

LSU-T-75-001

LSU 56-75-003

CIRCULATING COPY
Sea Grant Depository

Louisiana Wildlife and Fisheries Commission
Oysters, Water Bottoms and
Seafoods Division

DISTRIBUTION OF NUTRIENTS IN
LOUISIANA'S COASTAL WATERS INFLUENCED
BY THE MISSISSIPPI RIVER

Technical Bulletin No. 17
August 1975



EDWIN W. EDWARDS
Governor

LOUISIANA WILDLIFE
AND
FISHERIES COMMISSION

HARVEY CLAY LUTTRELL, *Chairman* Buckeye
DOYLE G. BERRY, *Vice-Chairman* Berwick
MARC DUPUY, JR. Marksville
JERRY G. JONES Cameron
JEAN LAPEYRE Houma
JIMMIE THOMPSON Alexandria
DONALD WILLE Bossier City

J. BURTON ANGELLE
Director

R. K. YANCEY
Asst. Director

L. S. ST. AMANT
Asst. Director

MARIAN "PIE" PENDLEY
Executive Assistant

HURLEY B. CAMPBELL
Executive Assistant

HARRY E. SCHAFER, JR., *Chief*
Oysters, Water Bottoms and Seafoods Division

MAX W. SUMMERS, *Assistant Chief*
Oysters, Water Bottoms and Seafoods Division

FEDERAL AID SECTION
WILLIAM S. PERRET, 88-309 *Coordinator*

LOUISIANA WILDLIFE AND FISHERIES COMMISSION
Oysters, Water Bottoms and
Seafoods Division

DISTRIBUTION OF NUTRIENTS IN
LOUISIANA'S COASTAL WATERS INFLUENCED
BY THE MISSISSIPPI RIVER¹

by
CLARA L. HO
and
BARNEY B. BARRETT

Technical Bulletin No. 17
August 1975

¹Part of this study was conducted in cooperation with NOAA, National Marine Fisheries Service, Public Law 88-309.

Table of Contents

	PAGE
ACKNOWLEDGMENTS	ix
ABSTRACT	xi
INTRODUCTION	1
PROCEDURES	3
Field Sampling	3
Analytical Methods	5
DISTRIBUTION OF NUTRIENTS DURING VARIOUS DISCHARGE STAGES OF THE MISSISSIPPI RIVER	6
CONTRIBUTION OF NUTRIENTS BY THE MISSISSIPPI RIVER AND MARSHES	27
SUMMARY AND CONCLUSIONS	36
LITERATURE CITED	38

List of Figures and Tables

FIGURES	PAGE
1A Sampling locations in the nearshore zone	2
1B Sampling locations in Caminada and Barataria Bays	4
2 Mean monthly Mississippi River discharge and total monthly coastal rainfall during 1973 compared with long-term means	7
3A Distribution of inorganic-N and salinity at selected stations in Caminada Bay and its nearshore zone, January 17, 1973	10
3B Distribution of dissolved SiO ₂ , organic-N, and PO ₄ ³⁻ -P at selected stations in Caminada Bay and its nearshore zone, January 17, 1973	10
4A Distribution of inorganic-N and salinity at selected stations in Caminada Bay and its nearshore zone, March 29, 1973	14
4B Distribution of dissolved SiO ₂ , organic-N and PO ₄ ³⁻ -P at selected stations in Caminada Bay and its nearshore zone, March 29, 1973	14
5A Distribution of inorganic-N and salinity at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, May 22, 1973	16
5B Distribution of dissolved SiO ₂ , organic-N and PO ₄ ³⁻ -P at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, May 22, 1973	17
6A Distribution of inorganic-N and salinity at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, September 20, 1973	22
6B Distribution of dissolved SiO ₂ , organic-N and PO ₄ ³⁻ -P at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, September 20, 1973	23
7 Seasonal changes in inorganic-N and salinity, (A) nearshore zone of Caminada Pass, (B) nearshore zone of Barataria Pass	29
8 Relationship between salinity and (NO ₃ ⁻ + NO ₂ ⁻)-N (A), PO ₄ ³⁻ -P (B), and dissolved SiO ₂ (C), in nearshore waters, January 17, 1973	30
9 Relationship between salinity and (NO ₃ ⁻ + NO ₂ ⁻)-N (A), PO ₄ ³⁻ -P (B), and dissolved SiO ₂ (C) in nearshore waters, March 29, 1973.....	31
10 Relationship between salinity and (NO ₃ ⁻ + NO ₂ ⁻)-N (A), PO ₄ ³⁻ -P (B), and dissolved SiO ₂ (C) in nearshore waters, May 22, 1973.....	32
11 Seasonal changes in inorganic-N and salinity	33
12 Relationship between salinity and (NO ₃ ⁻ + NO ₂ ⁻)-N (A), PO ₄ ³⁻ -P (B), and dissolved SiO ₂ (C) in Barataria Bay, March 29, 1973.....	34
13 Relationship between salinity and (NO ₃ ⁻ + NO ₂ ⁻)-N (A), PO ₄ ³⁻ -P (B), and dissolved SiO ₂ (C) in Caminada Bay, March 29, 1973.....	35
14 Seasonal changes in organic-N in Caminada and Barataria Bays and adjacent nearshore waters	37

TABLES

	PAGE
1 Nutrients in Caminada Bay, January 17, 1973	8
2 Nutrients in the nearshore zone adjacent to Caminada and Barataria Bays, January 17, 1973	9
3 Nutrients in Caminada Bay, March 29, 1973	12
4 Nutrients in Barataria Bay, March 29, 1973	12
5 Nutrients in the nearshore zone adjacent to Caminada and Barataria Bays, March 29, 1973	13
6 Nutrients in Caminada Bay, May 22, 1973	18
7 Nutrients in Barataria Bay, May 22, 1973	18
8 Nutrients in the nearshore zone adjacent to Caminada and Barataria Bays, May 22, 1973	18
9 Nutrients in the nearshore zone between Southwest Pass and Quatre Bayou Pass, May 22, 1973	19
10 Nutrients in Caminada Bay, September 20, 1973	24
11 Nutrients in the nearshore zone adjacent to Caminada and Barataria Bays, September 20, 1973	24
12 Nutrients in the nearshore zone between Southwest Pass and Quatre Bayou Pass, September 20, 1973	25
13 Nutrients in Barataria Bay, September 20, 1973	26
14 Estimated amount of selected nutrients discharged into Louisiana's coastal area between January and July 1973 by the Mississippi and Atchafalaya Rivers	27

Acknowledgments

This report was the result of a combined effort by the LSU Center for Wetland Resources and the Division of Oysters, Water Bottoms and Seafoods, Louisiana Wildlife and Fisheries Commission. Mr. Harry Schafer, Chief of this division, was instrumental in the cooperation provided by the Commission. Mr. Ralph Latapie, Supervisor of the Commission's Marine Laboratory, provided personnel and equipment, including boats, for the sampling trips. University support was provided by the Louisiana Sea Grant Program, part of a national program administered by the Office of Sea Grant, NOAA, U.S. Department of Commerce. A portion of this study was conducted in cooperation with NOAA, National Marine Fisheries Service, under Public Law 88-309.

Abstract

The volume of freshwater introduced into Louisiana's coastal zone during 1973, both by rainfall and river discharge, was the highest recorded since 1940. Selected nutrients (ammonium-N, [nitrate + nitrite]-N, phosphate-P, and dissolved silicate), organic-N, and salinity were measured in Louisiana coastal waters from the mouth of the Mississippi River to Caminada Bay during four sampling trips in 1973. Three of these sampling trips coincided with high river discharge, and the last sampling effort occurred during low river discharge. Resultant data showed the tremendous influence of the Mississippi River on nutrient concentrations in the coastal waters adjacent to the river mouth. River waters contributed large amounts of NO_3^- , dissolved SiO_2 , PO_4^{3-} , and organic-N to the Gulf of Mexico. Waters in the upper estuaries of Caminada and Barataria Bays were characterized by high NH_4^+ levels relative to the nearshore waters. During the low discharge period of the Mississippi River, nearshore waters were dominated by nutrient depleted seawater. Inorganic nutrients and organic-N levels in the bays and adjacent nearshore waters were higher than at the river mouth during the low discharge period. The primary source of nutrients to the bays during low river discharge is the surrounding marshes. The estimated combined weight of $(\text{NO}_3^- + \text{NO}_2^-)$ -N, PO_4^{3-} -P, dissolved SiO_2 , organic-N, and organic-C emptied into the Gulf by the Mississippi River between January and July 1973 was 12.9 billion kilograms (28.4 billion pounds). Nutrient contribution by the Mississippi River undoubtedly accounts for the high production of fisheries in this region of the Gulf.

Introduction

Louisiana coastal waters influenced by nutrients discharged by the Mississippi River system (including the Atchafalaya River) are among the most productive fishery areas in the United States. Gunter (1967) extended a line from Mobile Bay westward around the mouth of the Mississippi River to Sabine Lake and designated the circumscribed area as the "Fertile Fisheries Crescent." The discharge of the Atchafalaya River, which receives large quantities of Mississippi River water north of Baton Rouge, influences most of southwestern coastal Louisiana. The mainstream of the Mississippi River spreads its waters over much of southeastern coastal Louisiana.

The area investigated during this study was limited to Caminada and Barataria Bays and the near offshore waters between these bays and the mouth of the Mississippi River at Southwest Pass (Fig. 1A). This area, as compared to other regions equal in size, is probably the richest in both volume and variety of natural resources within the United States. Sulphur is mined in the area and hundreds of oil and gas wells are located both inshore and offshore. Private and charter boats fish these waters year-round, and deep sea sport fishing is exceptionally productive south of the Mississippi River mouth. The area produces great quantities of commercial and sport fish and supports a large oyster industry. Other major seafood production in the area includes crabs and shrimp. Since 1970, the annual catch of shrimp alone has exceeded 9 million kilograms (20 million pounds) in the area from Caminada Bay to Southwest Pass.

Riley (1937) found that the high chlorophyll content, which is indicative of phytoplankton productivity, near the Mississippi River mouth correlated well with the large amount of nutrients supplied by the river. He reported that the concentration of $\text{PO}_4^{3-}\text{-P}$ (about .016 mg/l) was 4 times higher than that of sea water in the vicinity. In a recent study by Alberts (1970), a much higher concentration of $\text{PO}_4^{3-}\text{-P}$ (0.086 to 0.128 mg/l) was reported near the Mississippi River mouth. He concluded that this river is a major contributor of P to the Gulf of Mexico with an estimated input of 1.4×10^6 mg/sec with a river flow rate of 1.78×10^7 l/sec.

With the exception of work by the Louisiana Wildlife and Fisheries Commission in 1968 and 1969, there are few comprehensive studies concerning organic and inorganic-N concentrations and their distribution in the coastal waters of the

Gulf of Mexico. The results of the Commission's work showed that $\text{NO}_3\text{-N}$ concentrations in areas influenced by the river was directly related to the volume of river discharge. During high Mississippi River discharge, most frequently occurring during the spring, much of the fresh river water flows westward along the coastline and enters the bays through passes open to the Gulf. The distribution of nutrients emptied into the Gulf by the Mississippi River depends primarily on the amount of discharge and the prevailing nearshore currents. (Barrett et al., 1971).

Analyses of waters collected during a previous investigation at Southwest Pass in February 1972 (Ho, 1972) showed high concentrations of $\text{NO}_3\text{-N}$ (1.8 mg/l), but low $\text{NH}_4^+\text{-N}$ levels (less than 0.06 mg/l). Concentrations of $\text{PO}_4^{3-}\text{-P}$ and dissolved SiO_2 were also high (0.07 mg/l and 5.0 mg/l, respectively), and salinity was low (less than 1 ‰). The $\text{NO}_3\text{-N}$ enriched river water is characteristic of the drainage from agricultural lands as a result of washout of fertilizers and feedlot wastes (Willrich and Smith, 1970; Kohl et al., 1971). The distribution pattern of nutrients discharged by the river, especially nitrogenous components (organic and inorganic) and their proportions in the nearshore waters west of Southwest Pass and associated estuaries (Caminada and Barataria Bays), have not been investigated in relation to the amount of water discharged. This lack of basic information prevents any realistic assessment of the true impact of the Mississippi River on coastal Louisiana.

The adverse effects of excessively high inputs of inorganic nutrients into natural environments, especially the highly productive estuarine systems, have been reported by many investigators, but such studies are limited in Louisiana estuaries. The photosynthetic activities or production of organic matter by phytoplankton in surface waters are accompanied by assimilation of inorganic nutrients from surrounding water. Therefore, the availability of these nutrients, especially N and P, most frequently controls and limits production of organic matter in aquatic environments. Ryther and Dunstan (1969) reported that Long Island bays, (1-2 m in depth) have a hard sandy bottom and traditionally supported a productive fisheries of oysters and hard clams. Introduction and growth of the duckling industry in this area resulted in organic pollution of the bays and subsequent development of dense algal blooms in the bay waters to the detriment of the

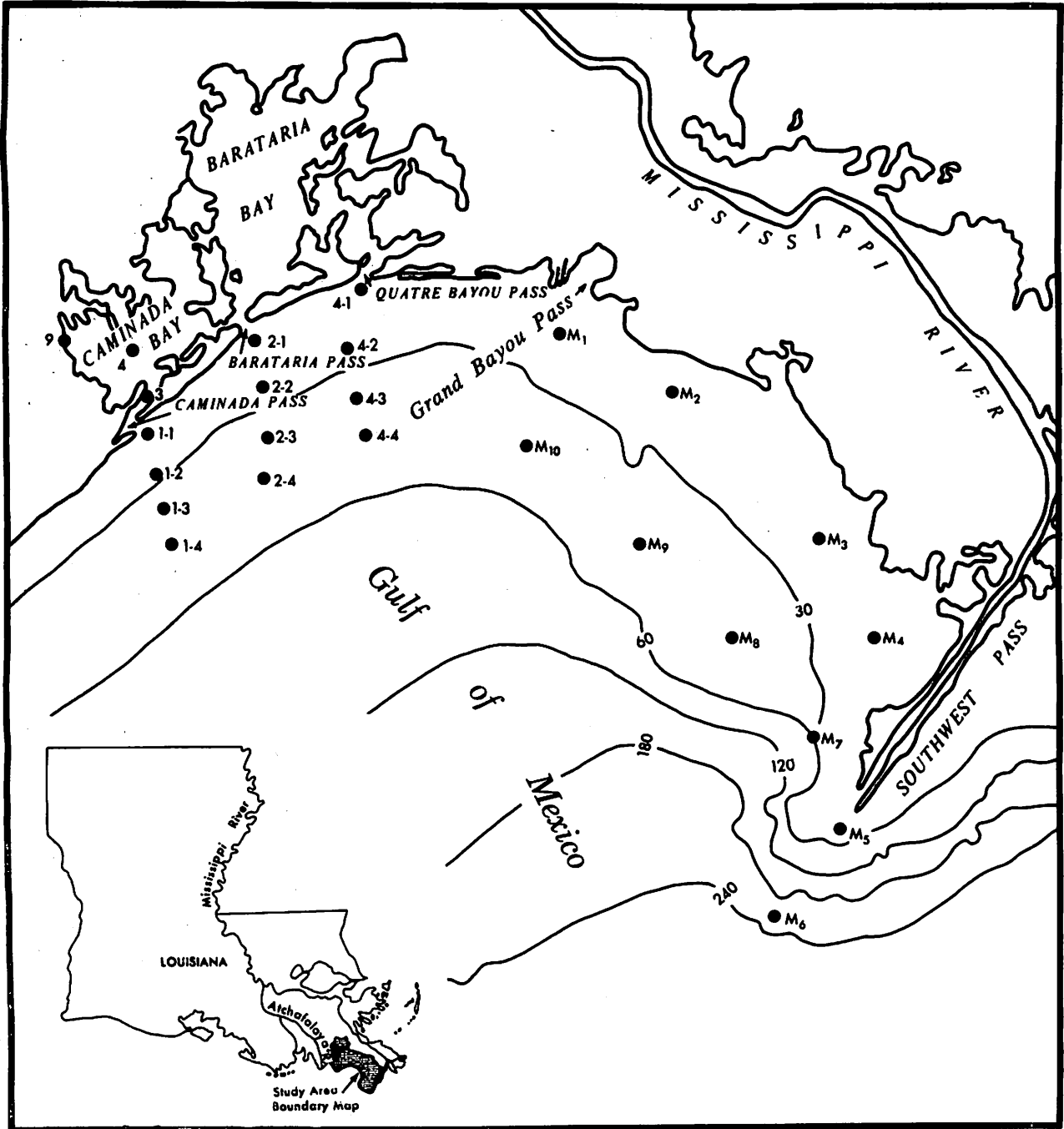


Figure 1A. Sampling locations in the nearshore zone.

shell fisheries. Phosphate distribution (max. concentration = 0.217 mg/l) was roughly coincident with that of phytoplankton in Long Island Bay. A similar correlation between chlorophyll-a and phosphorus in surface waters has been reported by Bartsch (1972) in Lake Minnetonka located in Minnesota. Hopkins et al. (1971) found that the Alafia and Manatee Rivers in Florida were high in nutrients and pigment concentrations, whereas the Waccassassa and Crystal Rivers, also located in Florida, have low pigment but intermediate nutrient levels. The direct relationship between pigment and nutrient levels was also identified in a water mass associated with the loop current in the Eastern Gulf of Mexico. These observations indicate the relationship between phytoplankton production as shown by pigment levels and the amount of available nutrients in a given environment. Humm (1973) reported that a variety of blue-green algae and sea lettuce in response to excessive concentrations of land nutrients becomes conspicuously abundant in some areas of the eastern Gulf of Mexico, especially during late winter and spring. The subsequent decay of algae and sea lettuce often causes anaerobic conditions resulting in fish kills. This decay occasionally results in the release of large quantities of H₂S which is toxic to benthic organisms when water exchange is slow. In Tampa Bay, the quantities of algae that develop each year are a product of added nutrients from sewage effluents discharged into this bay. Serruya (1971) attributed the winter algal bloom (December-May) in Lake Kinneret, Israel, to the active nutrient-supplying capacity of sediments and probably to the peak NO₃ input from the River Jordan. During this period, phytoplankton cell concentrations reached 4000/ml. For nine months of the year, this lake was under anoxic conditions, and the water column above the mud was rich in sulfides, NH₃, and CO₂. The close relationship between organic-N in surface sediments and inorganic nutrients associated with the overlying water

column has been established in some of the salt, brackish, and freshwater marshes as well as swamp forests in Louisiana's coastal zone (Ho and Schneider, 1974). Thomas (in Hayes, 1964) made an interesting comparison in three Swiss lakes between O₂ decline during the summer in the stagnant depths and the measured O₂ consumption in the laboratory of falling sediments collected on a submerged surface. The two estimates of oxygen decline were similar, suggesting that the amount of O₂ which disappeared from the lake was used up in the decomposition of falling organic matter during the period of study. Richards and Redfield (1954) found an inverse relationship between organic content of the sediments and oxygen content of the overlying water in the northwestern Gulf of Mexico. These observations imply that depletion of dissolved oxygen could take place in other aquatic environments where organic matter is high and water exchange is slow, such as the coastal waters of Louisiana adjacent to the mouth of the Mississippi River.

The objectives of this investigation were threefold: 1) to determine the concentration and distribution of the major available nutrients emptied into the Gulf of Mexico by the Mississippi River at various discharge stages; 2) to assess the importance of nutrient supply sources other than the Mississippi River, especially in estuarine systems; and 3) to provide basic information for future assessment of the Mississippi River's impact on fisheries production in the Gulf of Mexico and estuarine systems influenced by the river.

River discharge data used in this report were taken from "Stages and Discharges of the Mississippi River and Tributaries and other Watersheds in the New Orleans District," 1940-1973, published by the U. S. Army Corps of Engineers. The source of rainfall data was "Climatological Data" - Louisiana, 1956-1973, published by the U. S. Department of Commerce, Environmental Data Service.

Procedures

FIELD SAMPLING

Water samples were taken at 10 stations in Caminada Bay and at 12 stations in the adjacent offshore waters. These offshore stations consisted of three transects of four stations each (Figs. 1A and 1B). Water samples were collected in January, March, May, and September, 1973. Sampling

was extended to include Barataria Bay during the March, May, and September trips, and to the nearshore zone between Quatre Bayou Pass and the mouth of Southwest Pass in May and September. Bay waters were shallow (less than 1.5 meters [5 ft] average depth), and since vertical

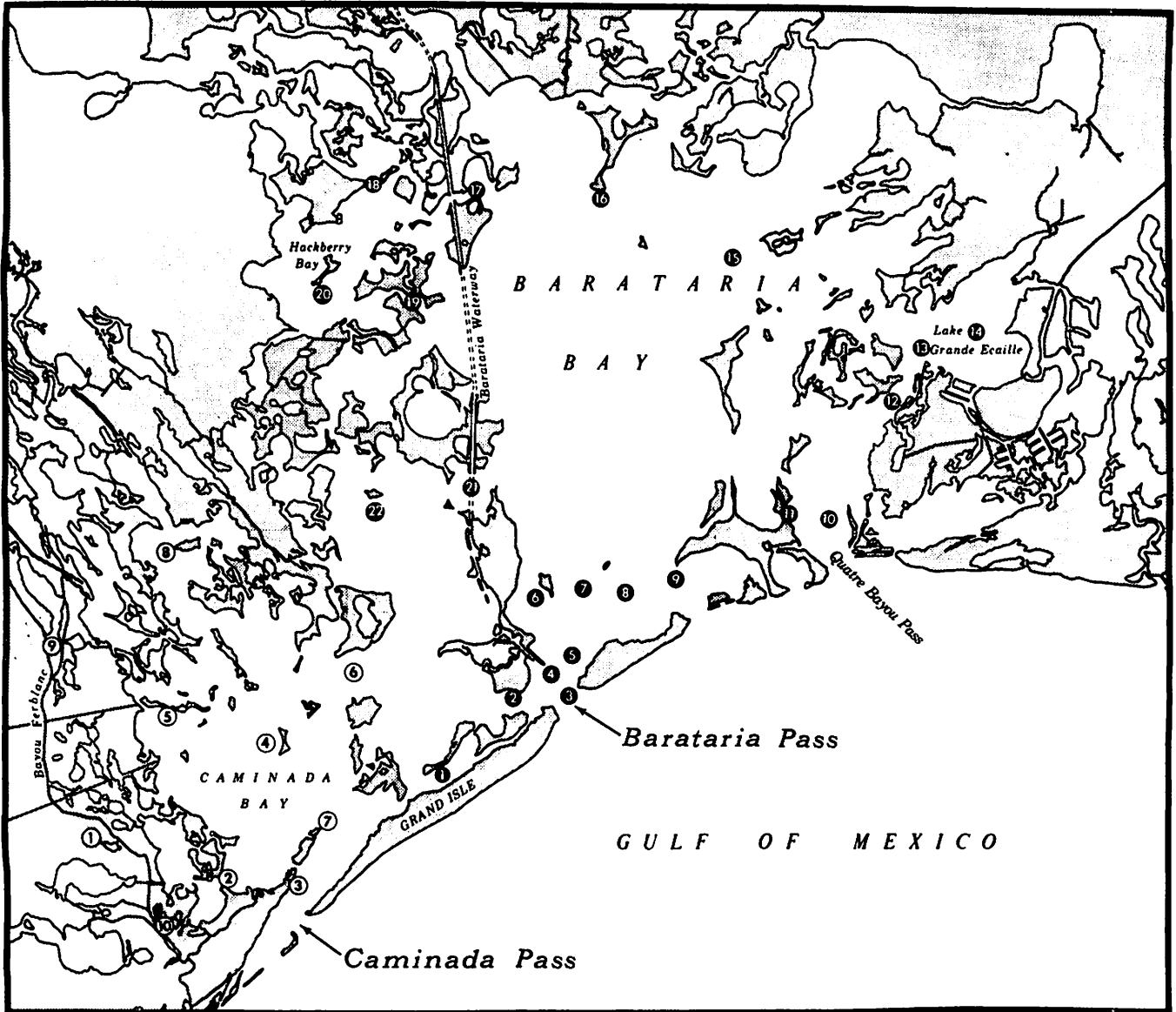


Figure 1B. Sampling locations in Caminada and Barataria Bays. For purposes of this paper, all stations designated by white numbers are considered to be in Barataria Bay and those with black numbers are in Caminada Bay.

stratification was not distinct, only surface waters were analyzed. Water depths in the offshore area ranged from 4 to 12 meters (14 to 40 ft), and stratification, especially during high river discharge and low wind velocity, was pronounced. Both surface and bottom waters at the offshore stations were collected for analyses.

All surface water samples were taken by dipping a 500 ml glass bottle by hand to a depth of 15 cm (six inches) below the surface. A Van Dorn sampler was used to take bottom water which was then transferred to a glass bottle. All water samples were preserved with 5 ml of chloroform, placed on ice during transport, and stored at 4°C in the laboratory. It has been recognized that this method of preservation is not ideal for preventing changes in concentrations of $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ from their initial levels at the time when samples were taken. Concentrations of these components tend to increase under this method of preservation due to cell destruction. Quick freezing by dry ice has been advocated to be the best method for long-term preservation because of high stability of these nutrients under freezing conditions. This may be true, but it does not rule out the fact that rupture of living cells followed by enzymatic hydrolysis of organic components and subsequent release of NH_4^+ and PO_4^{3-} may also occur. Consequently, the concentration of nutrients preserved by freezing may not represent their initial levels. Filtration has been used to remove living cells and organic detritus so that release of NH_4^+ and PO_4^{3-} from lysis may be avoided. However, our tests have shown that filtration invariably contaminates some components such as NH_4^+ and removes other components (e.g., $\text{PO}_4^{3-}\text{-P}$). The error resulting from filtration may be significant, particularly when very low concentrations of the nutrients NH_4^+ and $\text{PO}_4^{3-}\text{-P}$ are involved. It is regrettable that this aspect of sample handling has been consistently ignored by those who have adopted filtration as one of the required processes of water analysis. In spite of the potential drawback of chloroform as a preservative, meaningful relative values of nutrients (NH_4^+ , $\text{NO}_3^- + \text{NO}_2^-$, and PO_4^{3-}) can be obtained if water samples are consistently treated the same way and analyzed within a short period of time after collection. All samples taken for the present investigation were analyzed for NH_4^+ , NO_3^- , and PO_4^{3-} within 3 to 7 days after collection. Concentration of nutrient components under natural conditions may fluctuate to a great extent depending on such factors as river discharge, marsh runoff, upwelling and mixing of bottom waters by wind and tidal action, release from decomposition of organic detri-

tus in the water column, etc. Therefore, measurement of absolute values of nutrients at a given instantaneous moment was not attempted in this investigation.

ANALYTICAL METHODS

Ammonium-N: Twenty-five ml of water sample was pipetted into a 100 ml distillation flask which contained about 0.05 g MgO. The contents were steam distilled for 3 minutes at a distillation rate of 6.5 ml per minute. The distillate was collected into a 50 ml volumetric flask containing 1 ml 0.1 N HCl to absorb the NH_4^+ . The MgO used was reagent grade light MgO ignited at 800°C for 2 hours. No difference was found between the light and heavy MgO insofar as the recovery of NH_4^+ is concerned. Repeated tests showed that the recovery of NH_4^+ was the same regardless of whether redistilled water or seawater was used as the medium. Therefore, the distillation procedure can be successfully applied to both fresh and seawater analyses. Furthermore, separation of NH_4^+ by steam distillation eliminates practically all substances that may subsequently interfere with spectrophotometric measurement, and correction for background of each sample is not necessary.

(Ammonium + nitrate + nitrite)-N: Twenty-five ml water sample containing not more than 0.02 mg $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ was pipetted into a 100 ml distillation flask. About 0.3 g Devarda's alloy powder (<100 mesh) and 0.3 g MgO were added to the sample. The mixture was immediately distilled for four minutes. The $\text{NH}_4^+\text{-N}$ was measured spectrophotometrically using a procedure by Strickland and Parsons (1965) and Truesdale (1971) which was modified by our laboratory. In this modified procedure, 0.25 ml Chlorox, containing not less than 1.24 N NaOCl, and 0.4 g NaBr in 5 ml of 4 N NaOH was used to oxidize NH_4^+ to NO_2^- in 30 minutes. Excess NaOCl was destroyed by addition of 1 ml Na-arsenite after 5 minutes. The NO_2^- was complexed with sulfanilamide at a pH of 0.45; 6.5 ml of 50% HCl by volume is required for the acidification. After 5 minutes, 1 ml of N-(1-naphthyl)-ethylenediamine dihydrochloride solution was added for color development. Color was measured at 543 m μ after 15 minutes. This modified procedure requires less time as compared to the original Strickland and Parson's method, and reproducible results are obtainable. A standard containing 20 μg of $\text{NH}_4^+\text{-N}$ or $\text{NO}_3^-\text{-N}$ in 25 ml of water and a corresponding blank for $\text{NH}_4^+\text{-N}$ or $\text{NO}_3^-\text{-N}$ must be run with each batch of samples. To reduce the blank read-

ing for NO_3^- -N determination, it is advisable that the ground Devarda's alloy powder be heated at 120-150°C for one hour in an open dish (Golterman, 1971) and then stored in an air-tight glass container.

Kjeldahl-N: Twenty-five ml water sample was pipetted into a 100 ml distillation flask; 1 g catalyst (made with fine powder of K_2SO_4 , CuSO_4 and Se at a ratio of 10:1:0.1) was added, followed by 3 ml concentrated reagent grade H_2SO_4 . The mixture was digested on a micro-Kjeldahl rack for 1 hour after clearing at 375°C. Complete recovery of N occurs within 30 minutes digestion after clearing. The digest was steam-distilled with 13 ml 10 N NaOH for 4 minutes using the apparatus described in Bremner (1965). The distillate was collected into a 25 ml volumetric flask containing 1 ml 0.2 N HCl. NH_4^+ was measured spectrophotometrically 15 minutes after the addition of Nessler's reagent. The workable range of NH_4^+ -N concentration should be 0.5 to 2.5 $\mu\text{g}/\text{ml}$ when a 1 cm cell is used. Sample dilution must be made when NH_4^+ -N concentration exceeds 2.5 $\mu\text{g}/\text{ml}$, lest colloidal precipitation should occur. When NH_4^+ -N concentration is below 0.5 $\mu\text{g}/\text{ml}$ the more sensitive oxidation procedure described above is recommended.

Phosphate-P: A modified method from Strickland and Parsons (1965) was used. A 100 ml water sample containing about 2.5 to 25 $\mu\text{g PO}_4^{3-}$ -P was pipetted into a 250 ml separatory funnel. Samples less than 50 ml must be made up to a 100 ml volume with distilled water. Five ml of 25 percent H_2SO_4 was added followed by immediate addition of 4 ml NH_4^+ -molybdate solution. The phosphate and molybdate were allowed to react

for 5 minutes; the phosphomolybdate complex was then extracted with 18 ml ethylacetate by shaking the mixture gently. If the organic and aqueous layers did not separate, addition of a few drops of acetone cleared the separation. The aqueous layer was drained and discarded. Four ml freshly prepared ascorbic acid was added to reduce the phosphomolybdate complex. This was followed by addition of 2 ml potassium antimonyl tartrate. The mixture was shaken well, and the two layers were again allowed to separate. The aqueous layer was again discarded. The final blue organic portion was collected into a small cylinder for measuring. A standard solution containing 10 to 20 $\mu\text{g PO}_4^{3-}$ -P and a blank was run simultaneously in the same manner. The color intensity was measured at 710 $\text{m}\mu$ on a spectrophotometer after a 15 minute color development.

Total-P: A 100 ml sample was pipetted into a 250 ml evaporating dish and the water was evaporated at 105°C. The residue was ignited at 550°C for 2 hours to convert organic-P to inorganic-P which was then dissolved with 5 ml of 25 percent H_2SO_4 on a steam bath. Complete dissolution takes less than two hours. The content was transferred into a 250 ml separatory funnel, and the extraction of phosphate was made as described above.

Dissolved silicate: The procedure of Strickland and Parsons (1965) was followed.

Salinity: Chlorinity was measured by titrating with a standard solution of AgNO_3 (0.1N) using K-chromate as indicator (Strickland and Parsons, 1965). Salinity was calculated according to the formula of $S \text{ ‰} = 0.030 + 1.805 \text{ Cl ‰}$.

Distribution of Nutrients During Various Discharge Stages of the Mississippi River

Extremely high water occurred in coastal Louisiana during 1973. Between 1956 and 1972 annual Louisiana coastal rainfall averaged 147 cm (57.9 in), ranging from 109 cm (43 in) in 1962 to 182 cm (71.5 in) in 1961. Coastal rainfall during 1973 was 190 cm (74.8 in) with heaviest precipitation occurring during March, April, and September. Between 1940 and 1972 the annual average discharge of the Atchafalaya River measured at Simmesport, Louisiana, and the Mississippi River measured at Tarbert Landing, Mississippi was 5500 and 13,000 m^3/sec (194,000 and 463,000 cfs), respectively. During this time period, annual average discharge of the Atchafa-

laya River ranged from 2700 m^3/sec (95,000 cfs) in 1954 to 7500 m^3/sec (264,000 cfs) in 1945, and the Mississippi River ranged from 7600 m^3/sec (268,000 cfs) in 1963 to 20,000 m^3/sec (700,000 cfs) in 1950. Annual average discharge of these two rivers in 1973 was 10,800 m^3/sec (381,000 cfs) for the Atchafalaya River and 20,800 m^3/sec (735,000 cfs) for the Mississippi River.

The 1973 average monthly discharge of the Mississippi River measured at Tarbert Landing, which is approximately 480 km (300 miles) upstream from the river mouth, and the monthly coastal rainfall in Louisiana are presented in Figures 2A and 2B. Not all waters of the Mis-

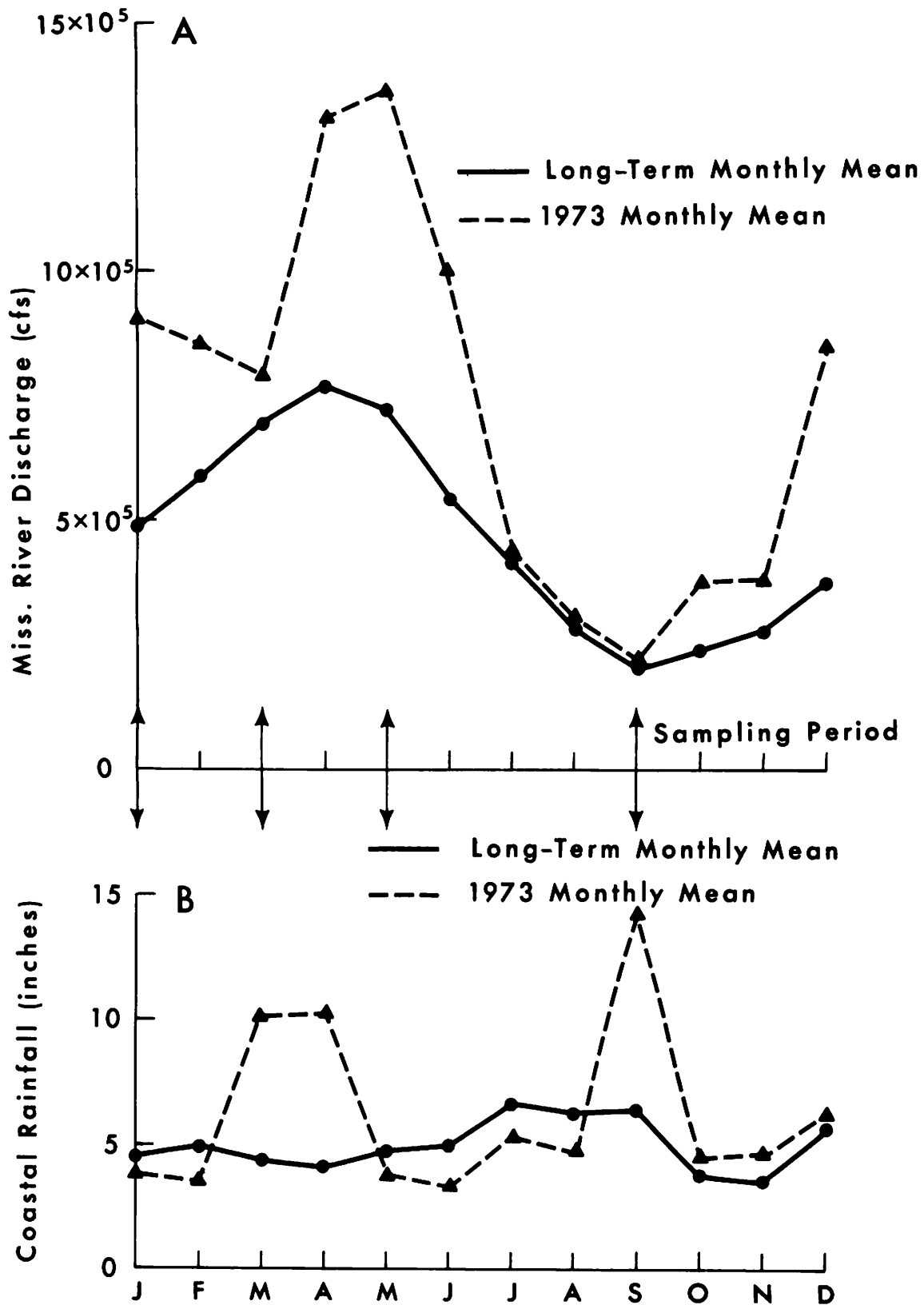


Figure 2. Mean monthly Mississippi River discharge and total monthly coastal rainfall during 1973 compared with long-term means.

Mississippi River were discharged at its mouth during 1973. The Morganza and Bonnet Carre Spillways funneled part of these waters into Lake Pontchartrain and the Atchafalaya River. Also, there were many crevasses in the Mississippi River levee below Point-a-la-Hache during 1973 which diverted large quantities of river water into Breton Sound. The extremely large amount of freshwater introduced into the coastal zone during 1973, both by rainfall and river discharge, brought about drastic changes in this area. Some of these changes measured during the four sampling periods were: reduction in salinity, drastic increase in nutrient concentration, and changes in nutrient composition. However, after effects on ecosystems due to introduction of large amounts of nutrients and organic matter are not well known.

The results of water analyses from the four sampling trips in 1973 are discussed below. Because of the unusually large amount of freshwater introduced into Louisiana coastal areas during 1973, nutrient concentrations and their

distributions during this year should be considered extreme rather than representative of average.

January 17, 1973—Caminada Bay and the Adjacent Offshore Area

Sampling locations are shown in Figures 1A and 1B and the nutrient concentrations are presented in Tables 1 and 2. The distribution of nutrients at selected stations in Caminada Bay and the adjacent nearshore zone with distance from the Mississippi River mouth is shown in Figures 3A and 3B. The tide was rising during the sampling period of January 17, ranging from 25 to 69 cm (10 to 27 inches) above msl (mean sea level). The December 1972 and January 1973 Mississippi River discharges of 22,200 m³/sec (784,000 cfs) and 25,900 m³/sec (913,000 cfs), respectively, were the highest for these months in the past 33 years. December 1972 rainfall was above average but January 1973 rainfall was slightly less than average (Fig. 2B).

Table 1
Nutrient Distribution in Caminada Bay (January 17, 1973)

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity
	(mg/l)						(‰)
C1	0.011	0.050	0.860	0.006	0.028	1.67	19.0
C2	0.017	0.022	0.600	0.008	0.024	1.70	20.8
C3	0.035	0.066	0.074	0.027	0.010	2.96	14.6
C4	0.032	0.026	0.230	0.011	0.040	1.94	20.3
C5	0.021	0.014	0.420	0.015	0.033	1.71	15.9
C6	0.005	0.014	0.279	0.013	0.036	2.61	13.6
C7	0.009	0.008	0.194	0.010	0.021	2.16	20.6
C8	0.014	0.010	0.889	0.018	0.019	2.10	9.8
C9	0.028	0.059	1.155	0.017	0.022	2.19	13.9
C10	0.004	0.004	0.538	0.011	0.027	1.75	19.6
Average	0.018	0.025	0.524	0.014	0.026	2.08	16.8

*The C prefix denotes Caminada Bay.

Table 2

Nutrient Distribution in the Nearshore Zone of Caminada and Barataria Bays
(January 17, 1973)

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₃ ⁻ +NO ₂ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
(mg/1)							
Caminada							
1-1 S	nil	0.093	0.225	0.027	0.058	3.13	14.0
1-1 B	0.024	0.661	0.101	0.039	0.017	3.07	14.6
1-2 S	0.006	0.330	0.201	0.011	0.061	3.27	15.2
1-2 B	0.024	0.501	0.176	0.036	0.025	2.33	17.0
1-3 S	0.005	0.362	0.089	0.005	0.042	2.76	19.3
1-3 B	0.021	0.196	0.104	0.028	0.024	1.54	30.2
1-4 S	0.003	0.344	0.153	0.020	0.060	2.76	19.7
1-4 B	0.019	0.126	0.394	0.026	0.011	1.70	32.0
Barataria							
2-1 S	0.003	0.778	0.122	0.032	0.016	2.76	8.1
2-1 B	nil	0.119	0.406	0.007	0.042	2.62	18.1
2-2 S	nil	0.694	0.350	0.024	0.033	3.73	9.8
2-2 B	0.003	0.032	0.222	0.005	0.026	2.68	19.7
2-3 S	nil	0.230	0.644	0.010	0.051	2.83	16.0
2-3 B	0.027	0.176	0.136	0.036	0.037	2.15	31.0
2-4 S	0.005	0.526	0.576	0.017	0.033	3.71	15.0
2-4 B	0.011	0.171	0.052	0.026	0.051	1.02	32.7
Quatre Bayou							
4-1 S	0.058	0.860	0.341	0.055	0.034	3.70	6.5
4-1 B	0.065	0.790	0.174	0.034	0.028	3.31	8.8
4-2 S	0.079	0.962	0.138	0.046	0.002	4.00	7.5
4-2 B	0.037	0.238	0.255	0.028	0.010	1.80	27.9
4-3 S	0.062	0.710	0.048	0.044	0.027	3.85	10.8
4-3 B	0.042	0.231	0.511	0.005	0.037	1.30	30.9
4-4 S	0.039	0.639	0.284	0.034	0.024	3.10	15.2
4-4 B	0.051	0.116	0.298	0.023	0.035	1.60	32.7
Averages							
1 S	0.004	0.282	0.167	0.016	0.056	2.98	17.1
1 B	0.022	0.371	0.194	0.032	0.019	2.16	23.4
2 S	0.002	0.557	0.423	0.021	0.033	3.26	12.2
2 B	0.010	0.125	0.204	0.018	0.039	2.12	25.4
4 S	0.060	0.633	0.203	0.045	0.022	3.66	10.0
4 B	0.049	0.344	0.310	0.023	0.027	2.00	24.2

S = surface water
B = bottom water

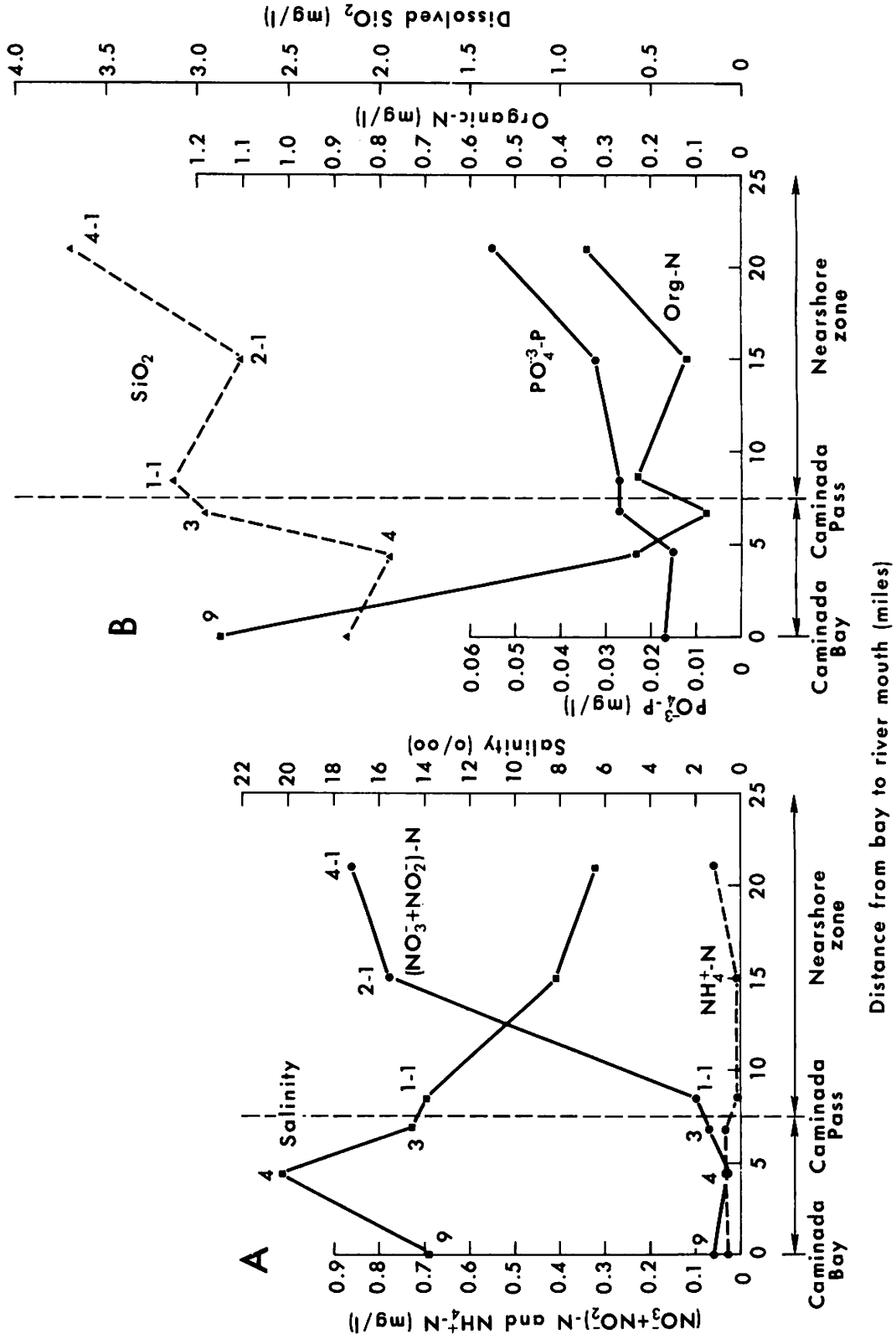


Figure 3. Distribution of chemical components at selected stations in Caminada Bay and its nearshore zone, January 17, 1973. (A) Salinity and inorganic-N, (B) dissolved SiO₂, organic-N, and PO₄³-P.

The variation between salinities in Caminada Bay and the near offshore zone suggests that waters in these two areas were not well mixed. Bay salinities decreased southward from 20.3 ‰ at Station 4 to 14.6 ‰ at Station 3. Nearshore salinities decreased eastward from 14.0 ‰ at Station 1-1 to 6.5 ‰ at Station 4-1. Low salinity nearshore waters were the result of dilution from exceptionally large amounts of freshwater discharged by the Mississippi River into the Gulf. These waters were characteristically high in $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ but low in $\text{NH}_4^+\text{-N}$. The inverse relationship between $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ and salinity is shown in Figure 3A. Low salinity in Caminada Bay at Station 9 as compared with Station 4 is the result of relatively freshwater marsh drainage. Dissolved SiO_2 and $\text{PO}_4^{3-}\text{-P}$ were lowest at the highest salinity station (Station 4) and highest at the lowest salinity station (Station 4-1). However, the inverse relationship of SiO_2 with salinity was not as consistent as the relationship of salinity with $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ because dissolved SiO_2 may have been removed from solution by suspended clay particles. Nutrient enriched river waters apparently did not reach beyond the southern part of Caminada Bay as indicated by high salinities and low nutrient concentrations in the center of the bay. Water quality at Station 9 near the marsh differed from that in the center of the bay and the nearshore zone in that SiO_2 and $\text{PO}_4^{3-}\text{-P}$ at Station 9 were much lower than in the nearshore area but higher than in the center of the bay. Dissolved organic-N was highest at Station 9 as compared to all other stations (Fig. 3B). These differences in water quality indicate that the marshes rather than the Mississippi River played the dominant role in influencing nutrient concentration and composition at stations near the marshes in Caminada Bay during this time period. The entire nearshore zone, especially east of Caminada Pass, was enriched with inorganic nutrients such as $(\text{NO}_3^- + \text{NO}_2^-)$, SiO_2 , and PO_4^{3-} discharged by the Mississippi River. In spite of high inorganic nutrient concentrations in near offshore areas, these nutrients, with the exception of $\text{NH}_4^+\text{-N}$, remained relatively low in Caminada Bay (Table 1). The average value of $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ from 10 stations in the bay was more than 10 times lower than that of the average surface nearshore waters (0.025 and 0.282 mg/l, respectively), but average organic-N was about 4 times higher in the bay than in nearshore waters (0.524 and 0.167 mg/l, respectively). These results suggest that the inorganic nutrient input from the Mississippi River into Caminada Bay from a westerly nearshore flow was not substan-

tial during this time. The water areas nearest the marshes in Caminada Bay, especially the northern and western areas, were influenced predominantly by water draining from the marshes, canals, and bayous as evidenced by low salinity and $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ and high dissolved organic-N.

Stratification of salinity and nutrients in the nearshore waters was evident (Table 2). Salinity generally was higher in bottom waters than in surface waters. The smallest salinity variation between top and bottom waters occurred at Station 4-1 which was influenced by the Mississippi River more than other stations. $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ was inversely proportional to salinity but was generally lower in bottom waters. $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ levels in bottom water at Station 1-1 (offshore from Caminada Pass) were higher than those at the surface, whereas the opposite was true at other nearshore stations. The inversion of nutrient-enriched surface water to the bottom near Caminada Pass could be caused by the so-called inversed current located in the Caminada nearshore region (U.S. Army Corps of Engineers, New Orleans District, 1971). The occasionally high organic-N in some of the nearshore bottom waters may have been caused by the inclusion of some surface sediment when the water samples were taken.

March 29, 1973—Caminada and Barataria Bays and the Adjacent Near Offshore Area

Nutrient levels in Caminada and Barataria Bays along with adjacent nearshore stations are shown in Tables 3 through 5. The pattern of nutrient changes at selected stations in Caminada Bay and its nearshore area with distance from the Mississippi River mouth are shown in Figures 4A and 4B. The tide was rising during the sampling period of March 29, 1973 ranging from 53 to 69 cm (21 to 27 inches) above msl. The mean Mississippi River discharge during February 1973 was 24,200 m³/sec (853,000 cfs) whereas, the February mean since 1940 is 16,500 m³/sec (582,000 cfs). The March 1973 mean Mississippi River discharge was 22,400 m³/sec (794,000 cfs) and the mean for this month since 1940 is 19,300 m³/sec (684,000 cfs). Coastal rainfall during February 1973 was 8.6 cm (3.4 inches), which is slightly less than average; however, the 25.6 cm (10.1 inches) which fell in March of 1973 was the highest March rainfall of record (Fig. 2A and 2B).

Wind velocity was high during this sampling

period. Distribution patterns of salinity and inorganic nutrients in Caminada Bay and its near offshore waters were similar to those in January, although concentrations differed due to vertical mixing by winds. Salinities at stations near the upper marshes in Caminada Bay were lower (12.0 ‰) than during January (13.9 ‰) which

may be attributed to dilution effects by the extremely high rainfall in March. Salinities in near-shore surface waters were uniform (about 16 to 16.8 ‰) but were much higher in March than during January. The higher nearshore surface salinities in March relative to those in January are probably due to an increase in vertical mix-

Table 3
Nutrient Distribution in Caminada Bay (March 29, 1973).

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
C1	0.071	0.038	0.675	0.003	0.004	1.65	16.4
C2	0.096	0.111	0.618	0.014	0.021	1.40	20.0
C3	0.071	0.197	0.280	0.035	0.038	1.98	18.2
C4	0.122	0.089	0.358	0.022	0.064	1.88	22.4
C5	0.113	0.111	0.459	0.007	0.037	1.66	14.4
C6	0.113	0.222	0.238	0.015	0.034	2.09	12.4
C7	0.140	0.116	0.214	0.019	0.041	1.76	21.3
C8	0.088	0.140	0.405	0.004	0.061	1.60	11.9
C9	0.051	0.053	0.585	0.004	0.039	1.46	12.0
C10	0.108	0.051	0.385	0.005	0.064	1.37	17.6
Average	0.098	0.113	0.422	0.013	0.040	1.69	16.7

*The C prefix denotes Caminada Bay.

Table 4
Nutrient Distribution in Barataria Bay (March 29, 1973).

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
B1	0.066	0.261	0.308	0.005	0.049	1.70	23.5
B2	0.038	0.285	0.325	0.030	0.005	2.37	15.3
B3	0.043	0.208	0.373	0.026	0.048	2.37	16.1
B4	0.050	0.247	0.324	0.034	0.024	2.00	15.0
B5	0.057	0.220	0.317	0.028	0.010	1.71	16.3
B6	0.057	0.250	0.036	0.028	0.021	2.34	15.5
B7	0.063	0.231	0.297	0.029	0.000	2.22	15.2
B8	0.047	0.180	0.208	0.027	0.013	2.28	16.3
B9	0.038	0.190	0.282	0.024	0.036	2.32	16.0
B10	0.057	0.240	0.224	0.031	0.016	2.70	15.2
B11	0.072	0.284	0.106	0.027	0.042	2.31	15.0
B12	0.052	0.336	0.166	0.037	0.029	2.84	12.2
B13	0.054	0.329	0.281	0.036	0.031	2.57	12.2
B14	0.043	0.198	0.374	0.015	0.049	1.99	15.3
B15	0.011	0.148	0.349	0.005	0.052	1.90	12.3
B16	0.084	0.201	0.344	0.026	0.033	1.80	6.4
B17	0.102	0.218	0.326	0.026	0.048	1.94	5.6
B18	0.122	0.305	0.639	0.027	0.036	1.09	4.1
B19	0.092	0.384	0.780	0.020	0.044	2.32	8.0
B20	0.068	0.375	0.605	0.019	0.038	2.13	8.0
B21	0.084	0.297	0.333	0.022	0.004	2.30	17.1
B22	0.121	0.300	0.438	0.023	0.029	2.08	14.8
Average	0.065	0.259	0.338	0.025	0.030	2.15	13.4

*The B prefix denotes Barataria Bay.

Table 5
Nutrient distribution in the Nearshore Zone of Caminada and Barataria Bays
(March 29, 1973).

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₃ ⁻ +NO ₂ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
(mg/l)							
Caminada							
1-1 S	0.112	0.483	0.750	0.042	0.001	1.34	16.1
1-1 B	0.096	0.189	0.595	0.039	0.020	1.36	26.2
1-2 S	0.075	0.448	0.592	0.027	0.004	2.23	18.7
1-2 B	0.080	0.166	0.529	0.015	0.006	1.31	31.4
1-3 S	0.046	0.353	0.641	0.034	0.0	1.31	22.1
1-3 B	0.044	0.153	0.507	0.018	0.010	1.34	30.9
1-4 S	0.046	0.097	0.613	0.020	0.001	0.99	30.9
1-4 B	0.051	0.080	0.319	0.016	0.007	1.21	32.0
Barataria							
2-1 S	0.061	0.520	0.880	0.038	0.005	1.36	16.8
2-1 B	0.059	0.465	0.741	0.034	0.001	2.43	17.0
2-2 S	0.066	0.477	0.578	0.041	0.014	2.43	17.4
2-2 B	0.050	0.454	0.438	0.032	0.008	2.33	19.7
2-3 S	0.037	0.276	0.619	0.023	0.012	1.16	22.7
2-3 B	0.030	0.196	0.657	0.018	0.009	1.71	28.3
2-4 S	0.017	0.153	0.401	0.015	0.033	0.76	30.2
2-4 B	0.036	0.069	0.346	0.018	0.001	0.89	31.2
Quatre							
4-1 S	0.040	0.463	0.683	0.055	0.004	2.53	16.0
4-1 B	0.059	0.412	0.582	0.050	0.001	2.43	18.9
4-2 S	0.037	0.527	0.356	0.040	0.001	2.33	15.8
4-2 B	0.032	0.252	0.465	0.028	0.0	1.69	22.7
4-3 S	0.026	0.317	1.168	0.044	0.002	2.39	14.7
4-3 B	0.025	0.552	0.387	0.019	0.012	1.21	27.2
4-4 S	0.021	0.130	0.527	0.012	0.023	0.68	28.3
4-4 B	0.009	0.066	0.453	0.016	0.001	1.11	29.0
Averages							
1 S	0.071	0.346	0.649	0.031	0.002	1.47	22.0
1 B	0.068	0.147	0.488	0.022	0.011	1.31	30.2
2 S	0.045	0.357	0.620	0.030	0.016	1.43	21.8
2 B	0.044	0.296	0.546	0.026	0.005	1.85	24.1
4 S	0.025	0.360	0.684	0.038	0.008	1.99	18.8
4 B	0.032	0.321	0.472	0.029	0.004	1.61	24.5

S = surface water
B = bottom water

ing in March and the reduction in Mississippi River discharge between these months (discharge in January was 25,900 m³/sec [913,000 cfs] versus 23,300 m³/sec [794,000 cfs] in March). The reduced river effect during March was also reflected in the slightly lower (NO₃⁻ + NO₂⁻)-N values during this month as compared to January (Tables 2 and 5). The higher concentration of NH₄⁺-N during March at nearly all stations as compared to January is probably due to stronger wave action in March which introduced into the water column NH₄⁺ rich interstitial water of bottom sediments. This mixing effect would be pro-

nounced in shallow waters associated with highly organic bottom sediments. Caminada Pass (Station 3) is constantly subjected to scouring by strong currents, thus sediments at this station are sandy and low in organic matter, and therefore, low NH₄⁺ values occur both in the water column and sediments.

The distribution pattern of PO₄³⁻-P throughout Caminada Bay and its near offshore area in March was also similar to that in January, i.e., low values in the bay increasing offshore towards the river mouth (Fig. 4B).

Dissolved SiO₂ was significantly lower in March

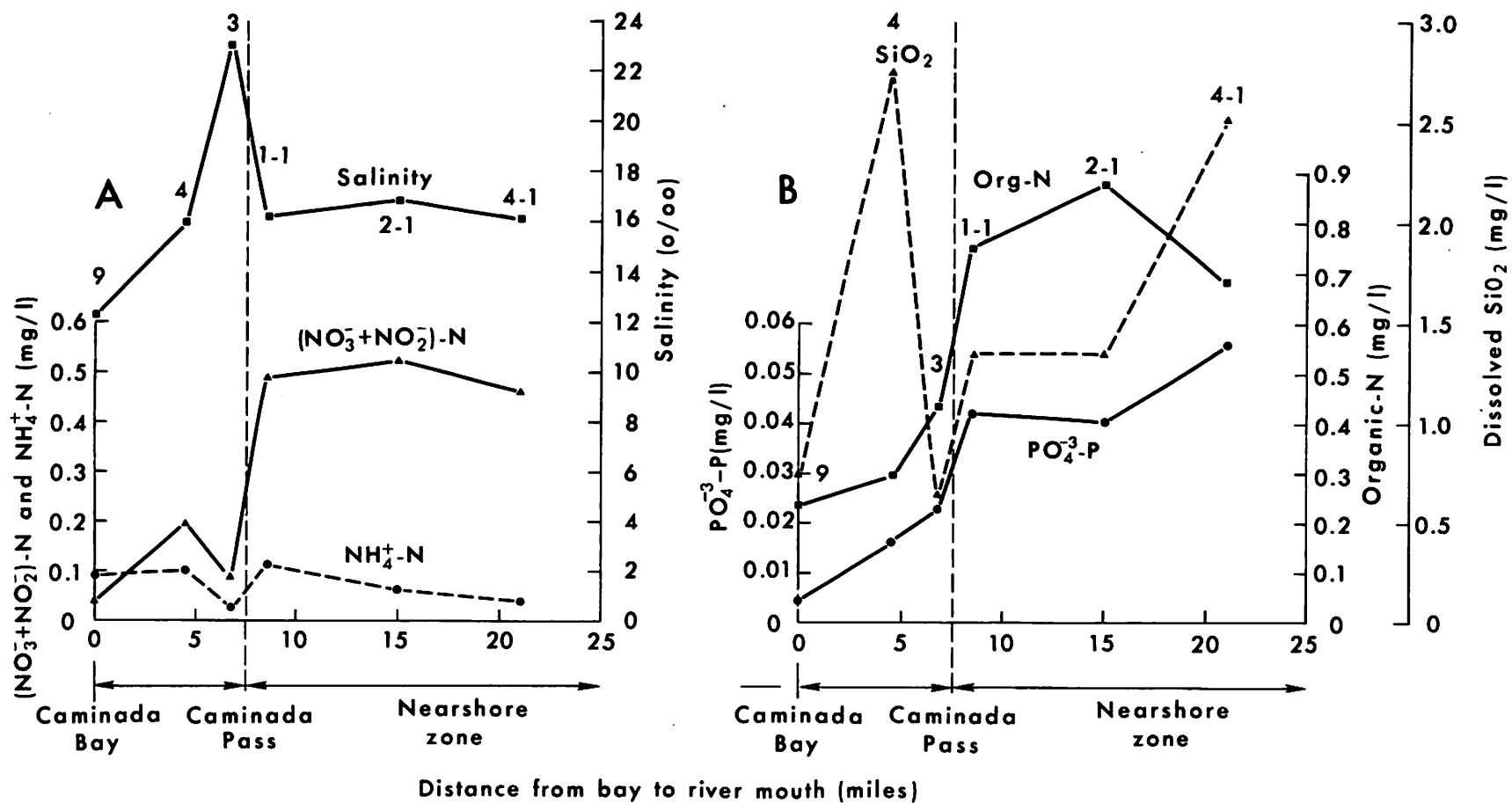


Figure 4. Distribution of chemical components at selected stations in Caminada Bay and its nearshore zone, March 29, 1973. (A) Salinity and inorganic-N, (B) organic-N, dissolved SiO₂, and PO₄³⁻-P.

than in January at all stations, except Station 4 in Caminada Bay. The inverse relationship between salinity and dissolved SiO_2 is well known (Bein et al., 1958). However, the pronounced fluctuation in SiO_2 at a relatively constant salinity level in the near offshore area could be indicative of removal of SiO_2 from solution by large amounts of suspended colloidal particles carried by the Mississippi River during periods of high discharge.

The nearshore bottom water at Stations 2-1 and 4-1 showed similar composition in salinity, $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$, and $\text{NH}_4^+\text{-N}$ as that in surface waters, indicating that the water column in these areas was well mixed (Table 5). However, Station 1-1 near Caminada Pass was the exception; chemical stratification in this region was pronounced. Salinity was 16.1 ‰ at the surface and 26.2 ‰ at the bottom. The bottom water also contained a low $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ value of 0.2 mg/l. The quality of bottom water rather than surface water at Station 1-1 exhibited some similarity to that of the surface water in Caminada Pass (Station 3), which had a salinity level of 23.0 ‰ and 0.08 mg/l $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$. This indicates a degree of water exchange between the nearshore bottom waters and Caminada Pass.

Dissolved organic-N and $\text{PO}_4^{3-}\text{-P}$ in bottom waters showed a similar distribution pattern to that of surface waters, but concentrations of these components were lower at the bottom than at the surface. Distribution of dissolved SiO_2 in the water column during March was reversed from the January conditions which showed lower dissolved SiO_2 in the bottom water than in the surface water (Tables 2 and 5). Some of the dissolved SiO_2 at the surface in March may have been removed from solution by suspended particles as a result of wind action. The effects of wind agitation would be reduced considerably at the bottom of the water column, thus accounting for higher dissolved SiO_2 at the bottom relative to concentrations at the surface.

Nutrient distribution in Caminada and Barataria bays is given in Tables 3 and 4. Comparison of the average values of 10 stations in Caminada Bay with 22 stations in Barataria Bay revealed that salinity in Barataria Bay was lower (13.5 ‰) than that in Caminada Bay (16.7 ‰). Much of the freshwater in Barataria Bay was drainage from the canals, bayous, and marshes in the northern reaches of this bay as indicated by the much lower salinity levels at Stations B18 through B22 as compared to those in the southern section near the passes (Table 4). The average concentration of $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ in Barataria Bay was more than twice as high as in Caminada Bay (0.259

and 0.113 mg/l, respectively), but $\text{NH}_4^+\text{-N}$ was slightly lower with an average of 0.065 mg/l in Barataria Bay as compared to 0.098 mg/l in Caminada Bay. Not all $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ in Barataria Bay can be attributed to Mississippi River discharge. Some undoubtedly came from drainage waters of the surrounding marshes and bayous as stations in the upper estuary contained more $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ than stations near the passes (Fig. 1 and Table 4). The fact that stations in Barataria Bay near Barataria Pass and those near Quatre Bayou Pass (Table 4) all showed higher $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ concentrations (from 0.21 to 0.28 mg/l) than those near Caminada Pass (0.12 to 0.20 mg/l at Station C7 and C3, respectively, Table 3) accompanied by lower salinity in Barataria Bay than in Caminada Bay supports the present opinion that more Mississippi River water enters Barataria Bay than Caminada Bay. Perhaps the number of openings to the Gulf in each of these bays, as well as the configuration, width, and angles of the passes with respect to the flow direction of nearshore waters all contributed to the degree of exchange between nearshore and bay waters. Also, Barataria Bay is closer to the discharge points of the Mississippi River than is Caminada Bay (Fig. 1).

Similar to $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$, average levels of $\text{PO}_4^{3-}\text{-P}$ and dissolved SiO_2 were also higher in Barataria Bay than in Caminada Bay. High Barataria Bay levels can be attributed to drainage water from the north and nearness to the Mississippi River mouth (Tables 3 and 4). The average dissolved organic-N and organic-P were slightly higher in Caminada Bay than in Barataria Bay, indicating more input from decomposition products of the marsh to Caminada Bay. The slightly higher average $\text{NH}_4^+\text{-N}$ (0.098 mg/l) in Caminada Bay than in Barataria Bay (0.065 mg/l) also supports this explanation.

May 22, 1973—Caminada and Barataria Bays, and the Near Offshore Area From Caminada Pass to Southwest Pass

Nutrient levels at selected stations in Caminada Bay and the near offshore zone from this bay to the Mississippi River mouth are shown in Figures 5A and 5B. Data from all stations are listed in tabular form in Tables 6 through 9. The tide was rising during the first part of this sampling period from 38 to 51 cm (15 to 20 inches) above msl, and latter samples were taken on a falling tide from 51 to 43 cm (20 to 17 inches) above msl. The discharge of the Mississippi River during 1973 was highest during May—38,000

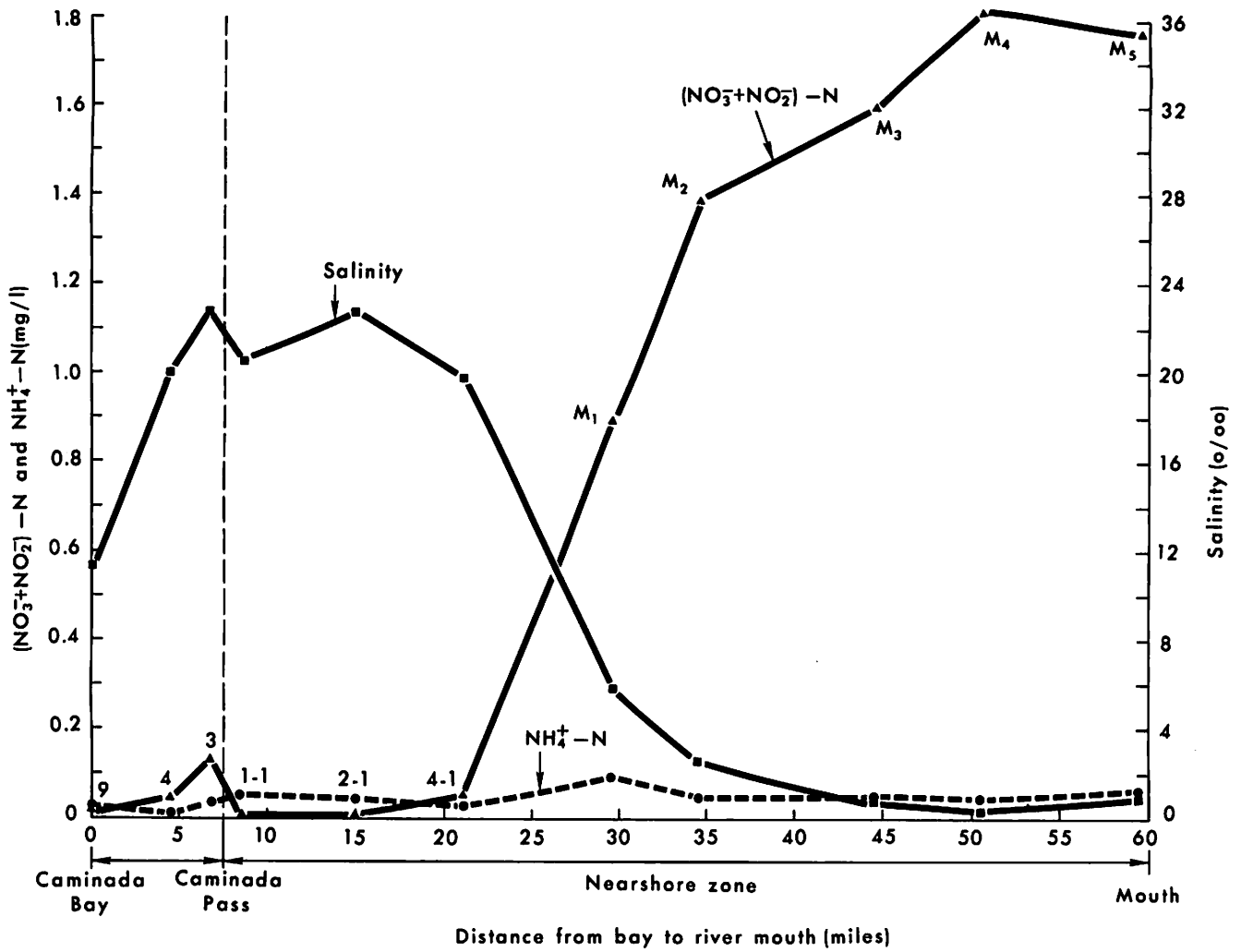


Figure 5A. Distribution of inorganic-N and salinity at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, May 22, 1973.

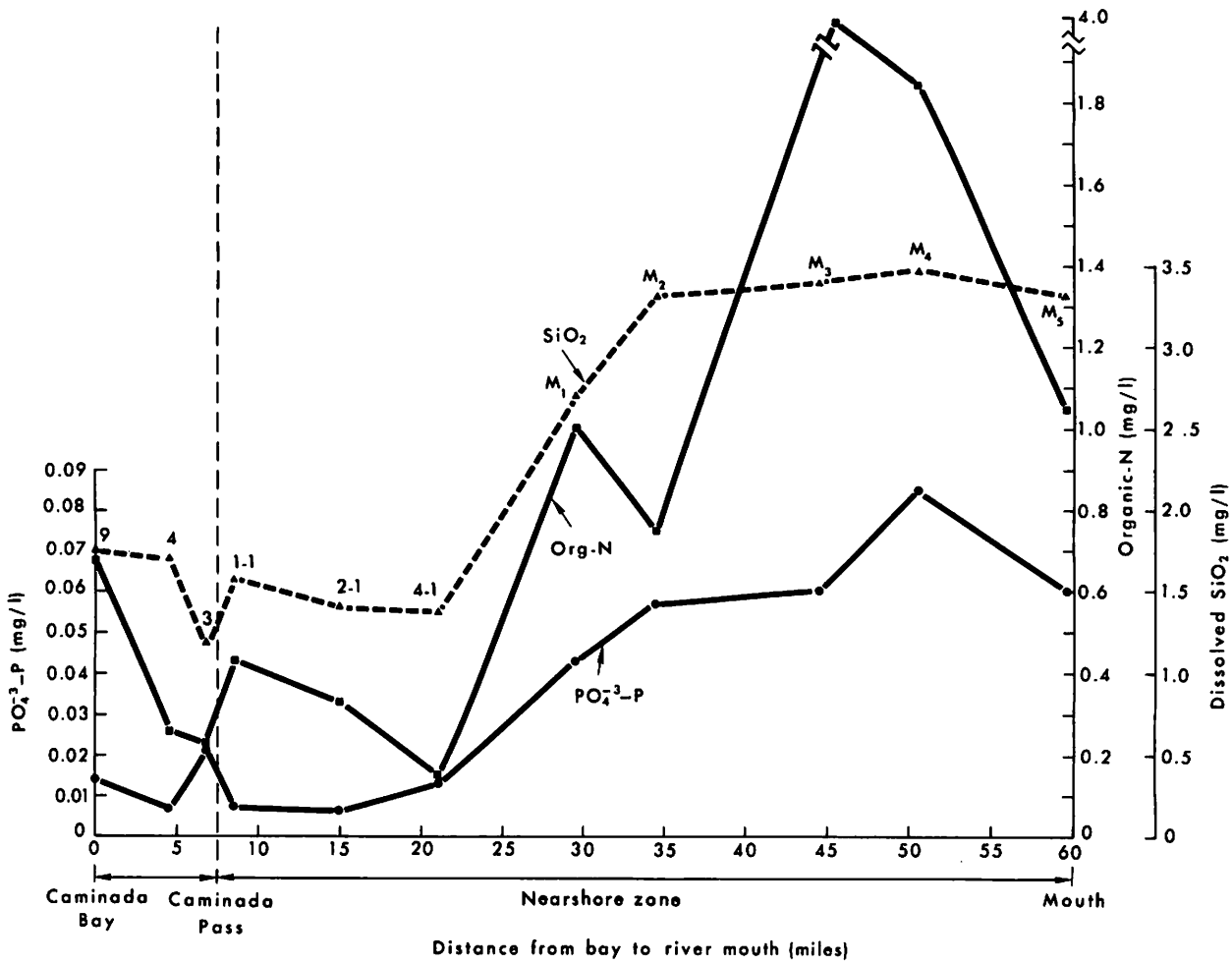


Figure 5B. Distribution of dissolved SiO₂, organic-N and PO₄³⁻-P at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, May 22, 1973.

Table 6
Nutrient Distribution in Caminada Bay (May 22, 1973).

Location* Sample	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
C1	0.007	0.006	1.179	0.016	0.047	1.52	13.6
C2	0.040	0.084	0.067	0.013	0.028	1.09	28.2
C3	0.028	0.129	0.228	0.021	0.003	1.18	22.7
C4	0.011	0.045	0.268	0.007	0.039	1.70	20.0
C5	0.011	0.046	0.082	0.015	0.033	1.61	16.2
C6	0.051	0.063	0.321	0.009	0.028	1.67	19.6
C7	0.028	0.075	0.628	0.009	0.021	1.23	27.2
C8	0.000	0.051	1.019	0.005	0.041	1.80	8.1
C9	0.017	0.010	0.681	0.014	0.042	1.75	11.3
C10	0.023	0.022	0.354	0.020	0.042	1.38	17.3
Average	0.022	0.053	0.483	0.011	0.032	1.49	18.5

*The C prefix denotes Caminada Bay.

Table 7
Nutrient Distribution in Barataria Bay (May 22, 1973).

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
B1	0.104	0.011	0.603	0.006	0.030	1.44	19.8
B3	0.085	0.034	0.799	0.013	0.018	1.42	19.9
B7	0.068	0.000	0.676	0.010	0.019	1.11	21.9
B10	0.018	0.021	0.843	0.017	0.051	1.85	16.0
B12	0.022	0.066	0.829	0.009	0.028	1.76	10.5
B14	0.002	0.021	1.044	0.012	0.033	1.86	10.6
B15	0.004	0.026	0.996	0.013	0.028	1.32	5.8
B16	0.002	0.038	1.044	0.023	0.034	0.79	1.2
B18	0.017	0.063	0.918	0.035	0.036	0.90	0.8
B20	0.023	0.019	0.908	0.017	0.044	0.84	1.2
B22	0.010	0.002	0.594	0.012	0.028	1.76	12.0
Average	0.032	0.027	0.841	0.015	0.032	1.37	10.9

*The B prefix denotes Barataria Bay.

Table 8
Nutrient Distribution in Nearshore Zone of Caminada and Barataria Bays (May 22, 1973).

Sample Location	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
Caminada							
1-1S	0.052	0.001	0.437	0.007	0.012	1.57	20.5
1-1B	0.043	0.007	0.275	0.006	0.023	1.38	21.0
1-2S	0.019	0.014	0.412	0.005	0.024	1.43	19.3
1-2B	0.050	0.018	0.212	0.010	0.017	0.98	31.6
1-3S	0.019	0.023	0.327	0.003	0.022	1.31	17.9
1-3B	0.149	0.000	—	0.016	0.026	1.94	31.2
1-4S	0.013	0.057	0.248	0.003	0.013	1.61	15.6
1-4B	0.027	0.020	0.575	0.016	0.019	1.28	32.8

Table 8—(continued)

Sample Location	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
(mg/l)							
Barataria							
2-1S	0.044	0.000	0.337	0.006	0.027	1.42	22.7
2-1B	0.042	0.013	0.753	0.009	0.028	1.18	24.5
2-2S	0.008	0.020	0.213	0.003	0.028	1.37	20.0
2-2B	0.121	0.015	0.117	0.007	0.033	1.19	24.7
2-3S	0.025	0.069	0.469	0.008	0.014	1.09	17.2
2-3B	0.031	0.038	—	0.005	0.019	1.02	25.3
2-4S	0.012	0.036	0.113	0.006	0.016	1.48	17.0
2-4B	0.202	0.003	0.145	0.036	0.028	1.75	33.4
Quatre Bayou							
4-1S	0.029	0.050	0.147	0.013	0.027	1.38	17.9
4-1B	0.036	0.075	0.112	0.016	0.035	1.32	19.4
4-2S	0.055	0.031	0.053	0.011	0.036	1.90	17.6
4-2B	0.033	0.064	0.257	0.009	0.027	1.50	18.4
4-3S	0.019	0.189	0.316	0.013	0.034	1.63	14.4
4-3B	0.339	0.005	0.149	0.040	0.019	2.15	30.9
4-4S	0.086	0.140	0.233	0.015	0.022	1.47	15.1
4-4B	0.255	0.007	0.173	0.032	0.013	1.28	31.6
Average							
1 S	0.025	0.023	0.356	0.004	0.018	1.48	18.3
1 B	0.067	0.011	0.354	0.012	0.021	1.40	29.2
2 S	0.022	0.031	0.283	0.005	0.021	1.34	19.2
2 B	0.099	0.017	0.338	0.014	0.027	1.29	27.0
4 S	0.047	0.102	0.187	0.013	0.030	1.60	16.2
4 B	0.165	0.037	0.173	0.024	0.024	1.56	24.6

S = surface water

B = bottom water

Table 9
Nutrient Distribution in Nearshore Zone
East of Quatre Bayou Pass and West of Southwest Pass of
the Mississippi River
(May 22, 1973).

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
(mg/l)							
1 to 2 miles from shoreline (about 14 ft. in depth)							
M1 S	0.091	0.888	1.043	0.043	0.036	2.70	6.0
M1 B	0.201	0.223	0.933	0.047	0.038	1.66	27.5
M2 S	0.046	1.386	0.748	0.057	0.031	3.32	2.5
M2 B	0.162	0.283	0.539	0.043	0.019	1.56	22.6
M3 S	0.045	1.606	3.976	0.060	0.035	3.42	0.8
M3 B	0.060	0.152	0.553	0.019	0.029	0.95	23.6
M4 S	0.042	1.815	1.865	0.085	0.020	3.47	0.3
M4 B	0.117	0.117	0.867	0.031	0.031	1.51	26.3
M5 S	0.061	1.773	1.056	0.060	0.036	3.32	0.9
M5 B	0.060	0.098	0.507	0.030	0.051	1.26	26.7
7 miles from shoreline (about 40 ft. in depth)							
M6 S	0.033	0.093	0.790	0.007	0.050	1.50	14.9
M6 B	0.016	0.039	0.325	0.012	0.032	0.86	33.3
M7 S	0.007	0.119	0.629	0.004	0.017	0.55	19.2
M7 B	0.004	0.158	0.610	0.007	0.022	0.90	19.3
M8 S	0.009	0.063	0.291	0.011	0.036	2.04	27.5
M8 B	0.005	0.104	0.558	0.011	0.007	0.56	25.8
M9 S	0.023	0.108	0.868	0.008	0.017	0.73	18.4
M9 B	0.072	0.081	0.492	0.023	0.010	0.84	29.4
M10 S	0.029	0.392	0.612	0.029	0.019	2.73	7.7
M10 B	0.049	0.122	0.473	0.016	0.004	1.75	28.1

Table 9—(continued)

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₃ ⁻ + NO ₂ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
Average							
1-2 miles S	0.057	1.493	1.738	0.061	0.032	3.24	2.1
B	0.120	0.174	0.680	0.034	0.034	1.39	25.3
7 miles S	0.019	0.174	0.702	0.011	0.028	1.51	17.5
B	0.030	0.081	0.428	0.013	0.015	0.98	27.2

S = surface waters

B = bottom waters

m³/sec (1,372,000 cfs)—which was also the highest May discharge recorded during the past 33 years. The discharge of 37,000 m³/sec (1,305,000 cfs) during April 1973 was the highest for that month since 1945. The volumes of water discharged during April and May of 1973 were 15,900 and 18,800 m³/sec (546,000 and 664,000 cfs), respectively, above the long-term averages for these months. Coastal rainfall during April 1973 was 26.4 cm (10.4 inches) which was 16 cm (6.3 inches) above the long-term average for this month. May 1973 coastal rainfall was 9.4 cm (3.7 inches) which was approximately 2.5 cm (1 inch) less than the long-term May average.

During this sampling period, salinity distribution varied from 6‰ in the nearshore zone of Grand Bayou Pass (Fig. 1A) to less than 1‰ at the mouth of the Mississippi River. Nearshore waters west of Grand Bayou Pass to Caminada Pass showed a high salinity level of 20 to 23‰. Salinity in Caminada Bay varied from 23‰ at Caminada Pass (Station 3) to a low of 11‰ near the marsh (Station 9) (Fig. 5A). As expected, distribution of (NO₃⁻ + NO₂⁻)-N was inversely proportional to salinity where influence by the Mississippi River prevailed. High concentrations of (NO₃⁻ + NO₂⁻)-N were found in the nearshore waters east of Grand Bayou Pass to the mouth of the Mississippi, ranging from 0.9 to 1.8 mg/l. These values agree with data obtained at the river mouth in February 1972 by Ho (1972). Nearshore waters west of Grand Bayou Pass contained little (NO₃⁻ + NO₂⁻)-N, ranging from a trace to 0.05 mg/l (Fig. 5A). NH₄⁺-N content was invariably low in all nearshore surface waters, ranging from 0.03 to 0.09 mg/l. The slightly higher NH₄⁺-N concentration adjacent to Grand Bayou Pass may be the result of local drainage water and/or upwelling of bottom waters in this area. Levels of NH₄⁺-N and (NO₃⁻ + NO₂⁻)-N in Caminada Bay were not similar to offshore values. Both components were in a depleted state of less than 0.02 mg/l near the marsh (Station 9); these com-

ponents were noticeably higher in the pass (Station 3), 0.03 mg/l of NH₄⁺-N, and 0.13 mg/l of (NO₃⁻ + NO₂⁻)-N. The center of the bay (Station 4) ranged between these levels (Fig. 5A). Depletion of inorganic-N in the bay was observed previously by Barrett et al. (1971) and Ho (1971) and could logically be attributed to more rapid phytoplankton uptake and a lower rate of replenishment. However, the reduction of (NO₃⁻ + NO₂⁻)-N accompanied by the absence of a substantial increase in organic-N (Fig. 5B) in the nearshore waters between Caminada Pass and Grand Bayou Pass cannot be explained solely by phytoplankton assimilation. The reduction of (NO₃⁻ + NO₂⁻)-N may have been caused by a displacement of (NO₃⁻ + NO₂⁻)-N enriched Mississippi water by low nutrient, high salinity seawater during this period due to a shift in current direction. Other evidence to support this reasoning was that surface salinity in this zone tended to decrease and (NO₃⁻ + NO₂⁻)-N increase seaward within the 11 km (7 mile) transect investigated (Table 8). This evidence further demonstrated the seaward diversion of Mississippi water by currents during this sampling period.

Concentrations of (NO₃⁻ + NO₂⁻)-N, organic-N, PO₄³⁻-P, and dissolved SiO₂ all increased sharply in nearshore waters which were directly influenced by Mississippi River discharge (i.e., in the region between Grand Bayou Pass and Southwest Pass) relative to the area west of Grand Bayou Pass. Organic-N varied from 0.75 to a high of 4.0 mg/l, PO₄³⁻-P ranged from 0.04 to 0.085 mg/l, and dissolved SiO₂ ranged from 2.7 to 3.5 mg/l east of Grand Bayou Pass, whereas west of this pass these components ranged from 0.15 to 0.43 mg/l, 0.006 to 0.013 mg/l, and 1.40 to 1.6 mg/l, respectively (Fig. 5B).

Selected stations inside Caminada Bay showed variations in organic-N, PO₄³⁻-P, and dissolved SiO₂, depending on the water source. Organic-N was highest near the marsh (0.7 mg/l, Station 9) but was low in the center of the bay as well as in the pass (0.2 to 0.25 mg/l). Dissolved SiO₂ was

lowest (1.2 mg/l) in the pass where salinity was highest; stations near the marsh (Station 9) and the center of the bay (Station 4) contained similar amounts of dissolved SiO_2 (1.7 mg/l). Slightly higher $\text{PO}_4\text{-P}$ in the pass (0.021 mg/l, Station 3) coincided with an increase in $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ at this station, indicating that both components may have been derived from waste disposal in the vicinity. $\text{PO}_4\text{-P}$ in the center of the bay and near the marsh was low, ranging from 0.007 to 0.014 mg/l (Fig. 5B).

Nutrients in Caminada and Barataria Bays varied widely, depending on the proximity to the sources of input (Tables 6 and 7). For example, $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ varied from 0.006 to 0.129 mg/l with a 10-station average of 0.053 mg/l in Caminada Bay, and from a trace to 0.066 mg/l with a 11-station average of 0.027 mg/l in Barataria Bay. The higher $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ values were probably associated with local waste disposal and drainage since stations away from these areas invariably contained low $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ values (e.g., Stations 1, 9, and 10 in Caminada Bay; Stations 1, 7, 10, 20 and 22 in Barataria Bay, Tables 6 and 7). The level of $\text{NH}_4^+\text{-N}$ was slightly lower in Caminada Bay, ranging from a trace to 0.05 mg/l with an average of 0.022 mg/l. Barataria Bay showed slightly higher $\text{NH}_4^+\text{-N}$ values, ranging from a trace to 0.104 mg/l with an average of 0.032 mg/l. Caminada Bay contained significantly lower organic-N than did Barataria Bay. Values for organic-N varied from 0.082 to 1.18 mg/l with an average of 0.48 mg/l in Caminada Bay and from 0.59 to 1.04 mg/l with an average of 0.84 mg/l in Barataria Bay. Water in areas near the upper marshes contained higher dissolved organic-N than areas to the south which were farther away from freshwater drainage. The high organic-N concentrations may be indicative of high productivity of plankton as a result of availability of nutrients, export of dissolved organics from the marshes, and/or waste disposal and low flushing rates in these areas. The present data are not sufficient to explain the quantitative aspect of the contribution by each of these mechanisms. Nevertheless, since available nutrients control and limit production of organic matter in an aquatic system and Barataria Bay water was demonstrated to contain more nutrients than Caminada Bay, higher organic-N in the former bay may be partially attributed to the direct consequence of nutrient enrichment. Organic-P, $\text{PO}_4\text{-P}$, and dissolved SiO_2 were similar in both bays, with averages of about 0.032, 0.01, and 1.40 mg/l, respectively (Tables 6 and 7).

The diversion of nutrient enriched Mississippi River water seaward east of Grand Bayou Pass

suggests that river water, as a nutrient supply source to Caminada and Barataria Bays, may subside during this time. Concentrations of $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ at stations near Quatre Bayou Pass and Barataria Pass (B1, B3, B7 and B10, Table 7) and their nearshore zone (Table 8) were lower than in areas distant from these regions. Therefore, it is concluded that the Mississippi River as a nutrient source to the bays was insignificant during this time, and nutrients in the bays were largely derived from drainage waters from the marshes and surrounding waterways along with sediment organic matter underlying the water column.

September 30, 1973—Caminada and Barataria Bays and the Near Offshore Area From Caminada Pass to Southwest Pass

Nutrient levels at selected stations in Caminada and Barataria Bays and the near offshore zone from Caminada Pass to the mouth of the Mississippi River are shown in Figures 6A and 6B. Data from this sampling trip are shown in Tables 10 through 13. The tide stage during the first part of this sampling trip was low slack at a height of 32 cm (12.5 inches) above msl. The latter part of the samples were taken during a rising tide from 32 to 43 cm (12.5 to 17 inches) above msl. The discharge of the Mississippi River during August and September of 1973 was 8,640 and 6,280 m^3/sec (305,000 and 222,000 cfs), respectively, which was the lowest volume of water discharged during the year and corresponded approximately to the long-term averages for these months. August coastal rainfall was 12.5 cm (4.9 inches) which is 3 cm (1.2 inches) below the long-term August average. September 1973 rainfall was 36.3 cm (14.3 inches) which was the highest rainfall occurring during any one month for the period between 1956 and 1973. The long-term average rainfall for September is 16 cm (6.3 inches) (Figs. 2A and 2B).

Salinity and nutrient levels in the entire nearshore zone changed drastically as compared to values obtained previously (Figs. 6A and 6B). Salinity was high throughout the entire nearshore zone studied, ranging from 23.6 to 30.0 ‰. Salinity at selected stations inside Caminada Bay, however, remained lower than that in the nearshore zone, with values of 16.5 ‰ at the center of the bay and 13.2 ‰ at Station 9 near the marsh.

Contrary to previous observations, concentrations of $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ in the nearshore waters east of Quatre Bayou Pass and west of Southwest Pass were depleted to an exceedingly low level of 0.001 to 0.003 mg/l, whereas nearshore waters west of Quatre Bayou and east of Caminada Pass

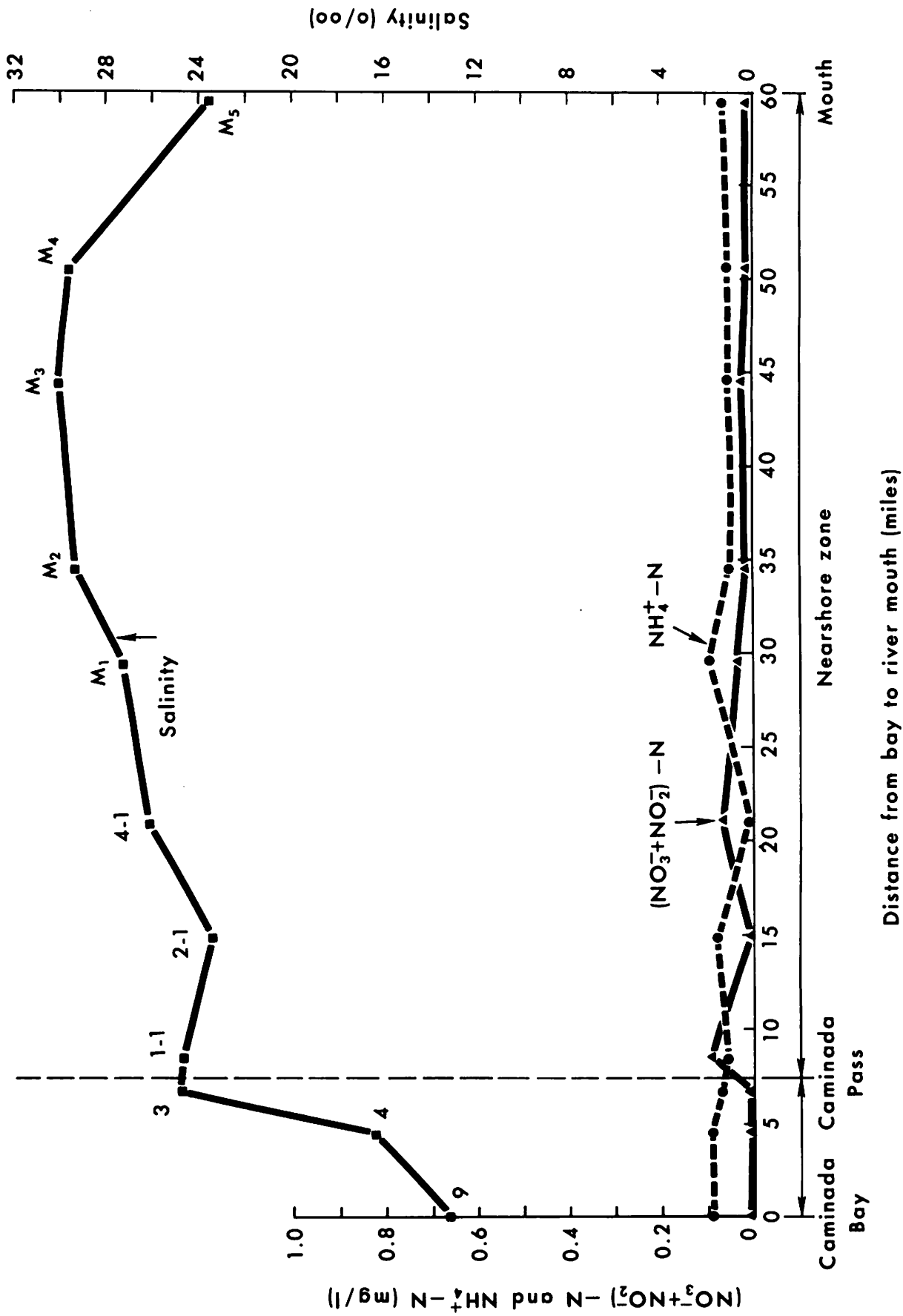


Figure 6A. Distribution of inorganic-N and salinity at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, September 20, 1973.

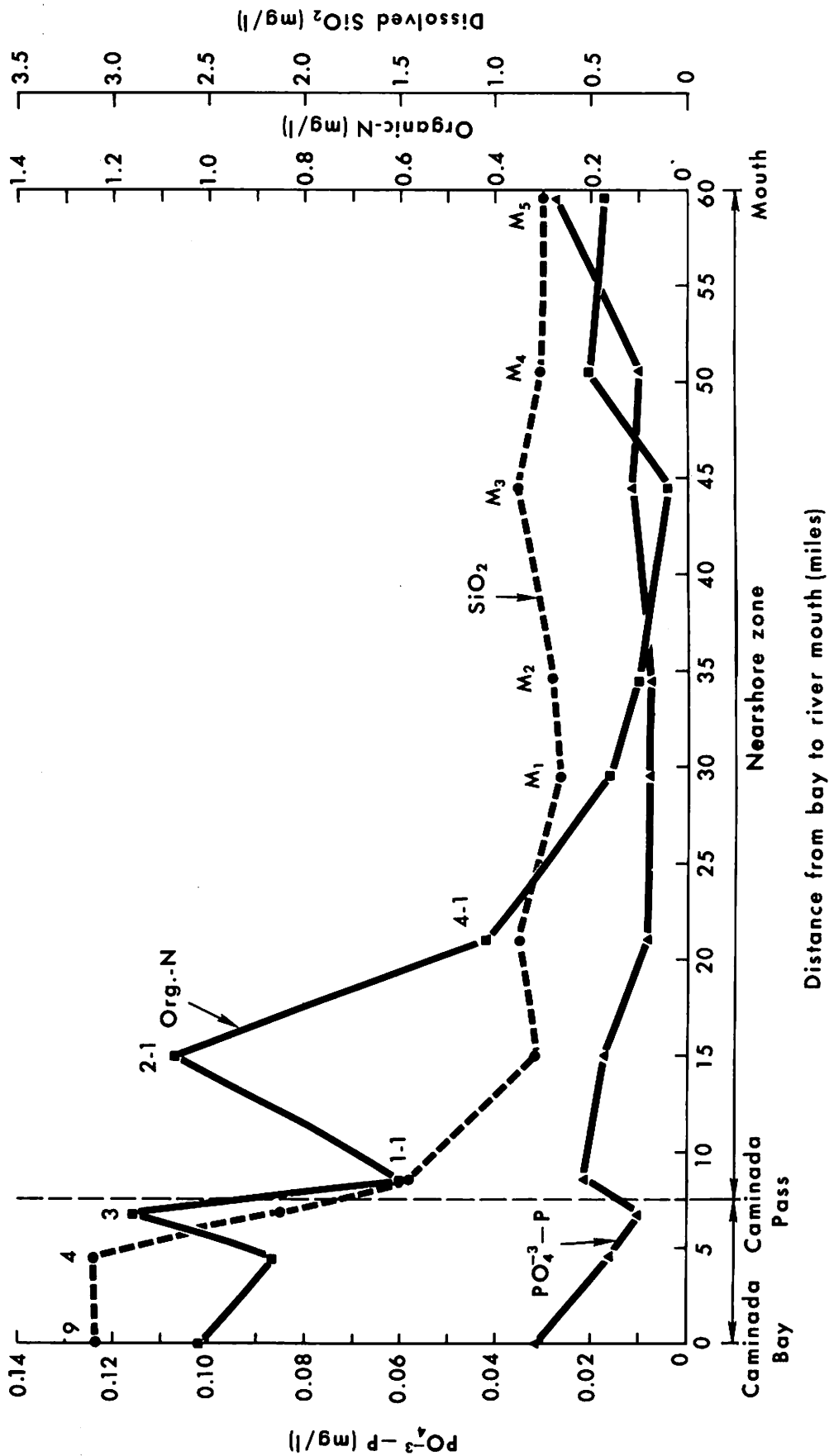


Figure 6B. Distribution of dissolved SiO_2 , organic-N and $PO_4^{3-}-P$ at selected stations in Caminada Bay, its nearshore zone and west of the Mississippi River mouth, September 20, 1973.

Table 10
Nutrient Distribution in Caminada Bay (September 20, 1973).

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
C1	0.030	0.037	0.676	0.021	0.071	2.90	18.5
C2	0.084	nil	0.521	0.019	0.029	2.48	24.9
C3	0.066	0.007	1.150	0.010	0.024	2.13	24.8
C4	0.090	0.001	0.871	0.016	0.039	3.11	16.5
C5	0.078	0.005	0.930	0.027	0.036	2.66	17.2
C6	0.080	nil	0.139	0.020	0.031	2.83	13.5
C7	0.073	0.007	0.579	0.014	0.029	2.73	20.3
C8	0.078	0.003	1.067	0.026	0.026	3.41	12.5
C9	0.090	0.004	1.019	0.031	0.035	3.08	13.2
C10	0.091	0.004	1.321	0.047	0.072	2.18	18.8
Average	0.076	0.006	0.827	0.023	0.039	2.75	18.0

*The prefix C denotes Caminada Bay.

Table 11
Nutrient Distribution in Nearshore Zone of Caminada and Barataria Bays (September 20, 1973).

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
Caminada Bay							
1-1 S	0.054	0.093	0.598	0.021	0.094	1.45	24.8
1-1 B	0.054	0.190	1.105	0.024	0.025	1.21	24.5
1-2 S	0.041	0.128	0.729	0.019	0.202	0.84	24.6
1-2 B	0.041	0.138	0.294	0.023	0.049	0.96	27.3
1-3 S	0.046	0.136	0.080	0.017	0.014	0.71	25.8
1-3 B	0.083	0.074	0.396	0.028	0.014	1.41	29.9
1-4 S	0.048	0.061	0.360	0.015	0.243	0.99	26.6
1-4 B	0.055	0.048	0.524	0.033	0.041	1.34	30.1
Barataria Bay							
2-1 S	0.079	nil	1.079	0.017	0.014	0.79	23.6
2-1 B	0.066	nil	0.641	0.009	0.022	0.68	25.0
2-2 S	0.059	nil	0.375	0.012	0.022	0.76	24.3
2-2 B	0.048	nil	0.097	0.012	0.021	0.73	25.0
2-3 S	0.036	0.016	0.190	0.016	0.006	0.63	25.2
2-3 B	0.043	nil	0.481	0.012	0.020	0.67	25.5
2-4 S	0.035	0.027	0.453	0.007	0.038	1.05	25.6
2-4 B	0.023	0.066	0.447	0.020	0.010	0.93	30.4
Quatre Bayou Pass							
4-1 S	0.009	0.064	0.425	0.008	0.026	0.87	26.2
4-1 B	nil	0.018	0.715	0.014	0.026	1.02	26.0
4-2 S	0.008	0.033	0.553	0.010	0.031	0.97	26.8
4-2 B	0.014	0.042	0.665	0.011	0.031	1.20	27.7
4-3 S	nil	0.051	1.195	0.017	0.021	1.27	26.9
4-3 B	0.02	0.071	0.849	0.027	0.028	1.17	27.8
4-4 S	nil	0.058	0.923	0.016	0.019	0.84	26.6
4-4 B							

Table 11—(continued)

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₃ ⁻ +NO ₂ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
Averages							
1 S	0.047	0.104	0.442	0.018	0.138	1.00	25.5
1 B	0.058	0.104	0.580	0.027	0.032	1.23	28.0
2 S	0.052	0.010	0.520	0.013	0.020	0.81	24.6
2 B	0.045	0.016	0.420	0.013	0.018	0.75	26.5
4 S	0.004	0.051	0.770	0.013	0.024	0.99	26.6
4 B	0.011	0.043	0.740	0.017	0.028	1.13	27.1

S = surface waters
B = bottom waters

Table 12
Nutrient Distribution in Nearshore Zone
East of Quatre Bayou Pass and West of Southwest Pass of
the Mississippi River
(September 20, 1973).

Nearshore Sample Location	NH ₄ ⁺ -N	(NO ₃ ⁻ +NO ₂ ⁻) -N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
1 to 2 miles from shoreline (about 14 ft. in depth)							
M1 S	0.043	0.028	0.160	0.008	0.014	0.64	27.3
M1 B	0.086	0.003	0.290	0.025	0.027	1.34	30.1
M2 S	0.049	0.013	0.098	0.007	0.016	0.70	29.3
M2 B	0.024	0.062	0.574	0.023	0.018	1.31	28.6
M3 S	0.038	0.016	0.037	0.011	0.044	0.88	30.1
M3 B	0.269	0.008	0.380	0.028	0.037	1.28	29.2
M4 S	0.044	0.011	0.201	0.010	0.029	0.76	29.7
M4 B	0.178	0.046	0.437	0.022	0.048	0.58	29.4
M5 S	0.049	0.012	0.172	0.027	0.018	0.76	23.6
M5 B	0.142	0.002	0.448	0.031	0.027	1.08	24.5
7 miles from shoreline (about 40 ft. in depth)							
M6 S	0.039	0.018	0.188	0.026	0.194	0.21	24.2
M6 B	0.185	0.033	0.345	0.052	0.013	0.36	27.3
M7 S	0.043	0.001	0.166	0.050	0.035	0.57	20.9
M7 B	0.104	0.020	0.332	0.025	0.002	0.81	23.7
M8 S	0.036	0.011	0.185	0.008	0.032	0.46	25.0
M8 B	0.080	0.040	0.245	0.009	0.020	0.67	29.1
M9 S	0.046	0.006	0.297	0.003	0.011	1.28	27.5
M9 B	0.090	0.048	0.124	0.024	0.011	1.11	29.8
M10 S	0.042	0.009	0.179	0.005	0.011	0.56	25.1
M10 B	0.172	0.000	0.494	0.036	0.027	1.43	26.5
Average							
1-2 miles S	0.045	0.016	0.134	0.013	0.024	0.75	28.0
1-2 miles B	0.140	0.024	0.426	0.026	0.031	1.12	26.4
7 miles S	0.041	0.009	0.203	0.018	0.057	0.42	24.5
7 miles B	0.126	0.023	0.308	0.029	0.015	0.88	27.3

S = surface waters
B = bottom waters

Table 13
Nutrient Distribution in Barataria Bay
(September 20, 1973).

Sample Location*	NH ₄ ⁺ -N	(NO ₂ ⁻ +NO ₃ ⁻)-N	Org-N	PO ₄ ³⁻ -P	Org-P	Diss. SiO ₂	Salinity (‰)
	(mg/l)						
B1	0.081	0.030	0.582	0.019	0.010	1.78	19.3
B3	0.069	0.030	0.474	0.018	0.033	1.43	25.4
B7	0.064	0.017	0.210	0.027	0.020	1.44	25.5
B10	0.073	0.011	0.521	0.020	0.027	1.50	26.2
B12	0.065	0.021	0.420	0.026	0.028	—	26.6
B14	0.064	0.022	0.764	0.029	0.037	1.86	13.9
B15	0.069	0.006	0.645	0.013	0.034	2.30	11.1
B16	0.075	0.021	0.782	0.019	0.045	2.54	7.9
B18	0.082	0.040	0.346	0.036	0.004	2.69	4.6
B20	0.064	0.009	0.730	0.025	0.035	2.44	5.2
B22	0.075	0.030	0.834	0.012	0.065	2.94	10.8
Average	0.071	0.022	0.574	0.022	0.031	1.96	16.1

*The prefix B denotes Barataria Bay.

showed higher (NO₂⁻ + NO₃⁻)-N values of 0.001 to 0.09 mg/l. NH₄⁺-N constituted the dominant fraction of the total inorganic-N composition throughout the entire study area. For example, NH₄⁺-N varied from 0.05 to 0.09 mg/l in the nearshore waters east of Quatre Bayou Pass, and from 0.001 to 0.08 mg/l west of the pass. The ratio between (NO₂⁻ + NO₃⁻)-N and NH₄⁺-N was especially striking in Caminada Bay. (NO₂⁻ + NO₃⁻)-N was depleted to only a trace, whereas NH₄⁺-N remained relatively high, ranging from 0.07 to 0.09 mg/l (Fig. 6A). The depletion of (NO₂⁻ + NO₃⁻)-N accompanied by relatively high levels of NH₄⁺-N is indicative of utilization of the former by phytoplankton resulting in organic-N synthesis followed by subsequent decomposition of the organic remains to NH₄⁺-N at the end of the phytoplankton growth period and subsequent decomposition. It should also be noted that the supply of (NO₂⁻ + NO₃⁻)-N by the Mississippi River to the entire nearshore zone and associated estuaries became essentially nil during this time. High coastal rainfall in September 1973 apparently did not contribute significant amounts of (NO₂⁻ + NO₃⁻)-N to the nearshore waters.

Levels of organic-N, dissolved SiO₂, and PO₄³⁻-P provided additional evidence regarding the relative importance of the marshes surrounding the bays and the Mississippi River as nutrient supply sources. Concentrations of these components in the nearshore waters east of Grand Bayou Pass all decreased to low levels characteristic of predominant seawater influence during this sampling period. For example, dissolved SiO₂ varied from 0.65 to 0.86 mg/l, organic-N from 0.04 to 0.2 mg/l, and PO₄³⁻-P from 0.008 to 0.027 mg/l in the

nearshore waters east of Grand Bayou Pass and west of Southwest Pass. Waters in the nearshore zone west of Grand Bayou Pass showed a much higher concentration of these components. Dissolved SiO₂ varied from 0.85 to 1.45 mg/l, organic-N from 0.42 to 1.07 mg/l, and PO₄³⁻-P from 0.008 to 0.021 mg/l. Concentrations of these components in Caminada Bay were relatively high. Dissolved SiO₂ changed from 2.1 to 3.1 mg/l, organic-N from 0.87 to 1.15 mg/l, and PO₄³⁻-P from 0.01 to 0.03 mg/l. The simultaneous enrichment of organic-N, NH₄⁺-N, PO₄³⁻-P, and perhaps SiO₂ in Caminada Bay and its nearshore zone suggests that these components were derived from decomposition of biological remains, thus providing the ecosystem with an important mechanism for regeneration of nutrients. Some of these components are exported offshore, therefore accounting for the substantially high levels of nutrients adjacent these bays relative to levels found near the river mouth (Fig. 6B).

Nutrient distribution in Caminada and Barataria Bays is shown in Tables 10 and 13, respectively. Salinity near the passes was invariably higher than in the upper marshes in both bays. Barataria Bay showed a salinity range of 4.7 to 26.6 ‰ with an average of 16.1 ‰. Salinity in Caminada Bay varied from 13.3 to 25.0 ‰ with an average of 18.1 ‰. This trend was consistent with that observed during May, indicating that Barataria Bay had continued to receive more fresh drainage waters than did Caminada Bay in September 1973. Associated with drainage waters into Barataria Bay was a higher level of (NO₂⁻ + NO₃⁻)-N as compared to Caminada Bay. For example, (NO₂⁻ + NO₃⁻)-N varied from 0.009 to 0.04

mg/l with an average of 0.022 mg/l in Barataria Bay, whereas Caminada Bay contained only a trace to 0.037 mg/l with an average of 0.006 mg/l. Contrary to the May trip, the average concentration of organic-N in September was higher in Caminada Bay (0.83 mg/l) than in Barataria Bay (0.57 mg/l). It is conceivable that more dissolved organic-N in Barataria Bay could have been exported to the nearshore zone via Barataria Pass

than through Caminada Pass, as indicated by correspondingly higher organic-N in the nearshore zone of Barataria Pass (1.07 mg/l) and lower organic-N offshore from Caminada Bay (0.6 mg/l) (Fig. 6B). The average content of dissolved SiO₂ was also higher in Caminada Bay than in Barataria Bay (2.75 and 1.96 mg/l, respectively). NH₄⁺-N, PO₄³⁻-P, and organic-P were about the same in both bays (Tables 10 and 13).

Contribution of Nutrients By the Mississippi River and Marshes

The average monthly maximum, minimum and mean discharge of the Mississippi River from January through July 1973 was 31,000 m³/sec, 22,900 m³/sec, and 26,900 m³/sec (1,093,000 cfs, 809,000 cfs, and 950,000 cfs), respectively. The mean value of 26,900 m³/sec (950,000 cfs) was used to estimate the quantities of selected nutrients discharged by the Mississippi River based on the following assumptions:

1. Surface water at Station M4 (Table 9, Fig. 1A) represented river water and concentrations of the components of the Mississippi River would not change significantly at various discharge stages from January through July of 1973. The basis for this assumption is the proximity of Station M4 to the river mouth, the similarity in concentrations of (NO₃⁻ + NO₂⁻)-N in February of 1972 at Southwest Pass and May 1973 at Station M4 (1.8 mg/l), and the higher levels of PO₄³⁻-P and dissolved SiO₂ and low salinity at this station as compared with other stations in May 1973.
2. Surface concentrations of nutrients at Station M4 in September 1973 represented the ambient nearshore concentration relatively free of Mississippi River influence (Station

M4, Table 12). Discharge in September 1973 was 6,200 m³/sec (220,000 cfs), whereas 38,800 m³/sec (1,370,000 cfs) was discharged during May 1973.

3. The net nutrient input of the Mississippi River into the Gulf of Mexico is the difference between the values at Station M4 in May, Table 9 and the corresponding values at this station in September, Table 12.

The estimated amount of nutrients discharged by the Mississippi River during the period of January through July, 1973 is shown in Table 14. The magnitude of inorganic and organic components introduced by this river during the first 7 months in 1973 was enormous—a combined weight of (NO₃⁻ + NO₂⁻)-N, PO₄³⁻-P, dissolved SiO₂, and organic-N totaling 3.06 billion kg (6.75 billion pounds). Dissolved organic-C was not analyzed from the water samples, but was calculated from a C/N ratio of 12. Thus, the calculated total dissolved organic-C discharged between January and July by the Mississippi River was 9.85 billion kg (21.7 billion pounds). Table 14 also presents an estimate of selected nutrients contributed to the Gulf by the Atchafalaya River. The volume of water discharged by the Atchafalaya River was approximately 50% of that dis-

Table 14

Estimated amount of selected nutrients discharged into Louisiana's coastal area between January and July 1973 by the Mississippi and Atchafalaya rivers.

	Nutrients (in billions of pounds)				
	(NO ₃ ⁻ +NO ₂ ⁻)-N	PO ₄ ³⁻ -P	Diss. SiO ₂	Org-N	Org-C
Mississippi River	1.96	0.08	2.90	1.81	21.70
Atchafalaya River	0.98	0.04	1.45	0.91	10.85

charged by the Mississippi River during 1973. Assuming that the concentrations of chemical components in the Atchafalaya River were the same as those in the waters of the Mississippi, then the amount of nutrients emptied into the coastal area at the Atchafalaya River mouth would be half that of the Mississippi River.

To estimate the impact on dissolved oxygen by organic matter emptied into the Gulf, it was assumed that river water contained 9 mg/l dissolved O_2 and that complete oxidation of 1 mole of organic-C requires 1 mole of dissolved O_2 in water to form 1 mole of CO_2 . Therefore, the molar ratio of dissolved organic-C/dissolved O_2 in river water would be 5.9. Ambient seawater would have an organic-C/dissolved O_2 ratio of 0.71 which is 8 times lower than that of river water. Organic matter may also be added to the nearshore Gulf waters by photosynthesis of phytoplankton which proliferates as a result of the abundant nutrients transported by the river, thus requiring more dissolved O_2 for its decomposition. The typical sequence of events which results from the introduction of excessive amounts of allochthonous organic matter and available nutrients into an aquatic system is an increase in oxygen demand due to photosynthetic production of organic matter by a phytoplankton bloom and subsequent depletion of dissolved O_2 due to decomposition of organic matter. This phenomenon has been observed in many aquatic systems such as the Great Lakes (Bartsch, 1972) and Lake Maracaibo, Venezuela (Battelle, 1974) and is well summarized by Warren (1971). The nutrient levels measured in our nearshore waters influenced by the Mississippi River were much higher than those found in the Great Lakes.

Low dissolved oxygen levels in the coastal waters of Louisiana have been reported numerous times since the early 1900's (Hedgpeth, 1957). The most recent report was in 1973 when a research team from Nicholls State University found low dissolved oxygen levels during late spring and early summer from Southwest Pass at the mouth of the Mississippi River to Ship Shoal, south of Morgan City (Nicholls State University, News Release, 1973). Low dissolved oxygen levels in these waters during 1973 may have affected benthic organisms, but catch data indicate that shrimp production was not impaired by oxygen depletion. The 1973 offshore brown shrimp catch was higher than the 1959 to 1973 average, and the offshore brown shrimp catch from Southwest Pass to Bayou Lafourche during 1973 was almost twice the average catch for this area.

The magnitude of average seasonal changes of $(NO_3^- + NO_2^-)$ -N, NH_4^+ -N, and salinity in the nearshore waters between Caminada and Barataria passes is illustrated in Figures 7A and 7B. The high levels of $(NO_3^- + NO_2^-)$ -N in both surface and bottom waters as a result of river discharge prior to May 1973 is evident in these nearshore waters. NH_4^+ -N was not a major component in the river water; therefore, it did not show a pronounced increase as a result of increased river discharge. The slight increase in NH_4^+ -N after January, especially in the bottom water, was probably the result of wave action which agitated the bottom sediments which contain NH_4^+ -N in the interstitial water. Other components of river origin such as PO_4^{3-} -P and dissolved SiO_2 would follow the same seasonal trend as that shown by $(NO_3^- + NO_2^-)$ -N.

That $(NO_3^- + NO_2^-)$ -N, PO_4^{3-} -P, and dissolved SiO_2 in the nearshore zone between Caminada Pass and the mouth of the Mississippi River from January to March were of Mississippi River origin was indicated by the inverse relationships of these components with salinity (Figures 8A to 10C). The lower the salinity, the higher the $(NO_3^- + NO_2^-)$ -N, PO_4^{3-} -P, and dissolved SiO_2 .

The inverse relationships between salinity and $(NO_3^- + NO_2^-)$ -N, PO_4^{3-} -P, and dissolved SiO_2 characteristic of Mississippi River waters did not apply to waters in the bays (Figures 12A to 12C for Barataria Bay; Figures 13A to 13C for Caminada Bay). The present evidence suggests that the Mississippi River influence on Barataria Bay was confined primarily to the southern region of this bay as these waters were characterized by only a slight variation in salinity (15 to 17 ‰) as well as narrow ranges of $(NO_3^- + NO_2^-)$ -N, PO_4^{3-} -P, and dissolved SiO_2 (Figs. 12A to 12C). This water mass can be distinguished from that in the northern region of the bay by lower salinity and a wider range in salinity and nutrient concentrations in the upper bay due to various sources of drainage water. For example, the Mississippi River-influenced southern region showed a salinity range of 14 to 17 ‰, whereas in the northern region, salinity varied from 4 to 12 ‰; $(NO_3^- + NO_2^-)$ -N varied from 0.18 to 0.30 mg/l in the southern region and from 0.15 to 0.38 mg/l in the northern part of the bay. PO_4^{3-} -P and dissolved SiO_2 (Figs. 12A to 12C) also had wider ranges in the upper bay as compared to the lower bay.

$(NO_3^- + NO_2^-)$ -N, PO_4^{3-} -P, and dissolved SiO_2 of river origin which entered Caminada Bay from nearshore waters were restricted to Caminada Pass (Figs. 13A to 13C). The low saline water of relatively low concentrations of $(NO_3^- + NO_2^-)$ -N,

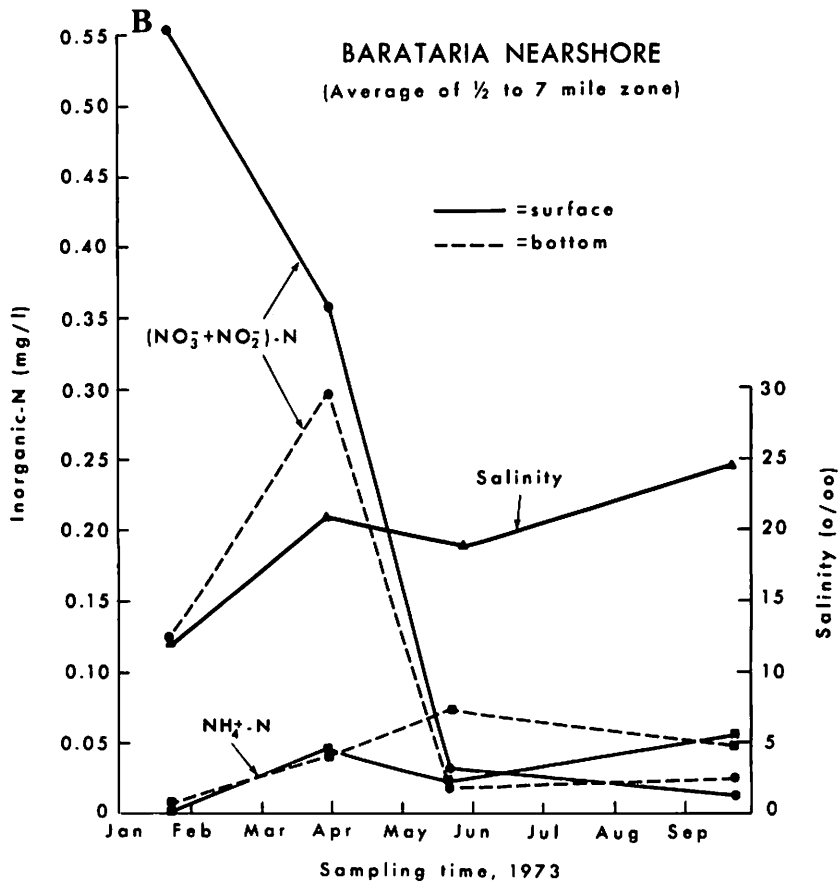
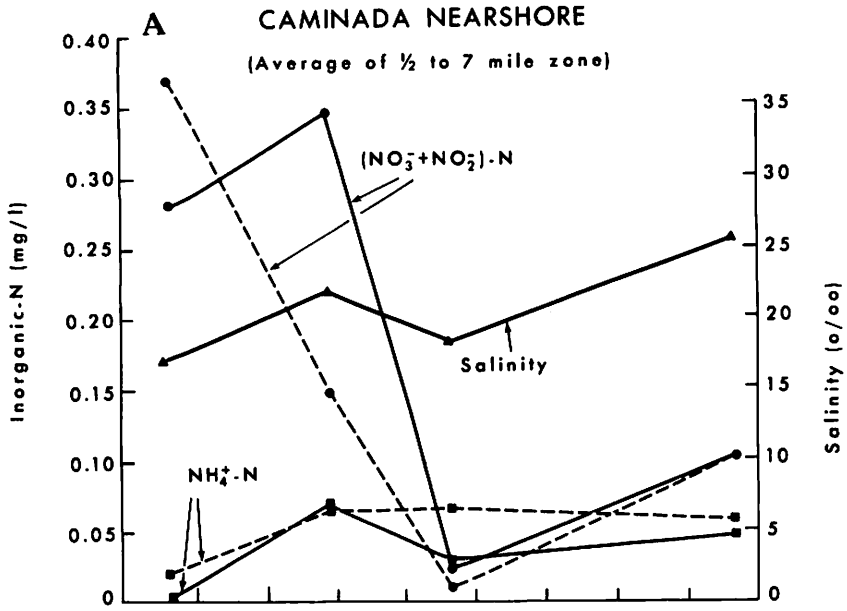


Figure 7. Seasonal changes in inorganic-N and salinity, (A) nearshore zone of Caminada Pass, (B) nearshore zone of Barataria Pass.

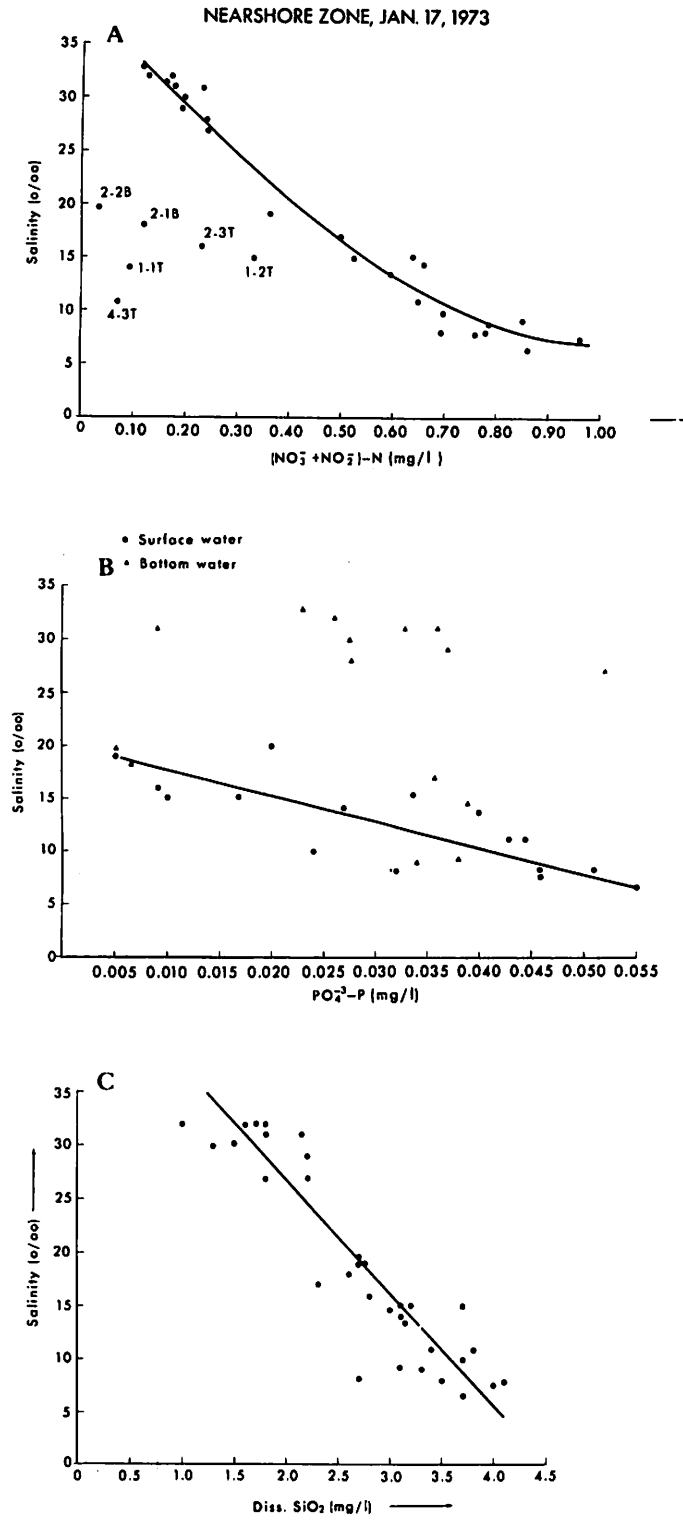


Figure 8. Relationship between salinity and $(\text{NO}_3^- + \text{NO}_2^-)\text{-N}$ (A), $\text{PO}_4^{3-}\text{-P}$ (B), and dissolved SiO_2 (C), in nearshore waters south of Barataria and Caminada Bays, (January 17, 1973).

NEARSHORE ZONE, MARCH 29, 1973

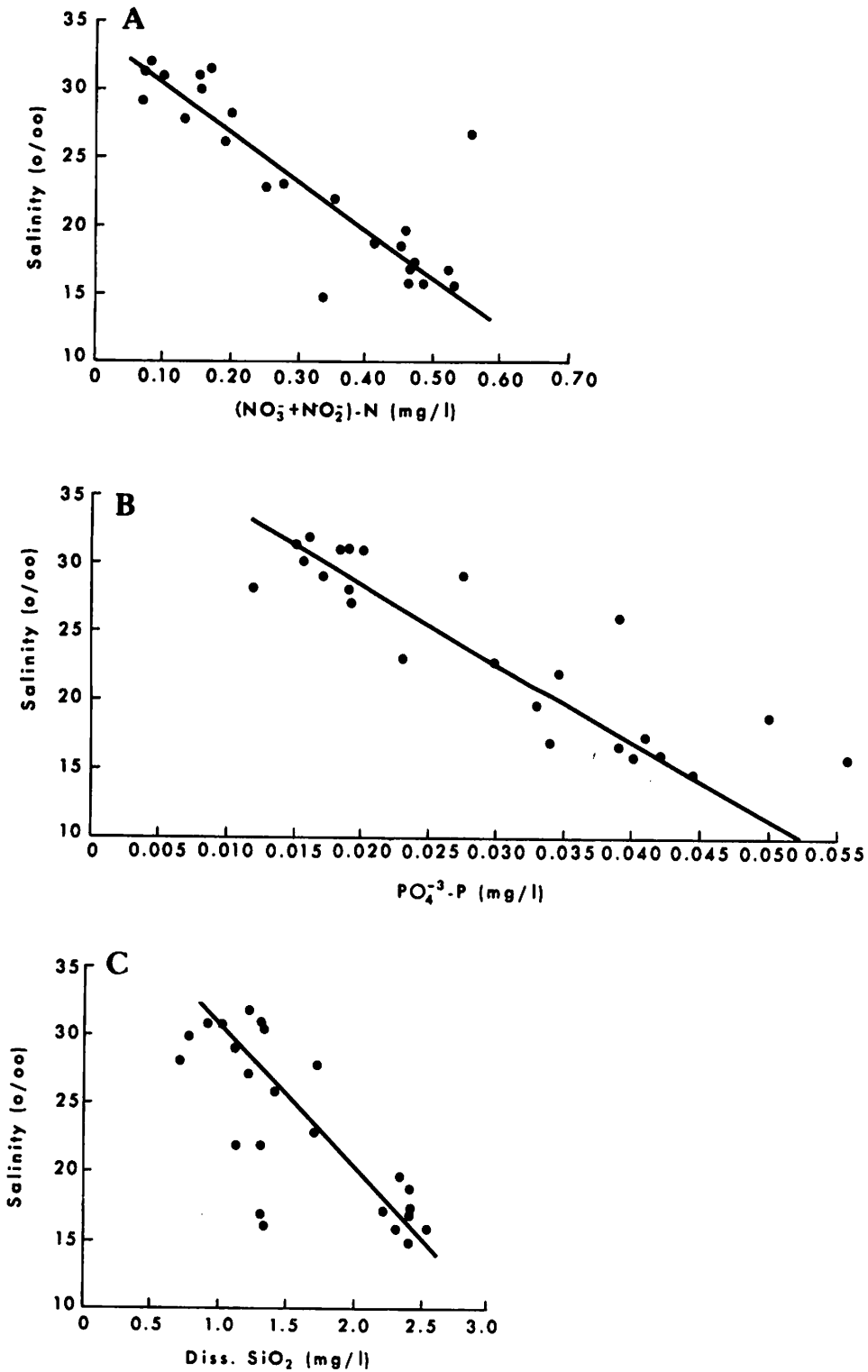


Figure 9. Relationship between salinity and $(\text{NO}_3 + \text{NO}_2)\text{-N}$ (A), $\text{PO}_4^{3-}\text{-P}$ (B), and dissolved SiO_2 (C), in nearshore waters south of Caminada and Barataria Bays, (March 29, 1973).

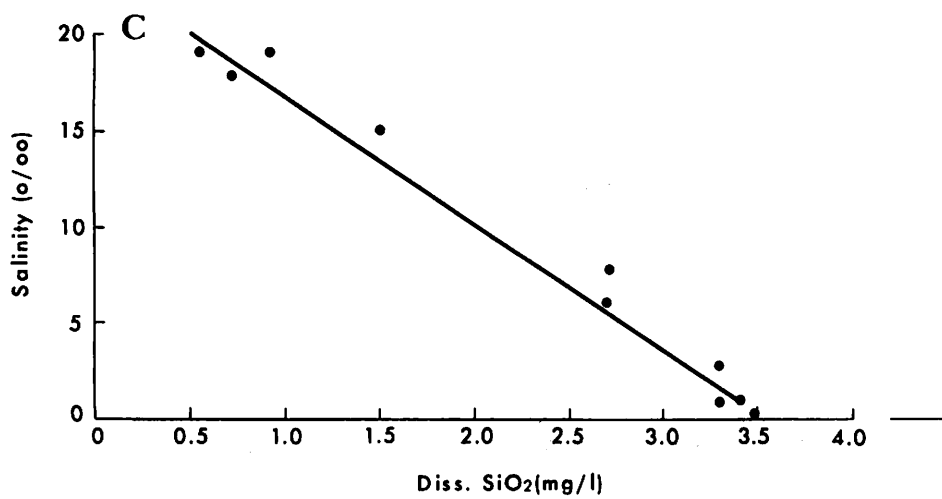
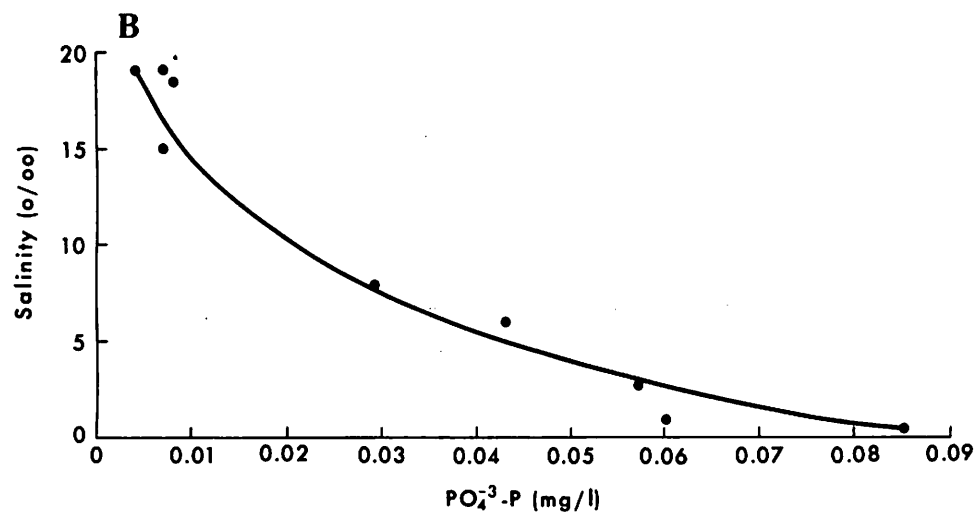
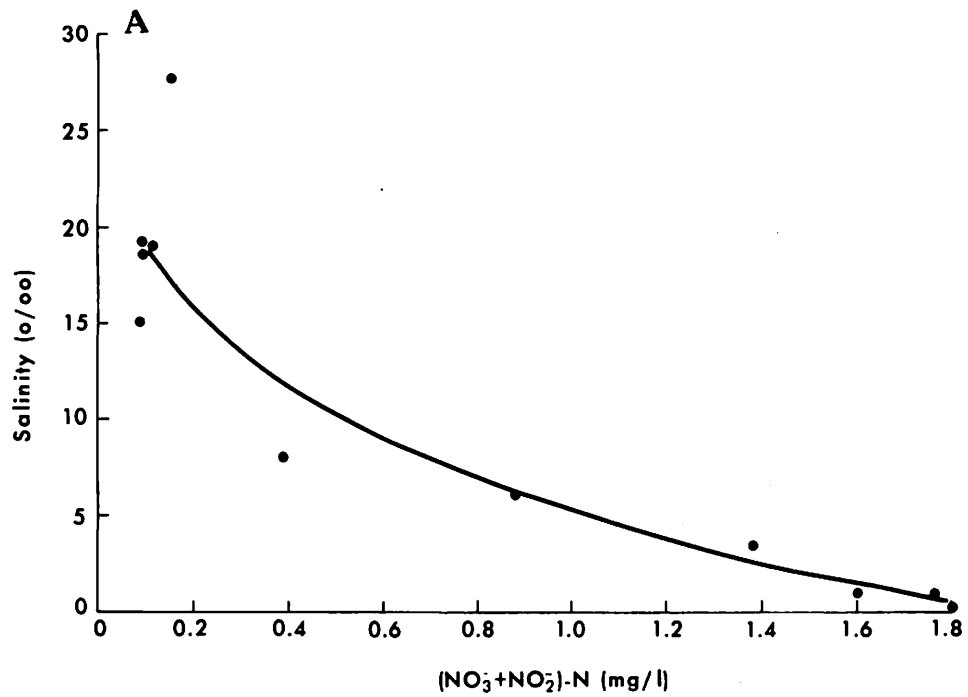


Figure 10. Relationship between salinity and (NO₃ + NO₂)-N (A), PO₄³⁻-P (B), and dissolved SiO₂ (C), in nearshore surface waters in the vicinity of the Mississippi River mouth, (May 22, 1973).

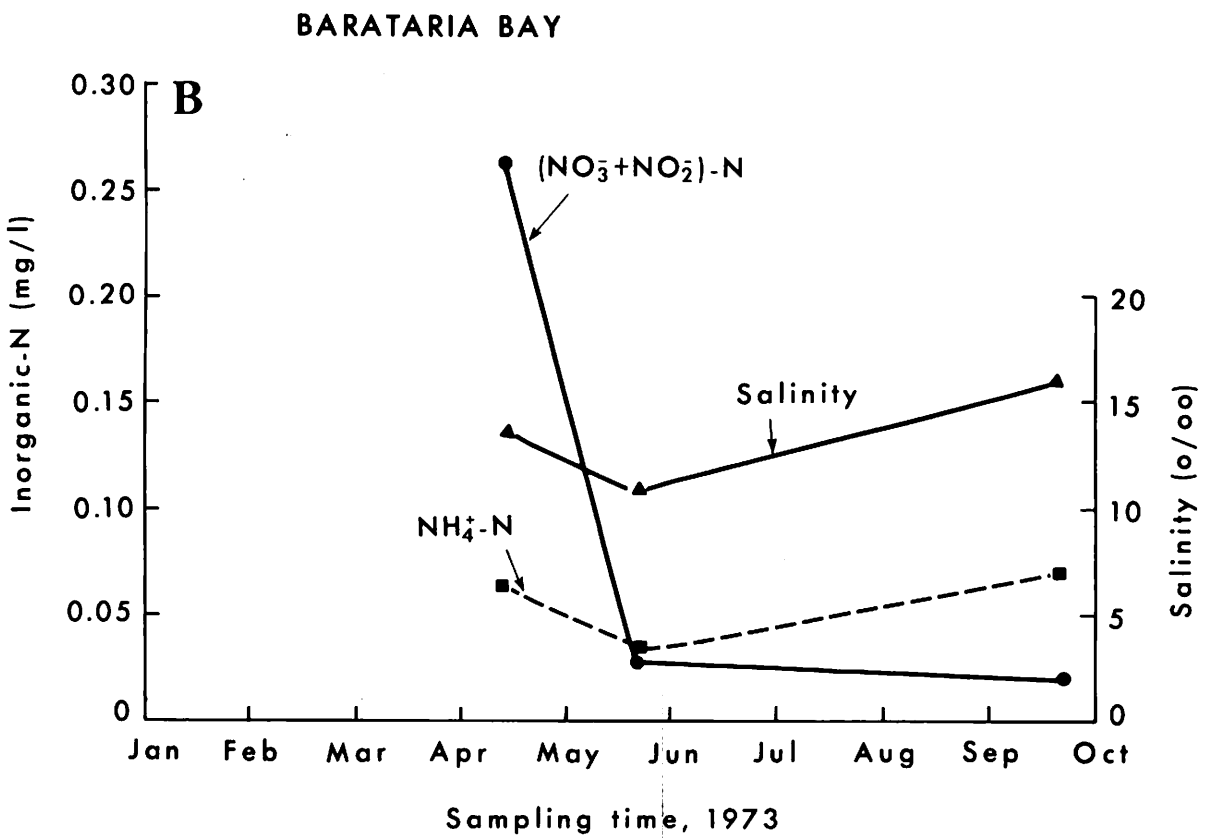
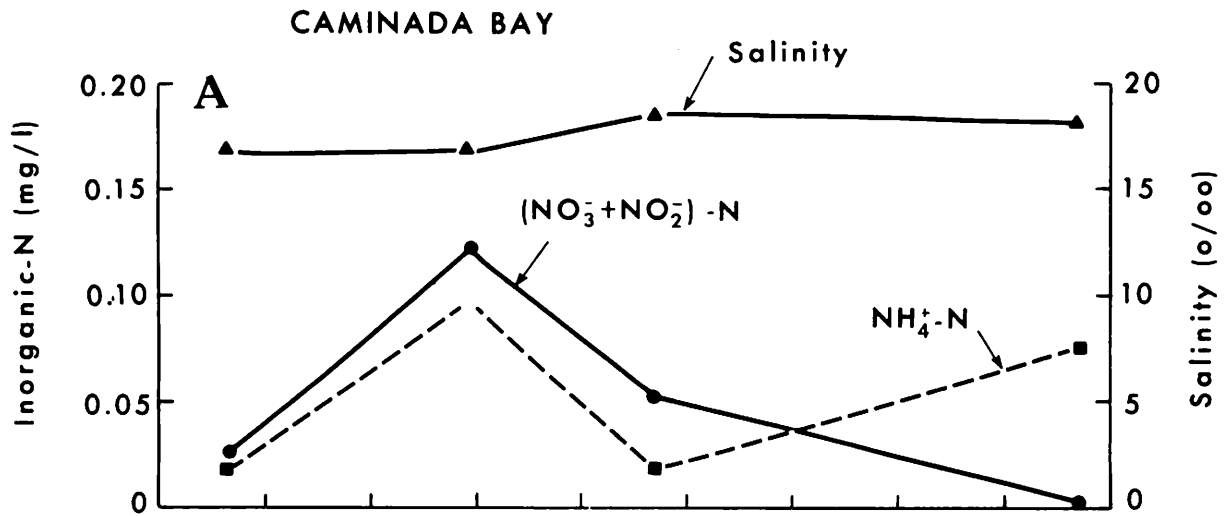


Figure 11. Seasonal changes in inorganic-N and salinity.

BARATARIA BAY, MARCH 29, 1973

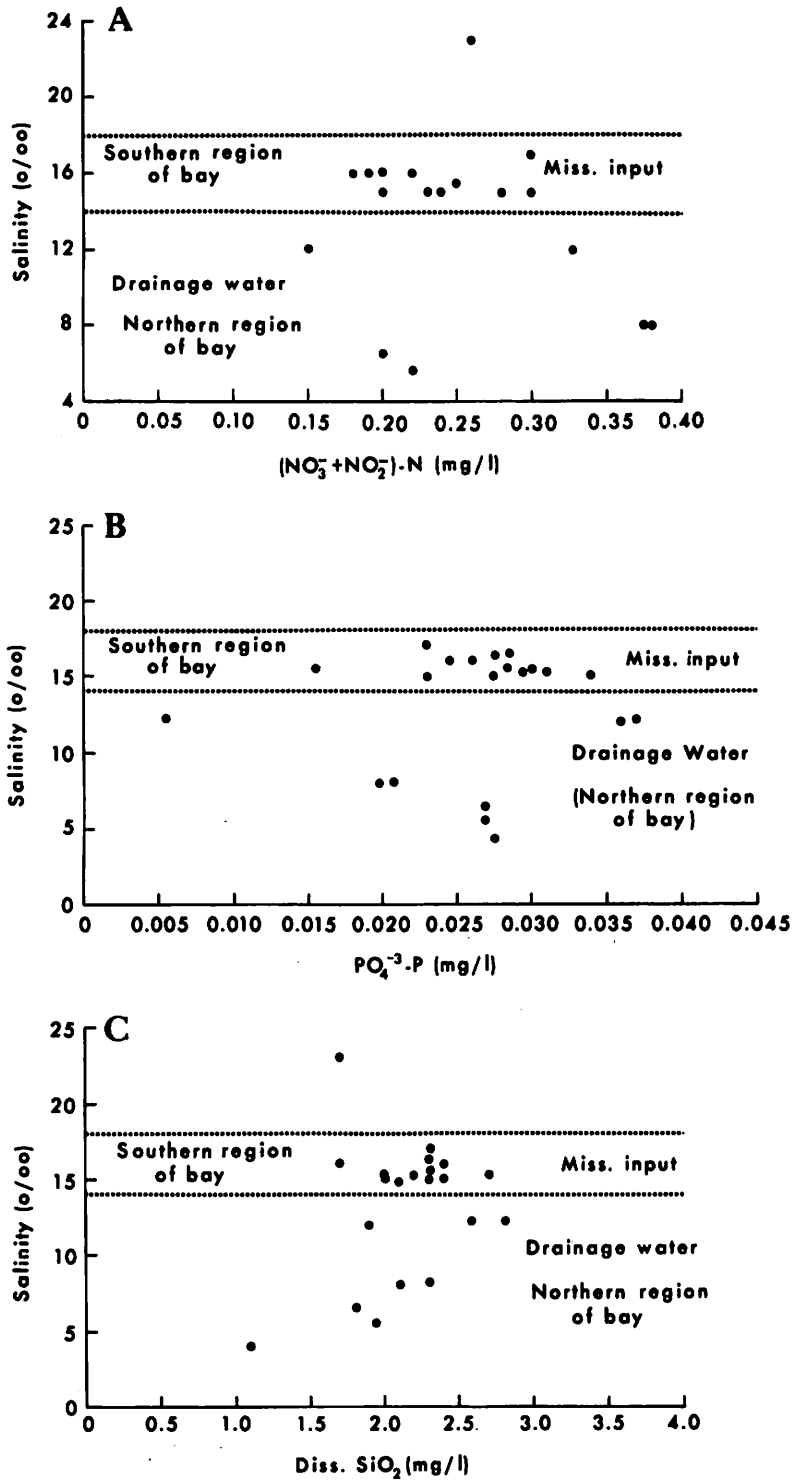


Figure 12. Relationship between salinity and (NO₃ + NO₂)-N (A), PO₄³⁻-P (B), and dissolved SiO₂ (C), in Barataria Bay, (March 29, 1973).

CAMINADA BAY, MARCH 29, 1973

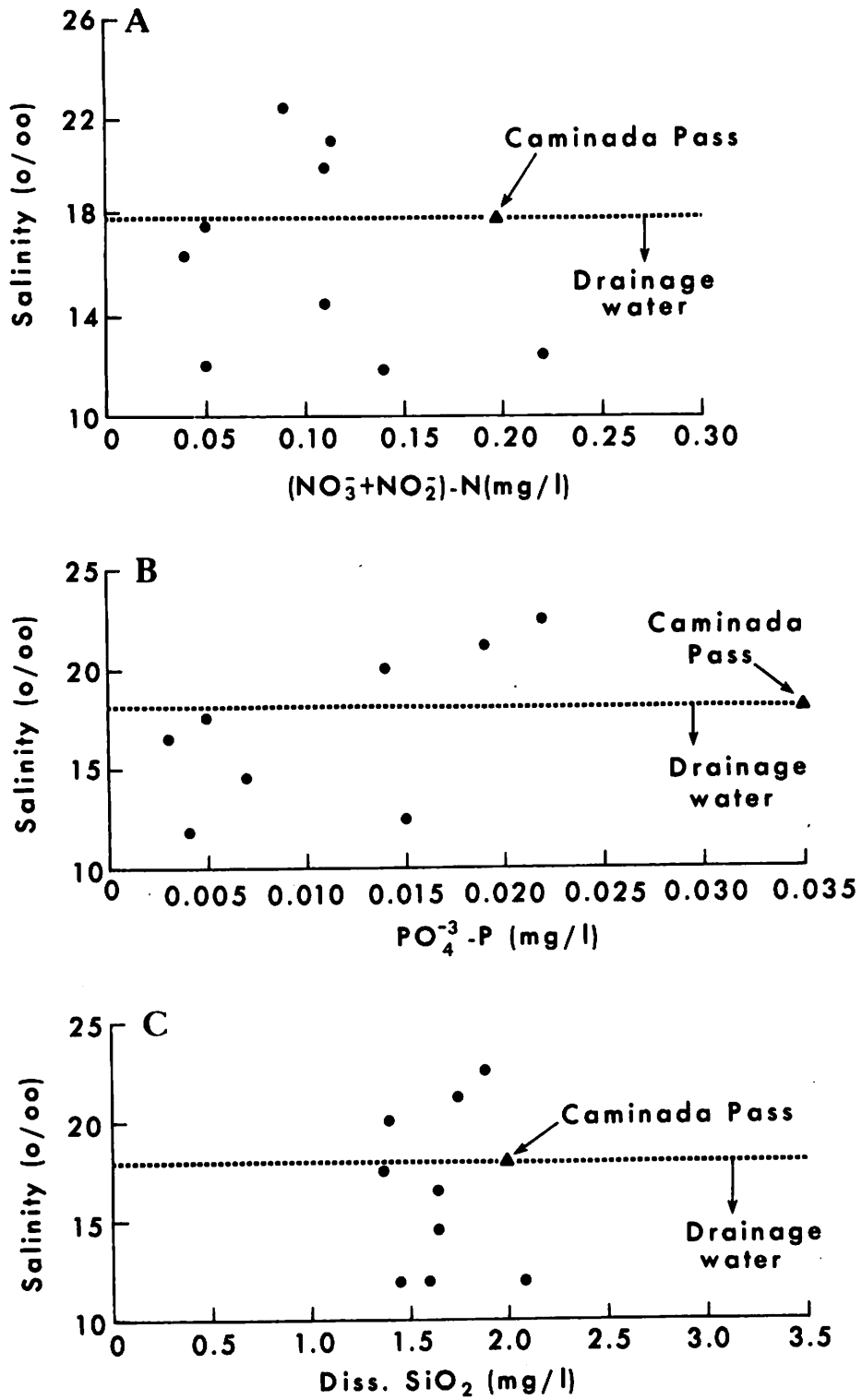


Figure 13. Relationship between salinity and $(\text{NO}_3 + \text{NO}_2)\text{-N}$ (A), $\text{PO}_4^{3-}\text{-P}$ (B), and dissolved SiO_2 (C), in Caminada Bay, (March 29, 1973).

$\text{PO}_4\text{-P}$, and dissolved SiO_2 , but high $\text{NH}_4\text{-N}$ (Fig. 11A), was characteristic of drainage water from the marshes rather than from the Mississippi River (Ho and Schneider, 1974). Furthermore, the presence of high saline water (20 to 23 ‰) between Caminada Pass (18 ‰) and the upper marshes (12 to 17 ‰) agrees with observations made in Barataria Bay, that is, there is very little mixing of surface nearshore waters and the waters of the northern parts of Caminada and Barataria Bays.

Average distribution of organic-N in nearshore waters south of Caminada and Barataria Bays exhibited a similar pattern to that of $(\text{NO}_3 + \text{NO}_2)\text{-N}$ (Figs. 14A and B). High organic-N in nearshore waters was associated with flooding of the Mississippi at the end of March, whereas low values were found in the bays at this time. This suggests that runoff waters within the Mississippi drainage area not only contributed to an increase in soluble inorganic components such as nitrate and phosphate but also organic matter to the river. Heavy rainfall prior to March was probably responsible for dilution of organic-N in the bays.

At the end of May, organic-N in nearshore waters adjacent the bays decreased sharply (Figs. 14A and B), but remained high near the river mouth (Fig. 5B). On the contrary, organic-N in the bays increased sharply, probably because of an increase in phytoplankton production as a result of nutrient enrichment during early spring. Organic-N production was especially pronounced in Barataria Bay as compared to Caminada Bay. The higher production in Barataria Bay may be

due to higher nutrient content from the larger drainage area of this bay. The low organic-N in nearshore waters coincided with low concentrations of inorganic nutrients, but high salinity values. As stated previously, low organic-N in nearshore waters may be the result of displacement of nutrient enriched Mississippi River waters by low nutrient seawater due to shifts in current patterns.

At the end of September, the average organic-N in nearshore waters south of Caminada and Barataria Bays increased relative to that in May, and the extent of increase was much greater in the nearshore water south of Barataria Bay (0.28 to 0.52 mg/l from May to September) than in the nearshore water south of Caminada Bay (0.35 to 0.44 mg/l), during the same time period. Contrary to the trend exhibited by nearshore waters, organic-N in Caminada Bay increased from March to September, but a sharp decrease occurred in Barataria Bay from May to September (Figs. 14A and B). This phenomenon may be explained by the fact that more organic-N was exported from Barataria Bay to its nearshore zone during the high coastal rainfall period in September 1973, whereas much less exportation took place from Caminada Bay. This explanation is supported by the estimation made in August 1947 by Marmer (1948). He stated that Barataria Pass drained about 8 times more water to the Gulf of Mexico than Caminada Pass during a tidal cycle. This estimate may still hold true for the passes at the present time. Therefore, the relative differences in organic matter transported to the Gulf from the two bays are expected.

Summary and Conclusions

Heavy flooding by the Mississippi River occurred throughout most of Louisiana's coastal area between January and July 1973. Rainfall was extremely high in this area in March, April and September 1973. During these periods when large amounts of freshwater were discharged into the coastal area, salinities were diluted and large amounts of land-derived inorganic nutrients (NO_3 , dissolved SiO_2 , PO_4) and organic-N were added to the coastal waters. The prevalence of NO_3 is characteristic of runoff waters from agricultural lands of the upper Mississippi Valley. Barataria and Caminada Bays contained much less $(\text{NO}_3 + \text{NO}_2)\text{-N}$ and more $\text{NH}_4\text{-N}$ relative to nearshore waters which are influenced by the Mississippi Riv-

er. These and other differences in chemical composition indicated that the influence of the Mississippi River on Barataria and Caminada Bays was limited to the lower region of these bays during the period of study. Sources of freshwater and associated nutrients introduced into the bays were largely runoff waters from the upper marshes via connecting waterways, bayous and drainage canals. During the latter part of May, 1973, river water flow in the nearshore zone of Barataria Bay was diverted eastward as a result of local changes in current direction. This was indicated by displacement of nutrient-rich river water by nutrient depleted seawater in the nearshore area south of Barataria Bay. However, waters west of the

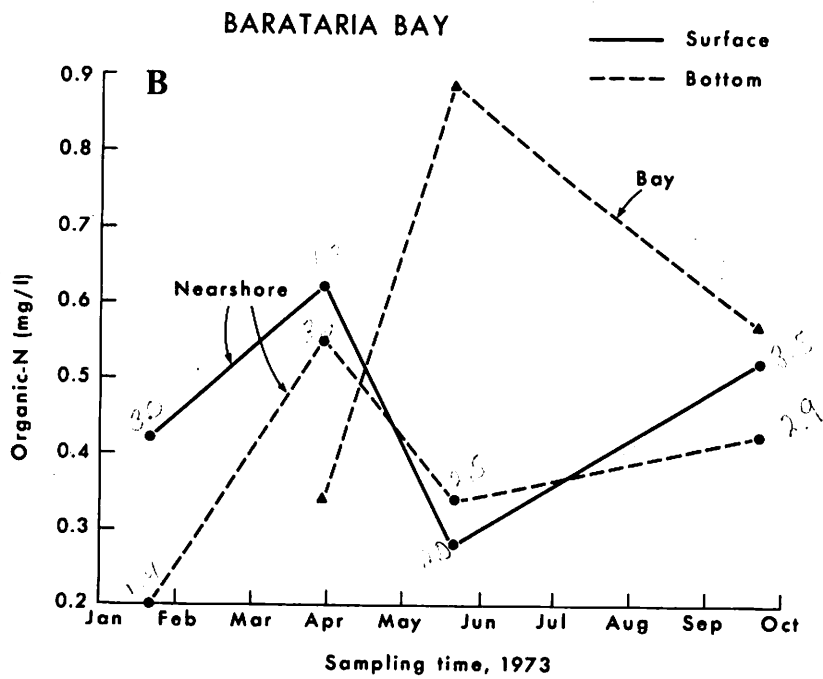
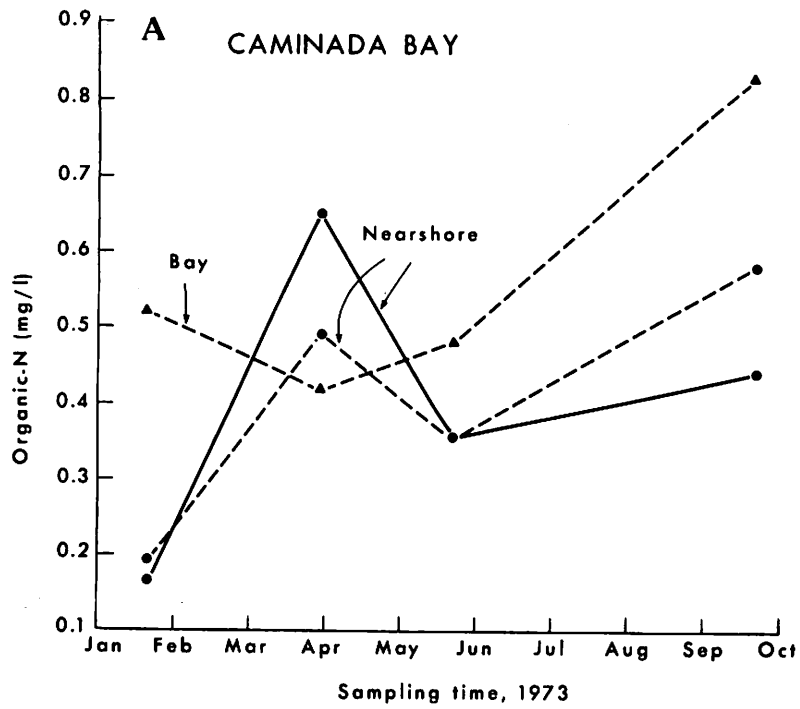


Figure 14. Seasonal changes in organic-N in Caminada and Barataria Bays and adjacent nearshore waters.

river mouth and east of Grand Bayou Pass remained exceedingly high in nutrients and low in salinity. At the end of September 1973, when the Mississippi River discharge was lowest, the entire nearshore waters were dominated by nutrient-depleted seawater. Inorganic nutrients and organic-N in the estuaries and the adjacent nearshore waters were much higher than at the river mouth during September which indicates the importance of the marshlands as a source of inorganic nutrients and organic matter to the estuaries and adjacent nearshore waters.

The estimated quantity of selected chemical components discharged by the Mississippi River from January through July 1973 was 28.4 billion pounds. Such vast amounts of inorganic nutrients

and organic matter undoubtedly are the primary factors which result in Louisiana's high fishery production. However, the combined impact of the continued increase in runoff waters from farm lands, uncontrolled disposal of industrial wastes, etc., may contribute to the slow deterioration of fishery-related industries in Louisiana. Reduction in dissolved oxygen may take place because of increases in oxygen demand as a result of large quantities of organic matter transported by the rivers and by algal blooms in response to excessive amounts of available nutrients. Severe and prolonged oxygen depletion in areas where water circulation is slow would have adverse effects on animal organisms in the area.

Literature Cited

- Alberts, J. 1970. Inorganic controls of dissolved phosphorus in the Gulf of Mexico. Ph.D. Thesis, Florida State Univ., 89 pp.
- Barrett, B. B., J. Tarver, W. Latapie, J. Pollard, W. Mock, G. Adkins, W. Gaidry, C. White, and J. Mathis. 1971. Hydrology. Phase II in Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. La. Wildlife and Fisheries Comm., pp. 9-130.
- Bartsch, A. F. 1972. Role of phosphorus eutrophication. Natl. Environ. Res. Center, U.S. Environ. Prot. Agency Rept. No. EPA-R3-72-001.
- Battelle Pacific Northwest Laboratories. 1974. Research report on effects of oil discharges and domestic and industrial wastewaters on the fisheries of Lake Maracaibo, Venezuela. Vol. 1, Ecological Characterization and Domestic and Industrial Wastes. Richland, Washington.
- Bein, G., D. Contois, and W. Thomas. 1958. Removal of soluble SiO_2 from freshwater entering the sea. *Geochim. Cosmochim. Acta*, 14: 35-54.
- Bremner, J. M. 1965. Inorganic forms of nitrogen, organic forms of nitrogen. *In Methods of Soil Analysis* (C. A. Black, ed.), Amer. Soc. of Agro.
- Golterman, H. L. 1971. Methods for chemical analysis of freshwaters. IBP Handbook No. 8, Blackwell Sci. Publications, Oxford and Edinburgh.
- Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. *In Estuaries* (G. H. Launff ed.), pp. 621-637.
- Hayes, F. 1964. The mud-water interface. *An Annual Review. Ocean. and Mar. Biol.*, 2:121-145.
- Hedgpeth, J. W. 1957. Treatise on marine ecology and paleoecology. Vol. 1, pp. 215-217. Waverly Press, Baltimore, MD.
- Ho, C. L. 1971. Seasonal changes in water and sediment chemistry in Barataria Bay. *Coastal Studies Institute Bull. No. 6* (special Sea Grant issue), Center for Wetland Resources, La. State Univ., Baton Rouge.
- . 1972. Preliminary investigation of water quality at the mouth of the Mississippi River. Center for Wetlands Resources, La. State Univ. (unpublished data).
- , and S. Schneider. 1974. Water and sediment chemistry. *In Environmental Assessment of a Louisiana Offshore Oil Port*, Vol. II, Section II; Technical Appendices VI through VII, p. VI.1-1-171, LOOP, Inc., New Orleans.
- Hopkins, T. L., R. Gibson, W. Gunn, J. Johnson, V. Maynard, and W. Weiss. 1971. Water quality. *In Mar. Sci. Inst. Anclote Environ. Rept.*, pp. 64-87.
- Humm, H. J. 1973. Benthic algae of the eastern Gulf of Mexico. *In A Summary of Knowledge of the Eastern Gulf of Mexico*, pp. 111B-6. Coordinated by the State Univ. System of Florida Institute of Oceanography.
- Kohl, D. H., G. B. Shearer, and B. Commoner. 1971. Fertilizer-N; Contribution to NO_3^- in surface water in a corn belt water shed. *Science*, 174:1331-1334.

- Marmer, H. A. 1948. The current in Barataria Bay. Texas A&M Res. Foundation Publ., College Station.
- Nicholls State University News Release. July 23, 1973. "Dead" water found.
- Richards, F. A., and A. C. Redfield. 1954. A correlation between the oxygen content of seawater and the organic content of marine sediments. Woods Hole Oceanographic Inst. Contr. No. 695, pp. 279-281.
- Riley, G. A. 1937. The significance of the Mississippi River drainage for biological conditions in the Gulf of Mexico. *J. Mar. Research*, 1:60-74.
- Ryther, J. H., and W. M. Dunstan. 1969. N, P and eutrophication in the coastal marine environment. *Science*, 171:1008-1013.
- Serruya, C. 1971. Lake Kinneret: The nutrient chemistry of the sediments. *Limn. Ocean.*, 16: 510-521.
- Strickland, J., and T. Parsons. 1965. A manual of seawater analyses. Fish. Res. Bd. (Canada) Bull. No. 125.
- Truesdale, V. 1971. A modified spectrophotometric method for the determination of ammonia (and amino acids) in natural waters, with particular reference to sea water. *Analyst*, 96:584-590.
- U.S. Army Corps of Engineers, New Orleans District. 1971. National Shoreline Study: Inventory - lower Mississippi region.
- _____. 1940-1973. Stages and discharges of the Mississippi River and tributaries and other watersheds in the New Orleans District.
- U.S. Dept. of Commerce. 1956-1973. Climatological Data. Environmental Data Service.
- Warren, E. C. 1971. Kinds of water pollution. *In* Biology and Water Pollution Control. W. B. Saunder, Philadelphia, Pa., p. 57-62.
- Willrich, T., and G. Smith. 1970. Agricultural practices and water quality. Iowa State Univ. Press, Ames.