FINAL REPORT

SYNTHESIS OF DATA ON ACARTIA TONSA IN TEXAS BAY SYSTEMS: CORRELATION BETWEEN ITS ABUNDANCE AND SELECTED ENVIRONMENTAL FACTORS

To

Texas Water Development Board
P.O. Box 13087 Capitol Station
Austin, Texas 78711

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Synthesis of data on _Acartia_ _tonsa_ in Texas bay systems: correlation between its abundance and selected environmental factors

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Introduction

Acartia tonsa is widely distributed in the coastal waters of the world oceans (McAlice, 1981). Along the Atlantic coast of America, it occurs from the Miramichi River estuary, New Brunswick (Bousfield, 1955) down to Bahia Forforescente, Puerto Rico (Gonzalez and Bowman, 1965). In Texas estuaries, it is abundant year-round in places where salinity ranges from 10-30‰ as well as in hypersaline environment of Laguna Madre and Baffin Bay where salinity may vary from 30 to 80‰.

A. tonsa is considered to be an important food item for many larval fish such as Gulf menhaden (*Brevoortia patronus*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*) and red drum (*Sciaenops ocellatus*) (Bass and Avault, 1975; Govoni *et al.*, 1983, 1986; Steen and Laroche, 1983). *Acartia* is also an important component of estuarine zooplankters, which feed mainly on phytoplankton and may sometimes control phytoplankton species composition and size distribution through grazing (Steele and Frost, 1977; Ryther and Sanders, 1980).

This study is being carried out to compare the adaptation of *A. tonsa* to the various temperatures and salinities encountered in six of the Texas estuarine systems. For this purpose, it is hypothesized that the copepod in each of the estuarine environments is actually different from one another in terms of physiology and reproduction. Indeed, they are probably subspecies adapted to local environmental conditions.

Some published data did indicate this tendency and listed below are some supporting evidences of this theory.

1. Salinity tolerance of *A. tonsa* varied with both time and location of samples, and thermal prehistory of the copepods affected their survival in diluted seawater (Lance, 1964).

2. Interbreeding of *Acartia clausi* between populations from east and west coasts resulted in inviable offspring (Carrillo B. -G. *et al.*, 1974).

3. A widespread copepod, *Scottolana canadensis*, showed significant genetic differentiation in its embryonic duration, egg size and newborn survival, when taken from a broad range of latitude and raised under the same experimental conditions (Lonsdale and Levinton, 1985).

A. tonsa in this study comes from six estuaries along the Texas coast; namely, Sabine, Trinity, Matagorda, San Antonio, Corpus Christi and Nueces Bays. *Acartia* abundance in each system is analyzed with emphasis on:

1. Seasonal pattern of the copepod, and variation in temperature and salinity.

2. Relative importance of temperature and salinity to the variation in *Acartia* populations and

3. Contour maps representing *Acartia* abundance at various temperature-salinity regimes.

The contour maps may be used for predictions regarding copepod seasonality, optimal copepod survival and possible responses of *Acartia* to salinity changes caused by freshwater inflow to the system.

Materials and Methods

The analytical procedures described below are designed to produce information necessary for evaluation of the hypothesis made in the previous section.

Data entry. Data provided by TWDB are first transferred from external tape to permanent files of the CDC Dual Cyber computer system, and then loaded to mini-disk of the IBM system 370. These data are finally reorganized and statistically analyzed using SAS software package (version 4).

Salinity and temperature effects. Stepwise multiple regressions are employed using SAS/GLM procedure. The percent of variance in *Acartia* associated with each of the environmental factors or with their combined effects is also evaluated and tested by the F-ratio statistic. The relative importance of temperature and salinity to copepod abundance is compared by the method of principal component analysis contained in the same SAS software package.

Contour plot. A contour map of *Acartia* abundance over salinity and temperature possibly encountered in each of the environments is generated using SAS/Graphic programs. There are 7-8 zones defined for each estuarine system, with temperatures ranging from 0 to 36°C and salinity from 0 to 35‰.

Results

Corpus Christi Bay. Samples were collected during the period from 15 October 1975 to 22 June 1976. Data of 1975 covered October, November and December only, while samples of 1976 covered January (2 times), February (2 times), March, April, May (3 times) and June (2 times). A total of 96 samples were collected from the 5 stations: 53, 127, 142, 147 and 200.

Variations in water temperature during the sampling period are shown in Figure 1; mean lowest temperature of 9.3°C was recorded during the winter and highest (28.8°C) was observed in the summer of 1976.

In contrast with changes of water temperature, mean salinities in Corpus Christi Bay were generally very consistent during the 1975-1976 period (Fig. 2), with overall mean around 30‰. Lower salinity did occur in late spring of 1976, in which case salinity as low as 8.4‰ was recorded in part of the bay.

Seasonal variations of *A. tonsa* in Corpus Christi Bay are shown in Figure 3. On pooled data basis, sampling dates have significant effect on *Acartia* abundance ($F = 3.59$, $P < 0.01$), suggesting that seasonal variations of copepod abundance are significant. On the contrary, collecting sites within the bay are not found to be significantly different from each other in *Acartia* abundance ($F = 2.22$, $P > 0.07$), indicating possible homogeneous distribution of *A. tonsa* in Corpus Christi Bay.

The relationships among *Acartia* abundance, temperature and salinity can be best described by:

Acartia abundance = 1421.5 + 3542.2 x Temperature - 167.9 x (Temperature)^2 - 1777.3 x Salinity - 2.4 x (Salinity)^2 + 118.5 x Temperature x Salinity ($F = 3.36$, $P < 0.01$).

The corresponding response curves are shown in Figure 4. Analysis on the relative importance of temperature and salinity to *Acartia* abundance (Fig. 5) further suggests that temperature is the component contributing more to *Acartia* variations in Corpus Christi Bay (Eigenvectors: temperature (0.9997) vs. salinity (0.0210)).

Nueces Bay. Samples were collected between 20 December 1972 to 7 October 1974 from 20 stations. A total of 709 observations were made in the Nueces Bay during this sampling period.

Mean temperature variations in the bay were similar in both 1973 and 1974 (Fig. 6). Temperatures were low during winter and averaged about 7.5°C in 1972-73 and 12.5°C in 1973-74, and then gradually increased to maximum during the summer months; the mean summer temperature was 29.2°C.

Salinities within the bay varied greatly with both seasons and stations (Fig. 7). Annual changes in salinity were also significant. For example, salinities recorded during the winter of 1972-1973 were much higher than those of 1973-1974 and the differences might amount to ± 10‰ on several occasions.

As those in Corpus Christi Bay, *Acartia* populations in Nueces Bay were rather evenly distributed among stations (Fig. 8). One-way ANOVA indicates that there is no strong relationship between *Acartia* abundance and sampling stations ($F = 1.59$, $P > 0.05$). However, seasonal variations of the copepod are found to be significant at 1% level. The optimal response equation of *Acartia* to temperature and salinity is depicted in Figure 9 and is defined by:

Acartia abundance = 4300.1 + 129.9 x Temperature - 5.6 x (Temperature)^2 + 88.9 x Salinity - 15.6 x (Salinity)^2 + 17.1 x Temperature x Salinity ($F = 14.45$, $P < 0.01$).

Principal component analysis results in no surprise that salinity is contributing more to the variations of *Acartia* abundance in Nueces Bay. Eigenvectors are -0.1630 and 0.9866 for temperature and salinity respectively (Fig. 10).

<u>San Antonio Bay</u>. Seasonal changes of temperature in San Antonio Bay is presented in Figure 11, and the patterns are very similar to that observed in Nueces Bay. Season highs of 33°C were recorded during summer while lows (about 6.5°C) were found during winter.

Seasonal variations in salinity are shown in Figure 12. Salinity near the river mouth was negligible, and it increased gradually outward in response to river flow. Salinities were low, often less than 10‰ during the sampling period. Salinities > 20‰ were only occasionally recorded during winter and early spring of 1973.

Copepods in the San Antonio Bay were obtained from 11 stations and on 63 different cruises during the 1972-1974 period. One-way ANOVA shows that dates of collection, but not sampling sites, have significant impact on the variations of *Acartia* population ($F = 2.66$, $P < 0.01$). In general, *A. tonsa* were higher in late spring and summer than in winter; the highest densities may sometimes reach over $50,000/m^3$, while a minimum of zero density could also occur (Fig. 13). The response equation of *Acartia* to temperature and salinity is shown below, and the corresponding contour map is presented in Figure 14.

Acartia abundance = -4183.1 + 154.1 x temperature + 3.3 x $(\text{Temperature})^2$ + 1071.5 x Salinity - 36.9 x $(\text{Salinity})^2$ + 0.4 x Temperature x Salinity ($F = 11.97$, $P < 0.01$).

As is the case in Nueces Bay, salinity is the major factor in determining the variation of *A. tonsa* in the system. Eigenvectors from principal component analysis are -0.4648 for temperature and 0.8853 for salinity (Fig. 15).

<u>Matagorda Bay</u>. Seasonal changes in temperature, salinity and *Acartia* abundance from 21 February 1973 to 5 June 1976 are presented in Figures 16, 17 and 18. A total of 426 samples were collected during this period covering 19 stations in the Matagorda Bay.

Seasonal temperatures ranged from 7°C recorded in the winter of 1975-1976 to 31.5°C in the summer of 1975. Salinity also varied greatly with both seasons and stations, and spanned from near freshwater to about 25‰.

Acartia abundance in Matagorda Bay was low compared to that of other estuarine systems described above. The mean densities were generally below $1000/m^3$ for most of the times during the year. Higher densities did occur sometimes during the summer, as the cases noted in the early summer of 1976.

One-way ANOVA indicates that differences in *Acartia* abundance between stations were not significant during the sampling period ($F = 1.53$, $P > 0.07$). A significant relationship, however, is observed between copepod abundance and seasons ($F = 3.51$, $P < 0.01$). The relationship among copepods, temperature, and salinity is shown in Figure 19 and is best defined by the following equation:

Acartia abundance = 136.8 + 3.6x Temperature + 0.2 x $(\text{Temperature})^2$ - 82.8 x Salinity + 3.5 x $(\text{Salinity})^2$ + 1.5 x Temperature x Salinity ($F = 11.31$, $P < 0.01$).

Again, it is the salinity which plays a more important role in determining the variation of *Acartia* abundance in the Matagorda Bay. Eigenvectors from principal component analysis are -0.2867 for temperature and 0.9580 for salinity. The corresponding plot is presented in Figure 20.

Trinity Bay. A total of 328 samples were obtained from 6 stations in the Trinity Bay during the 1975-1976 period. Mean temperatures in the bay ranged from about 11.0°C during winter to 30.4°C in August. These variations in water temperature in 1975-1976 are shown in Figure 21.

Mean salinities in Trinity Bay varied from 3.8‰ to 14.8‰; peak salinity occurred in February 1976 and then declined to the low of about 3.8‰ in July 1976. In 1975 mean salinities recorded during the fall were between 8.6 to 12.3‰ (Fig. 22).

Throughout the sampling period, *Acartia tonsa* were low in their densities (Fig. 23); mean densities were seldom over $400/m^3$. One-way ANOVA suggests that both collection sites and dates have significant effects on the variation in *Acartia* abundance; both factors are significant at 1% level.

The relationship among the *A. tonsa* abundance, temperature and salinity can be defined as follows:

Acartia abundance = -302.2 + 10.8 x Temperature + 0.1 x (Temperature)^2 + 36.3 x Salinity - 0.8 x (Salinity)^2 - 0.9 x Temperature x Salinity ($F = 14.00$, $P < 0.01$).

The contour map corresponding to the above equation is presented in Figure 24. PCA (Fig. 25) suggests that temperature is a more important factor than salinity in influencing the variation in *Acartia* abundance (Eigenvectors: temperature (0.9131) vs. salinity (-0.4076).

Sabine System. Temperatures in Sabine system follow a similar pattern observed in other Texas bay systems; highs were recorded in August and lows were in December and January. Mean temperatures during the year ranged from 11.5 to about 32°C (Fig. 26).

Salinities were generally low and often below 10‰ (Fig. 27); salinities greater than 10‰ were occasionally recorded during October 1974, and July and August 1976. Salinities remained below 2‰ in winter and spring of 1974-1975, while in the winter of 1975-1976, mean salinities were well above 6‰.

A total of 167 samples were collected from 13 stations during the 1974-1976 period. Seasonal variations in *A. tonsa* abundance are shown in Figure 28. As is the case in the Trinity Bay, *A. tonsa* in the Sabine system varies significantly both from season to season ($F = 10.39$, $P < 0.01$) and from station to station ($F = 2.98$, $P < 0.01$). The following equation best describes the relationship of *Acartia* abundance to the two factors of temperature and salinity.

Acartia abundance = $-359.7 + 30.9 \times \text{Temperature} - 0.6 \times (\text{Temperature})^2 + 26.7 \times \text{Salinity} - 1.1 \times (\text{Salinity})^2 - 0.1 \times \text{Temperature} \times \text{Salinity}$ ($F = 22.98$, $P < 0.01$).

Figure 29 is the contour plot representing the possible response of *Acartia* to changes in temperature and salinity. Principal component analysis (Fig. 30) shows that temperature plays an important role in determining *Acartia* abundance in the Sabine estuarine system. Eigenvectors from PCA are 0.9871 for temperature and -0.1599 for salinity.

Discussion and Conclusion

The copepod *Acartia tonsa* is the most important estuarine zooplankter along the Atlantic coast (Ambler, 1985; Breuer, 1957, 1962; Conover, 1956; Cooper, 1967; Cronin, 1962; Deevey, 1952, 1960; Fish, 1925; Heinle, 1966; Holland *et al.*, 1974; Jeffries, 1962; Lee and McAlice, 1979; Livingston, 1981;

Martin, 1965; McIlwain, 1968; Sage and Herman, 1972; Woodmansee, 1958). Factors controlling seasonal succession and abundance of the copepod have been related to food resources, predators, prey density, temperature and salinity (Durbin *et al.*, 1983; Johnson, 1980; Knatz, 1978; Lance, 1964; Martin, 1965; Sullivan and McManus, 1986). In this study, we examine only the historical zooplankton data and endeavor to determine if there is strong association between the *Acartia* abundance and the two environmental factors; temperature and salinity.

The historical data are analyzed under the assumptions that 1) zooplankton were collected with the same gear type and in the same manner throughout the estuarine systems and the sampling periods, 2) sampling sites were randomly selected and were representative of conditions possibly encountered in the system and 3) sampling intervals of 2 to 8 weeks, as was the case in this study, would not greatly affect the fidelity of the response model built for *Acartia* populations.

Significant seasonal variations of both temperature and salinity were noted in each drainage system in this study, with the exception of salinity changes in Corpus Christi Bay ($F = 1.32$, $P > 0.216$). The high (> 25‰) and nearly constant salinity recorded between October 1975 and June 1976 may explain the case encountered in Corpus Christi Bay. ANOVA results also indicate significant seasonal variations in *Acartia* abundance among the 6 estuarine systems. If all data were pooled together, the association of *Acartia* population with temperature and salinity can be represented in the contour map (Fig. 31) and defined by the following equation:

Acartia abundance = -63.880 + 151.541 x Temperature - 3.916 x $(\text{Temperature})^2$ - 231.507 x Salinity + 6.044 x $(\text{Salinity})^2$ + 13.062 x Temperature x Salinity

Principal component analysis over all data points reveals that salinity is more important than temperature in regulating variations in *Acartia* abundance. Eigenvectors are -0.196 for temperature and 0.981 for salinity (Fig. 32).

It appears that freshwater inflow will have great impact on the population dynamics of *A. tonsa* in Texas estuarine systems. However, on pooled data basis, the results often conceal important processes which might be characteristic to the individual system. For this reason, individual systems are treated separately and summarized as follows:

1. Systems in which *Acartia tonsa* shows significant seasonal variation include Corpus Christi, Nueces, San Antonio and Matagorda Bays
2. Systems in which the *Acartia* population varies significantly with both seasons and locations include Sabine and Trinity Bays
3. Systems in which temperature is a more important factor in determining variations in *Acartia* abundance include Corpus Christi, Sabine and Trinity Bays
4. Systems in which salinity plays a more important role than temperature in determining variations in *Acartia* abundance include Nueces, San Antonio and Matagorda Bays.

Using Duncan's multiple range test, the 6 draining systems can be further classified into 4 groups: A) Corpus Christi Bay B) Nueces C) San Antonio D) Matagorda, Sabine and Trinity bays. The detailed results are given as follows:

Group	Mean *Acartia* Density	Number of Observations	Location
A	15,916	96	Corpus Christi
B	6,296	708	Nueces
C	5,113	330	San Antonio
D	423	419	Matagorda
D	75	167	Sabine
D	42	328	Trinity

The social implications of this project are its most important aspect; the end product suggests that freshwater inflow is important to the estuarine zooplankter *Acartia tonsa* in Texas estuaries. The results also indicate that *A. tonsa* in each drainage system will respond differently to salinity variation accompanied by temperature changes as shown in the contour maps. These results should provide various government agencies with critical data needed in evaluating the possible environmental impacts of man's activities on the ecosystem of estuaries. The implications to society are also significant; alteration of the estuarine habitats may lead to changes not only in zooplankton population but also in larvae or juveniles of economically-important fish which feed on *Acartia tonsa* or other estuarine zooplankters.

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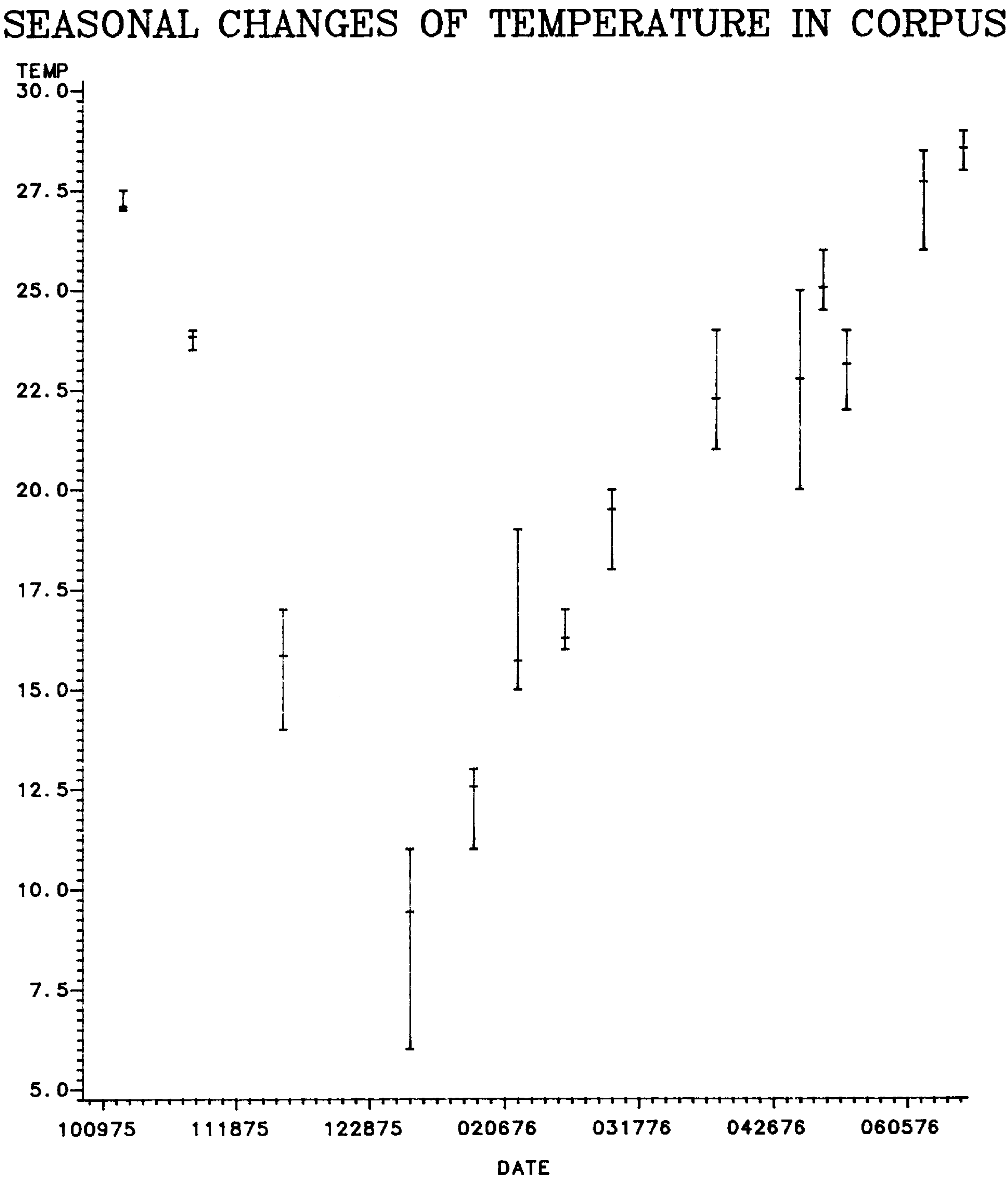
SEASONAL CHANGES OF TEMPERATURE IN CORPUS
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Figure 1.

SEASONAL CHANGES OF SALINITY IN CORPUS

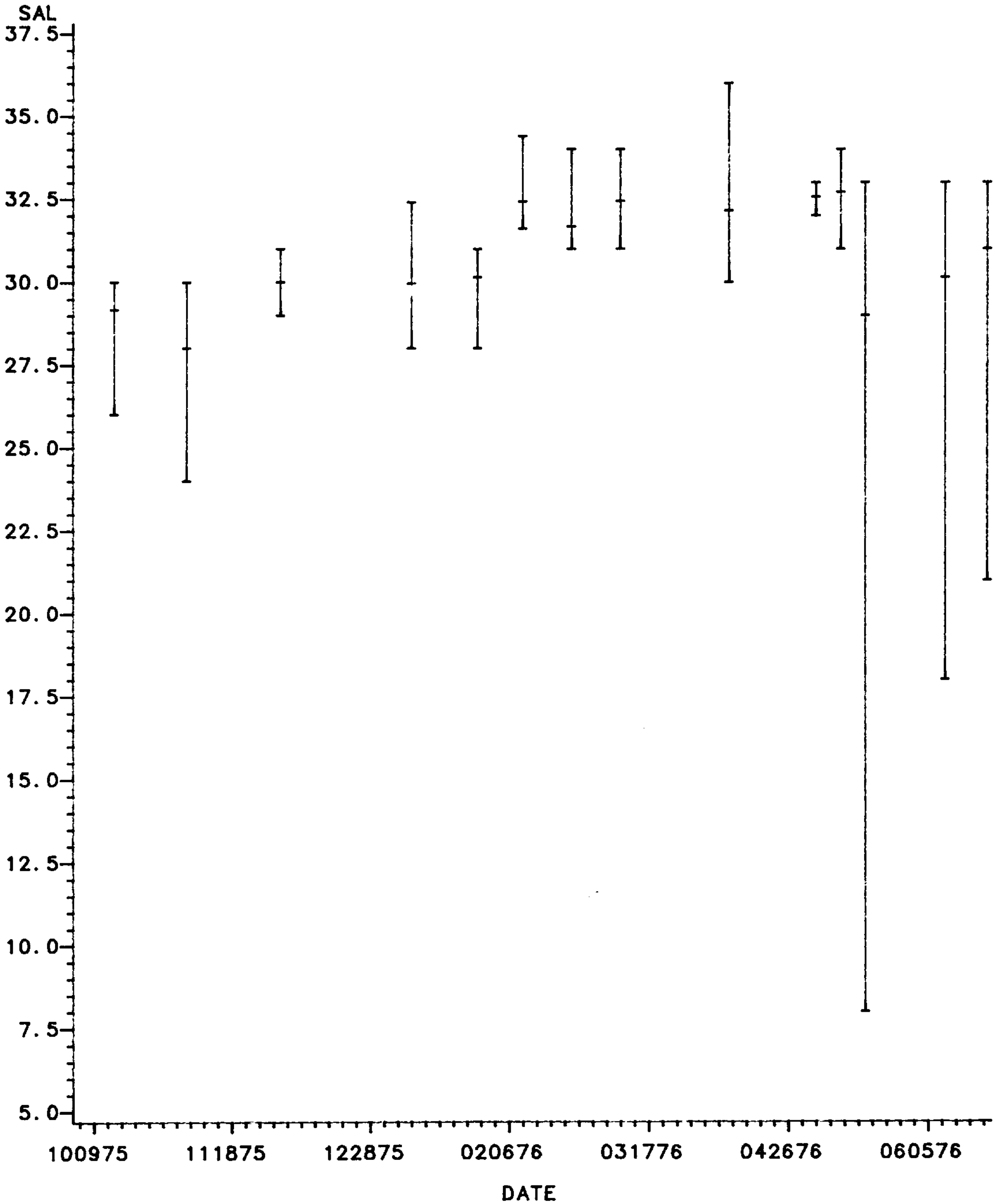
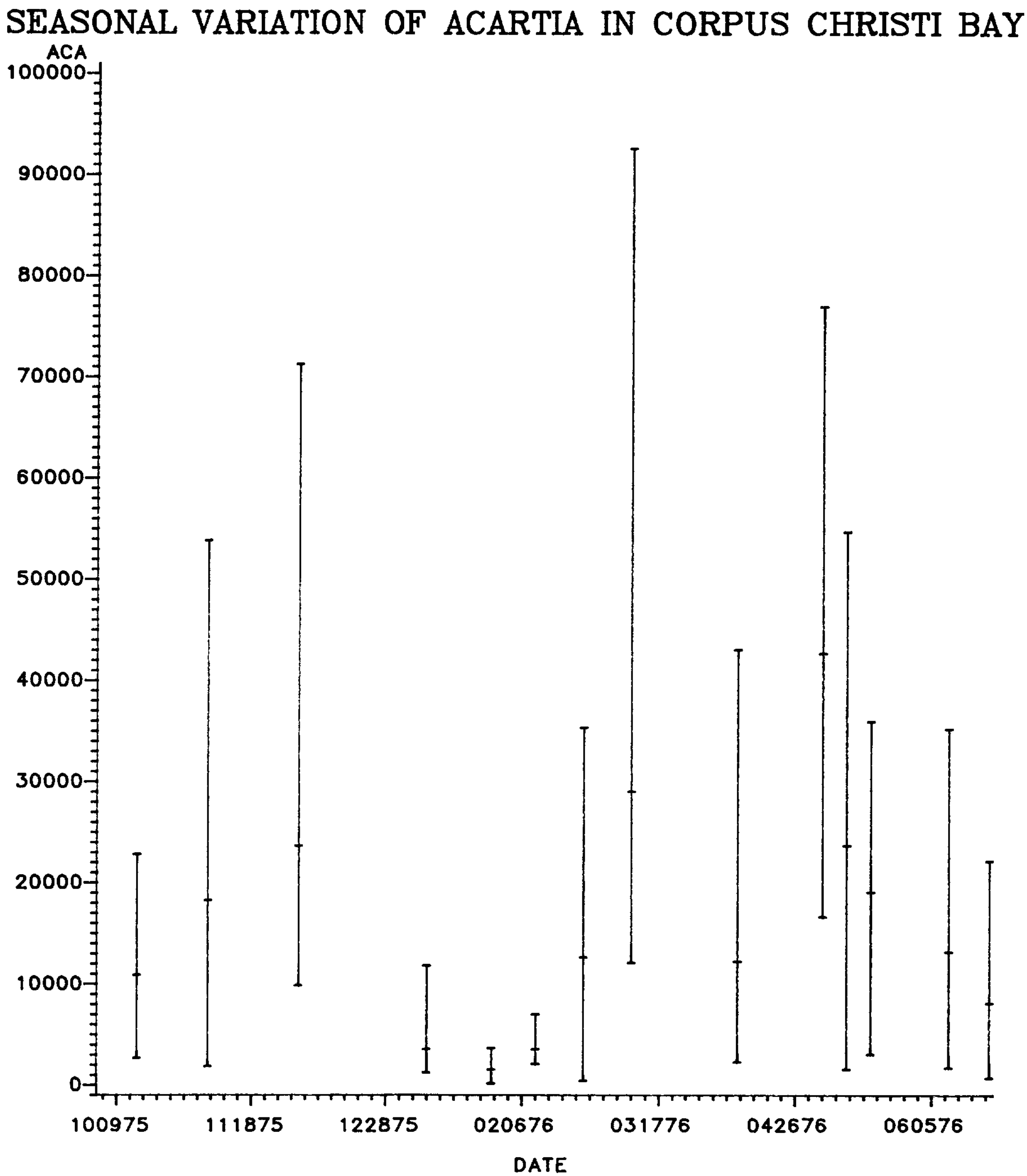


Figure 2.


SEASONAL VARIATION OF ACARTIA IN CORPUS CHRISTI BAY
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60000
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0
100975
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Figure 3.

RESPONSE OF ACARTIA TO TEMPERATURE AND SALINITY (CORPUS)

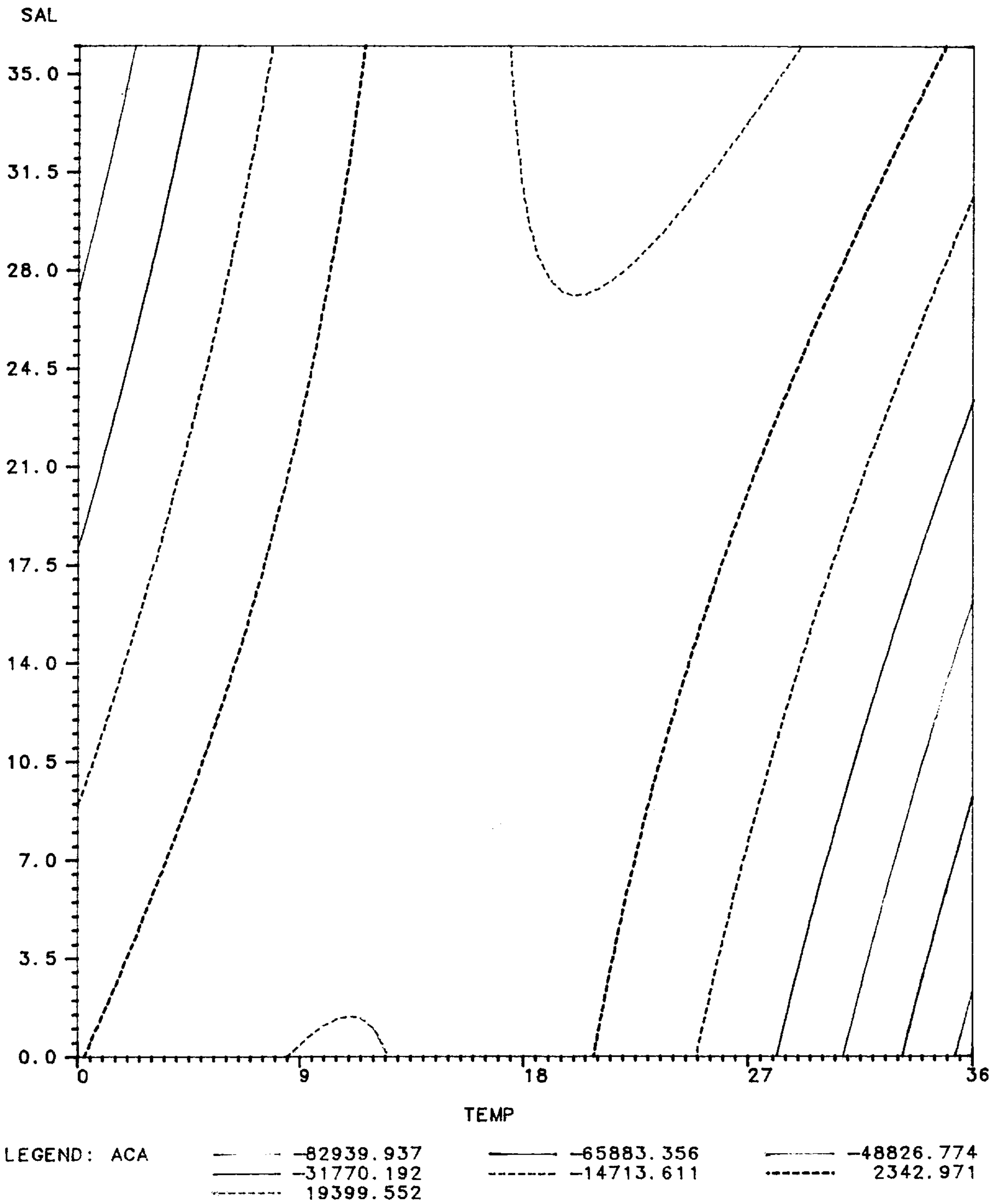
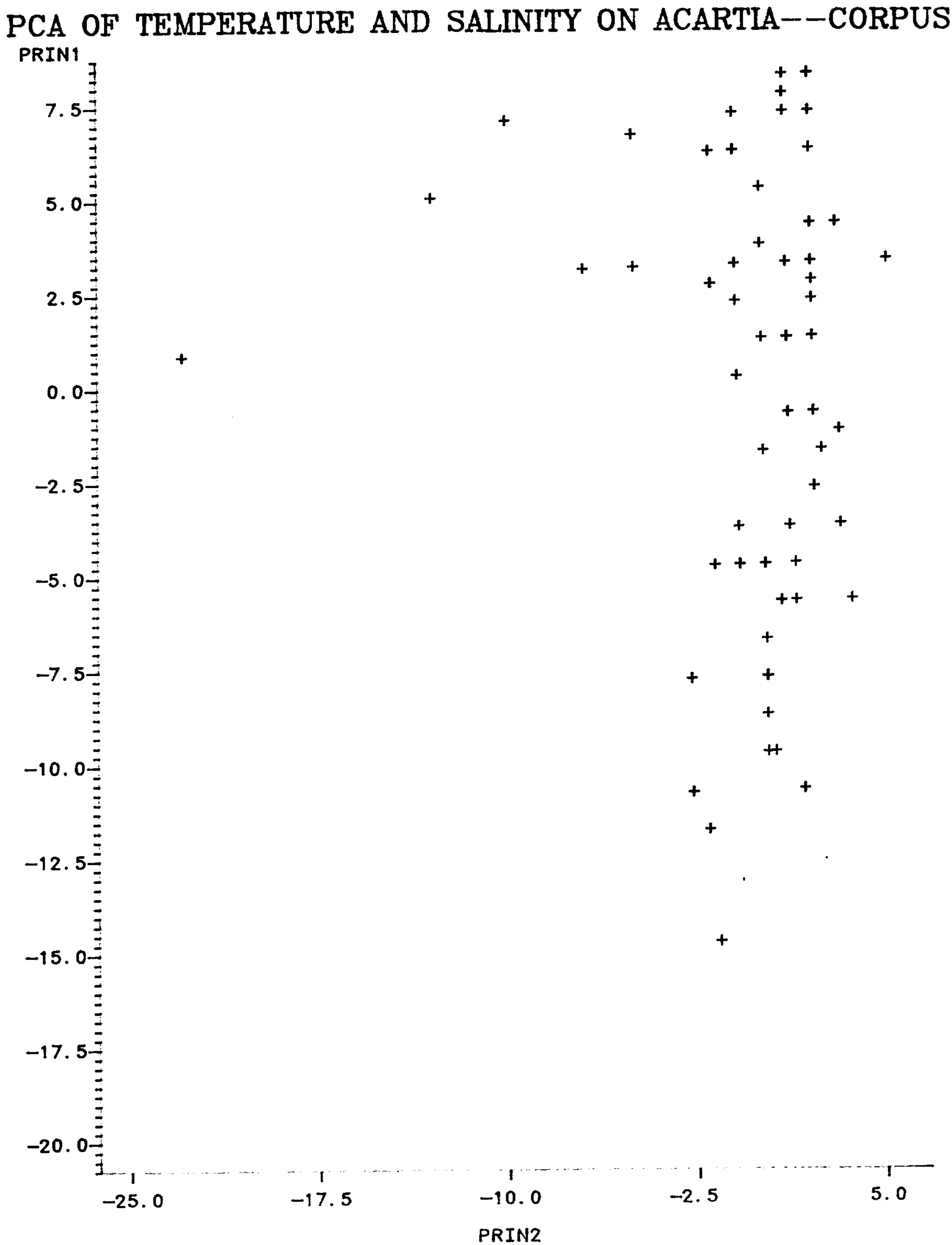


Figure 4.



PCA OF TEMPERATURE AND SALINITY ON ACARTIA--CORPUS
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2.5
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
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-17.5
-10.0
-2.5
5.0
PRIN2

Figure 5

SEASONAL CHANGES OF TEMPERATURE IN NUECES

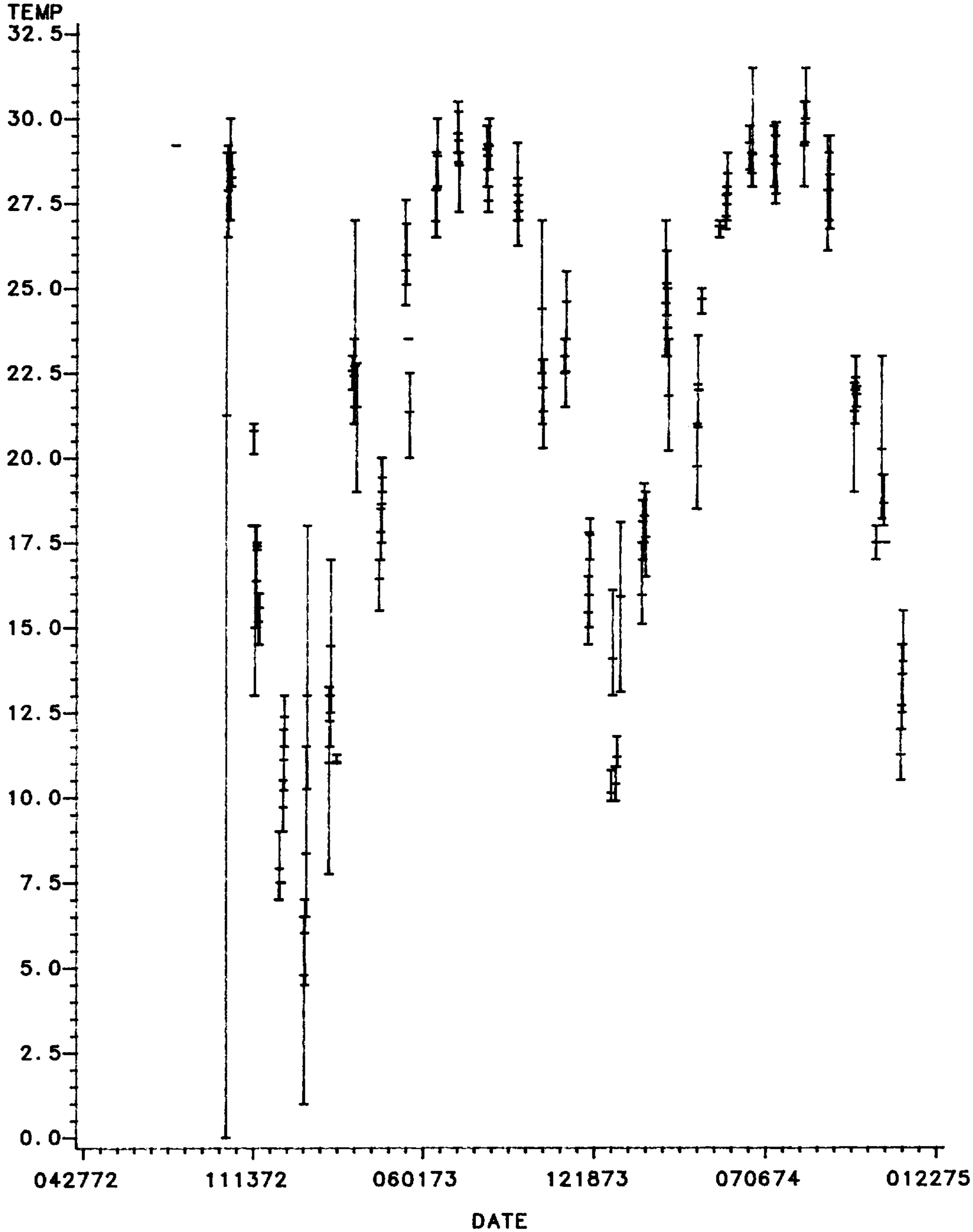

Figure 6.

SEASONAL CHANGES OF SALINITY IN NUECES

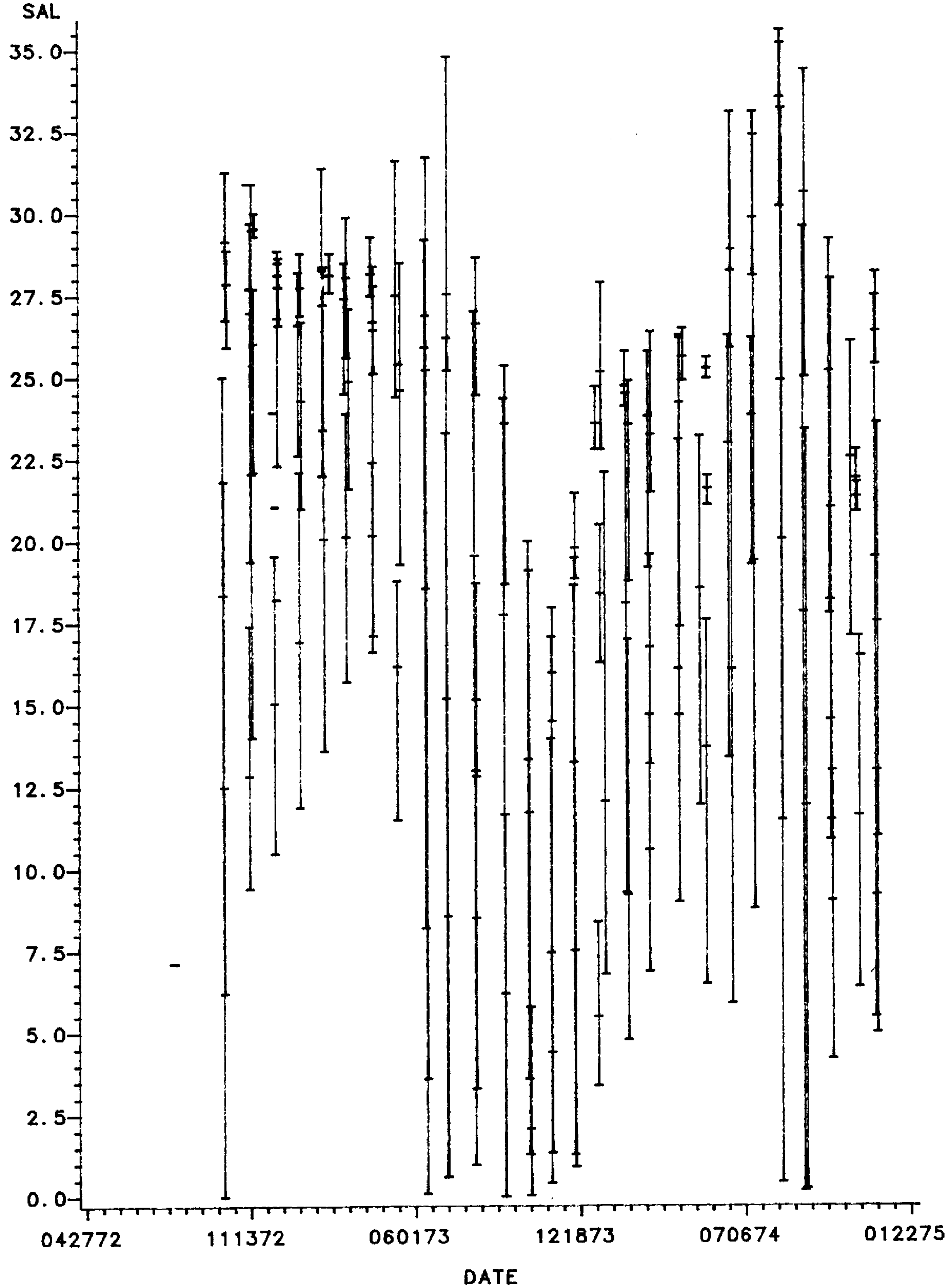

Figure 7.

SEASONAL VARIATION OF ACARTIA IN NUECES BAY

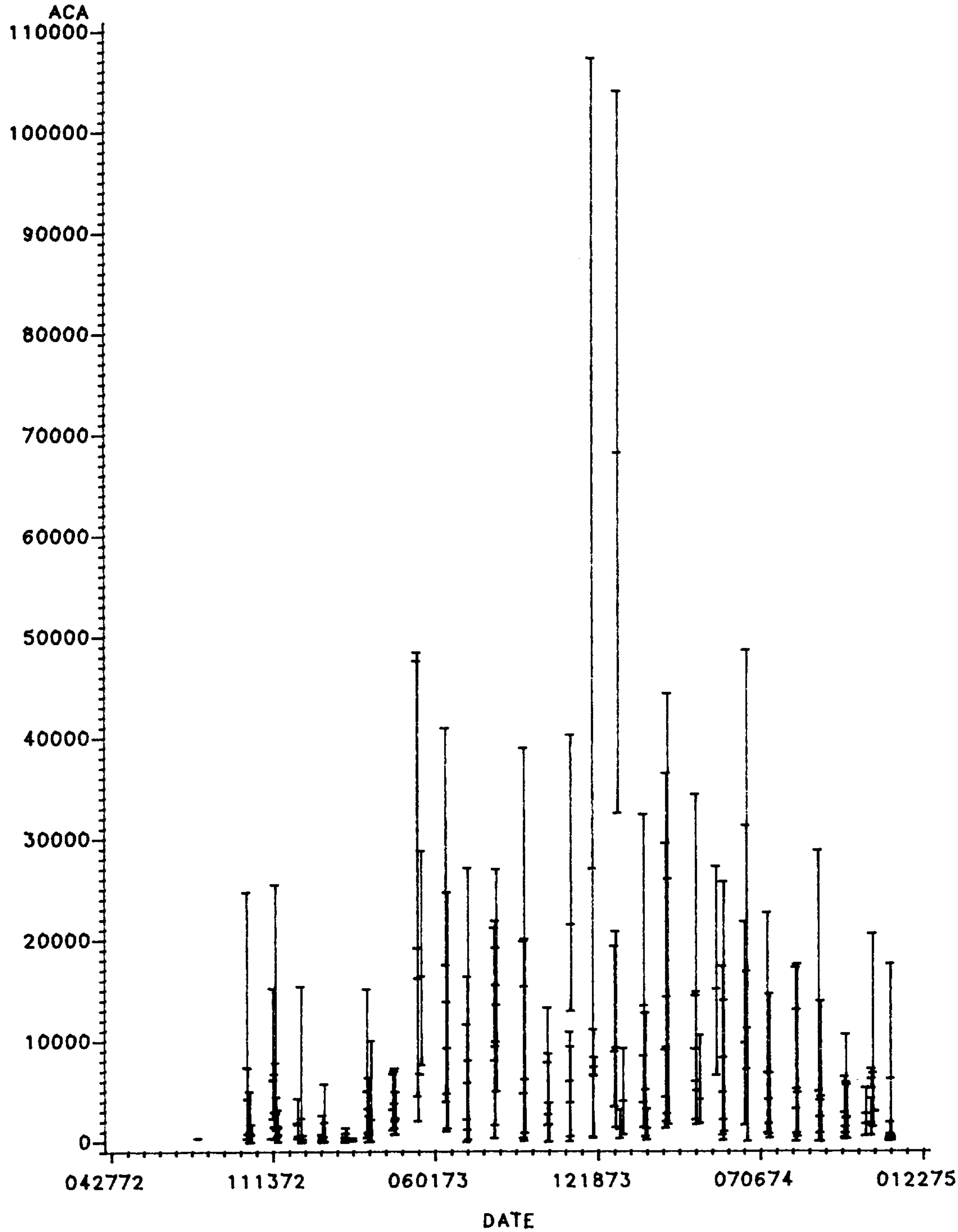

Figure 8.

RESPONSE OF ACARTIA TO TEMPERATURE AND SALINITY (NUECES BAY)

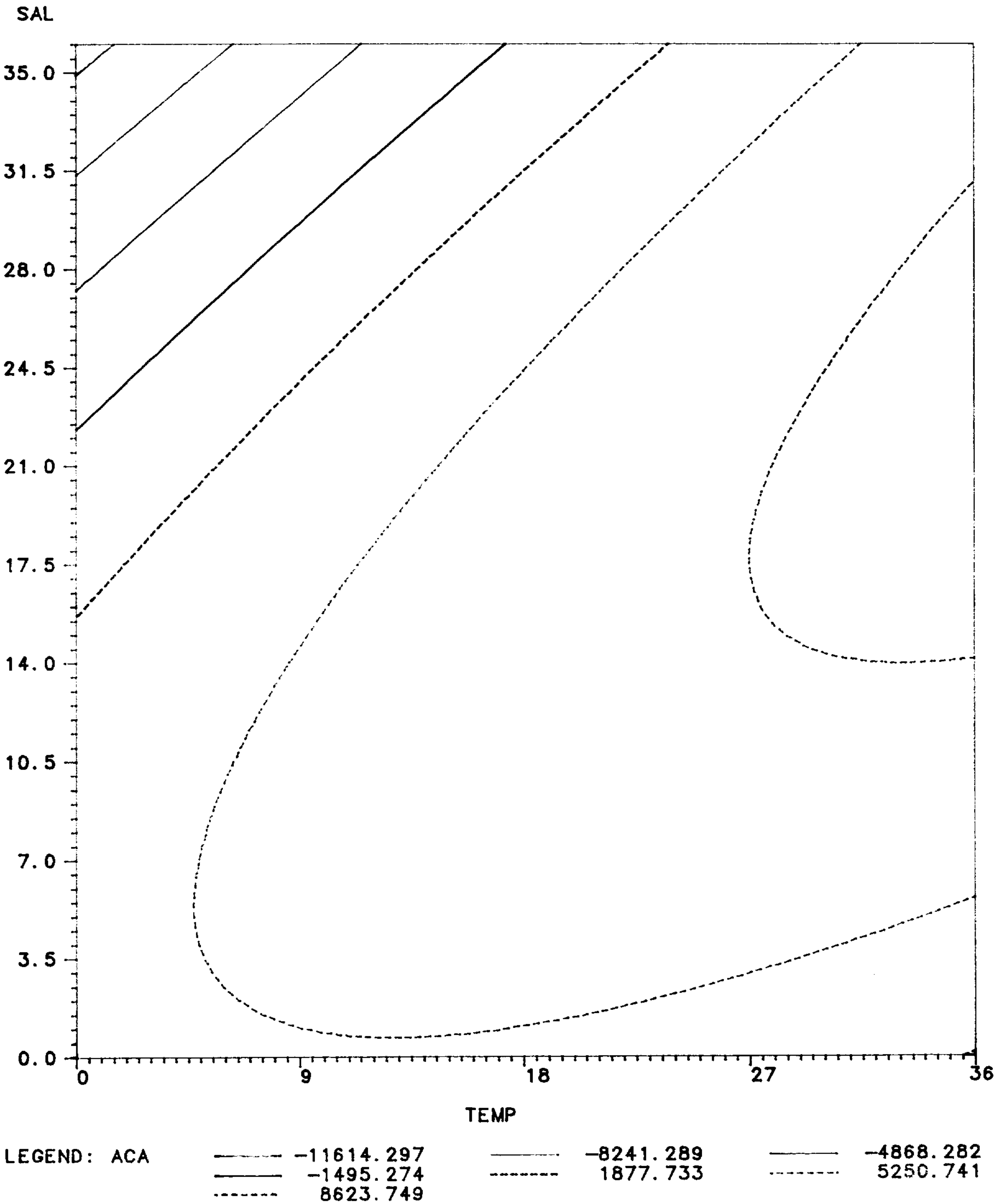

Figure 9.

PCA OF TEMPERATURE AND SALINITY ON ACARTIA--NUECES

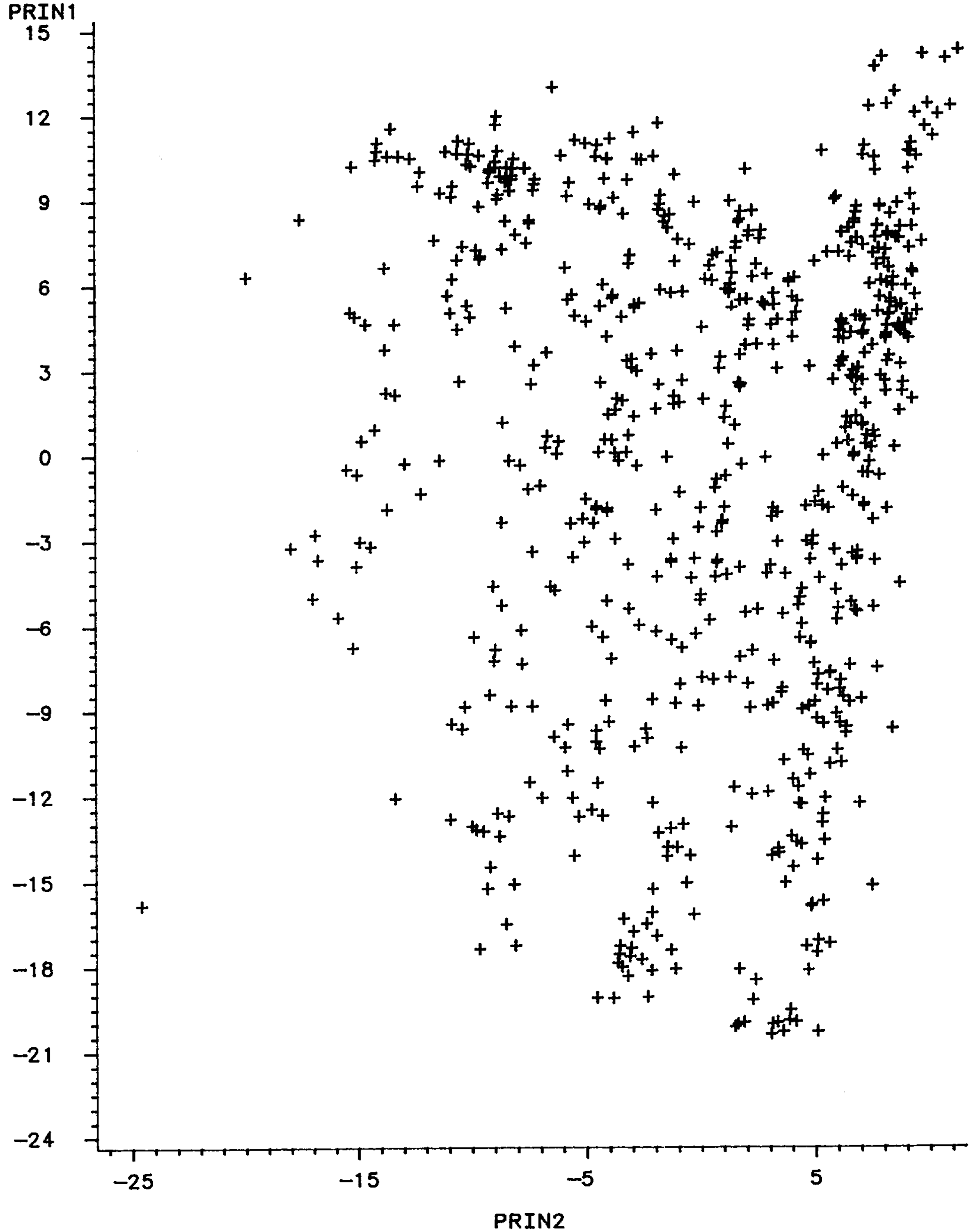

Figure 10.

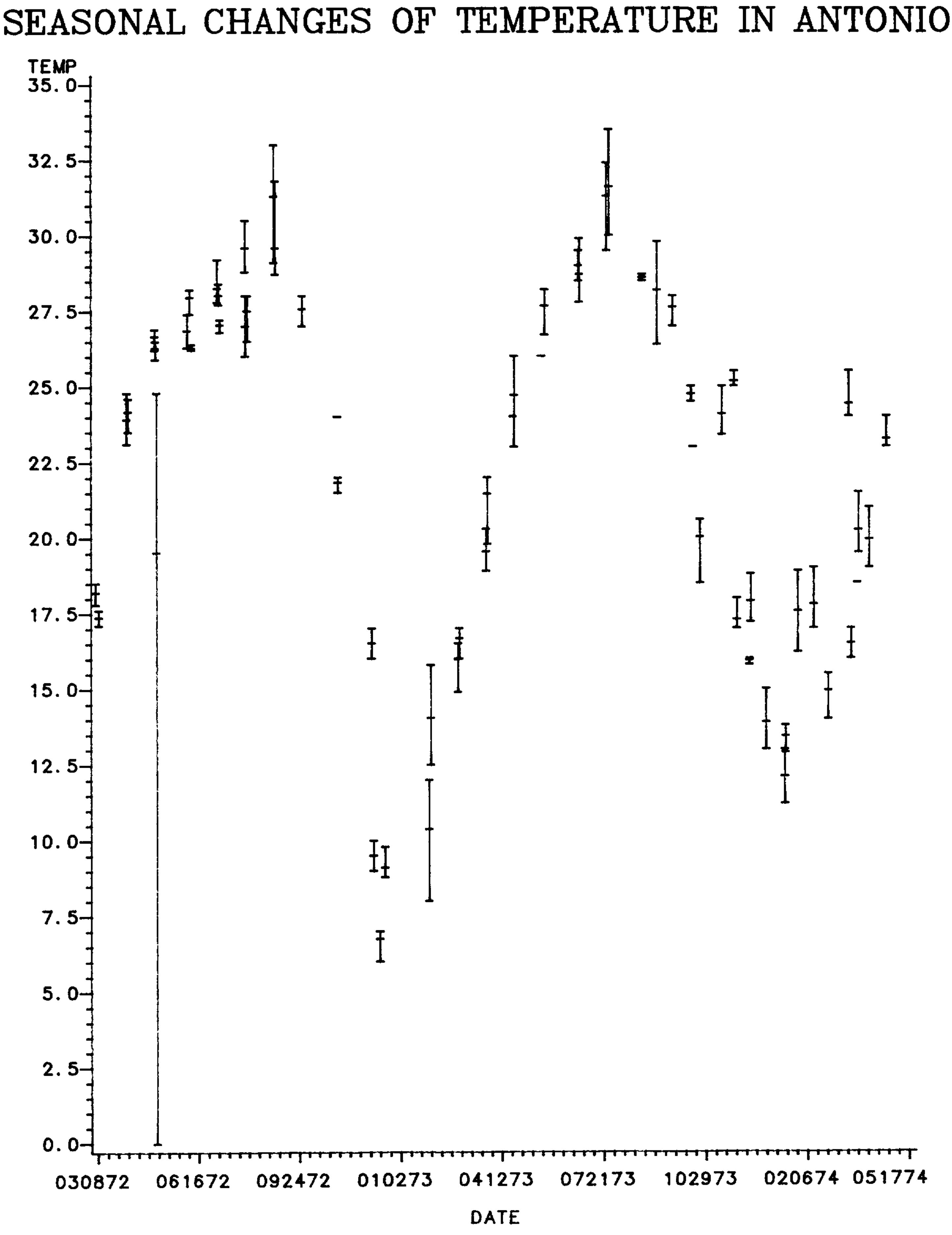
SEASONAL CHANGES OF TEMPERATURE IN ANTONIO
TEMP
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
030872
061672
092472
010273
041273
072173
102973
020674
051774
DATE

Figure 11.

SEASONAL CHANGES OF SALINITY IN ANTONIO

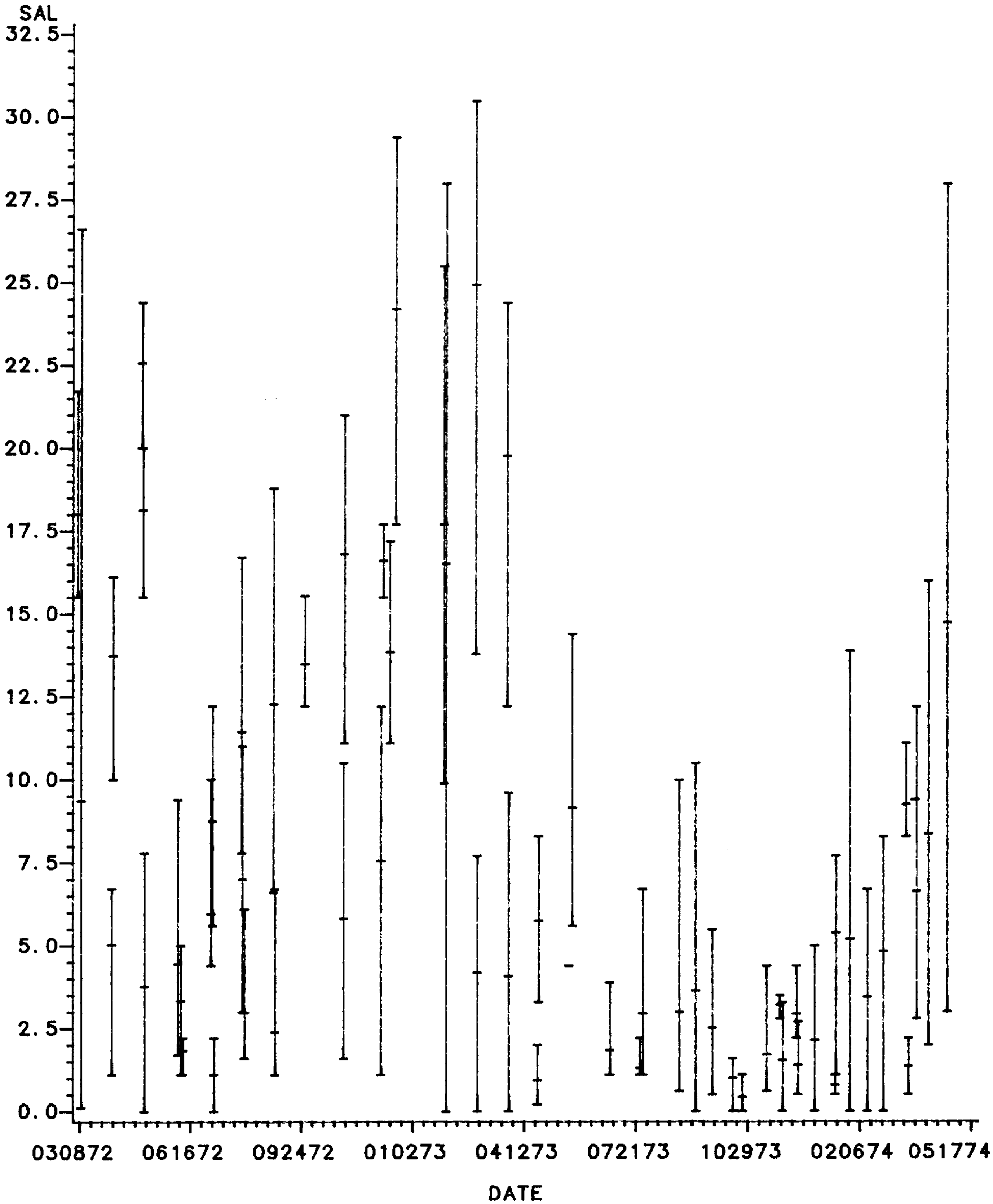

Figure 12.

SEASONAL VARIATION OF ACARTIA IN SAN ANTONIO BAY

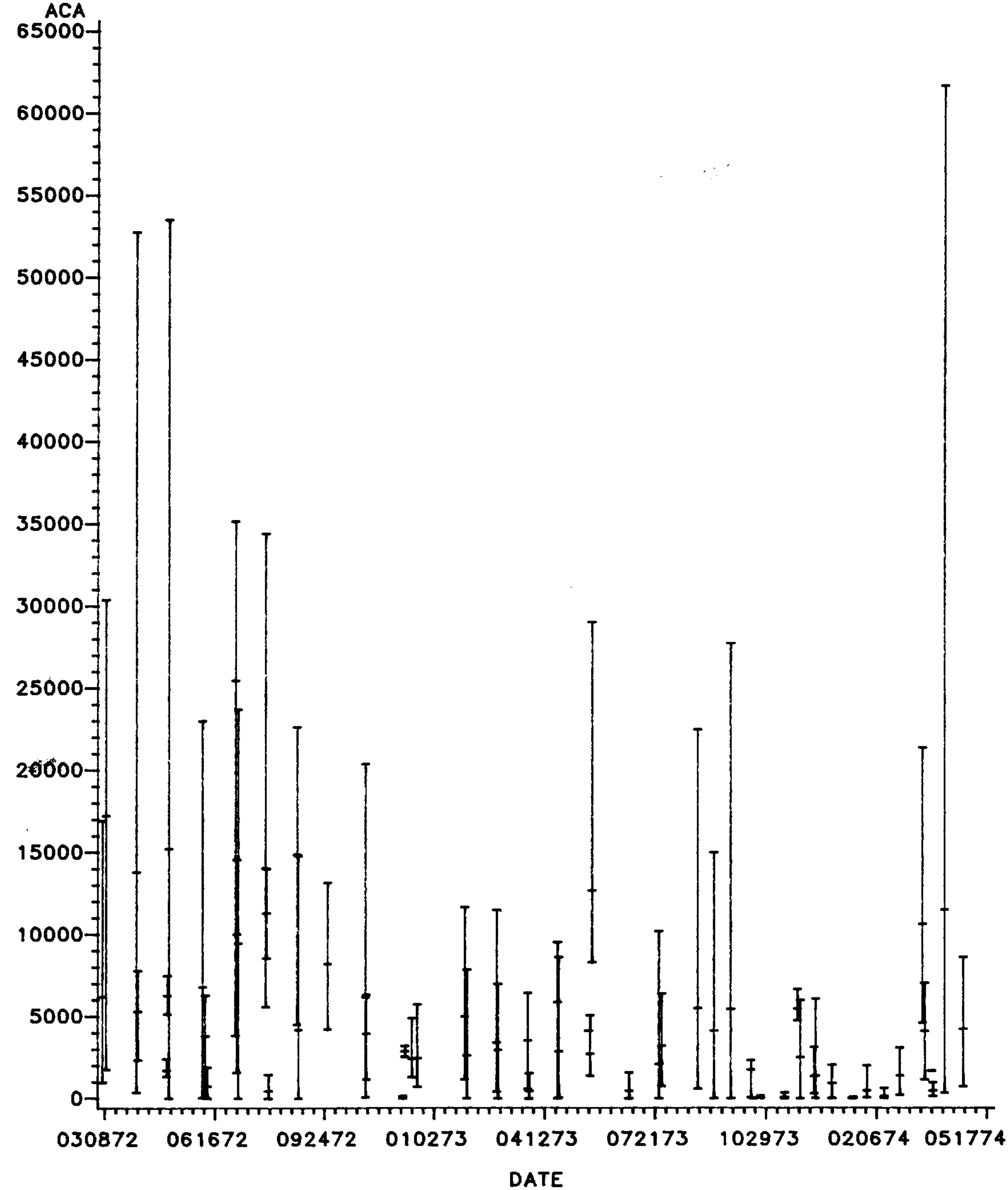

Figure 13.

RESPONSE OF ACARTIA TO TEMPERATURE AND SALINITY (SAN ANTONIO BAY)

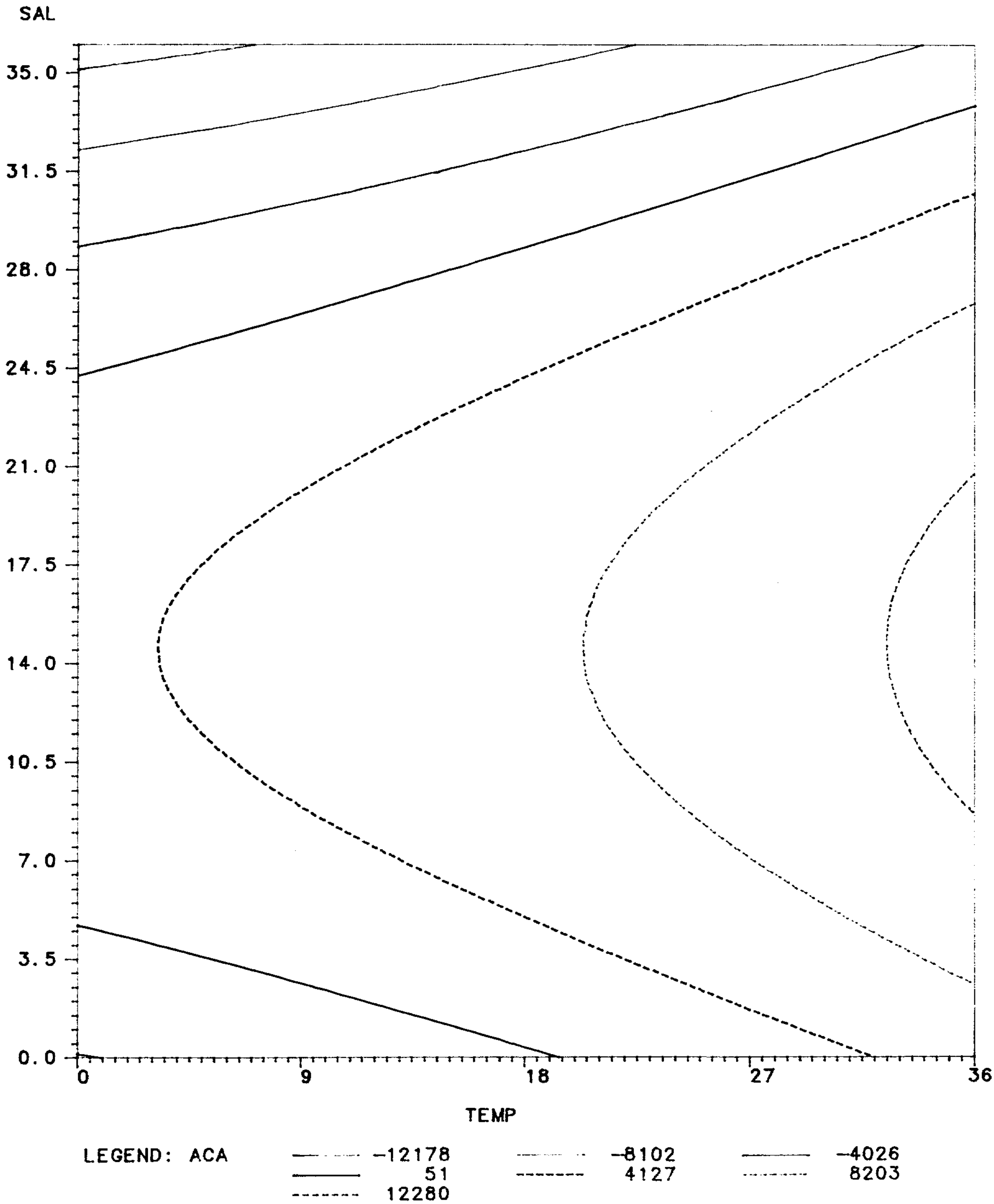

Figure 14.

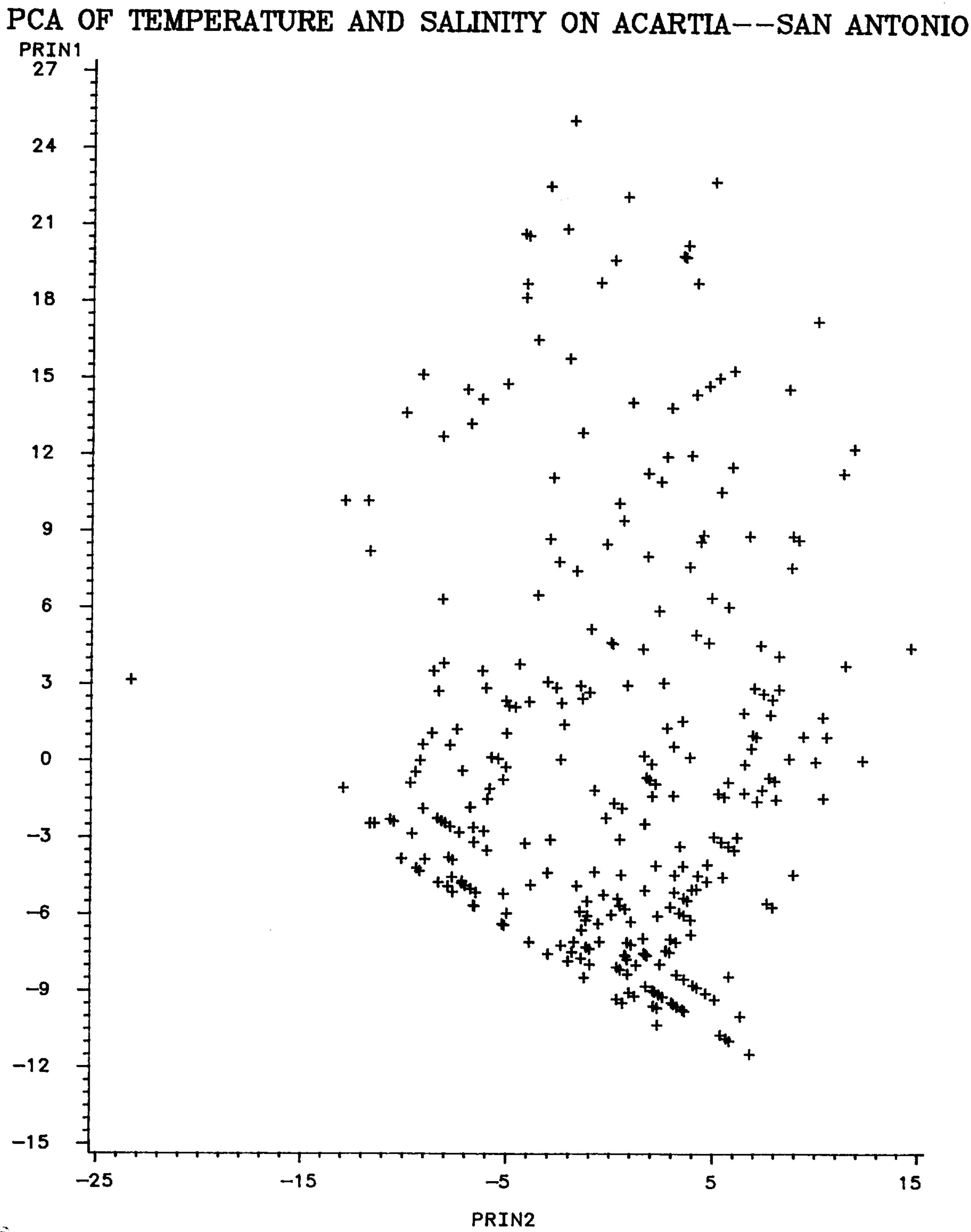
PCA OF TEMPERATURE AND SALINITY ON ACARTIA--SAN ANTONIO
PRIN1
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
-12
-15
-25
-15
-5
5
15
PRIN2

Figure 15.

SEASONAL CHANGES OF TEMPERATURE IN MATAGORDA

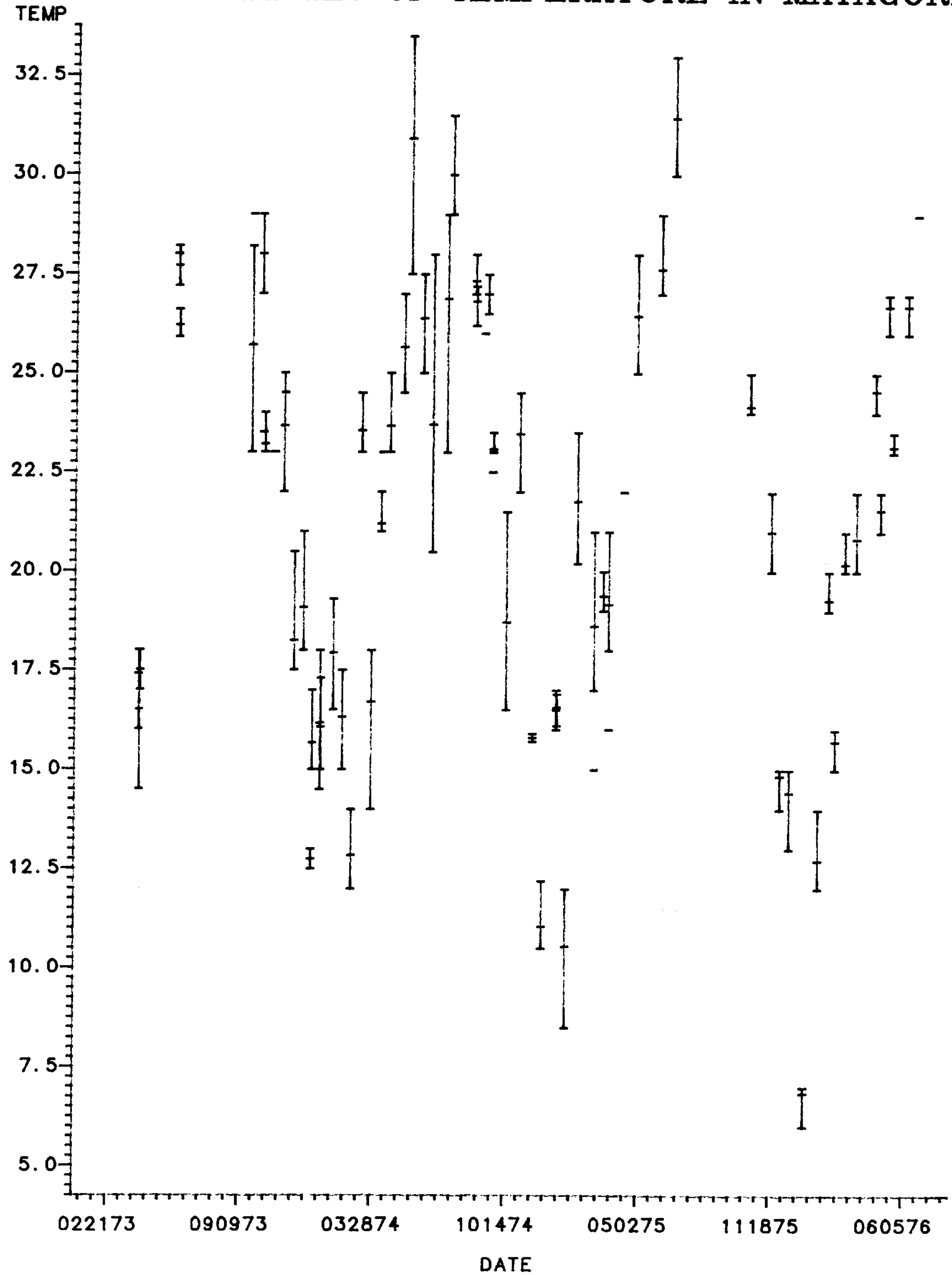

Figure 16.

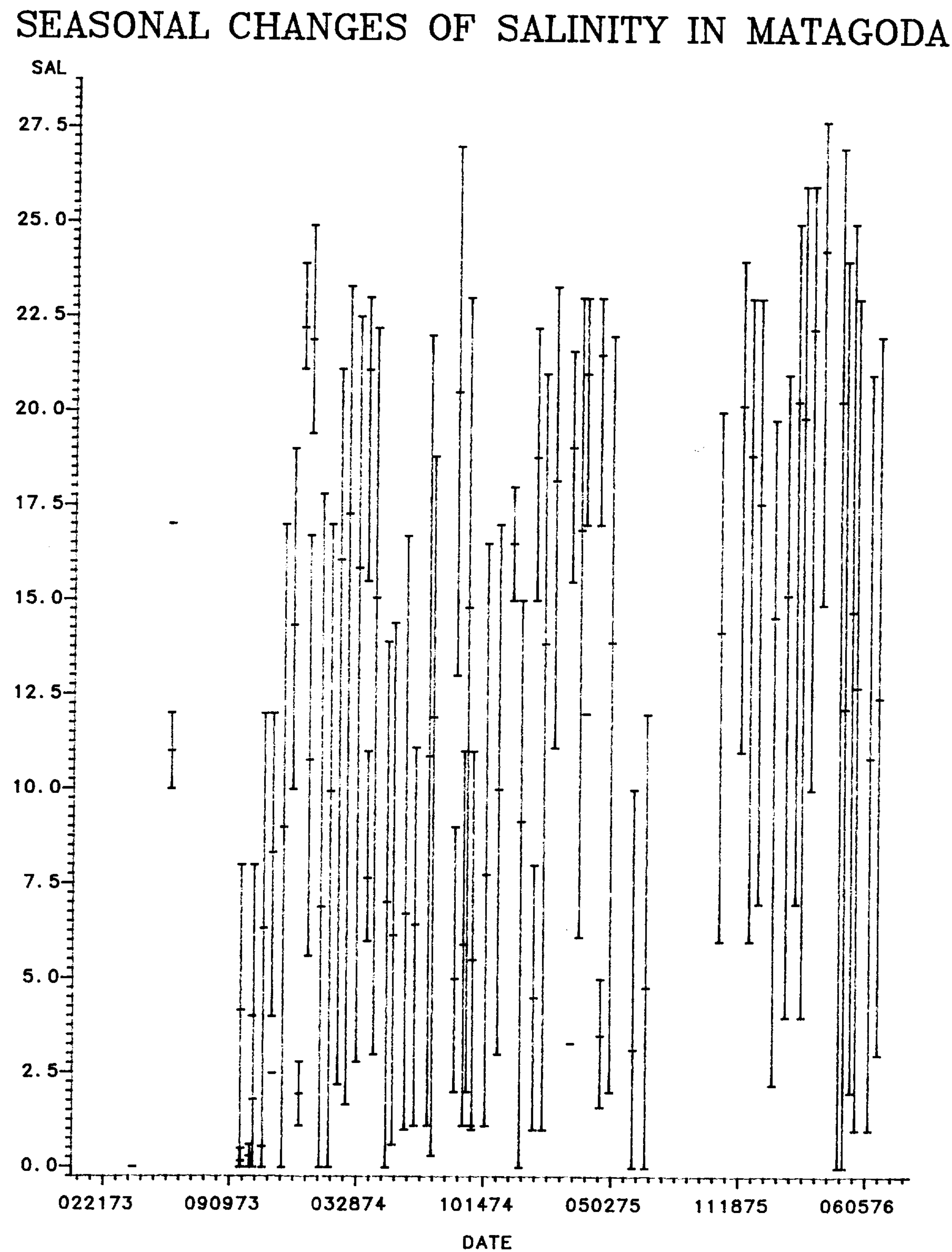
SEASONAL CHANGES OF SALINITY IN MATAGODA
SAL
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
022173
090973
032874
101474
050275
111875
060576
DATE

Figure 17.

SEASONAL VARIATION OF ACARTIA IN MATAGORDA BAY

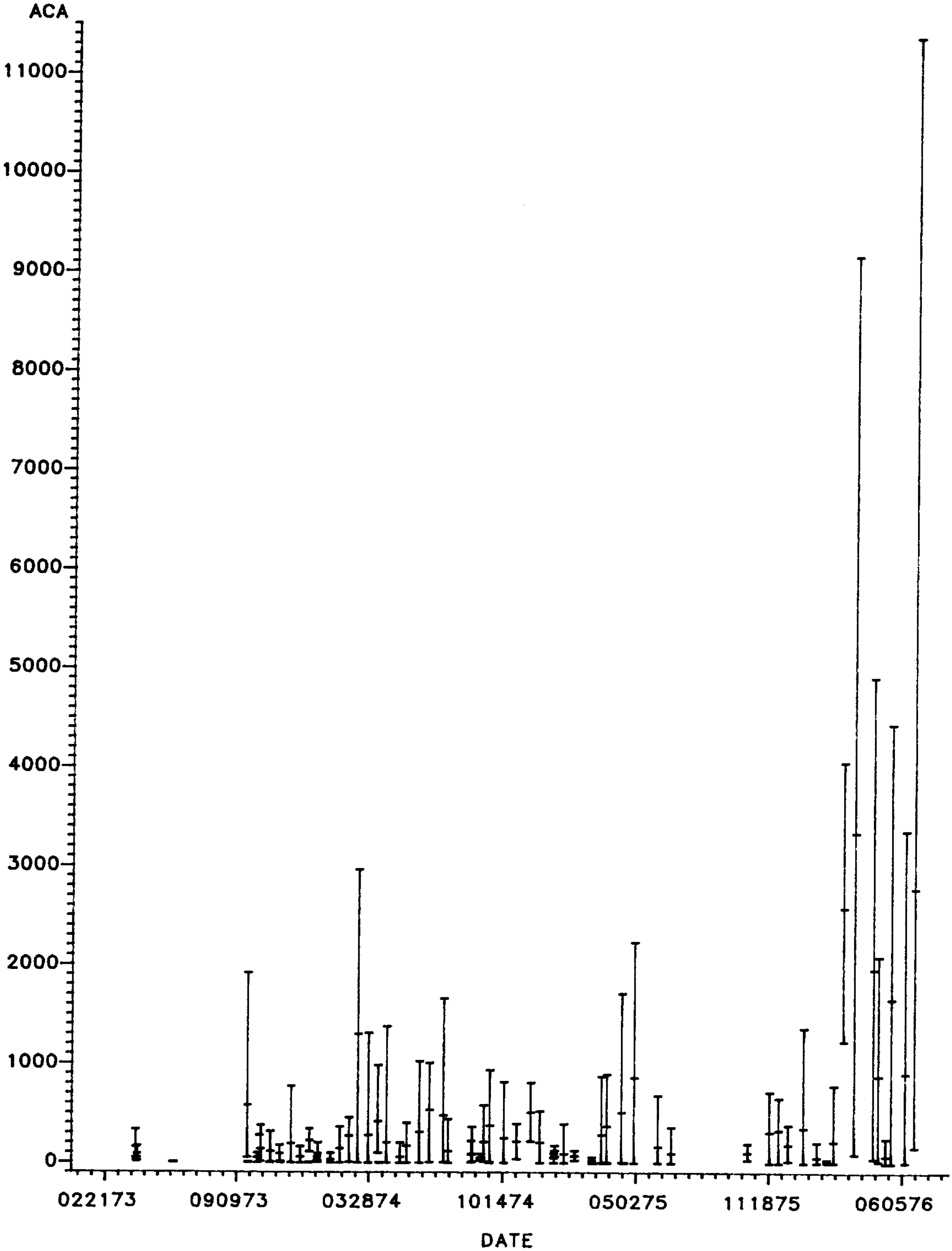

Figure 18.

RESPONSE OF ACARTIA TO TEMPERATURE AND SALINITY (MATAGORDA BAY)

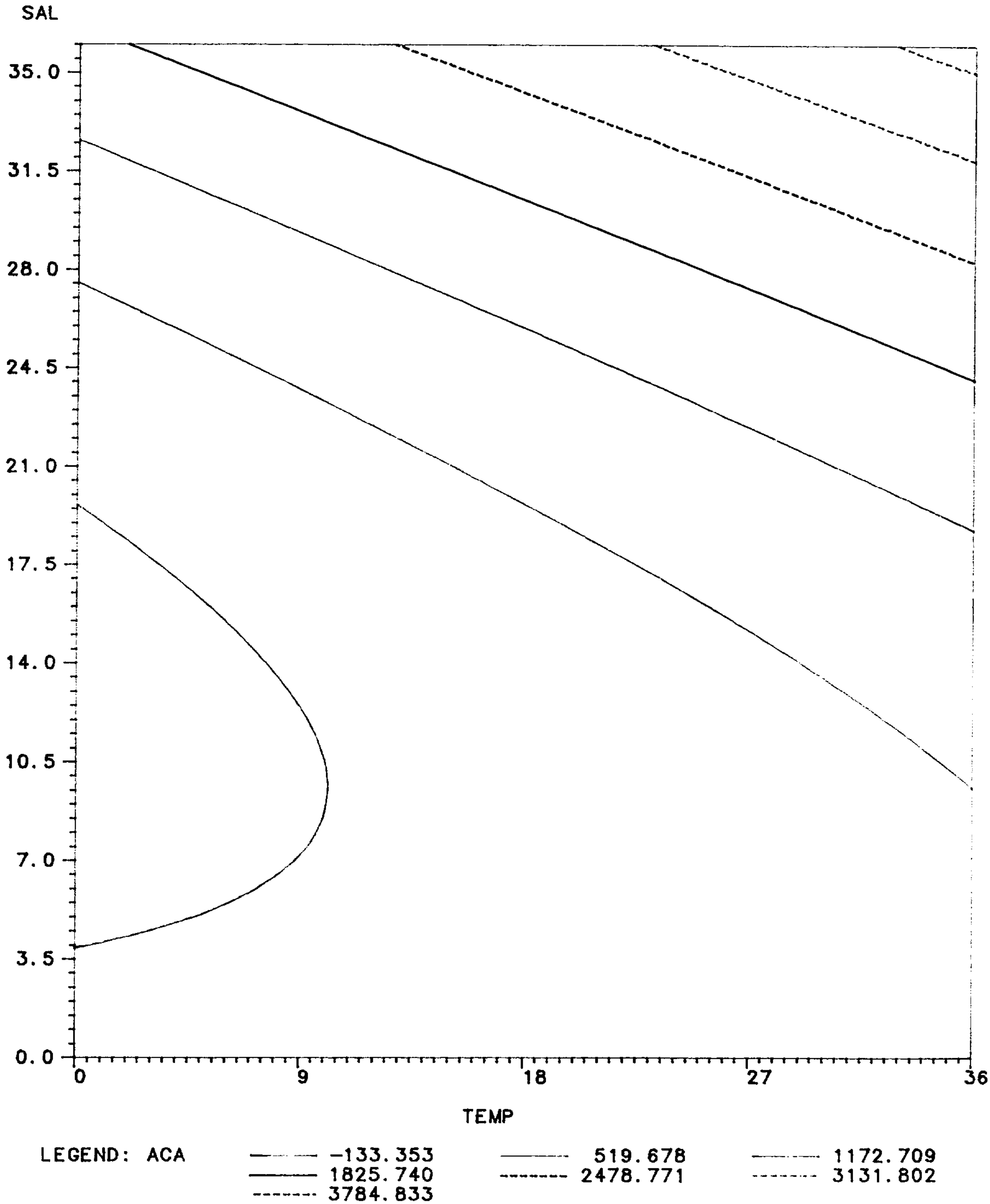

Figure 19.

PCA OF TEMPERATURE AND SALINITY ON ACARTIA--MATAGORDA

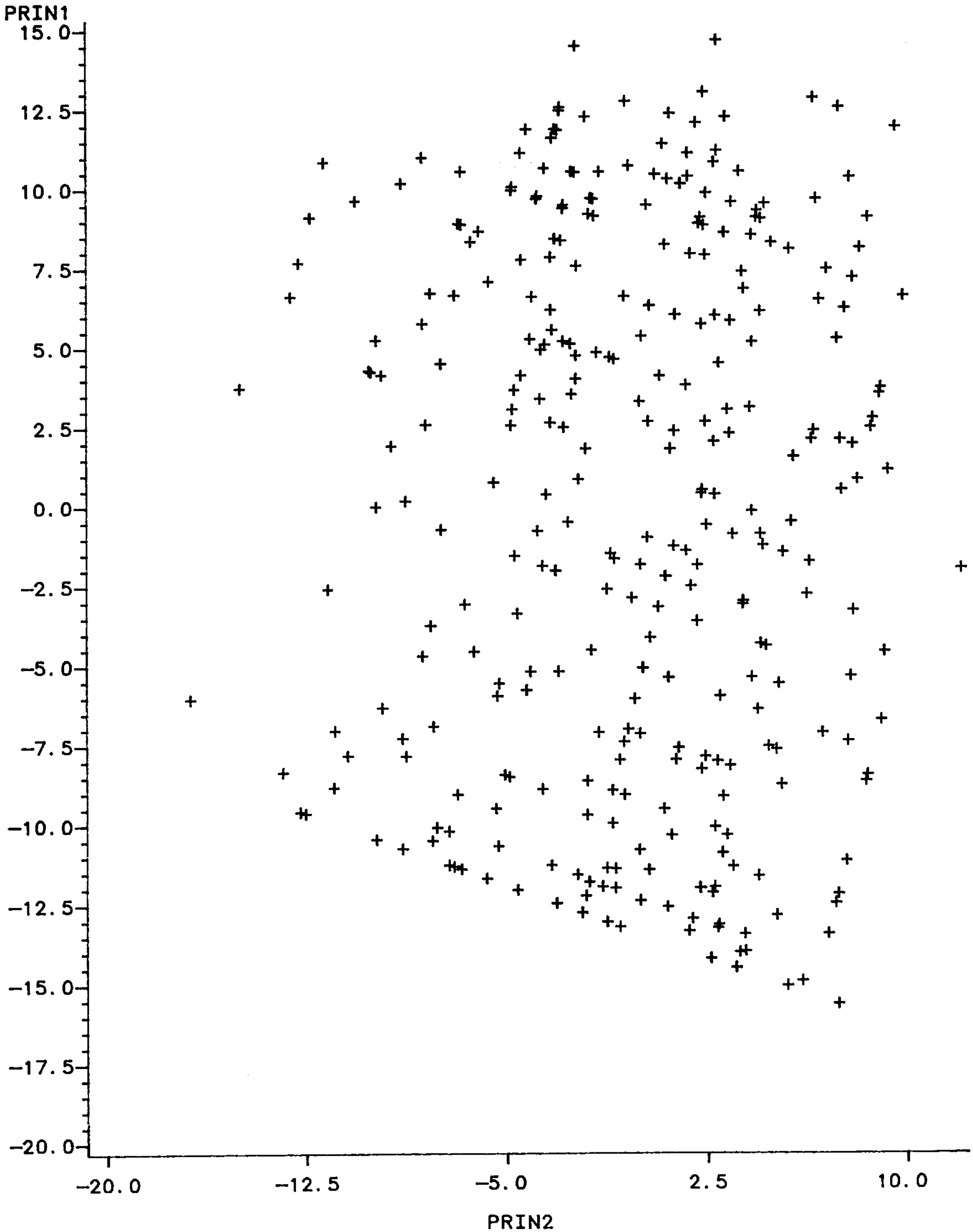

Figure 20.

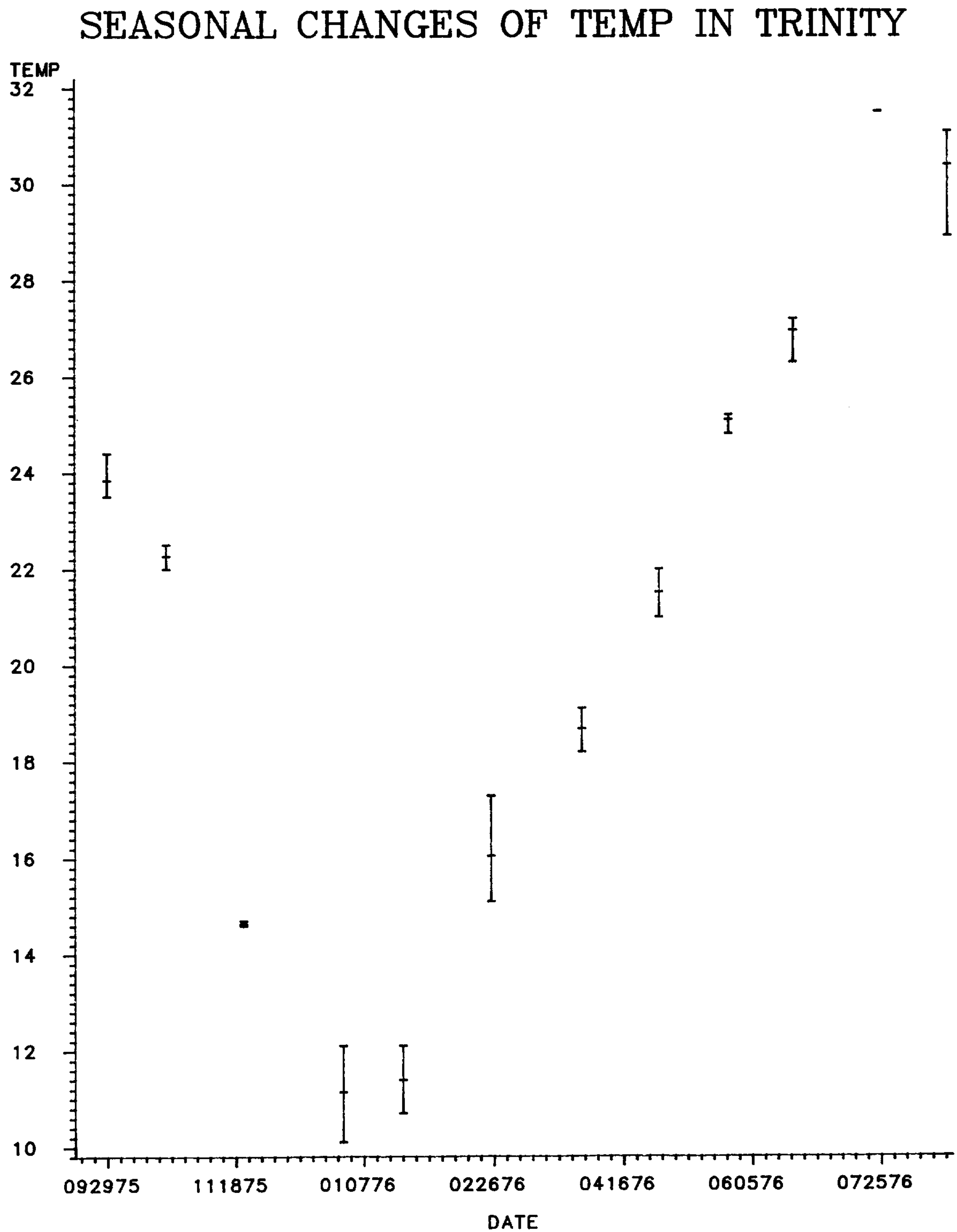
SEASONAL CHANGES OF TEMP IN TRINITY
TEMP
32
30
28
26
24
22
20
18
16
14
12
10
092975
111875
010776
022676
041676
060576
072576
DATE

Figure 21.

SEASONAL CHANGES OF SALINITY IN TRINITY

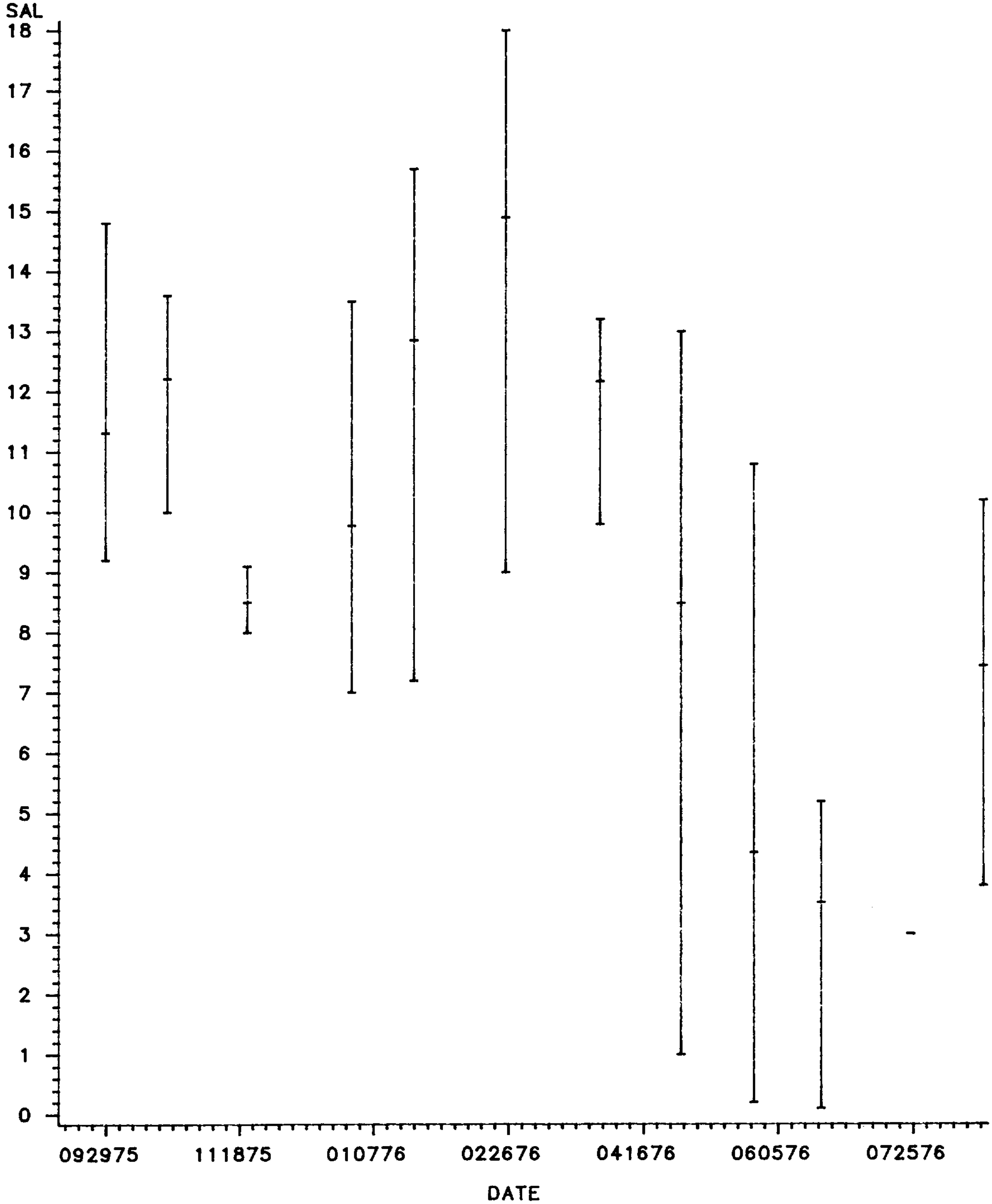

Figure 22.

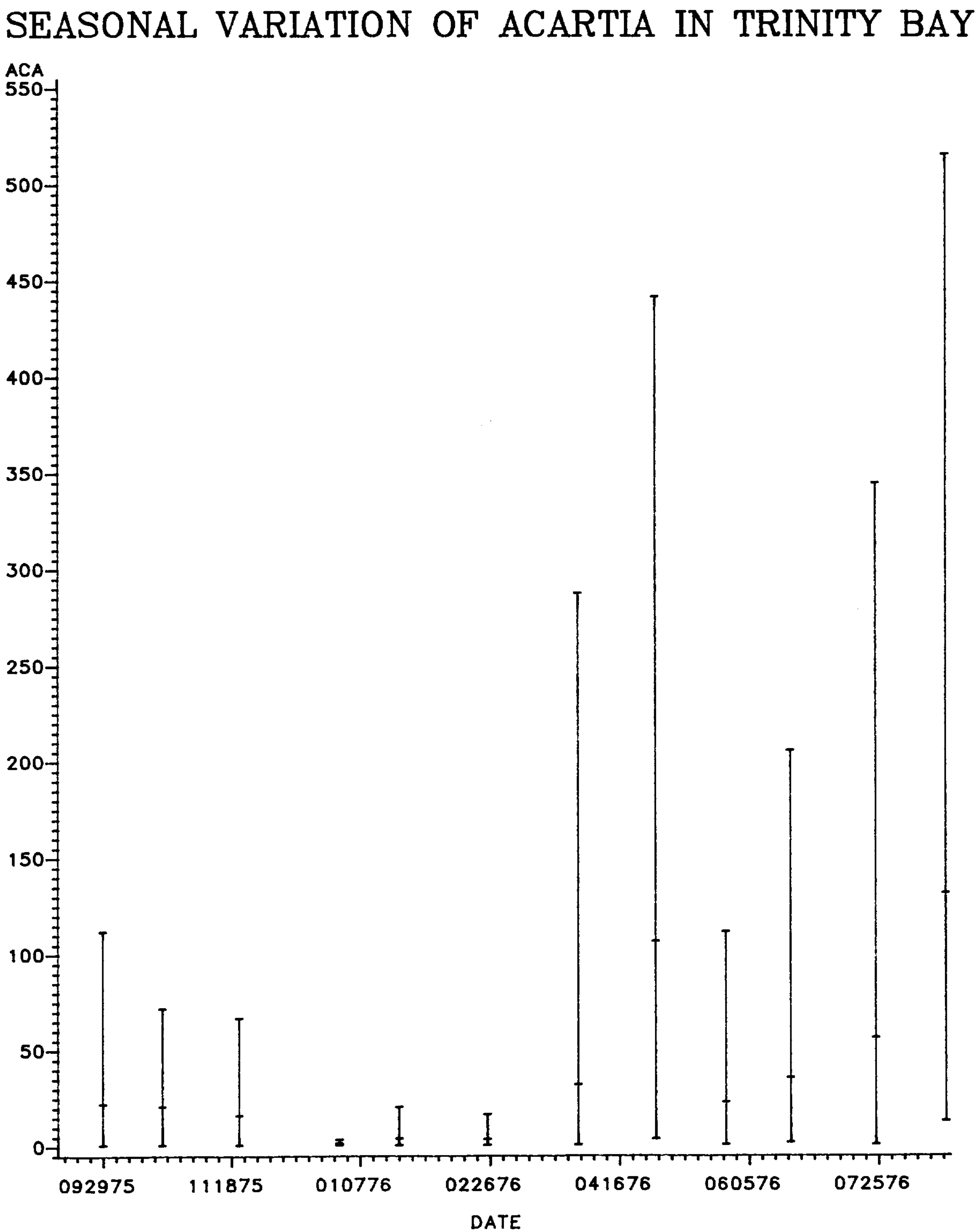
SEASONAL VARIATION OF ACARTIA IN TRINITY BAY
ACA
550
500
450
400
350
300
250
200
150
100
50
0
092975
111875
010776
022676
041676
060576
072576
DATE

Figure 23.

RESPONSE OF ACARTIA TO TEMPERATURE AND SALINITY (TRINITY)

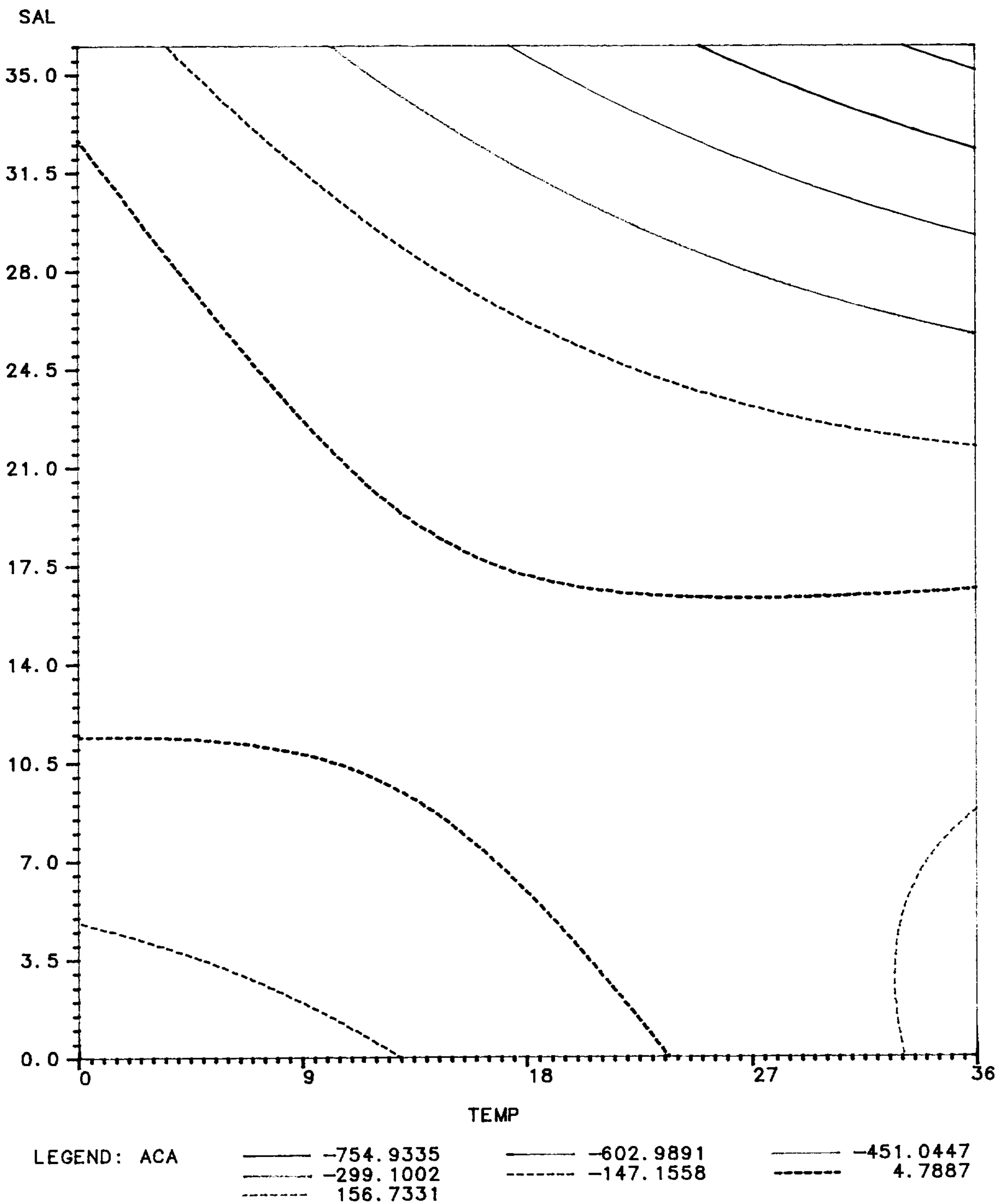

Figure 24.

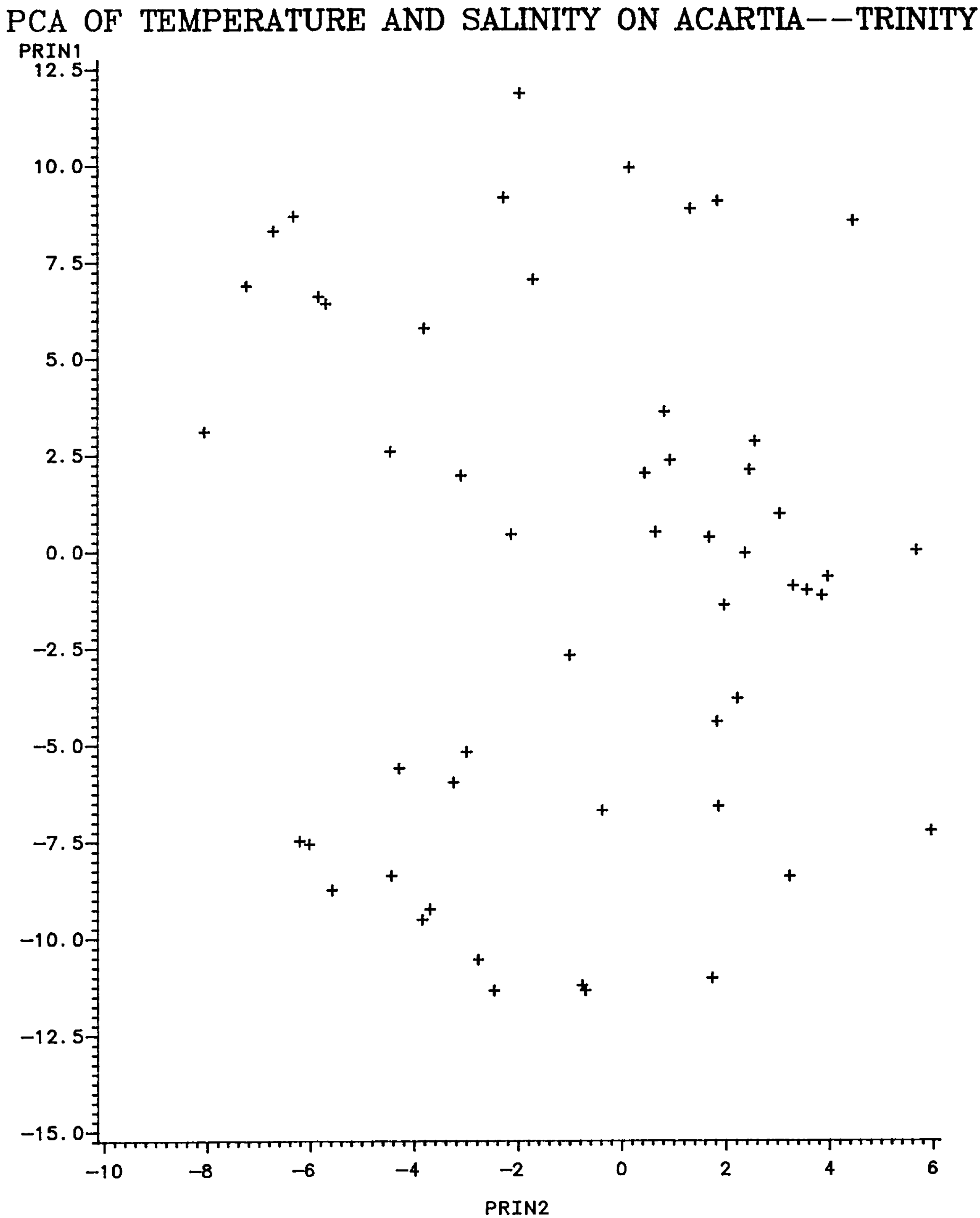
PCA OF TEMPERATURE AND SALINITY ON ACARTIA--TRINITY
PRIN1
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-10
-8
-6
-4
-2
0
2
4
6
PRIN2

Figure 25.

SEASONAL CHANGES OF TEMPERATURE IN SABINE

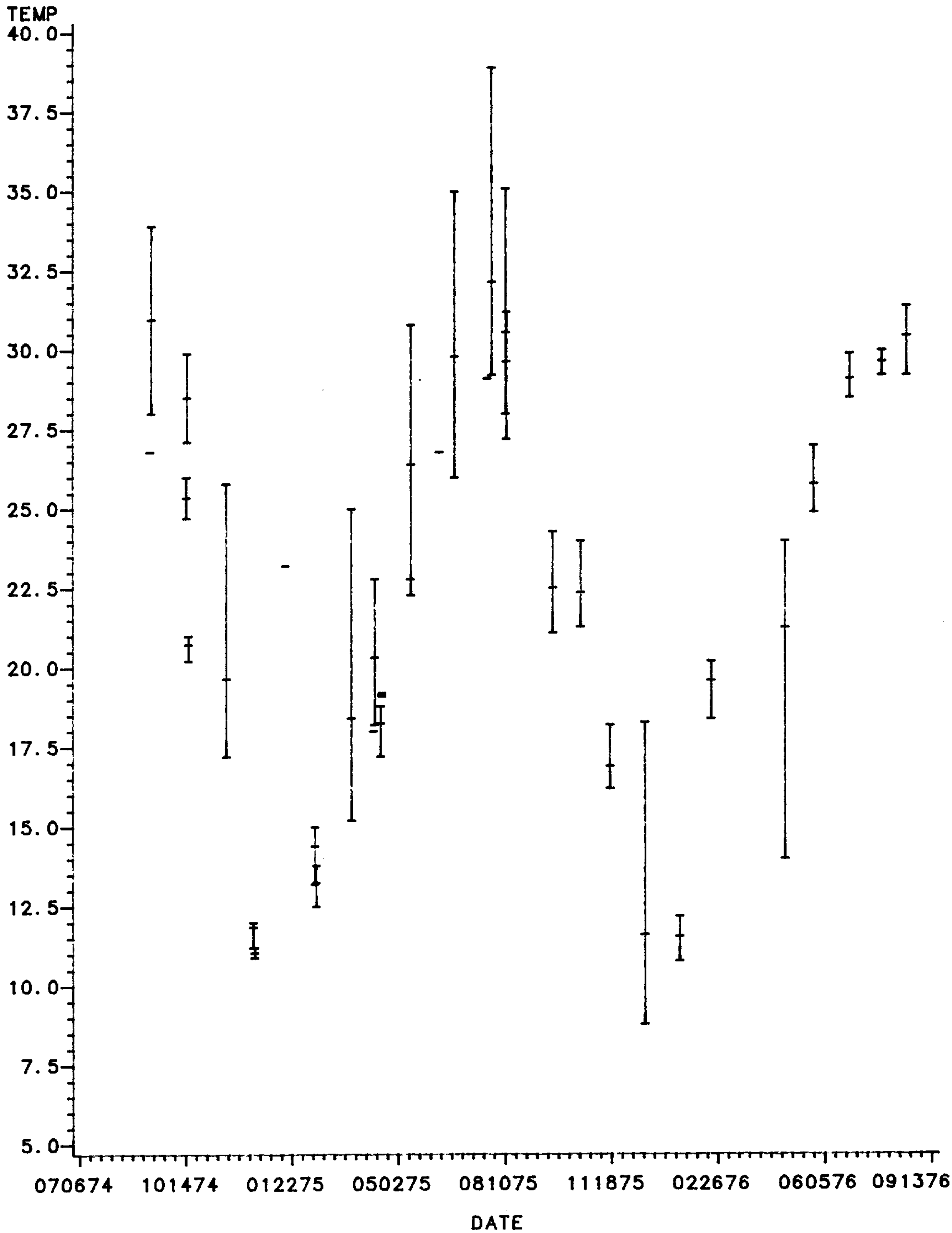

Figure 26.

SESONAL CHANGES OF SALINITY IN SABINE

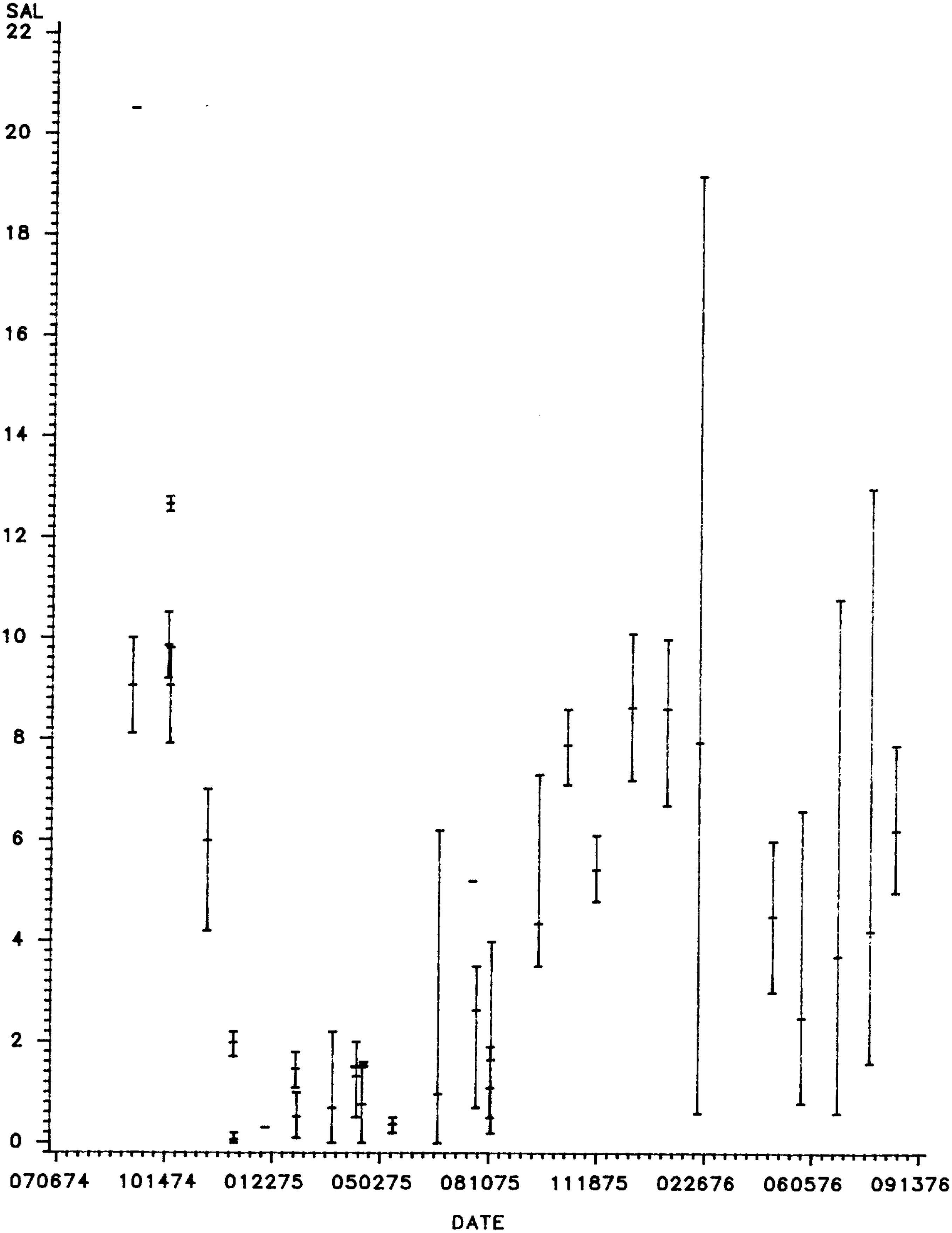

Figure 27.

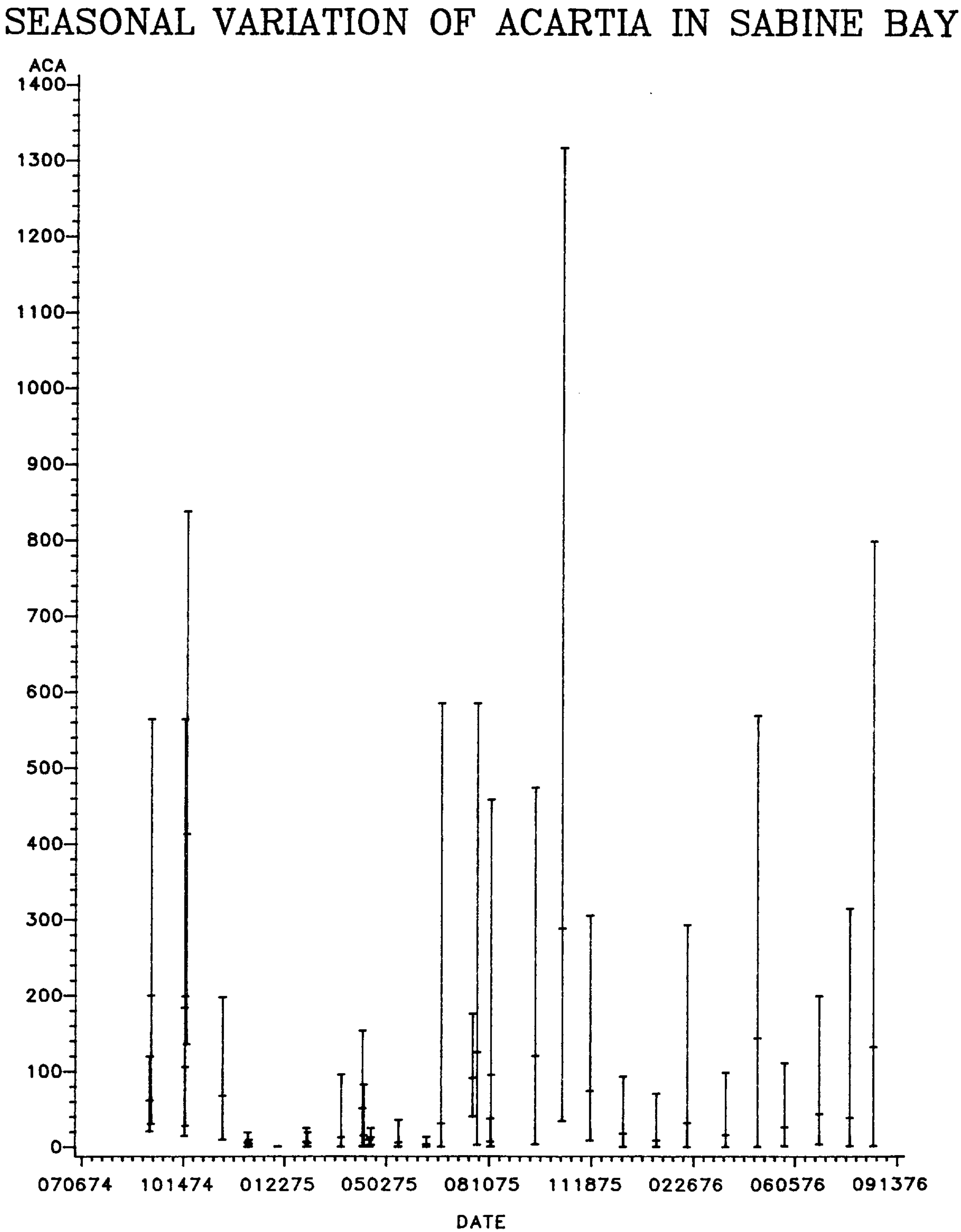
SEASONAL VARIATION OF ACARTIA IN SABINE BAY
ACA
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
070674
101474
012275
050275
081075
111875
022676
060576
091376
DATE

Figure 28.

RESPONSE EQUATION FOR ACARTIA ABUNDANCE WITH TEMP AND SALINITY-SABINE

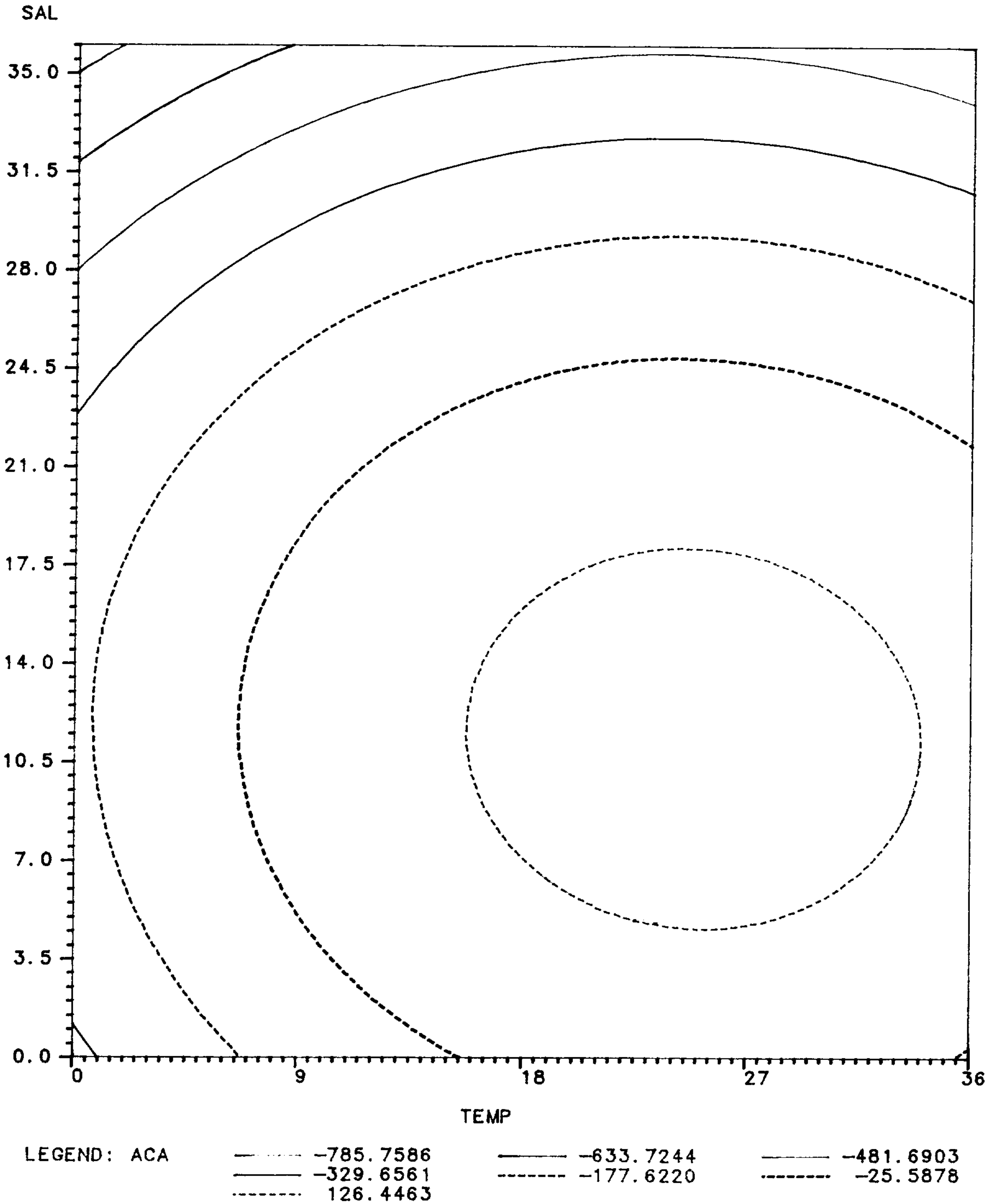

Figure 29.

PCA OF TEMPERATURE AND SALINITY ON ACARTIA--SABINE

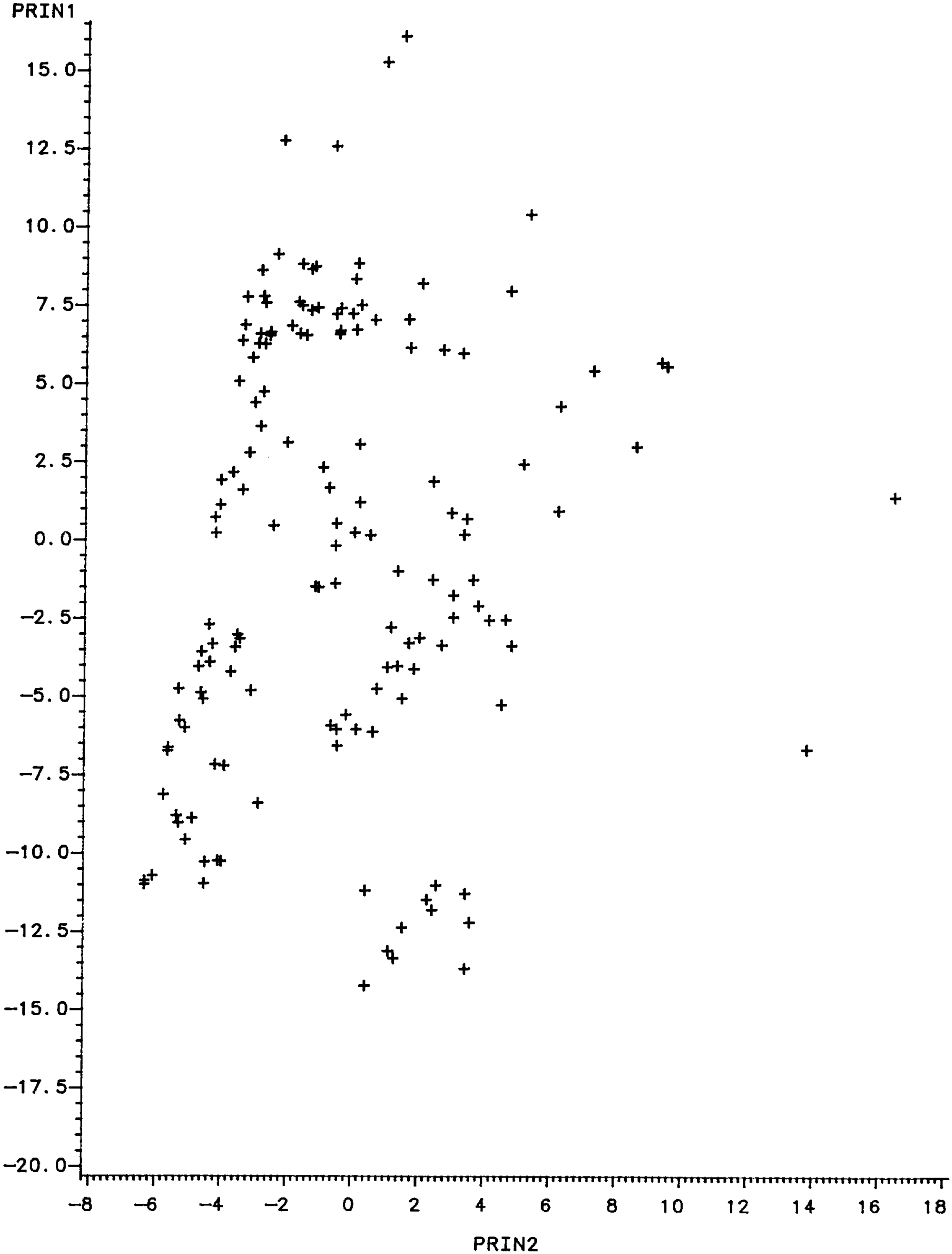

Figure 30.

RESPONSE OF ACARTIA ABUNDANCE TO TEMPERATURE AND SALINITY

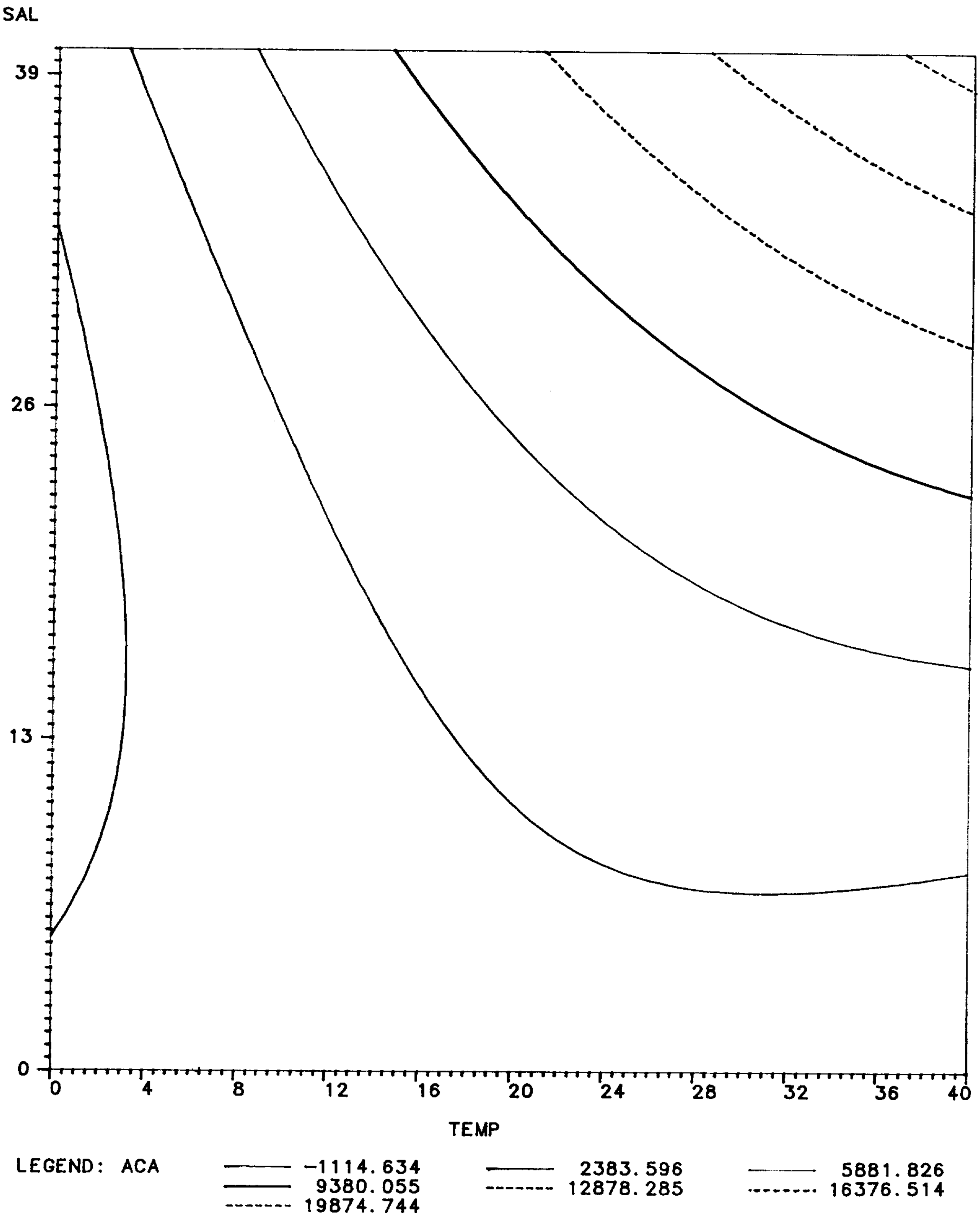

Figure 31.

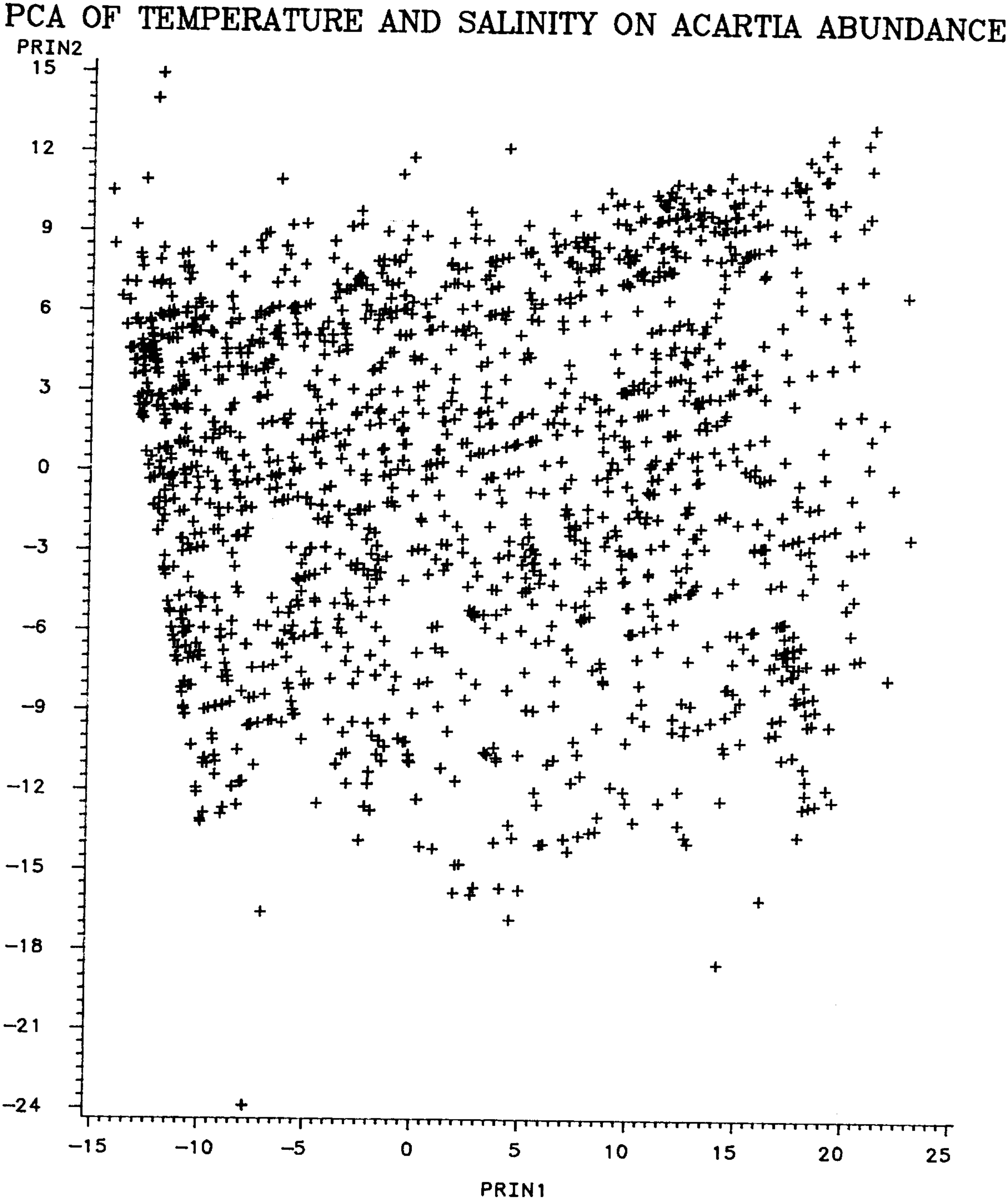
PCA OF TEMPERATURE AND SALINITY ON ACARTIA ABUNDANCE
PRIN2
15
12
9
6
3
0
-3
-6
-9
-12
-15
-18
-21
-24
-15
-10
-5
0
5
10
15
20
25
PRIN1

Figure 32.