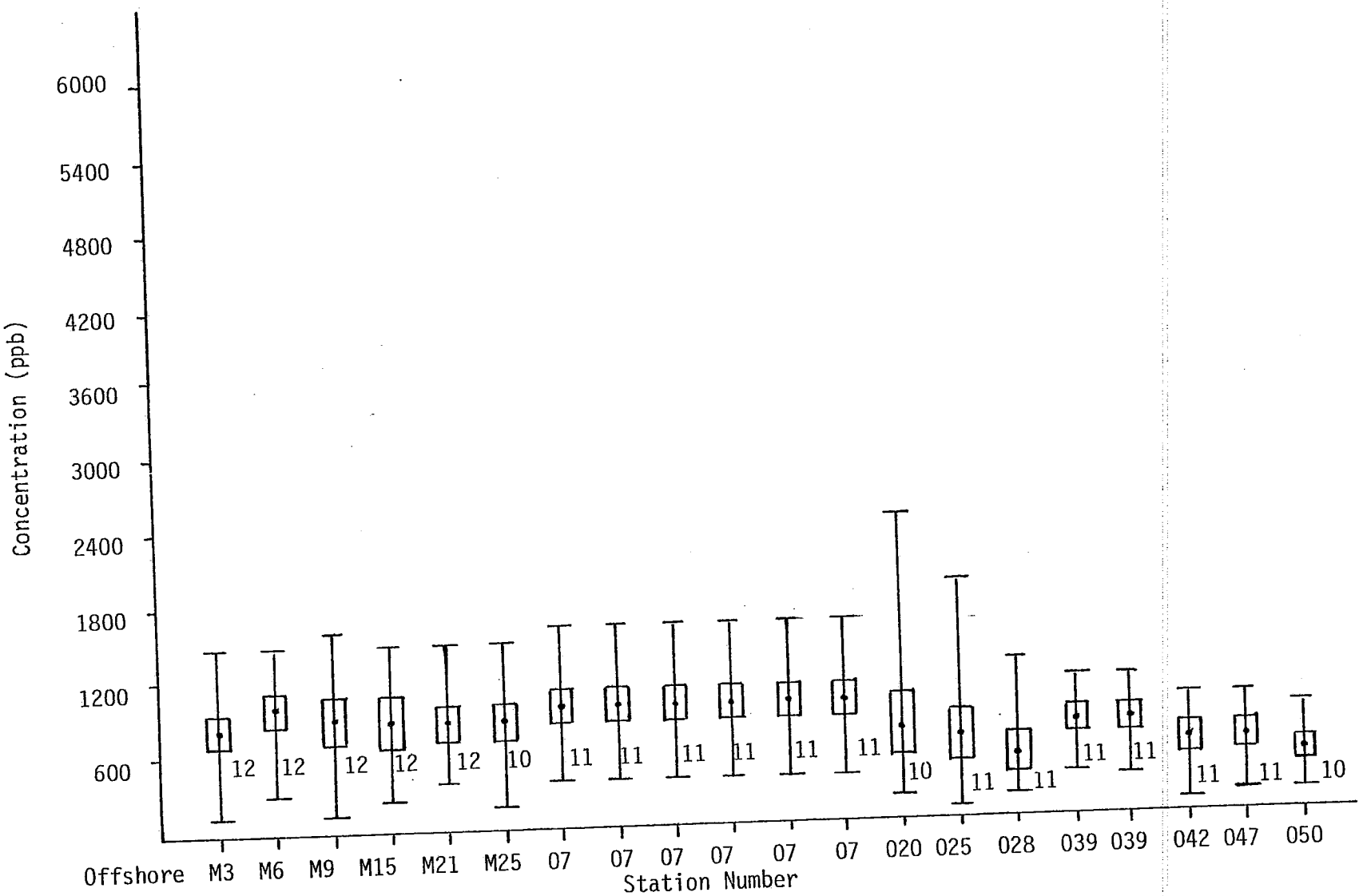


Figure 20. Annual Average Concentrations of Soluble Reactive Silica at Offshore Stations in 1979.

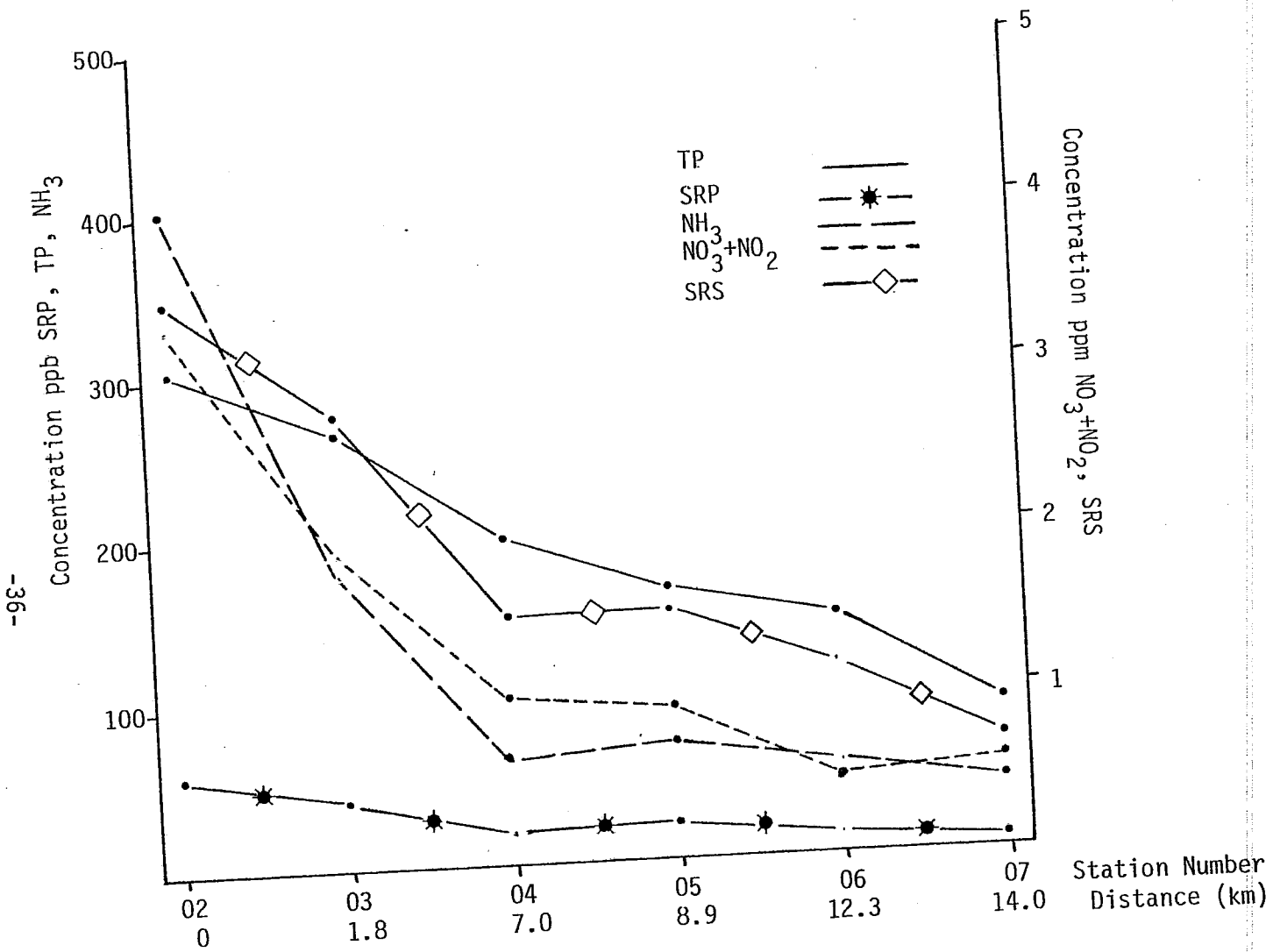


Figure 21. Annual Average Concentrations of Total Phosphorus, Soluble Reactive Phosphorus, Ammonia, Nitrate plus Nitrite, and Soluble Reactive Silica for the Maumee Bay Transect, 1978.

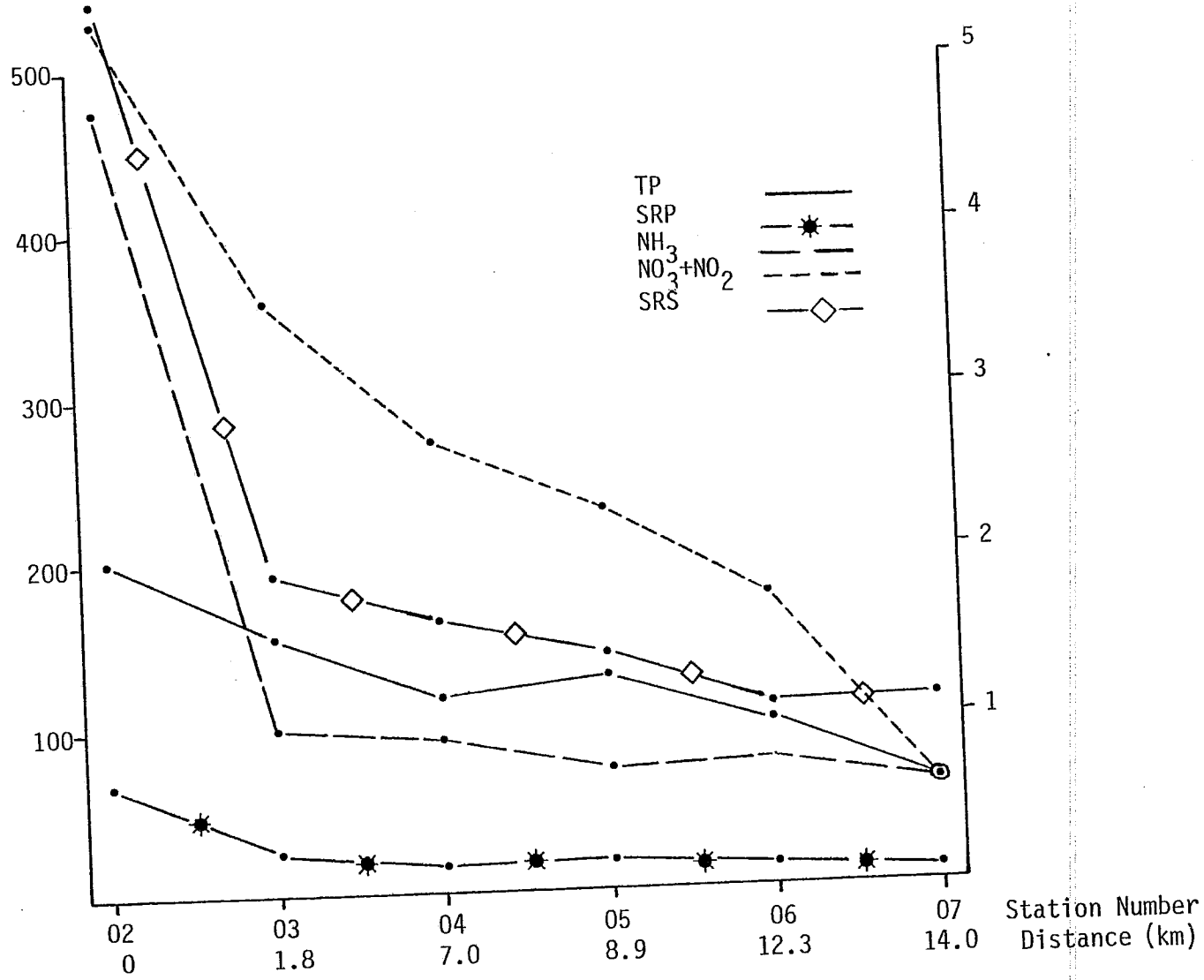


Figure 22. Annual Average Concentrations of Total Phosphorus, Soluble Reactive Phosphorus, Ammonia, Nitrate plus Nitrite, and Soluble Reactive Silica for the Maumee Bay Transect, 1979.

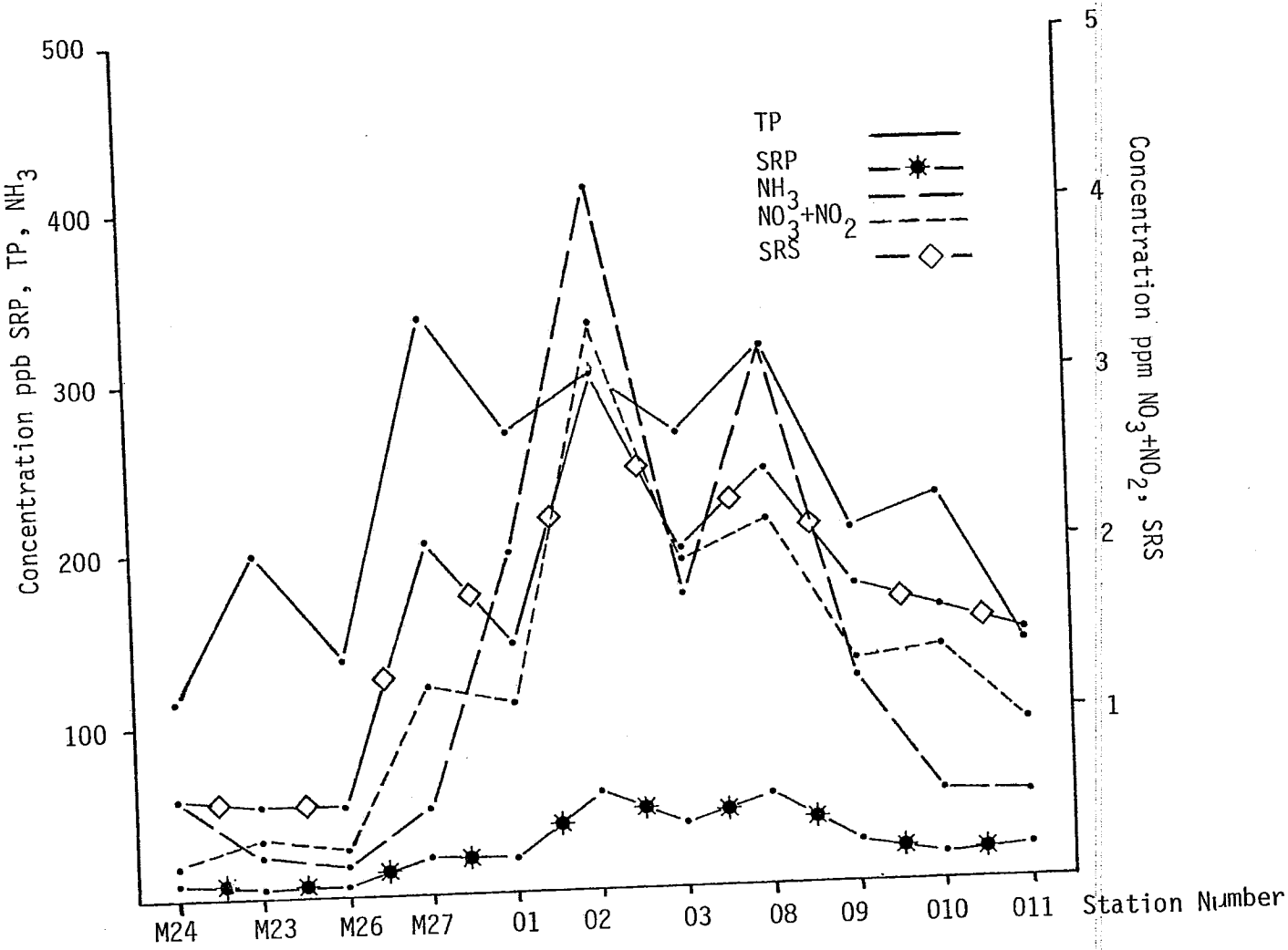


Figure 23. Annual Average Concentrations for Total Phosphorus, Soluble Reactive Phosphorus, Ammonia, Nitrate plus Nitrite and Soluble Reactive Silica for Stations Along the Maumee Bay Shoreline, 1978.

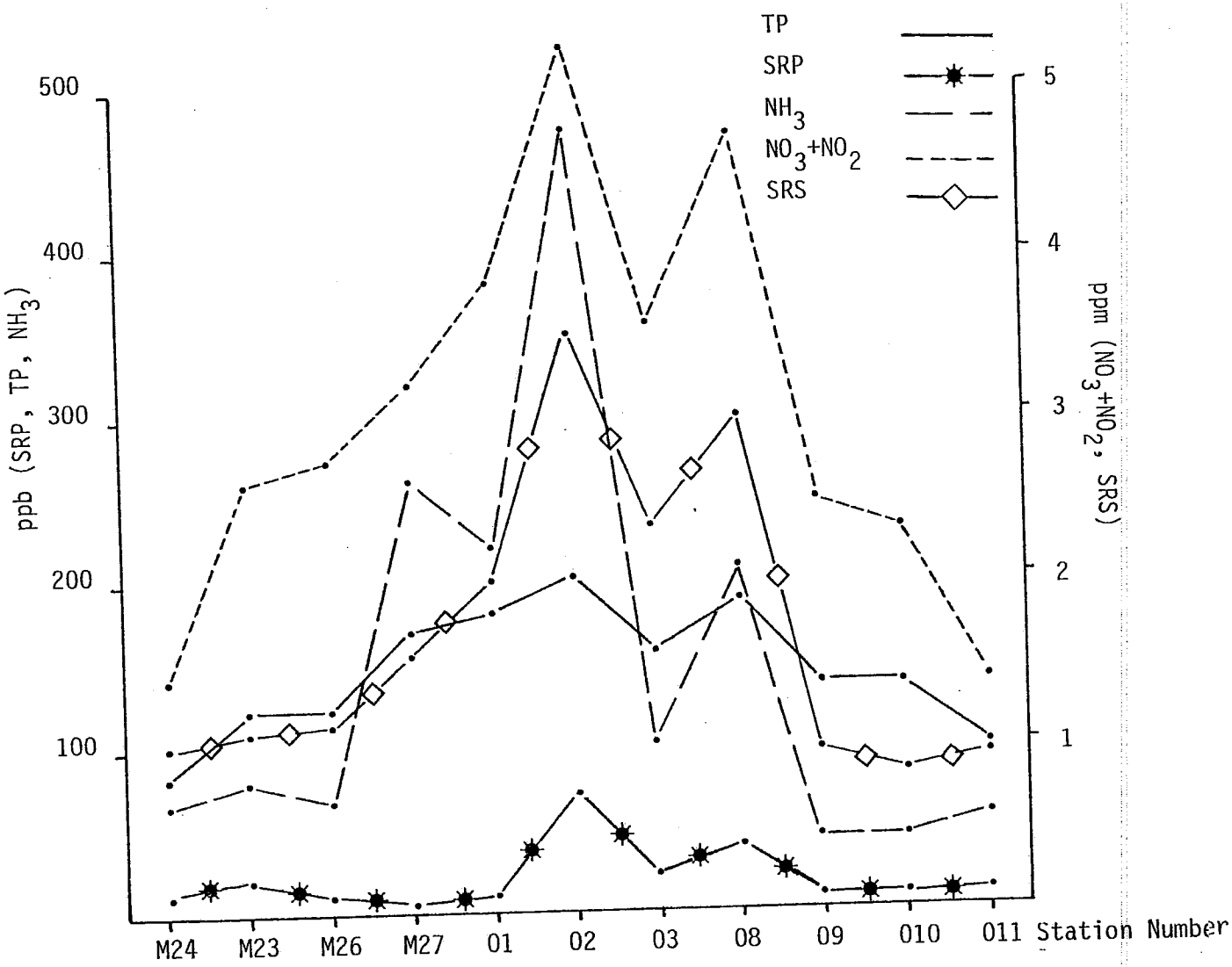


Figure 24. Annual Average Concentrations for Total Phosphorus, Soluble Reactive Phosphorus, Ammonia, Nitrate plus Nitrite, and Soluble Reactive Silica for Stations Along the Maumee Bay Shoreline, 1979.

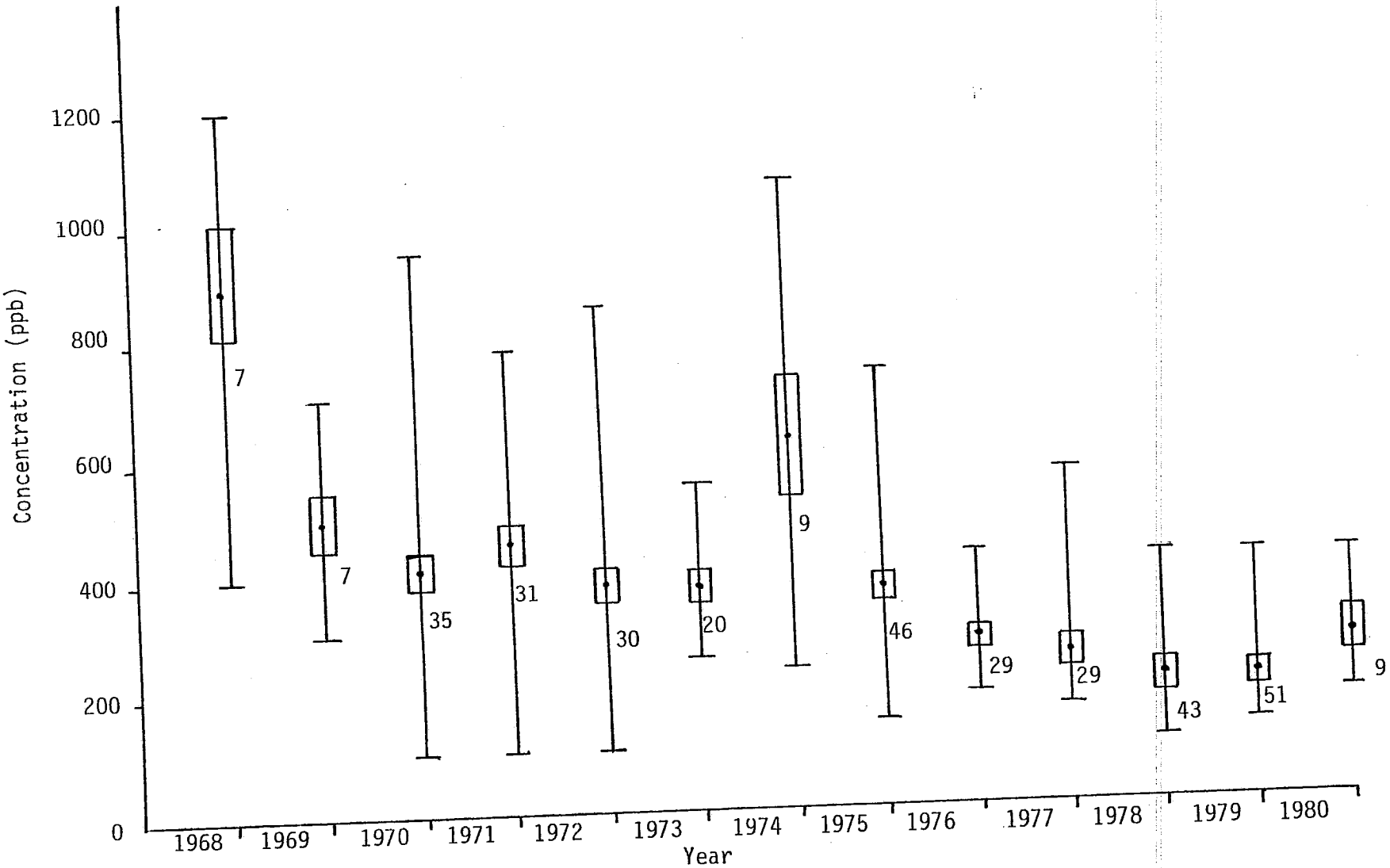


Figure 25. Historical Trends for Total Phosphorus, Maumee Bay Station 02, 1968-1979.

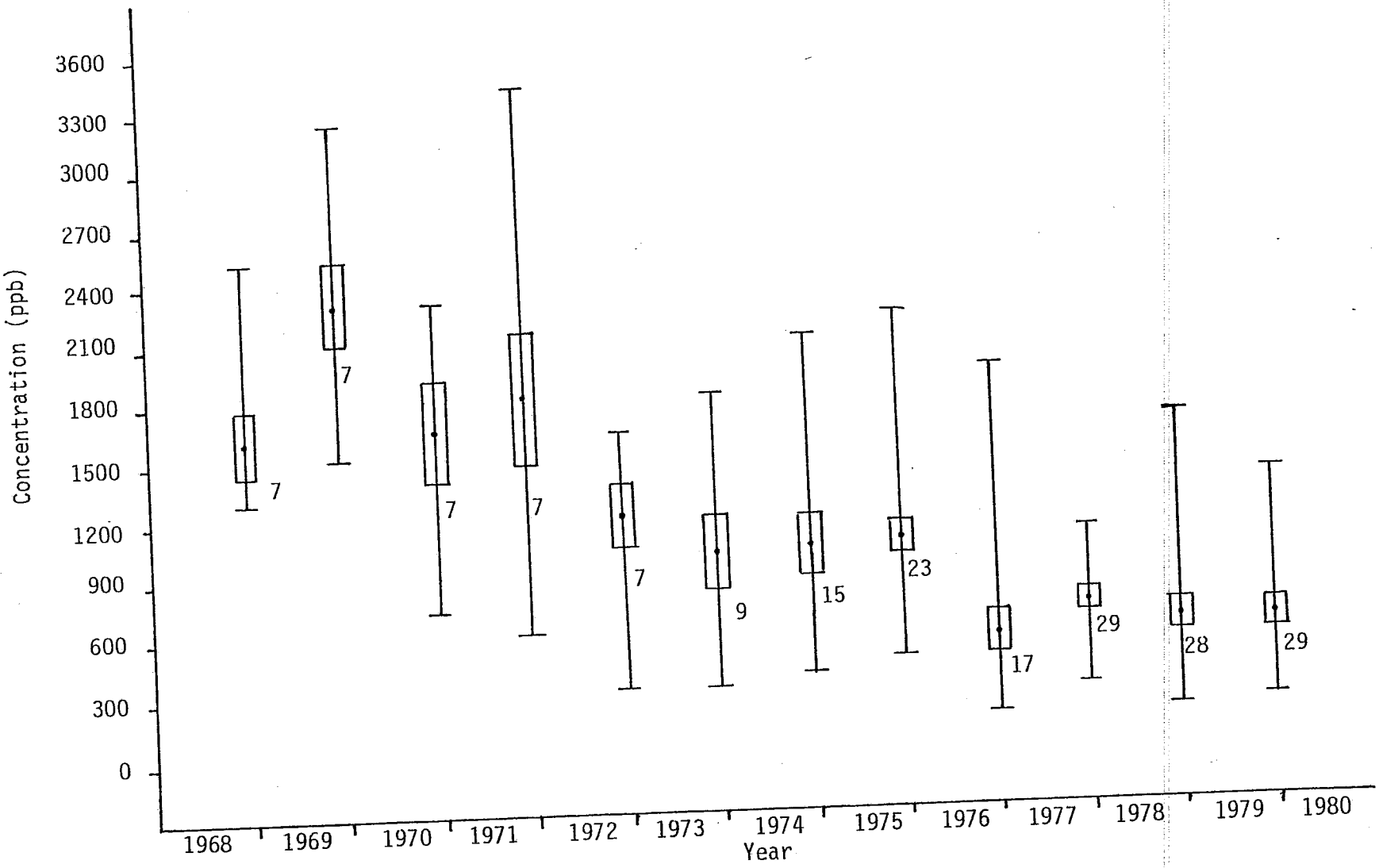


Figure 26. Historical Trends for Ammonia, Maumee Bay Station 02, 1968-1979.

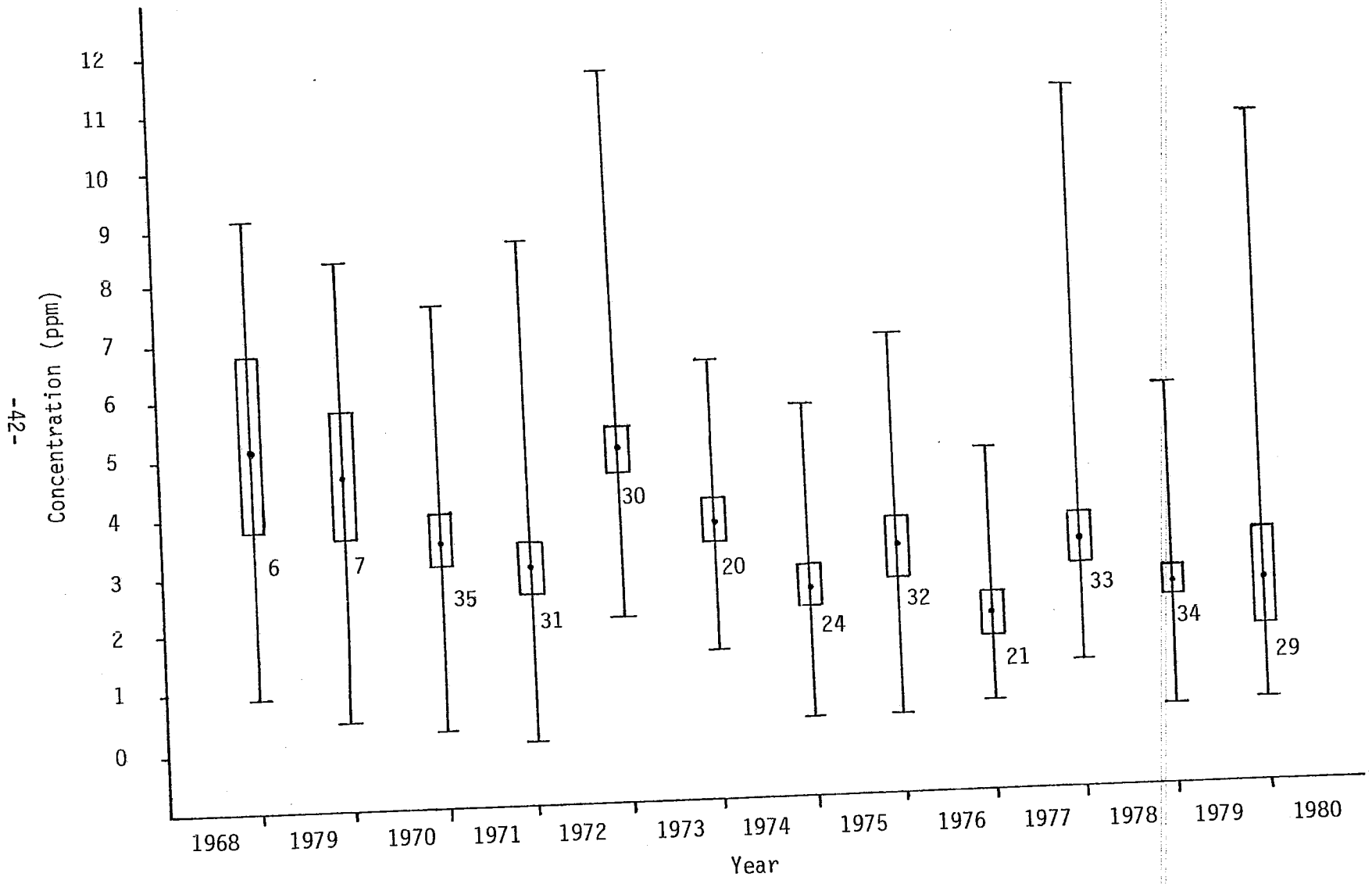
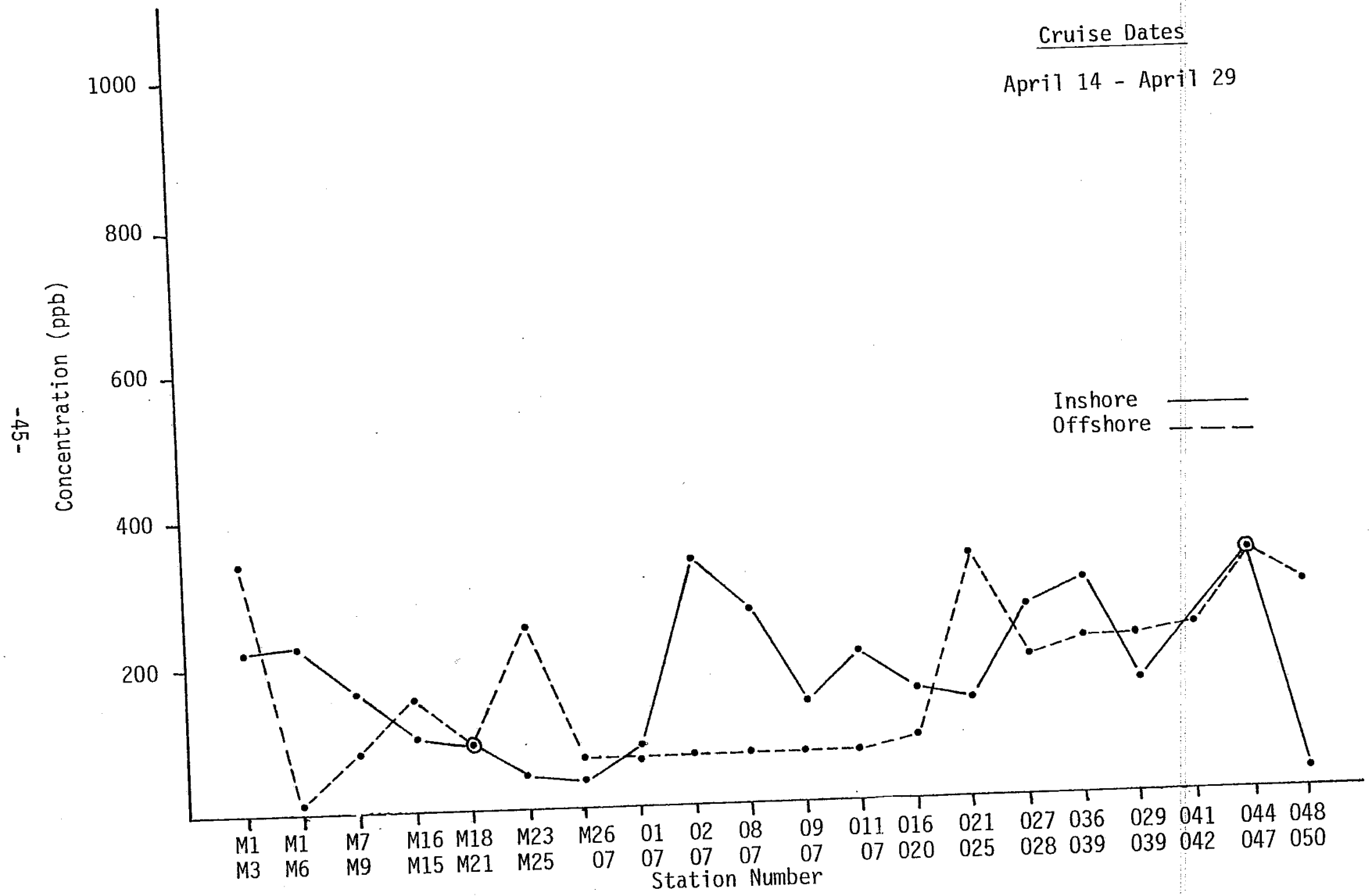


Figure 27. Historical Trends for Nitrate-Nitrite, Maumee Bay Station 02, 1968-1979.

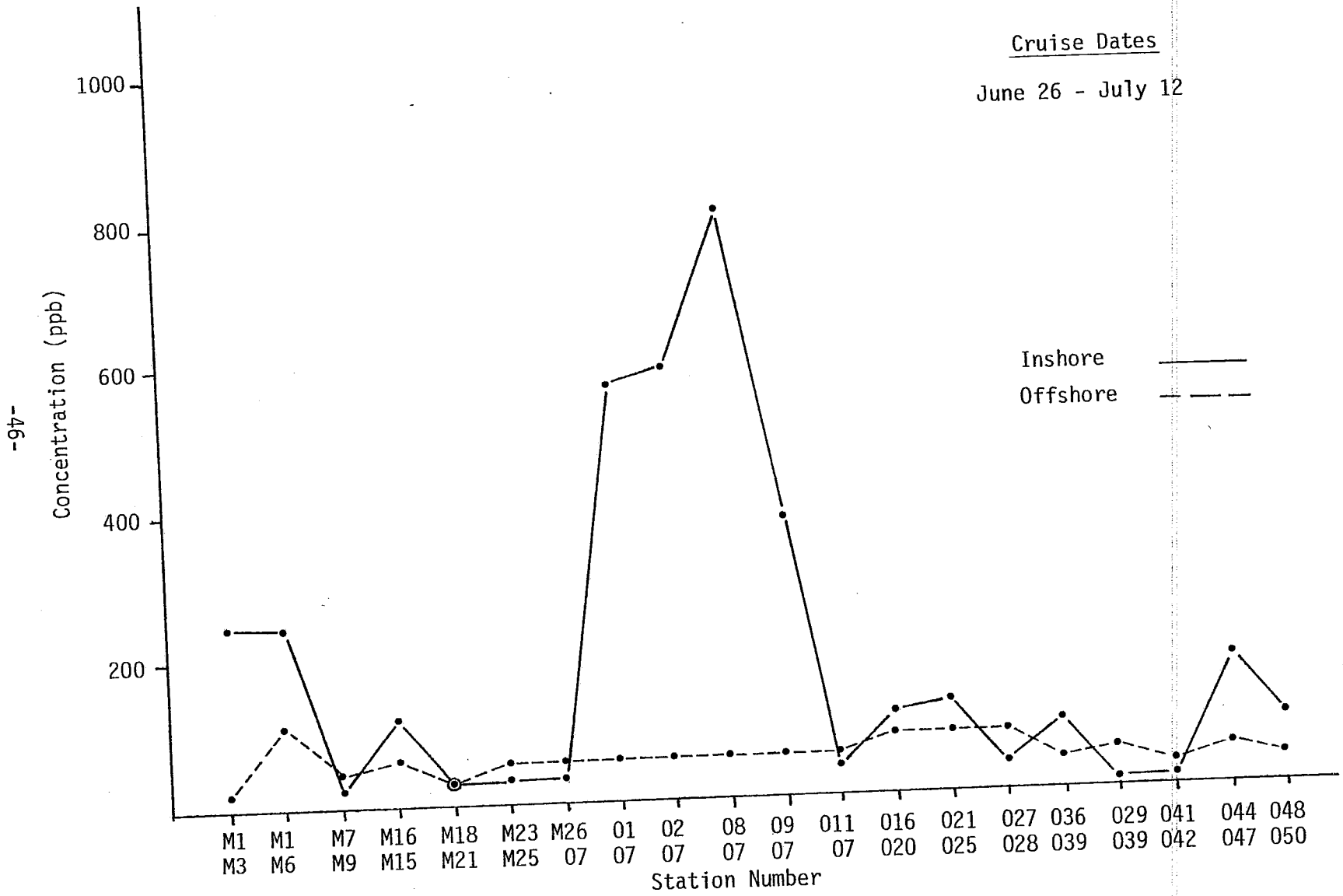
APPENDIX

APPENDIX A

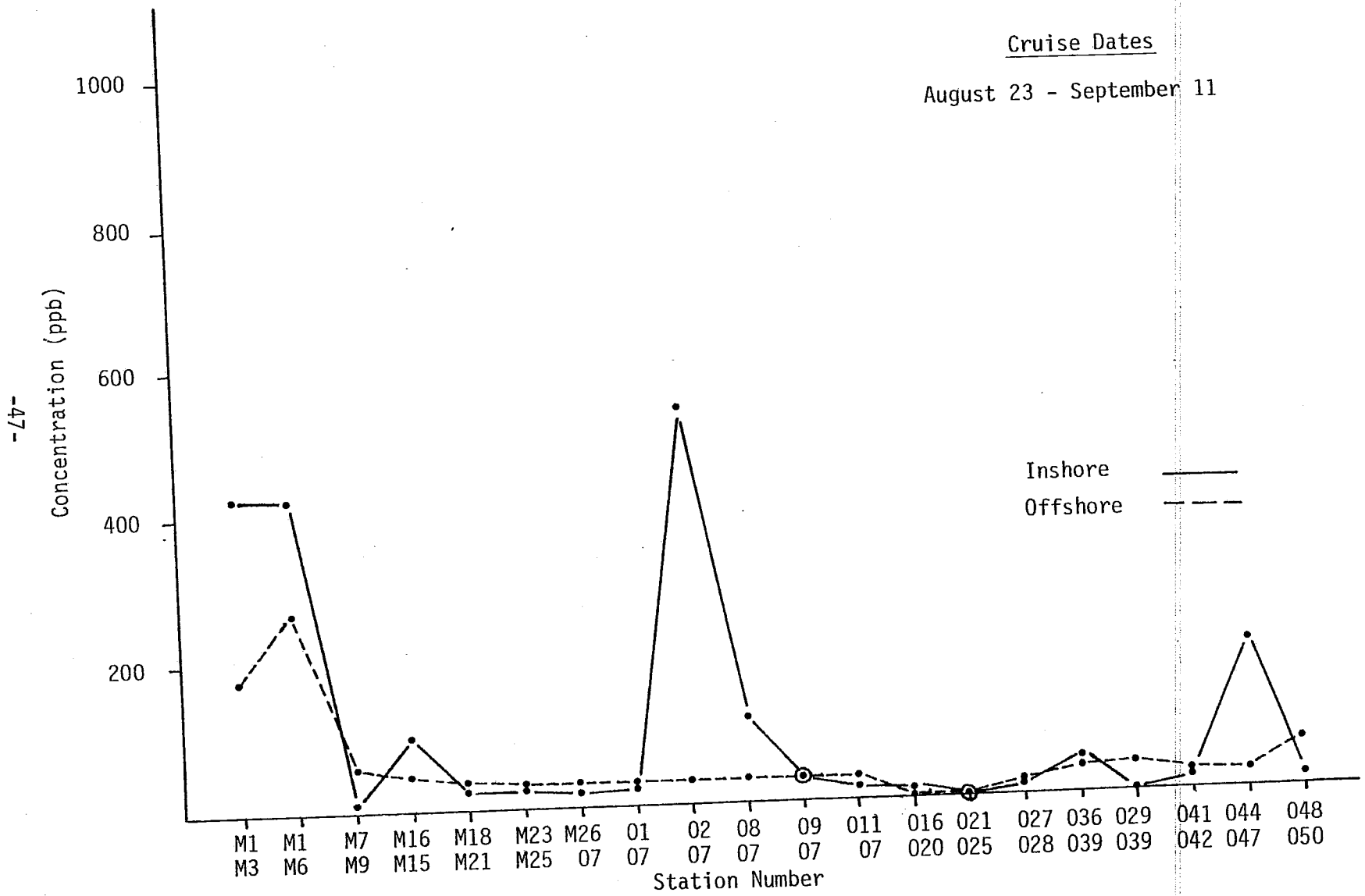
AMMONIA PLOTS



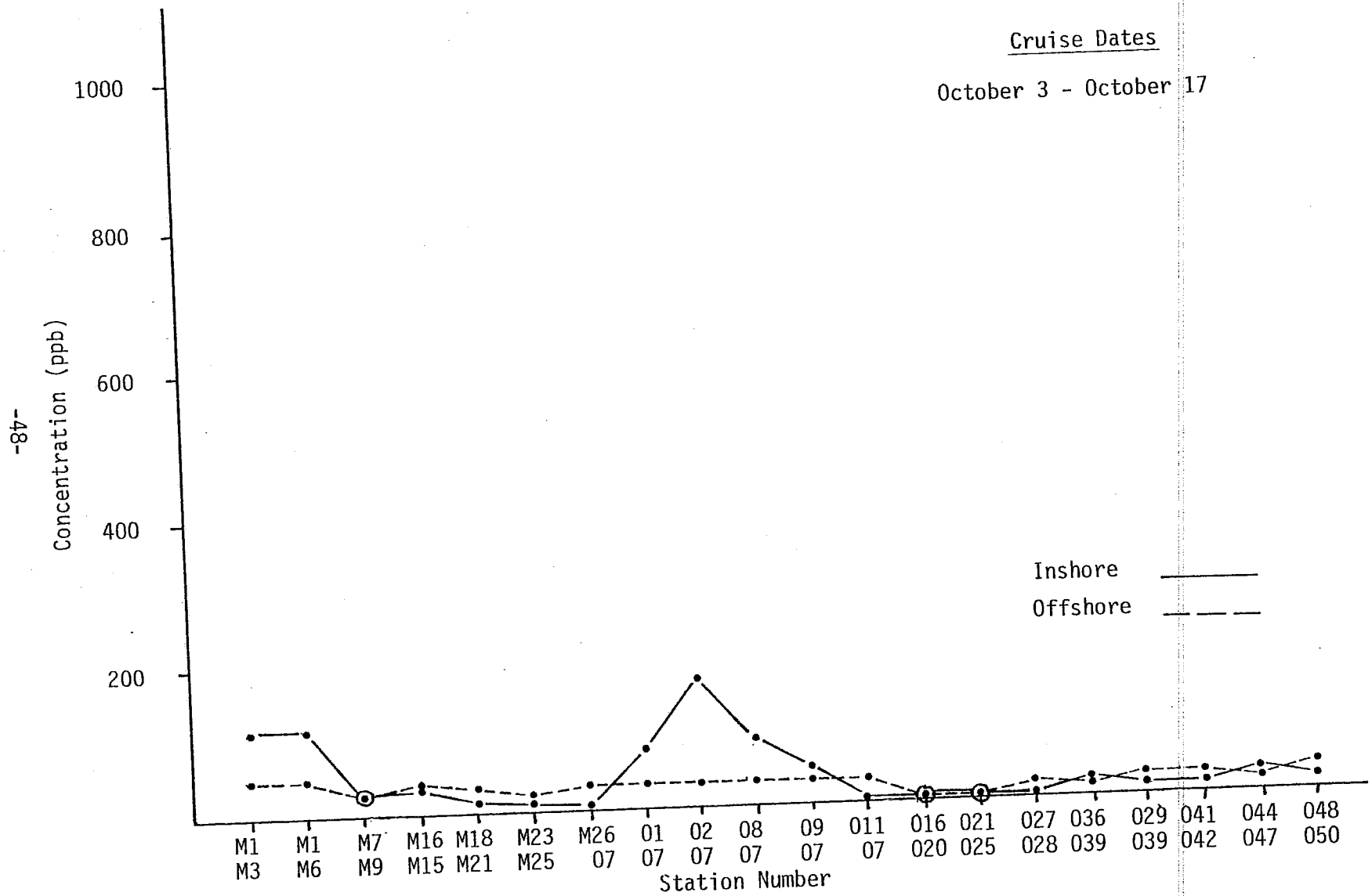
Ammonia Concentration at Inshore and Offshore Stations for Cruise 1 of 1978.



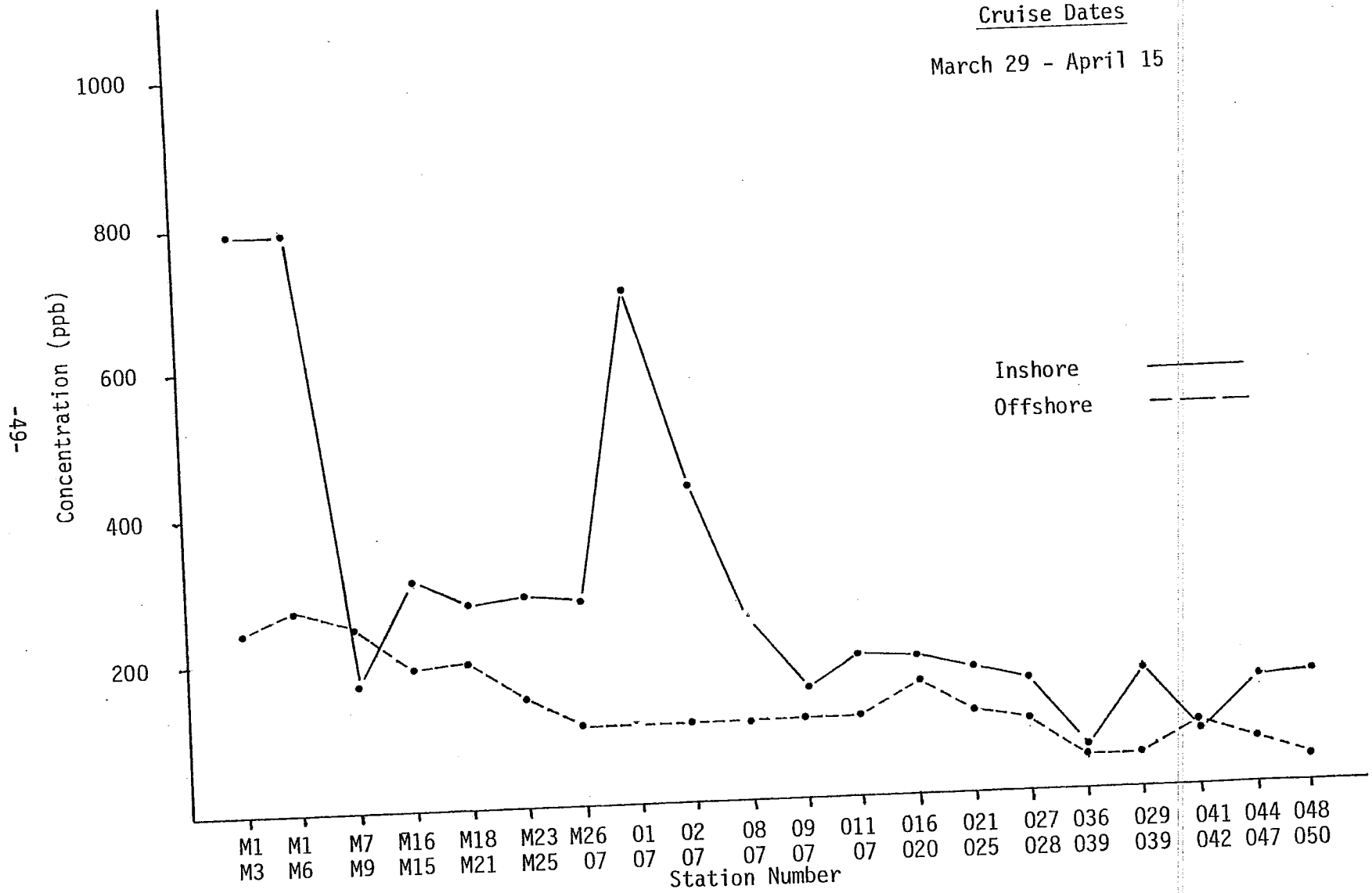
Ammonia Concentration at Inshore and Offshore Stations for Cruise 2 of 1978.



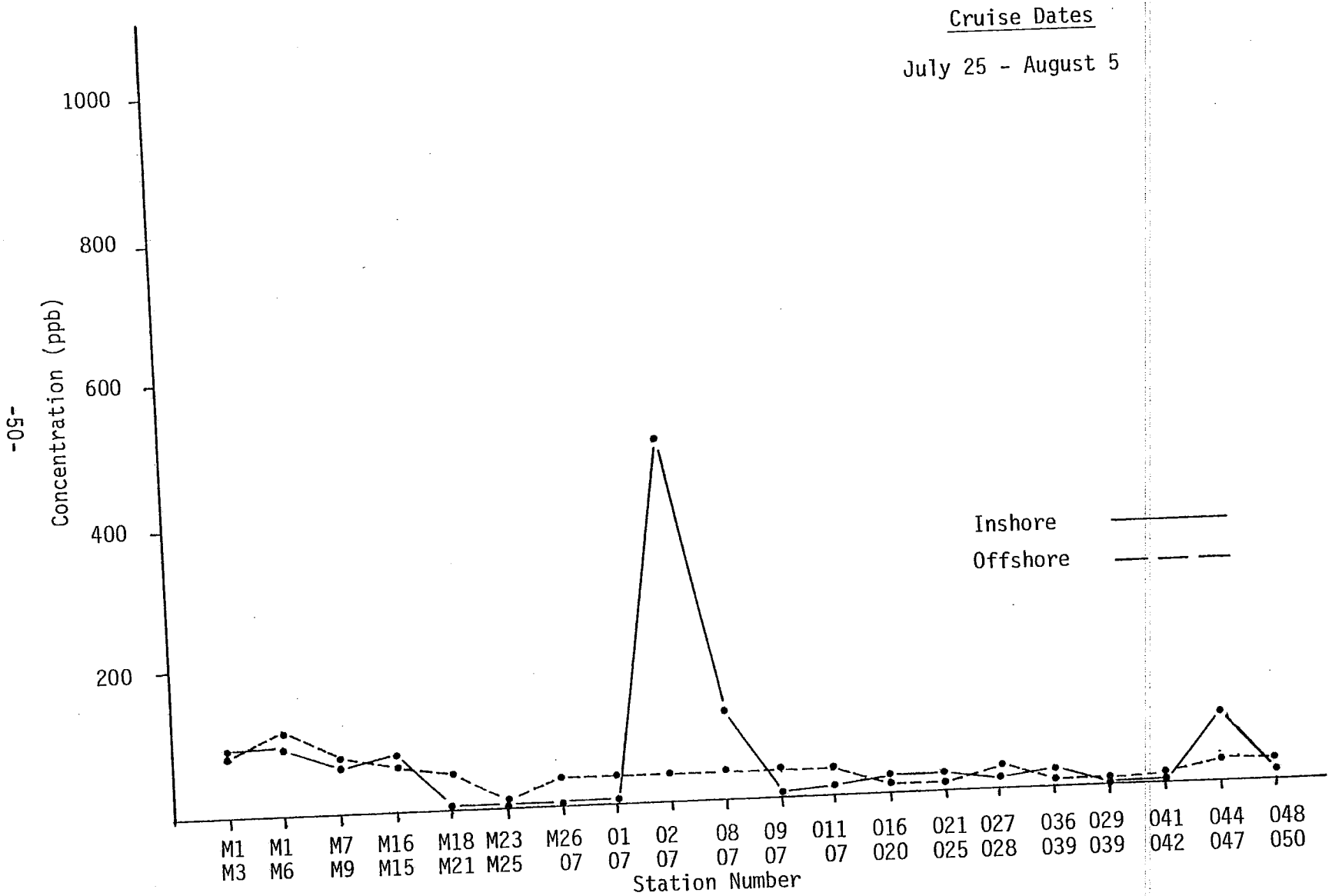
Ammonia Concentration at Inshore and Offshore Stations for Cruise 3 of 1978.



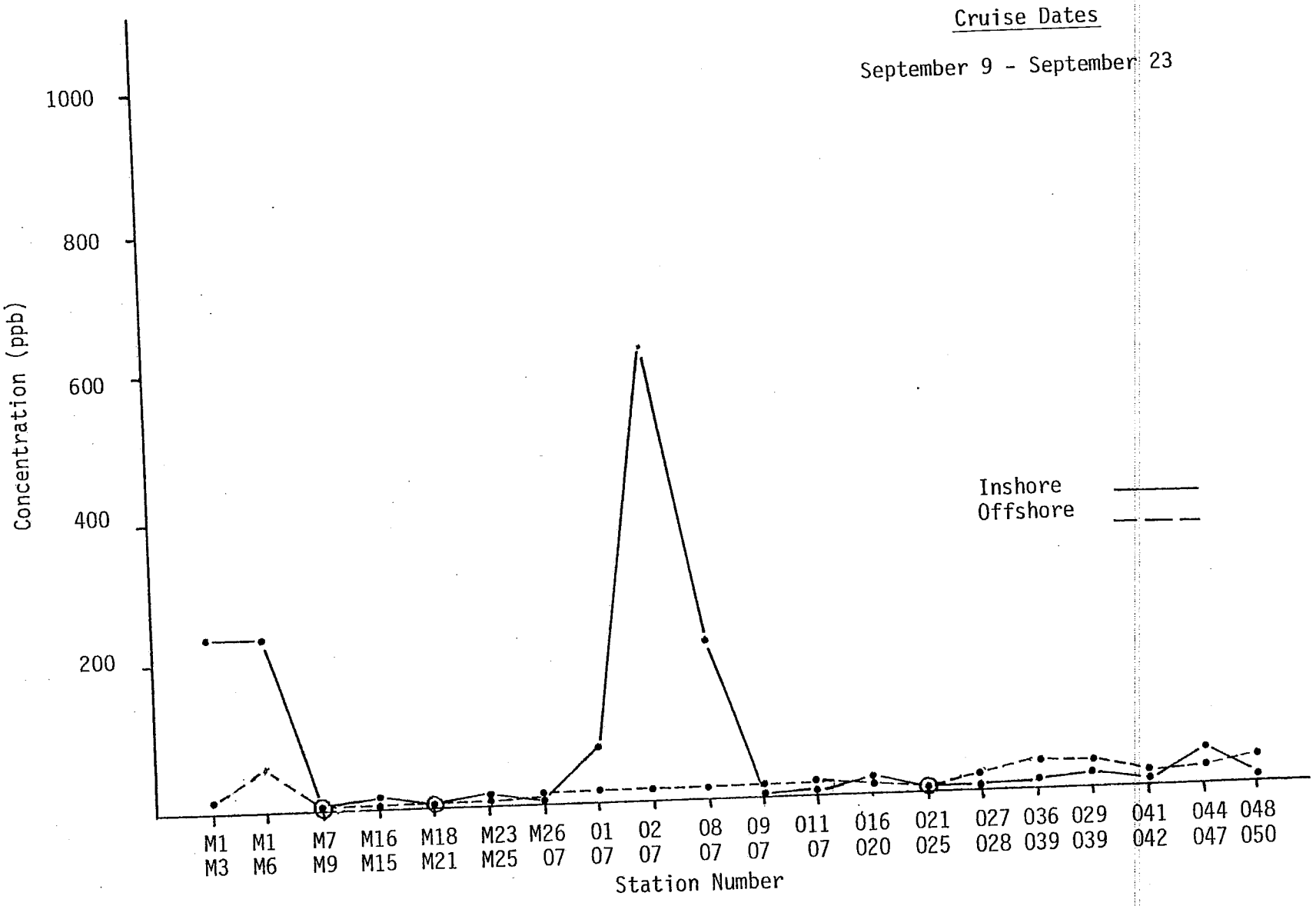
Ammonia Concentration at Inshore and Offshore Stations for Cruise 4 of 1978.



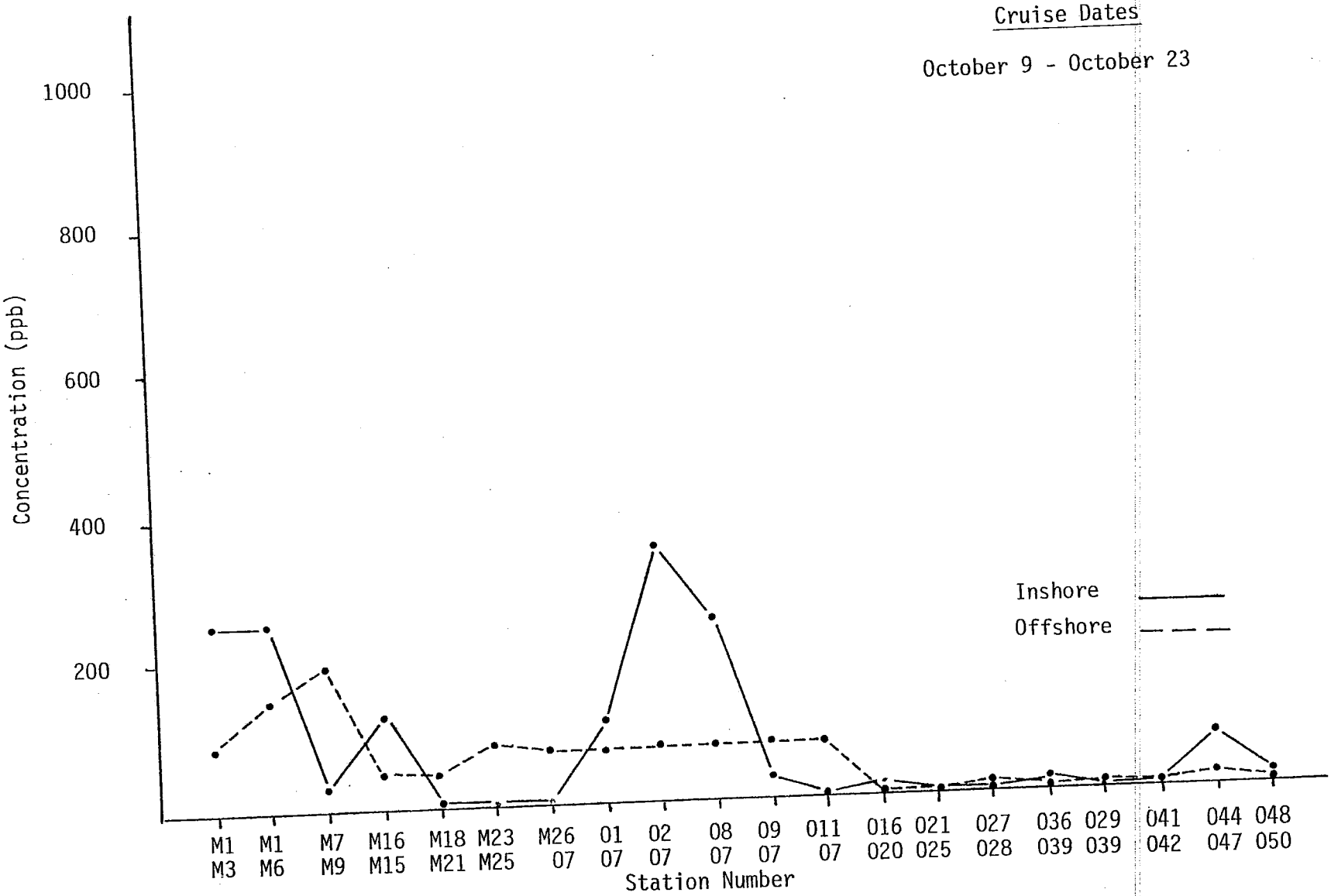
Ammonia Concentration at Inshore and Offshore Stations for Cruise 1 of 1979.



Ammonia Concentration at Inshore and Offshore Stations for Cruise 2 of 1979.



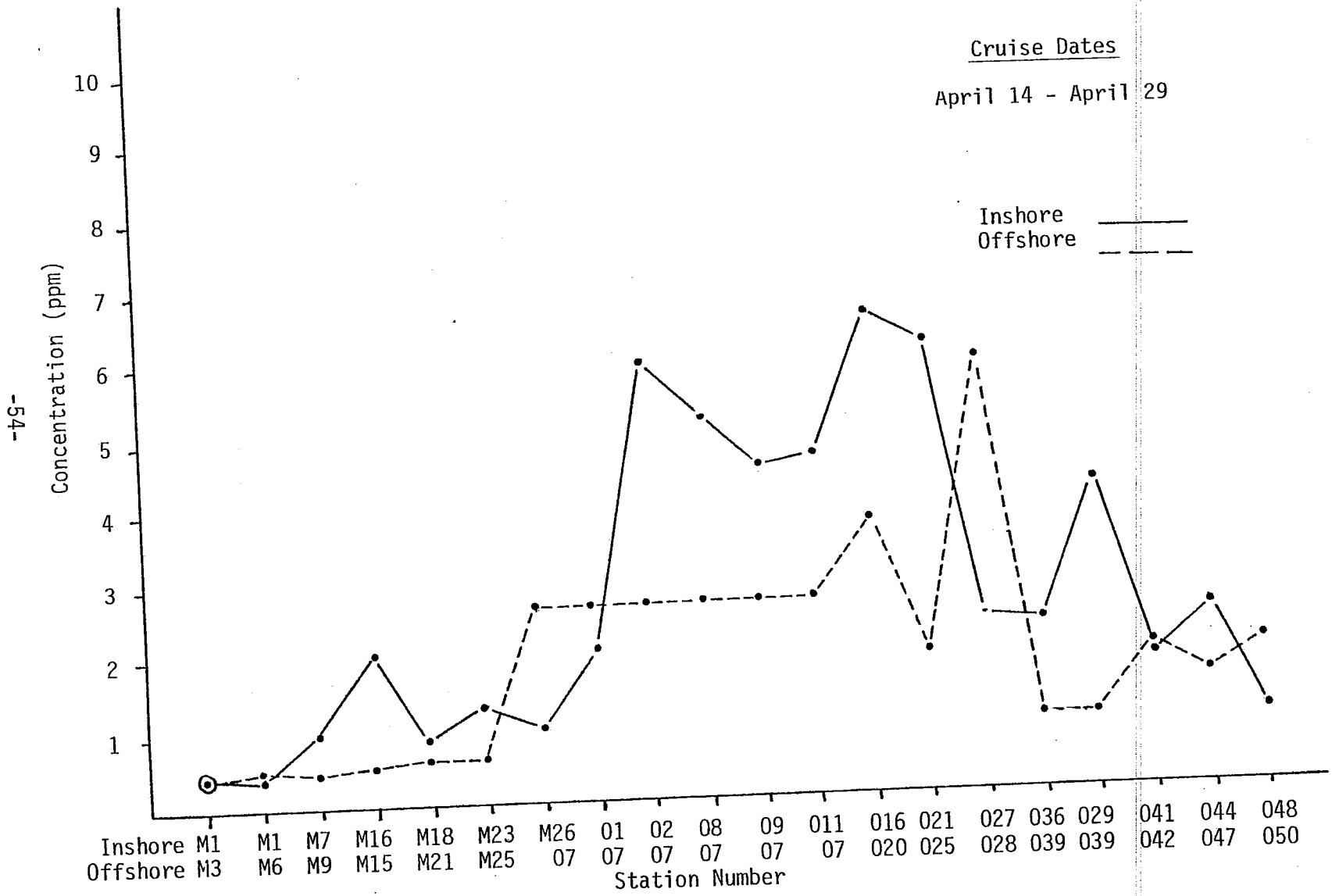
Ammonia Concentration at Inshore and Offshore Stations for Cruise 3 of 1979.



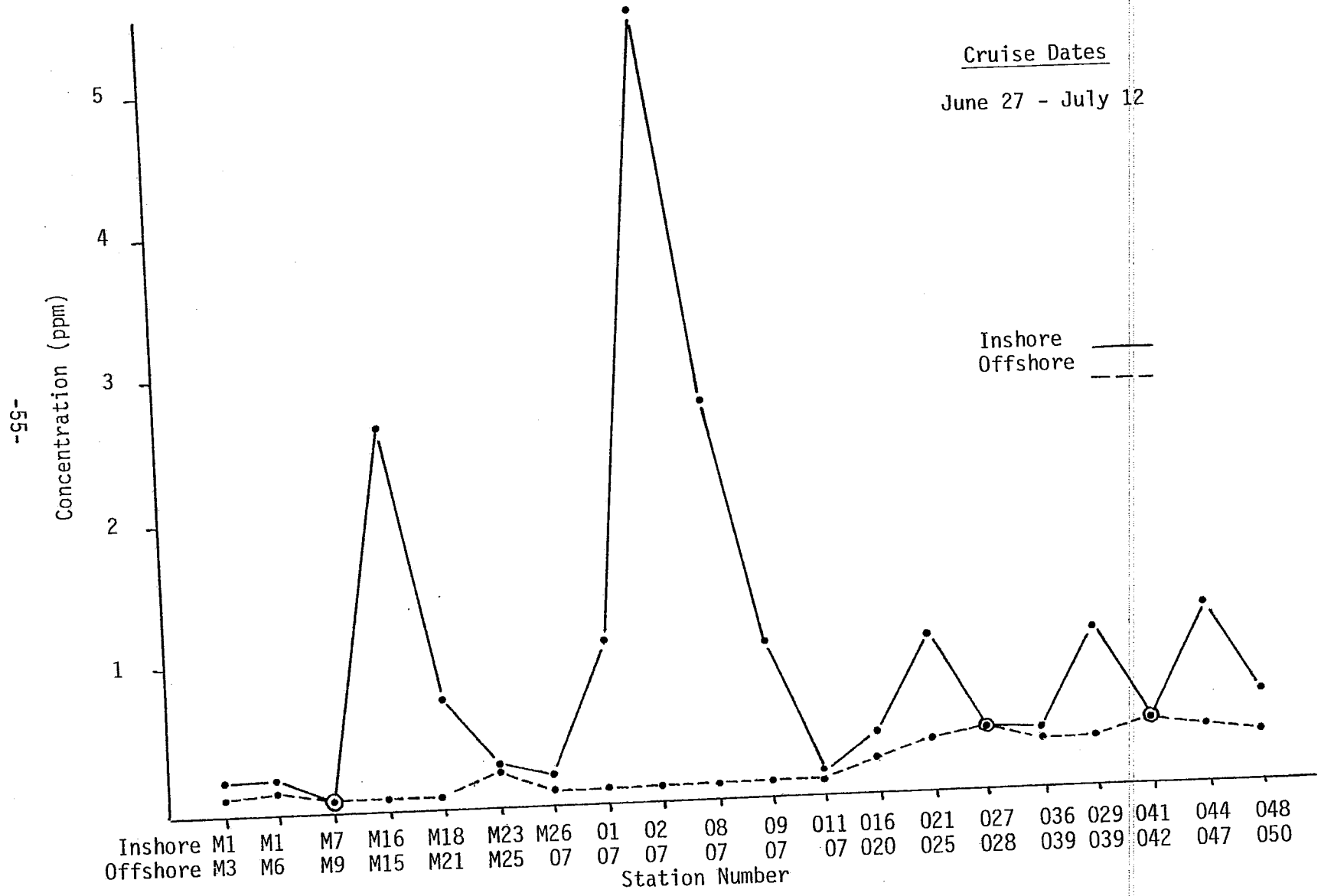
Ammonia Concentration at Inshore and Offshore Stations for Cruise 4 of 1979.

APPENDIX B

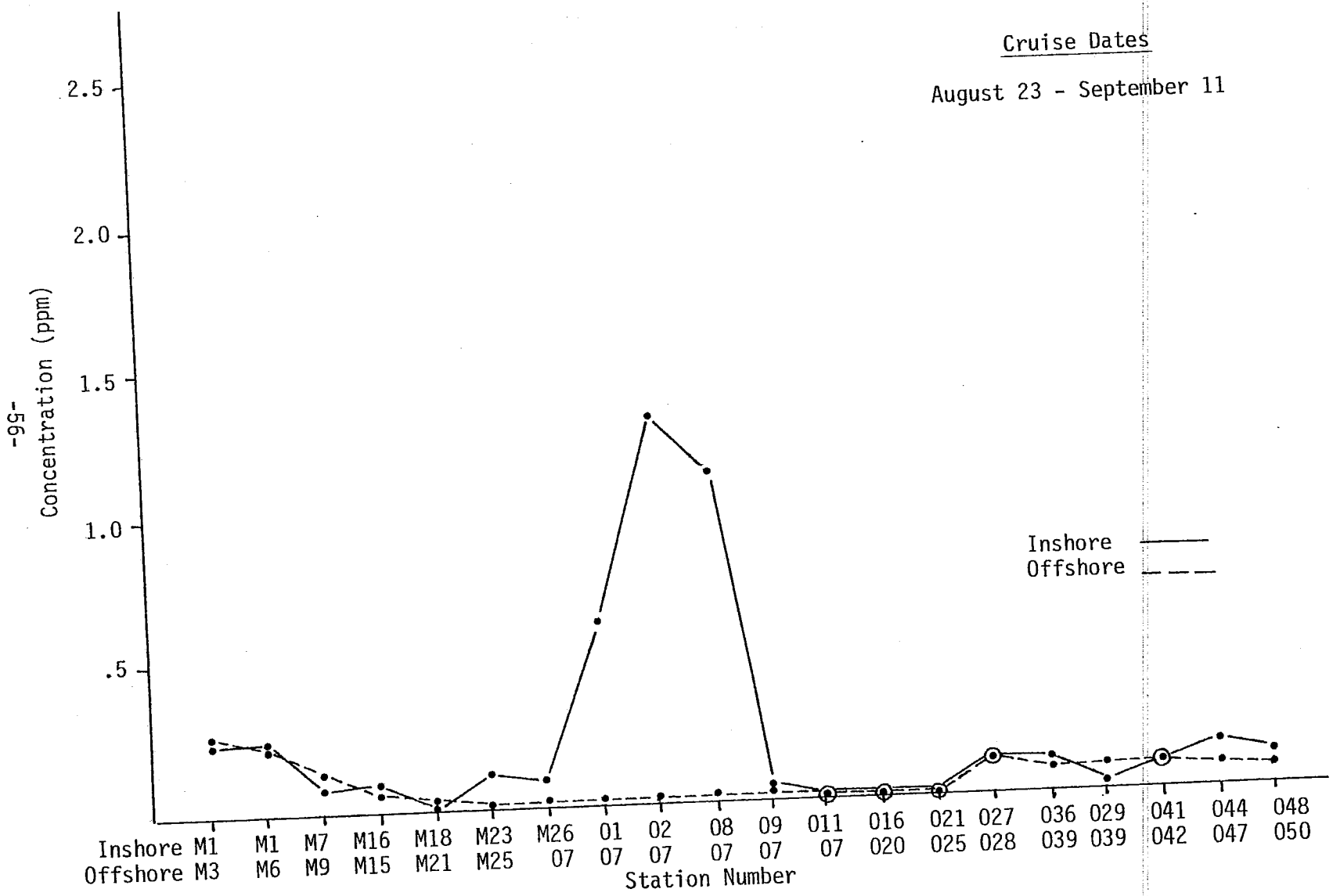
NITRATE + NITRITE PLOTS



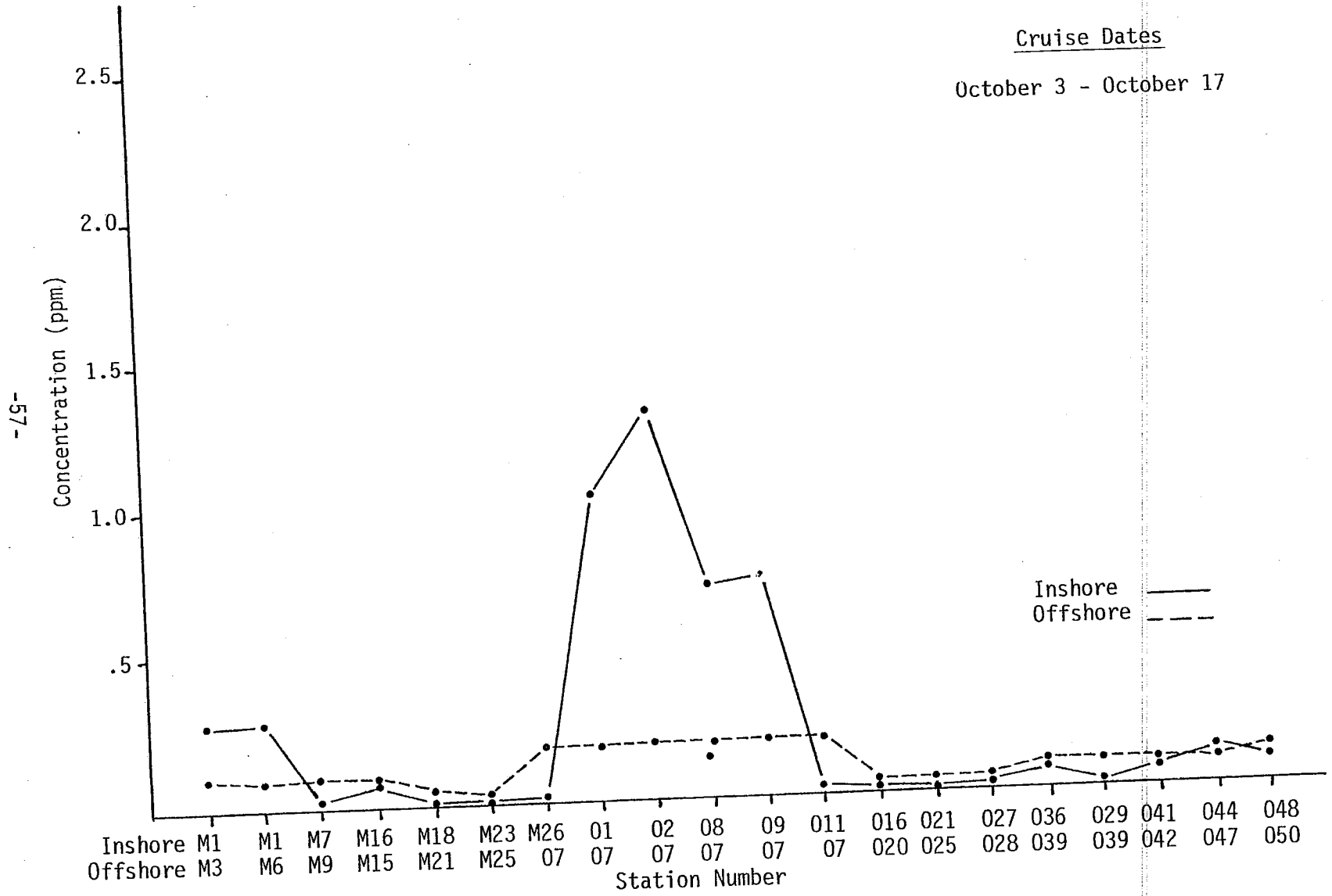
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 1 of 1978.



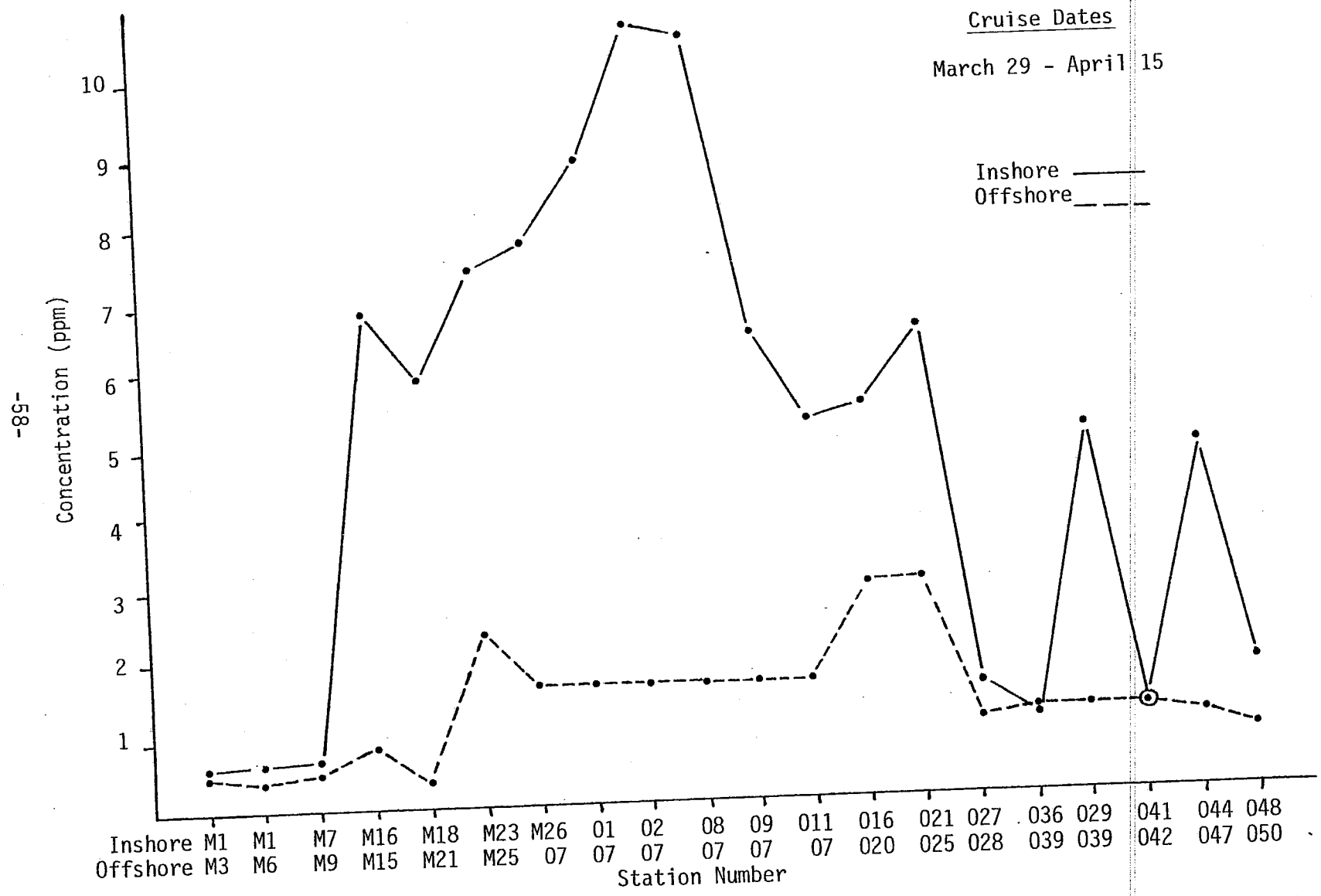
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 2 of 1978.



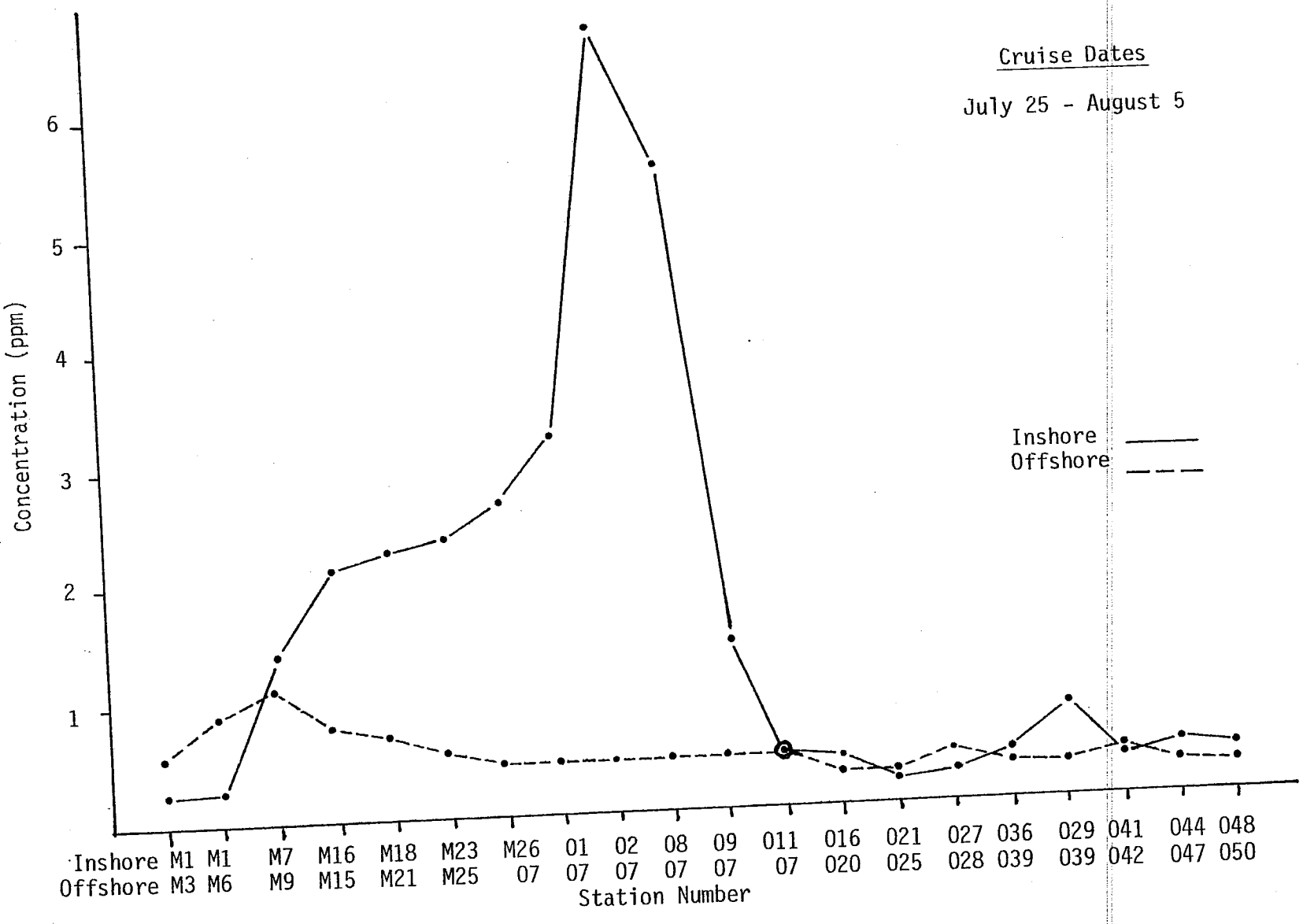
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 3 of 1978.



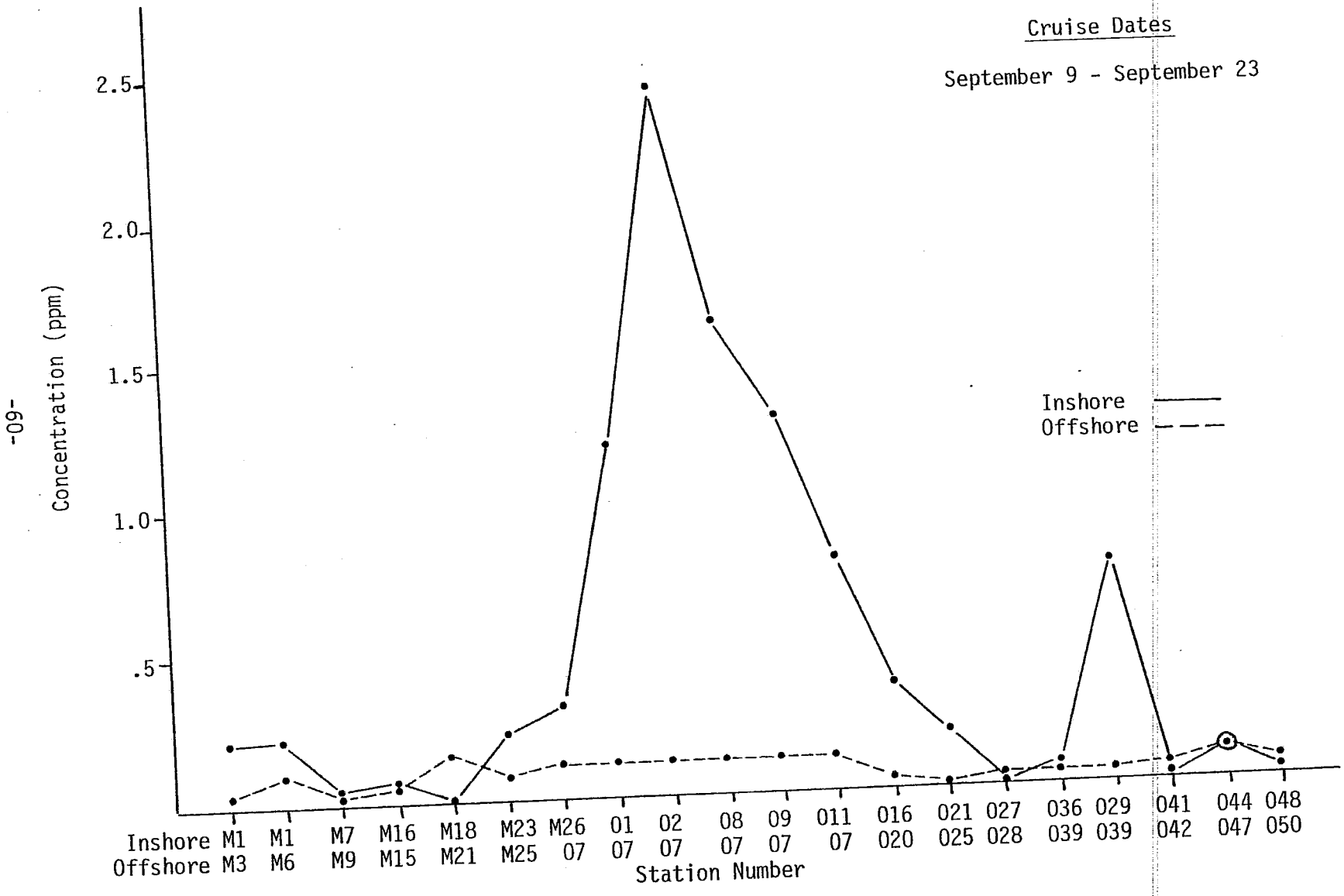
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 4 of 1978.



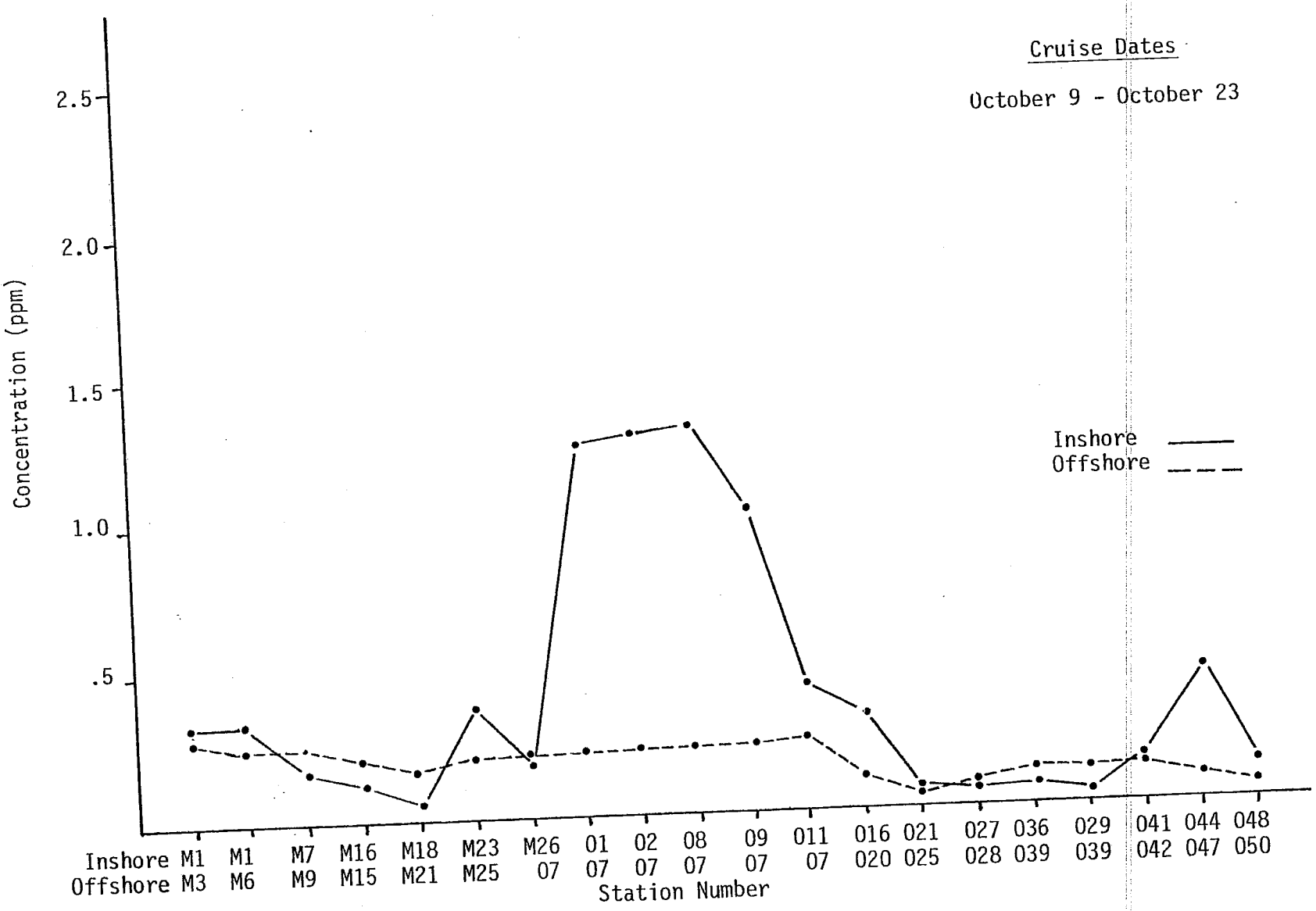
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 1 of 1979.



Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 2 of 1979.



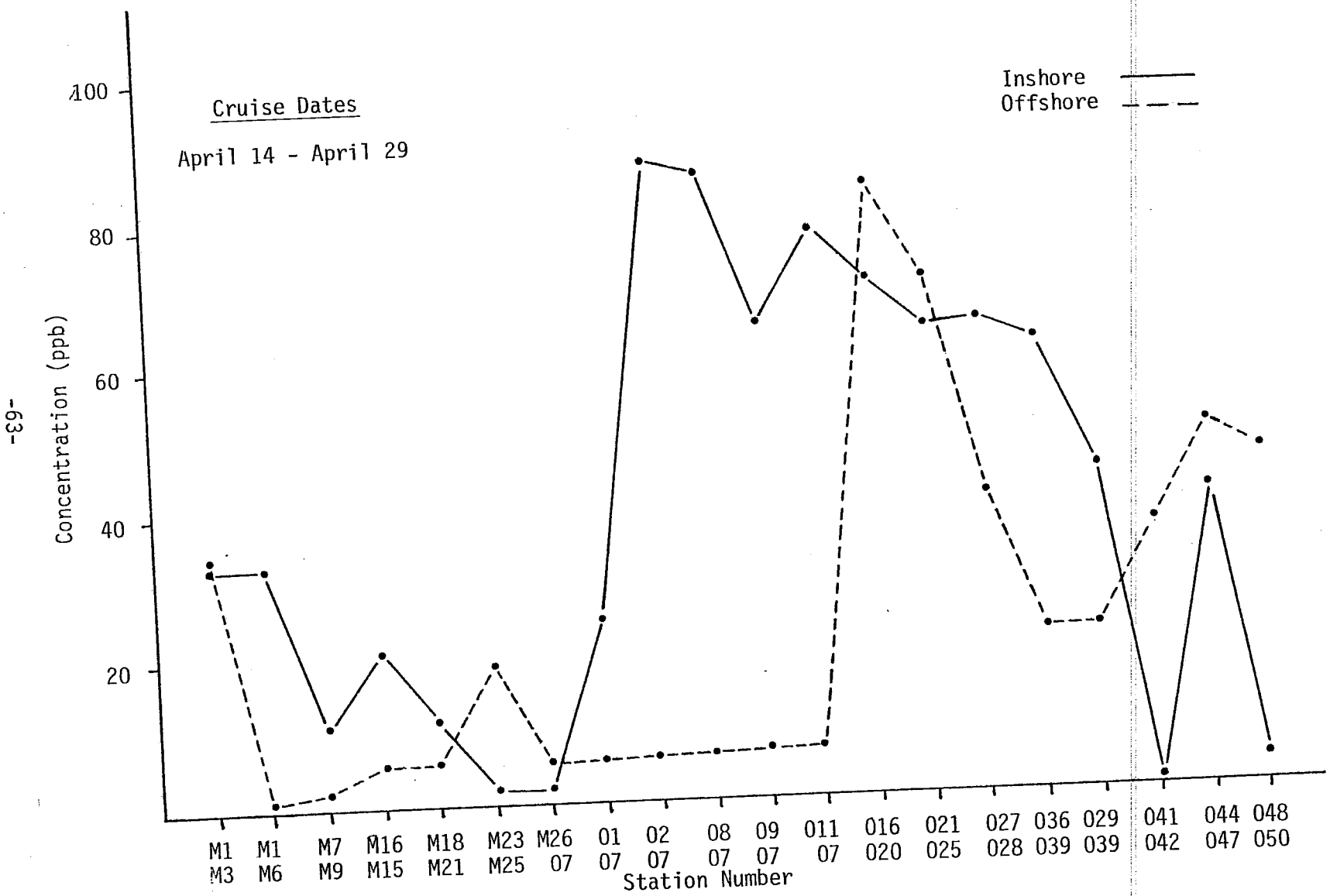
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 3 of 1979.



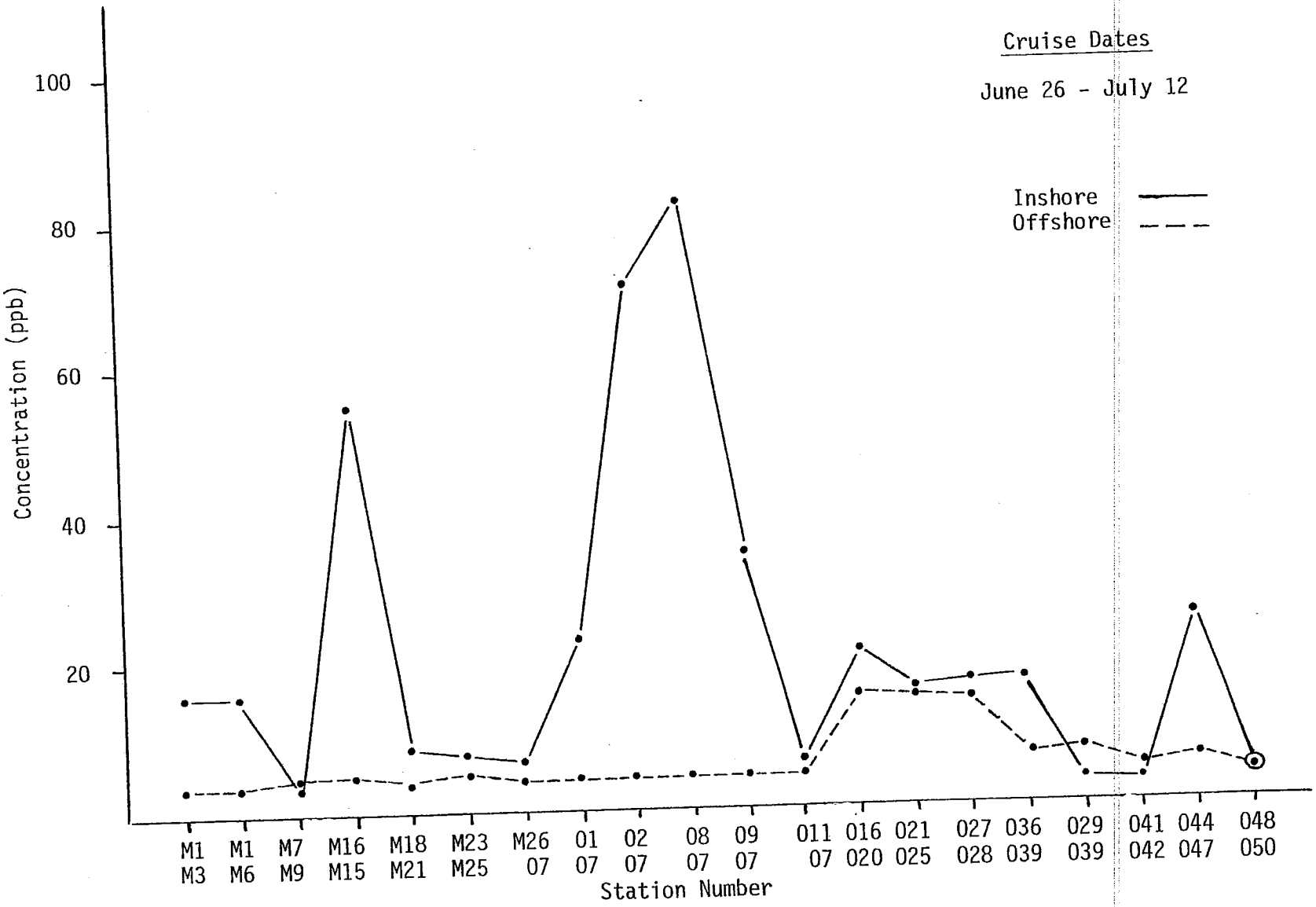
Nitrate-Nitrite Concentration at Inshore and Offshore Stations for Cruise 4 of 1979.

APPENDIX C

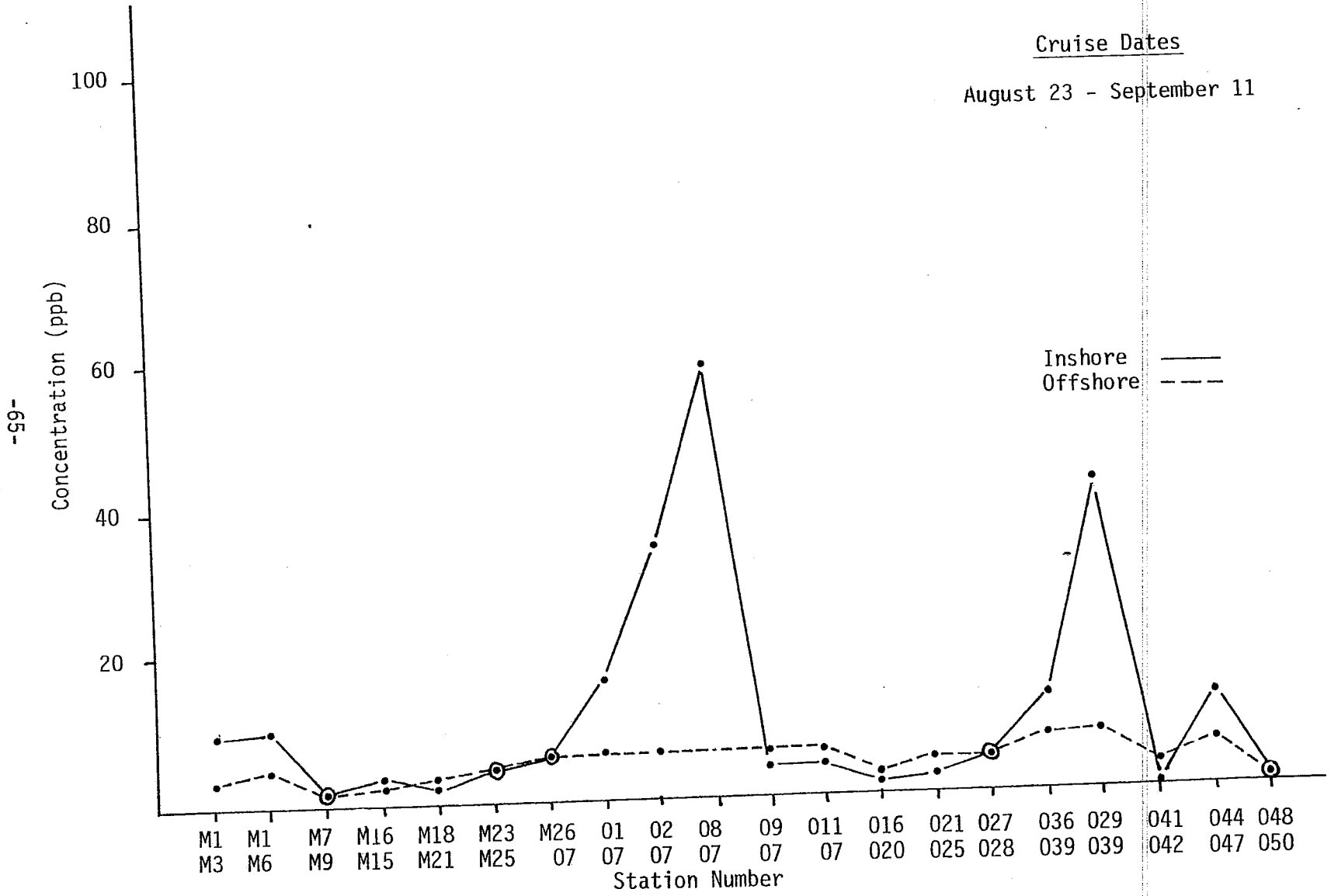
SOLUBLE REACTIVE PHOSPHORUS PLOTS



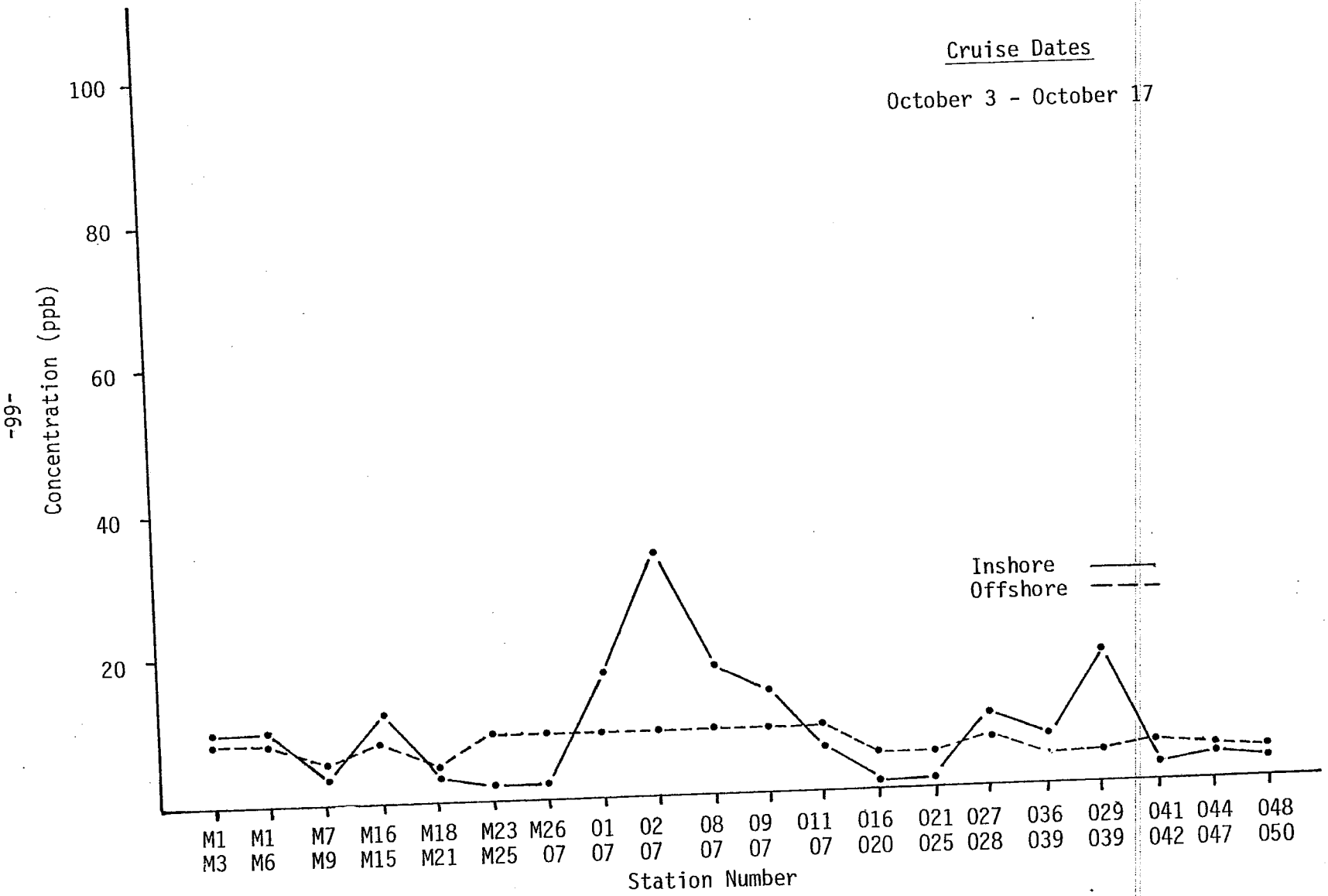
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 1 of 1978.



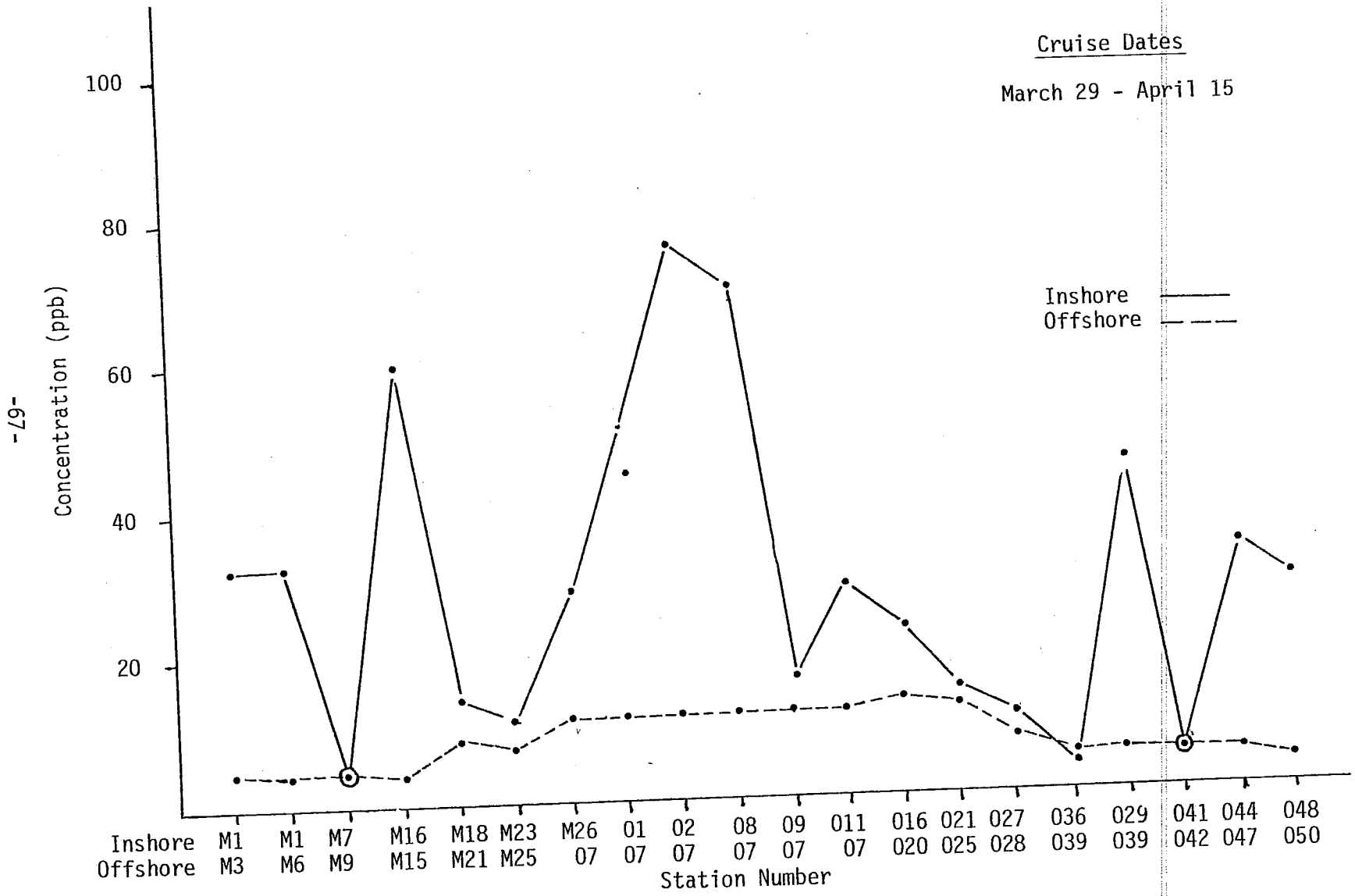
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 2 of 1978.



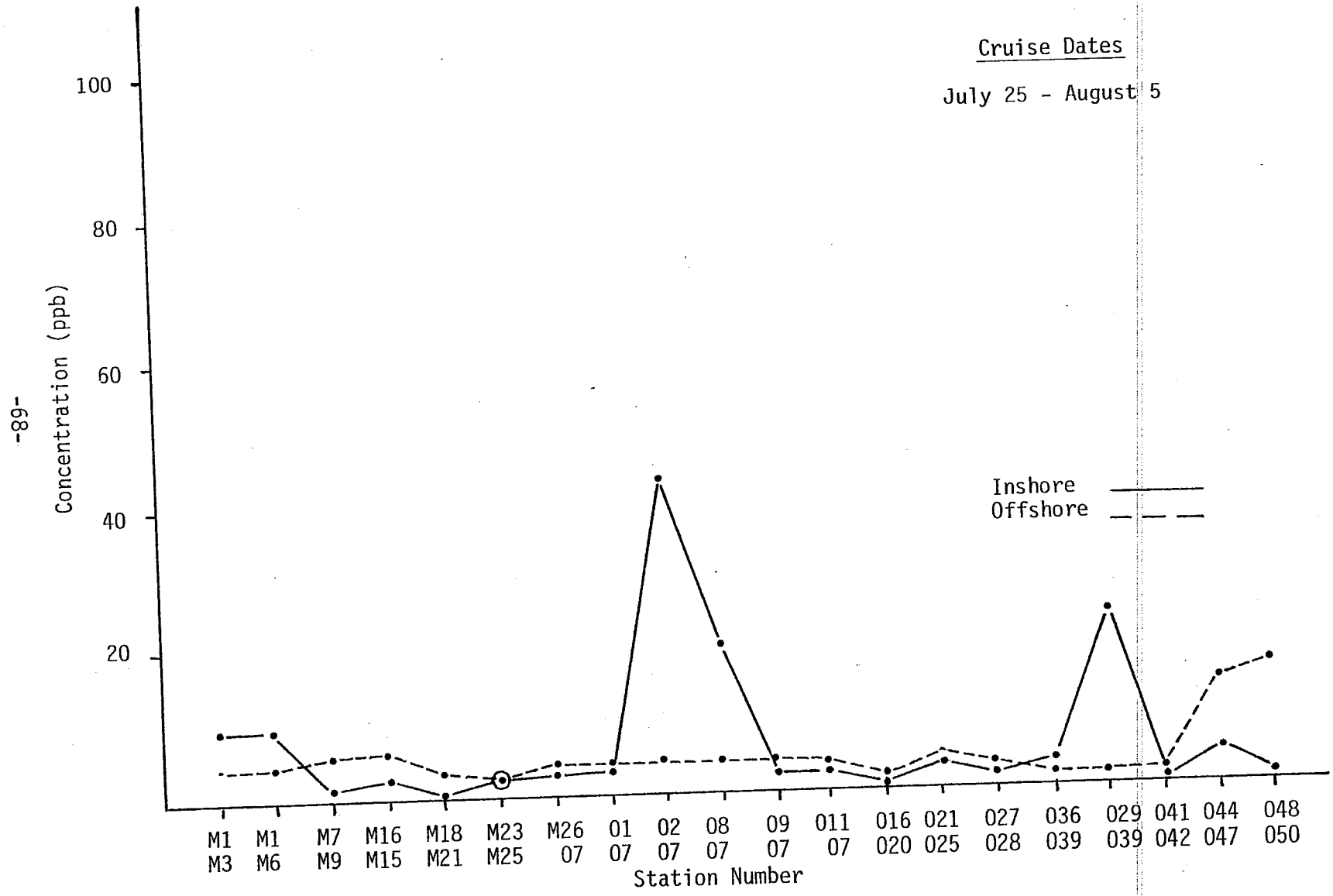
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 3 of 1978.



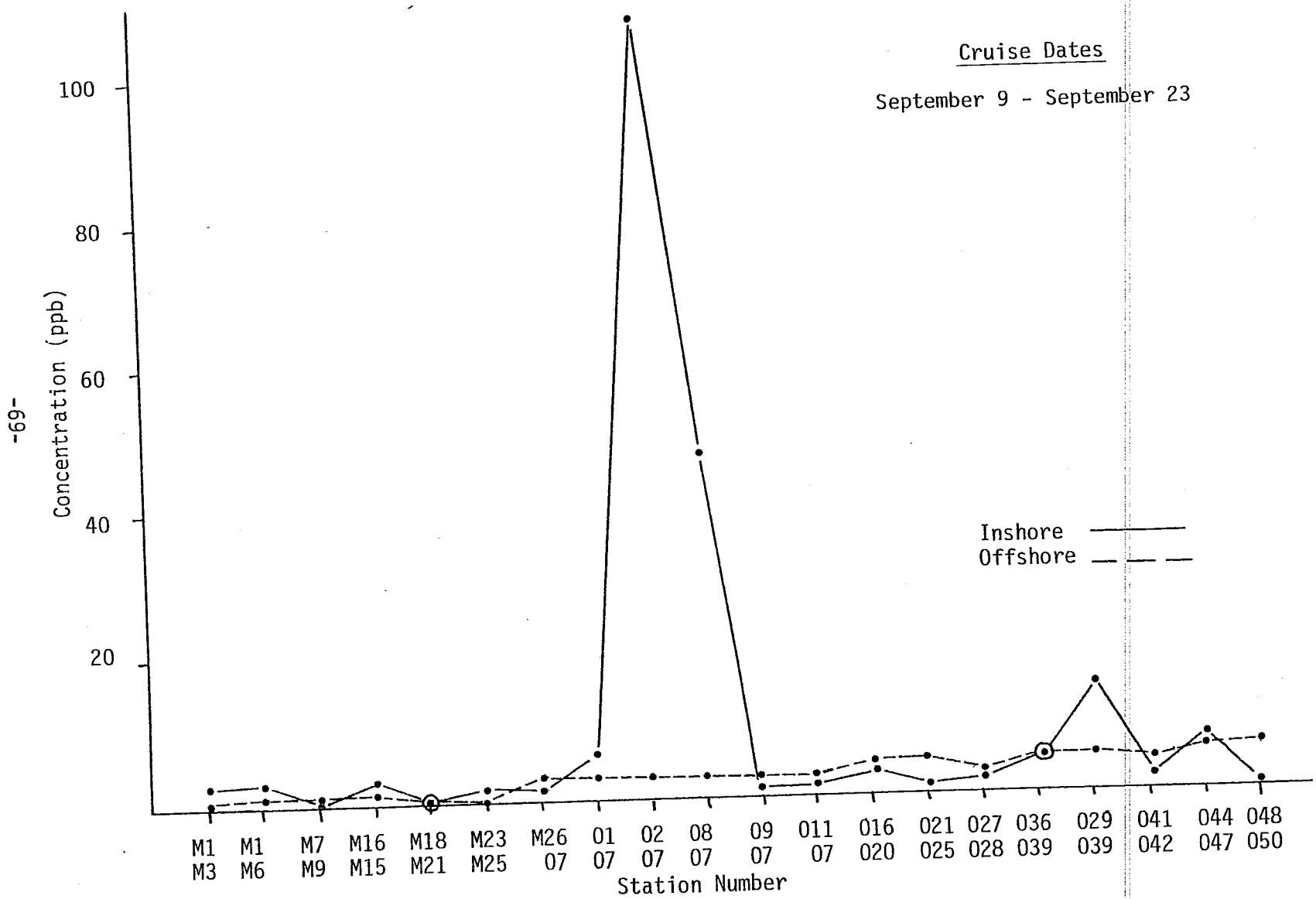
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 4 of 1978.



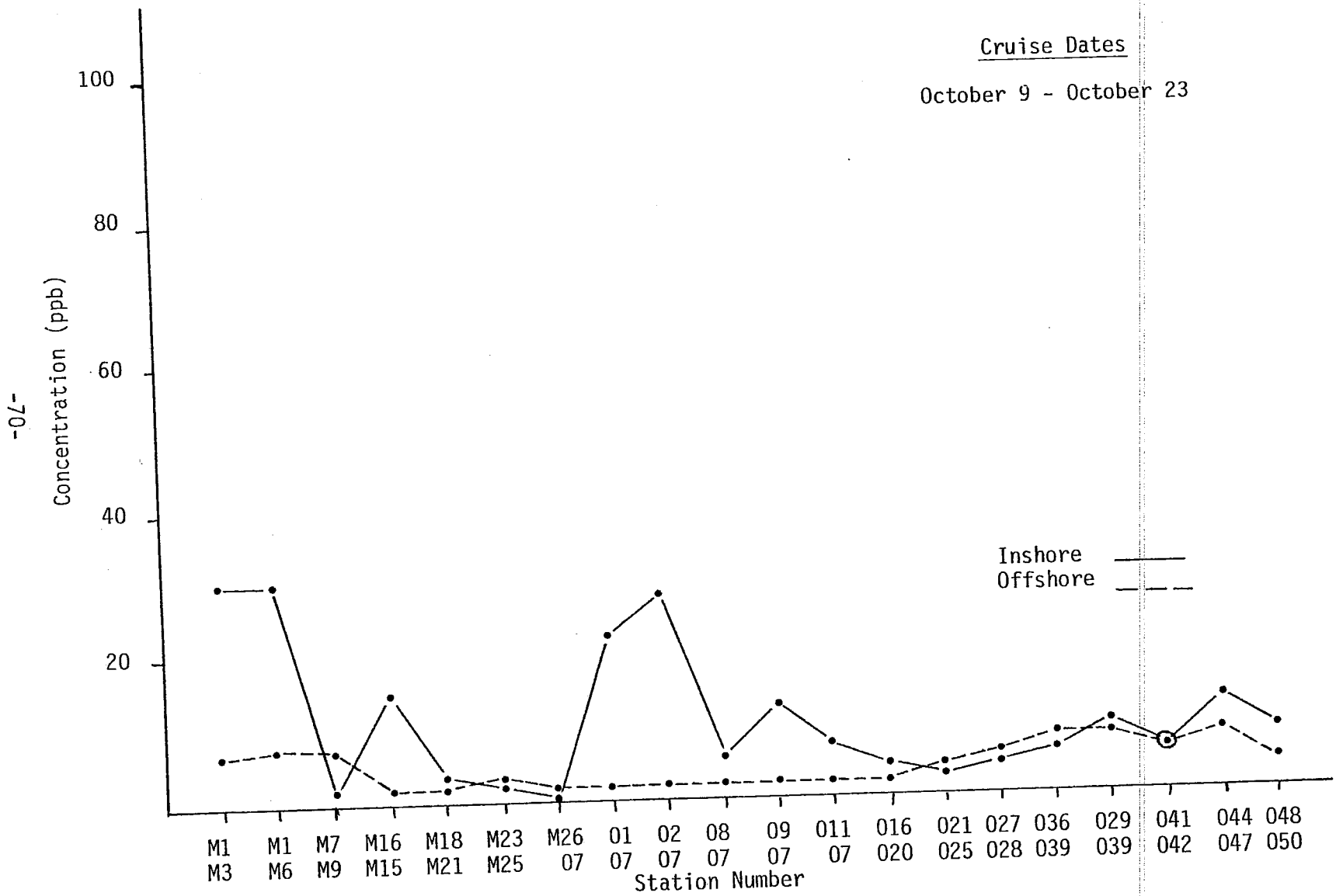
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 1 of 1979.



Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 2 of 1979.



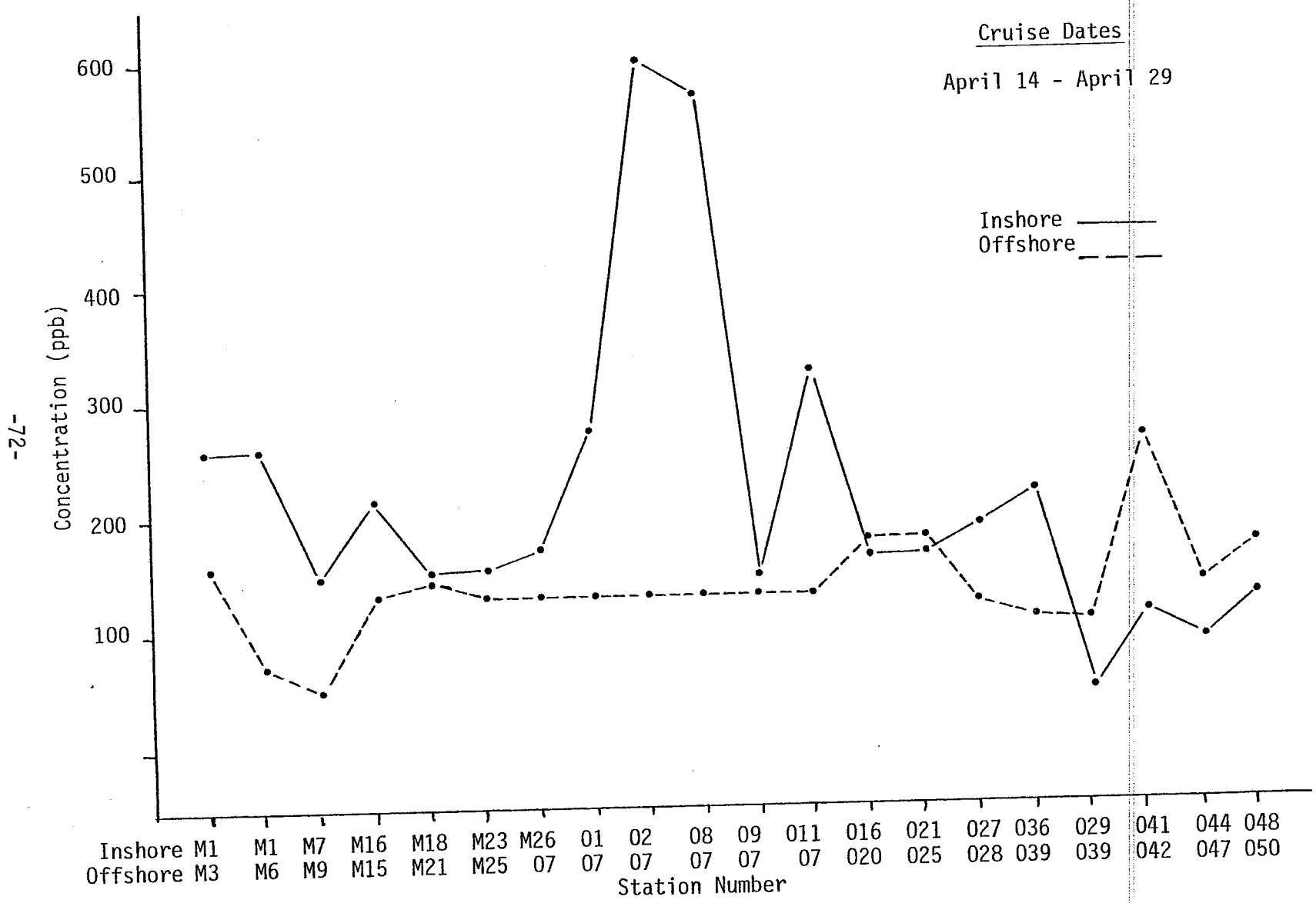
. Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 3 of 1979.



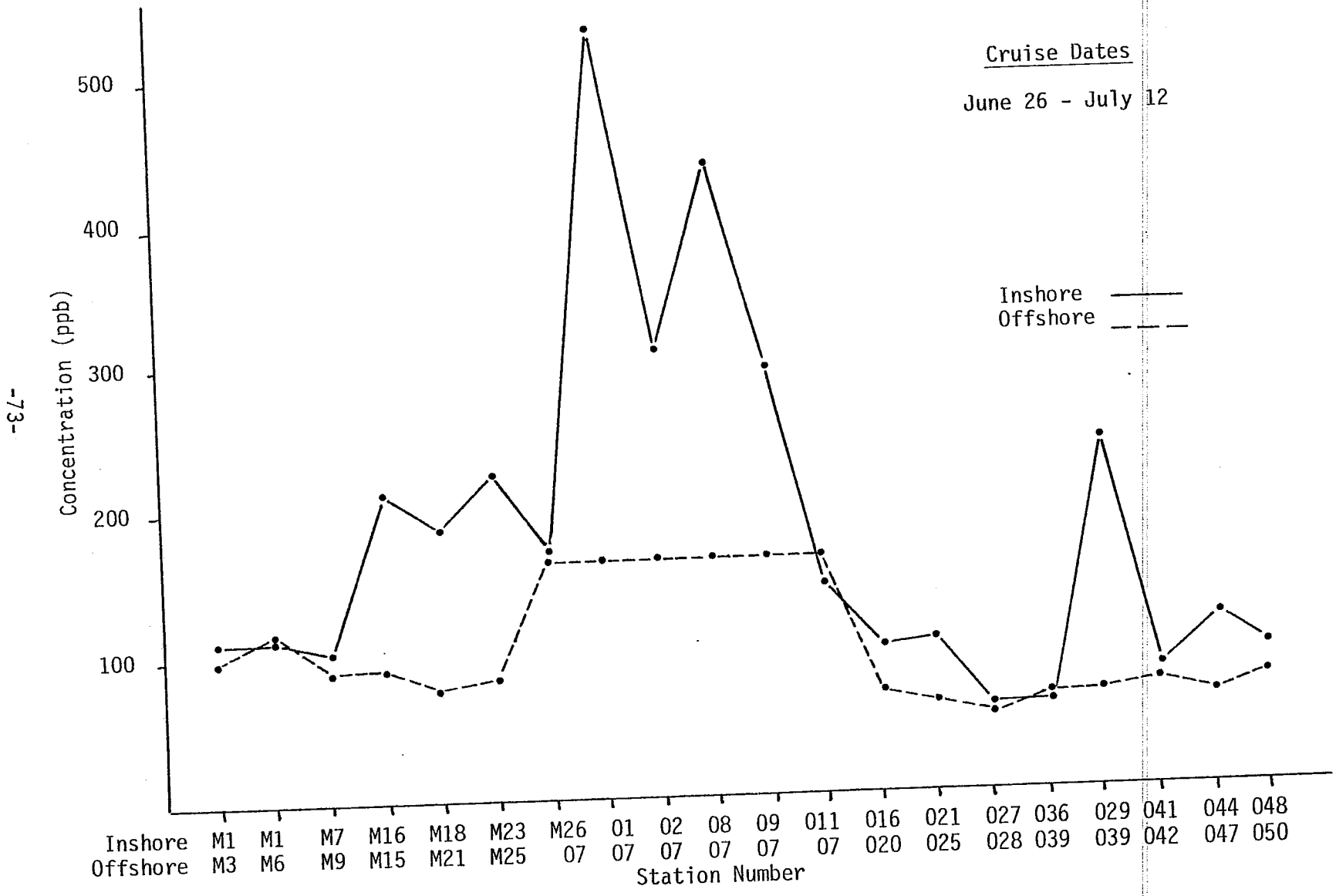
Soluble Reactive Phosphorus Concentration at Inshore and Offshore Stations for Cruise 4 of 1979.

APPENDIX D

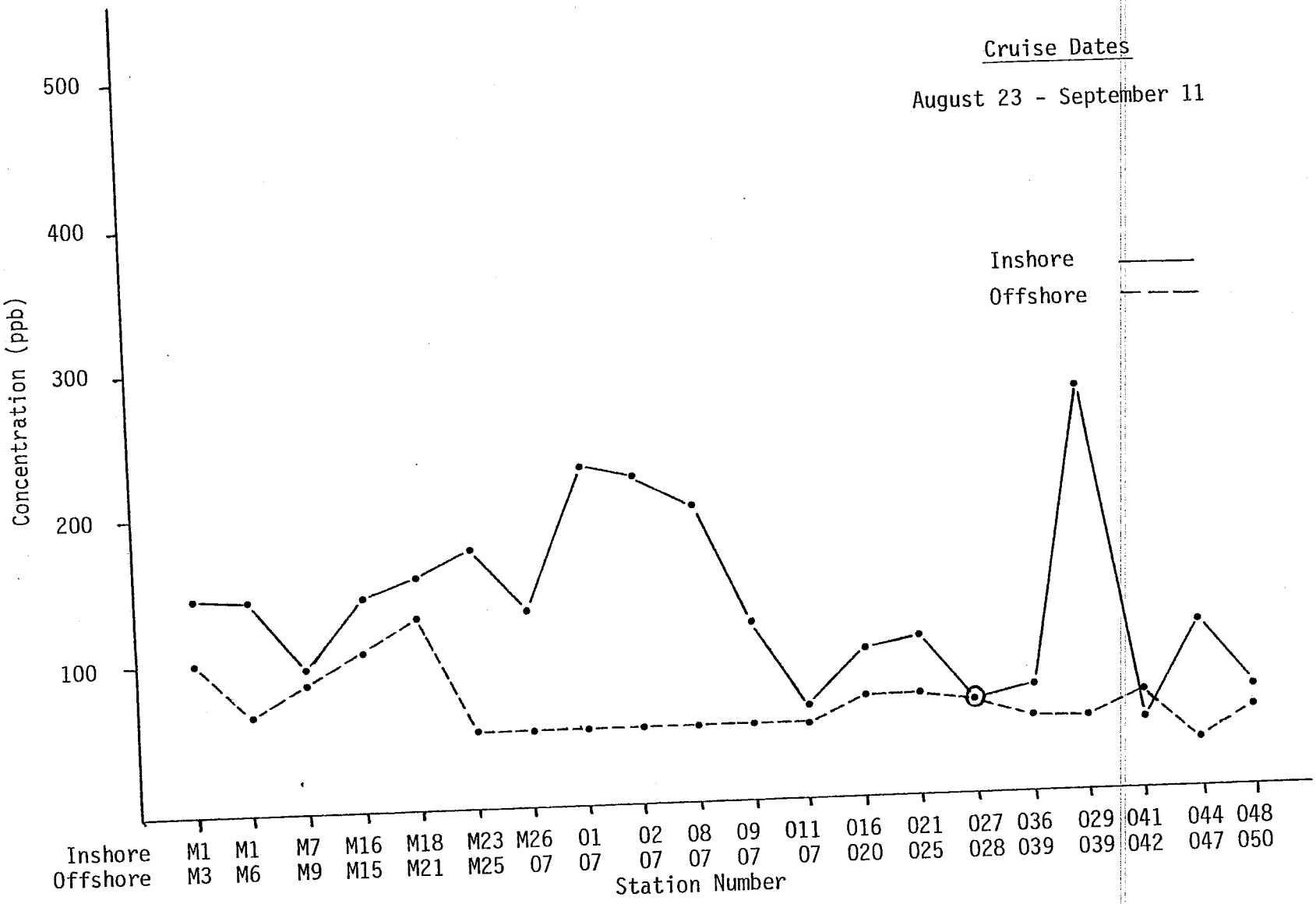
TOTAL PHOSPHORUS PLOTS



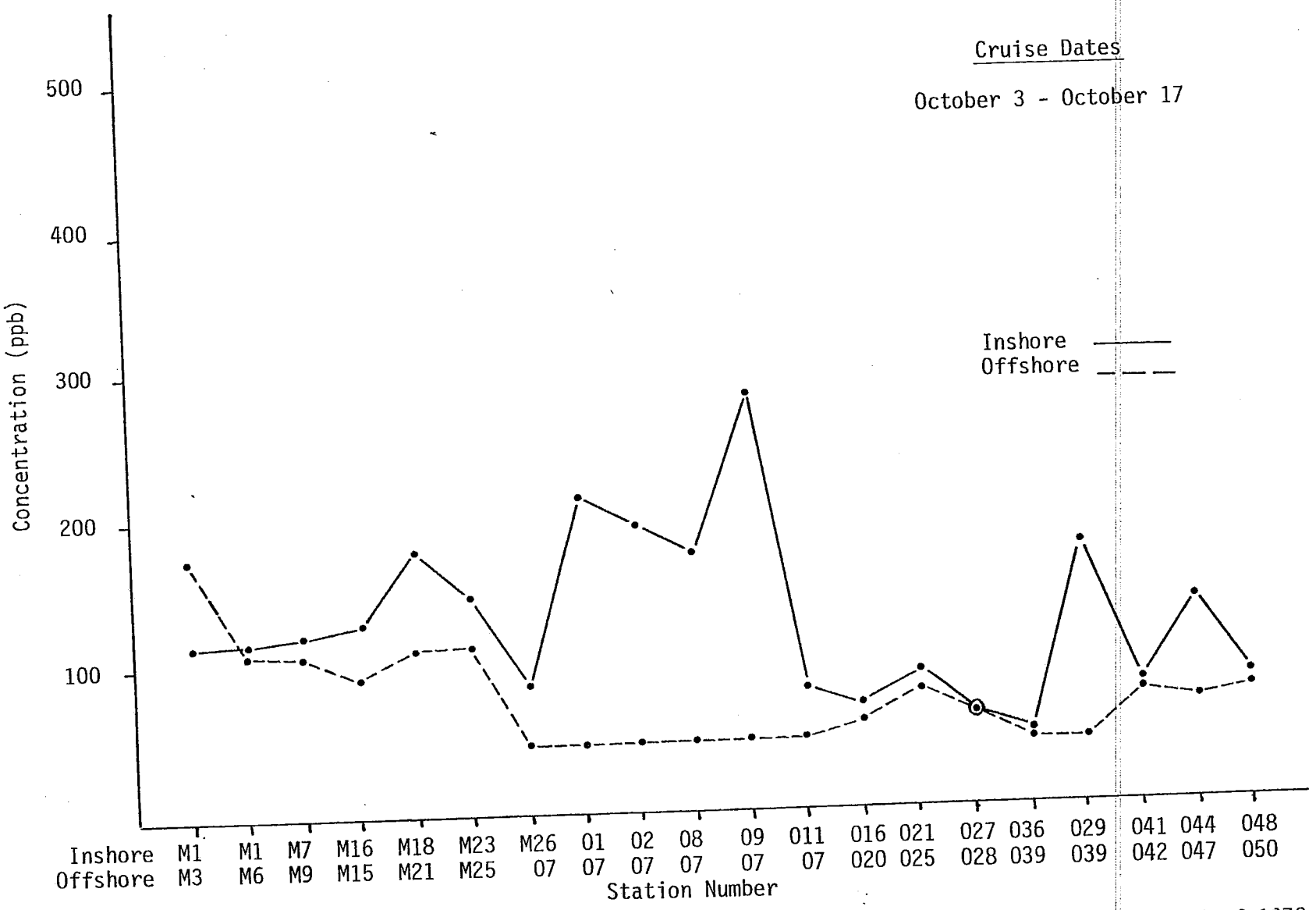
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 1 of 1978.



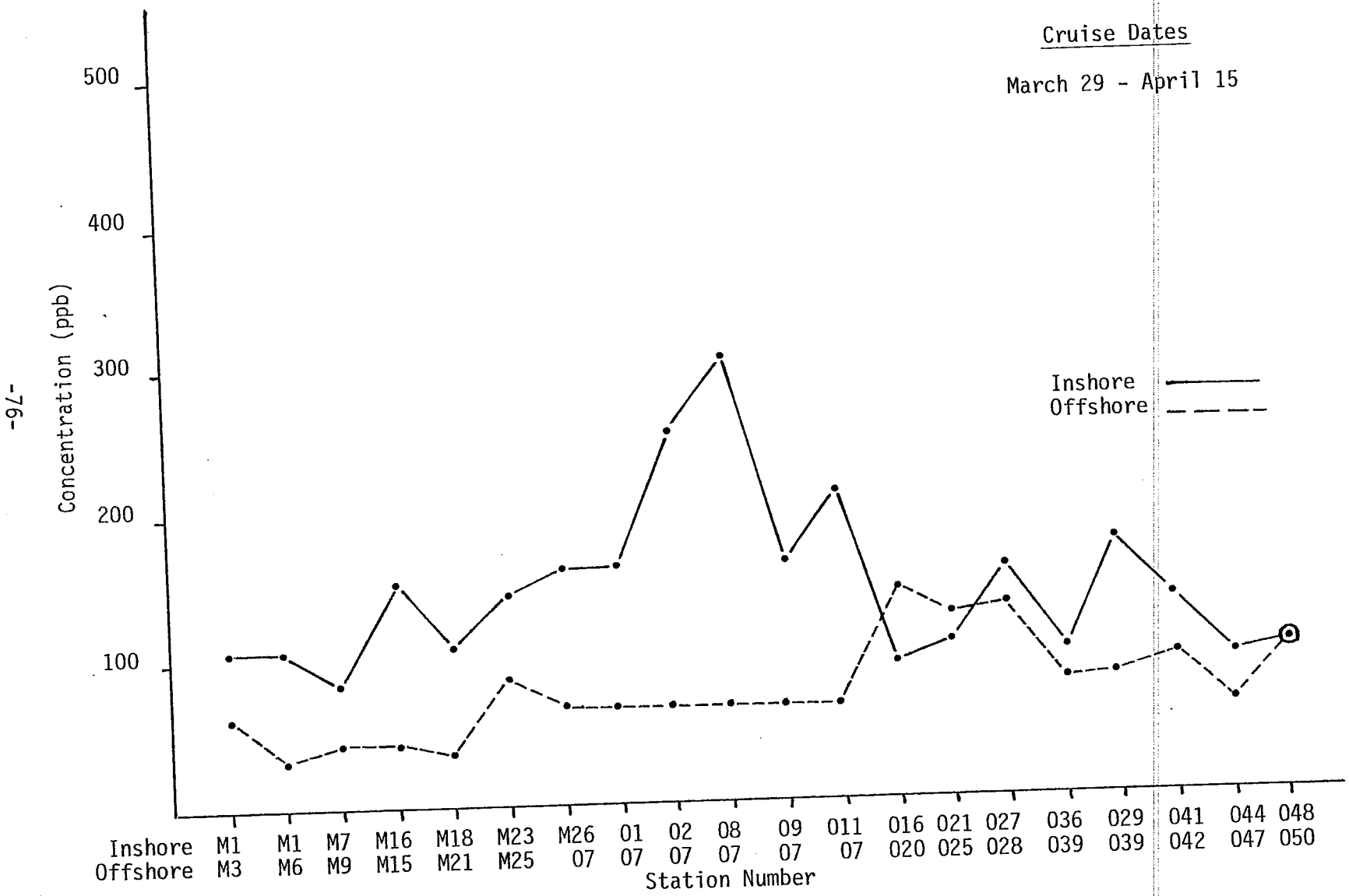
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 2 of 1978.



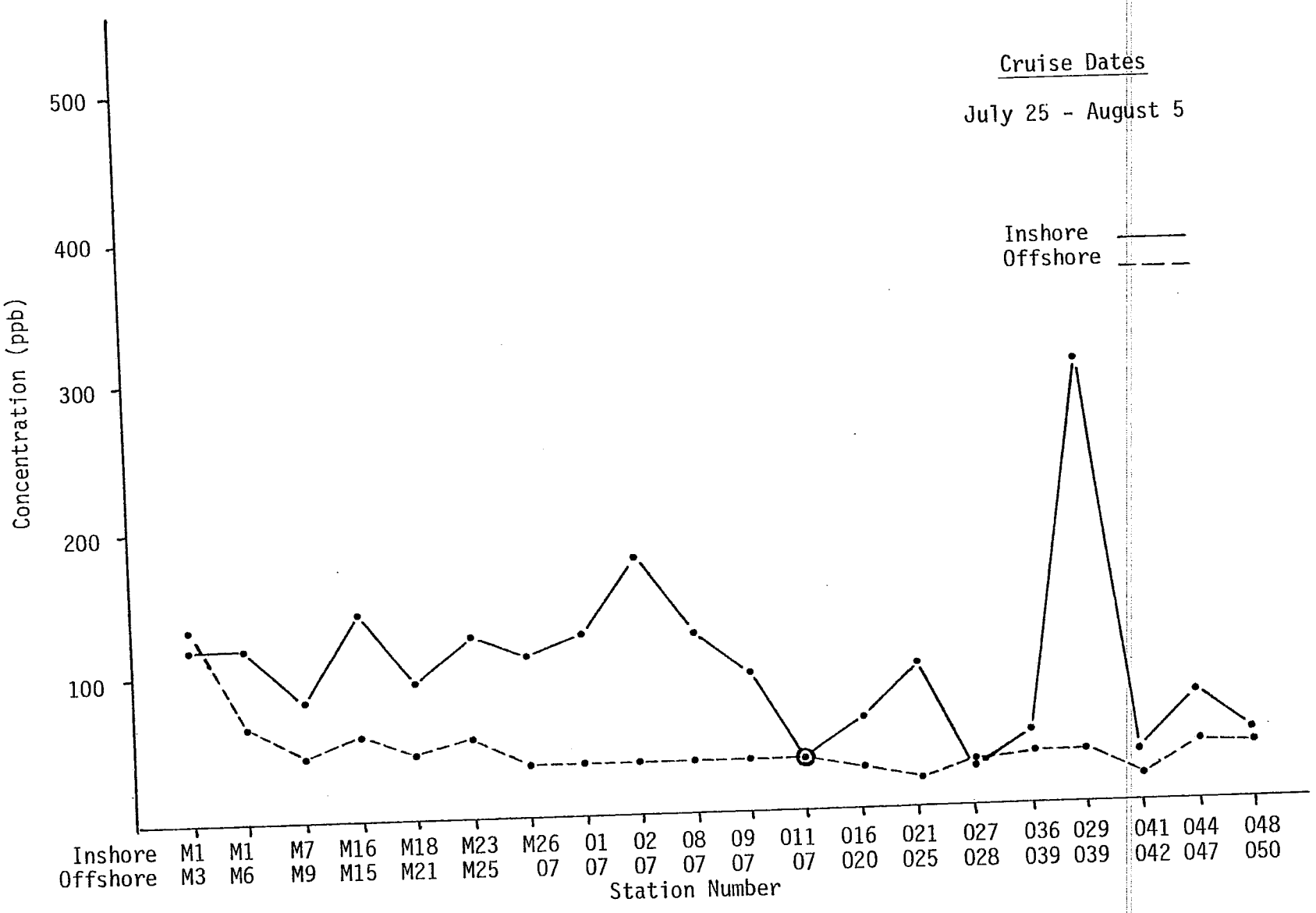
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 3 of 1978.



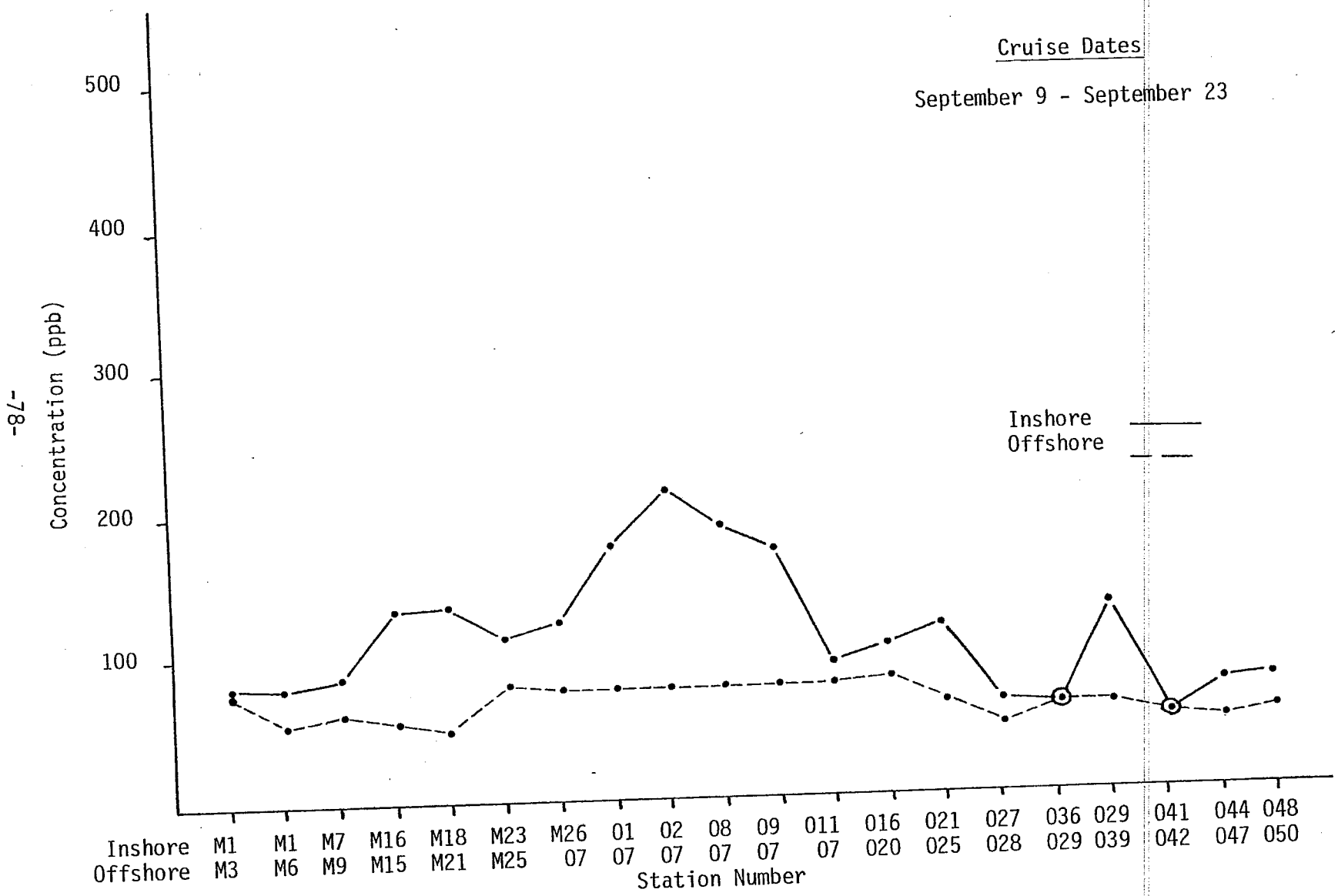
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 4 of 1978.



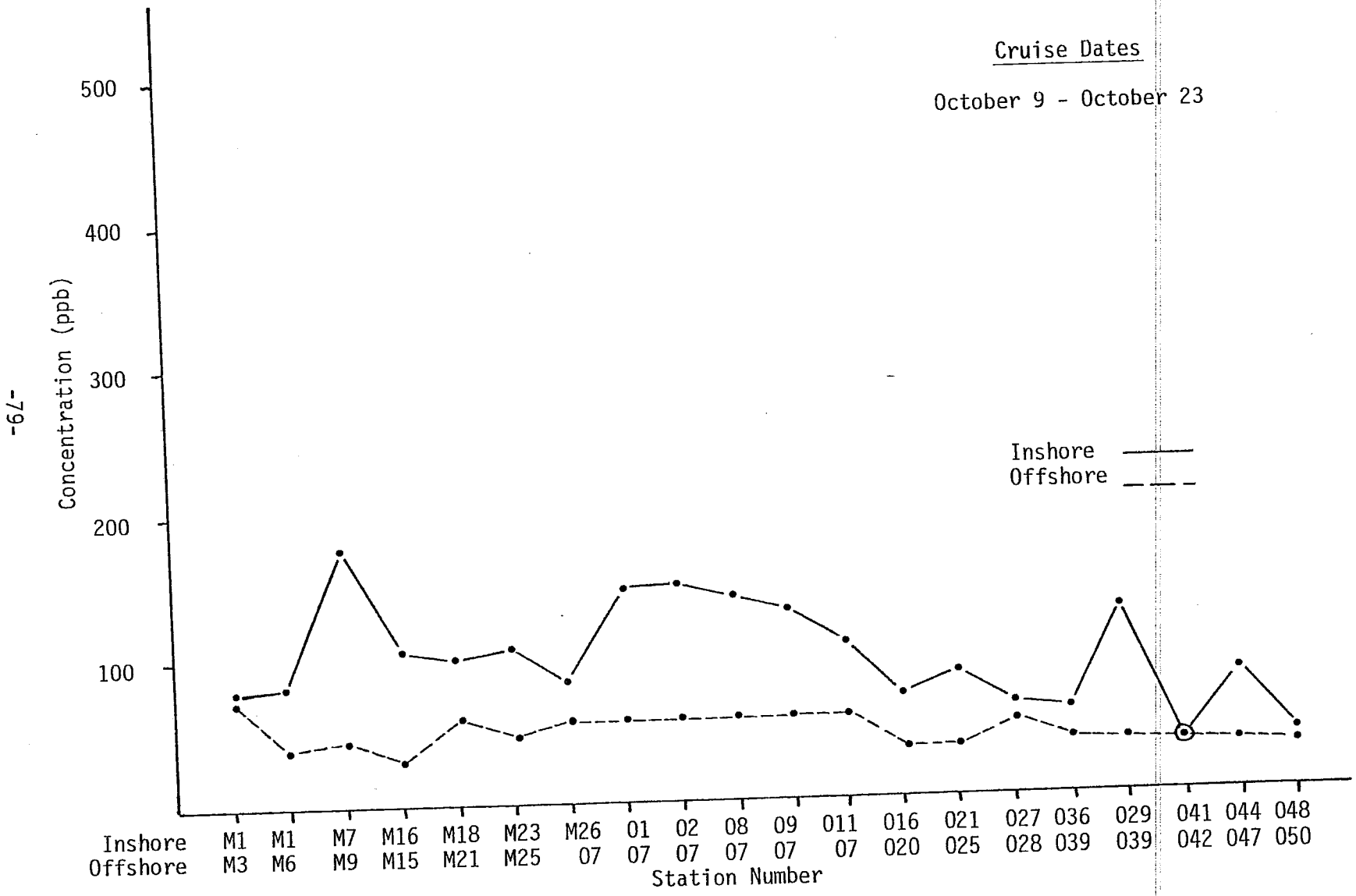
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 1 of 1979.



Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 2 of 1979.



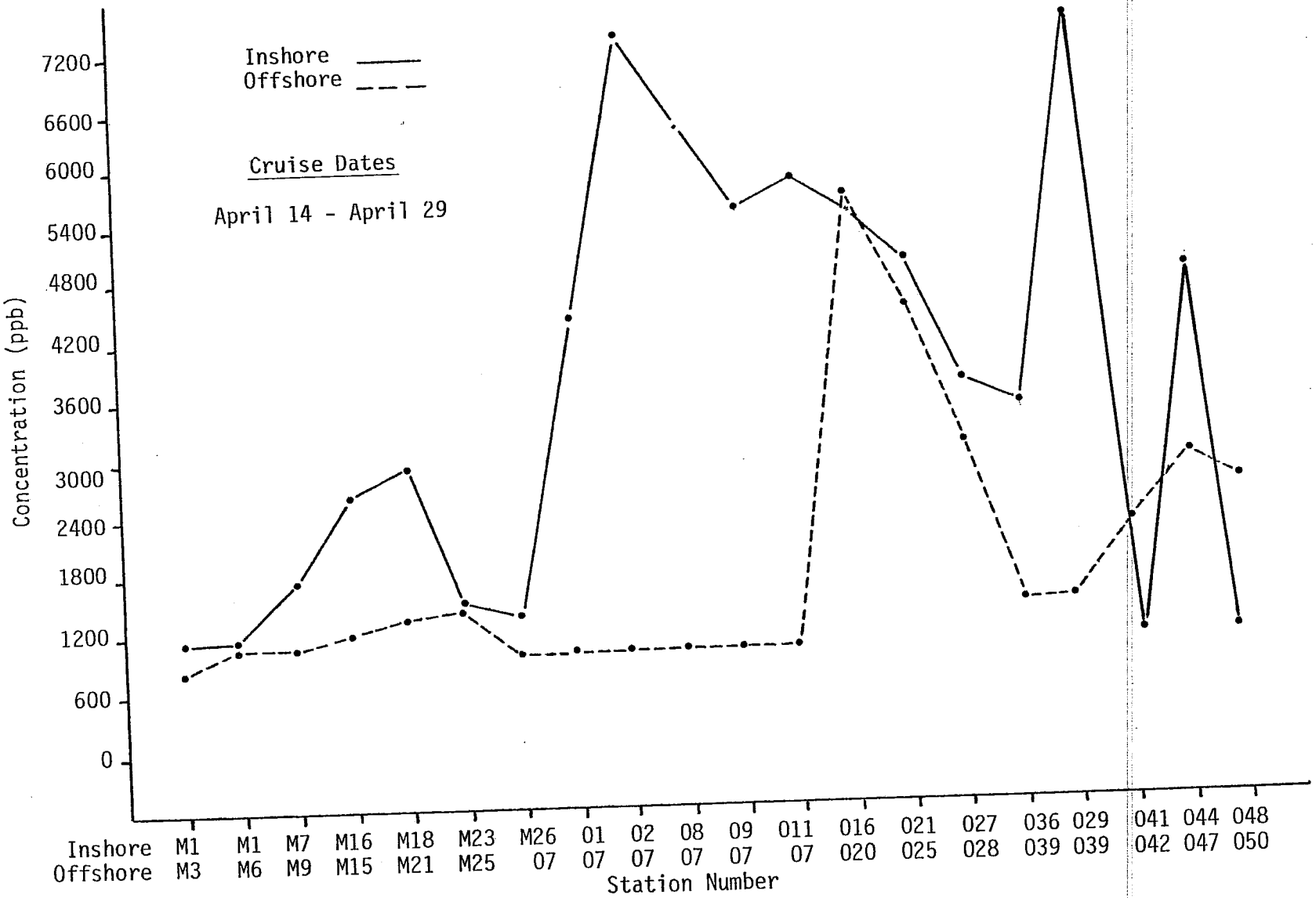
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 3 of 1979.



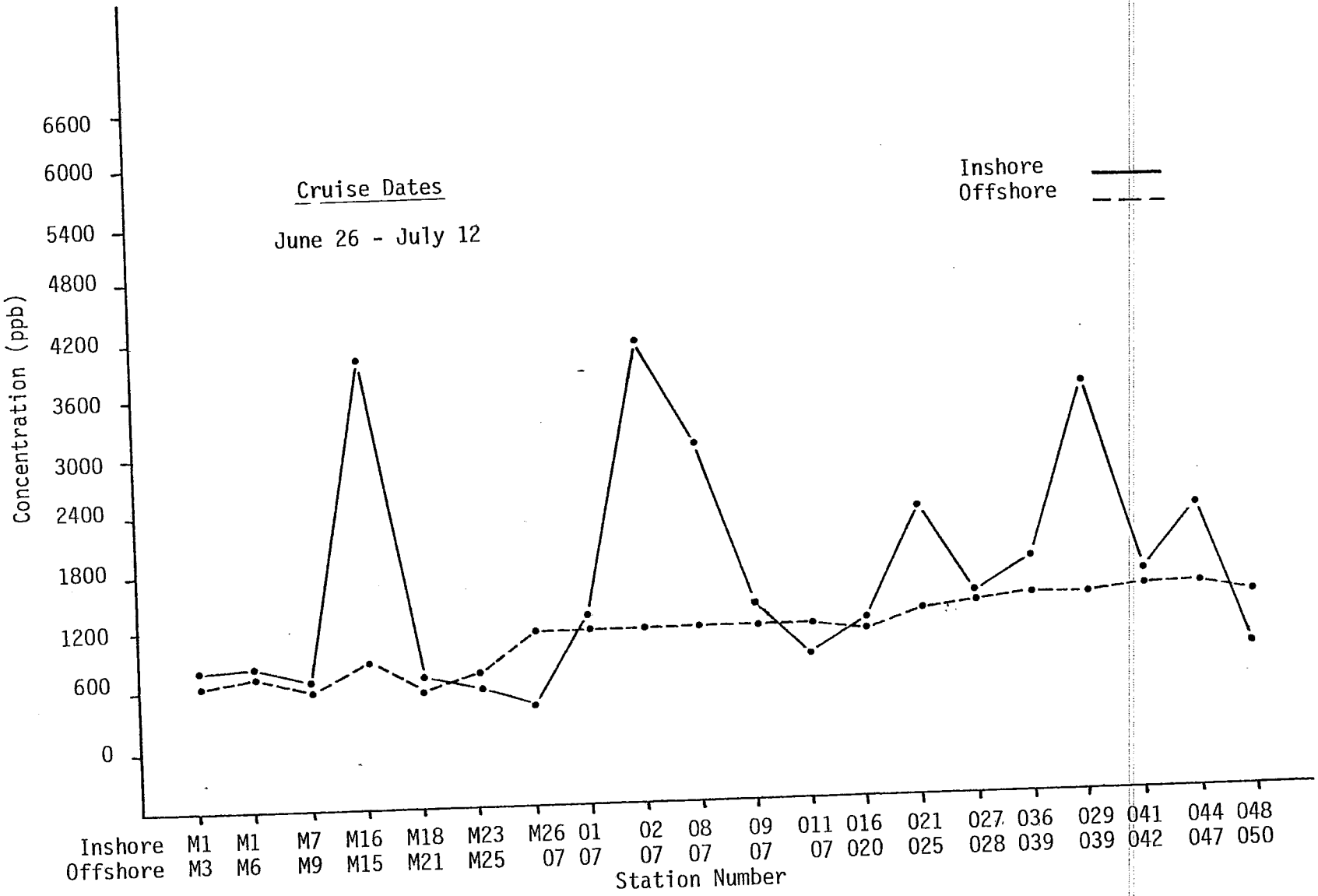
Total Phosphorus Concentration at Inshore and Offshore Stations for Cruise 4 of 1979.

APPENDIX E

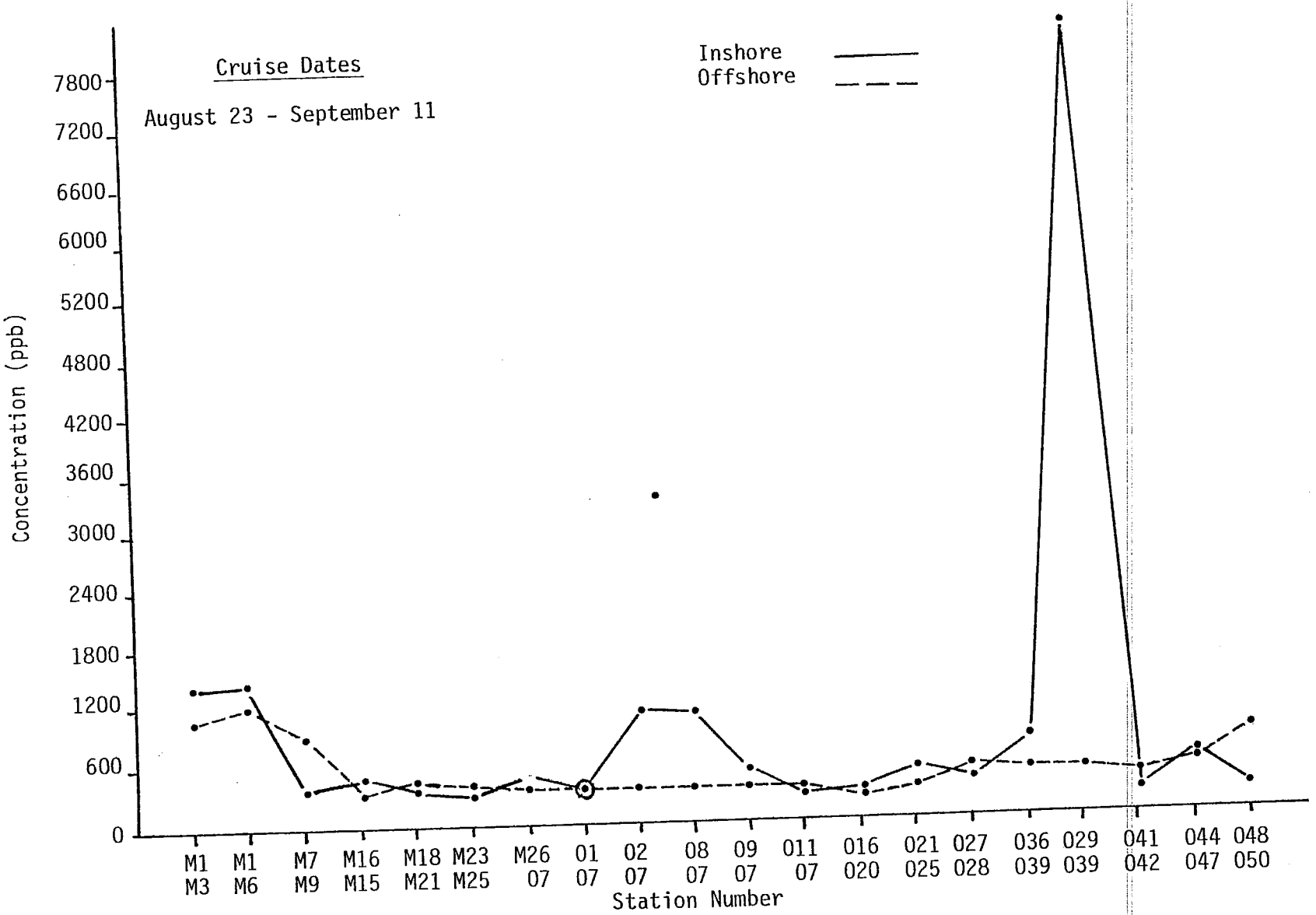
SOLUBLE REACTIVE SILICA PLOTS



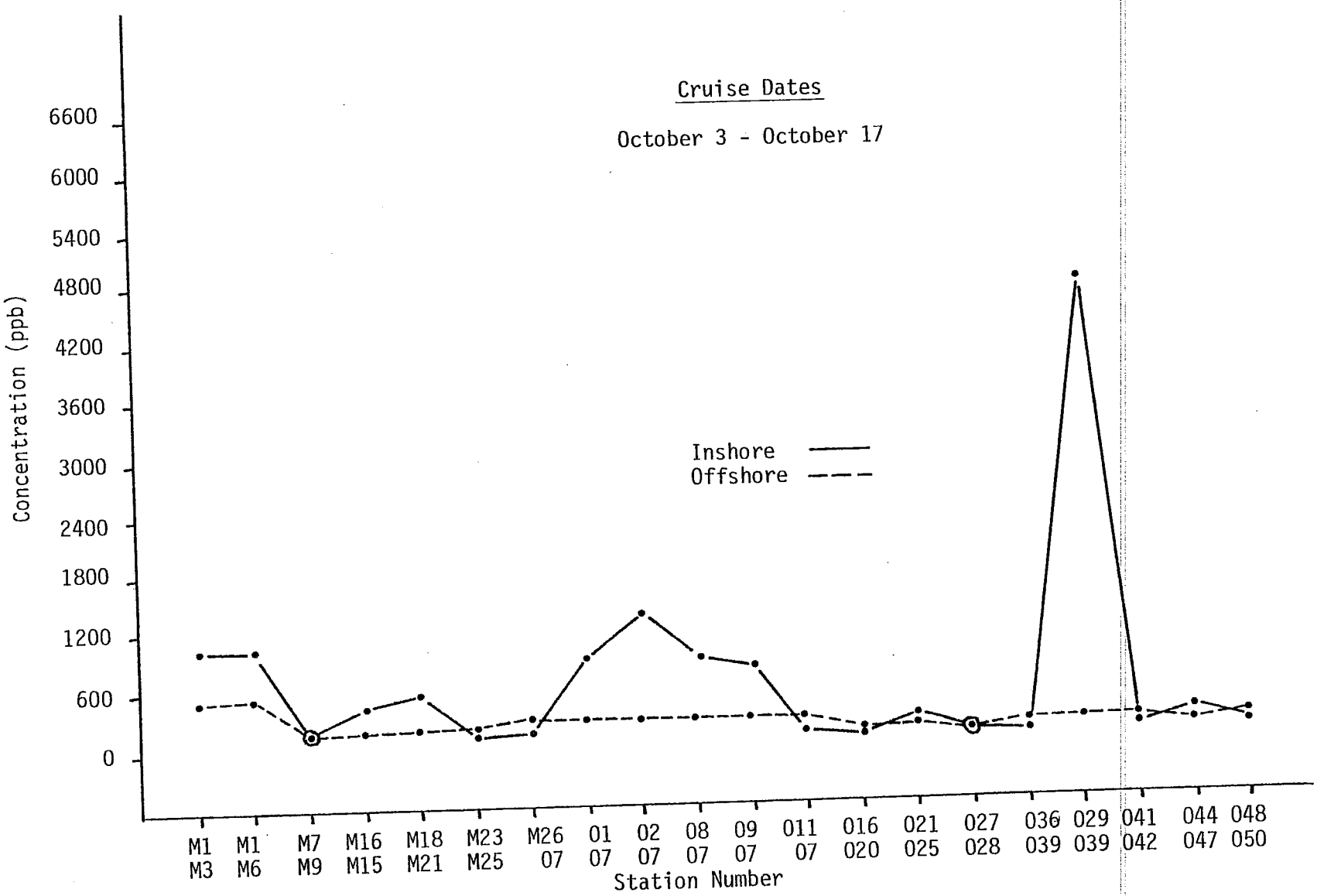
Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 1 of 1978.



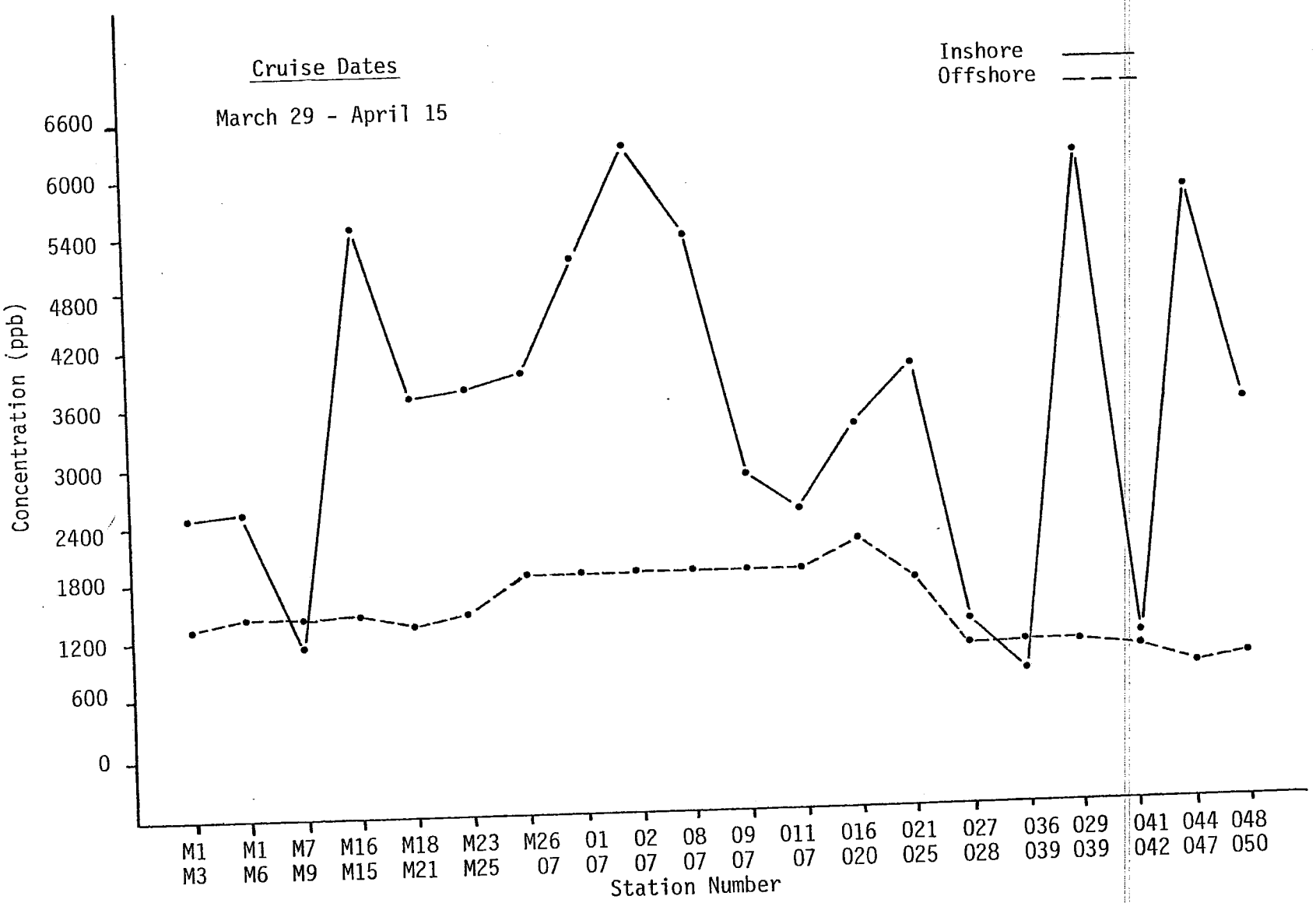
Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 2 of 1978.



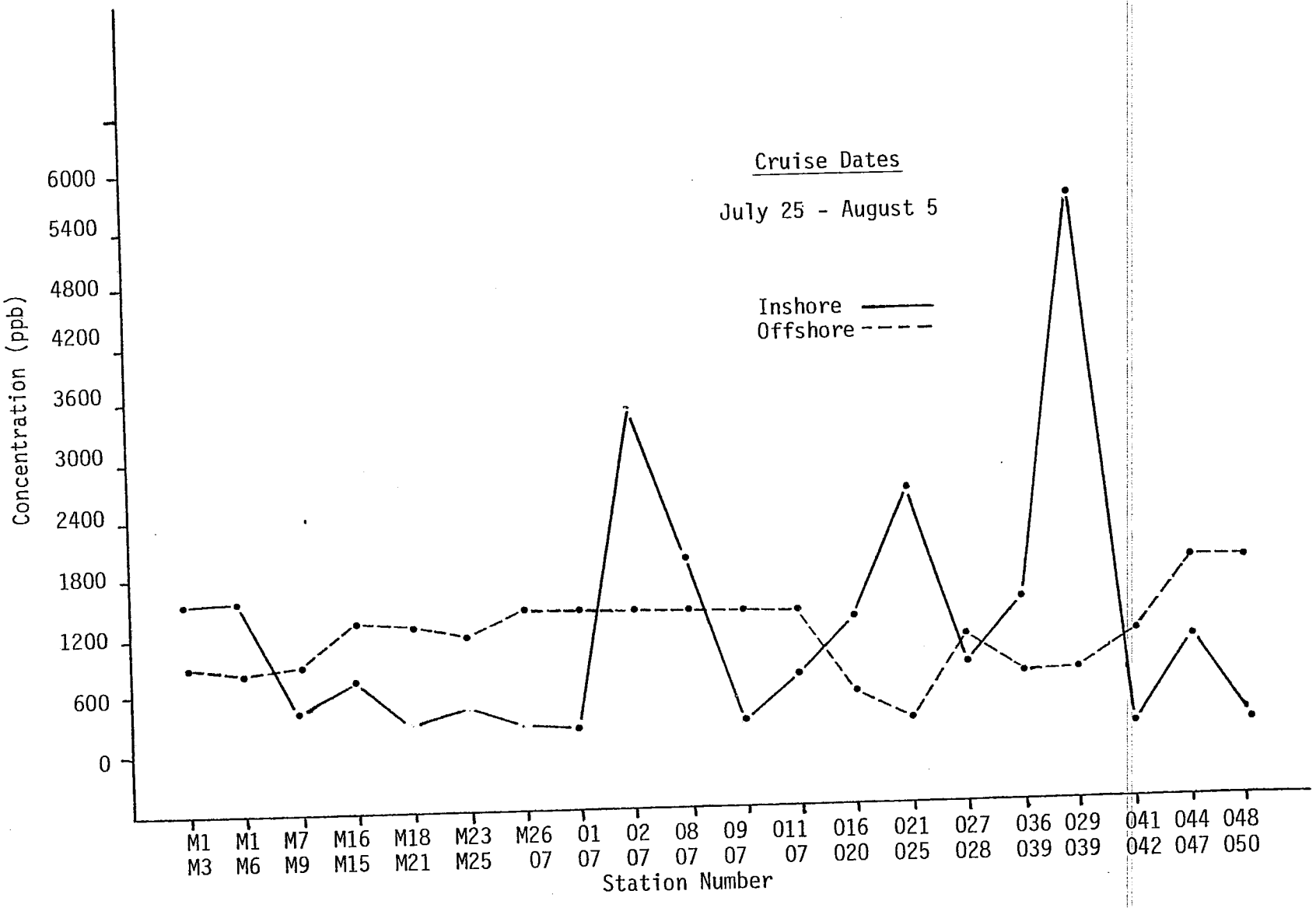
Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 3 of 1978.



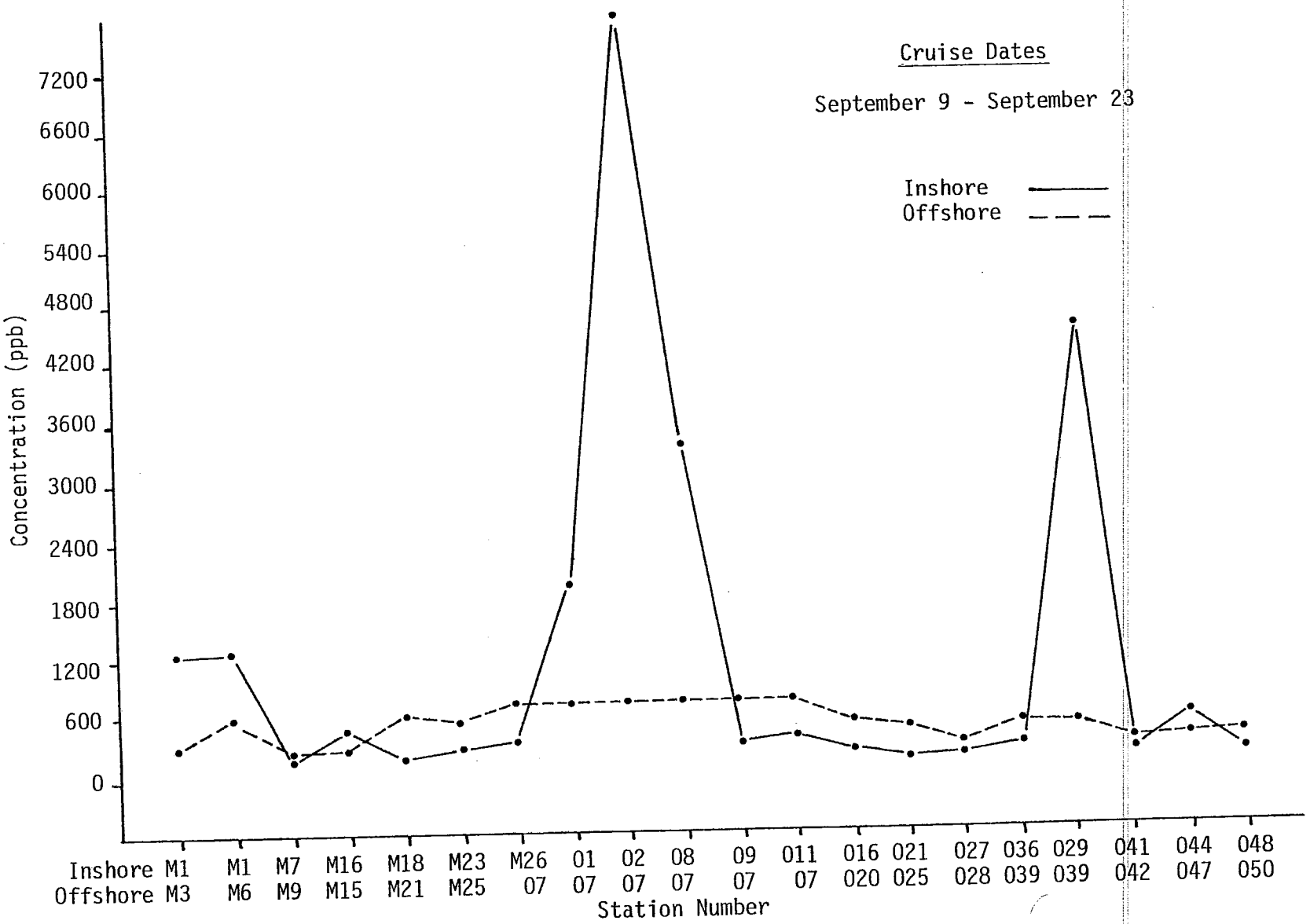
Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 4 of 1978.



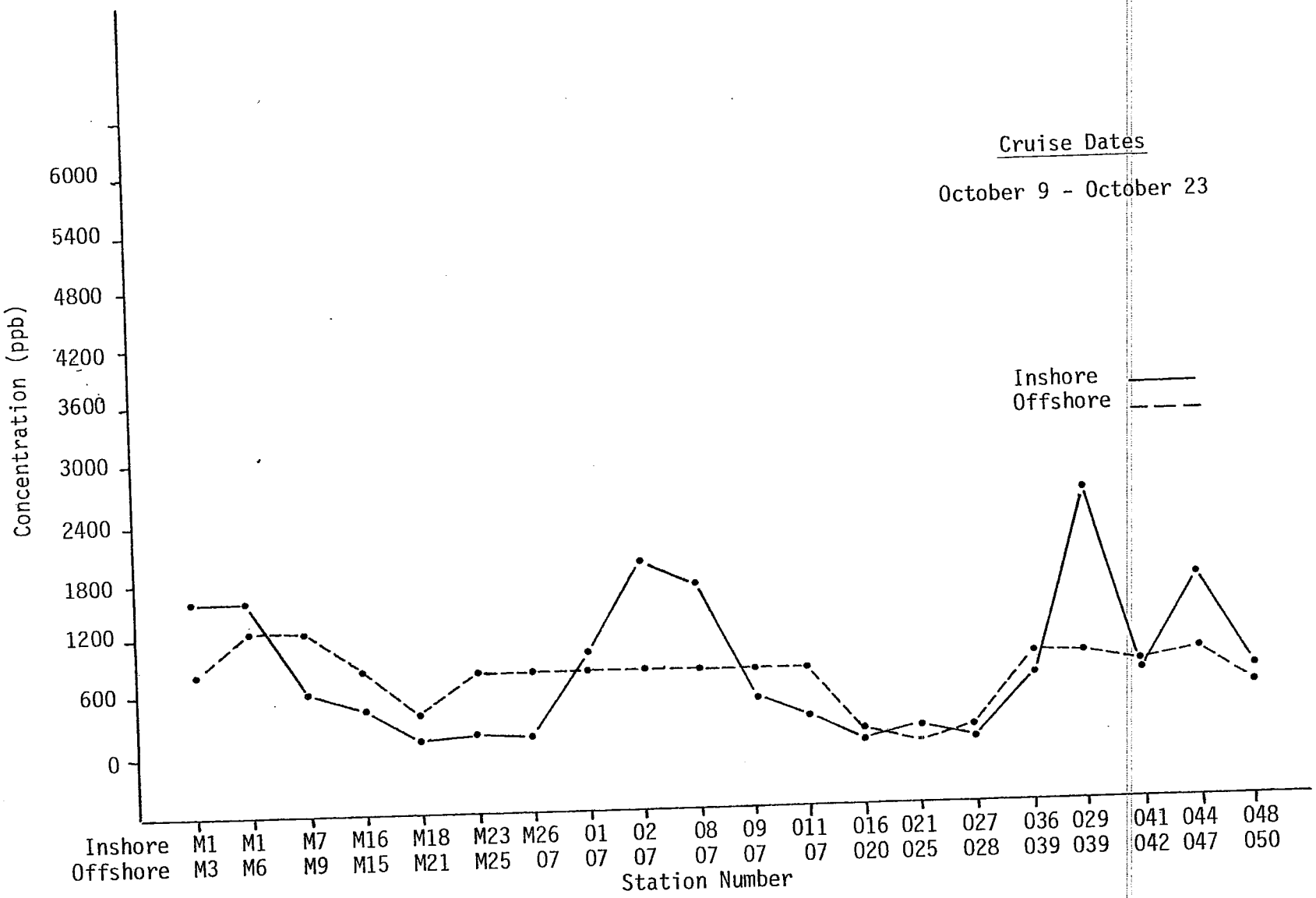
Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 1 of 1979.



Soluble Reactive Silica Concentration at Inshore and Offshore Stations for Cruise 2 of 1979.



Silica Concentration at Inshore and Offshore Stations for Cruise 3 of 1979.



Silica Concentration at Inshore and Offshore Stations for Cruise 4 of 1979.