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# Mapping salinity in an oligohaline tropical coastal lagoon with MSS and TM Landsat imagery

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**RESUMEN**

Los Mapas Temáticos Multi-banda para Salinidad generados por las correlaciones entre los datos superficiales *in situ* y los datos remotos "simultáneos" registrados por sensores MSS y TM de satélites Landsat se obtuvieron para tres períodos: Verano 1981, Verano 1987 e Invierno 1988-89. El cuerpo de agua bajo estudio es la laguna tropical Coyuca de Benítez, en el Estado de Guerrero, México. Es una laguna oligohalina, con salinidades entre 0 y 5 mg/l (o $10^{-3}$). Los resultados preliminares de los modelos estadísticos calculados por regresión lineal múltiple mostraron coeficientes de determinación ($R^2$) altos, desde 0.75 hasta 0.99, con valores de significación desde 0.1 hasta 0.0001. La precisión de los Mapas Temáticos se evaluó teniendo en cuenta los datos *in situ* y los Mapas de Isolíneas. Los Mapas Temáticos de Salinidad mostraron la zonación general sugerida por los Mapas de Isolíneas. Los porcentajes de los campos de entrenamiento predichos correctamente (correspondientes a los puntos de muestreo) fueron: 100% para el Verano 1981 con una imagen MSS, 90% para el Verano 1987 con una imagen TM y 80% para el Invierno 1988-89 con una imagen TM.

**PALABRAS CLAVE:** salinidad, oligohalina, mapeo, datos Landsat, laguna, percepción remota.

**ABSTRACT**

The Salinity Multi-band Thematic Maps generated by the correlations between the surficial *in situ* data and the "simultaneous" remote Landsat data (MSS and TM) are obtained for three seasons: Summer 1981, Summer 1987 and Winter 1988-89. The water body under study is the tropical coastal lagoon Coyuca de Benítez, Guerrero, México. It is an oligohaline lagoon with salinity from 0 to 5 mg/l (or $10^{-3}$). The preliminar results of the statistical models calculated by multiple linear regression show high coefficients of determination ($R^2$), from 0.75 to 0.99 with P-values from 0.1 to 0.0001. The accuracy of the Thematic Maps is evaluated with *in situ* data and Isoline Maps. The Salinity Thematic Maps showed the general zonation suggested by the Isoline Maps. The percentages of well predicted training fields (corresponding to the sampling points) were: 100% for Summer 1981 with MSS data, 90% for Summer 1987 with TM data and 80% for Winter 1988-89 with TM data.

**KEY WORDS**: salinity, brackish water, mapping, Landsat data, lagoon, remote sensing.

## INTRODUCTION

The dynamics of the coastal lagoon Coyuca de Benítez, Guerrero, have been studied from 1981 to 1991 by using *in situ* and remote data. Some results are available from the literature (Ruiz-Azuara *et al.*, 1983a; Ruiz-Azuara *et al.*, 1983b; Ruiz-Azuara, 1985a; Ruiz-Azuara 1985b; Aguirre *et al.*, 1989; Ruiz-Azuara *et al.*, 1989 and Pérez *et al.*, 1989). Several hydrobiological parameters were analyzed: net primary production, chlorophyll-a, Secchi disk depth, pH, water temperature, total suspended solids, zooplankton, salinity, nutrients, and others at different seasons during the period mentioned. The main goal of this project was to evaluate the usefulness of remote sensing data for modeling and monitoring water quality in a small tropical coastal lagoon. Different types of remote images were available: analogical and digital; aerial and spatial. All of these types had some valuable information for monitoring the dynamics of the water body. High coefficients of determination ($R^2$), and high levels of significance were shown by the statistical models obtained by multiple linear regression for most of the parameters studied at the Coyuca de Benítez Lagoon (Ruiz-Azuara, 1985a; Ruiz-Azuara *et al.*, 1989).

In this paper the selected parameter was salinity.

Salinity is a very important chemical component for aquatic ecological systems and for human life. Spatial distribution of most organisms inside water is determined by this variable.

For salinity (measured as chlorinity), a model including sampling points in the open sand bar was obtained (Ruiz-Azuara, 1985a). The adjusted determination coefficient was 0.999, for salinity values from 3.3 to 33.6 PPT (or $10^{-3}$).

In the literature there are some interesting results for salinity "or conductivity" (Khorram, 1985; Khorram and Cheshire, 1985; Pelkey and Khorram, 1987; Cheshire and Khorram, 1987). Their models had determination coefficients from 0.33 to 0.94, the values of salinity corresponding to the entire San Francisco Bay and Delta were from 0.1 to 30 PPT (or $10^{-3}$). For the Neuse River Estuary the salinity values were from 0 to 17.9 PPT (or $10^{-3}$). The conductivity on North Carolina's nutrient-sensitive reservoirs was from 40 to 250 UMHOs.

In Coyuca de Benítez Lagoon, the salinity is lower than 5 mg/l (PPT or $10^{-3}$). It is an oligohaline water body.

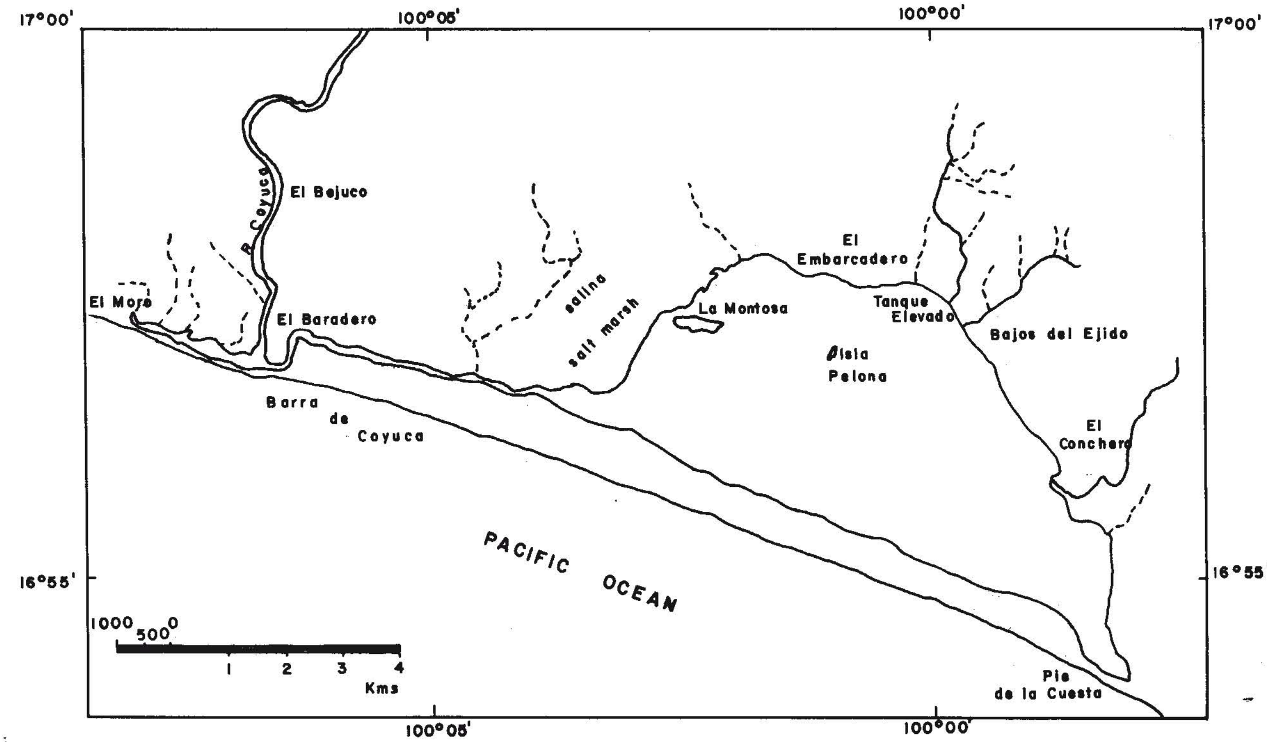


Fig. 1. Map of Coyuca de Benítez, Guerrero coastal lagoon.

In this paper, a methodology for the multi-temporal monitoring of the surface water salinity in a small oligohaline tropical coastal lagoon is presented. It includes the use of acquired "simultaneous" high resolution multispectral remote imagery and *in situ* data.

## STUDY AREA

Coyuca de Benítez Lagoon is located at Lat. N. 16° 54' and Long W. 100° 03' (DETENAL, 1981), approximately 20 km from Acapulco.

The lagoon covers an approximate area of 34 $km^2$ (Yáñez-Arancibia, 1977). The climate classification following the Köppen system modified by García (1981) is AW1(W)i, subhumid tropical with rains in summer and draftiness in winter, with canicula. The lagoon has contributions of fresh-water from the Coyuca River and the Las Cruces Rivulet and also of sea-water when the sand bar is opened (Figure 1). The vegetation around the lagoon consists of tropical forest over the flat land matrix, with associations of tule, reed-grass, mangrove, huizachal and palm trees (Guzmán, 1975; D.G.U.P., 1970).

## METHODOLOGY

During the last 10 years we have been developing and implementing the methodology described in Figure 2. The "simultaneous" sampling and acquiring of the remote imagery (MSS and TM Landsat in this case) is vital to this methodology. We use " " to note that the *in situ* data were not taken exactly at the same time, but on the same day with some difference, from a few minutes to three hours, due to equipment restrictions (one boat, one portable radiometer). The salinity measurements were obtained with the following methods: for Summer 1981, the chlorinity was measured and later the equivalent PPT were calculated. For Summer 1987 and Winter 1988-89, a portable AO Reichert Salinity Refractometer (Scale: 0-160 PPT or 0/00 or $10^{-3}$; Accuracy: 1 PPT) was used.

Due to the presence of water as the main component of the TM sub-images we were using, a simple atmospheric correction (shifting the histograms of bands 1 to 4 until 0 gray level) was applied (Schowengerdt, 1983; Sabins, 1987).

The simple and multiple linear regression models were calculated between the *in situ* and remote data. The mean values of the digital numbers (Sabins, 1987) at the training fields, $R_i$'s, their ratios $C_{ij}$'s, the principal components $PC_i$'s, their ratios $CPC_{ij}$'s and the sampling hour, $H_s$, were considered as predictor variables.

With the best single and multiple statistical regression models (linear or logarithmic), the multi-band Thematic Maps generated by the Correlations (T.M.G.C.) were processed. The resulting T.M.G.C.'s were evaluated with respect to the field data and compared with the traditional Salinity Isoline Maps. The usefulness of the multi-temporal T.M.G.C.'s required the selection of common classes and symbols for easy visual analysis of the evolution of the water body during the period of study.

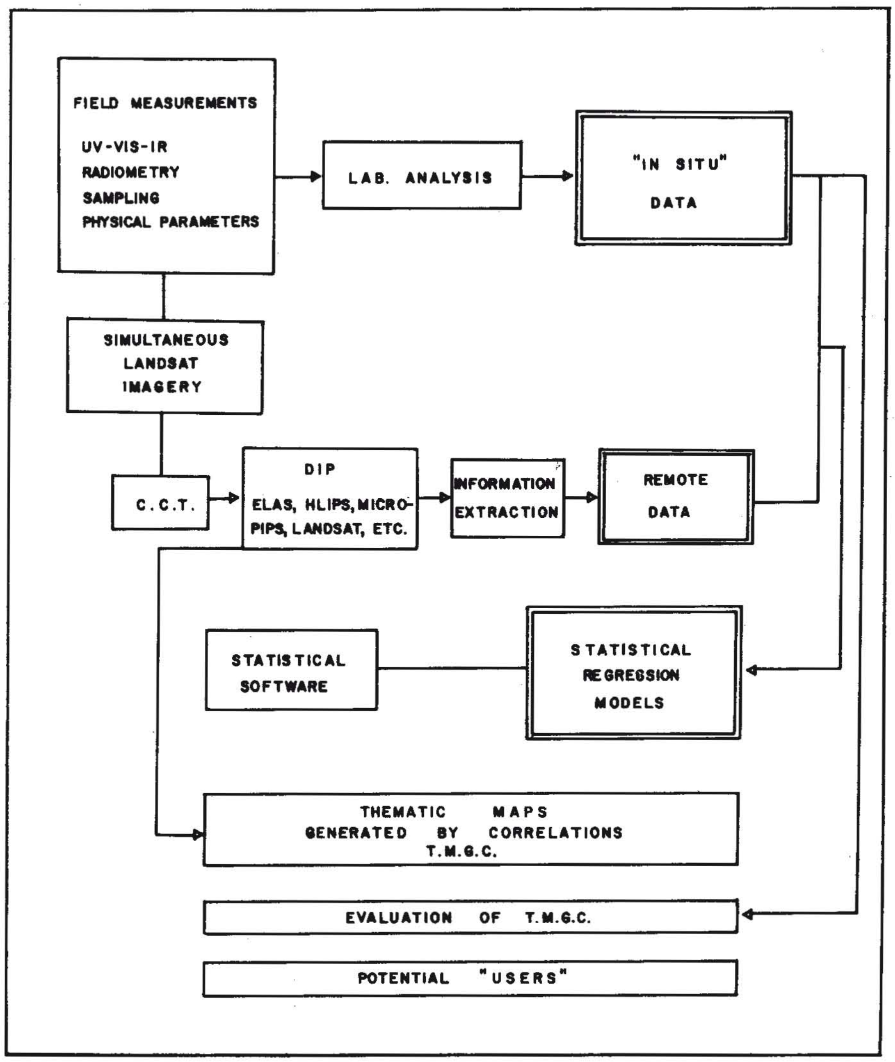


Fig. 2. Methodology.

## RESULTS

The results will be presented for the different dates: Summer 1981, Summer 1987 and Winter 1988-89.

Summer 1981:

The bar was opened at that time. Ten sample points were chosen (Figure 3). 5 points were sampled "simultaneously" with the Landsat MSS image on August 1st., 1981 (points 6 to 10). The other five (points 1 to 5) were sampled the day before. Two points were selected out of the lagoon (P5 and P10). They are in the Coyuca River with point 5 corresponding to the sand bar. Point 4 is in the mouth of the river. The effect of the open sand bar over this point will be shown later.

The correlation coefficients for the linear regression between salinity (SAL) and bands, principal components and sampling hour are shown in Table I. The highest absolute value was 0.9947 with MSS band 4. The statistical summary for multiple regression models corresponding to Summer 1981 is in Table II. The selected model is presented in Table III.

The plot of SAL predicted values vs. SAL observed values is shown in Figure 4. The fit is very good. The map of superficial SAL isolines for field data is in Figure 5. The salinity *in situ* data are shown in Figures 6a-d. For Summer 1981, the values inside the lagoon had values lower than 4 mg/l or $10^{-3}$. Point 10 with 4.86 mg/l (PPT or $10^{-3}$) and point 4, sampled at July 31st, with 5.8 PPT had larger salinity due to the effect of the open sand bar. Point 5 showed 33.6 PPT (or $10^{-3}$) at the open sand bar. The Summer 1981 SAL Thematic Map generated by the best Simple and Multiple Correlations is shown in Figure 7. It is a multi-band classified map showing two classes: SAL-34 (3<SAL<4 PPT) and SAL-56 (5<SAL<6 PPT). The analysis of this M.T.G.C. showed accuracy of 100%, not only for points 6 to 9 considered for modeling but also for points 1 to 4, not considered for modeling. Due to the resolution around 80 m. for the MSS images, it is meaningless to try to predict the values of points 5 and 10, located in the Coyuca River because it is narrower than the

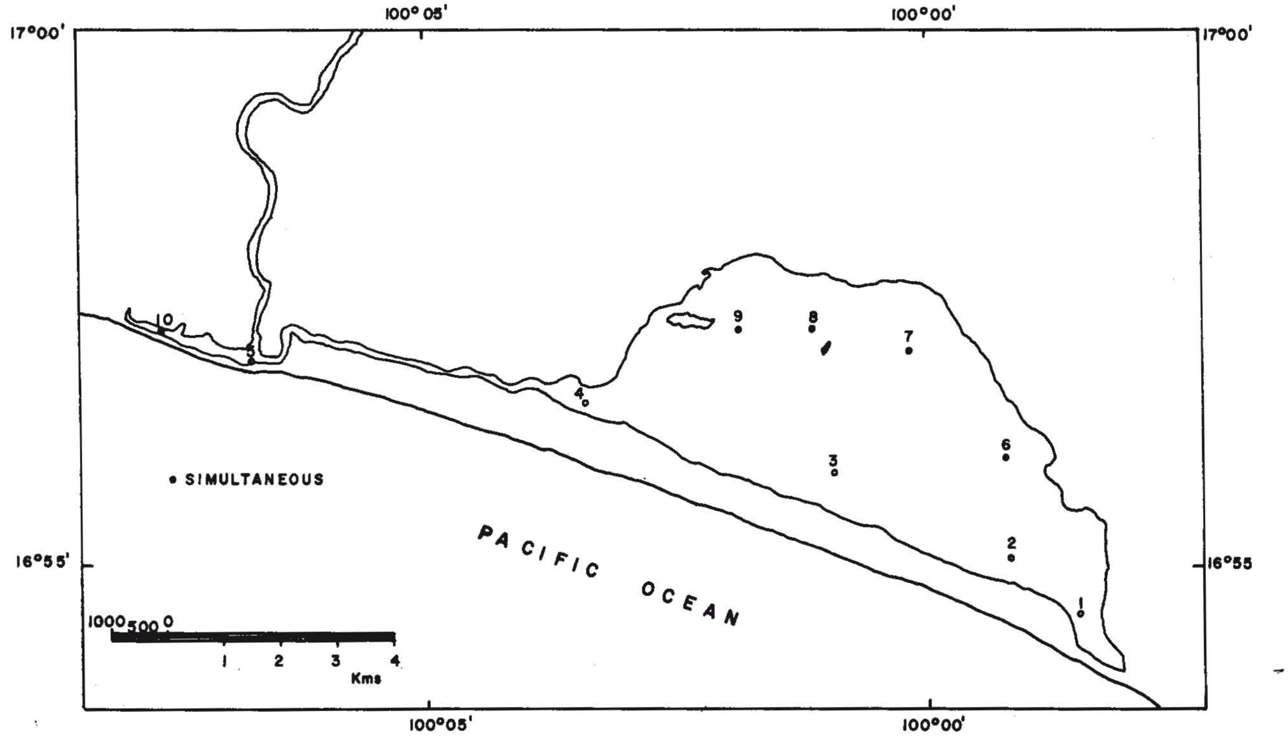


Fig. 3. Summer 1981 sample points.

TABLE I

SIMPLE LINEAR REGRESSION : SUMMER 1981

SAL VS. Hs, $R_i$'s, $C_{ij}$'s, $PC_i$'s.

| VARIABLE | R |
|---|---|
| Hs | 0.7856 |
| $R_1$ | -0.6478 |
| $R_2$ | 0.9190 |
| $R_3$ | 0.9894 |
| $R_4$ | 0.9947 |
| $C_{12}$ | -0.9878 |
| $C_{13}$ | -0.9766 |
| $C_{14}$ | -0.9144 |
| $C_{23}$ | -0.9764 |
| $C_{24}$ | -0.9162 |
| $C_{34}$ | -0.9169 |
| $PC_1$ | -0.9922 |
| $PC_2$ | 1.0000 |
| $PC_3$ | -0.5689 |
| $PC_4$ | -0.5661 |

TABLE II

STATISTICAL SUMMARY OF SAL SUMMER 1981 MULTIPLE REGRESSION MODELS

| PREDICTOR VARIABLES | $R^2$ | ADJ. $R^2$ | D.F. | F | P-VALUE | S.E.E. |
|---|---|---|---|---|---|---|
| Hs, $R_i$ | 0.99999 | 0.99997 | 3/1 | 47862.9 | 0.0033 | 0.00356 |
| Hs, $C_{ij}$ | 0.98396 | 0.96791 | 2/2 | 61.3314 | 0.0160 | 0.12078 |
| Hs, $R_i$, $C_{ij}$ | 0.99508 | 0.98031 | 3/1 | 67.3696 | 0.0881 | 0.09463 |

TABLE III

SAL SELECTED MODELS *

SUMMER 1981

$$SAL = -0.24\ (0.006)\ R_2 + 0.14\ (0.009)\ R_4 + 0.13\ (0.004)\ Hs + 4.47$$

SUMMER 1987

$$SAL = -0.93\ (0.094)\ PC_4 + 0.674\ (0.115)\ PC_6 - 0.184\ (0.023)\ Hs + 19.75$$

WINTER 1988-89

$$SAL = -75.35\ (28.06)\ C_{35} + 61.41\ (21.51)\ C_{47} + 4.47\ (4.62)\ R_1 - 0.54\ (0.31)\ R_6 - 47.84\ (47.75)\ C_{12} - 973.56\ (819.51)\ C_{26} - 95.72\ (37.59)\ C_{57} + 105.23\ (40.08)\ C_{34} + 15.21\ (15.89)\ C_{25} + 1024.62\ (833.57)\ C_{56} + 0.39\ (1.05)\ C_{67} + 85.2$$

* STANDARD ERRORS SHOWN IN PARENTHESIS.

pixel resolution. The comparison of the traditional Salinity Isolines Map in Figure 5 with the Summer 1981 SAL Thematic Map in Figure 7 shows the same zonation for the selected classes.

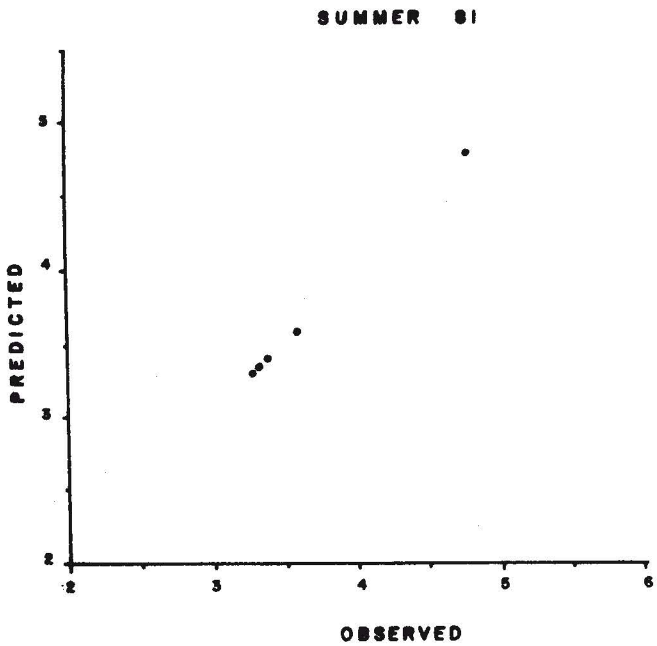


Fig. 4. SAL81 predicted values vs SAL81 observed values.

Summer 1987:

The night before the sampling day it was raining. The day of the sample started out cloudy and became clear later. The 17th of August TM image showed clouds only over one zone of the lagoon covering mainly three sample points: 1, 2 and 3. From the 15 sample points chosen (Figure 8), 10 were used for the regression model: 4, 6, 7, 8, 9, 13, 15, 16, 17 and 18. All of them were sampled "simultaneously" with the TM Landsat image acquisition on the 17th of August, 1987. With ten sample points selected, free of clouds, the simple and multiple regression models were calculated. The results are presented in Tables IV and V. The ranges of the *in situ* SAL data taken "simultaneously" with the TM image are shown in Figure 6c. The salinity values go from 3 to 4.2 PPT (or $10^{-3}$).

The correlation coefficients for the linear regression between SAL and bands, ratios, principal components and sampling hour are shown in Table IV. The highest absolute value was: 0.6935 with the fourth principal component $PC_4$. The statistical summary for multiple regression models corresponding to Summer 1987 is in Table V. The selected model is in Table III. It has high coefficient of determination, 0.96; and high significance with P-value 0.0001. The plot of SAL predicted values vs. SAL observed values is shown in Figure 9. It suggests a good concordancy. The SAL Isolines Map based on the SAL87 field data is presented in Figure 10. The SAL Summer 1987

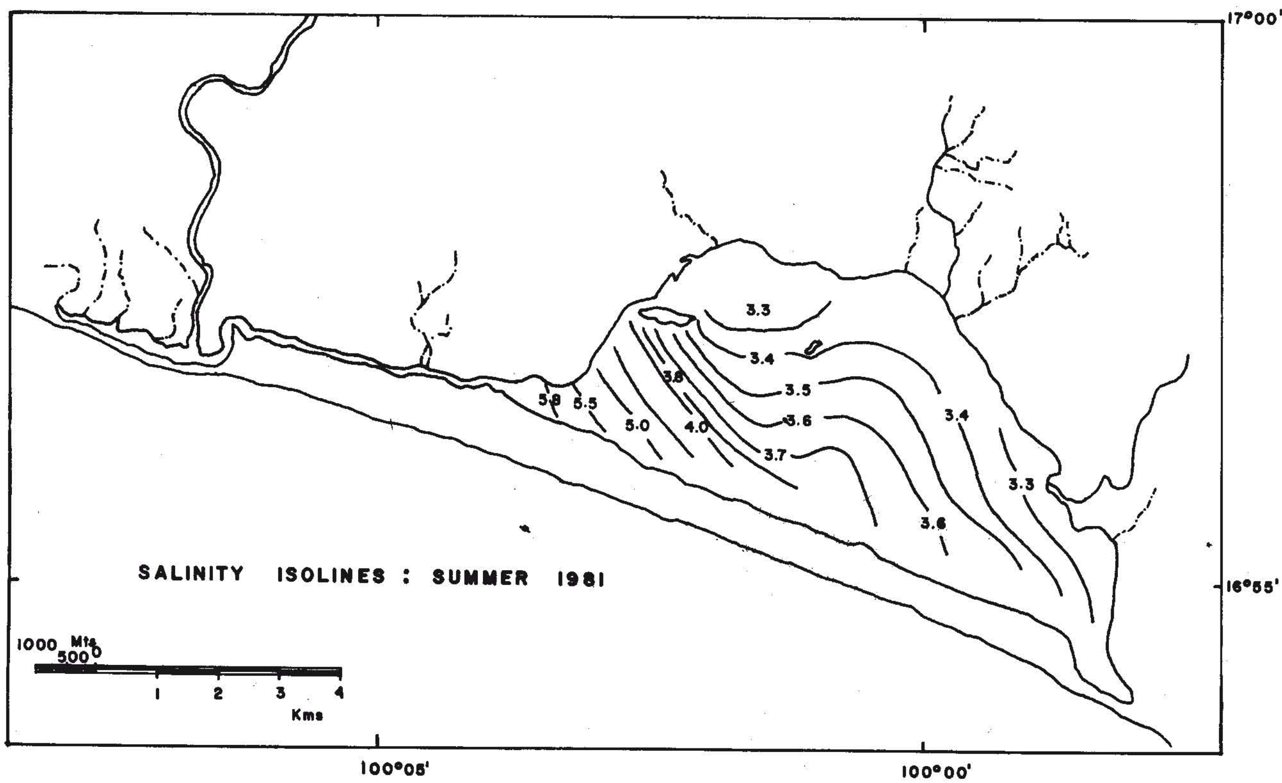


Fig. 5. Summer 1981 SAL Isolines Map.

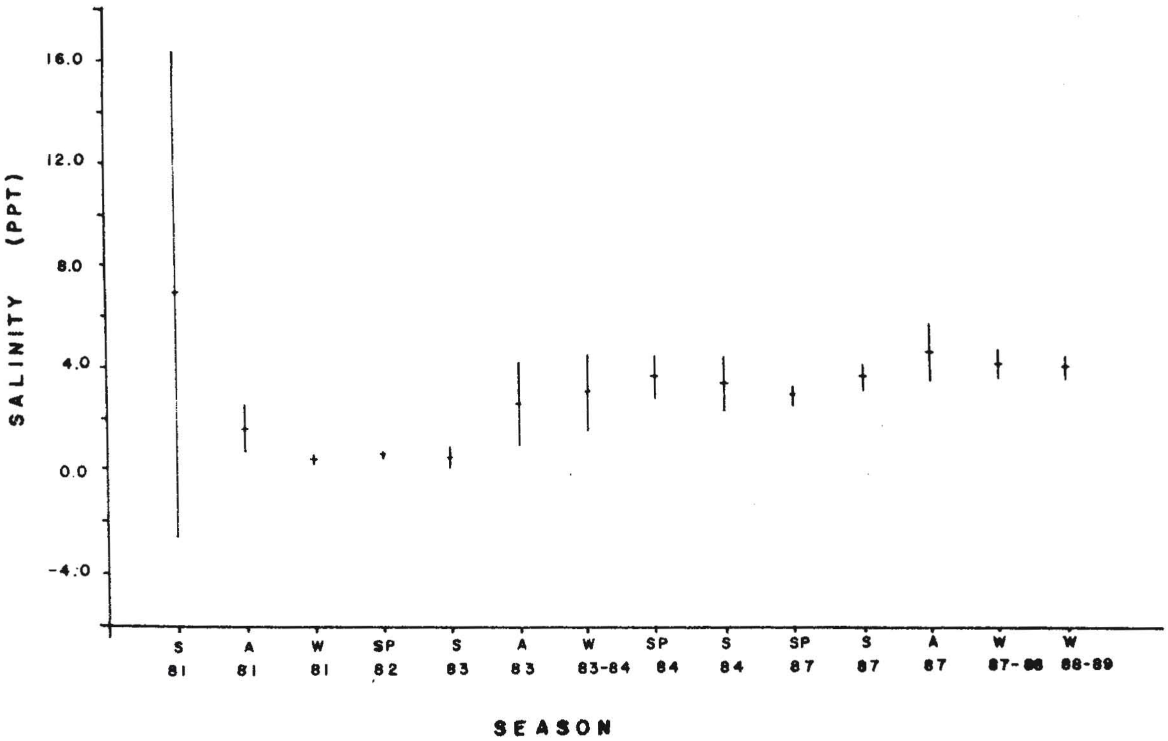


Fig. 6. Salinity *in situ* data. a) Seasonal variations of the mean salinity.

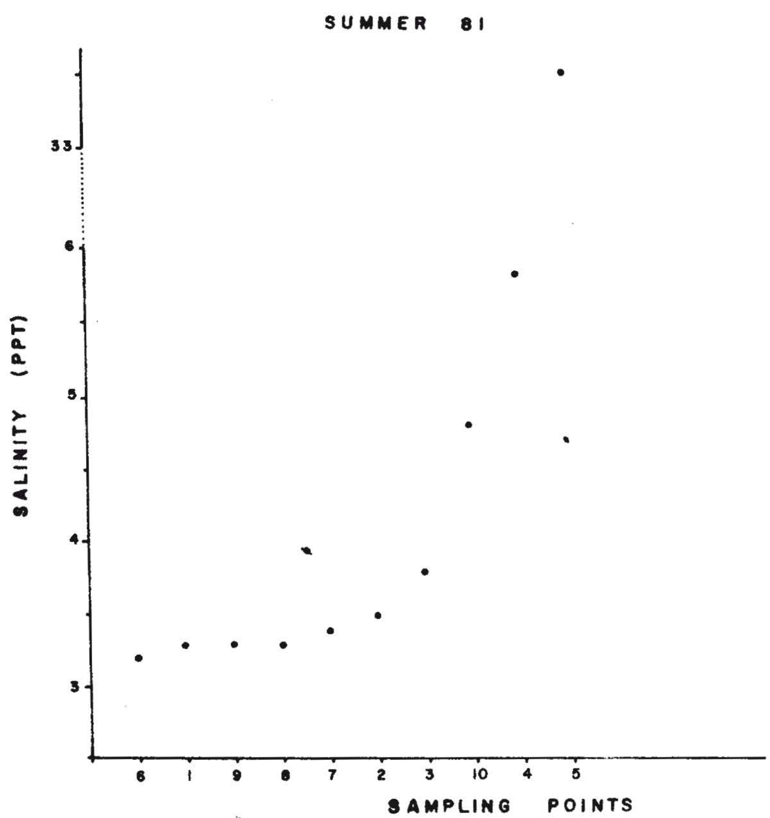


Fig. 6. Salinity *in situ* data. b) Summer 1981: SAL data.

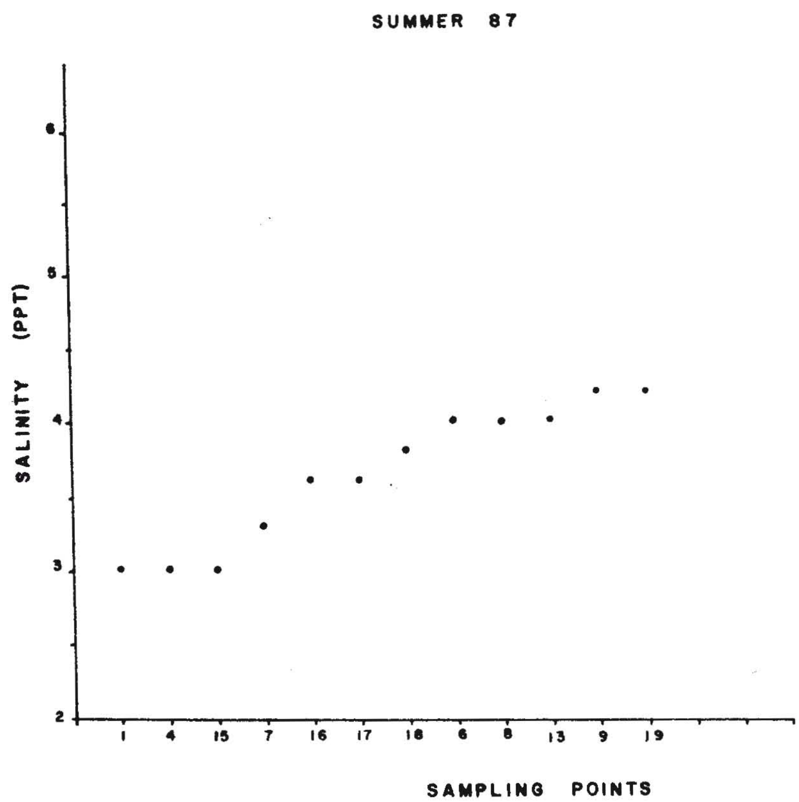


Fig. 6. Salinity *in situ* data. c) Summer 1987: SAL data.

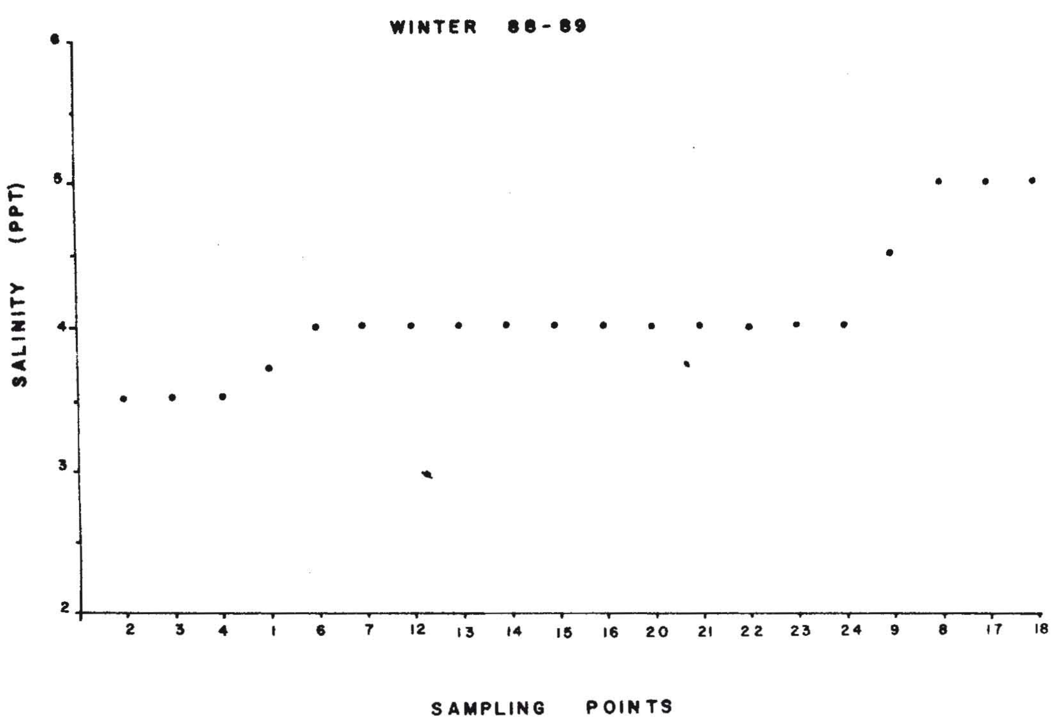


Fig. 6. Salinity *in situ* data. d) Winter 1988-89: SAL data.

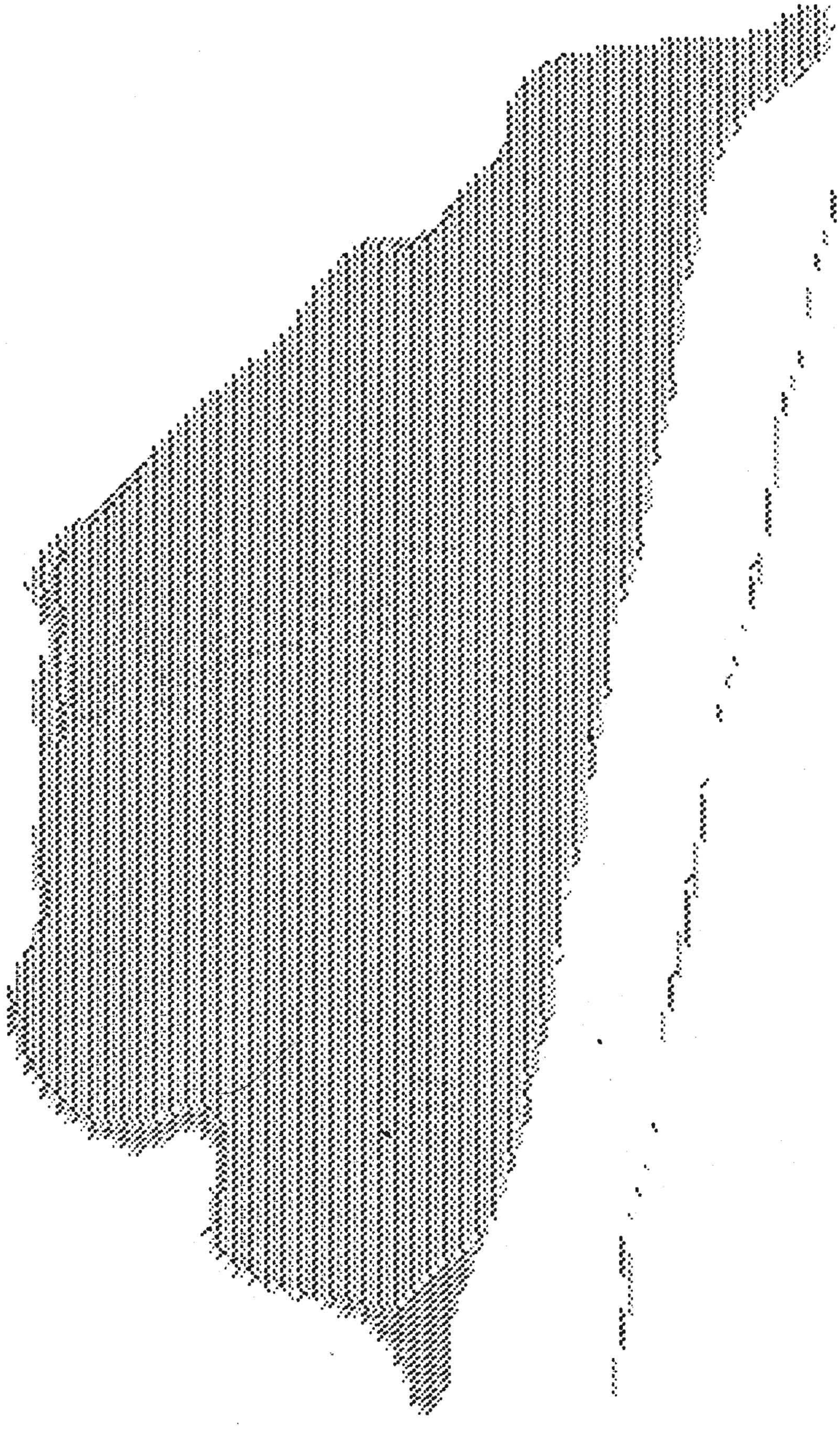

Fig. 7. Summer 1981 SAL Thematic Map (T.M.G.C.).

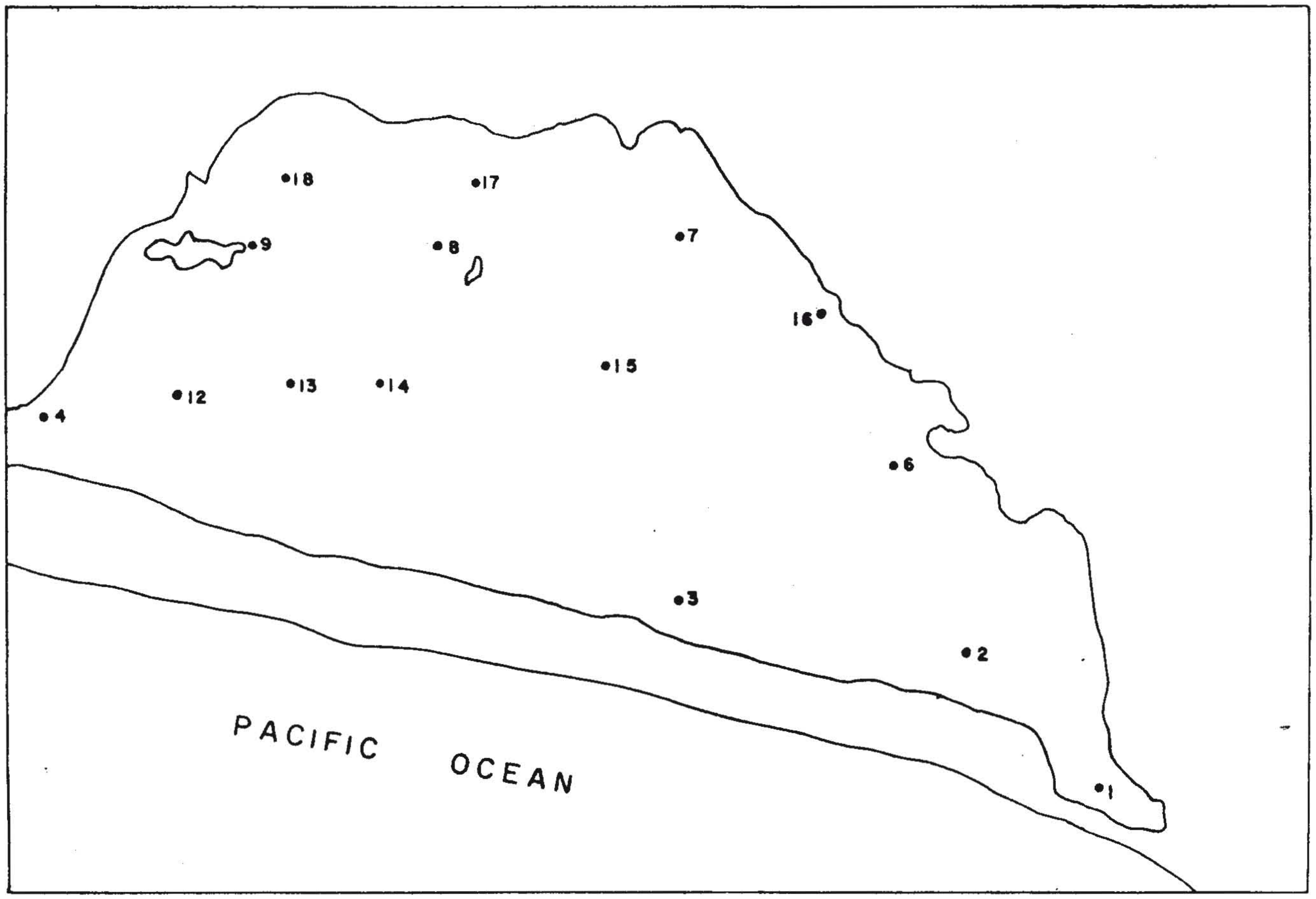


Fig. 8. Summer 1987 sample points.

TABLE IV

SIMPLE LINEAR REGRESSION : SUMMER 1987

SAL VS. Hs, $R_i$'s, $C_{ij}$'s, $PC_i$'s, $CPC_{ij}$'s.

| VARIABLE | R | VARIABLE | R |
|---|---|---|---|
| Hs | -0.2859 | | |
| $R_1$ | -0.3023 | $PC_1$ | -0.5038 |
| $R_2$ | -0.0687 | $PC_2$ | -0.0825 |
| $R_3$ | -0.2971 | $PC_3$ | 0.2319 |
| $R_4$ | -0.4012 | $PC_4$ | -0.6935 |
| $R_5$ | -0.4126 | $PC_5$ | -0.4983 |
| $R_6$ | -0.0301 | $PC_6$ | -0.4520 |
| $R_7$ | -0.0205 | $PC_7$ | -0.2994 |
| $C_{12}$ | -0.3609 | $CPC_{12}$ | -0.3593 |
| $C_{13}$ | 0.1600 | $CPC_{13}$ | -0.4771 |
| $C_{14}$ | 0.2502 | $CPC_{14}$ | 0.5046 |
| $C_{15}$ | 0.2567 | $CPC_{15}$ | -0.1928 |
| $C_{16}$ | -0.2815 | $CPC_{16}$ | 0.3709 |
| $C_{17}$ | -0.3303 | $CPC_{17}$ | 0.2089 |
| $C_{23}$ | 0.4365 | $CPC_{23}$ | -0.1766 |
| $C_{24}$ | 0.3285 | $CPC_{24}$ | 0.66[illegible]9 |
| $C_{25}$ | 0.4170 | $CPC_{25}$ | 0.3672 |
| $C_{26}$ | -0.0642 | $CPC_{26}$ | 0.3805 |
| $C_{27}$ | -0.0639 | $CPC_{27}$ | 0.2087 |
| $C_{34}$ | 0.2247 | $CPC_{34}$ | 0.6517 |
| $C_{35}$ | 0.2006 | $CPC_{35}$ | 0.4703 |
| $C_{36}$ | -0.2843 | $CPC_{36}$ | 0.3981 |
| $C_{37}$ | -0.4901 | $CPC_{37}$ | 0.2132 |
| $C_{45}$ | -0.1998 | $CPC_{45}$ | -0.5752 |
| $C_{46}$ | -0.3949 | $CPC_{46}$ | 0.2915 |
| $C_{47}$ | -0.4040 | $CPC_{47}$ | 0.1966 |
| $C_{56}$ | -0.3970 | $CPC_{56}$ | 0.3505 |
| $C_{57}$ | -0.6015 | $CPC_{57}$ | 0.2102 |
| $C_{67}$ | -0.0249 | $CPC_{67}$ | 0.2085 |

TABLE V

STATISTICAL SUMMARY OF SAL SUMMER 1987 MULTIPLE REGRESSION MODELS

| PREDICTOR VARIABLES | $R^2$ | ADJ. $R^2$ | D.F. | F | P-VALUE | S.E.E. |
|---|---|---|---|---|---|---|
| $R_i$ | 0.34155 | 0.15342 | 2/7 | 1.8155 | 0.2316 | 0.39575 |
| Hs, $R_i$ | 0.45622 | 0.18433 | 3/6 | 1.6780 | 0.2697 | 0.38846 |
| Hs, $R_i$, $C_{ij}$ | 0.36178 | 0.28201 | 1/8 | 4.5343 | 0.0658 | 0.36446 |
| Hs, $PC_i$ | 0.95935 | 0.93900 | 3/6 | 47.182 | 0.0001 | 0.10623 |
| Hs, $CPC_{ij}$ | 0.43951 | 0.36945 | 1/8 | 6.2733 | 0.0367 | 0.34154 |

Thematic Map generated by the best simple and multiple correlations is shown in Figure 11. It is a multi-band classified map showing two classes: SAL-34 (3<SAL<4 PPT) and SAL-45 (4<SAL<5 PPT). The Thematic Map showed a predominant zone with the class SAL-34 and small zones with the class SAL-45. The same general behavior is shown in the SAL Isolines Map (Figure 10). The mentioned SAL Thematic Map for Summer 1987 was obtained with bands $B_5$ and $PC_1$ showing 90% of accuracy. Points 6 and 9 showed a small shift, probably due to differences between sampling hour and time of the satellite pass over the zone, and also due to the presence of superficial currents around point 9. The Thematic Map calculated with the best multiple regression model showed also the same accuracy but with stripping due to the noise in the original TM principal components, $CP_4$ and $CP_6$.

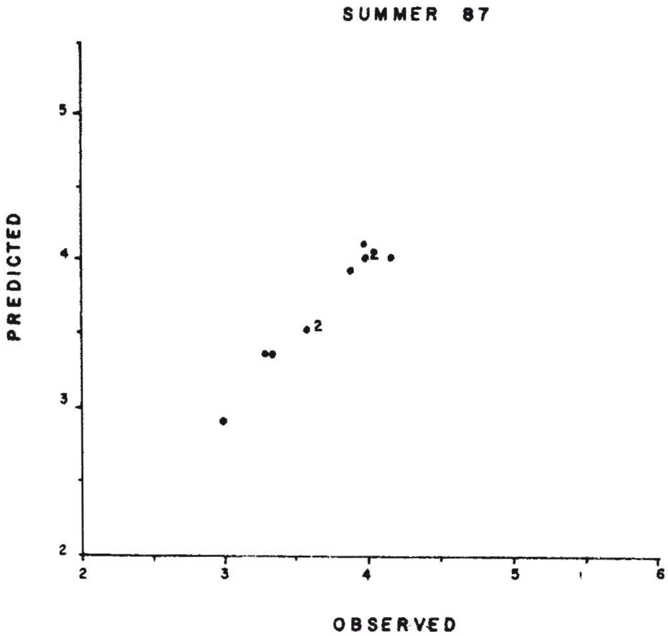


Fig. 9. SAL87 predicted values vs. SAL87 observed values.

Winter 1988-89:

On the 18th of January, 1989 a cloud-free TM image for the zone of the lagoon was acquired. The radiometric equipment and the general methodology was improved reducing sampling time and 20 points were sampled "simultaneously" with the Landsat satellite passing over the Coyuca de Benítez lagoon in Guerrero. The sampling points are marked in Figure 12. The salinity values measured *in situ* are shown in Figure 6d. The correlation coefficients of the simple linear regression for the SAL88-89 set of points with sampling hour, bands, principal components and the corresponding ratios are shown in Table VI. The highest absolute value was 0.5492 with $C_{47}$. The statistical summary for multiple regression models corresponding to salinity for Winter 1988-89 is in Table VII. The selected model is presented in Table III. The determination coefficient is 0.75, and the D.F. is 11/8. The P-value is 0.1435. All the correlations were lower than those obtained for Summer's. The plot of SAL88-89 predicted values vs. SAL88-89 observed values is shown in Figure 13. The points show some dispersion. The SAL88-89 Isolines Map based on the field data is presented in Figure 14. It showed a salinity gradient increasing from the outer shoreline to the inner shoreline. The SAL Winter 1988-89 Thematic Map generated by the best simple and multiple correlations is shown in Figure 15. It is a multi-band classified map showing three classes: SAL-34 (3<SAL<4 PPT), SAL-45 (4<SAL<5 PPT) and SAL-56 (SAL ≥ 5 PPT). The general tendency with a salinity gradient increasing from the outer shoreline to the inner shoreline showed by the SAL88-89 Isolines Map is also in the T.M.

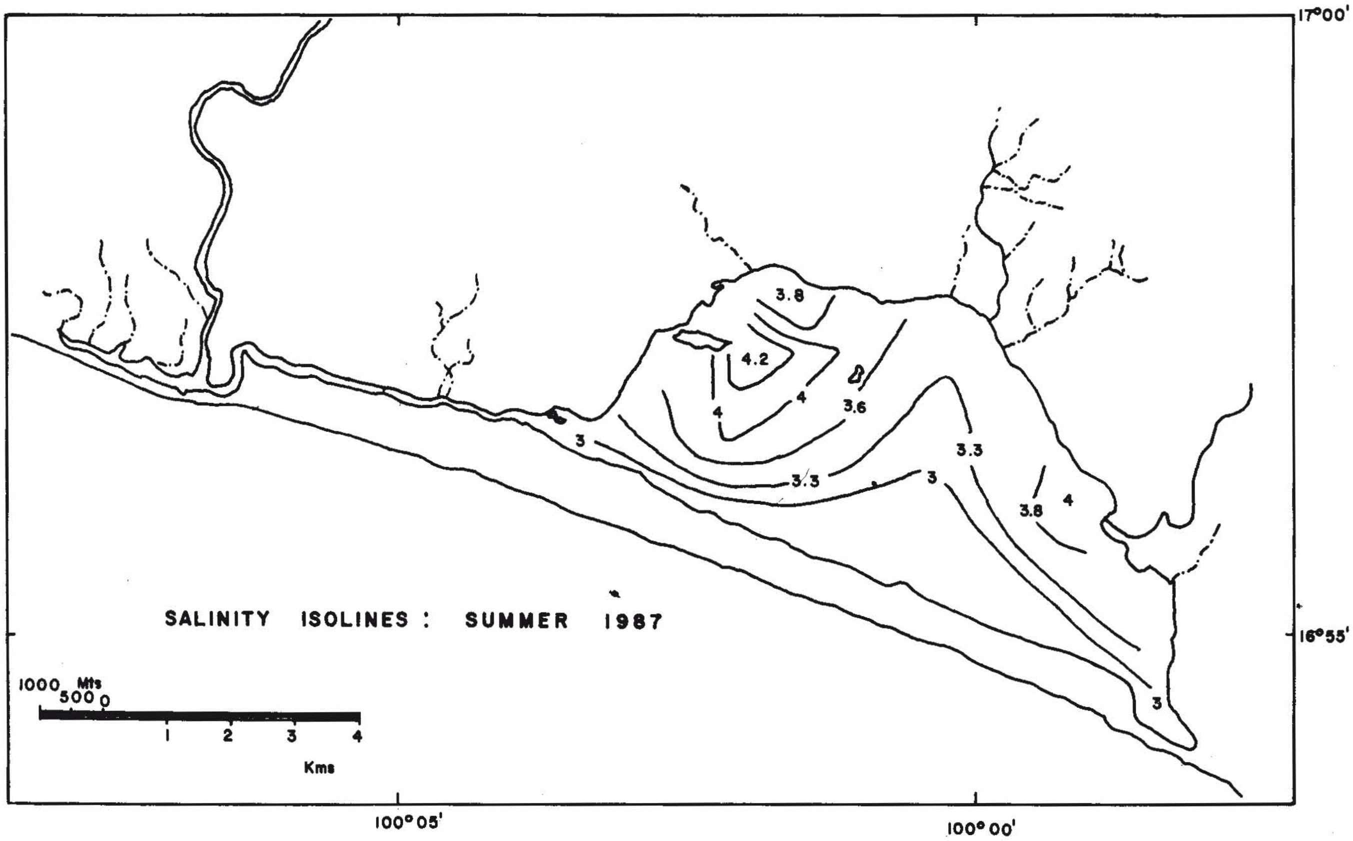


Fig. 10. Summer 1987 SAL Isolines Map.

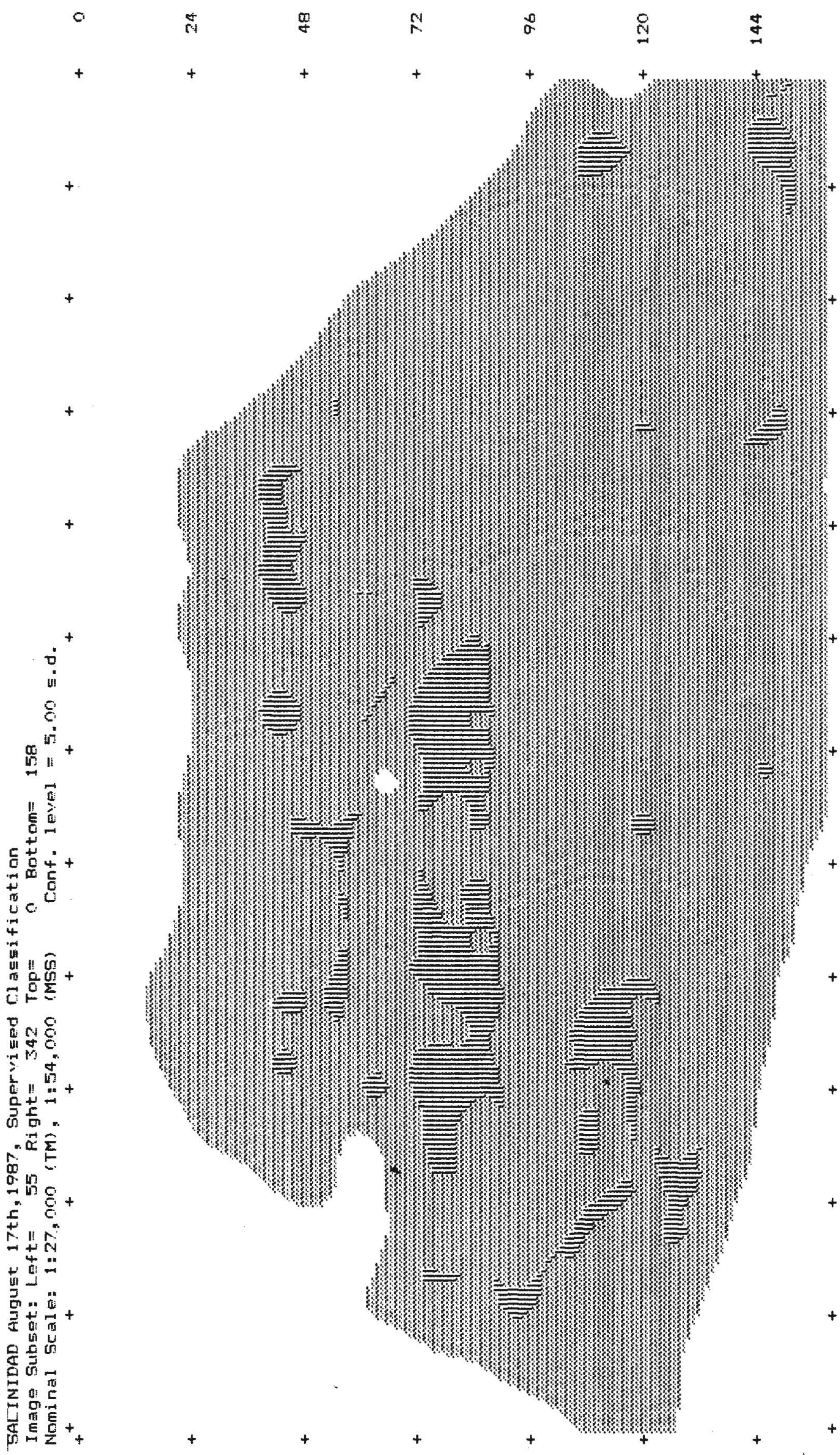


Fig. 11. Summer 1987 SAL Thematic Map (T.M.G.C.)

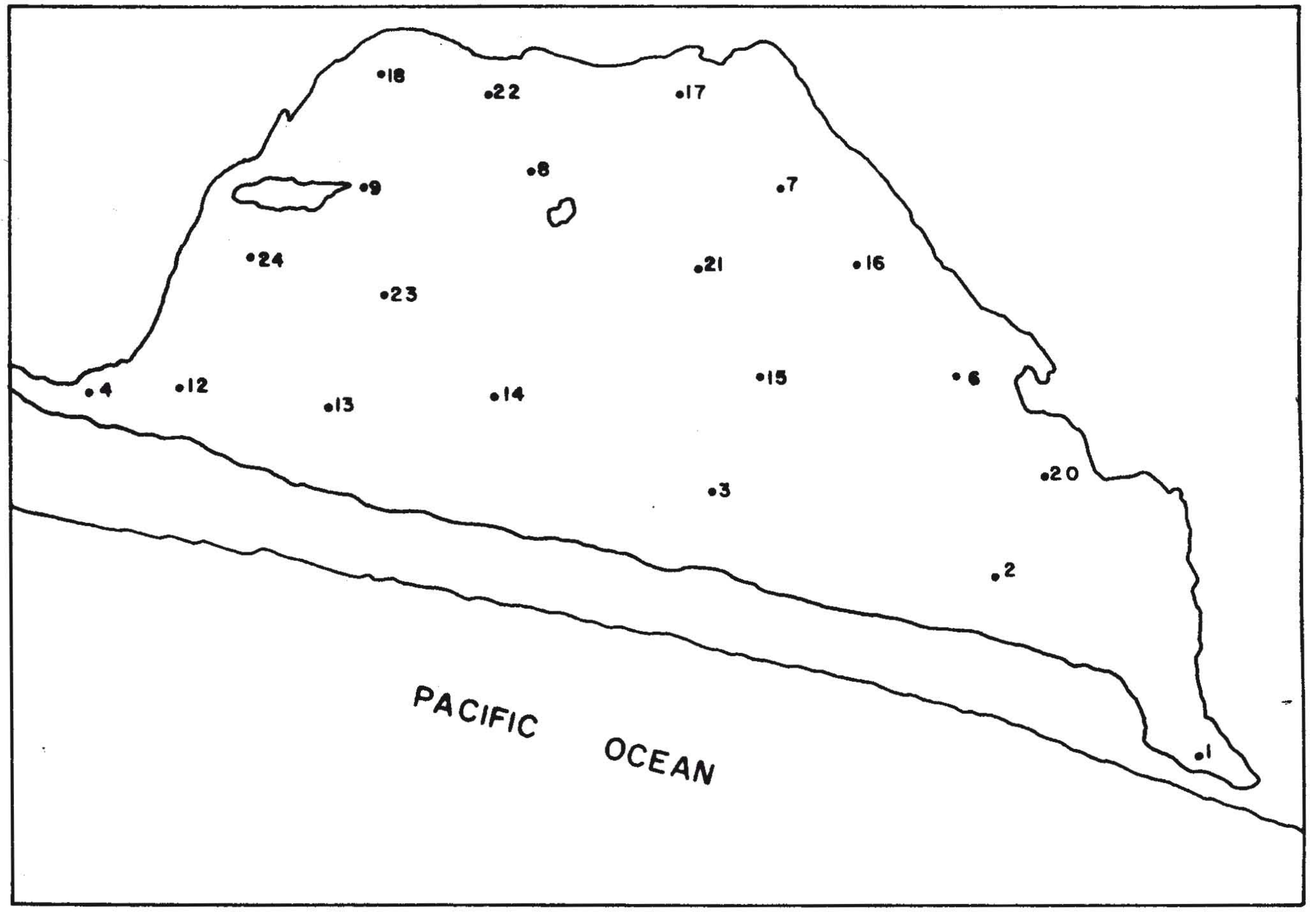


Fig. 12. Winter 1988-89 sample points.

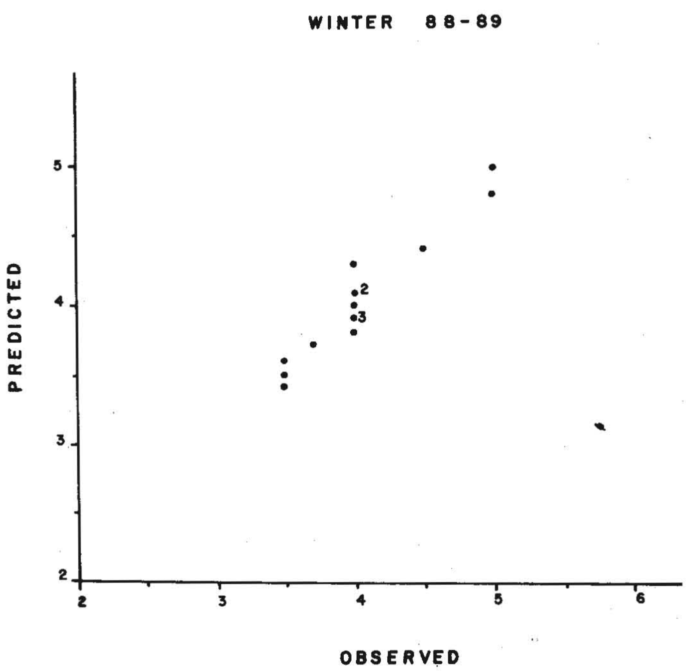


Fig. 13. SAL88-89 predicted values vs. SAL88-89 observed values.

G.C. obtained for Winter 1988-89. However, the SAL88-89 Thematic Map overestimated the southeast zone around point 2. The accuracy of the Winter 1988-89 SAL Thematic Map is approximately 80%. Points 3, 12 and 24 are slightly shifted. Points 12 and 24 are in the zone with superficial currents and point 3 was one of the last sampled, having larger difference between sampling hour and the time when the Landsat satellite overflew the lagoon.

## CONCLUSIONS

In this paper a general methodology for monitoring the superficial water quality in a small coastal lagoon is applied to the parameter salinity with low values of concentration. The results are encouraging due to the high percentage of accuracy. However, the implementation of this kind of studies with "simultaneous" sampling as well as acquisition of the Landsat imagery is difficult. The following points must be considered:

1. Due to the dynamics of the tropical coastal lagoons, the simultaneity of *in situ* and remote data is considered indispensable.

2. The selection of sample points for modeling is also

TABLE VI

SIMPLE LINEAR REGRESSION : WINTER 1988 - 89

SAL VS. Hs, $R_i$'s, $C_{ij}$'s, $PC_i$'s, $CPC_{ij}$'s.

| VARIABLE | R | VARIABLE | R |
|---|---|---|---|
| Hs | -0.2288 | | |
| $R_1$ | 0.2330 | $PC_1$ | 0.2811 |
| $R_2$ | 0.3928 | $PC_2$ | -0.2438 |
| $R_3$ | 0.2903 | $PC_3$ | -0.2199 |
| $R_4$ | 0.2671 | $PC_4$ | 0.2761 |
| $R_5$ | -0.2099 | $PC_5$ | -0.2187 |
| $R_6$ | 0.1242 | $PC_6$ | 0.0375 |
| $R_7$ | -0.3223 | $PC_7$ | 0.0088 |
| $C_{12}$ | -0.1728 | $CPC_{12}$ | 0.3046 |
| $C_{13}$ | 0.0274 | $CPC_{13}$ | 0.2911 |
| $C_{14}$ | 0.0233 | $CPC_{14}$ | 0.0887 |
| $C_{15}$ | 0.3909 | $CPC_{15}$ | 0.2955 |
| $C_{16}$ | 0.2133 | $CPC_{16}$ | -0.0170 |
| $C_{17}$ | 0.3960 | $CPC_{17}$ | 0.0348 |
| $C_{23}$ | 0.3056 | $CPC_{23}$ | -0.1907 |
| $C_{24}$ | 0.2140 | $CPC_{24}$ | -0.3834 |
| $C_{25}$ | 0.4916 | $CPC_{25}$ | -0.0195 |
| $C_{26}$ | 0.3846 | $CPC_{26}$ | -0.1337 |
| $C_{27}$ | 0.5121 | $CPC_{27}$ | 0.0097 |
| $C_{34}$ | -0.0153 | $CPC_{34}$ | -0.4945 |
| $C_{35}$ | 0.5306 | $CPC_{35}$ | 0.0745 |
| $C_{36}$ | 0.2665 | $CPC_{36}$ | -0.1008 |
| $C_{37}$ | 0.5336 | $CPC_{37}$ | 0.0168 |
| $C_{45}$ | 0.5087 | $CPC_{45}$ | 0.2729 |
| $C_{46}$ | 0.2479 | $CPC_{46}$ | -0.0359 |
| $C_{47}$ | 0.5492 | $CPC_{47}$ | 0.0308 |
| $C_{56}$ | -0.2164 | $CPC_{56}$ | -0.1288 |
| $C_{57}$ | 0.1700 | $CPC_{57}$ | 0.0148 |
| $C_{67}$ | 0.3093 | $CPC_{67}$ | 0.0281 |

TABLE VII

STATISTICAL SUMMARY OF SAL WINTER 1988-89 MULTIPLE REGRESSION MODELS

| PREDICTOR VARIABLES | $R^2$ | ADJ. $R^2$ | D.F. | F | P-VALUE | S.E.E. |
|---|---|---|---|---|---|---|
| $R_i$ | 0.28809 | 0.15461 | 3/16 | 2.1583 | 0.1329 | 0.41707 |
| Hs, $R_i$ | 0.39904 | 0.23878 | 4/15 | 2.4900 | 0.0876 | 0.39576 |
| $C_{ij}$ | 0.30168 | 0.26288 | 1/18 | 7.7761 | 0.0121 | 0.38944 |
| Hs, $C_{ij}$ | 0.44595 | 0.38076 | 2/17 | 6.8414 | 0.0066 | 0.35695 |
| $R_i$, $C_{ij}$ | 0.74717 | 0.39954 | 11/8 | 2.1493 | 0.1435 | 0.35150 |
| $PC_i$ | 0.19083 | 0.03911 | 3/16 | 1.2578 | 0.3222 | 0.44465 |
| Hs, $PC_i$ | 0.28031 | 0.08839 | 4/15 | 1.4606 | 0.2632 | 0.43309 |
| $CPC_{ij}$ | 0.24456 | 0.20259 | 1/18 | 5.8272 | 0.0267 | 0.40506 |
| Hs, $CPC_{ij}$ | 0.33630 | 0.25822 | 2/17 | 4.3071 | 0.0307 | 0.39067 |

very important, not only the number, but also the position must be considered carefully.

3. The multi-band classification by using the maximum probable likelihood algorithm) with the best simple and multiple regression models has been very functional, increasing the accuracy of the isolated classified models considered in a previous study (Ruiz-Azuara *et al.*, 1989). In the aforementioned paper, the classified Thematic Maps were representative of the mean values. In the present paper both the general zonation and a high percentage of accuracy for prediction of the training fields were obtained.

4. In the case presented, both MSS and TM Landsat images were very useful with high levels of accuracy with respect to the *in situ* data.

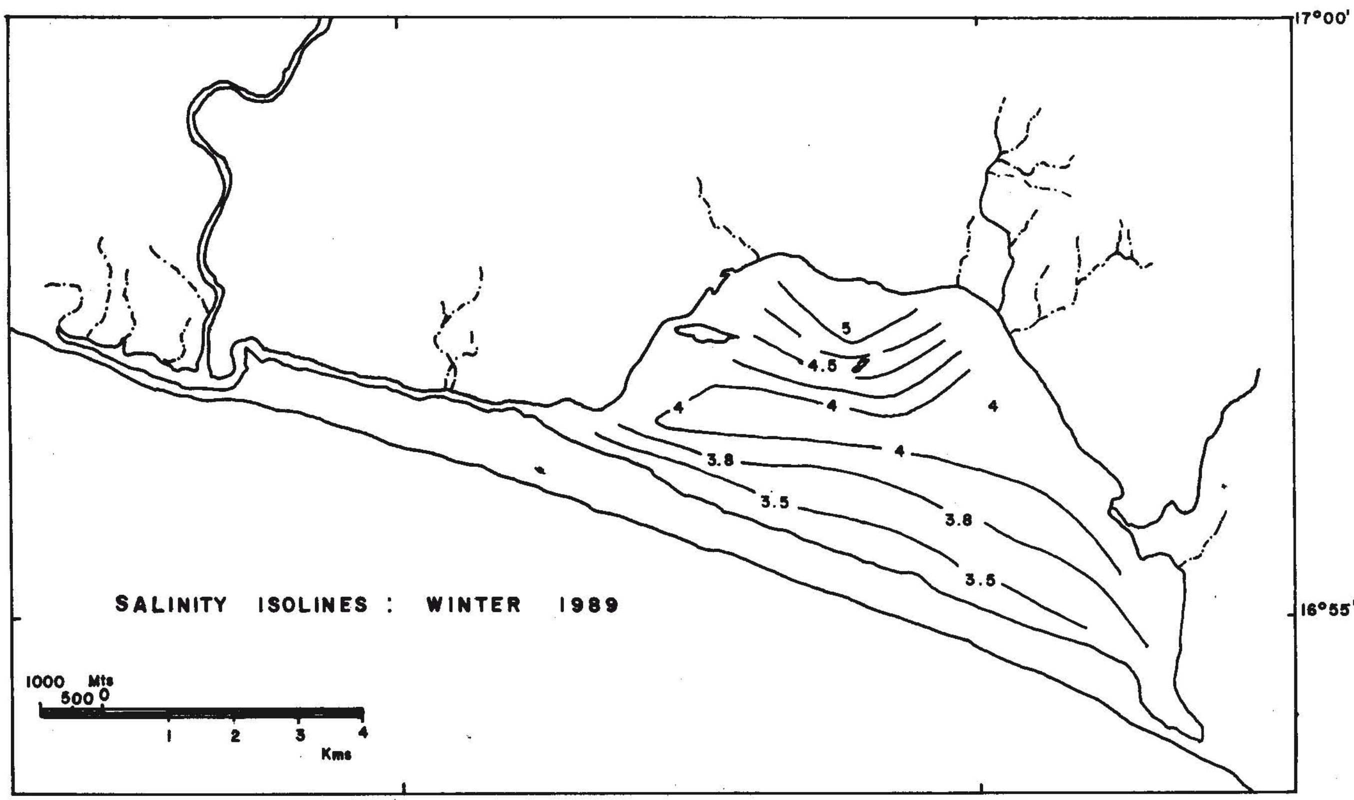


Fig. 14. Winter 1988-89 SAL Isolines Map.

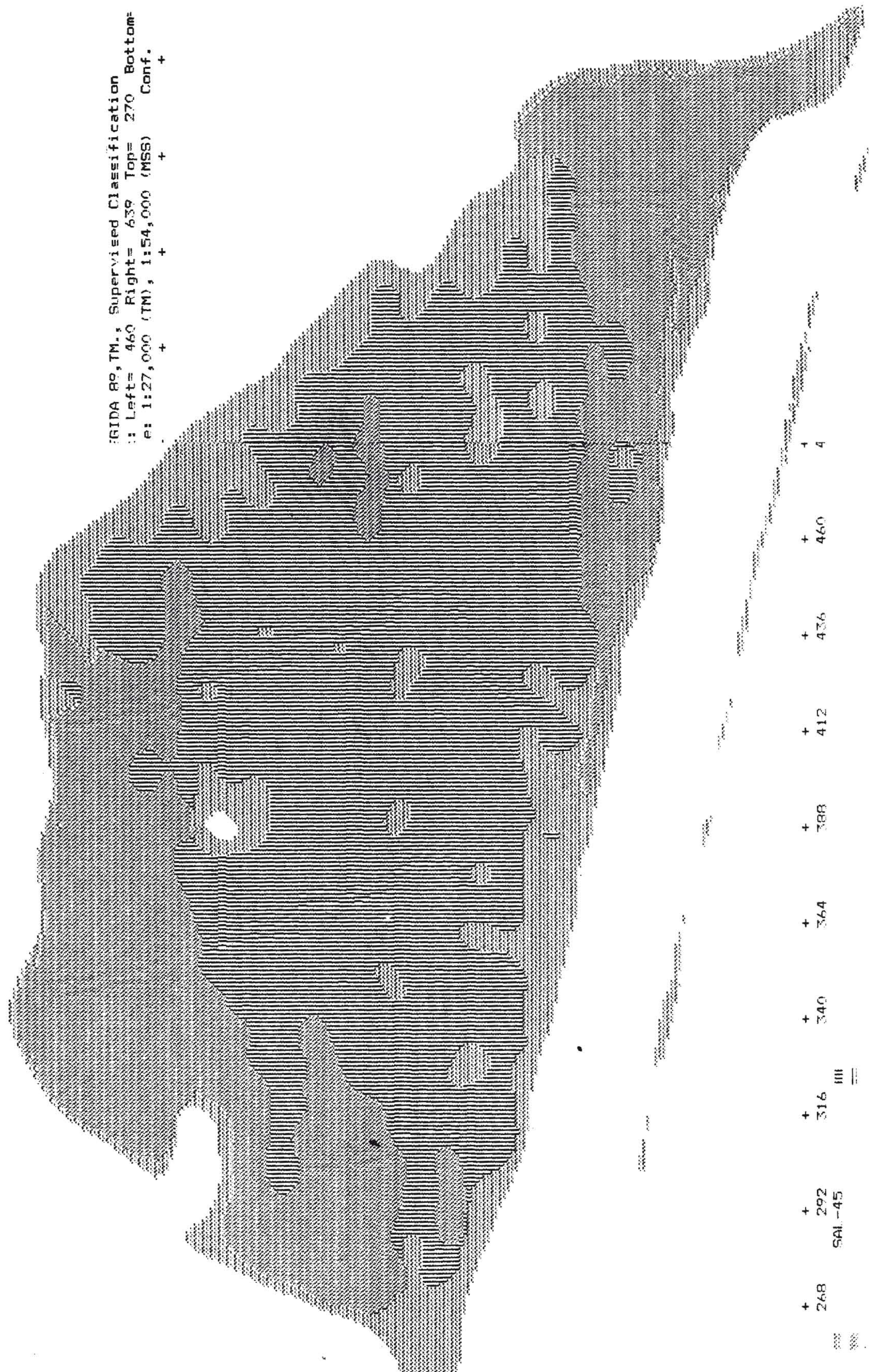


Fig. 15. Winter 1988-89 SAL Thematic Map (T.M.G.C.).

5. In the brackish Coyuca de Benítez Lagoon, the application of the general proposed methodology to the salinity parameter with low values of concentration gave good results.

6. The advantages and the inherent difficulties of the proposed methodology for monitoring salinity in an oligohaline water body (or any other hydrobiological parameter) should be evaluated for each particular case before being applied in any other water body.

7. In general, the main difficulty consists in the "simultaneity" of the *in situ* and remote data.

8. The great advantage of the proposed methodology is the flexibility with respect to the selection of the different classes. Once you have the selected simple and multiple statistical models, you can chose the appropriate bands and the corresponding training fields. The range of the classes depends on the particular interest of each research.

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