SEASONAL PATTERNS OF ALKALINITY IN THE SAN FRANCISCO BAY ESTUARINE SYSTEM, CALIFORNIA, DURING 1980

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Metric to Inch-Pound Conversion Table

Multiply SI units	by	to obtain inch-pound units
kilometer	0.6214	mile
meter	3.281	feet
liter	1.057	quart
cubic meter	264.2	gallon
cubic meter per second	35.31	cubic foot per second
gram	0.03527	ounce

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ABSTRACT

Salinity and alkalinity were measured in the near-surface waters of the San Francisco Bay estuarine system at two-week intervals during 1980. Results are presented in figures and as numerical values, and the analytical methods are detailed. Fresh water flow to the Bay from the Sacramento-San Joaquin River Delta was $3.2 \times 10^{10} m^3$ during 1980. The transport of alkalinity to the Bay from the Delta during 1980 was 3.8×10^{10} equivalents; this estimate is based on the average fresh water alkalinity concentrations, as indicated by the North San Francisco Bay (North Bay) salinity-alkalinity distributions. Salinity-alkalinity distributions in North Bay are primarily the result of conservative mixing of fresh water from the Delta with sea water from the adjacent Pacific Ocean. Nonlinear distributions appear to result from alkalinity variations in the fresh water mixing member rather than in-estuary sources or sinks or variations in the seawater mixing member. Large late-summer changes in the North Bay salinity-alkalinity distribution appear to have been caused by Delta fresh water alkalinity variations associted with the inflow of agricultural waste waters.

South San Francisco Bay (South Bay) salinity-alkalinity distributions show effects of variations in the fresh water flow rate from the Delta, fresh water inflow from local streams, and inflow of municipal waste waters. Alkalinity typically increased as salinity decreased southward in South Bay; a southward-increasing waste-derived alkalinity component was identifiable throughout the year. Near-linear salinity-alkalinity distributions persisted during spring through fall and are attributed to a combination of factors, including the locations of the major waste outfalls and the bathymetry of the embayment. Curvature of the distributions in the northern reach of South Bay appeared to follow changes in the North Bay salinity field.

INTRODUCTION

Riverborne dissolved substances are commonly distributed in estuarine waters in proportion to the fraction (mixing ratio) of fresh water in the fresh water-sea water mixture (conservative mixing, Liss, 1976). Salinity provides a practical measure of the mixing ratio because salt concentrations in rivers are generally less than one percent of that in sea water. Alkalinity, a conservative chemical quantity (Stumm and Morgan, 1981), is moderately concentrated in both river and sea waters (Livingstone, 1963; Harvey, 1966). Wong (1979) showed that salinity-alkalinity mixing plots can identify fresh- and brackish-water sources when mixing results in a linear salinity-alkalinity relation. Similarly, some time-dependent alkalinity variations in the fresh water flow to an estuary should be identifiable by the linearity or nonlinearity of the salinity-alkalinity relations (Loder and Reichard, 1981). The effects of in-estuary sources and sinks can also be seen under certain conditions (Liss, 1979). Both linear and nonlinear salinity-alkalinity relations have been observed in San Francisco Bay (Spiker and Schemel, 1979; Conomos and others, 1979; Schemel, 1981), indicating that they may be the result of simple mixing or a combination of many sources and processes.

Waters of the San Francisco Bay estuarine system (fig. 1) were sampled by the U.S. Geological Survey at near-two-week intervals during calendar year 1980 (CY80). CY80 cruises were extended to February 1981 for a final sampling following the first major winter storm. Two research vessels were used. The smaller vessel navigated the shallow reaches of the Bay (fig. 1A) while the other occupied adjacent locations in the deep channels (fig. 1B). This report presents salinity and alkalinity measurements for the samples collected during the regularly-scheduled CY80 cruises. Tables of the numerical values and salinity-alkalinity mixing plots constitute the appendix. The general patterns and seasonal variations in the salinity-alkalinity distributions during 1980 and their major causes are discussed. Fluxes of dissolved inorganic carbon (DIC) to the Bay from the Sacramento-San Joaquin river system are estimated and details of the analytical methods are presented.

San Francisco Bay is a large and geographically-complex estuarine system that is surrounded by dense urban areas (fig. 1; see Conomos, 1979, for a summary of Bay hydrology). North Bay is the estuary of the Sacramento and San Joaquin river system; the area of interconnecting channels at their confluence is referred to as the Delta. Together these rivers drain about 40 percent of the surface area of California. North Bay comprises a series of large embayments connected by straits extending from the Delta to the Golden Gate. Fresh water flow from the Delta (Delta outflow) is about 90 percent of the total fresh water flow to the Bay. Major Delta outflow rate variations are due to seasonal weather patterns, which typically exhibit a winter-spring storm season and a dry summer-fall period (fig. 2). Total 1980 Delta outflow was $3.2 \times 10^{10} m^3$ (U.S. Geological Survey 1981a); 74 percent of this flow occurred during January through March (winter).

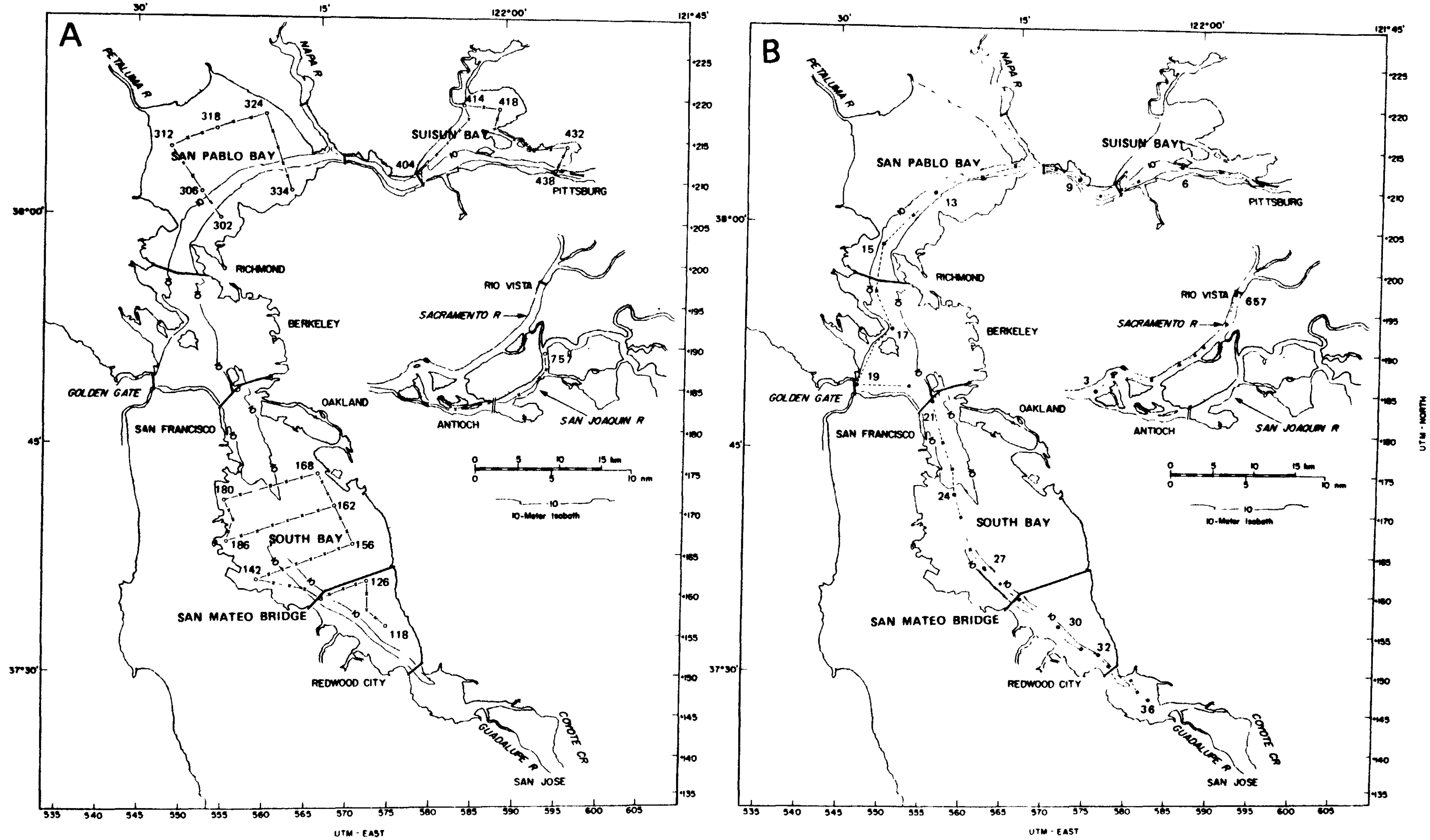

Figure 1. Station locations in San Francisco Bay and the Sacramento-San Joaquin Delta.

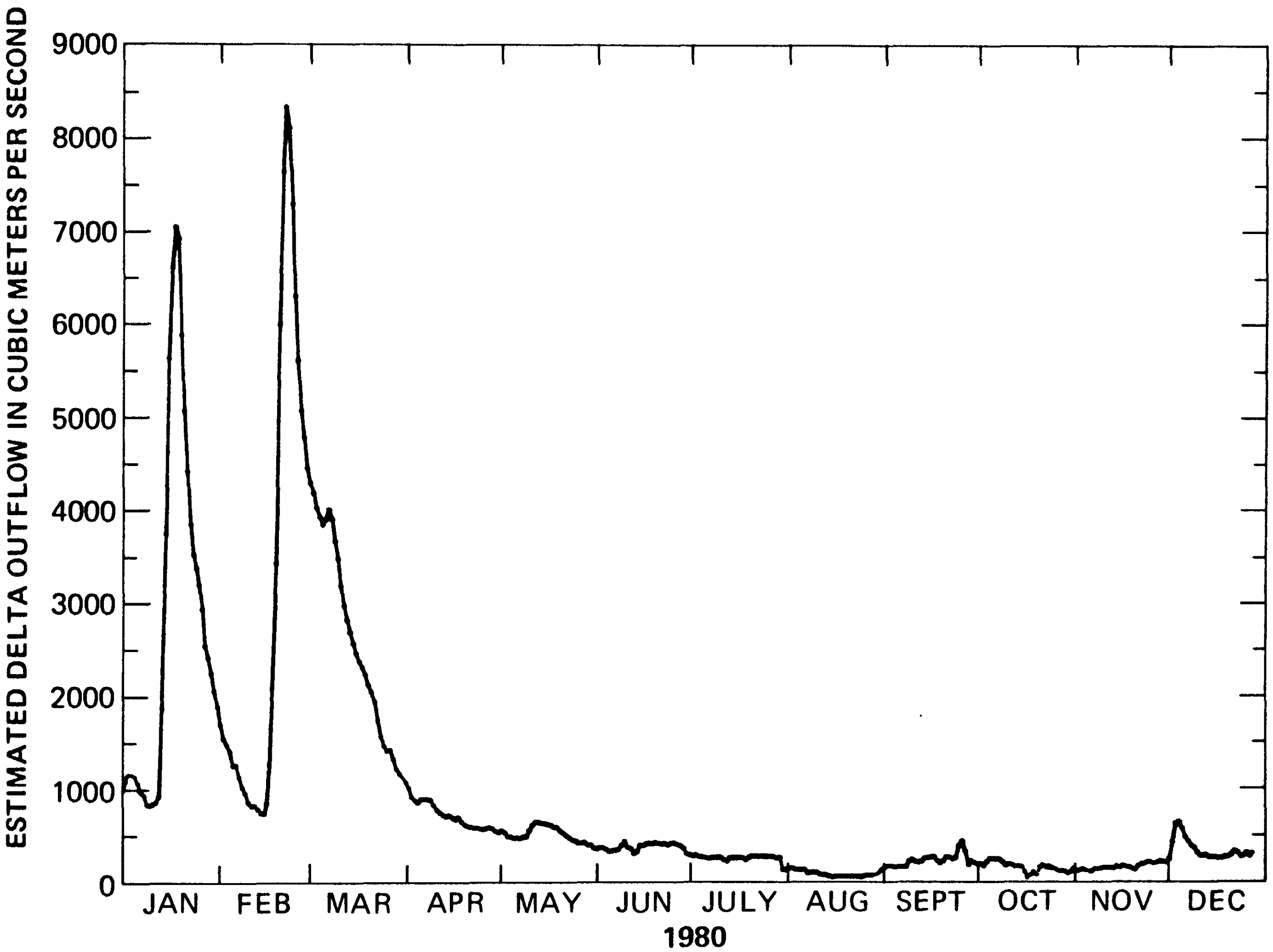

Figure 2. Estimated Delta outflow (daily averages) for 1980.

Extensive surface-water demands, primarily from agricultural users, limit fresh water flow to the Bay. During spring through mid-fall, Delta outflow rates are largely controlled by reservoir releases. Reservoir management also results in sometimes-large Delta outflow composition variations, such as the specific conductance and alkalinity variations during the 1980 irrigation season that were described by Schemel (1984).

Previous studies show that alkalinity can be near-linearly related to salinity in North Bay, at least during periods of high and moderate Delta outflow (Spiker and Schemel, 1979). Nonlinear salinity-alkalinity relations were observed during a prolonged period of low Delta outflow (1975-1977) and have also been noted during summer and fall of other years. An objective of this study is to determine if nonlinear relations during normal summer-fall low Delta-outflow conditions are primarily due to variations in the Delta outflow alkalinity or the effects of in-estuary sources and sinks or other factors.

South Bay is a large embayment extending southeast from the seaward reach of North Bay. Delta outflow rate is a primary factor affecting the salinity in South Bay (McCulloch and others, 1970); Carlson and McCulloch, 1974; Imberger and others, 1975). High Delta outflow rates have a large effect on the South Bay salinity field, but in some instances even small increases of a few hundred m^3sec^{-1} can be effective in decreasing salinities in the reach north of the San Mateo Bridge (northern reach; fig. 1). Many salinity variations in the northern reach are primarily related to changes in the North Bay salinity field. For example, a large increase in Delta outflow can change the North Bay salinity field within a few days. As the fresh water moves seaward, the salinity field is compressed and shifts seaward. North Bay water adjacent to South Bay becomes less saline, enters the South Bay mostly during the flood tides, and decreases the ambient salinity by mixing. Very high Delta outflow rates (about 2000-3000 m^3sec^{-1}) induce salinity stratification in South Bay.

Local stream inflow to South Bay is highly seasonal. For example, about 82 percent of the total 1980 water-year (October 1979-September 1980) flow occurred during the month of February (U.S. Geological Survey 1981b). Most of the fresh water inflow (94 percent of the 1980 water-year total) entered the reach south of the San Mateo Bridge (southern reach). These local stream inflows were effective in decreasing the salinity of waters in the southern reach during 1980 (Dedini and others, 1982).

Alkalinity typically increases as salinity decreases southward in South Bay, the opposite of the salinity-alkalinity relation observed in North Bay and most other estuaries. The most-probable high-alkalinity low-salinity source is waste water (Spiker and Schemel, 1979); however, the substrate is also a known source of alkalinity to South Bay waters (Hammond, 1981). An objective here is to better document seasonal distributions of salinity and alkalinity in South Bay in order to identify the effects of mixing and local sources.

METHODS

Water samples were collected at near-two-week intervals during the neap tides at locations in the Bay and in the Sacramento and San Joaquin River channels of the Delta (fig. 1; table 1). Most of the samples were collected from the R/V Polaris, which occupied stations in the deep channels of the Bay. A 2m-depth sample was routinely collected at the vertical stations, those locations where hydrographic measurements were usually made from the surface to within 2m of the substrate. Additional samples that do not correspond to numbered station locations were collected in North Bay as necessary to define the salinity-alkalinity distribution; salinity intervals of approximately 3 $^{o}/oo$ or less were sampled during the summer and fall cruises. A shallow-water location was sampled by the R/V Estero in South Bay, San Pablo Bay, and Suisun Bay during most cruises. Fresh water from both the Sacramento and San Joaquin Rivers was sampled by either vessel during most cruises.

Sampling Procedures

Water samples were drawn from the pumping systems on the R/V Polaris (Schemel and Dedini, 1979) and R/V Estero (Dedini and Schemel, 1980). Water was pumped from an intake at a depth of approximately 1m on the R/V Estero. The bow intake on the R/V Polaris is at a depth of approximately 2m. Locations shown with specified depths (z) in the appendix tables (A through X) were sampled with the submersible pump on the R/V Polaris.

A 1L polyethylene bottle was filled from the discharge line of the flow-sample salinometer; samples were taken only when the salinometer reading was nearly constant. A salinity bottle (100mL glass) was filled from the 1L bottle. The salinometer reading was recorded; this reading was later compared with the sample salinity (as determined in the laboratory) in order to assure the accuracy of the salinometer on the vessel. Two 100mL aliquots were vacuum filtered through a 47mm-diameter glass-fiber filter (Type A/E, Gelman Instrument Co., Ann Arbor, Michigan)[1/] and discarded before the sample for analysis was filtered. This procedure rinsed the filtration apparatus and "preclogged" the filter, facilitating the retention of fine particles. Glass-fiber filters were chosen because they remove most of the suspended particulate matter, yet allow rapid filtration, thus minimizing errors due to evaporation and contamination.

1/ The mention of brand names is for identification purposes and does not constitute endorsement by the U.S. Geological Survey.

Table 1. Hydrographic stations located in the shoals (left) and deep channels (right) of San Francisco Bay and the Sacramento-San Joaquin Delta.

Station	Latitude (N)	Longitude (W)
156	37°38.4'	122°12.2'
162	37°41.1'	122°14.0'
318	38° 5.4'	122°23.5'
329	38° 3.7'	122°18.3'
416	38° 7.0'	122° 2.3'
418	38° 6.8'	122° 0.7'
420	38° 6.4'	122° 1.0'
San Joaquin River Station		
757	38° 5.1'	121°40.6'

Number	Name	Latitude (N)	Longitude (W)
657	Rio Vista	38° 8.9'	121°41.3'
1	Winter Is.	38 2.4	121 50.4
2	Chain Is.	38 3.8	121 51.3
3	Pittsburg	38 3.0	121 52.7
4	Simmons Pt.	38 2.9	121 56.1
5	Middle Ground	38 3.6	121 58.8
6	Roe Is.	38 3.9	122 2.1
7	Avon Pier	38 2.9	122 5.8
8	Martinez	38 1.8	122 9.1
9	Benicia	38 3.0	122 10.4
10	Crockett	38 3.6	122 13.5
11	Mare Is.	38 3.7	122 15.8
12	Hercules	38 3.1	122 18.7
13	N. of Pt. Pinole	38 1.9	122 21.9
14	W. of Pt. Pinole	38 0.5	122 24.1
15	Pt. San Pablo	37 58.2	122 26.2
16	Red Rock	37 54.9	122 27.0
17	Raccoon Str.	37 52.9	122 25.6
19	Golden Gate	37 49.1	122 28.3
20	Blossom Rock	37 49.0	122 24.3
21	Bay Bridge	37 48.0	122 22.2
22	Potrero Pt.	37 45.7	122 21.5
23	Hunters Pt.	37 43.6	122 20.2
24	Candlestick Pt.	37 42.0	122 20.3
25	Oyster Pt.	37 40.3	122 19.5
26	San Bruno Shoal	37 38.2	122 19.0
27	SFO	37 37.1	122 17.5
28	N. San Mateo Br.	37 36.0	122 16.2
29	S. San Mateo Br.	37 34.9	122 14.8
30	Redwood Cr.	37 33.3	122 11.5
31	Coyote Hills	37 31.8	122 9.4
32	Ravenswood Pt.	37 31.1	122 8.1
33	Dumbarton Br.	37 30.6	122 7.4
34	Newark Slough	37 29.6	122 5.3
35	Palo Alto	37 28.9	122 4.7
36	Calaveras Pt.	37 28.3	122 3.8

In some cases, when particle loads were extremely high, the filters were quickly clogged and one or two filter changes were necessary in order to obtain a sample volume adequate for the analysis; each filter was rinsed with at least 50 mL of sample. Alkalinity samples were stored in 250mL polyethylene bottles at room temperature for 1 to 4 days before analysis at the shore-based laboratory.

Analytical Procedures

A high-precision inductive laboratory salinometer (RS-7B, Beckman Instruments, Fullerton, Calif.) was used to measure the conductivity ratios of samples relative to standard sea water (Instit. of Oceanog. Sciences, Wormley, England). Salinities were calculated from the equation of Cox and others (1967), which is based on the chlorinities and conductivity ratios of a set of natural water samples. Salinity (1.80655 x chlorinity) is expressed as a function of the conductivity ratio plus an empirical constant, 0.090 $^{o}/oo$ that, in effect, compensates for the dissolved solids present when chlorinity is zero in natural fresh waters. Therefore, negative salinities are possible in natural fresh waters that differ in composition from the "world" average composition predicted by the equation of Cox and others. A few negative salinities were calculated in this study. The equation of Cox and others was intended primarily for seawater analyses and can become inaccurate at saliniies less than about 2 $^{o}/oo$.

The precision of the laboratory salinometer is on the order of $\pm$0.003 $^{o}/oo$; these salinities are reported to the nearest 0.001 $^{o}/oo$. In a few cases, salinity samples were not taken from the alkalinity sample and the reported values are estimates based on the flow-sample salinometer reading (Dedini and others, 1981). The estimated salinities are reported to the nearest 0.01 $^{o}/oo$ and are accurate within $\pm$0.05 $^{o}/oo$.

Alkalinity was determined by potentiometric titration with hydrochloric acid. The bicarbonate endpoint was calculated by the method originally proposed by Gran (1952) and applied to sea water analyses by Dyrssen (1965). The apparatus is similar to that described by Edmond (1970), but with one important exception; the reaction flask assembly does not include a plunger to accommodate the volume increase resulting from the titrant additions (fig. 3). Rather, an overflow capillary tube allows a volume equal to that of the addition to be expelled from the reaction flask. This method was chosen because it eliminates the possibility of large errors resulting from pressure effects on the reference electrode electrolyte flow (D. E. Hammond, oral communication, 1977). The resulting systematic error was minimized by increasing the titrant concentration to 0.5 N. In the Bay, a maximum titrant volume of 0.7mL is required to reach the endpoint of the 125mL sample. Therefore, because each titration was not corrected for the expelled sample volume, the measurements could be low by as much as 0.5 percent, which is equivalent to 0.012meq L^{-1} in sea water. This systematic error decreases with decreasing salinity in North Bay, but could be larger under certain conditions in South Bay.

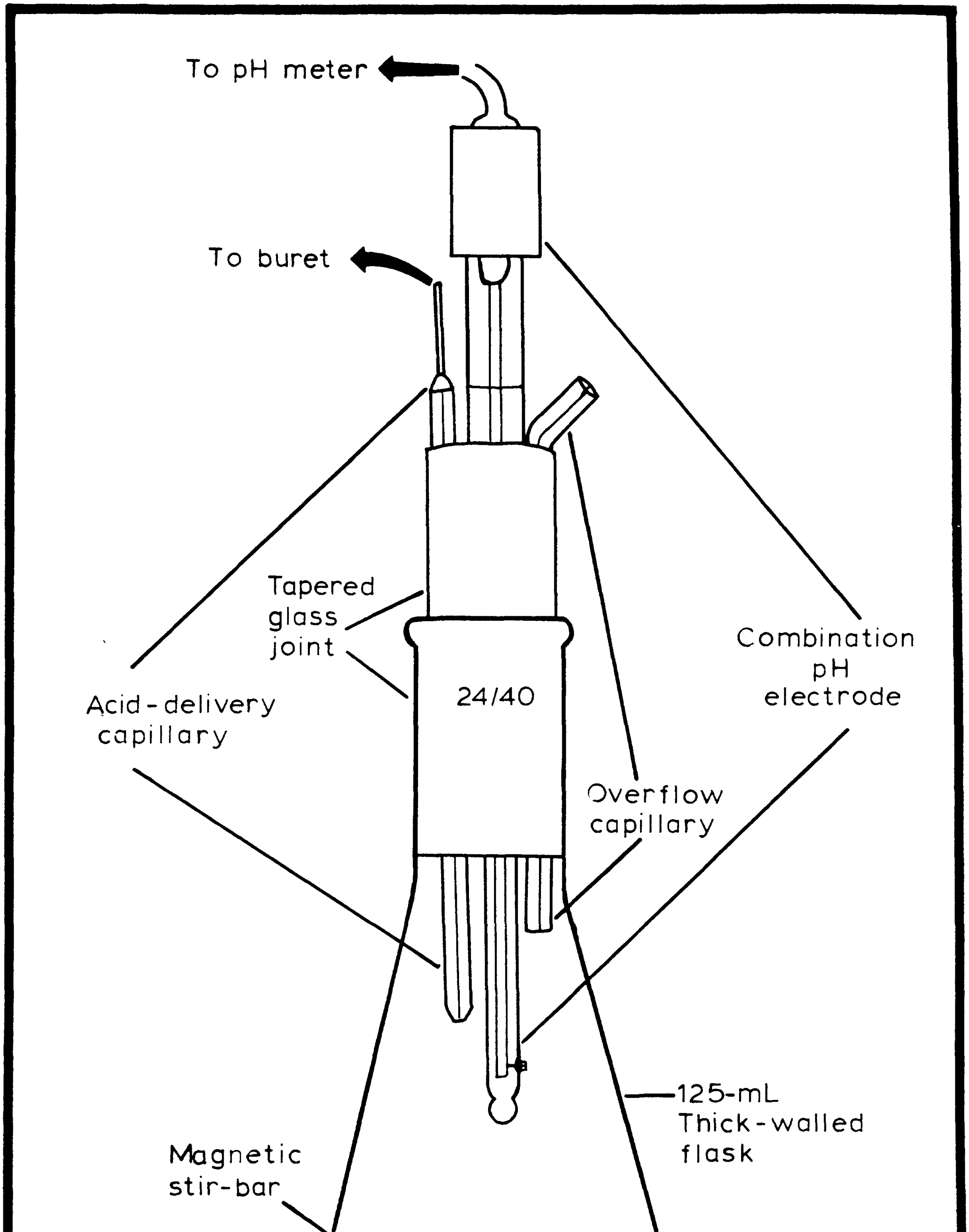

Figure 3. Alkalinity titration flask assembly.

Samples were titrated in a water bath thermostated to within ±0.2 °C. Samples were stirred with a teflon-coated magnetic stir-bar. Acid was delivered through a fine capillary tube by a 1mL-capacity Digi-Pet buret (Manostat Corp., New York, Cat.No.71-635-035). Potentials from a Model 476050 combination electrode (Corning Instru., Medfield, Mass.) were measured with a Model 801A pH meter (Orion Research Inc., Cambridge, Mass.). Data were recorded as millivolts; the electrode was not routinely calibrated in pH units for the alkalinity titrations. Electrode response was periodically checked with pH 7.41 and 4.01 (at 25 °C) buffers (Beckman Instru., Fullerton, Calif.); response was typically within 1 percent of the theoretical value.

The precision of the alkalinity method was tested with samples from three locations representing the ranges of salinity and alkalinity encountered in the Bay. Results are summarized in table 2; the relative precision ranges from 0.33 to 0.61 percent (one standard deviation).

The titrant concentration was checked bimonthly. Two batches of titrant were used for the CY80 cruises, but the first batch was used only for the first cruise (08-09 January 1980). The first batch was discarded because of what was found to be a high level of organic contamination in the distilled water used to dilute the concentrate. A suitable calibration could not be made. The estimate of the concentration is probably high; this is discussed with the results. Both batches were prepared from 0.5 N Titrisol (Cat.No.19971, EM Labor. Inc., New York), an analytical concentrate with a certified accuracy of ±0.2 percent. The acid was standardized by potentiometric titration of a primary standard sodium carbonate solution. A 1mL aliquot of the standard solution was added to about 100mL of distilled water in the reaction flask with a volume-calibrated syringe. Approximately 0.2mL of titrant was required to reach the endpoint, at which time another aliquot was added and titrated without refilling the buret. Five or more additions were made; titrations were run over the entire volume range of the buret at least twice. The average acid concentration for the second batch over the entire year was 0.5033 N±0.0025 (one standard deviation).

Errors attributable to volume calibrations were small in comparison to the uncertainty in the acid concentration. The volume of the syringe was reproducible to within 0.1 percent and the volume of the reaction flask was reproducible to within 0.06 percent.

Table 2. Results from 16,17 July 1980 Replicate Samples.

Station	32	19	3
Salinity (estimated)	25.7	31.1	0.2
Sample: 1	2.372	2.252	1.018
2	2.365	2.269	1.023
3	2.353	2.252	1.035
4	2.353	2.269	1.020
5	2.360	2.254	1.022
6	2.367	2.270	1.019
Mean value	2.362	2.261	1.023
Standard deviation	0.0077	0.0092	0.0062
Percentage of value	0.33	0.41	0.61

RESULTS

The CY80 salinity and alkalinity data are presented in appendix figures and tables A through X. These measurements were made on samples collected at various stages of the tide. Data are not normalized or adjusted to uniform tidal conditions. Tidal effects were minimized by sampling during the neap tide cycles.

North Bay and Delta

The salinity-alkalinity (mathematical) relations in North Bay were established as least-squares linear fits to the deep channel station data for each cruise (table 3). Salinity-alkalinity relations in the seaward reach (salinities exceeding about 15 $^{o}/oo$) closely fit linear functions for all of the cruises. The linear functions were extended to lower salinities using the criterion that lower-salinity data would be included in the line until the alkalinity of the lowest-salinity point differed by more than 50 μeq L^{-1} from the value calculated from the linear function. Liss (1976) suggested that in order to establish nonconservative behavior the difference needs to be at least 10 percent, or about 0.1 meq L^{-1} in this case. The 50 μeq L^{-1} limit was chosen because; 1) it is about 20 percent larger than the largest differences that were observed at midsalinities in North Bay, 2) it identifies only large differences that cannot be readily attributed to normal analytical error, and 3) it allows the line to extend to low salinities in most cases. Extending the line to as low salinities as practicable is advantageous because the zero-salinity intercept value becomes a longer-time-averaged estimate of the Delta outflow alkalinity.

The average of the correlation coefficients (r^2) of the 22 linear functions is 0.9977. The mean absolute difference between the measured alkalinity and that calculated from the sample salinity and the linear function is 12 μeq L^{-1}. Only one measurement from the seaward reach fails to meet the criterion (Stn.19, 05 August); this is probably due to a sampling error. In general, the largest differences occur at low salinities. All but three deep-channel samples with

Table 3. Results from the linear regression analysis of measurements made in North San Francisco Bay.

Date	Range of linear fit		Linear fit coefficients		
	highest salinity	lowest salinity	zero-salinity intercept	slope	correlation (r squared)
09 JAN 80	29.916	0.803	1.255	0.03490	0.9985
23 JAN 80	28.699	-0.001	1.001	0.03865	0.9978
06 FEB 80	29.321	0.087	1.202	0.03221	0.9985
05 MAR 80	25.651	0.011	1.123	0.03346	0.9962
19 MAR 80	26.733	0.028	1.254	0.03061	0.9993
09 APR 80	31.574	3.201	1.244	0.03193	0.9977
23 APR 80	32.478	0.219	1.222	0.03281	0.9988
08 MAY 80	31.630	0.324	1.159	0.03502	0.9972
22 MAY 80	31.381	0.030	1.102	0.03693	0.9989
05 JUN 80	31.302	0.040	1.186	0.03362	0.9984
18 JUN 80	31.875	0.095	1.217	0.03243	0.9968
02 JUL 80	31.725	0.544	1.148	0.03536	0.9973
17 JUL 80	32.194	3.258	1.106	0.03684	0.9974
05 AUG 80	31.225	0.465	1.074	0.03742	0.9987
19 AUG 80	32.604	2.231	1.112	0.03612	0.9987
04 SEP 80	31.777	2.675	1.219	0.03272	0.9968
17 SEP 80	32.285	5.603	1.314	0.02962	0.9974
16 OCT 80	32.794	1.950	1.456	0.02431	0.9976
29 OCT 80	32.290	4.025	1.374	0.02779	0.9968
13 NOV 80	31.854	3.775	1.328	0.02962	0.9958
17 DEC 80	31.018	2.004	1.214	0.03321	0.9969
10 FEB 81	31.234	0.231	1.179	0.03321	0.9978

salinities greater than 2 $^{o}/oo$ meet the criterion. The most-landward stations and the Delta river channel stations generally exceed the criterion. Only 10 of the 17 samples from Station 3, four 4 of the 19 samples from Rio Vista (Sacramento River), and one of the 10 samples from the San Joaquin River meet the criterion.

Samples from the shallow-water stations fit closely to the lines determined by the deep-station samples for most of the cruises. Most (25 of 28) of the shallow-water data meet the criterion. The average absolute difference between the alkalinity calculated from the sample salinity and the linear function and the measured alkalinity of those samples that meet the criterion is 27 µeq L^{-1}. No consistent pattern of higher or lower concentrations in the shoals is apparent.

The zero-salinity intercepts of the linear functions (zero-salinity alkalinity, ZSA) are an estimate of the average Delta outflow alkalinity over a period of time perhaps as long as that necessary for fresh water to mix through the estuary (flushing time, as defined by Dyer, 1973). The periods between the cruises are probably similar to the flushing times during winter, but they are shorter during the remainder of the year (Conomos, 1979). The range of the ZSA values is small relative to the wide seasonal range of Delta outflow rate. Therefore, alkalinity and dissolved inorganic carbon (DIC) transport to the Bay is seasonally modulated primarily by variations in Delta outflow rate. Annual and seasonal average ZSA values compare closely with flow-weighted average concentrations in the Sacramento River during 1980 (Schemel, 1983). The annual mean ZSA is 1.23 meq L^{-1}, the same as the flow-weighted average alkalinity for the Sacramento River. Winter averages are 1.167 meq L^{-1} for ZSA and 1.23 meq L^{-1} for the Sacramento River; spring through fall (April through December) averages are 1.215 meq L^{-1} or ZSA and 1.18 meq L^{-1} or the Sacramento River. Using the average ZSA value, the estimated winter transport of alkalinity to the Bay from the Delta is 2.8×10^{10} equivalents, which is 74 percent of the 1980 total. This transport can be expressed as DIC if we assume that the alkalinity is attributable to bicarbonate ion only. The resulting estimate of the 1980 transport of DIC to the Bay from the Delta is 4.5×10^{11} grams, which compares closely to the value of 4.7×10^{11} grams based on Sacramento River composition (Schemel, 1983).

Seasonal variations in the ZSA value are treated in the discussion section; however, it is important here to note that the seasonal variability in the ZSA value is much larger than the "apparent" variability in the alkalinity of a "hypothetical" oceanic mixing-member calculated from the linear functions at a salinity of 33.5 $^{o}/oo$ (fig. 4). Some of the oceanic mixing-member variability shown in figure 4 is undoubtedly error introduced by using a linear function to describe curved salinity-alkalinity relations in the landward reach of North Bay (see discussion). However, the results from the seaward reach of North Bay should converge on the oceanic mixing-member composition within the seasonal ranges of salinity and alkalinity. The accuracy of the analyses can be evaluated by comparing the specific alkalinity (alkalinity per unit chlorinity) of the predicted oceanic mixing-member with the results from other coastal studies.

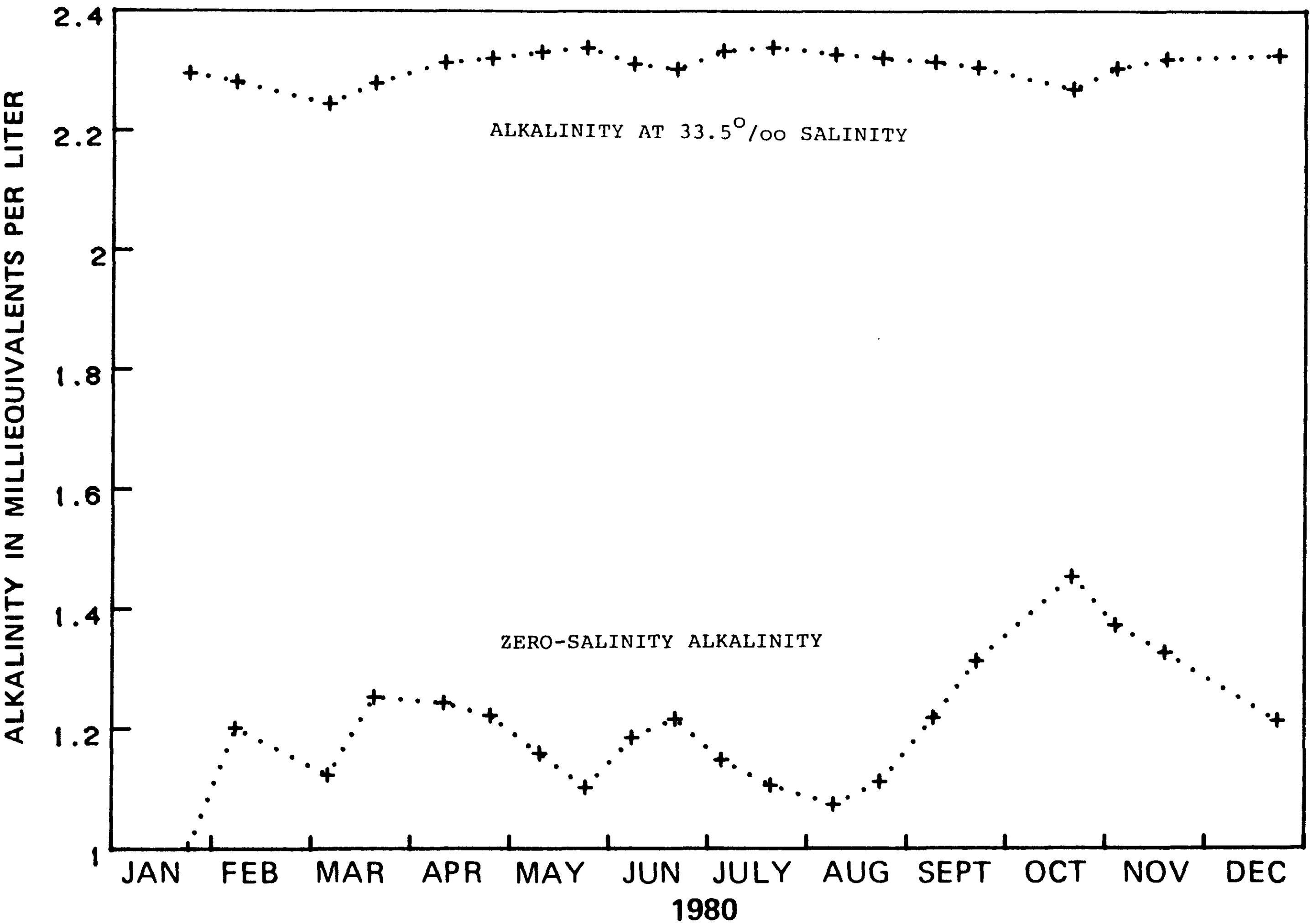

Figure 4. Zero-salinity alkalinity and the alkalinity at 33.5 °/oo salinity computed from the linear fits to the North San Francisco Bay salinity and alkalinity data (table 3.).

All salinities higher than 20 $^{o}/oo$ are plotted against their respective alkalinities in figure 5. Measurements from the 08-09 January 1980 cruise appear to be higher than the other observations, indicating that the estimate of the acid normality is high; these results and the one sample from August that did not meet the linear fit criterion (the circled points) are not included in the linear fit to the data.

Surface salinities measured just north of the Golden Gate (approx. Lat 39N) and landward of 125W Longitude ranged from 32.62 to 33.66 $^{o}/oo$ (Reed and Laird, 1966). Surface salinities measured by Schemel and others (1978) between the Golden Gate and the shelf break ranged from 33.0 to 33.8 $^{o}/oo$. Higher salinities were measured in the deeper waters in both studies; salinities ranging from 34 to 34.5 $^{o}/oo$ were measured in waters deeper than 100m by Reed and Laird. The above studies indicate that the salinity of the oceanic mixing-member could vary by as much as 2 $^{o}/oo$. Few of the salinities measured in this study were as high as the ocean range. Salinities exceeding 32 $^{o}/oo$ were observed only at the Golden Gate and then only during late summer and fall. All but one of these 7 observations were measured at 30m or deeper depths; the highest salinity was 32.794 $^{o}/oo$ (40m depth).

Park (1966;1968) measured the salinities and alkalinities of surface waters off the coast of Oregon that were not affected by the fresh water flow from the Columbia River and found that the specific alkalinity in the upper 200m was almost constant at 0.124. Columbia River plume waters were identified by salinities of less than 32.5 $^{o}/oo$ with specific alkalinities greater than 0.127. Specific alkalinities in the surface coastal Pacific Ocean waters measured by Schemel and others (1978) ranged from 0.123 to 0.127. Measureents in the above studies were made by the method of Anderson and Robinson (1946) or slight modifications of that method, which is a different analytical procedure from the method used in this study. Specific alkalinities calculated from the linear fit to the data in figure 5 do closely agree with those of Park and Schemel and others. The specific alkalinity computed from the linear fit for a salinity of 32.5 $^{o}/oo$ is 0.127. Similarly, specific alkalinities for 33.0 and 33.8 $^{o}/oo$ are 0.126 and 0.124, respectively. The mean specific alkalinity for the seven samples with salinities greater than 32 $^{o}/oo$ is 0.127 (mean salinity of 32.347 $^{o}/oo$). Although this agreement does not truly verify the accuracies of the analyses, it does indicate that the results are accurate at the 1 to 2 percent level.

South Bay

The linearity of the salinity-alkalinity relation in the seaward reach of North Bay during all of the cruises provides a tracer of North Bay water that is useful in the interpretation of South Bay salinity-alkalinity distributions. South Bay waters sampled north of about Station 25 have alkalinity-salinity ratios that are similar to the adjacent North Bay waters. In other words, these points fit close to the North Bay mixing line. This is rarely true for waters south of Station 25, where the alkalinity was always higher than the alkalinity at the same salinity in North Bay during the same cruise. We define this

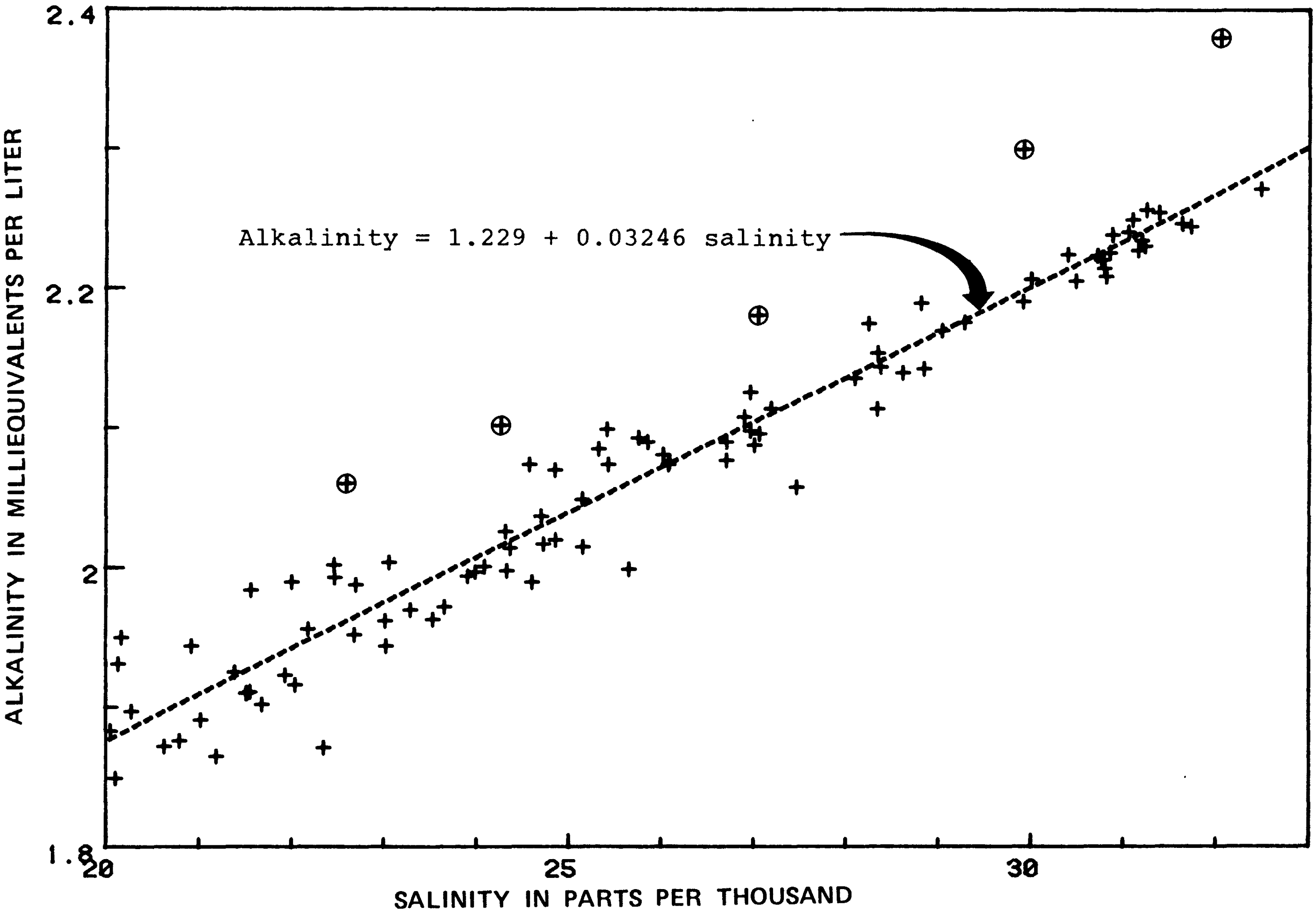

Figure 5. Alkalinity and salinity data from the seaward reach of North San Francisco Bay. Circled data points are not included in the linear fit.

alkalinity difference between North Bay and South Bay (at the same salinity) as the "excess alkalinity" (XSA). The XSA identifies a component of the alkalinity that is unique to South Bay, in that it cannot be attributed to mixing with North Bay water or with fresh water having the same alkalinity as that of the Delta outflow.

The mean values and ranges of the salinity and XSA at locations in the deep channel of South Bay are shown in figure 6. The distinct pattern of decreasing salinity and increasing XSA southward persists all year, in spite of the variability in seasonal fresh water inflow and the range of tidal conditions during which these measurements were made. Salinities are lowest during winter and higher by an average of about 10 $^{o}/oo$ during summer, but summer, spring, and winter mean XSA values are comparable in magnitude. The mean XSA values (fig. 6) and the distributions during individual cruises (see appendix figures) show that the salinity-alkalinity distributions are generally near-linear from about Station 27 to 32 and that the linearity often extends to locations farther north and south and to shallow-water locations (table 4). Exceptions occurred during two winter cruises that coincided with periods of rapidly-changing Delta outflow (08 January 1980 and 05 February 1980). Expressing the South Bay data as linear functions reduces the effects of the differing tidal conditions during and between cruises. Although the salinities and alkalinities at locations in South Bay can change significantly from low to high water, the slope of the salinity-alkalinity linear relation probably does not vary greatly due to tides alone.

The slopes and (zero-salinity) intercepts of the linear functions show a seasonal pattern (table 4). Intercepts are largest and slopes are most-negative during late summer, when salinities are highest South Bay-wide. Slopes are positive and intercepts are low during January and December, following periods of increased Delta outflow. Winter salinity-alkalinity distributions are curved to varying degrees. Distributions were concave towards higher salinities when Delta outflow was decreasing. Curvature can also be seen in the winter, spring, and summer-fall mean XSA distributions (fig. 6).

Only four of the 17 shallow-water samples differed in alkalinity significantly from the deep-channel salinity-alkalinity relations. The 05 February 1980 and 16 December 1980 samples coincided with periods of changing Delta outflow and complex salinity-alkalinity distributions. The two samples during April were taken during periods when Delta outflow was decreasing and salinities were rapidly increasing in the deep channel. Shallow water stations were less saline and lower in alkalinity than the adjacent deep-channel stations during April.

DISCUSSION

Seasonal variations in the North Bay and South Bay salinity-alkalinity distributions and (mathematical) relations appear to be most related to variations in Delta outflow rate and composition. Major factors that influenced or

Table 4. Results from the linear regression analysis of measurements made in South San Francisco Bay.

Cruise Date	Stations Included in fit	Number of Stations	Average Absolute Difference 1/	Intercept	Slope	Correlation (r^2)	Comments
08JAN80	- - -	- - -	- - -	- - -	- - -	- - -	curved:concave to low salinity.
23JAN80	21-32	5	17	0.660	0.0663	0.989	reverse of normal relation.
05FEB80	- - -	- - -	- - -	- - -	- - -	- - -	curved.
04MAR80	30-36	3	27	3.758	-0.1417	0.975	curved and complex in north.
18MAR80	30-36	3	19	3.924	-0.1598	0.989	higher salinity in north.
08APR80	27-36	4	5	2.882	-0.0471	0.997	
22APR80	27-36	4	5	3.305	-0.0607	0.995	
07MAY	27-36+162	5	35	3.418	-0.0631	0.862	curved:concave to high salinity.
21MAY	27-36	4	5	2.891	-0.0332	0.987	
04JUN80	24-36	5	10	3.791	-0.0650	0.983	
17JUN80	24-36	5	26	4.113	-0.0748	0.912	slightly concave to high salinity.
01JUL80	24-36	5	12	4.548	-0.0880	0.988	
16JUL80	21-36+168 162	8	11	4.262	-0.0750	0.987	
04AUG80	21-32+162	6	10	4.330	-0.0744	0.952	
18AUG80	21-32	5	13	5.108	-0.0979	0.971	
03SEP80	27-36+162	5	5	6.141	-0.1306	0.998	
16SEP80	24-36	5	9	6.146	-0.1278	0.997	
03OCT80	27-32	3	3	7.171	-0.1634	0.999	curved:concave to low salinity.
15OCT80	27-32	3	8	6.046	-0.1236	0.986	curved:concave to low salinity.
28OCT80	27-32	3	15	5.916	-0.1204	0.963	curved:concave to low salinity.
12NOV80	27-33A	4	2	5.406	-0.1028	0.999	curved:concave to low salinity.
16DEC80	21-27	3	3	-0.777	+0.1042	0.997	appears to be intersection of two lines/ concave to low salinity.
16DEC80	27-36	5	5	2.964	-0.0223	0.932	
09FEB80	27-36+162	5	15	3.167	-0.0357	0.942	curved:concave to low salinity.

1/ Average absolute difference between the observed alkalinity and the linear fit value for the salinity of the sample in meq L^{-1}.

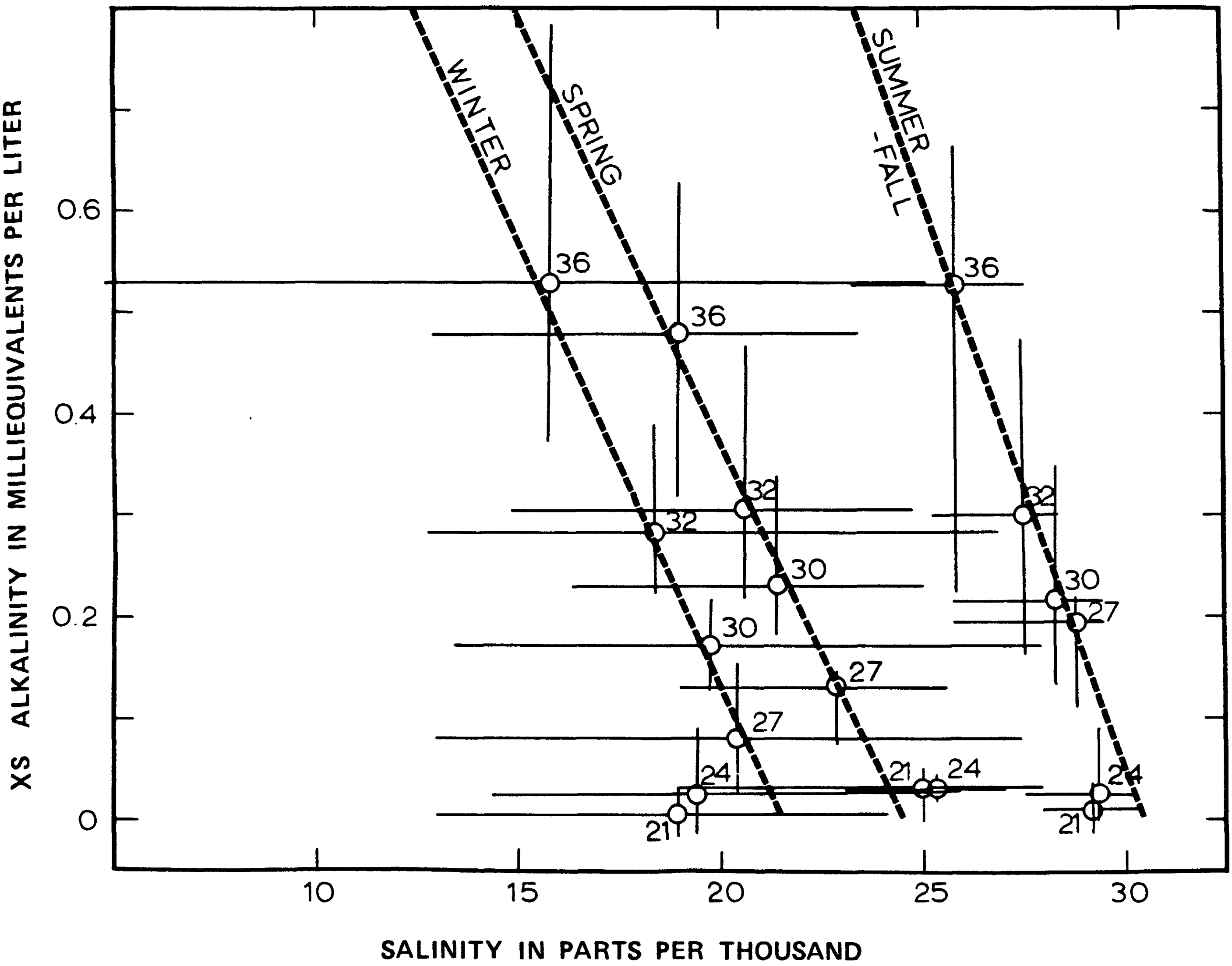

Figure 6. Seasonal Distribution of excess alkalinity in South San Francisco Bay.

controlled the Sacramento River flow rate and composition during 1980 have been summarized by Schemel (1984) and are briefly described below. The Sacramento River contributed about 76 percent of the fresh water flow to the Delta during 1980 and 1980 North Bay salinity-alkalinity relations indicate that Delta outflow alkalinity was close to the alkalinity of the Sacramento River, at least on annual and seasonal bases. During winter, Sacramento River flow rates varied in response to the intensities and frequency of storms. Alkalinity and salinity concentrations varied in the manner characteristic of natural stream systems, where the increased surface runoff from storms generally decreases the the concentrations of most solutes. Spring through fall Sacramento River flow rate variations were largely the result of reservoir management, although river flows to the Delta do show small flow rate increases due to precipitation during spring. Spring through fall salinity and alkalinity variations were generally attributable to releases of waters from the major reservoirs on the three largest tributaries and the inflow of waste waters (primarily agricultural). Waste water inflow effects were most evident during August and September of 1980.

North Bay and Delta

The alkalinity measurements in the Sacramento and San Joaquin River channels of the Delta and the ZSA values provide estimates of the Delta outflow alkalinity that differ in that the ZSA value is a time-averaged estimate, whereas the others are instantaneous measurements (fig. 7). The differences between the ZSA value and the Delta measurements during a single cruise are probably either a measure of the short-term variability in the Delta outflow alkalinity or an indication that the North Bay had not fully responded to a long-term variation in Delta outflow alkalinity at that time. Estuary flushing times were short (on the order of several days; Conomos, 1979) in North Bay during winter because Delta outflow rates were high. Results from the winter cruises generally fit very close to the respective linear functions; however, the very-low salinity and fresh waters in the North Bay and Delta often differed significantly from the linear functions and the ZSA value. Fresh waters sampled at different locations exhibited a sometimes-wide range of alkalinity during the same cruise. Loder and Reichard (1981) mathematically simulated the effects of fresh water (mixing member) composition variability on the estuarine distribution of a conservative constituent. Their results show that curvature and broadening of the theoretical mixing line is primarily related to the frequency and amplitude of the variation relative to the estuarine flushing time. Short-term (high frequency), low amplitude variations with short flushing times produce salinity-alkalinity distributions with characteristics that are similar to those that were observed in North Bay during winter. Short term variability and other factors make it difficult to determine the compositions of waters flowing to the Delta and the Delta outflow. Therefore, the ZSA is probably a better estimate of the average Delta outflow alkalinity than could (in practice) be measured by sampling the Delta outflow during most times of the year.

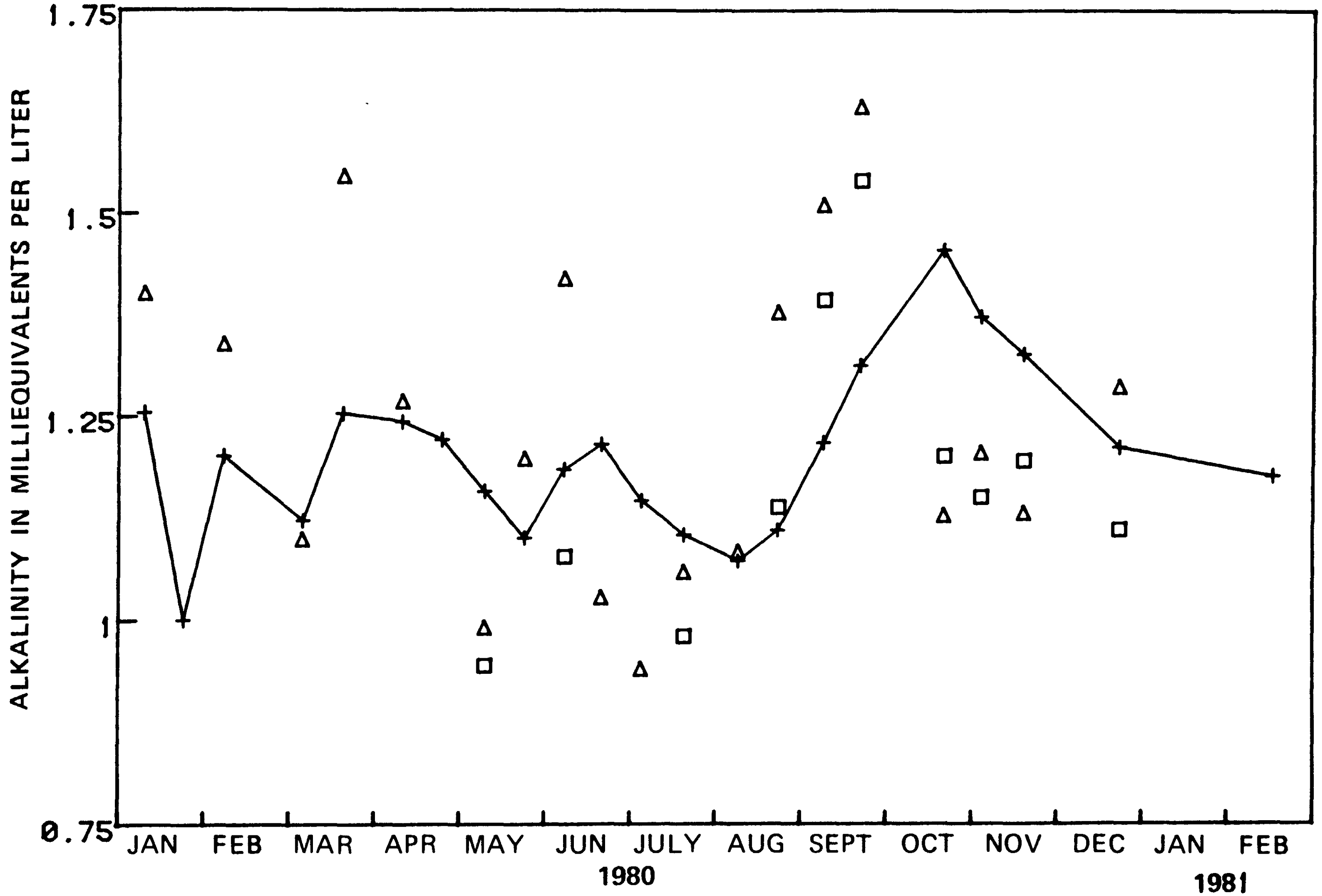

Figure 7. Variation of the zero-salinity alkalinity with time in North San Francisco Bay and the results from the Sacramento River (triangles) and San Joaquin River (squares) channels in the Delta.

Long-term variability (on the order of the flushing time) of the Delta outflow alkalinity is evident during most of the year. The ZSA values tend to follow the trends of the Delta measurements as they increase or decrease with time. Several trends that are on the order of 2 and 4 weeks can be seen during winter and spring (fig. 7). The ZSA value appears to lag behind the Delta variability by a period of time that is perhaps similar to the flushing time. The long-term variation during summer and fall is undoubtedly the result of a major increase in the alkalinity of the Delta outflow during summer and a rapid decrease during fall; this event was described in more detail by Schemel (1984). In this case, the ZSA values lag the Delta measurements by about 8 weeks. The long lag time is presumably an effect of the lowest Delta outflows resulting in the longest flushing time. The late-September decrease in Delta outflow alkalinity occurred over a period of just a few days. The ZSA value indicates that the North Bay did not fully respond to this event until December; Delta outflow rates were roughly in the range of 150-250m^3sec^{-1} during that period. Peterson and others (1978) estimated the advective water-replacement time for a Delta outflow of 200m^3sec^{-1} to be about 45 days. In this case, it appears that the time necessary for North Bay to respond fully is close to the time necessary for replacement of fresh water in the estuary.

Another consequence of the large summer-fall alkalinity variation in the Delta outflow and the long flushing times is that the late-summer and fall salinity-alkalinity distributions in North Bay show distinct curvature as the variation mixes seaward (fig. 8). These distributions are similar in nature to examples simulated by Loder and Reichard (1981) for net increases and decreases in the fresh water mixing member concentrations, but they are also similar to the idealized distributions presented by Liss (1976), that indicate in-estuary sources and sinks. The late-August salinity-alkalinity distribution is very linear, indicating that no large variations in Delta outflow alkalinity had occurred over a period of time on the order of the flushing time. The September distributions are concave towards higher alkalinity at low salinities and alkalinity increased with time in the estuary as the variation propagated seaward. The September distributions could easily be mistaken for evidence of an in-estuary sink rather than the result of a Delta outflow alkalinity increase. The rapid decrease in Delta outflow alkalinity during late September reversed the trend. Mid-and late-October salinity-alkalinity distributions are convex towards higher alkalinities at low salinities. Alkalinities generally decreased in the estuary into mid-December. The October distributions could be easily mistaken for evidence of an in-estuary source. These distributions illustrate the importance of knowing the time-dependent composition variations in the mixing source waters.

Differences between the shallow-water and deep-channel compositions were generally small except when large variations in Delta outflow and/or composition occurred. The observed differences are probably consequences of the circulation, mixing, and variations in Delta outflow composition rather than evidence for in-estuary sources and sinks. Although other alkalinity sources exist in North Bay, their effects appear to be small.

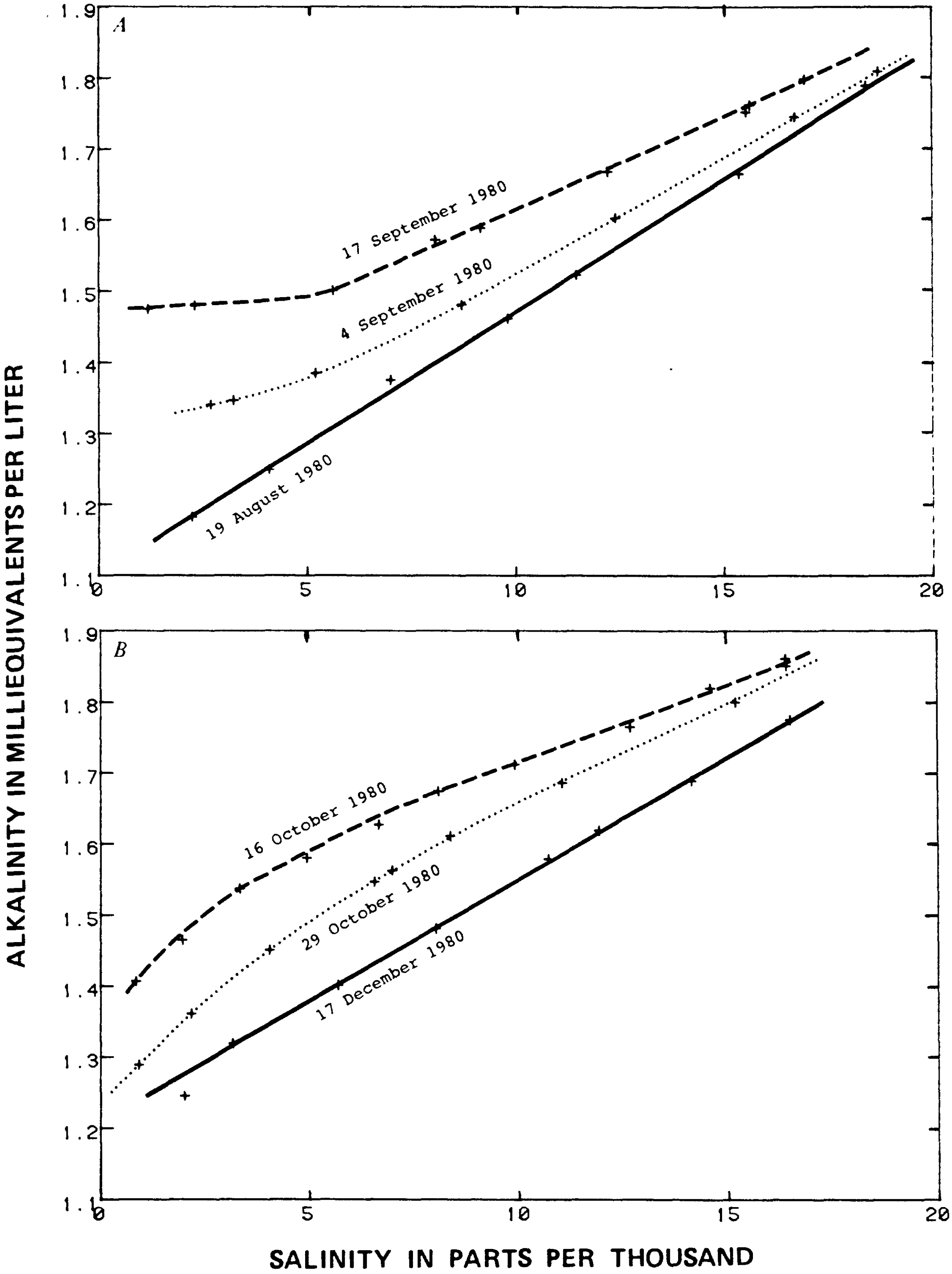

Figure 8. Distributions of alkalinity in North San Francisco Bay during periods of increasing (A) and decreasing (B) Delta outflow alkalinity.

South Bay

The linearity of the deep-channel station salinity-alkalinity relation in South Bay during most of the year indicates that the distributions are primarily the result of the mixing of two (apparent) major sources, one of which is North Bay water. The typical salinity decrease and XSA increase southward indicate that the other mixing member is a highly alkaline lower-salinity source. In reality, we can identify many large point sources of alkalinity to South Bay. Furthermore, the geography and bathymetry of the basin (fig. 9), the resulting circulation patterns, and the locations of the major municipal waste outfalls are all important factors in producing the distributions. South Bay is surrounded by a densely populated urban area and waste waters enter at many locations; however, almost one-half of the municipal waste flow to South Bay is discharged into the small basin south of the Dumbarton Bridge. This small basin contains only 3 percent of the total South Bay volume (at mean lower-low water, MLLW; Selleck and others, 1966). About one-fourth of the municipal waste is discharged into the extreme northern reach of South Bay, where it is rapidly diluted and the observed XSA values are low. Mid-South Bay discharges do not directly enter the deep channel and are diluted by ambient shoal waters before they mix into the deep channel. The average municipal waste inflow rate to South Bay was about $1.5 \times 10^6 m^3 \ day^{-1}$ (based on available data from the dischargers and estimates supplied by the Regional Water Quality Control Board, Oakland, California). On an annual basis, the total 1980 waste inflow south of the Dumbarton Bridge was roughly four times the volume of its basin at MLLW, whereas the section between the San Mateo Bridge and the Dumbarton Bridge received a volume of waste equivalent to its volume at MLLW. Consequently, the effect of waste waters on receiving waters in the deep channel is greatest south of the Dumbarton Bridge.

Mixing with water from North Bay is presumably the primary mechanism for removing most waste-derived substances from South Bay. The 3 m-contour shows the narrow deep channel in the southern reach of South Bay and the broad shoals (fig. 9). Mixing is induced by tidal motion, primarily, which is greatest in the deep channel. More-efficient mixing in the deep channel and the concentration gradients created by the locations of the major waste outfalls (and the receiving water volumes) may be the most important factors maintaining the linear distributions in the absence of large variations in Delta outflow and local stream inflow.

The South Bay salinity-alkalinity distributions are sensitive to variations in Delta outflow rate and local stream inflow. The 08 January 1980 South Bay distribution shows the effect of a late-fall increase in Delta outflow rate to the $1000 m^3 sec^{-1}$ level (fig. 2; appendix fig. A). Salinities in the northern reach of South Bay were about 2 to 5 $^o/oo$ less than what is typical for fall and the distribution pattern indicates that northern reach water has mixed with lower-salinity water from North Bay. The first major flood event began during mid-January. The data from 23 January 1980 show the seaward shift in the North

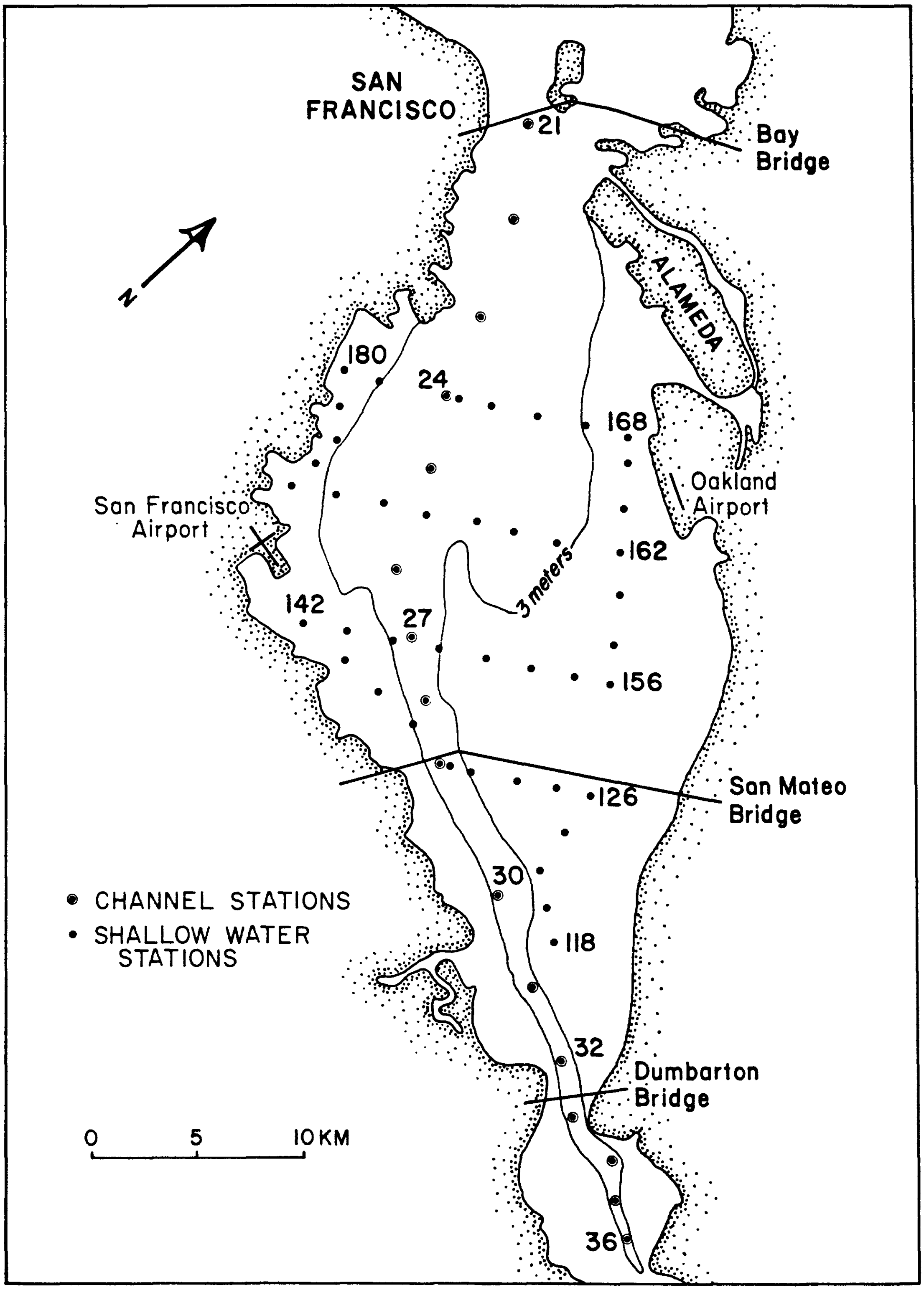

Figure 9. Station locations and bathymetry of South Francisco Bay.

Bay salinity field and the reduction of salinity and alkalinity South Bay-wide (appendix fig. B). The 23 January cruise is the only one during which both salinity and alkalinity increased southward in both the northern and southern reaches of South Bay, indicating that Delta outflow was more effective than local stream inflow in diluting South Bay waters during this storm event. Delta outflow had decreased to below 2000m^3sec^{-1} by 5 February 1980 and the distribution (appendix fig. C) shows that more-saline waters were adjacent to South Bay and that the northern reach of South Bay contained water with North Bay salinity-alkalinity characteristics. These large changes in the North Bay and South Bay distributions illustrate how fast both Bays respond to large variations (increases and decreases) in Delta outflow rate.

The second and larger of the CY80 major flood events commenced during mid-February. The samples obtained during the 20 February 1980 cruise indicate substantial decreases in the southern reach salinities. On 4 March 1980 salinities South Bay-wide were at least 5 $^{o}/oo$ less than they were on 5 February 1980; however, the typical pattern of decreasing salinity southward was maintained. The highest 1980 local stream inflow rates occurred between the 5 February 1980 and 4 March 1980 cruises. The fresh water flow to the southern reach of South Bay during that period was equivalent to about 85 percent or more of its volume at MLLW and roughly four times the volume of local stream inflow that entered the southern reach during the first major storm (U.S. Geological Survey, 1981b). Very high inflow from local streams during the second storm event caused salinities in the southern reach to be lower than those in the northern reach, in contrast to the distribution during late January 1980.

Other effects of increasing Delta outflow were observed during the 16 December 1980 and 9 February 1981 cruises (appendix figs. W and X). Both these storm events created distributions that were similar to that observed during the 8 January 1980 cruise, when dilution of the northern and southern extremes of South Bay was most apparent and salinities were highest in mid-South Bay.

A smaller but important effect of increasing Delta outflow was observed during the early-and mid-October cruises. The lowest 1980 Delta outflow rates occurred during August (110 m^3sec^{-1} average for the month). Delta outflow rates were higher during September (250 m^3sec^{-1} average for the month) and a pulse of Delta outflow to 330 m^3sec^{-1} (average) occurred over the last week of September. This event (the pulse) or the general increase in Delta outflow rate during September appears to have caused a shift of the North Bay salinity field and a reduction of salinity in the northern reach of South Bay by about 1 to 2 $^{o}/oo$ (appendix figs. R, S, and T). This is similar to magnitude to the effect predicted by Imberger and others (1977). Therefore, the existence of higher salinities in mid-South Bay during October was primarily the result of dilution of the northern reach of South Bay. Consideration of the October distributions alone might lead to the conclusion that the high evaporation rates during summer had increased the salinity in mid-South Bay. This illustrates that time-dependent variations in Delta outflow rate and the effect on the North Bay salinity field must be considered when interpreting South Bay distributions.

SUMMARY AND CONCLUSIONS

The CY80 data illustrate how the entire San Francisco Bay system dynamically responds to variations in Delta outflow rate and composition. Previous studies have documented the changes in the geographic location of the salinity field and other features of the estuary with variations in Delta outflow rate. This report shows the variability in the distribution of alkalinity, as an independent conservative constituent, relative to the salinity field. Even though the salinity-alkalinity relations in North Bay are typically linear, short-term and long-term variations in the Delta outflow composition indicate that steady-state conditions rarely, if ever, persisted for much longer than the duration of time necessary for fresh water to mix through the estuary during 1980. This is an important factor to consider when relating the distributions of other dissolved substances to in-estuary processes or testing the conservative nature of dissolved substances in the Bay by the use of mixing models.

The average Delta outflow alkalinity estimated from the North Bay measurements compares closely with that of the Sacramento River. Therefore, for alkalinity and perhaps other dissolved constituents, time-dependent variations in the Sacramento River concentrations may also identify periods when conservative mixing in North Bay will result in nonlinear salinity-constituent relations.

Distributions of dissolved substances in South Bay can be more easily and perhaps more accurately interpreted when they are related to salinity and when the salinity-constituent distributions are compared to the North Bay distributions. The effects of both large and small variations in Delta outflow rate on North and South Bays must be considered.

ACKNOWLEDGMENTS

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REFERENCES CITED

Anderson, D. H., and Robinson, R. J., 1946, Rapid determination of the alkalinity of sea water: Industrial and Engineering Chemistry [Analytical Edition] v. 18, no. 12, p. 767-769.

Carlson, P. R., and McCulloch, D. S., 1974, Aerial observations of suspended sediment plumes in San Francisco Bay and the adjacent Pacific Ocean: Journal of Research, U.S. Geological Survey, v. 2, no. 5, p. 47-84.

Conomos, T. J., 1979, Properties and circulation of San Francisco Bay Waters, in Conomos, T. J., ed., San Francisco Bay: The Urbanized Estuary: American Association for the Advancement of Science, San Francisco, California, p. 47-84.

Conomos, T. J., Smith, R. E., Peterson, D. H., Hager, S. W., and Schemel, L. E., 1979, Processes affecting the seasonal distributions of water properties in the San Francisco Bay estuarine system, in Conomos, T. J., ed., San Francisco Bay: The Urbanized Estuary: American Association for the Advancement of Science, San Francisco, California, p. 115-142.

Cox, R. A., Culkin, F., and Riley, J. P., 1967, The electrical conductivity/chlorinity relationship in natural sea water: Deep-Sea Research, v. 14, p. 203-220.

Dedini, L. A., and Schemel, L. E., 1980, A continuous water-sampling and multi-parameter-measurement system for estuaries: an improved system for small vessels: U.S. Geological Survey Open-File Report 80-1293, 49 p.

Dedini, L. A., Schemel, L. E., and Tembruell, M. A., 1982, Salinity and temperature measurements in San Francisco Bay waters, 1980: U.S. Geological Survey Open-File Report 82-125, 130 p.

Dyer, K. R., 1972, Estuaries: a Physical Introduction: John Wiley and Sons, New York, 140 p.

Dyrssen, David, 1965, A Gran titration of sea water on board Sagitta: Acta Chem. Scand., v. 19, no 5, p. 1265.

Edmond, J. M., 1970, High precision determination of titration, alkalinity and total carbon dioxide content of sea water by potentiometric titration: Deep-Sea Research, v. 17, p. 737-750.

Gran, G., 1953, Determination of the equivalence point in potentiometric titrations. Part II: Analyst, v. 77, p. 661-671.

Hammond, D. E., 1981, Nutrient exchange across the sediment-water interface in San Francisco Bay: EOS, v. 62, no. 45, p. 925.

Harvey, H. W., 1966, The chemistry and fertility of sea waters: Cambridge University Press, 240 p.

Imberger, Jorg, Kirkland, Jr., W. B., and Fischer, H. B., 1977, The effect of delta outflow on density stratification in San Francisco Bay: Report to Association of Bay Area Governments, Rep. HBF-77/02, Berkeley, Calif., 109 p.

Liss, P. S., 1976, Conservative and nonconservative behavior of dissolved constituents during estuarine mixing, in Burton, J. B. and Liss, P. S., eds., Estuarine Chemistry: Academic Press, London, p. 93-130.

Livingstone, D. A., 1963, Chemical composition of rivers and lakes. Data of Geochemistry: U.S. Geological Survey Professional Paper 440G, 64 p.

Loder, T. C., and Reichard, R. P., 1981, The dynamics of conversative mixing in estuaries: Estuaries, v. 4, no. 11, p. 64-69.
McCulloch, D. S., Peterson, D. H., Carlson, P. R., and Conomos, T. J., 1970, Some effects of freshwater inflow on the flushing of South San Francisco Bay: A preliminary report: U.S. Geological Survey Circular 637A, 27 p.
Park, Kilho, 1966, Columbia River plume identification by specific alkalinity: Limnology and Oceanography, v. 11, p. 118-120.
---, 1968, Alkalinity and pH off the coast of Oregon: Deep-Sea Research, v. 15, p. 171-183.
Peterson, D. H., Festa, J. F., and Conomos, T. J., 1978, Numerical simulation of dissolved silica in the San Francisco Bay: Estuarine and Coastal Marine Science, v. 7, p. 99-116.
Reed, R. K. and Laird, N. P., 1966, An oceanographic section off the California coast, February 1966: U.S. Department of Commerce, Environmental Science Services Administration, Technical Memorandum POL-3, 51 p.
Schemel, L. E., 1981, Transport and distribution of dissolved organic and dissolved inorganic carbon in the San Francisco Bay estuarine system: Estuaries, v. 4, no. 3, p. 251-252.
---, 1983, Salinity, alkalinity, and dissolved and particulate organic carbon in the Sacramento River water at Rio Vista, California, and at other locations in the Sacramento-San Joaquin Delta, 1980: U.S. Geological Survey Water Resources Investigations Report 83-4059, 69 p.
Schemel, L. E., Alpine, A. E., Cole, B. E., Dedini, L. A., and Spiker, E. C., 1978, Water and sediment measurements in San Francisco Bay, California: U.S. Geological Survey Open-File Report 78-973, 28 p.
Schemel, L. E., and Dedini, L. A., 1979, A continuous water-sampling and multi-parameter measurement system for estuaries: U.S. Geological Survey Open-File Report 79-273, 92 p.
Selleck, R. E., Pearson, E. A., Glenne, Bard, and Storrs, P. N., 1962, Physical and hydrological characteristics of San Francisco Bay, Final report of a comprehensive study of San Franciscod Bay: University of California, Sanitary Engineering Research Laboratory Report 65-10, Berkeley, California, 99 p.
Spiker, E. C., and Schemel, L. E., 1979, Distribution and stable-isotope composition of carbon in San Francisco Bay, in San Francisco Bay: The urbanized Estuary: American Association for the Advancement of Science, San Francisco, California, p. 115-142.
Stum, Werner, and Morgan, J. J., 1981, Aquatic Chemistry, second edition: John Wiley and Sons, Inc., New York, 780 p.
U.S. Geological Survey, 1981a, Water Resources Data for California, Volume 4: U.S. Geological Survey Water-Data Report CA-80-4, 451 p.
---, 1981b, Water Resources Data for California, Volume 2: U.S. Geological Survey Water-Data Report CA-80-2, 519 p.
Wong, G. T., 1979, Alkalinity and pH in the southern Chesapeake Bay and the James River estuary: Limnology and Oceanography, v. 24, no. 5, p. 970-977.

APPENDIX

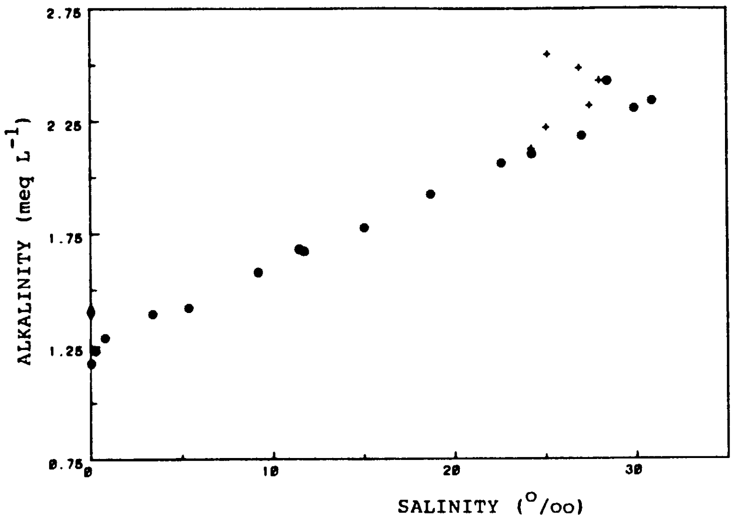

Figure A. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 08-09 January 1980. Shoal samples are in circles.

Table A. 08-09 January 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
08 January 1980: South Bay			
36/2	25.13	2.545	0.413
32/2	26.89	2.484	0.291
30/2	27.98	2.428	0.196
27/2	27.481	2.316	0.102
24/2	25.06	2.220	0.090
21/2	24.21	2.125	0.025
156	28.425	2.427	0.180

Table A continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Measured Alkalinity minus calculated
08 January 1980: North Bay			
19/2	30.90	2.336	+0.002
09 January 1980: North Bay			
17/4	29.916	2.300	+0.001
17/2	27.040	2.181	-0.018
17	24.261	2.102	0.000
15	15.054	1.773	-0.008
15	18.751	1.923	+0.013
15/9	22.594	2.060	+0.016
12	11.738	1.669	+0.004
10	9.222	1.578	+0.001
6/7	5.401	1.417	-0.027
6/5	3.384	1.389	+0.016
6/2	0.803	1.285	+0.002
5	0.046	1.173	-0.084
657/2	0.029	1.401	+0.145
318	11.46	1.678	+0.023
418	0.284	1.233	-0.032

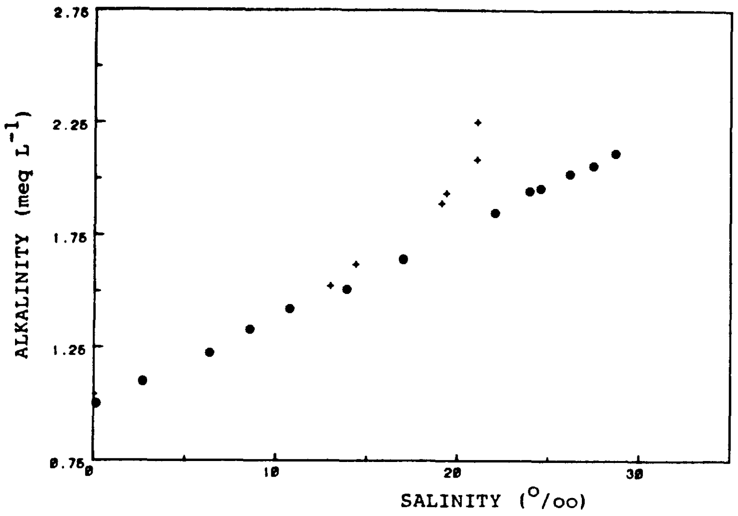

Figure B. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦). 23-24 January 1980. Shoal samples are in circles.

Table B. 23-24 January 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
23 January 1980: South Bay			
36/2	21.015	2.251	0.438
32/2	21.033	2.085	0.271
30/2	19.369	1.935	0.185
27/2	19.099	1.890	0.151
24/2	14.358	1.619	0.063
21/2	12.979	1.523	0.020

Table B continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
23 January 1980: North Bay			
19/2	24.540	1.959	+0.009
19/5	22.015	1.850	-0.002
19/10	23.930	1.945	+0.019
19/13	28.699	2.112	+0.002
19/22	26.172	2.022	+0.010
24 January 1980: North Bay			
17/20	16.963	1.643	-0.014
17/14	27.461	2.058	-0.005
17/6	10.720	1.420	+0.004
17/2	8.547	1.327	-0.004
15	6.363	1.223	-0.002
9/0	-0.001	1.042	+0.041
Lat.(N)/Lon.(W)			
38°03' 122°19'	2.717	1.100	-0.006
36°52' 122°24.5'	13.863	1.508	-0.029

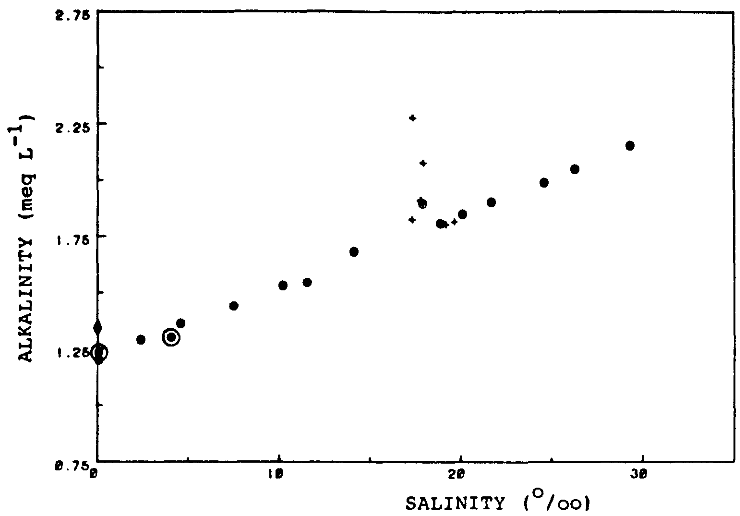

Figure C. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 05-06 February 1980. Shoal samples are in circles.

Table C. 05-06 February 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
05 February 1980: South Bay			
36/2	17.329	2.276	0.516
32/2	17.933	2.077	0.297
30/2	17.763	1.910	0.136
27/2	17.305	1.825	0.066
24/2	19.174	1.804	-0.016
21/2	19.640	1.816	-0.019
156	17.889	1.896	0.118

Table C continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
5 February 1980: North Bay			
19/2	26.295	2.049	0.000
19/20	29.321	2.153	+0.007
06 February 1980: North Bay			
17/2	14.136	1.679	+0.021
15/10	21.683	1.902	+0.001
15/8	18.912	1.808	-0.004
15/2	10.178	1.531	+0.001
13/2	11.538	1.544	-0.030
11	4.598	1.362	+0.011
10	2.371	1.289	+0.010
9/15	7.519	1.439	-0.006
6	0.087	1.199	-0.006
657	0.015	1.339	+0.136
318	4.064	1.298	-0.035
418	0.057	1.231	+0.027
19/2	24.600	1.990	-0.005
Lat.(N)/Lon.(W)			
36°50.6' 122°27.1'	20.103	1.849	-0.001

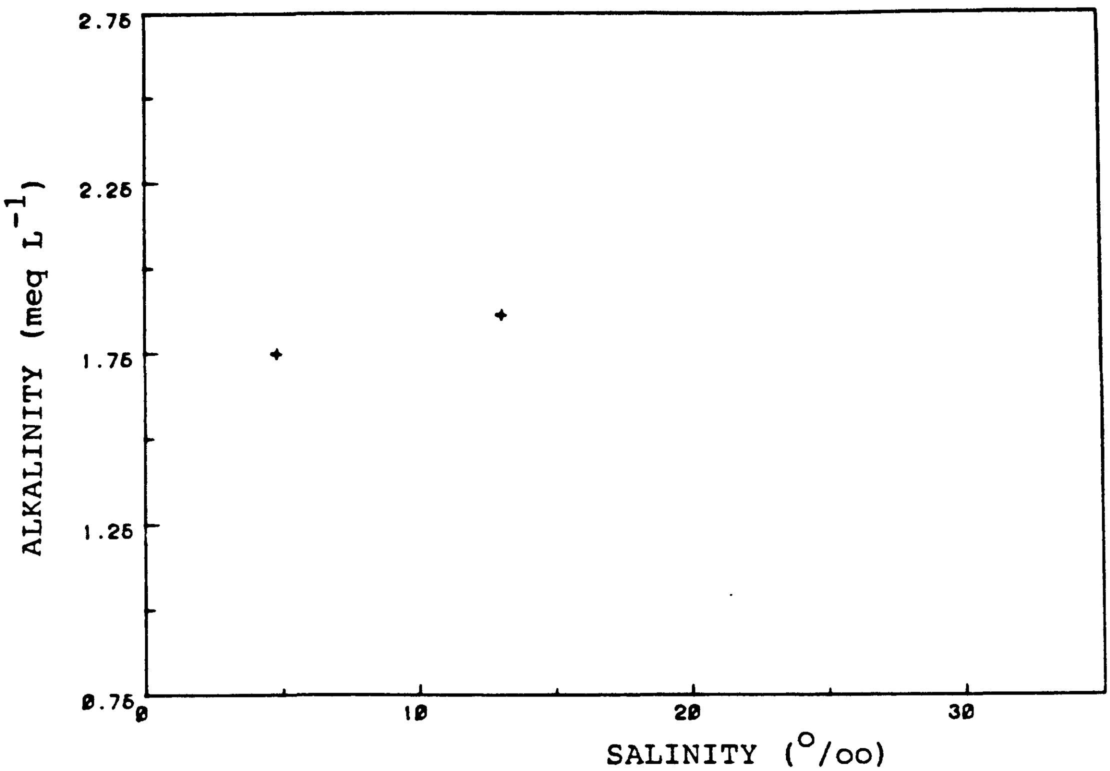

Figure D. Salinity-alkalinity distribution in South San Francisco Bay, 20 February 1980.

Table D. 20 February 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
20 February 1980: South Bay			
36/2	4.833	1.730	0.372
32/2	12.839	1.842	0.226
cruise aborted			

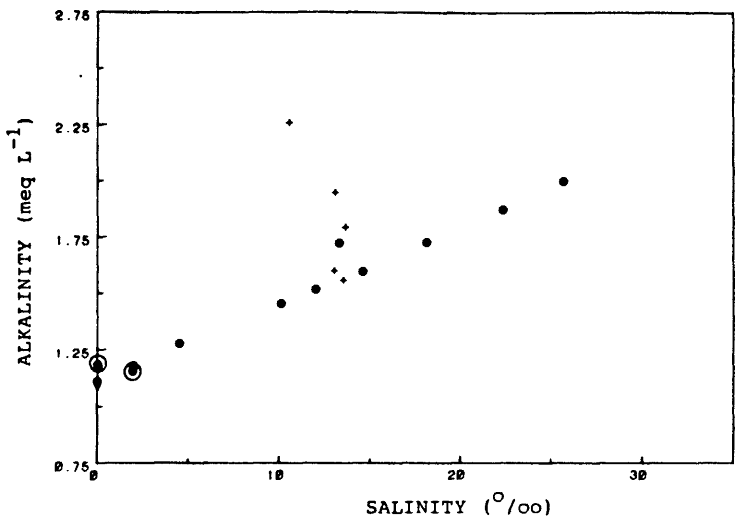

Figure E. Salinity-alkalinity distribution in North (●) and South (+) San Francisco Bay and the delta (♦), 04-05 March 1980. Shoal samples are in circles.

Table E. 04-05 March 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
04 March 1980: South Bay			
36/2	10.522	2.259	0.784
32/2	13.049	1.949	0.389
30/2	13.613	1.795	0.217
27/2	13.003	1.602	0.044
24/2	14.605	1.599	-0.013
21/2	13.491	1.560	-0.014
156	13.258	1.723	0.156

Table E continued. 05 March 1980

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
17/25	25.651	1.999	+0.018
17/15	22.349	1.871	0.000
17/10	18.095	1.725	-0.004
17/5	14.593	1.597	-0.014
17/2	11.954	1.518	-0.005
17/0	10.097	1.452	-0.038
15/5	4.533	1.276	+0.001
15/0	2.004	1.178	-0.012
10	0.032	1.170	+0.046
3/2	0.011	1.104	-0.020
657/2	0.0	1.100	-0.023
318	1.935	1.155	-0.033
418	0.036	1.182	+0.058

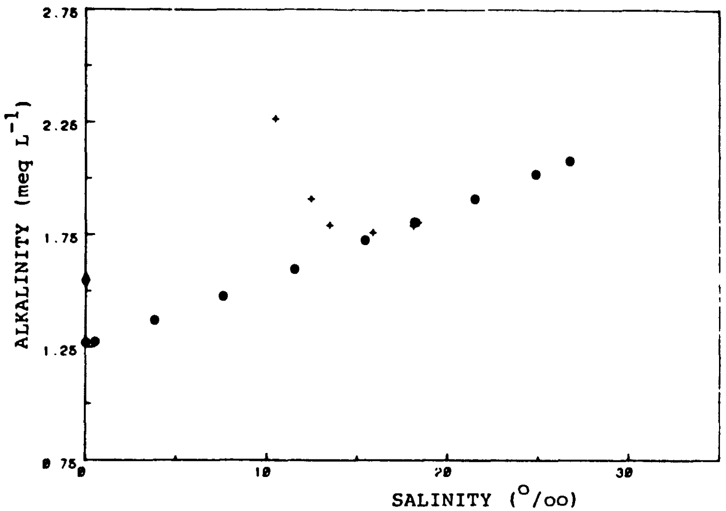

Figure F. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 18-19 March 1980. Shoal samples are in circles.

Table F. 18-19 March 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
18 March 1980: South Bay			
36/2	10.434	2.266	0.693
32/2	12.421	1.909	0.275
30/2	13.446	1.794	0.128
27/2	15.833	1.761	0.022
24/2	18.071	1.792	-0.015
21/2	18.357	1.808	-0.008

Table F continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
18 March 1980: North Bay			
19/2	26.733	2.078	+0.006
Lat.(N)/Lon.(W)			
36°50.6' 122°27.1' 20-m depth	21.513	1.910	-0.003
19 March 1980: North Bay			
17/5	18.183	1.807	-0.003
17/2	15.424	1.725	-0.001
15/10	11.516	1.597	-0.009
15/5	7.589	1.474	-0.012
12/5	3.817	1.366	-0.004
12/2	0.541	1.273	+0.003
3/2	0.028	1.270	+0.016
657	0.031	1.546	+0.292
19/40	24.851	2.020	+0.006

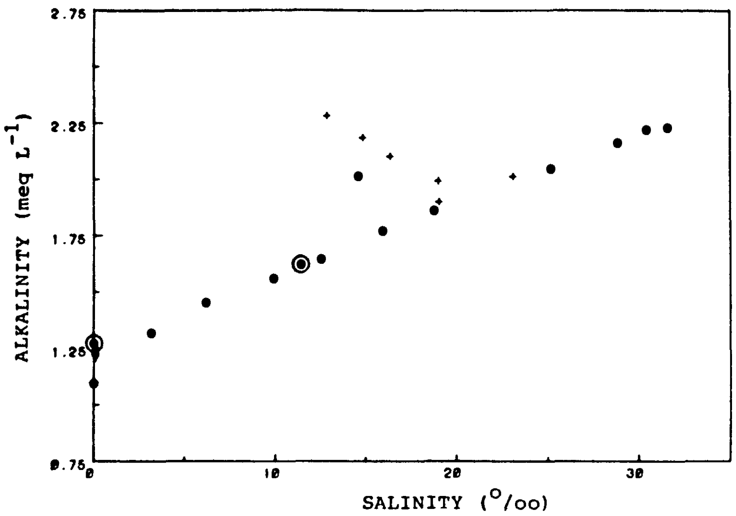

Figure G. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 08-09 April 1980. Shoal samples are in circles.

Table G. 08-09 April 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
08 April 1980: South Bay			
36/2	12.830	2.281	0.627
32/2	14.840	2.185	0.467
30/2	16.315	2.103	0.338
27/2	18.985	1.993	0.143
24/2	23.076	2.013	0.032
21/2	19.017	1.901	0.050
162	14.597	2.014	0.304

Table G continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
08 April 1980: North Bay			
19/29	31.574	2.228	-0.034
19/10	30.431	2.218	+0.003
19/2	28.818	2.163	-0.001
09 April 1980: North Bay			
17/2	25.142	2.049	+0.003
16	18.785	1.862	+0.018
15/2	15.895	1.771	+0.020
13	12.538	1.646	+0.002
9/9	9.899	1.558	-0.002
9/0	6.191	1.452	+0.011
8	3.201	1.317	-0.029
3/2	0.027	1.092	-0.153
657	0.012	1.269	+0.025
318	11.406	1.622	+0.014
418	0.068	1.223	-0.023

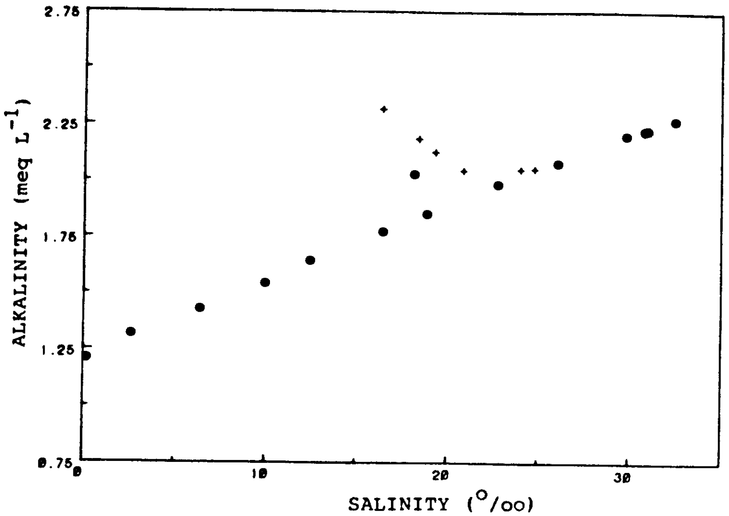

Figure H. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 22-23 April 1980. Shoal samples are in circles.

Table H. 22-23 April 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
22 April 1980: South Bay			
36/2	16.364	2.318	0.559
32/2	18.350	2.187	0.363
30/2	19.250	2.128	0.274
27/2	20.849	2.048	0.142
24/2	24.023	2.052	0.042
21/2	24.744	2.055	0.021
156	18.114	2.031	0.215

Table H continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
22 April 1980: North Bay			
19/35	30.977	2.226	-0.012
19/20	30.790	2.222	-0.010
19/2	29.780	2.202	+0.003
23 April 1980: North Bay			
17/3	26.014	2.081	+0.006
17/0	18.886	1.847	+0.006
15/0	16.396	1.773	+0.014
13	12.440	1.644	+0.014
9/10	9.926	1.539	-0.008
9/2	6.389	1.425	-0.006
8	2.643	1.316	+0.008
6/0	0.219	1.207	-0.022
19/38	32.478	2.272	-0.015
Lat. (N)/Lon. (W)			
37°55.0' 122°25.2'	22.695	1.988	+0.022

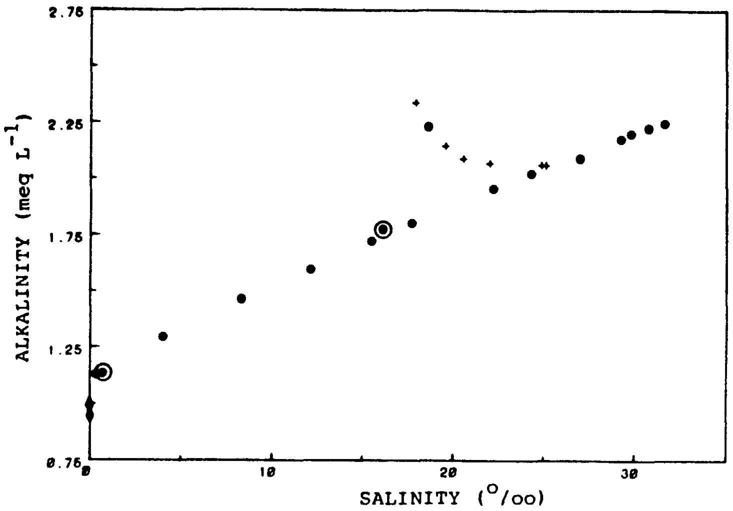

Figure I. Salinity-alkalinity distribution in North (•) and South (+) San Francisco Bay and the delta (♦), 07-08 May 1980. Shoal samples are in circles.

Table I. 07-08 May 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
07 MAY 1980: South Bay			
36/2	17.884	2.337	0.552
32/2	19.552	2.145	0.301
30/2	20.548	2.088	0.209
27/2	22.011	2.069	0.139
24/2	24.883	2.062	0.032
21/2	25.131	2.061	0.022
162	18.603	2.229	0.419

Table I continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
07 MAY 1980: North Bay			
19/40	30.767	2.224	-0.013
19/2	29.824	2.200	-0.004
08 MAY 1980: North Bay			
17/30	31.630	2.247	-0.020
17/2	29.272	2.176	-0.008
16	24.314	2.026	+0.015
15/10	26.998	2.088	-0.017
15/2	22.179	1.956	+0.020
13/3	17.700	1.802	+0.023
13/0	15.494	1.723	+0.021
11	12.141	1.596	+0.012
9/5	8.318	1.465	+0.014
7	4.005	1.296	-0.003
6/2	0.324	1.128	-0.043
657/2	-0.012	0.992	-0.166
318	16.102	1.774	+0.051
418	0.677	1.134	-0.049
757	0.018	0.945	+0.215

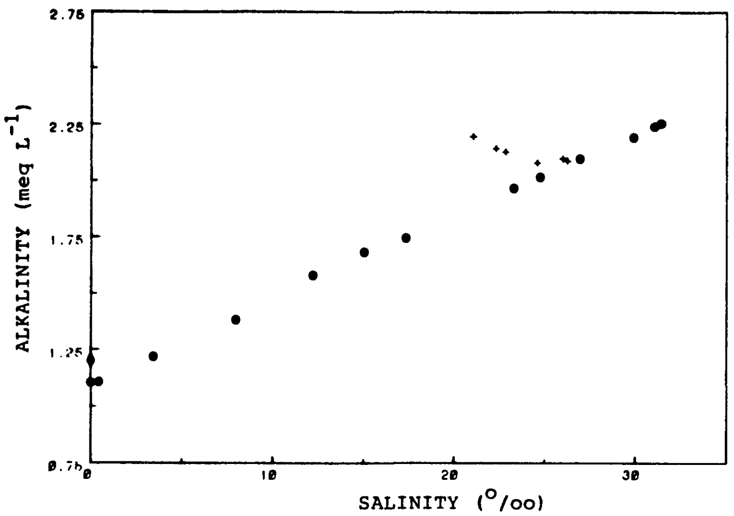

Figure J. Salinity-alkalinity distribution in North (●) and South (✚) San Francisco Bay and the delta (♦), 21-22 May 1980. Shoal samples are in circles.

Table J. 21-22 May 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
21 May 1980: South Bay			
36/2	21.046	2.199	0.320
32/2	22.319	2.145	0.219
30/2	22.840	2.131	0.186
27/2	24.555	2.081	0.072
24/2	25.244	2.089	0.018
21/2	25.992	2.100	0.038

Table J continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
22 MAY 1980:North Bay			
19/40	31.381	2.255	-0.006
19/2	31.049	2.241	-0.008
17/10	29.910	2.191	-0.015
17/2	26.956	2.098	+0.001
17/0	24.721	2.017	+0.002
15/2	23.291	1.970	+0.008
13/2	17.328	1.746	+0.004
13/0	15.008	1.683	+0.027
11	12.238	1.581	+0.027
9/2	7.968	1.381	-0.015
7	3.450	1.218	+0.011
6/2	0.458	1.107	-0.012
3/2	0.030	1.102	-0.001
657/2	0.012	1.199	+0.097

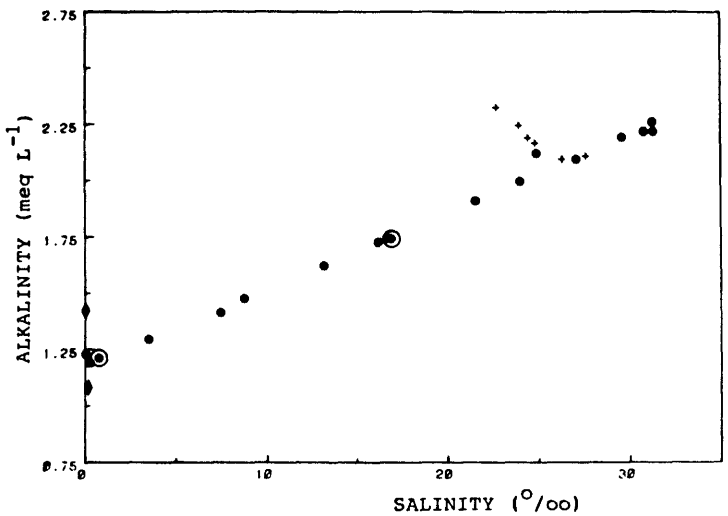

Figure K. Salinity-alkalinity distribution in North (●) and South (+) San Francisco Bay and the delta (♦), 04-05 June 1980. Shoal samples are in circles.

Table K. 04-05 June 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
04 June 1980: South Bay			
36/2	22.65	2.326	0.379
32/2	23.919	2.245	0.255
30/2	24.440	2.190	0.182
27/2	24.830	2.167	0.146
24/2	26.273	2.095	0.026
21/2	27.570	2.109	-0.004
162	24.875	2.124	0.102

Table K continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
04 June 1980: North Bay			
19/40	31.302	2.219	-0.019
19/2	29.595	2.192	+0.012
05 June 1980: North Bay			
17/30	31.245	2.257	+0.021
17/5	30.787	2.215	-0.007
15/10	27.056	2.096	+0.001
15/5	23.983	1.997	+0.005
15/0	21.507	1.910	+0.001
14	16.153	1.727	-0.002
13/2	16.721	1.743	-0.005
12	13.166	1.623	-0.005
9/10	8.763	1.477	-0.003
9/0	7.500	1.414	-0.024
8	3.528	1.296	-0.008
6/2	0.285	1.186	-0.009
3/2	0.040	1.227	+0.040
657/2	0.033	1.420	+0.233
420	0.784	1.210	-0.001
329	16.851	1.743	-0.009
757	0.145	1.079	-0.111

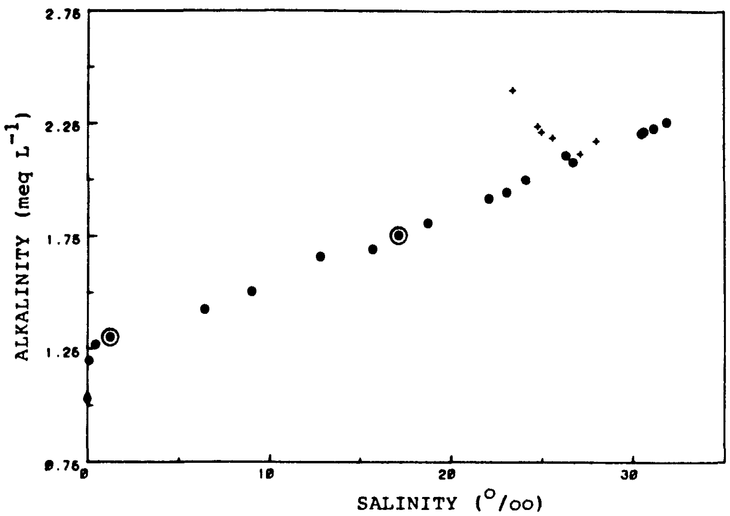

Figure L. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 17-18 June 1980. Shoal samples are in circles.

Table L. 17-18 June 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
17 June 1980: South Bay			
36/2	23.406	2.400	0.424
32/2	24.755	2.239	0.219
30/2	24.978	2.214	0.187
27/2	25.590	2.187	0.140
24/2	27.102	2.115	0.019
21/2	27.988	2.172	0.047
162	26.314	2.108	0.038

Table L continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
17 June 1980: North Bay			
19/38	31.875	2.256	+0.005
19/2	30.624	2.215	+0.005
18 June 1980: North Bay			
17/20	31.153	2.228	+0.001
17/2	30.484	2.206	0.000
15/15	26.698	2.077	-0.006
15/5	24.081	2.001	+0.003
15/0	23.026	1.944	-0.020
13/5	22.038	1.916	-0.016
13/2	18.711	1.809	-0.015
12	12.787	1.659	+0.027
9/15	8.983	1.504	-0.004
9/2	6.448	1.426	0.000
6/0	0.454	1.268	+0.036
3/2	0.095	1.197	-0.023
657/2	-0.002	1.029	-0.188
318	17.071	1.755	-0.016
418	1.223	1.300	+0.043
Lat.(N)/Lon.(W)			
38°02.4' 122°21.0'	15.668	1.694	-0.031

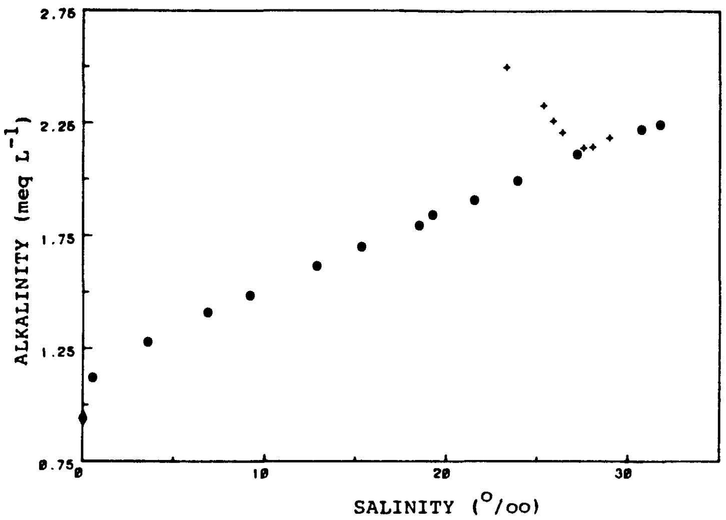

Figure M. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 01-02 July 1980. Shoal samples are in circles.

Table M. 01-02 July 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
01 July 1980: South Bay			
36/2	23.340	2,500	0.527
32/2	25.330	2.329	0.285
30/2	25.857	2.262	0.200
27/2	26.384	2.208	0.127
24/2	27.550	2.141	0.019
21/10	28.965	2.186	0.014
21/2	28.044	2.146	0.006

Table M continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
02 July 1980: North Bay			
19/40	31.725	2.245	-0.024
19/2	30.710	2.224	-0.010
17/2	27.181	2.114	+0.005
15/10	23.902	1.994	+0.001
15/5	21.549	1.911	+0.001
15/2	19.218	1.846	+0.019
13/0	18.505	1.799	-0.003
12/2	15.327	1.702	+0.012
11	12.884	1.614	+0.011
9/0	9.180	1.484	+0.012
8	6.880	1.408	+0.017
6/2	3.593	1.280	+0.005
3/2	0.544	1.119	+0.002
657/2	0.003	0.941	-0.207

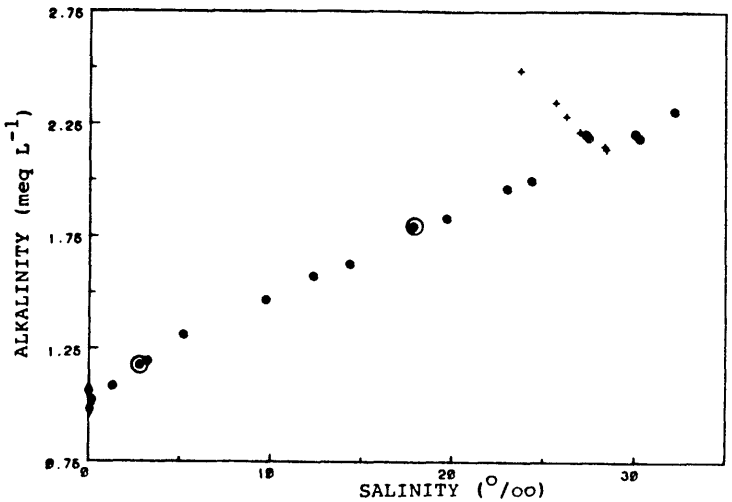

Figure N. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 16-17 July 1980. Shoal samples are in circles.

Table N. 16-17 July 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
16 July 1980: South Bay			
36/2	23.729	2.490	0.510
32/2	25.680	2.347	0.295
30/2	26.272	2.287	0.213
27/2	26.987	2.217	0.117
24/2	28.362	2.153	0.002
21/2	28.451	2.140	-0.014
162	27.485	2.192	0.073
168	27.331	2.204	0.091

Table N continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
16 July 1980: North Bay			
19/40	32.194	2.308	+0.016
19/2	30.273	2.187	-0.034
17 July 1980: North Bay			
17/2	29.997	2.207	-0.004
15/10	24.327	1.998	-0.004
15/2	23.018	1.962	+0.008
14	19.661	1.831	0.000
13/0	17.718	1.787	+0.028
10	12.335	1.573	+0.013
9/0	9.745	1.470	+0.005
7	3.258	1.194	-0.032
6/2	1.304	1.085	-0.069
3/2	0.157	1.020	-0.092
657/2	0.001	1.060	-0.046
318	17.807	1.789	+0.027
416	2.835	1.176	-0.035
757	0.079	0.981	-0.128
Lat.(N)/Lon.(W)			
38°03.6' 122°13.8'	14.347	1.628	-0.007
38°01.9' 122°08.6'	5.216	1.310	+0.012

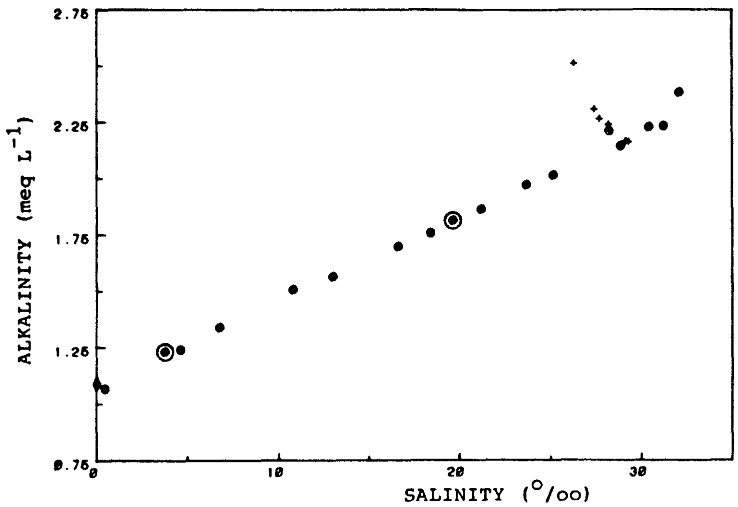

Figure O. Salinity-alkalinity distributions in North (●) and South (✦) San Francisco Bay and the delta (♦), 04-05 August 1980. Shoal samples are in circles.

Table O. 04-05 August 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
04 August 1980: South Bay			
36/2	26.241	2.512	0.456
32/2	27.380	2.308	0.209
30/2	27.670	2.265	0.156
27/2	28.168	2.239	0.111
24/2	29.092	2.165	0.002
21/2	29.255	2.163	-0.006
162	28.209	2.211	0.081

Table O continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
05 August 1980: North Bay			
19	32.046	2.380	+0.104
17/30	31.225	2.231	-0.014
17/2	30.395	2.225	+0.011
15/15	28.838	2.143	-0.012
15/2	25.150	2.015	-0.002
13/2	23.653	1.972	+0.011
12	21.191	1.865	-0.003
9/2	16.587	1.697	+0.002
9/15	18.407	1.760	-0.004
6/2	6.780	1.337	+0.010
3/2	0.465	1.068	-0.022
657/2	-0.002	1.085	+0.013
318	19.626	1.815	+0.006
418	3.796	1.231	+0.016
Lat.(N)/Lon.(W)			
38°03.6' 122°00.0'	4.625	1.239	-0.007
38°03.5' 122°04.3'	10.784	1.506	+0.029
38°02.5' 122°06.7'	13.018	1.563	+0.002

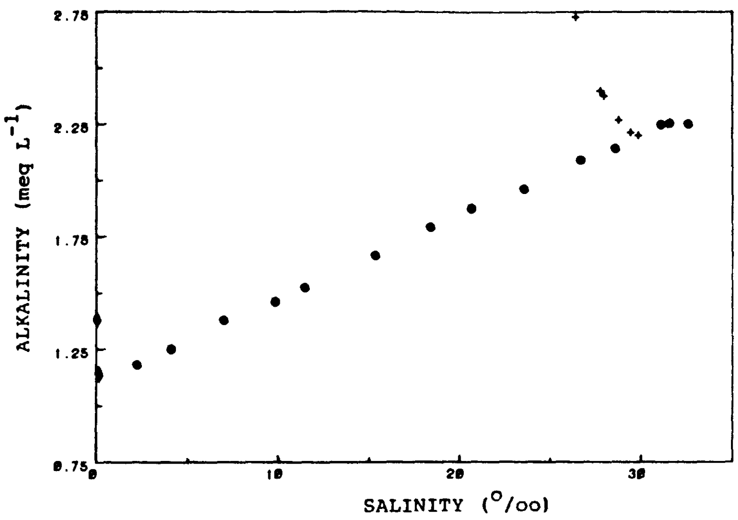

Figure P. Salinity-alkalinity distribution in North (●) and South (+) San Francisco Bay and the delta (♦), 18-19 August 1980. Shoal samples are in circles.

Table P. 18-19 August 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity meq L^{-1})	Excess Alkalinity (meq L^{-1})
18 August 1980: South Bay			
36/2	26.407	2.727	0.661
32/2	27.751	2.398	0.284
30/2	27.955	2.376	0.254
27/2	28.792	2.269	0.117
24/2	29.430	2.214	0.039
21/2	29.858	2.203	0.013

Table P continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
18 August 1980: North Bay			
19/2	31.555	2.252	+0.001
19/40	32.604	2.252	-0.037
19 August 1980: North Bay			
17/2	31.110	2.250	-0.015
15/2	26.698	2.090	+0.014
15/15	28.610	2.140	-0.005
13/2	23.532	1.963	+0.001
12	20.629	1.872	-0.013
9/2	15.369	1.666	-0.001
9/10	18.423	1.790	+0.013
7	11.454	1.523	-0.002
6/2	6.999	1.376	+0.011
6/5	9.806	1.462	-0.004
3/2	2.231	1.182	-0.010
657/2	0.013	1.379	+0.267
757	0.143	1.140	+0.023
Lat.(N)/Lon.(W)			
38°03.3' 122°57.4'	4.078	1.249	-0.010

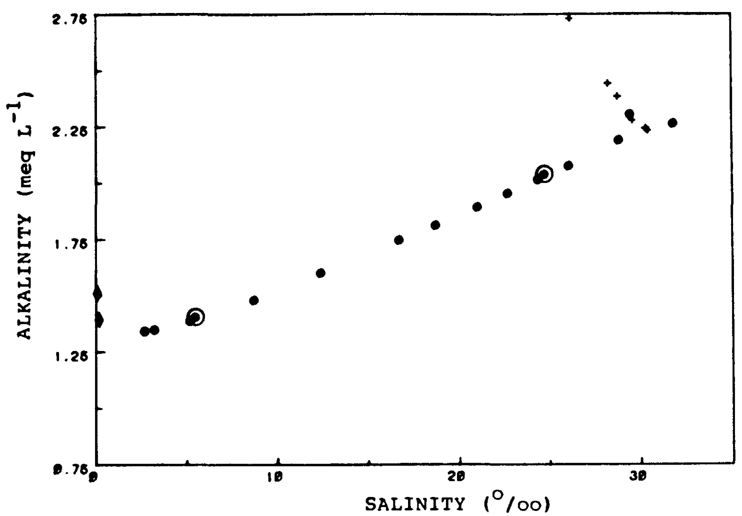

Figure Q. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 03-04 September 1980. Shoal samples are in circles.

Table Q. 03-04 September 1980 salinity and alkalinity results.

Station/Z (m)	Salinity ($^{o}/oo$)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
03 September 1980: South Bay			
36/2	26.146	2.730	0.656
32/2	28.230	2.442	0.299
30/2	28.752	2.384	0.224
27/2	29.568	2.278	0.092
24/2	30.299	2.242	0.032
21/2	30.414	2.233	0.019
162	29.440	2.304	0.122

Table Q continued.

Station/Z (m)	Salinity ($^{o}/oo$)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
03 September 1980: North Bay			
19/40	31.766	2.263	+0.004
19/2	31.777	2.264	+0.005
04 September 1980: North Bay			
17/2	28.805	2.190	+0.028
15/5	26.081	2.076	+0.003
15/2	24.696	2.037	+0.010
13/2	24.359	2.014	-0.002
12	21.024	1.891	-0.016
11	18.713	1.810	-0.021
9/2	16.702	1.746	-0.020
6/2	8.691	1.481	-0.023
5	5.193	1.385	-0.004
4	3.213	1.347	+0.023
3/2	2.675	1.341	+0.034
657/2	0.065	1.511	+0.290
318	22.680	1.952	-0.009
418	5.475	1.403	+0.005
757	0.134	1.394	+0.170
Lat.(N)/Lon.(W)			
38°02.1' 122°07.6'	12.388	1.603	-0.022

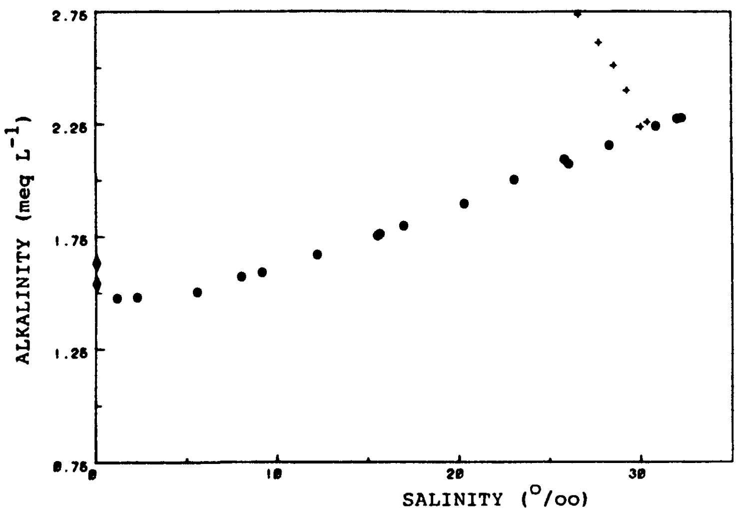

Figure R. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 16-17 September 1980. Shoal samples are in circles.

Table R. 16-17 September 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
16 September 1980: South Bay			
36/2	26.607	2.735	0.633
32/2	27.734	2.611	0.476
30/2	28.560	2.509	0.349
27/2	29.264	2.400	0.219
24/2	30.385	2.258	0.044
21/2	30.022	2.237	0.034

Table R continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
16 September 1980: North Bay			
19/40	32.285	2.277	+0.007
19/2	32.055	2.273	+0.009
17 September 1980: North Bay			
17/2	30.873	2.239	+0.011
15/2	26.071	2.074	-0.012
15/10	28.339	2.154	0.000
13/2	25.849	2.090	+0.010
13/0	23.056	2.004	+0.007
12	20.275	1.897	-0.018
9/4	16.943	1.799	-0.017
9/2	15.537	1.753	-0.021
6/5	9.149	1.589	+0.004
6/2	8.060	1.572	+0.019
5	5.603	1.501	+0.021
4	2.294	1.480	+0.098
3/2	1.171	1.475	+0.126
657/2	0.025	1.632	+0.317
757	0.067	1.541	+0.225
Lat.(N)/Lon.(W)			
38°03.8' 122°14.1'	15.626	1.763	-0.014
38°02.3' 122°10.0'	12.202	1.669	-0.007

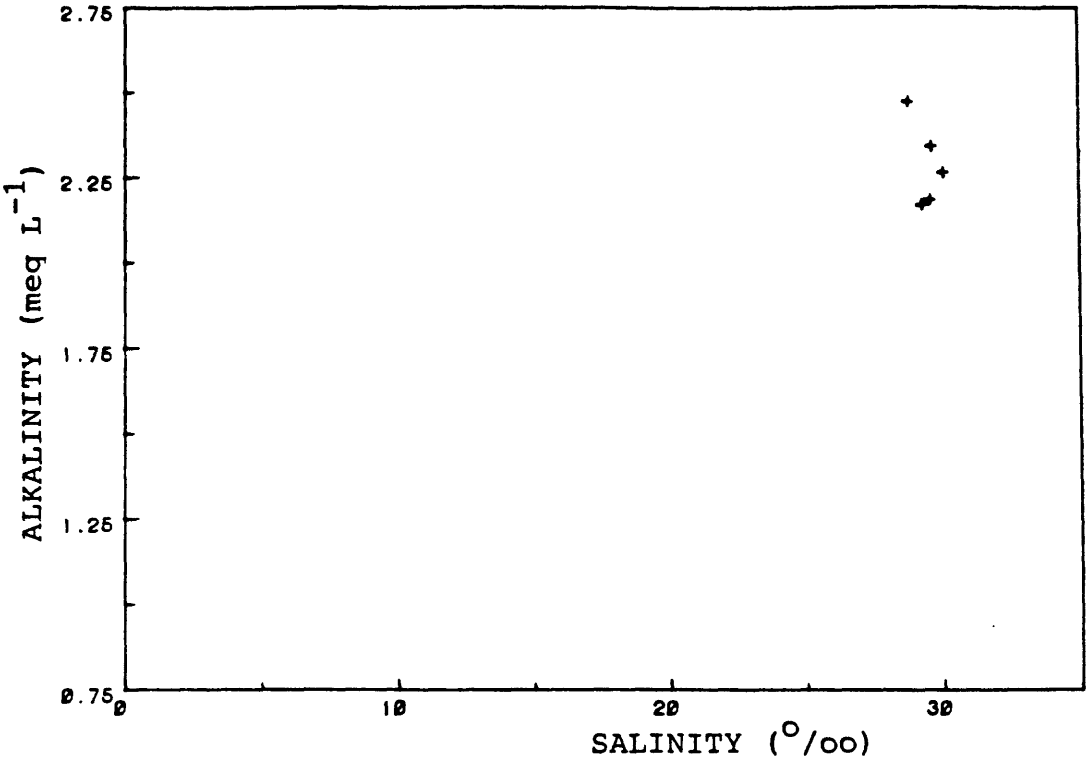

Figure S. Salinity-alkalinity distribution in South San Francisco Bay, 03 October 1980.

Table S. 03 October 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
32	28.734	2.473	0.308
30	29.573	2.342	0.152
27	30.010	2.263	0.060
24	29.513	2.184	-0.004
21	29.220	2.169	-0.010

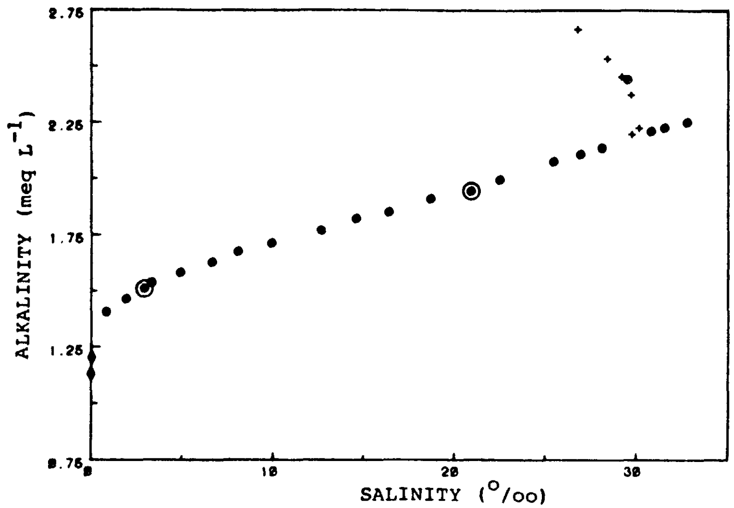

Figure T. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and in the delta (♦), 15-16 October 1980. Shoal samples are in circles.

Table T. 15-16 October 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
15 October 1980: South Bay			
36/2	26.742	2.663	0.557
32/2	28.393	2.533	0.378
30/2	29.157	2.454	0.289
27/2	29.688	2.371	0.193
24/2	30.046	2.224	0.038
21/2	29.755	2.196	0.017
162	29.484	2.441	0.268

Table T continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
15 October 1980: North Bay			
19/40	32.794	2.250	-0.004
19/2	31.539	2.223	0.000
16 October 1980: North Bay			
17/2	30.808	2.209	+0.004
15/5	28.088	2.136	-0.003
15/2	26.890	2.108	-0.002
13/2	25.426	2.074	0.000
9/4	14.584	1.820	+0.009
9/0	12.659	1.765	+0.001
6/2	8.074	1.674	+0.021
4	1.950	1.465	-0.039
3/2	0.839	1.407	-0.070
657/2	-0.005	1.130	-0.326
318	20.922	1.944	-0.021
418	2.920	1.509	-0.018
757	0.018	1.203	-0.254
Lat. (N)/Lon. (W)			
38°03.0' 122°19.8'	22.466	1.993	-0.009
38°03.7' 122°17.4'	18.690	1.909	-0.002
38°03.7' 122°14.1'	16.393	1.851	-0.004
38°03.5' 122°04.2'	9.901	1.712	+0.015
38°03.8' 122°03.5'	6.651	1.627	+0.009
38°03.6' 121°58.9'	4.927	1.580	+0.004
38°03.1' 121°56.9'	3.318	1.537	0.000

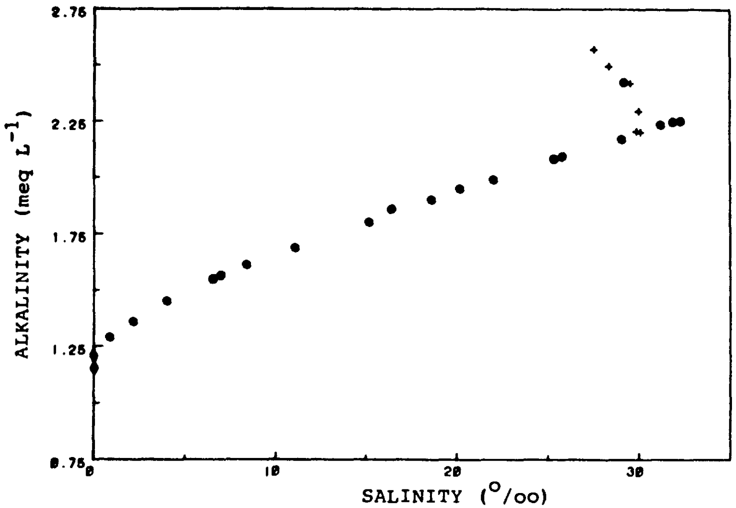

Figure U. Salinity-alkalinity distribution in North (•) and South (+) San Francisco Bay and the delta (♦), 28-29 October 1980. Shoal samples are in circles.

Table U. 28-29 October 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
28 October 1980: South Bay			
32/2	28.312	2.496	0.335
30/2	29.177	2.425	0.240
27/2	29.964	2.296	0.089
24/2	29.853	2.206	0.002
21/2	30.075	2.203	-0.007
162	29.509	2.420	0.226

Table U continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
28 October 1980: North Bay			
19/40	32.290	2.252	-0.019
19/2	31.878	2.248	-0.011
29 October 1980: North Bay			
17/2	31.191	2.235	-0.005
15/5	29.033	2.170	-0.010
15/2	25.752	2.093	+0.004
13/2	25.319	2.085	+0.008
9/2	15.179	1.800	+0.005
6/2	6.964	1.563	-0.004
3/2	0.904	1.289	-0.110
657/2	0.001	1.207	-0.167
757/2	0.018	1.153	-0.141
Lat. (N)/Lon. (W)			
38°02.7' 122°19.3'	22.001	1.990	+0.005
38°03.4' 122°17.0'	18.601	1.903	+0.013
38°03.5' 122°14.5'	20.167	1.950	+0.016
38°03.7' 122°13.6'	16.375	1.861	+0.032
38°02.1' 122°08.7'	11.037	1.686	+0.005
38°02.8' 122°06.2'	8.361	1.611	+0.005
38°03.8' 122°01.8'	6.544	1.547	-0.008
38°03.6' 122°00.1'	4.025	1.451	-0.034
38°03.1' 121°56.9'	2.162	1.361	-0.073

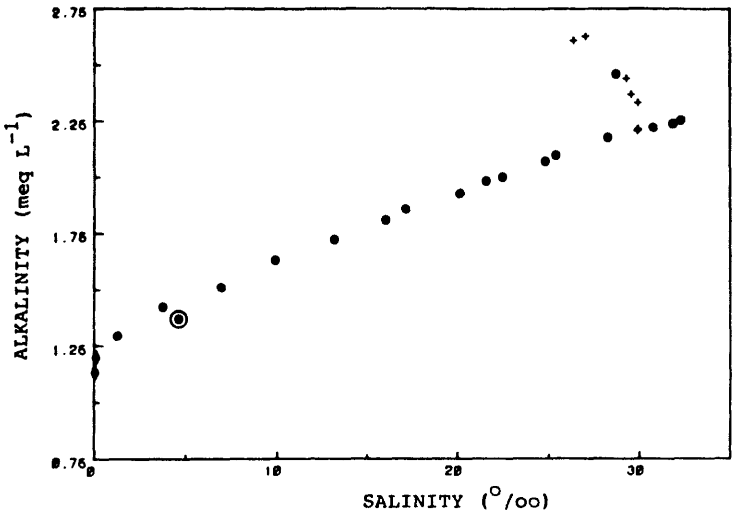

Figure V. Salinity-alkalinity distribution in North (●) and South (+) San Francisco Bay and the delta (♦), 12-13 November 1980. Shoal samples are in circles.

Table V. 12-13 November 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
12 November 1980: South Bay			
36/2	26.360	2.610	0.501
32/2	28.714	2.457	0.278
30/2	29.538	2.368	0.165
27/2	29.906	2.333	0.119
24/2	29.867	2.206	-0.007
21/2	29.936	2.214	-0.001
162	29.280	2.439	0.244
additional sample: 37°00.0'N.Lat 122°06.8'W.Lon.			
33A/2	27.043	2.626	0.497

Table V continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
12 November 1980: North Bay			
19/30	32.208	2.252	-0.033
19/2	31.854	2.236	-0.035
13 November 1980: North Bay			
17/2	30.755	2.221	-0.018
15/8	28.238	2.175	+0.011
15/2	25.411	2.099	+0.018
13/2	24.844	2.070	+0.006
12	22.459	2.002	+0.009
11	17.143	1.858	+0.022
9/20	20.132	1.931	+0.007
9/2	16.025	1.810	+0.007
8	13.185	1.723	+0.005
6/2	6.953	1.511	-0.023
3/2	1.276	1.295	-0.071
657/2	0.012	1.133	-0.195
757	0.078	1.197	-0.133
Lat.(N)/Lon.(W)			
38°03.9' 122°03.1'	9.897	1.630	+0.009
38°03.6' 121°58.9'	3.775	1.422	-0.018

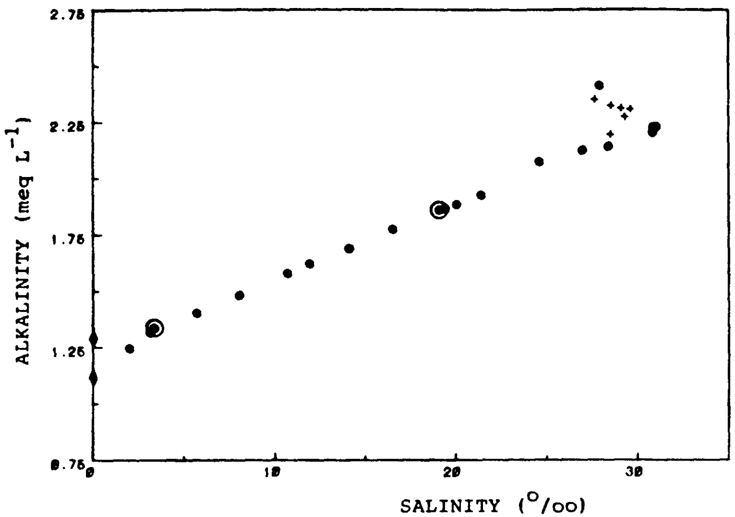

Figure W. Salinity-alkalinity distribution in North (●) and South (+) San Francisco Bay and the delta (♦), 16-17 December 1980. Shoal samples are in circles.

Table W. 16-17 December 1980 salinity and alkalinity results.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
16 December 1980: South Bay			
36/2	27.628	2.353	0.221
32/2	28.541	2.323	0.161
30/2	29.091	2.314	0.134
27/2	29.597	2.310	0.113
24/2	29.325	2.275	0.087
21/2	28.521	2.196	0.035
162	27.888	2.414	0.274

Table W continued.

Station/Z (m)	Salinity (^{o}/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
16 December 1980: North Bay			
19/40	31.018	2.228	-0.017
19/2	30.850	2.209	-0.030
17 December 1980: North Bay			
17/2	28.369	2.144	-0.013
17/20	30.846	2.226	-0.013
15/2	26.957	2.126	+0.016
13/2	24.566	2.074	+0.044
12	19.421	1.868	+0.009
11	21.381	1.925	+0.001
9/2	20.045	1.883	+0.003
6/2	11.918	1.619	+0.009
5	5.679	1.401	-0.002
3/2	2.004	1.245	-0.036
657/2	0.008	1.288	+0.073
757	0.015	1.113	-0.102
318	19.080	1.862	+0.014
418	3.347	1.333	+0.007
Lat.(N)/Lon.(W)			
38°02.6' 122°06.5'	16.488	1.775	+0.013
38°03.5' 122°04.2'	14.125	1.689	+0.006
38°03.8' 122°03.5'	10.706	1.579	+0.009
38°03.8' 122°01.2'	8.017	1.481	0.000
38°02.7' 121°55.0'	3.154	1.319	0.000

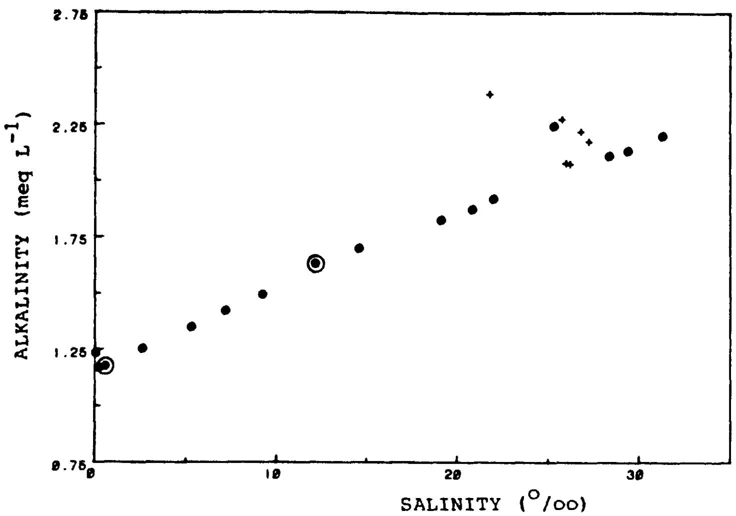

Figure X. Salinity-alkalinity distribution in North (●) and South (✦) San Francisco Bay and the delta (♦), 09-10 February 1981. Shoal samples are in circles.

Table X. 09-10 February 1981 salinity and alkalinity results.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq L^{-1})	Excess Alkalinity (meq L^{-1})
09 February 1980: South Bay			
36/2	21.709	2.389	0.489
32/2	25.270	2.247	0.229
30/2	26.765	2.221	0.153
27/2	27.186	2.177	0.095
24/2	25.936	2.081	0.041
21/2	26.165	2.076	0.028
162	25.716	2.275	0.242

Table X continued.

Station/Z (m)	Salinity (°/oo)	Alkalinity (meq l^{-1})	Measured Alkalinity minus calculated
09 February 1981: North Bay			
19/2	29.387	2.135	-0.021
19/40	31.234	2.202	-0.015
10 February 1981: North Bay			
17/2	28.327	2.114	-0.006
15/2	19.071	1.825	+0.012
15/12	21.932	1.923	+0.015
13/2	20.793	1.876	+0.006
12/0	14.564	1.700	+0.037
10/0	9.219	1.494	+0.008
9/2	7.141	1.419	+0.002
9	5.303	1.350	-0.006
8	2.617	1.252	-0.014
6/2	0.231	1.168	-0.019
3/2	0.060	1.234	-0.053
318	12.110	1.632	+0.050
418	0.562	1.174	-0.024