SOUTH FLORIDA RESEARCH CENTER

Report T-653
An Analysis of Surface Water Nutrient Concentrations in the Shark River Slough, 1972-1980

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Everglades National Park, located at the southern tip of Florida, consists of an area of 5633 km^2, more than 90%, of which is either permanently or seasonally inundated by water. The Shark River Slough is the largest freshwater flow system in the park (991 km^2). It serves as an important area for water storage and recharge to the Biscayne aquifer, provides critical habitat for a diverse assemblage of marsh dwelling fauna and flora, and acts as a major source of freshwater input into the estuarine areas of Everglades National Park.

The Shark River Slough, as it exists today, is the southernmost remnant of a much larger freshwater drainage system, which once flowed unimpeded from the Kissimmee River drainage towards the southwest, across the southern third of Florida and into the Gulf of Mexico.

Extensive man-made alterations to the natural flow pattern for the purposes of flood control, land reclamation and water storage have greatly altered the hydrological regime north of Everglades National Park. The once unregulated slow moving sheetflow regime is now a complex system of levees, canals, water storage impoundments and water control structures (Figure 1) which influence both the quantity and quality of water entering the Shark River Slough.

Today, the area that once comprised the historical Everglades south of Lake Okeechobee can be divided into three functional areas. The Everglades Agricultural Area (EAA) immediately south of Lake Okeechobee is a highly productive agricultural area of about 2850 km^2. Of this, approximately 75% of the area has been developed into agricultural usage supporting three principle crops including sugar (45%), pasture (20%) and vegetable crops (10%). Most of the remaining 25% is undeveloped, with less than 5% consisting of the urban areas of Clewiston, South Bay and Belle Glade (Dickson et al., 1978).

The five water conservation areas of the South Florida Water Management District (SFWMD) are located south of the Everglades Agricultural Area. These water conservation areas consist of approximately 4,750 km^2 of marsh-type wetlands that were once part of the historic Everglades. Today, a network of canals, levees, gates and pumps encircle the system and allow the artificial manipulation of water levels within and throughout these areas for the purposes of flood control and water storage.

Everglades National Park, located south of the conservation areas is the third functional area. Conservation Area 3A, and its associated delivery canals form the northern boundary of the present day Shark River Slough and serve as the major source of surface water inflow into the slough. Under an agreement derived by the United States Congress, through its Committee on Public Works, a minimum annual water delivery of 260,000 acre feet is guaranteed to the slough from the conservation areas and canals to the north (U.S. Senate, 1970).

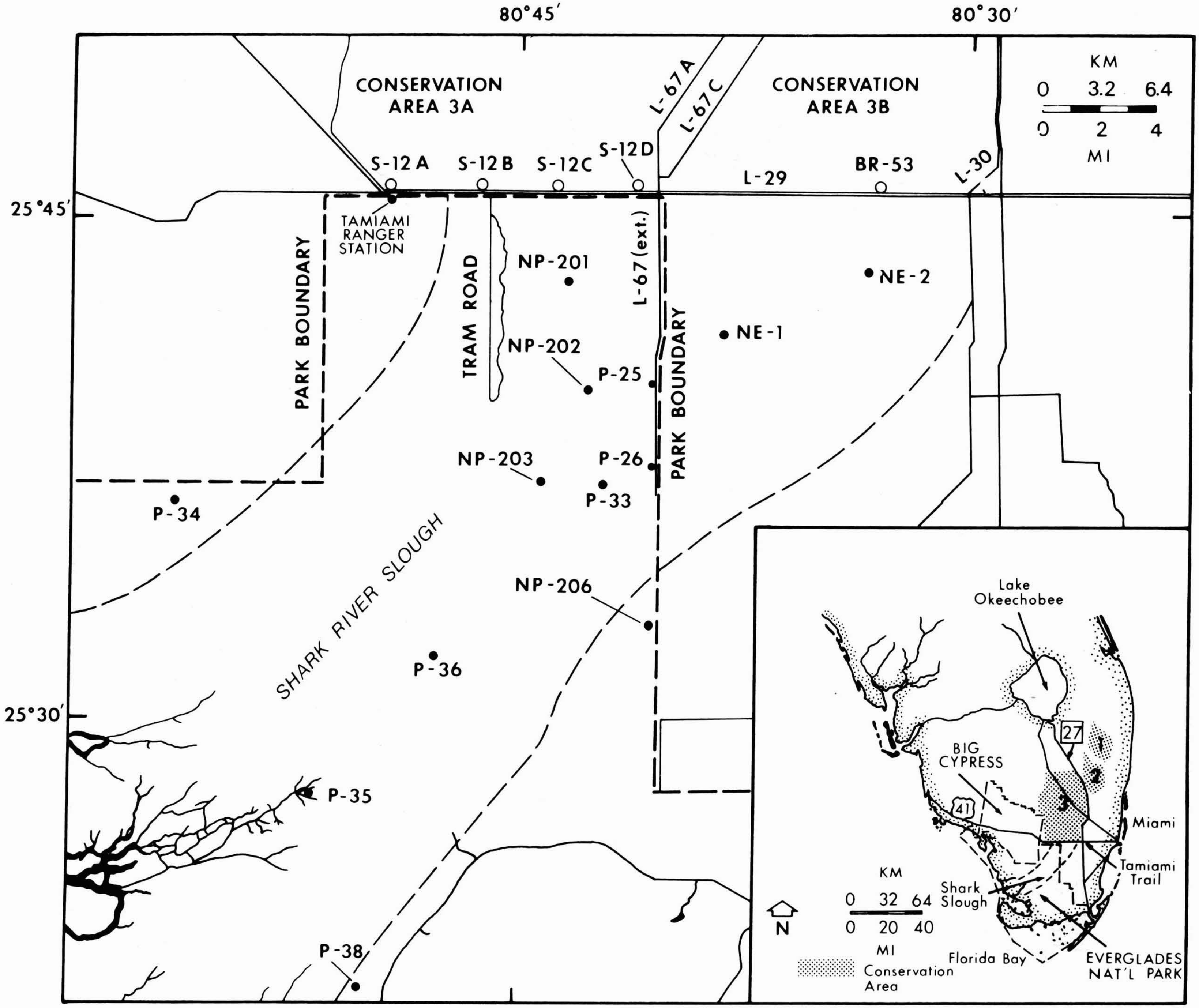

Figure 1: Map of the Shark River Slough, Everglades National Park.

Surface water nutrient concentrations as well as nutrient import and export budgets vary significantly from area to area, largely as a function of watershed usage. Surface water quality and nutrient budgets for the Everglades Agricultural Area have previously been addressed by both the U.S. Geological Survey (McPherson, et al., 1976) and the South Florida Water Management District (Dickson, et al., 1978). Both of these studies reported elevated surface water nutrient concentrations in the Everglades Agricultural Area, presumably as a result of agricultural activity.

Nutrient inflow and outflow budgets for the water conservation areas have been computed for July, 1972-June, 1973 (Waller, 1975) and 1978-1979 (Millar, 1981). In addition, the overall surface water quality in the conservation areas have previously been discussed by Freiberger (1972), McPherson (1973) and Waller and Earle (1975), while the effects of water quality on periphyton have been studied by Swift (1981). These waters, whose source are a combination of precipitation and surface inflow from the north, have nutrient concentrations generally lower than that found in the Everglades Agricultural Area, but which may be locally elevated in canals and areas influenced by surface inflow from the Everglades Agricultural Area (Millar, 1981).

While limited surface water nutrient data have been available for the Shark River Slough since the mid-1960's, little of this information has been published. Goolsby et al. (1976) reported on a few nutrient parameters in the Shark Slough region from 1966-1971. Joyner (1973) and Miller (1975) further list nutrient concentrations in the slough, but make no attempt at cause and effect analysis. McPherson (1970) completed a hydrobiological assessment for the Shark River estuary but nutrient parameters were not addressed.

It is not until 1972 that the systematic analysis of the most important nutrient parameters including total ammonia, total nitrite, total nitrate, total organic nitrogen, total orthophosphorous, total phosphorous, total inorganic carbon, total organic carbon and total carbon was begun as a cooperative National Park Service (NPS)/U.S. Geological Survey (USGS) effort. Data from this program have been incorporated into the national USGS WATSTORE data base.

It is the purpose of this paper to utilize this data base in order to assess surface water nutrient conditions in the Shark River Slough from 1972-1980. Seasonal (wet vs. dry), geographic (station vs. station) and temporal (year vs. year) trends will be discussed for both stations located within Shark Slough (P-33, P-34, P-35, P-36, P-38, NP-201, NP-202, NP-206, NE-1, NE-2) and those stations located in the delivery canal adjacent to the slough (S-12A, S-12B, S-12C, S-12D, P-25, P-26, Br-53). In addition, nutrient concentrations recorded in the slough and delivery canal stations in 1978 and 1979 will be compared with those found in the conservation areas during a comprehensive water quality study completed by the South Florida Water Management District (Millar, 1981).

METHODS

The analysis of a complete nutrient data set was begun in the Shark River Slough in 1972. During the early phases of this program (July 1972-May 1975) nutrient analysis was accomplished on apporoximately monthly basis at delivery canal stations S-12A, S-12C, S-12D and Bridge 53 and on a less regular basis at P-33, P-34, P-35, P-36 and P-38 located in the Shark River Slough proper and S-12B located in the delivery canal (Figure 1).

Little sampling was completed from May 1975 until June 1978 when a systematic, semi-annual water quality sampling program was initiated throughout Everglades National Park. This new program, designed to monitor change in the long-term water quality trends within the park was tied into the annual hydrological cycle with sampling occurring during rising water and falling water periods as determined by the hydrograph at P-33. Additionally, several new stations were added to the monitoring network at this time including NP-201, NP-202, and NP-206 located in the slough; NE-1 and NE-2 located in northeast Shark Slough; and P-25 and P-26 located in the L-67 extended canal.

Nutrient parameters monitored as part of this study include total ammonia nitrogen (USGS 00610), total nitrite nitrogen (USGS 00615), total nitrate nitrogen (USGS 00620), total organic nitrogen (USGS 00605), total nitrogen (USGS 00600), total orthophosphate phosphorus (USGS 70507), total phosphorus (USGS 00605), total inorganic carbon (USGS 00685), total organic carbon (USGS 00680) and total carbon. In addition, stage and specific conductance (USGS 00005) were utilized to assess wet season vs. dry season environmental conditions.

Analysis of these water samples for nutrient parameters was accomplished by the U.S. Geological Survey at laboratories in Ocala, Florida and Atlanta, Georgia according to USGS methods published in Methods for Determination of Inorganic Substances in Water and Fluvial Sediments (USGS, 1979) and Standard Methods for the Analysis of Water and Wastewater (APHA, 1979). The results of these analyses were provided to the National Park Service for analysis in the form of a WATSTORE data retrieval. These data were used for the subsequent evaluation.

The distinction between wet season and dry season environmental conditions was made in two separate ways. For canal stations, wet season conditions were said to predominate during the months of May-October when more than 80% of the rainfall occurs in south Florida. Dry season conditions were said to be predominant during the other six months of the year.

For slough stations, wet season and dry season conditions were based upon stage and specific conductance data and varied from year-to-year and from station-to-station. Wet season conditions were said to prevail at a station when the water level was greater than 0.5 ft above the ground surface elevation of the station and when specific conductance was less than 700 umhos/cm^2. Conversely, dry season conditions resulted when the water level fell below 0.5 ft above ground surface elevation and specific conductance rose above 700 umhos/cm^2.

By selecting seasonal conditions based upon water level and specific conductance, a more responsive and accurate analysis was possible. While rainfall in the slough does follow distinct seasonal patterns, rainfall amounts do vary from year-to-year. In some years, the slough begins to dry as early as February, and in other years not at all. Similarly, the onset of dry season environmental conditions does, to an extent, depend upon the geographic location and elevation of the station. Stations at higher elevations, on the edge of the slough tend to exhibit dry season conditions earlier than those of lower elevation in the central slough.

Wet season and dry season mean concentrations and standard deviations were then determined for all parameters. An Analysis of Variance (Sokal and Rohlf, 1970) statistical evaluation was made utilizing a standard program on the Wang 2200 computer system in order to identify data trends for all parameters; seasonally (wet season vs. dry season), geographically (among the stations) and temporally (from year-to-year). When significant variability is noted, data are plotted to assess the trend (i.e., positive vs. negative etc.), and where possible, cause and effect mechanisms are proposed.

Maps showing the geographic distribution of mean wet season concentrations are constructed for many nutrients for the years 1972, 1978, 1979 and 1980. These maps are especially useful in 1978 and 1979 when nutrient concentrations can be compared to those of the three conservation areas reported by Millar (1981).

RESULTS

Nitrogen

Nitrogen in a freshwater marsh system such as the Everglades, occurs in many forms including ammonia, nitrite, nitrate, and a large number of organic forms commonly analyzed collectively as total organic nitrogen. This analysis addresses those forms commonly considered most readily available for primary biological uptake (ammonia and nitrite + nitrate, as well as total nitrogen which is the sum of the concentrations of ammonia, nitrite, nitrate and total organic nitrogen.

Sources of nitrogen in the everglades system include atmospheric sources, nitrogen fixation in both the water and sediments and inputs from surface and groundwater inflow. Nitrogen losses from the system include nutrients taken up from the water plants (and subsequently temporarily stored), nitrogen lost through denitrification and sediment accumulation, and nitrogen exported through outflow of water into the Shark River estuary.

Nutrient input from atmospheric sources including precipitation and dryfall are highly variable and respond to both meteorological conditions and the location of the watershed to natural and man-made sources. In south Florida, nutrient concentrations in rainfall have been reported by Joyner (1974), Waller and Earle (1975), Irwin and Kirkland (1980) and others. While some bulk precipitation nutrient data are available for the Shark River Slough, significant improvements in collection methodology over the last several years leaves earlier atmospheric input data open to question. Improved wetfall/dryfall collectors and analytical methodology conforming to nationally prescribed standards are currently being utilized at stations located throughout south Florida including the South Florida Research Center at Everglades (NPS/National Atmospheric Deposition Program), the Tamiami Ranger Station (Environmental Sciences and Engineering, Gainesville, Florida) and at the Audubon Corkscrew Sanctuary (University of Florida, Gainesville, Florida). It is anticipated that these stations will establish long-term trends and regional variability in the nutrient concentration of rainfall that can be applied to the Shark River Slough. In addition the SFWMD also collects rainfall nutrient data in South Florida with which they calculate nutrient loading in the conservation areas (Dickson et al., 1978; Millar, 1981).

The amount or importance of the in situ fixation of nitrogen in slough waters and sediments has not been quantified in the everglades system. However, a comparative review of nitrogen fixation in other shallow freshwater systems (Hardy, 1973) suggests that nitrogen fixation by blue-green algae may contribute an appreciable amount of nitrogen to a shallow, warm, low nutrient system such as the Everglades.

While the role of plant uptake of nitrogen and denitrification in wetland soils are generally acknowledged as being significant, the precise mechanisms employed and accurate quantification are still lacking. Bartlett et al. (1979) discuss the function of wetland soils as important denitrifiers. Steward and Ornes (1975), Frederico et al. (1978) and Davis (1981) all discuss the natural removal of nutrients by slow-flowing marsh systems. Additionally, flowing wetland systems which possess a sufficient soil depth have successfully been utilized in central Florida to remove nutrients from secondarily treated effluent (Zoltek et al., 1979; Dolan et al., 1981).

Mean annual wet season and dry season ammonia (NH_4), nitrite + nitrate (NO_2 + NO_3), and total nitrogen concentrations are presented for delivery canal and slough stations in Tables 1-3. An analysis of these data show that mean annual concentrations of ammonia, nitrite, nitrate and total nitrogen vary significantly ($p = .05$) between wet season and dry season for all stations within the slough (Table 4). Seasonal variability, however, was found to be significant in the canal stations only for ammonia and not for either nitrite + nitrate or total nitrogen. This difference in seasonal variability between the slough stations and canal stations can be attributed to environmental conditions. During the dry season, the few remaining pools in the slough tend to concentrate wildlife. This increased biological density coupled with increased evaporation serves to increase nutrient

Table 1. Mean wet season and mean dry season NH_4-N (mg/l) for Shark Slough and delivery canal stations (1972-1980).

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	.17	.06	.48	.10	.08						.06	.82	.04	.06			.76
1973	.15	.04	.32	.08							.03	.21	.03	.03			.56
1974											.03	.21	.05	.05			.61
1975	.05	.07	.07										.02				
1976	.03	.03											.13				
1977	.08							.03					.10				
1978	.03	.06	.04	.01	.02	.02		.06	.09	.04			.03	.03	.01	.03	.52
1979	.05	.03	.06	.00	.00	.02	.09	.03	.11	.03	.03		.03	.02	.02	.04	.45
1980	.10	.04	.24	.04	.05	.06	.10	.02			.03		.03	.02	.04	.03	.20
Dry Season:																	
1972	.10	.06	1.20		1.10												
1973	.20	.05		.26	.12						.25	.28	.20	.11			.60
1974	.79	.13		.24							.10	.13	.15	.10			.54
1975	1.00	.15	1.60	.46							.17	1.10	.18	.06			.46
1976												.47	.28	.15			
1977	1.60	.18										.24	.23				
1978													.08			.05	.61
1979																.05	.41
1980																.05	.42

Table 2. Mean wet season and mean dry season $NO_2 + NO_3$-N (mg/l) for Shark Slough and delivery canal stations (1972-1980).

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	.03	.03	.03	.20	.06						.01	.36	.03	.07			.01
1973	.00	.01	.02	.01							.02	.01	.02	.20			.03
1974											.02	.01	.41	.44			.06
1975	.01	.02	.02														
1976	.01	.01											.47				
1977	.01							.00									
1978	.01	.01	.01	.01	.00	.00		.08					.01	.02	.04	.02	.03
1979	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.01		.01	.02	.04	.13	.02
1980	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.01		.01	.02	.03	.02	.02
Dry Season:																	
1972	.01	.02			.04							.05					
1973	.00	.02	.01	.01	.02						.10	.02	.14	.16			.03
1974	.05	.01		.43							.14	.02	.13	.12			.08
1975	.02	.03	.16	.06							.10	.00	.15	.08			.02
1976												.11	.15	.15			
1977	.02	.13										.03	.49				
1978													.27			.02	.05
1979																.05	.05
1980																.05	.03

Table 3. Mean wet season and mean dry season total nitrogen as -N (mg/l) for Shark Slough and delivery canal stations (1972-1980).

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	1.60	1.20	2.31	2.30	0.75						1.97	4.08	1.44	1.76			1.15
1973	1.65	1.60	2.10	0.97							1.35	1.62	1.19	1.72			0.91
1974											1.43		2.08	2.20			3.22
1975	1.86	1.20	2.20														
1976	2.24	1.40											2.20				
1977	1.79							0.53					1.39				
1978	1.65	1.20	1.55	1.00	0.80	1.85		0.83	2.04	1.96			1.35	1.35	1.20	1.20	1.87
1979	1.95	1.00	1.95	0.89	0.61	2.10	2.30	0.88	1.97	1.59	1.35		1.50	1.85	1.80	1.88	2.04
1980	1.60	1.07	1.00	1.18	0.66	1.55	1.55	1.87			1.00		1.00	1.20	1.30	1.15	1.25
Dry Season:																	
1972	3.51	4.38	4.60	0.57								1.10					
1973	2.60	1.82		2.70							2.01		1.91	1.77			1.68
1974	10.00	8.64		1.70							2.03	1.75	2.03	1.96			1.80
1975	1.90	2.20	13.00								1.88		1.85	1.48			1.83
1976												3.10	2.15	1.84			
1977	13.00	2.80										2.50	2.22				
1978													1.65			1.30	1.65
1979																1.57	2.72
1980																1.75	2.13

Table 4. Results of analysis of variance evaluation for significant variability, seasonally, temporally and geographically for NH_4, NO_2 + NO_3 and total nitrogen.

	NH_4	NO_2 + NO_3	Total Nitrogen
Wet season vs. dry season (slough stations)	SIG	SIG = .05	SIG
Wet season vs. dry season (canal stations)	SIG	NS	NS
Station vs. station (wet season slough stations)	NS	NS	SIG
Station vs. station (wet season canal stations)	SIG	NS	NS
Station vs. station (wet season canal stations without S-12B and Br-53)	NS		
Year vs. year (wet season slough stations)	NS	SIG = .05 NS = .01	NS
Year vs. year (wet season canal stations)	NS	SIG = .05 NS = .01	NS
Slough vs. canal (wet season all stations)	NS	SIG	NS

SIG = Significant Variability
NS = Not Significant

Note: One way analysis of variance for groups of unequal size was computed according to the methods prescribed by Sokal and Rohlf (1970). Significance was determined at the P = .05 and P = .01 level utilizing F- value significance tables of Rohlf and Sokal (1970).

concentrations many times above wet season levels. While biological concentration also occurs during the dry season in the canals, its effects are not as pronounced as those found in the shallower slough.

A temporal analysis (1972-80) of ammonia, nitrite + nitrate and total nitrogen in both slough and canal stations (Figure 2 and Table 4) indicates that there has been no temporal trend in either ammonia or total nitrogen concentrations. Mean annual wet season ammonia in the slough ranged from .03 mg/l in 1976 to .18 mg/l in 1972. Mean annual wet season ammonia in the delivery canal stations S-12A, S-12C and S-12D showed less variability and ranged from .03 mg/l in 1979 to a maximum of .05 mg/l in 1972. While no significant variability was found between the ammonia data for the slough and that of the delivery canal, significant variability did exist among two sets of canal stations, one consisting of S-12A, S-12C and S-12D and a second consisting of S-12B and Br-53 (Figure 3 and Table 4). Mean annual wet season ammonia was significantly higher at canal stations Br-53 ($\bar{x}$ = .52 mg/l) and S-12B ($\bar{x}$ = .41 mg/l) than it was for canal stations S-12A ($\bar{x}$ = .04 mg/l), S-12C ($\bar{x}$ = .05 mg/l) and S-12D ($\bar{x}$ = .04 mg/l). These increased ammonia concentrations were found throughout the period of this study (though S-12B was only sampled from 1972-1975). The reason for higher ammonia concentrations at Br-53 and S-12B is possibly related to the close proximity of human habitations (i.e., Coopertown near Br-53, Miccosukee Texaco and restaurant at S-12B) at these locations. Figure 3 shows that mean annual ammonia are similar in slough stations P-33 and P-35 and canal delivery stations S-12D.

Mean wet season ammonia concentrations are presented for canal delivery stations and slough stations for 1972, 1978, 1979 and 1980 (Figure 4). These data indicate that with the exception of canal stations S-12B and Br-53, mean wet season ammonia concentrations are generally less than 0.1 mg/l. An exception to this was sometimes found at P-36 (1972 and 1980) a station located in central Shark Slough, but the reason for the higher concentrations at this location are not known.

Mean wet season total nitrite and nitrate concentrations were generally less than .04 mg/l (Table 2). Temporally, mean wet season total nitrite + nitrate concentrations varied significantly at p = .05, but not at p = .01 for both slough and canal delivery stations. This variability was brought about by elevated nitrite + nitrate concentrations in the slough during 1972 ($\bar{x}$ = .07 mg/l) and in the canal delivery stations during 1972, 1973 and 1974 ($\bar{x}$ = .12 mg/l). Significantly lower nitrite + nitrate concentrations have been found in both the slough and delivery canal since 1978.

While total nitrite + nitrate concentrations did not vary significantly either among slough stations or canal delivery stations, the nitrite + nitrate concentrations were significantly lower in the slough stations when compared to the delivery canal stations. Since 1978, the mean wet season nitrite + nitrate concentrations in the slough averaged .013 mg/l while that found in the delivery canal averaged .027 mg/l. Presumably, the lower concentrations in the slough are the result of

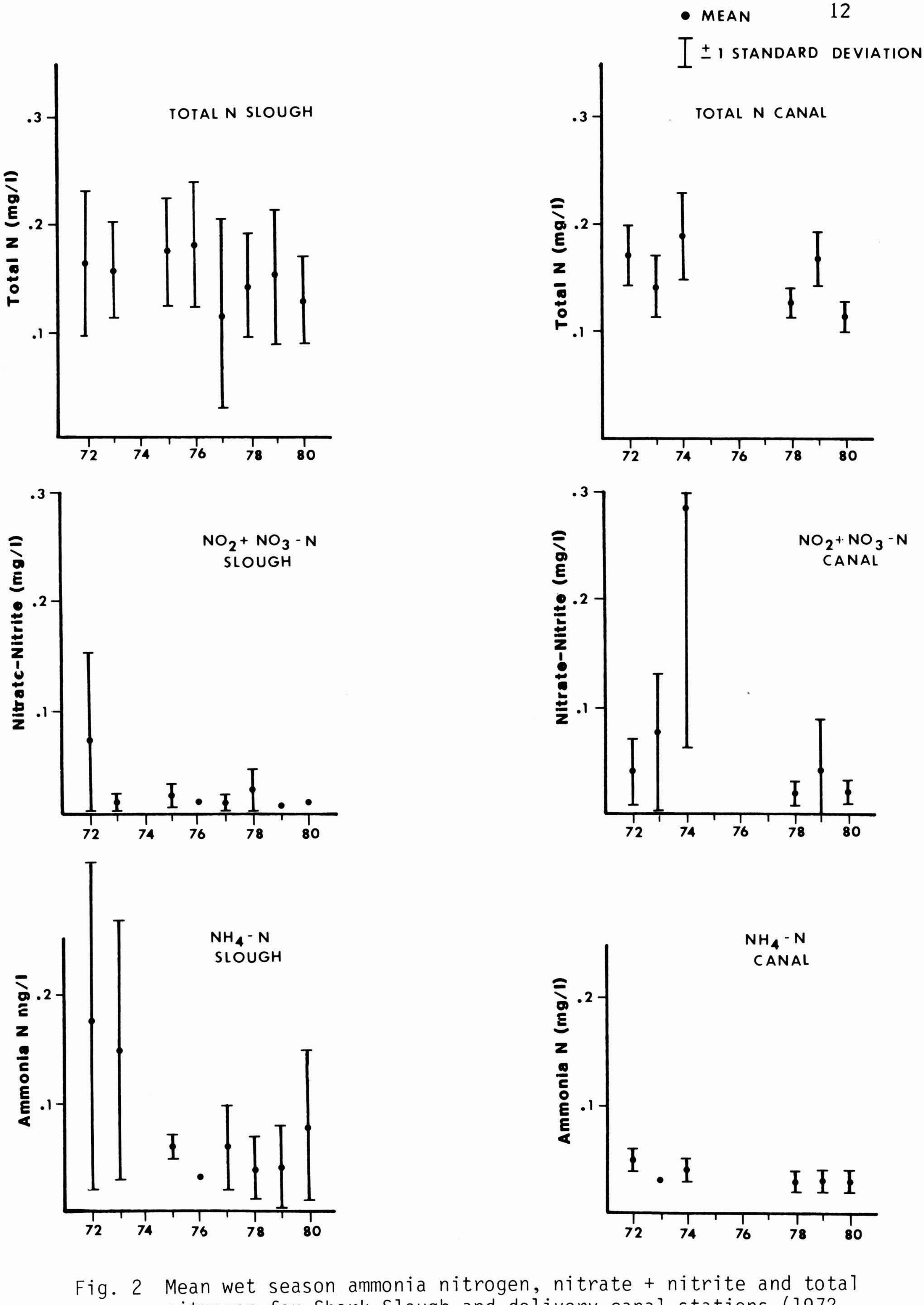

Fig. 2 Mean wet season ammonia nitrogen, nitrate + nitrite and total nitrogen for Shark Slough and delivery canal stations (1972-1980).

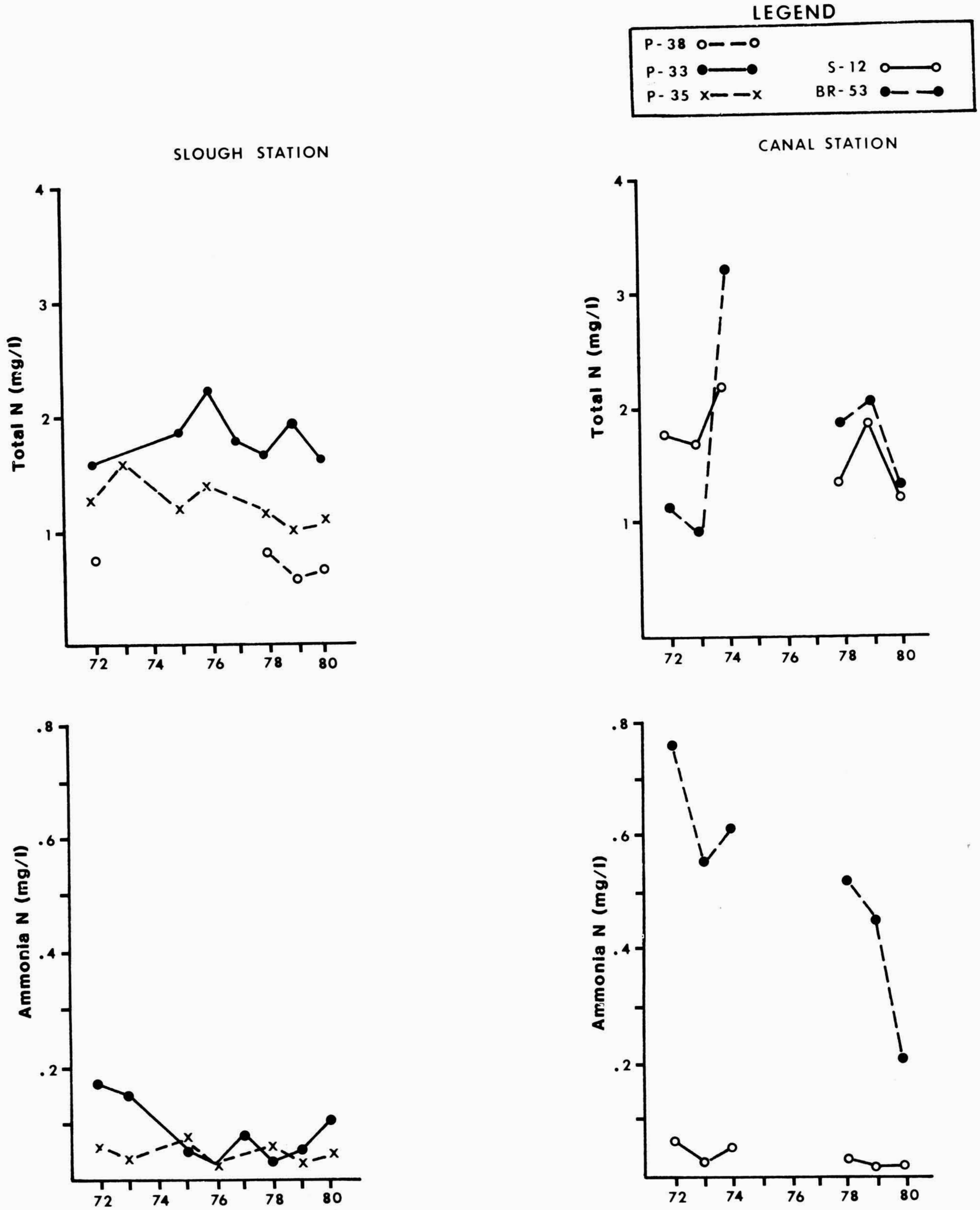

Fig. 3 Mean annual wet season ammonia and total nitrogen concentrations for selected slough and delivery canal stations (1972-1980).

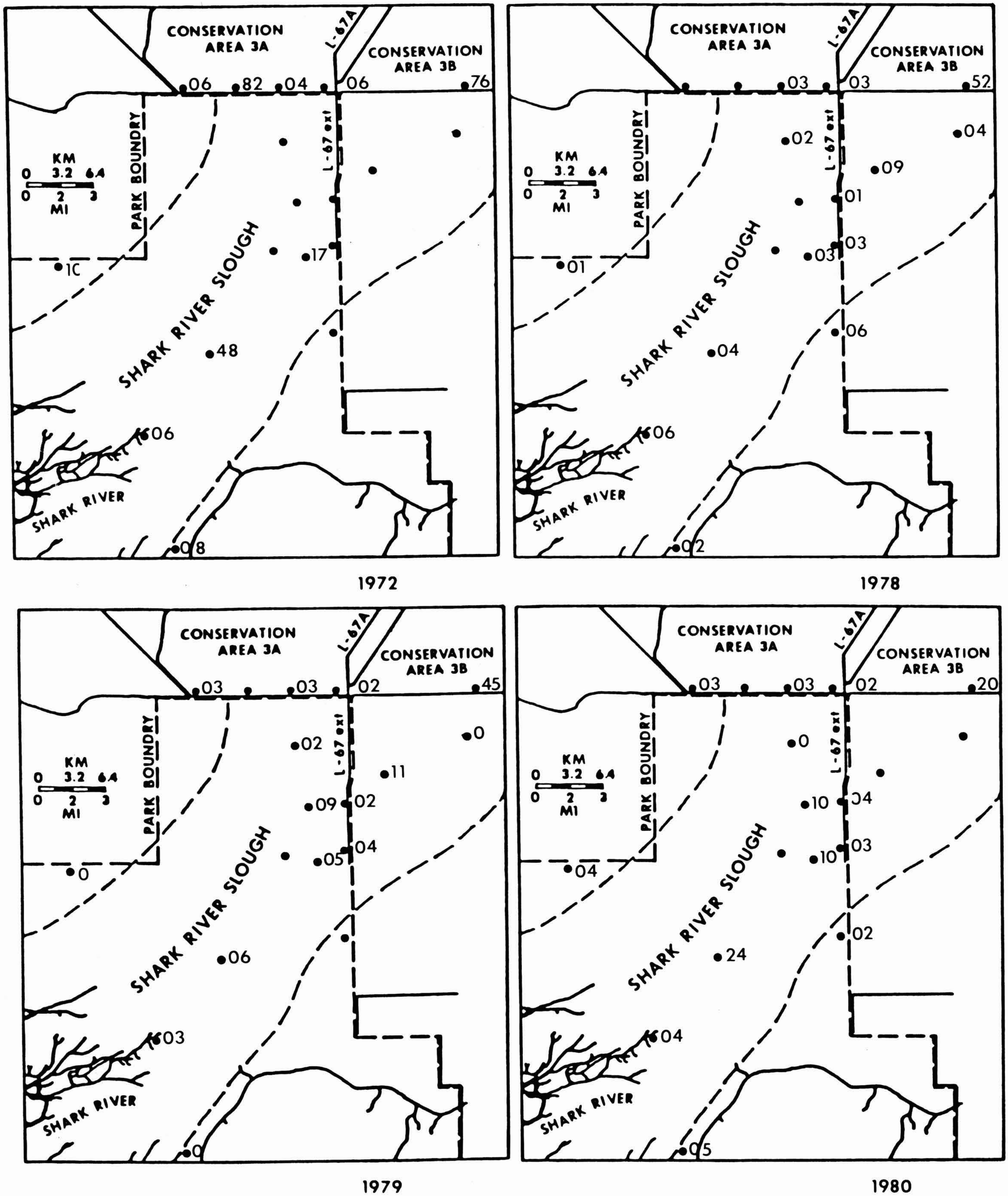

Fig. 4 Mean wet season ammonia nitrogen concentration (mg/l) in Shark Slough, 1972, 1978, 1979 and 1980.

greater primary production uptake by periphyton. However, in both canal and slough stations the concentrations are extremely low. Figure 5 presents mean wet season nitrite + nitrate concentrations for 1972, 1978, 1979 and 1980.

Mean wet season and dry season total nitrogen concentrations, like those of total nitrite + nitrate significantly varied seasonally in the slough but not in the delivery canal stations (Tables 3 and 4). Mean total wet season nitrogen in the slough ranged from a low of 1.16 mg/l in 1977 to a maximum of 1.82 mg/l in 1976. These levels for the slough did not vary significantly from those found at the delivery canal sites which ranged from 1.15 mg/l in 1980 to a maximum of 2.08 mg/l in 1972 (Figure 2).

Mean wet season total nitrogen did, however, vary significantly ($p = .05$) among stations located in the slough (Tables 3 and 4). Stations NP-206, P-38, P-34 and P-35 had consistently lower concentrations than either slough stations or the canal delivery stations. Mean wet season total nitrogen for 1972, 1978, 1979 and 1980 are presented in Table 6.

An analysis of surface water nitrogen concentrations throughout the south Florida system for 1978-1979 is possible by comparing the data presented in this study with that reported for the conservation areas by the South Florida Water Management District (Millar, 1981). This report indicates that water quality in the conservation areas is largely a function of the land use of the drainage basins which flow into the area. Thus, as might be expected, the nitrogen concentrations of surface inflows into the Water Conservation Areas from the Everglades Agricultural Area are relatively high due to both the organic nature of the soils and the buildup of years of fertilizer use (Waller and Earle, 1975). The highest total nitrogen concentrations in the conservation areas were found at structures S5A (5.32 mg/l) and S5AS (5.20 mg/l) at the north end of Conservation Area 1, and generally decreased as the water flowed south.

For water conservation area stations monitored by the South Florida Water Management District, the two year mean (1978-79) for total nitrogen ranged from a low of 1.44 mg/l for the L-28 Interceptor Canal in the Big Cypress to 5.32 mg/l at S5A (agricultural). During this same period the total nitrogen concentration within the Shark River Slough ranged from 0.61 mg/l at P-38 to 2.10 mg/l at NP-201.

Phosphorus

Like nitrogen, many different forms of inorganic and organic phosphorus occur in natural freshwater systems. Unlike nitrogen, however, there is only one important form of inorganic phosphorus, known as orthophosphorus (PO_4). The most important quantity, however, in terms of the metabolic characteristics of a freshwater system, is the total phosphorus (TP) content of unfiltered water, which consists of phosphorus in suspension as particulate matter and dissolved phosphorus (Juday, 1927). In this analysis we discuss both total orthophosphorus (PO_4) and total phosphorus (TP).

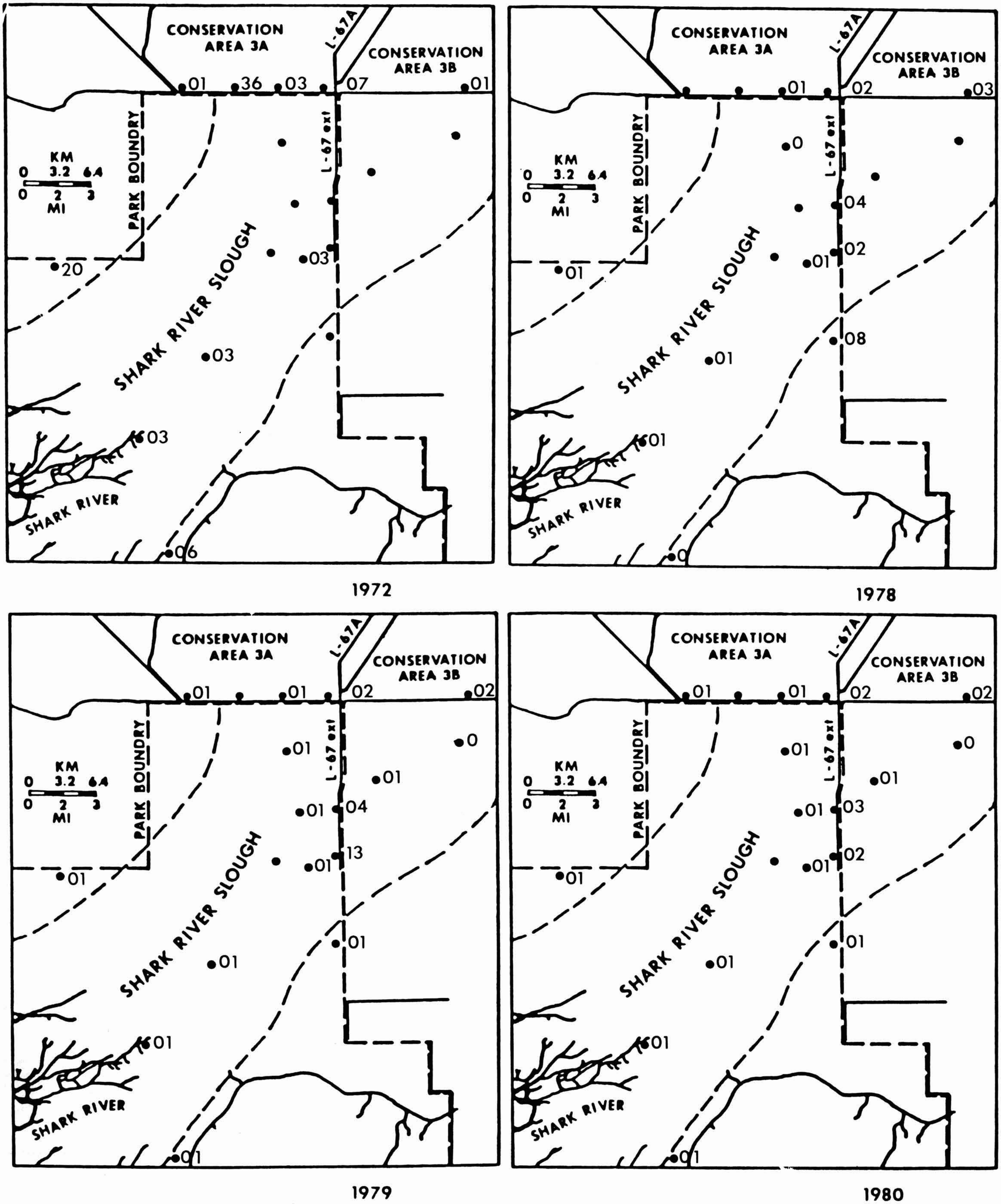

Fig. 5. Mean wet season nitrite + nitrate concentrations (mg/l) in Shark Slough, 1972, 1978, 1979, and 1980.

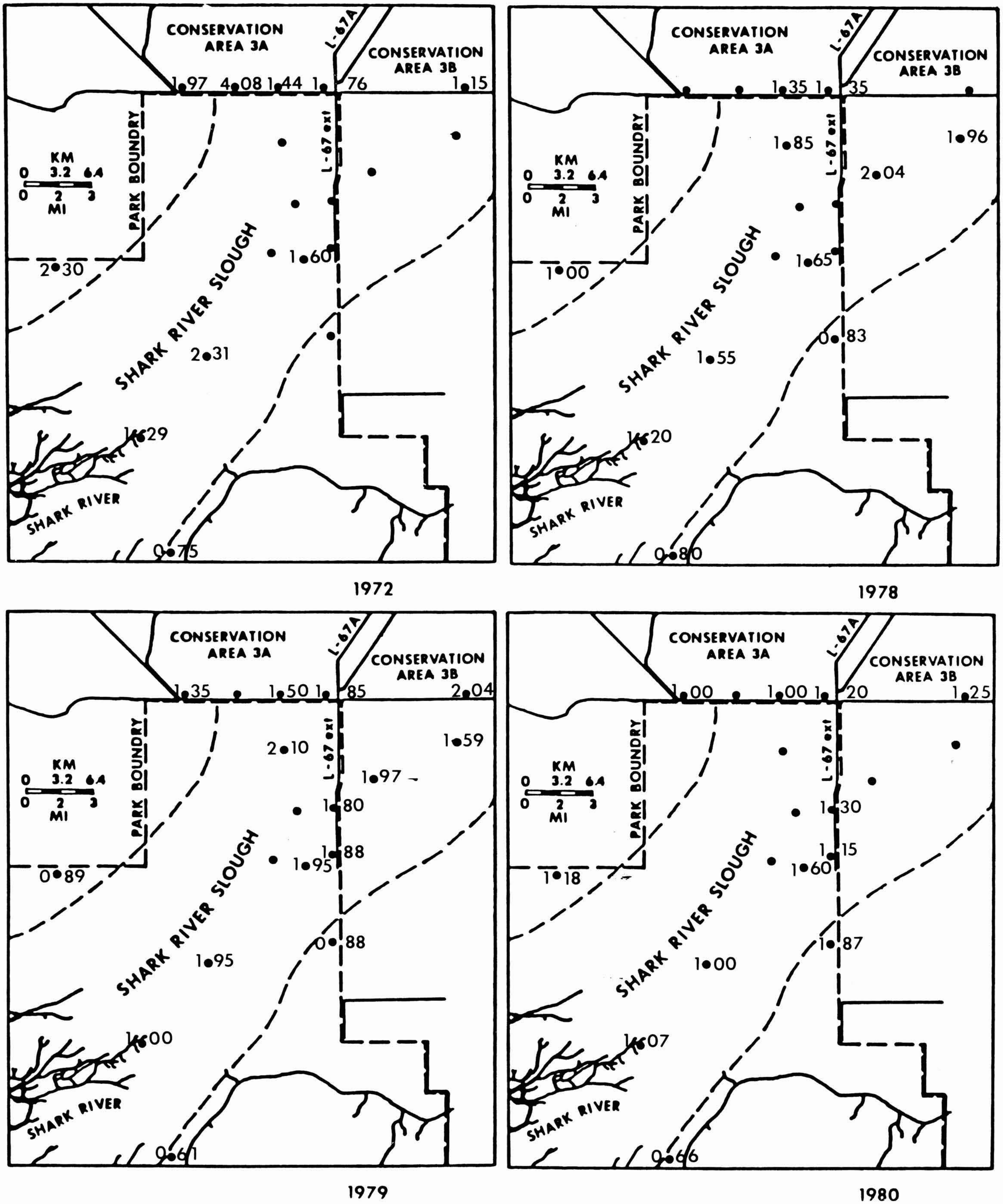

Fig. 6 Mean wet season total nitrogen concentrations (mg/l) for Shark Slough 1972, 1978, 1979, 1980.

Total phosphorus concentrations in most uncontaminated surface waters range from .010 mg/l to .050 mg/l (Wetzel, 1975). Vollenweider (1968) demonstrates that the amount of total phosphorus generally increases with system productivity and that lakes exhibiting less than .010 mg/l total phosphorus are usually oligotrophic while those containing more than .100 mg/l total phosphorus are usually hyper-eutrophic.

In the Shark River Slough, mean wet season concentrations (1972-1980) of orthophosphorus and total phosphorus are low, with mean wet season orthophosphorus ranging from .001 mg/l in 1978 and 1979 to .013 mg/l in 1973 (Table 5). Similarly, mean wet season total phosphorus ranged from .007 mg/l in 1975 to .023 mg/l in 1973 (Table 6).

Concentrations of orthophosphorus and total phosphorus at the canal delivery sites are also low, ranging from .002 mg/l in 1978 to .030 mg/l in 1973 for orthophosphorus and from .013 mg/l in 1978 to .060 mg/l in 1973 for total phosphorus.

An analysis of variance evaluation of the mean wet season and mean dry season data (Table 7) indicates that both orthophosphorus and total phosphorus vary significantly by season in the stations located within the slough, but do not vary significantly seasonally at the canal delivery sites. It is probable that the higher dry season concentrations can be attributed to the seasonal concentration of wildlife around the remaining pools, and higher evaporation during the dry season, and that the effects of these are more pronounced in the slough than in the canal system.

A temporal analysis of mean wet season data indicates that there has been no significant change in orthophosphorus or total phosphorus concentrations from 1972 through 1980 at either slough stations or canal delivery sites (Table 7). Figure 7 shows that during this period orthophosphorus was generally less than .005 mg/l as P while total phosphorus was usually not greater than .015 mg/l as P.

A station-by-station analysis of orthophosphorus and total phosphorus data indicated no significant variability either between slough and canal stations or among the various stations of each group (Table 7). Figure 8 shows mean annual wet season concentrations on a year-to-year basis for representative stations located both in the slough and in the delivery canal system.

Figures 9 and 10 present mean annual wet season orthophosphorus and total phosphorus throughout the study area for the years 1972, 1978, 1979 and 1980. These data further show the low orthophosphorus and total phosphorus concentrations found in the Shark River Slough throughout the period of this study.

The distribution of total phosphorus concentrations in the water conservation areas north of the Shark River Slough are available for 1978-1979 (Millar, 1981). As with the total nitrogen data, total phosphorus concentrations are highest at those locations receiving drainage from the Everglades Agricultural Area

Table 5. Mean wet season and mean dry season total orthophosphorus as -P (mg/l) for Shark Slough and delivery canal stations (1972-1980).

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	.004	.005	.002	.001	.001						.006		.003	.003			.002
1973	.012	.010	.013	.020							.006	.110	.007	.006			.007
1974											.003	.005	.008	.006			.005
1975	.010	.000	.000										.012				
1976	.000	.000											.011				
1977	.000							.000					.007				
1978	.000	.000	.000	.000	.000	.000		.005	.001	.000			.000	.005	.000	.002	.002
1979	.000	.003	.005	.000	.000	.000	.000	.005	.001	.000	.005		.005	.010	.005	.003	.008
1980	.010	.005	.000	.005	.000	.010	.005	.000			.005		.000	.010	.015	.005	.015
Dry Season:																	
1972	.015	.107	.015		.020												
1973	.004	.001		.010							.016	.012	.009	.005			.004
1974	.030	.015		.040							.013	.005	.013	.010			.011
1975	.050	.007	.050	.010							.010		.012	.004			.002
1976												.010	.009	.005			
1977	.020	.030										.010	.010				
1978													.009			.005	.010
1979																.005	
1980																.003	

Table 6. Mean wet season and mean dry season total phosphorus as -P (mg/l) for Shark Slough and delivery canal stations (1972-80).

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	.013	.025	.002	.002	.002						.013		.011	.011			.010
1973	.034	.020	.015	.020							.016		.014	.011			.013
1974											.036	.020	.020	.024			.026
1975	.010	.010	.000														
1976	.010	.010											.034				
1977	.010							.010					.018				
1978	.005	.010	.015	.010	.000	.005		.020					.010	.010	.010	.023	.030
1979	.010	.040	.025	.010	.000	.010	.015	.015	.007	.010	.010		.015	.020	.020	.017	.014
1980	.010	.010	.010	.010	.015	.010	.010	.010	.010	.009	.010		.010	.011	.030	.015	.020
Dry Season:																	
1972	.015	.129	.050		.050												
1973	.004	.002		.004							.028	.025	.021	.260			.008
1974	.030	.020		.110							.032	.050	.030	.020			.019
1975		.010	.100	.010							.028		.050	.013			.023
1976												.020	.028	.023			
1977	.220	.100										.030	.030				
1978													.023			.015	.010
1979																.017	.032
1980																.015	.010

Table 7. Results of analysis of variance evaluation for significant variability seasonally, temporally and geographically for total orthophosphorus and total phosphorus.

	Total Orthophosphorus	Total Phosphorus
Wet season vs. dry season (slough stations)	SIG	SIG
Wet season vs. dry season (canal stations)	NS	NS
Station vs. station (wet season slough stations)	NS	NS
Station vs. station (wet season canal stations)	NS	NS
Year vs. year (wet season slough stations)	NS	NS
Year vs. year (wet season canal stations)	NS	NS
Slough vs. canal (wet season)	SIG = .05 NS = .01	SIG = .05 NS = .01

SIG = Significant Variability
NS = Not Significant

Note: One way analysis of variance for groups of unequal size was computed according to methods prescribed by Sokal and Rohlf (1970). Significance was determined at the P = .05 and P = .01 level utilizing F- value significance tables of Rohlf and Sokal (1970).

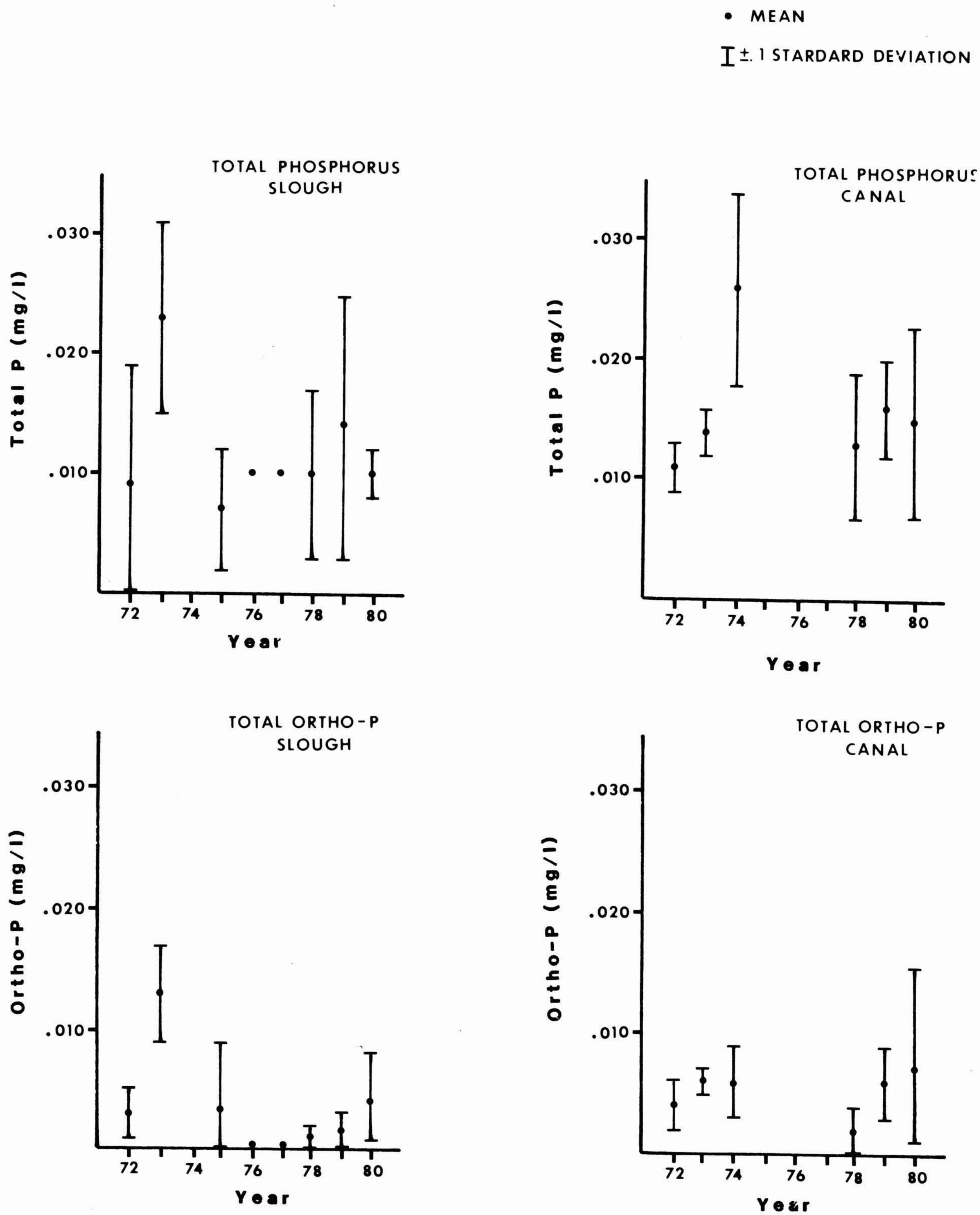

Fig. 7 Mean wet season orthophosphorus and total phosphorus for Shark Slough and delivery canal stations (1972 - 1980).

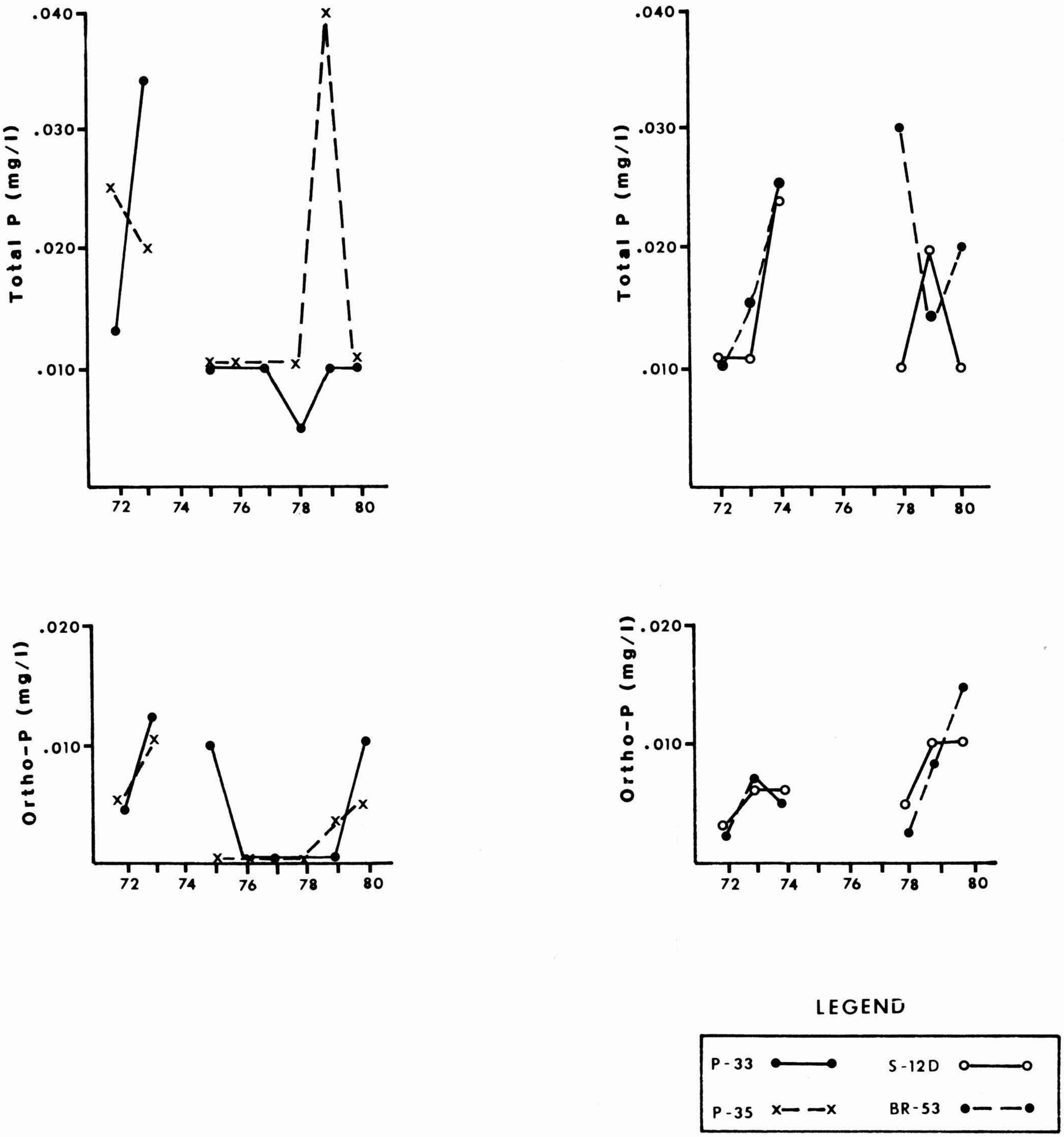

Fig. 8 Mean annual wet season orthophosphorus and total phosphorus for selected slough and canal stations (1972 - 1980).

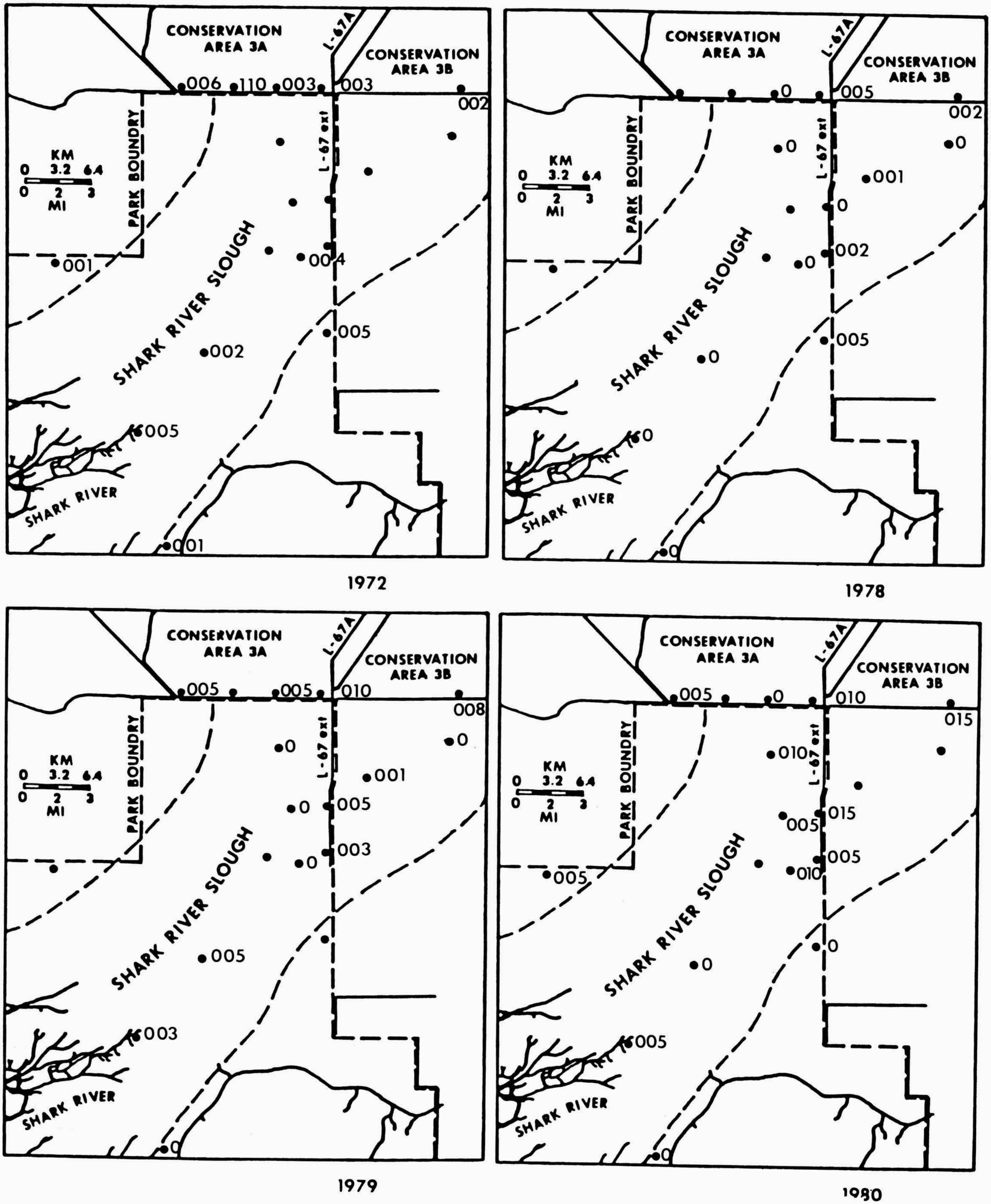

Fig. 9 Mean wet season total orthophosphorus concentrations (mg/l) in Shark Slough, 1972, 1978, 1979 and 1980.

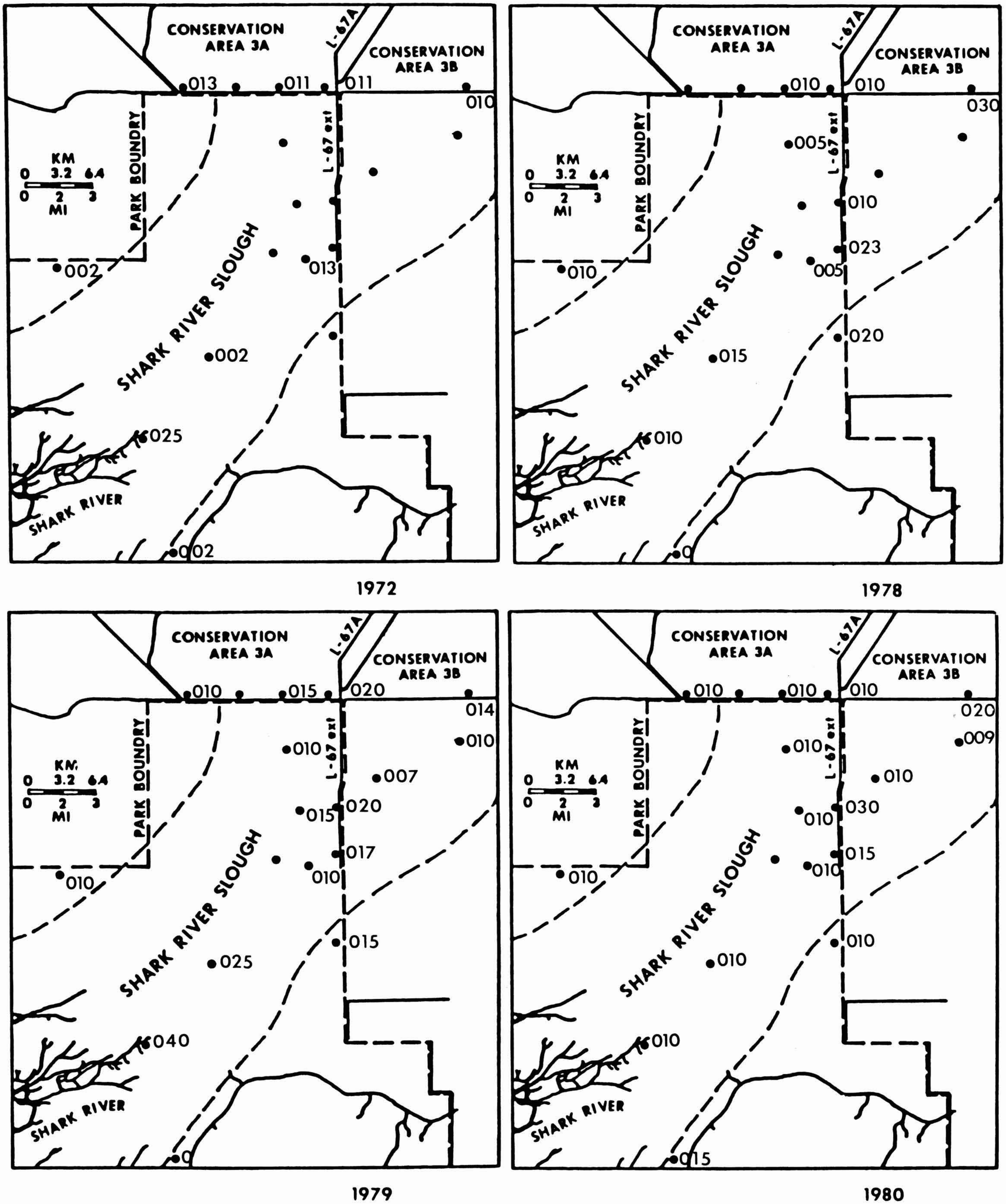

Fig. 10 Mean wet season total phosphorus concentrations (mg/l) in Shark Slough, 1972, 1978, 1979 and 1980.

(S5AS = 0.123 mg/l, S5A = 0.120 mg/l, S10D = 0.093 mg/l) and the lowest at the southern ends of Conservation Areas 2 and 3A (S3E = 0.008 mg/l, S14S = 0.008 mg/l, S-12A = 0.009 mg/l). These data indicate that the water conservation areas act as important filters for the nutrients being released from agricultural areas to the north.

Carbon

The bulk of dissolved carbon found in unpolluted freshwater systems occurs as dissolved inorganic carbon in the form of carbon dioxide, carbonate and bicarbonate. The complex equilibrium chemistry governing the predominance of particular forms is well known (Stumm and Morgan, 1970) and responds largely to pH.

While inorganic carbon constitutes a major nutrient of photosynthetic metabolism by both algae and submerged macrophytes, the huge atmospheric reservoir of available CO_2 assures that inorganic carbon is rarely the limiting nutrient in primary production. Because of the dynamic nature of the cycling of inorganic carbon, then, the concentration of inorganic carbon at any one location at any time is important only as an indicator of gross deviation from the natural system. Furthermore, because of the diurnal nature of photosynthesis much caution must be exercised when interpreting cause and effect relationships of changes in the concentrations of inorganic carbon.

Mean wet season total inorganic carbon (TIC) concentrations ranged from a low of 36 mg/l in 1978 to a maximum of 50 mg/l in 1972 for slough stations and from 33 mg/l (1973) to 41 mg/l (1978) at canal delivery station (Table 8). While significant seasonal variability was found at the slough stations, this was not the situation for delivery canal locations (Table 9). The increase in dry season concentrations at slough sites is most probably related to greater evaporation and differences in primary productivity rates in the shallow slough pools.

Year-to-year variability was found for total inorganic carbon concentrations at the slough stations (Table 9). While this can be seen as a slightly decreasing trend (Figure 11) in TIC concentration, the large standard deviations around the mean make this appear more to be an artifact due to small sample size than to naturally occurring processes. No similar temporal trend was noted for TIC concentrations at the canal delivery stations.

Significant geographic variability was noted for the canal delivery sites (Table 9), primarily as a response to higher mean wet season total inorganic carbon concentrations at Br-53 ($\bar{x}$ = 59.3 mg/l) than at the S-12 delivery sites ($\bar{x}$ = 33.0 mg/l). While higher mean annual total inorganic carbon concentrations at Br-53 can be seen in Figure 12, the reasons for them are not known.

Table 8. Mean wet season and mean dry season total inorganic carbon as -C (mg/l) for Shark Slough and delivery canal stations.

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	58	45	47	50							32	22	26	42			56
1973	44	38	44	34							28	32	33	44			61
1974											30		28	46			64
1975	37	32	41														
1976	41	35															
1977																	
1978	44	27	38	26	29	39		48	41	32				37	43	44	56
1979																	
1980																	
Dry Season:																	
1972												28					
1973	41	64		79							35		42	50			64
1974	63	63		63							35	35	42	50			63
1975		50	38	54							35		37	40			62
1976																	
1977	62	69															
1978																	
1979																	
1980																	

Table 9. Results of analysis of variance evaluation for significant variability seasonally, temporally and geographically for total inorganic carbon, total organic carbon and total carbon.

	Total Inorganic Carbon	Total Organic Carbon	Total Carbon
Wet season vs. dry season (slough stations)	SIG	NS	SIG
Wet season vs. dry season (canal stations)	NS	NS	NS
Station vs. station (wet season slough stations)	NS	NS	SIG
Station vs. station (wet season canal stations)	SIG	NS	NS
Year by year (wet season slough stations)	SIG = .05 NS = .01	NS	NS
Year vs. year (wet season canal stations)	NS	NS	NS
Slough vs. canal (wet season)	NS	NS	NS

SIG = Significant Variability
NS = Not Significant

Note: One way analysis of variance for groups of unequal size was computed according to the methods prescribed by Sokal and Rohlf (1970). Significance was determined at the P = .01 level utilizing F- value significance tables of Rohlf and Sokal (1970).

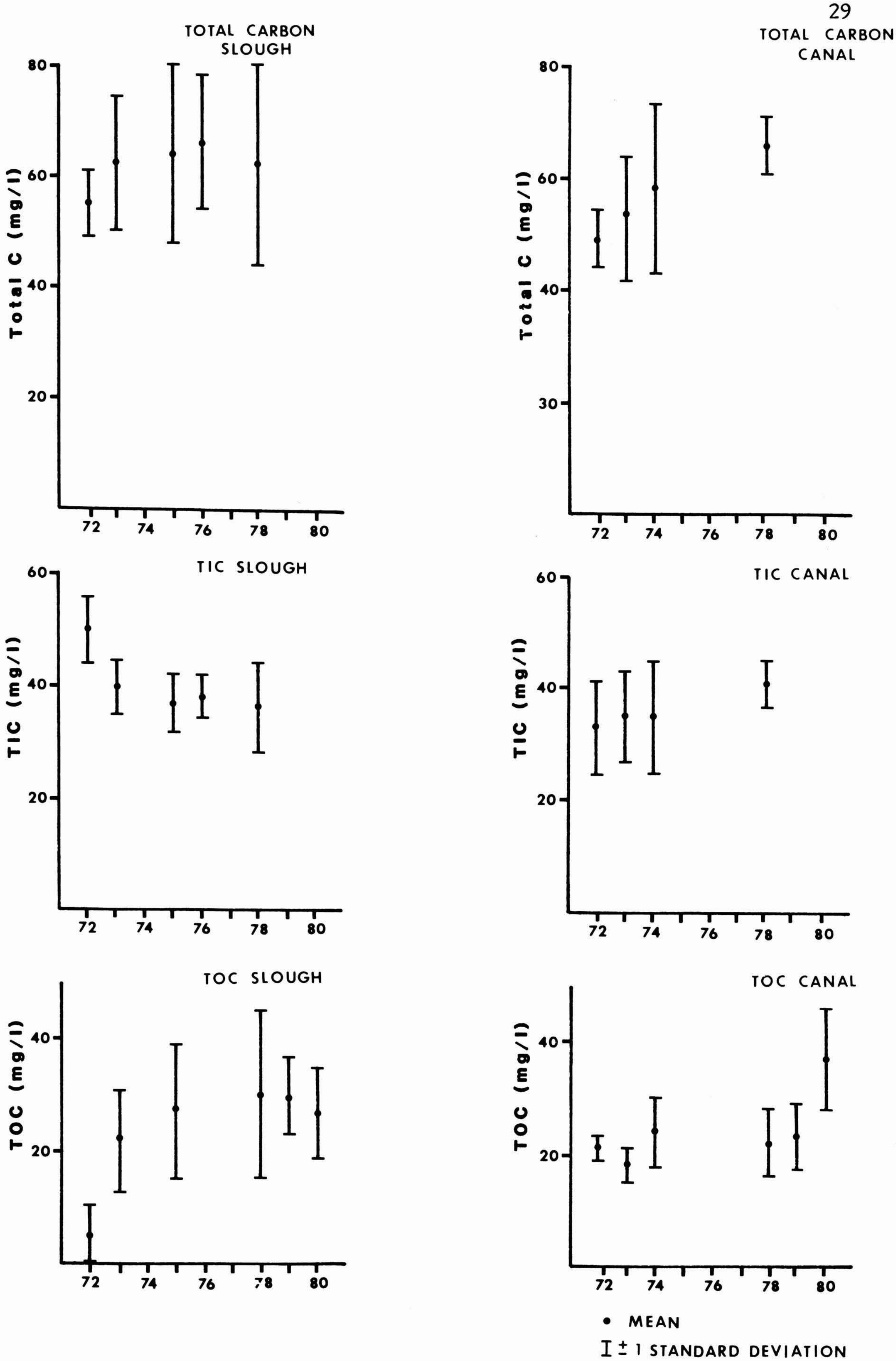

Fig. 11. Mean wet season total inorganic carbon, total organic carbon, and total carbon for Shark Slough and delivery canal stations (1972-1980).

Mean wet season TIC concentrations have not been available for Shark Slough since 1979. However, a comparison of 1972 and 1978 concentrations (Figure 13) indicates that little change has occurred overall throughout the study area.

The sources, forms and cycling of dissolved organic carbon in freshwater systems vary greatly from those of TIC. First, the major pool of organic carbon in the system is soluble and second, two major sources of organic carbon occur: autochthonous which is created by photosynthesis within the system and allochthonous which comes in both dissolved and particulate forms from the surrounding drainage basin. In both cases, the mechanisms determining the concentration of organic carbon are quite different from those determining the concentrations of inorganic carbon.

Mean wet season concentrations of total organic carbon ranged from 5 mg/l (1972) to 30 mg/l (1978, 1979) at the slough stations and from 18 mg/l to 37 mg/l at the delivery canal stations (Table 10). While standard deviations were quite large (Figure 11) within individual years, no significant variability was found seasonally, temporally or geographically either within slough stations or canal delivery stations (Table 9).

Figure 12 further shows that little variability occurred among the mean wet season TOC concentrations of slough stations and canal stations. Geographic distributions of mean wet season TOC are shown for all slough and canal stations for 1972, 1978, 1979, and 1980 (Figure 14). From these consistency can be shown among the canal delivery sites for all years, while much lower concentrations of TOC were found at the slough sites in 1972.

Total carbon is the sum of inorganic carbon and organic carbon. While the data are limited, mean annual wet season total carbon ranged from 55 mg/l (1972) to 66 mg/l (1976) at slough sites and from 57 mg/l (1972) to 70 mg/l (1978) at canal sites (Table 11). As with total inorganic carbon, significant seasonal trends were found among the in-slough stations but not among canal stations (Table 9). Total carbon did not vary significantly by year, but did vary significantly by station for both slough and canal stations. While an evaluation of this trend is difficult because of the small sample size, mean wet season total carbon at Br-53 always exceeded that found at the other canal delivery sites. The reason for this is not known.

Figure 15 displays mean annual wet season total carbon concentrations for 1972 and 1978. While total carbon concentrations are comparable, it again can be seen that concentrations at Br-53 exceed those found at all other stations.

CONCLUSIONS

The results of this study indicate that surface water nutrient concentrations within the Shark River Slough and at the canal delivery points to the slough have not changed significantly during the period of the study (1972-80). Unlike specific conductance and dissolved ion concentrations which have increased appreciably

Table 10. Mean wet season and mean dry season total organic carbon as -C (mg/l) for Shark Slough and delivery canal stations.

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	4	4	12	1							22	25	21	21			20
1973	17	18	35	19							16	34	17	22			19
1974											18		24	29			21
1975	22	18	41														
1976	33	22											31				
1977	17							8					21				
1978	39	23	33	16	15	62		18	29	34			13	24	26	25	26
1979	28	35	30			32	28	16	40	31	18		19	23	21	32	21
1980	28	29	23	43	19	25	28	19			36		28	50	42	30	27
Dry Season:																	
1972																	
1973	6	4		6							19	20	19	27			28
1974	73	61		7							25		30	48			37
1975		36	52	20							22	27	24	25			60
1976													33	32		18	
1977	68	32										28	33			17	
1978												49				29	
1979																	
1980																	

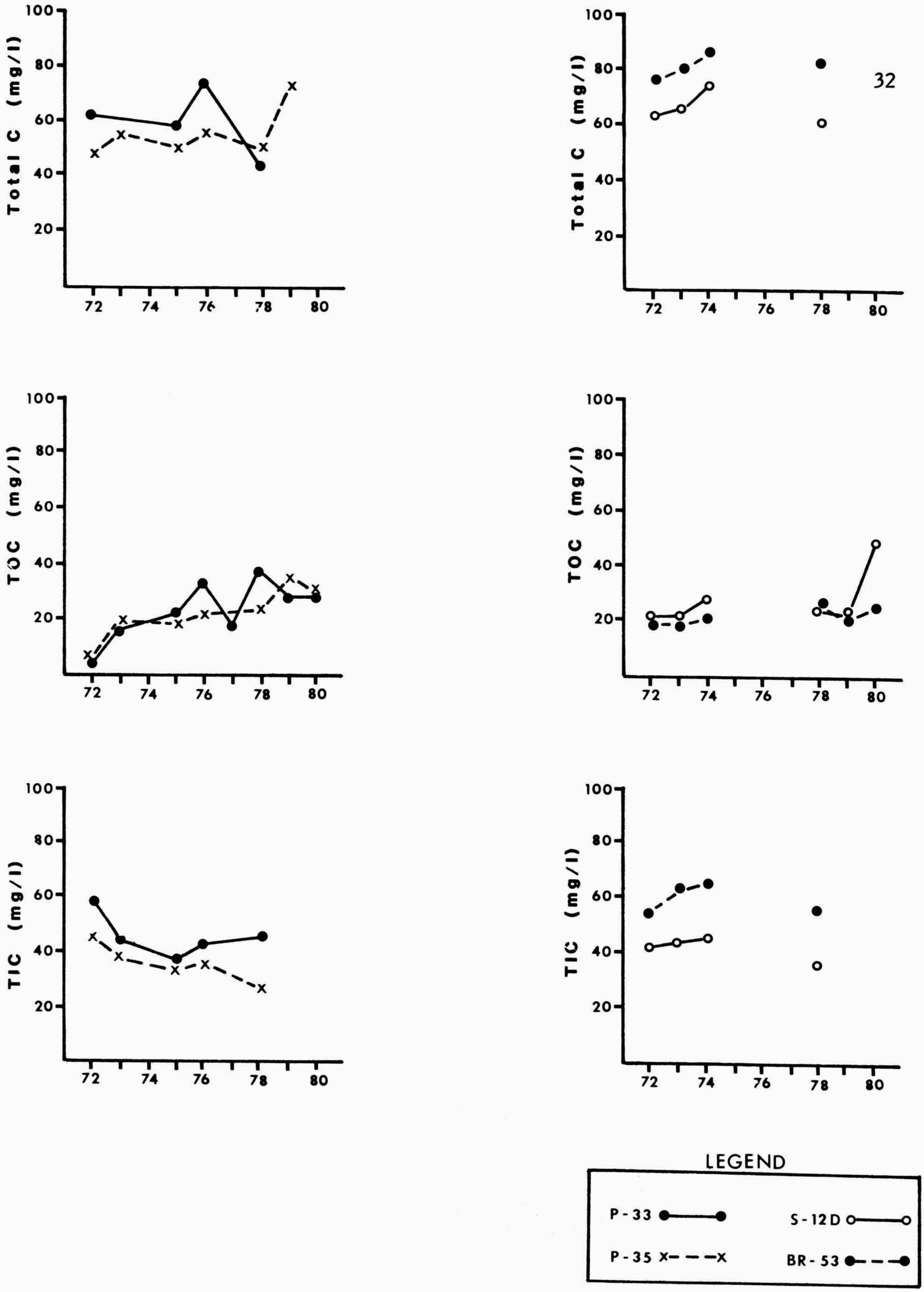

Fig. 12 Mean annual wet season total inorganic carbon, total organic carbon, and total carbon for selected canal and slough stations (1972 - 1980).

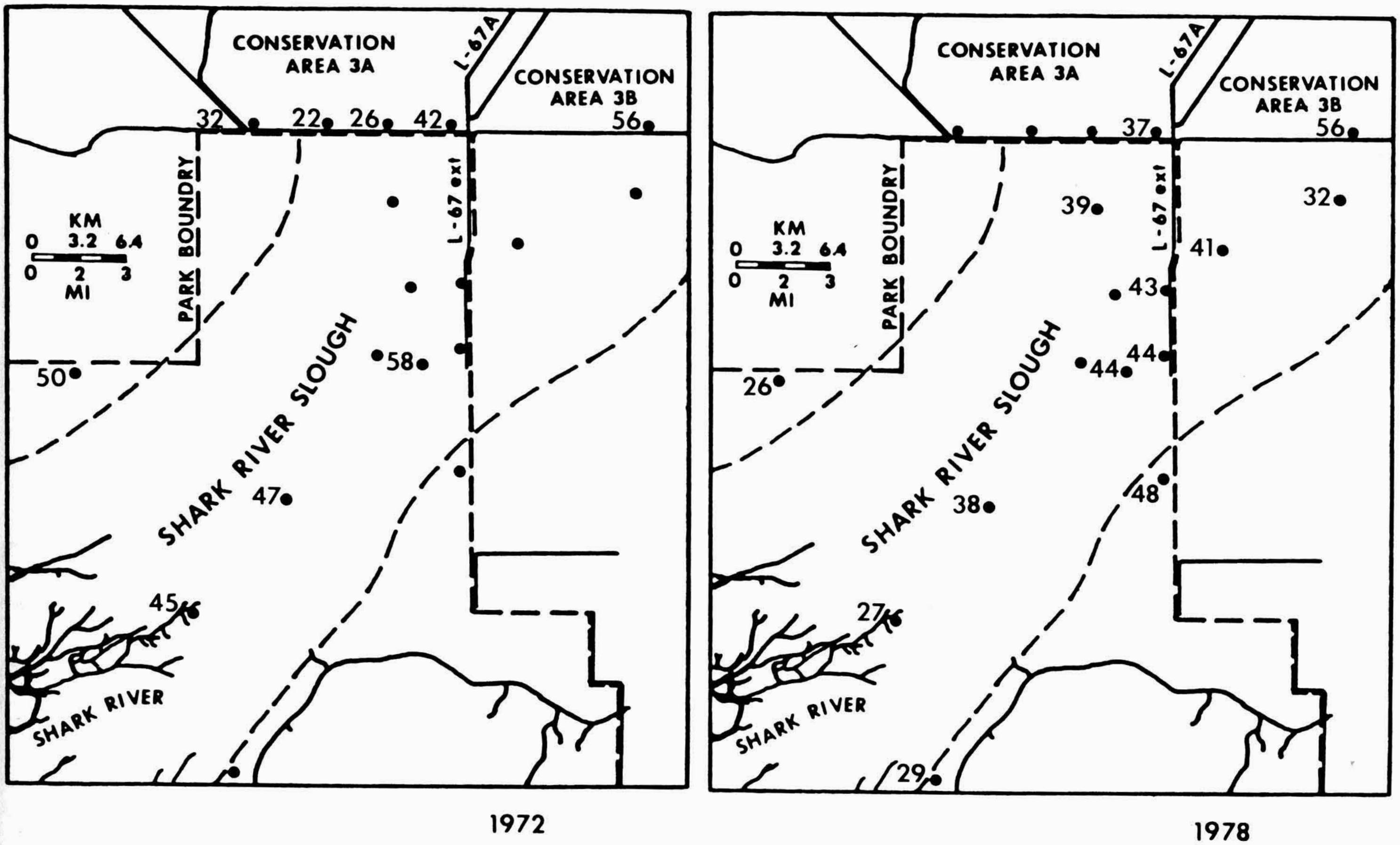

Fig. 13 Mean wet season total inorganic carbon (TIC) concentrations (mg/l) in Shark Slough, 1972 and 1980.

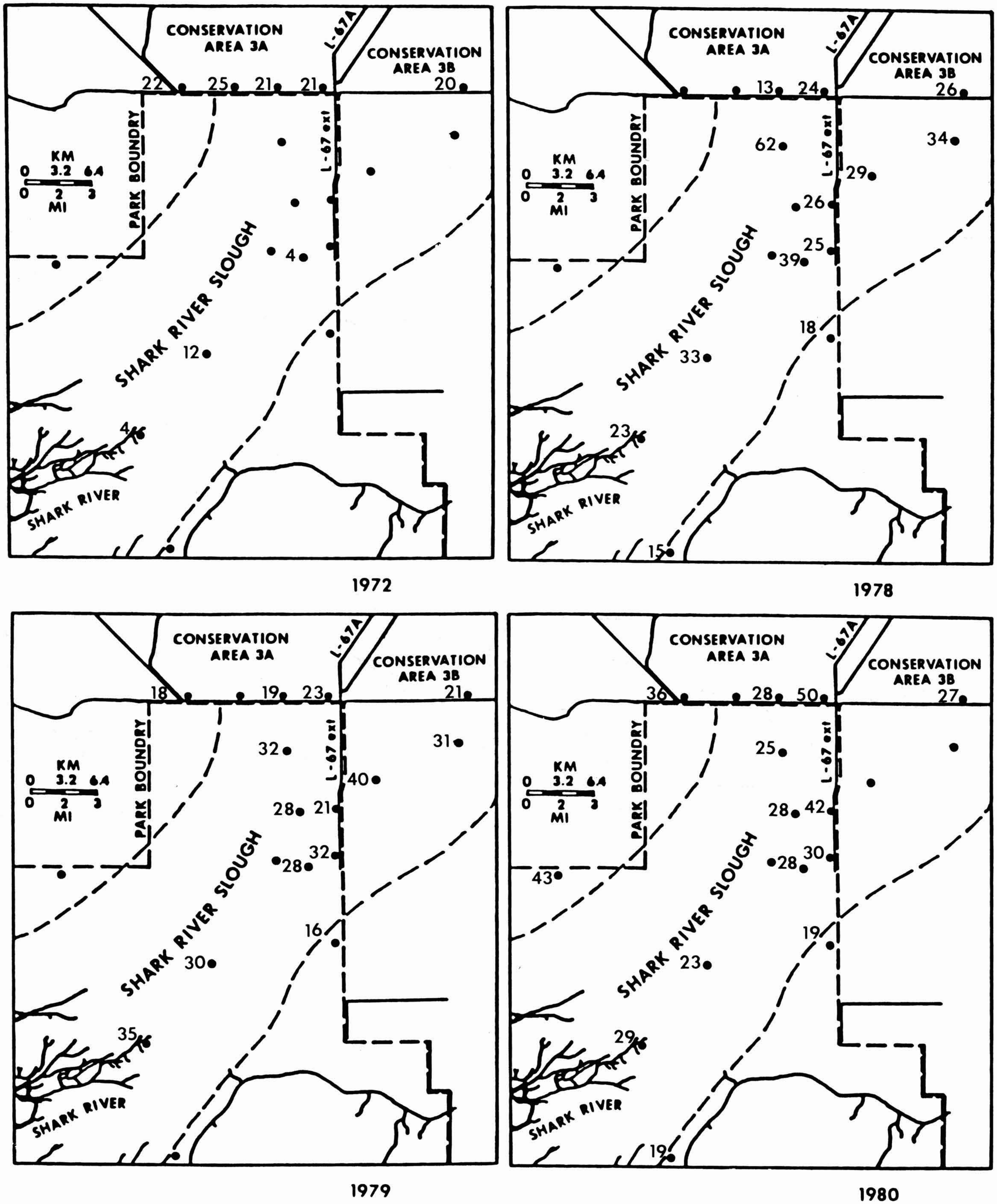

Fig. 14 Mean wet season total organic carbon (TOC) concentration (mg/l) in Shark Slough, 1972, 1978, 1979, and 1980.

Table 11. Mean wet season and mean dry season total carbon as C (mg/l) for Shark Slough and delivery canal stations.

	Slough Stations										Canal Stations						
Year	P-33	P-35	P-36	P-34	P-38	NP-201	NP-202	NP-206	NE-1	NE-2	S-12A	S-12B	S-12C	S-12D	P-25	P-26	Br-53
Wet Season:																	
1972	62	49	59	51							54	47	47	63			76
1973	61	56	79	53							44	66	50	66			80
1974											48		52	75			85
1975	59	50	82														
1976	74	57															
1977																	
1978	42	50	71	42	44	101		66	70	68				61	64	64	82
1979		71															
1980																	
Dry Season:																	
1972												48					
1973	47	68		85							54		61	77			78
1974	136	124		70							60	62	72	98			91
1975		86	90	74							57		61	65			83
1976												73					
1977	130	101										82					
1978																58	76
1979																	
1980																	

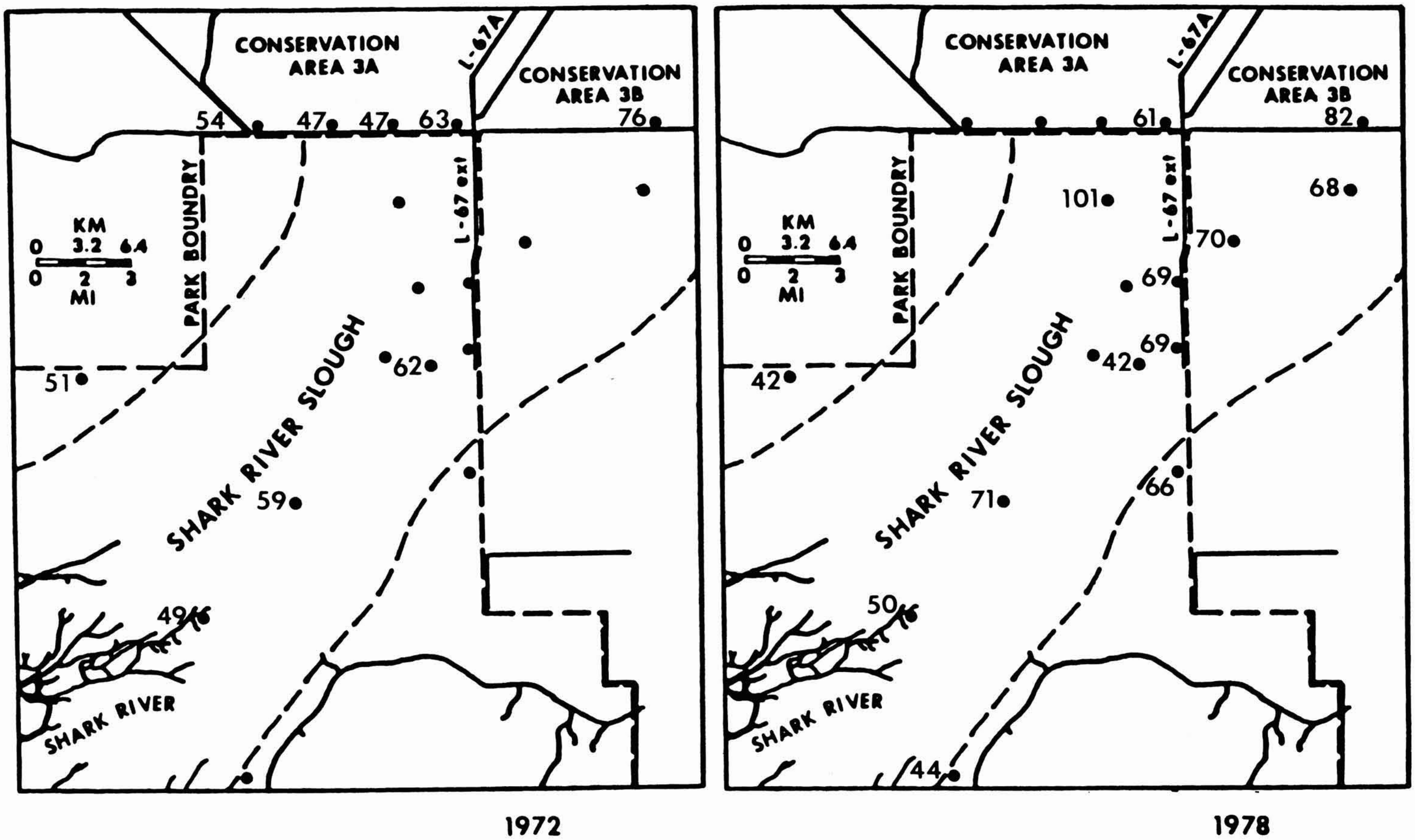

Fig. 15 Mean wet season total carbon concentrations (mg/l) for Shark Slough, 1972 and 1978.

with the shift of surface water delivery from natural sheet flow to a delivery canal regime (Flora and Rosendahl, 1981), nutrient concentrations remain among the lowest in the South Florida system and appear to be largely unaffected by either man's change in the hydrological regime or on land use patterns. A major reason for the maintenance of the low water nutrient levels during this period of substantial hydrological change appears to be the extensive assimulative capacity of the marsh system for the nonconservative nutrients, and the absence of any overwhelming change of man-made point source input (i.e., sewage effluent, urban runoff or non-point source input) in the immediate vicinity of the Shark River Slough.

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