MONITORING WATER QUALITY IN A SMALL MEXICAN COASTAL LAGOON WITH "SIMULTANEOUS" LANDSAT IMAGERY: MULTI-TEMPORAL APPROACH.

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ABSTRACT:

The Water Quality in the Coyuca de Benitez coastal lagoon was studied from 1981 to 1989. Surface water hydrobiological parameters Thematic Maps generated by the best simple and multiple correlations between "simultaneous" in situ and Landsat (MSS & TM) data, having accuracies higher then 80% for the main Water Quality parameters, were obtained. Three dates were reported: Summer'81, Summer'87 and Winter'88-89.

Key Words: Water Quality, Coastal Lagoon, Tropical, Mexican, Remote Sensing, Landsat data, Thematic Maps.

I. INTRODUCTION.

The Water Quality 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, Pérez et al., 1989 and Ruiz-Azuara & Pérez, 1992. Several hydrobiological parameters were analyzed: net primary production, chlorophyll-a, Secchi disk depth, pH, water temperature, total suspended solids, zooplankton, phytoplankton, salinity, nutriments, 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. In this paper, the results obtained with MSS & TM Landsat data (acquired "simultaneously" to the in situ data) were considered. 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, Ruiz-Azuara & Pérez, 1992). The Thematic Maps Generated by Correlations (T.M.G.C.), were calculated following different criteria. The kind of information that we can obtain from the corresponding products varies. The most elaborate Thematic Maps, called, Multiband T.M.G.C.'s, showed accuracies higher than 80% for the main Water Quality parameters studied. The multi-temporal approach is illustrated for three dates: Summer 1981, Summer 1987 and Winter 1988-89.

In this paper, the general aspects of the multi-temporal approach are presented. The role of the Multiband T.M.G.C.'s is discussed.

II. STUDY AREA.

Coyuca de Benítez Lagoon is located between: 16° 54' and 16° 58' Lat. N.; 99° 57' and 100° 03' Long. W. (CETENAL, 1981).

The lagoon covers an approximate area of 34 km² (Yañez-Arancibia, 1978). The climate classification following Köppen system modified by García (1988) is AW"(W)i, subhumid tropical with rains in summer and draftiness in winter. 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, 1976; D.G.U.P., 1970).

III. METHODOLOGY.

During the last 11 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 proposed methodology includes acquisition of the UV-VIS-IR radiometric measurements. These field data are simultaneous to the sampling. The detailed analysis of these results will be reported in a separate paper. It considers the qualitative analysis of the reflectance and normalized emergent radiation (i.e., fraction of the incident radiation merging in the vertical direction) curves within the range 0.3 to 0.9 μm. Manipulating the last curves, a simulation of the characteristic response of different water qualities observed from different satellite sensors, with bands in this range, can be done. It becomes very useful when the Private Company contracted do not acquire the "simultaneous" prepaid satellite image. That happened to us in two occasions.

Due to the presence of water as a 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 Jr., 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 Jr., 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 and logarithmic), the Multiband 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 Isoline Maps.

When "simultaneous" remote and in situ data were acquired, the same procedure was applied.. For each date, a collection of T.M.G.C.'s was obtained. One T.M.G.C. for each Water Quality parameter measured.

The multi-temporal approach considers all the T.M.G.C.'s for the same hydrobiological parameter. The usefulness of the multi-temporal T.M.G.C.'s required the selection of common classes and symbols for easy visual analysis. The T.M.G.C.'s processed under these conditions can be used to follow the changes of the water body occurred during the period of study (with respect to the particular hydrobiological parameter studied).

In our case, we have "simultaneous" remote and in situ data for three dates: Summer 1981, Summer 1987 and Winter 1988-89.

As we mentioned before, more than 10 variables were evaluated in each temporal experience. Then, more than 30 T.M.G.C.'s were obtained. Besides that, for each date, the in situ data, the corresponding Isoline Maps and the Simple and Multiple regression models were calculated. The specific results for the different variables are being reported separately. In this case, as an example, the variable salinity, recently published (Ruiz-Azuara & Pérez, 1992), was chosen.

In this paper, the former results are used to show the contribution of the simple and multiple linear regression models to the Multiband T.M.G.C.'s. There is another aspect that is included also. The visual quality of the final product depends of the image processing used.

The different criteria used for T.M.G.C.'s are:

1. Analysis of Unclassified T.M.G.C. obtained for the best multiple regression model.

2. Analysis of Classified T.M.G.C. obtained for the best multiple regression model.

3. Analysis of Filtered Classified T.M.G.C. obtained for the best simple and multiple regression models (Multiband T.M.G.C.).

IV. RESULTS.

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

IV.1 Sampling Points

The Figure 3 shows the considered sampling points for Summer 1981 (Figure 3a), Summer 1987 (Figure 3b) and Winter 1988-89 (Figure 3c).

Summer 1981:

The bar was opened at that time. ten sample points were chosen (Figure 3a). 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.

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, 3 (Figure 3b). From the 15 sample points chosen (in the Figure 3b), 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.

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 acquisition of the TM Landsat image. The sampling points are marked in Figure 3c.

From 1981 to 1989, the number of sampling points increased as well as the number of Water Quality studied. From 1987 only points inside the lagoon were considered.

IV.2 Field Measurements and Regression Models.

The values of the field measurements (Salinity in this case) and its comparison with the predictions of the selected regression models (Ruiz-Azuara & Pérez, 1992) are shown in the Figure 4. The three dates were included. The in situ data were ordered from the lowest to the largest value. The number of the sampling point is written in the horizontal axis.

Summer 1981:

The salinity inside the lagoon had values lower than 4 mg/l or 10^{-3} (Figure 4a). 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 at the open sand bar.

The selected multiple regression model (Ruiz-Azuara & Pérez, 1992), including MSS bands 2 and 4, predicted very well the observed values (Figure 4b). It has $R^2 = 0.99$ and P-value 0.003.

Summer 1987:

The ranges of the in situ SAL data taken "simultaneously" with the TM image are shown in Figure 4c. The salinity values go from 3 to 4.2 PPT.

The selected multiple regression model (Ruiz-Azuara & Pérez, 1992), including principal components 4 and 6 has $R^2 = 0.96$ with P-value 0.0001. The plot of SAL predicted values vs. SAL observed values is shown in Figure 4d. It suggests a good concordancy.

Winter 1988-89:

The salinity values measured in situ for this date

are shown in Figure 4e. Three levels are suggested: 3.5, >4 and 5 PPT.

The selected multiple regression model (Ruiz-Azaura & Pérez, 1992), contains bands and ratios, with $R^2 = 0.75$, P-value= 0.1435 and D.F.= 11/8. All the correlations were lower than those obtained for Summer's. The plot of SAL predicted values vs. SAL observed values is shown in Figure 4f. It shows good tendency but some dispersion of the points.

IV.3 Isoline and Thematic Maps.

The salinity numerical values were statistically modeled in section IV.3, showing good concordancy. In this section, its spatial distribution is considered.

The **in situ** data were used to draw the Salinity Isoline Maps (Figure 5).

The Thematic Maps Generated by Correlations were obtained for the three dates: Summer 1981, Summer 1987 and Winter 1988-89 (Figure 6).

Summer 1981:

The Summer 1981 SAL T.M.G.C. is a multi-band classified map (Figure 6a) 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 pixel resolution. The comparison of the traditional Salinity Isolines Map (Figure 5a) with the Summer 1981 SAL T.M.G.C. (Figure 6a) shows the same zonation for the selected classes. The Unclassified T.M.G.C. showed the difference between the open sand bar and the lagoon. The Monoband Classified T.M.G.C.(Ruiz-Azara et al., 1989) represented the salinity mean value. The Multiband T.M.G.C. gave the best results.

Summer 1987:

The SAL Summer 1987 Multiband T.M.G.C. is shown in Figure 6b. It is a filtered 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 for Summer 1987 (Figure 5b). The mentioned SAL T.M.G.C. for Summer 1987 was obtained with bands B5 and PC1 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 T.M.G.C. 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, CP4 and CP6.

Winter 1988-89:

The SAL88-89 Isolines Map (Figure 5c) showed a salinity gradient increasing from the outer shoreline to the inner shoreline. The SAL Winter 1988-89 T.M.G.C. (Figure 6c) is a multiband 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 from the outer shoreline to the inner shoreline showed by the SAL88-89 Isolines Map is also in the T.M.G.C. obtained for Winter 1988-89. However, the SAL88-89 T.M.G.C. overestimated the southeast zone around point 2. The accuracy of the Winter 1988-89 SAL T.M.G.C. 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.

V. CONCLUSIONS.

In this paper the general methodology proposed for monitoring the superficial water quality in a small lagoon was illustrated with the parameter salinity. It is an interesting example because the Coyuca de Benítez Lagoon is oligohaline. The salinity was lower than 5 PPT when the sand bar was closed. The results are encouraging due to the high percentage of accuracy predicting the salinity values at the sampled points. However, the implementation of this kind of studies with "simultaneous" sampling as well as acquisition of the Landsat imagery is very 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 very important, not only the number, but also the position must be considered carefully.

3. The Multiband 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-Azaura et al., 1989). In the aforementioned paper, the Monoband Classified Thematic Maps were representative of the mean values. In the present example, both the general zonation and a high percentage of accuracy for prediction of the training fields were obtained.

4. The advantages and the inherent difficulties of the proposed methodology for monitoring Water Quality should be evaluated for each particular case before being applied in any other water body.

5. In general, the main difficulty consists in the "simultaneity" of the **in situ** and remote data. As a users of the satellite imagery we must have warranties from the contracted Company. The field work is very expensive and should be done again if the contracted image was not acquired. That situation increases the cost of the project in a out of control proportion. We are not including here the presence of clouds but the capacity of the Company for transmit the image from the Satellite to the Ground Station.

VI. ACKNOWLEDGMENTS.

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VII. FIGURES.
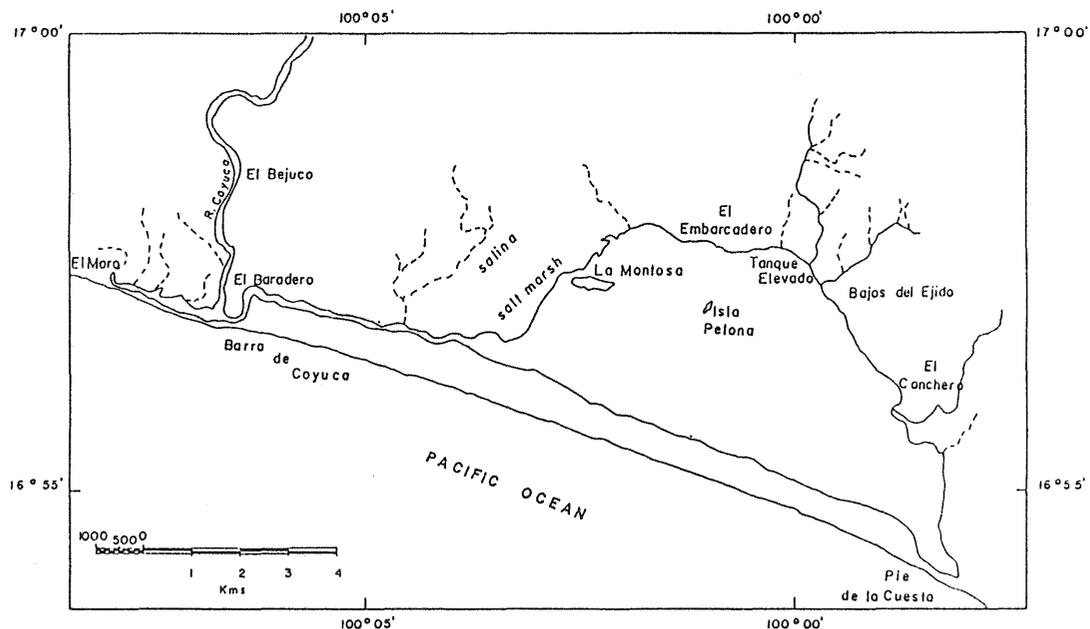
Figure 1. Map of Coyuca de Benitez, Guerrero coastal lagoon.

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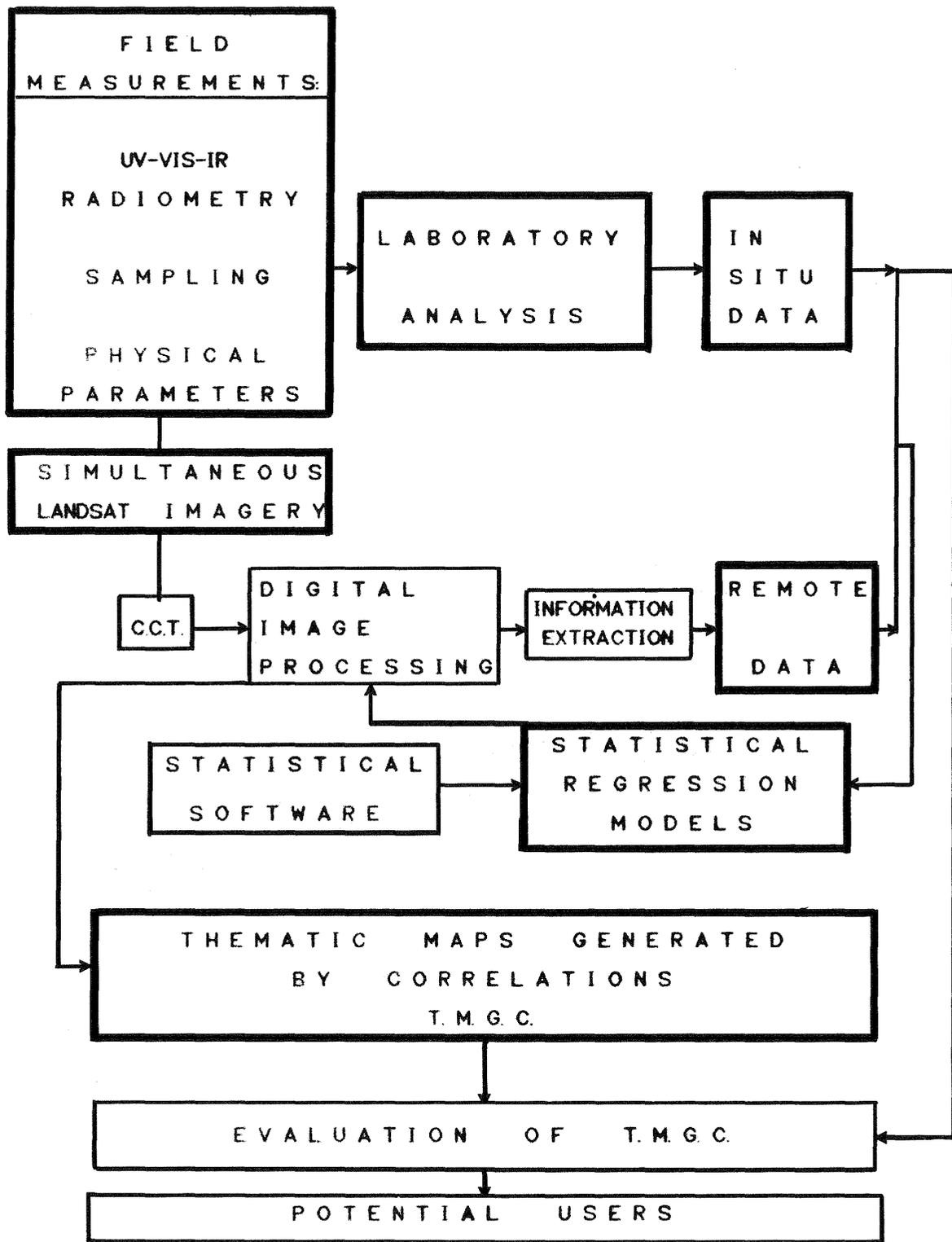
Figure 2. Methodology.
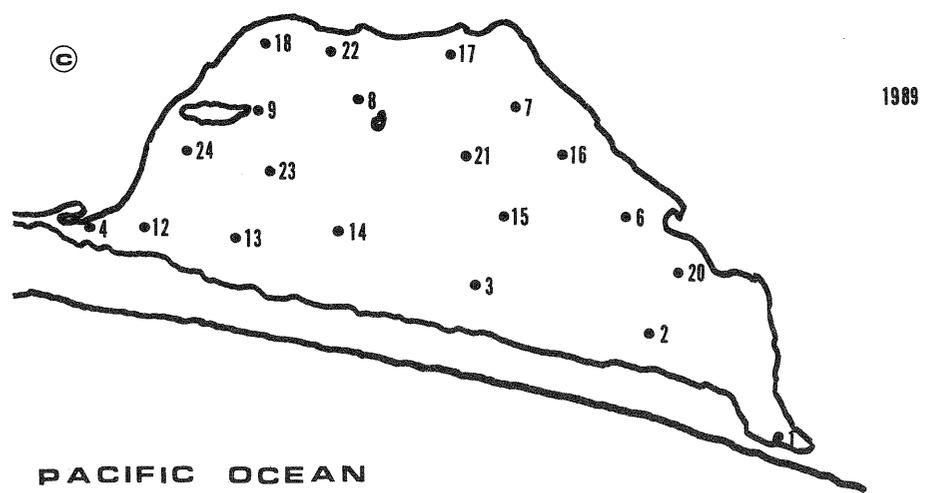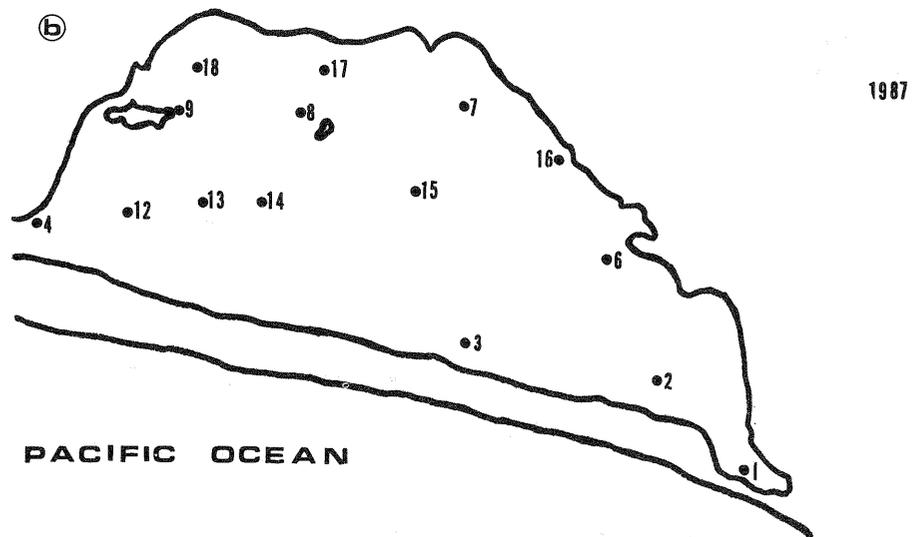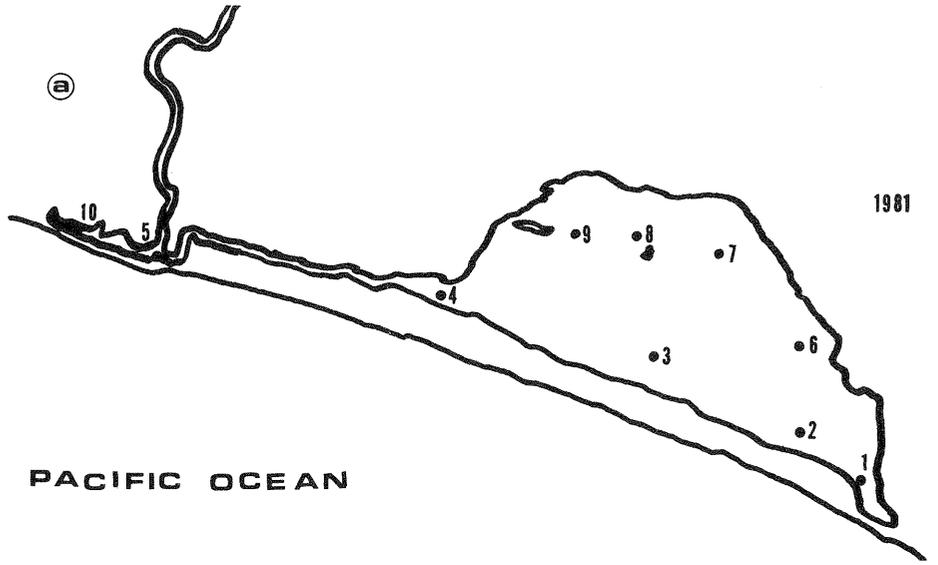
Figure 3. Sampling Points.
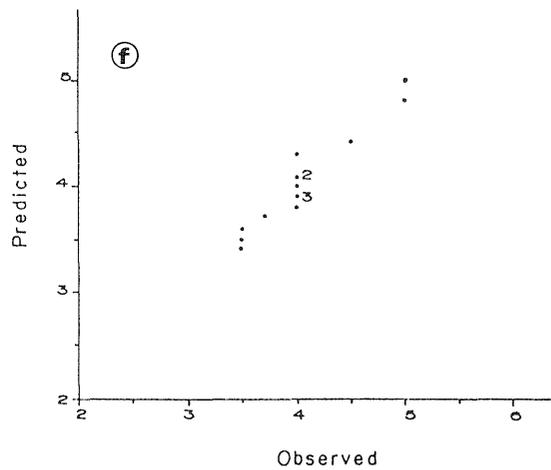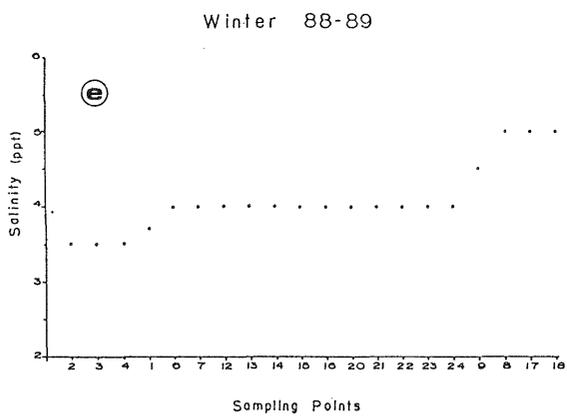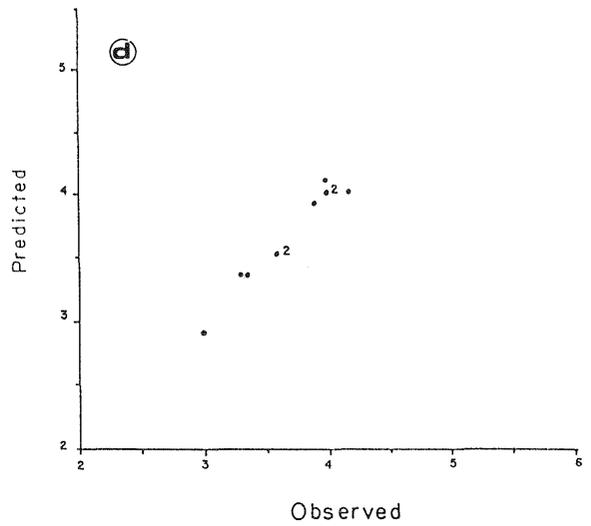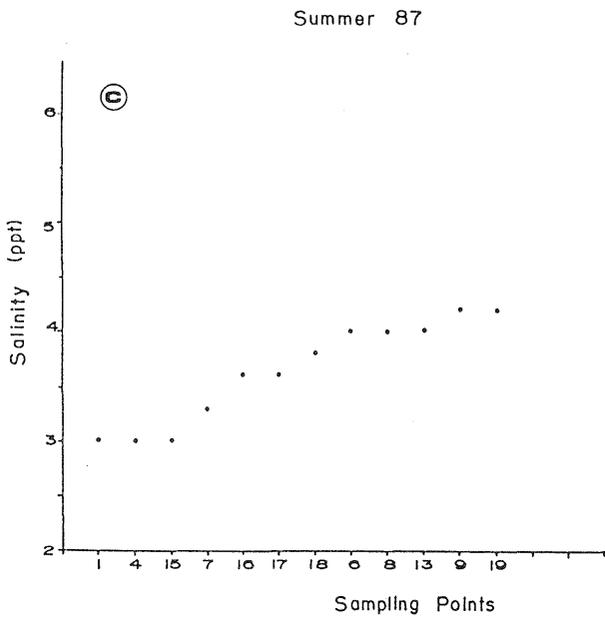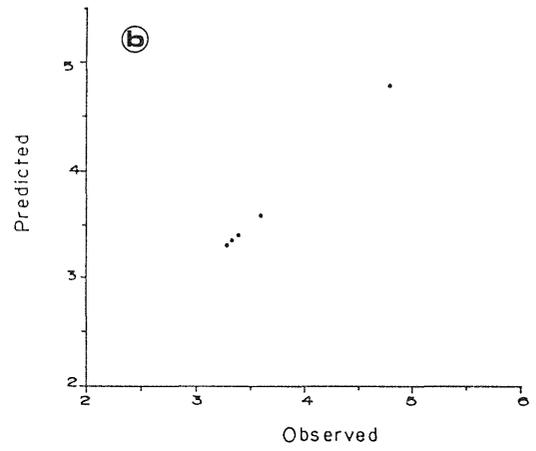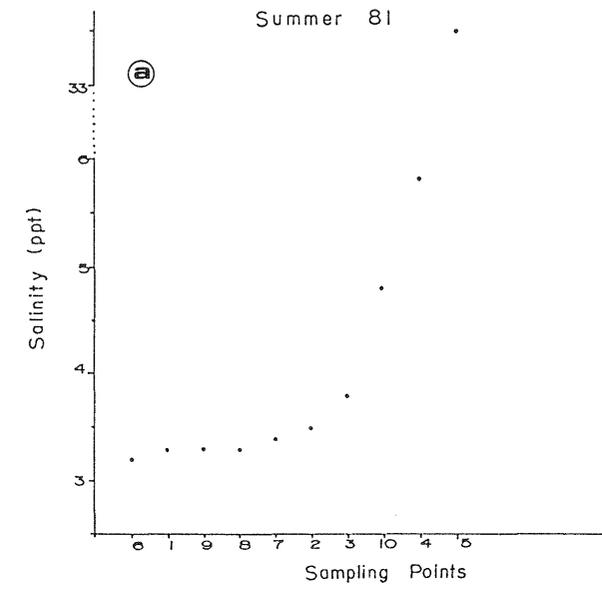
Figure 4. Field data and predicted values.

Figure 5. Isoline Maps.

(a)

1981

SAL-34 ≈≈≈
SAL-56 \\\\

(b)

1987

SAL-34 ≈≈≈
SAL-45 ||||

(c)

1989

SAL-34 ≈≈≈
SAL-45 |||||
SAL-56 \\\\
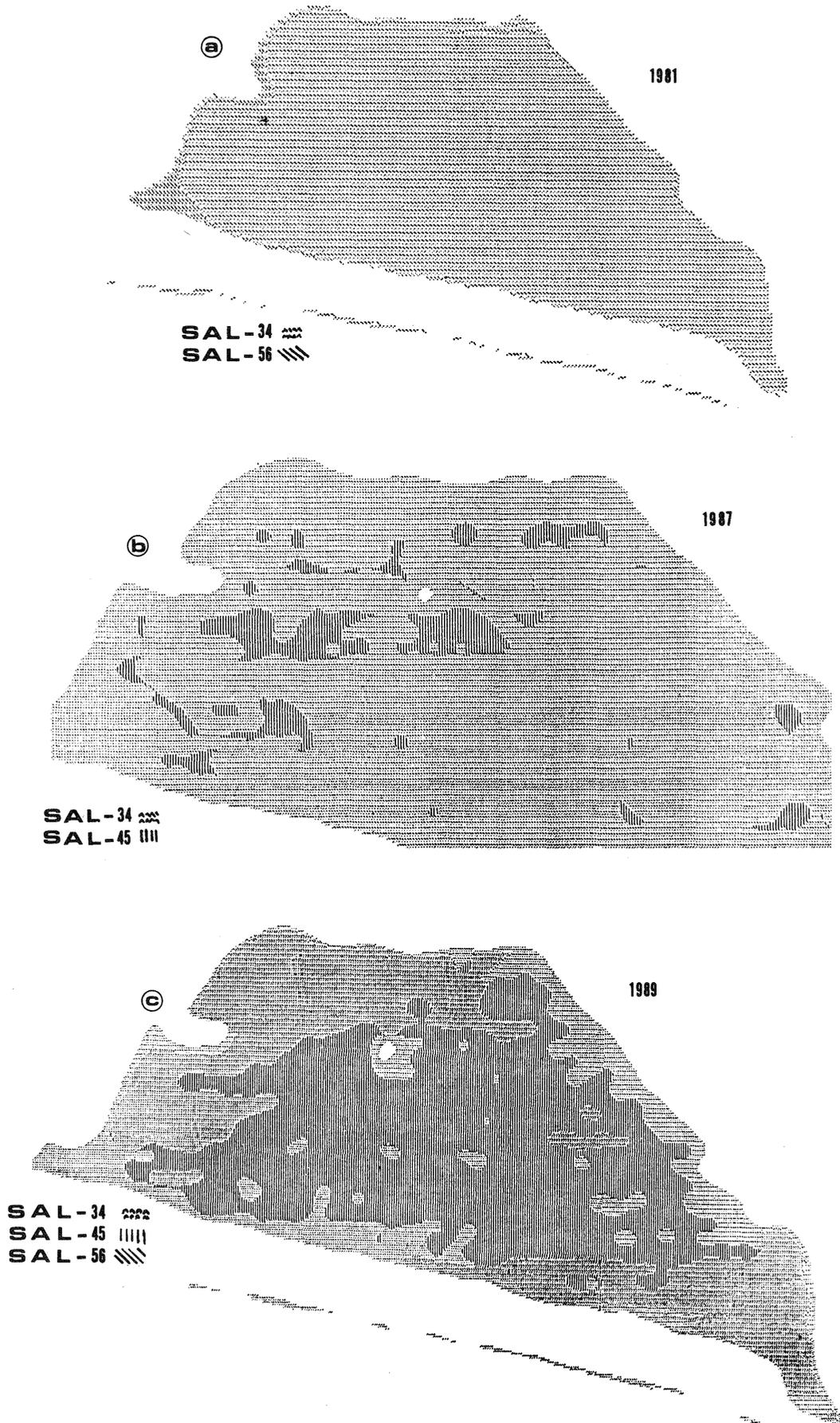
Figure 6. Thematic Maps (T.M.G.C.)