DFG Exhibit 28

Exhibit 28, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/ Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta

LONG-TERM TRENDS IN ZOOPLANKTON DISTRIBUTION AND ABUNDANCE IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

EXECUTIVE SUMMARY

There has been a long-term decline in abundance of all native zooplankton taxa with the exception of the copepod *Acartia* and also *Neomysis*. However, three accidentally introduced Asian copepods became abundant in 1979 and 1980 and have helped maintain total copepod populations. One of them, *Sinocalanus*, is suspected of virtually eliminating a native but relatively scarce *Diaptomus* species in much of the Delta and may have affected the distribution and perhaps abundance of the important native *Eurytemora*. Phytoplankton, DFG data as determined by chlorophyll *a*, has also undergone a long term decline. Regression analysis showed that chlorophyll *a* was the variable most often significantly related to the decline in zooplankton and variations in *Neomysis* abundance. Since most zooplankton studied here feed at least in part on phytoplankton, their decline most probably reflects the effects of a smaller food supply.

An analysis of zooplankton abundance in Old River indicates that abundance is unrelated to volume of export pumping at the south Delta pumping plants. But zooplankton abundance in the San Joaquin River at the mouth of Old River appears to be sharply reduced by cross-Delta flow to the pumps. We were unable to distinguish the effects of reverse flow on zooplankton in the San Joaquin River from the effects of salinity intrusion.

LONG-TERM TRENDS IN ZOOPLANKTON DISTRIBUTION AND ABUNDANCE IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

A REPORT FOR THE STATE WATER RESOURCES CONTROL BOARD HEARINGS

INTRODUCTION

Zooplankton is a general name for small aquatic animals that constitute an essential food source for fish, especially young fish and all stages of many forage fishes. These often microscopic animals feed heavily on phytoplankton and thus transfer the energy of primary production to higher trophic levels.

The zooplankton studied by the Department of Fish and Game in the Sacramento-San Joaquin Estuary can be divided into four groups. These are: 1) the opossum shrimp, Neomysis mercedis, 2) small crustaceans called copepods, 3) other crustaceans known as cladocerans, and 4) a separate phylum of tiny animals called rotifers.

Members of all of these zooplankton groups have been found in stomachs of young-of-the-year striped bass but rotifers are not very important. Adult copepods, especially Eurytemora affinis, and cladocerans are the first food items taken by young striped bass. As young bass grow, they switch to a diet dominated by Neomysis.

Neomysis is the least numerous but the largest of the zooplankton, ranging in size from 2 to 17 mm. Adult copepods and cladocerans are approximately the same length, 0.25 to 2.0 mm for cladocerans (depending on species), and 0.5 to 1.4 mm for copepods (again species dependent). Copepods and cladocerans reach about equal densities if all life stages are considered. The most numerous but smallest of the zooplankton are the rotifers which range from only 0.08 to 0.3 mm in length.

Most zooplankton are primarily herbivorous. The copepods, Eurytemora affinis and Sinocalanus doerrii feed on a variety of diatoms, green and blue-green algae and flagellated protozoans. Centric diatoms of the genera Coscinodiscus, and Skeletonema are the most inportant cells in their diets (Orsi 1987) (Figure 1). The chain-forming diatom, Melosira, which has been creating dense blooms in the delta in recent years, is also consumed. But during such blooms copepod guts are often empty. At lower concentrations of Melosira its cells are found in the copepods, sometimes in considerable numbers.

Two cladocerans species studied from the estuary, Daphnia parvula and Bosmina longirostris feed heavily on Chlamydomonas but Melosira can also be an important food item. The cladocerans also consume a wide variety of centric diatoms, green and blue-green algae (Orsi 1987).

Neomysis is omnivorous and may obtain more of its food requirements from smaller zooplankton than from phytoplankton (Siegfried and Kopache 1980). It is large enough to handle Melosira chains, and by breaking them may provide food of manageable size for the smaller zooplankton.

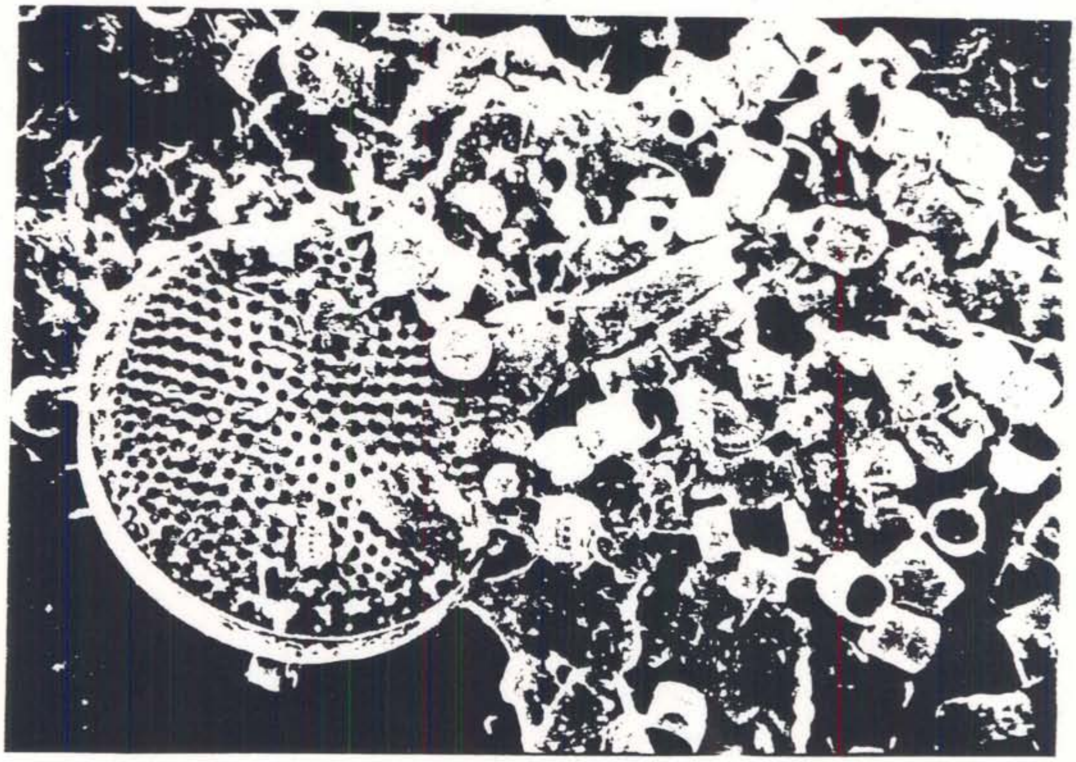


Fig. 1. Eurytemora gut contents from a specimen taken in Suisun Bay in May 1986. The large cell is Coscinodiscus, the small cells are Skeletonema potamos. The elongated cell to the right and just above center is Melosira granulata var. angustissima. This is a scanning electron micrograph at a magnification of 1480 times.

Rotifer food habits have not been studied in this estuary. In other areas they have been found to feed on small phytoplankton (Gliwicz 1969) or protozoa and small cladocerans in the case of large, predatory rotifers (Monakov 1972).

Salinity regulates the distribution of all zooplankton species. There are groups of freshwater, estuarine and marine coastal zooplankton in the estuary. All of the cladocerans are freshwater species although they range or are carried downstream in low numbers as far as the entrapment zone near the upstream end of the salinity gradient. Freshwater copepods are Diaptomus spp., Cyclops spp. and the rare Epischura nevadensis and Osphranticum labronectum. The introduced Chinese cyclopoid copepod, Limnoithona sinensis reaches its greatest abundance in freshwater but is also found in fair numbers in the entrapment zone (Ferrari and Orsi 1983). Another introduced Chinese copepod, this one a calanoid, Sinocalanus doerrii, appears to be a freshwater species that ranges into the entrapment zone (Orsi et al. 1983). Most rotifers are also freshwater species.

Among the estuarine copepods is the native Eurytemora affinis which achieves greatest abundance in the entrapment zone but also extends far upstream into freshwater (Ambler et al. 1985, Orsi and Mecum 1986). The only estuarine rotifer is Synchaeta bicornis, another entrapment zone species with an extensive freshwater range (Ambler et al. 1985, Orsi and Mecum 1986). Other estuarine copepods are most abundant seaward of the entrapment zone. These are Acartia californensis and A. clausi s.l. (Ambler et al. 1985) and Oithona davisae an introduced Asian copepod that reaches its greatest abundance in South San Francisco Bay (Ferrari and Orsi 1984, Ambler et al. 1985). The DFG sampling rarely extends far enough downstream to catch more than an occasional stray member of the marine zooplankton.

Much of the zooplankton data has been analyzed and presented in published papers, e.g., Knutson and Orsi (1983); Orsi and Mecum (1986) but due to data processing problems much of the 1979-1985 data has not been available long enough for an in-depth analysis. We are continuing the work and if significant new conclusions are developed prior to the time of testimony, we will inform the Board.

METHODS

Sampling Frequency and Stations

The monitoring program began collecting *Neomysis* in the upper Sacramento-San Joaquin estuary in June, 1968 and zooplankton in January, 1971. Surveys were initially conducted once a month year-round. In 1972 two surveys were run from April through October and in 1976 another survey was added to March. A single survey was conducted monthly from December through February, 1968-1972 and 1977-1982.

Over the years 88 stations have been sampled in San Pablo Bay, Carquinez Strait, Suisun Bay and the Delta (Figure 2). Not all of them were occupied during a specific survey or year. The river kilometer index designation, station numbers and years sampled are listed in Table 1. Stations in San Pablo Bay and

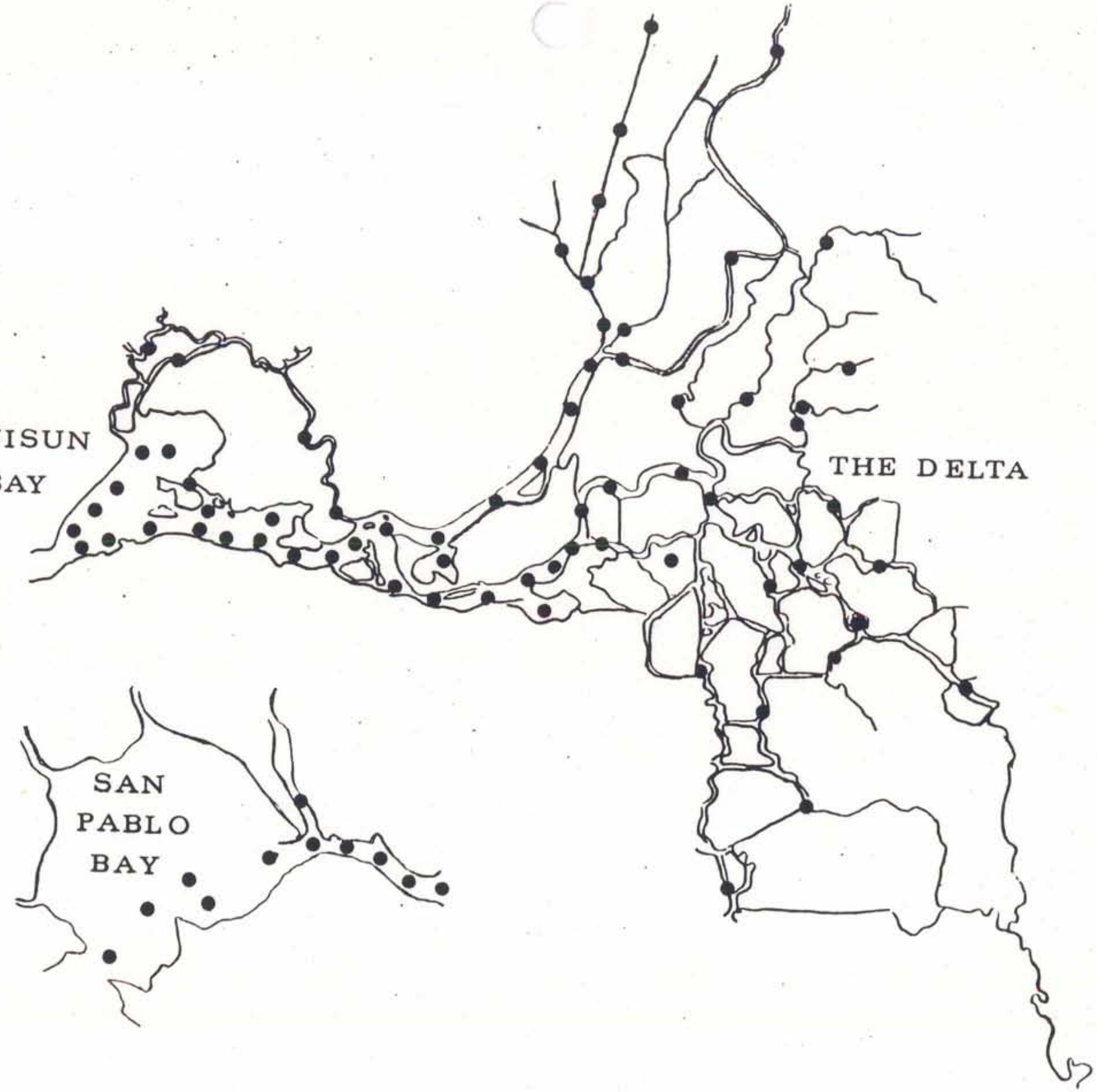


Fig. 2. Map of zooplankton sampling stations in San Pablo Bay, Suisun Bay and the delta. Not all stations were sampled on every survey.

Carquinez Strait were usually not sampled when the pre-tow surface electrical conductivity at them was above 20,000 umhos. Stations located in the Delta frequently were not sampled until March. A number of stations in the northern Delta were sampled only during 1977, the second year of the 1976-1977 drought.

Field Methods

Samples were taken from a 19 foot boat equiped with an "A frame" and winch. Surface temperature, Secchi disc reading and surface electrical conductivity (EC) were taken at each station. Surface EC samples were originally collected at the beginning of each tow and measured in the laboratory. Beginning in January, 1981 a field conductivity meter was used. All EC measurements were standardized to 25 C. Since 1982 surface and bottom pre and post-tow EC measurements have been taken at stations where the pre-tow EC was equal to or greater than 1000 m/s. Chlorophyll a measurement began in March 1976. For this parameter a 3.8 liter bottle was filled approximately half full with water pumped from a depth of 1 meter and two 100 ml sub-samples were drawn from it and aspirated separately through 47 mm diameter glass fiber filters, pore size 0.3 um. The filters were then frozen on dry ice. Chlorophyll a was measured at the Sacramento office of the Federal Bureau of Reclamation.

The Neomysis net was initially made of 1 mm silk bolting cloth, was 1 m long and had a mouth area of 0.1 sq. m. From 1971 through 1973 it was made of 0.93 mm mesh nylon cloth and had a mouth area of .07 sq. m and was 0.7 m long. In 1974 mesh size was reduced to 0.505 mm and mouth area to 0.064 sq. m. while length was increased to 1.48 m. The use of the latter net was prompted by Miller's (1977) finding that 0.505 mm mesh sampled 2 and 3 mm mysids more efficiently. In all years it tapered to 7.6 cm at the cod end where a polyethylene jar screened with 0.505 mm mesh wire cloth captured the mysids. Until 1973, Pygmy flow meters were used to estimate water volumes filtered by the Neomysis net. Since then, General Oceanics model 2030 flow meters have been used.

The Clarke-Bumpus net was mounted directly above the Neomysis net. It had a mouth area of 0.013 sq. m and was made of 154 um mesh nylon cloth (No. 10 mesh). It was 73 cm long and tapered to 4.5 cm diameter at the cod end. A stainless steel bottle with a screened opening collected the captured organisms. Stepwise bottom to surface oblique tows lasting 10 minutes were made except when high algal concentrations clogged the nets and forced a reduction to 5 minutes. Microzooplankton were collected at the end of the tow using a pump emptying into a 19 liter carboy. The hose was raised from bottom to surface to provide a vertical sample. The carboy was then shaken and a 1.5 to 1.9 liter subsample drawn. All Neomysis and zooplankton samples were preserved in 10% formalin with Rose Bengal dye added to aid in separating the animals from detritus and algae.

Laboratory Methods

Neomysis samples were spread evenly in a square tray equipped with removable partitions for subsampling. Those samples which appeared to have more than 400 specimens were divided into 4, 16 or 64 subsamples. All the mysids in a selected subsample were counted. Initially, a minimum count of 200 was required. This was increased to 400 in 1984. The first 100 mysids counted were measured to the nearest millimeter from the eye to the base of the telson. Beginning in 1976 they were identified as being juvenile, gravid female, non-gravid female or male. Twenty females per sample, if available, with full brood pouches had their young counted and assigned to three developmental stages: eggs comma-shaped embryos and eyed embryos.

Clarke-Bumpus samples were concentrated by pouring them through a cup screened with 154 um mesh. Water was then added to the sample and the volume recorded. The sample was stirred to distribute the animals homogenously and a 1 ml sub-sample extracted with an automatic pipet and placed in a Sedgwick-Rafter cell. All animals were identified and counted under a compound microscope. Additional 1 ml sub-samples were examined until at least 200 animals had been counted.

The pump samples were processed by measuring and recording the sample volume, then concentrating the sample by pouring it through a cup with 154 um mesh followed by one with 43 um mesh. The organisms retained by the 43 um mesh were identified and counted in a Sedgwick-Rafter cell.

The zooplankton taxa identified varied over the years. From 1972 to 1975 an effort was made to identify organisms to species. Thereafter, the genus level was used except for important species or when only one species was present in a genus.

Calculations

The total number of Neomysis per cubic meter was calculated using the following equation:

$$N = T \times S/V$$

Where:

N = the number of Neomysis per cubic meter

T = mean number of mysids counted in tray segment(s) subsampled

S = number of tray segments

V = volume of water filtered through the net (m^3)

The number per cubic meter for each zooplankton taxon taken in the Clarke-Bumpus net was calculated as follows:

$$Z = C \times V/S \times N$$

Where:

Z = number of zooplankton per cubic meter

C = number of specimens counted

V = sample volume (ml)

S = number of Sedgwick-Rafter Cells counted

N = volume of water strained by the net (m^3)

The number per cubic meter for the pump was calculated by the equation:

$$M = C*L/V$$

Where:

M = organisms per cubic meter

C = the number of specimens counted

L = the number of milliliters in 1 cubic meter (1*10 E6)

V = the sample volume in millliliters

The Clarke-Bumpus and pump values of each taxon were then summed.

Computer Data Storage

The data was stored in the Environmental Protection Agency's STORET water quality data base under the agency code 21CAL-85, the read only unlocking key for which is BIOSDAT. Only pre-tow surface EC measurements are in STORET.

Media and SMK codes for Neomysis are I.ARTHU and 582 respectively. The number per cubic meter, length frequencies and sex were stored under different UMK codes. These codes are used in conjunction with parameter code 71233. UMK code 0N010000 yields the total number of Neomysis per cubic meter and UMK code 0N0100xx gives the number of Neomysis per cubic meter at a given length where "xx" is replaced by the two digit number representing the length in millimeters. The egg and embryo counts were not placed in STORET.

Three UMK codes are used with the zooplankton data. UMK code 0S010000 gives the sum of the number per cubic meter for the Table 2

Clarke-Bumpus sample and the pump sample. When only the Clarke-Bumpus sample is available the UMK code is 0C010000 and when only the pump sample is available the UMK code is 0P010000. All three codes are used in conjunction with parameter code 71233.

Method of Analysis

This report uses annual (March to November) averages of zooplankton abundance and independent environmental variables in multiple regressions to evaluate which independent variables affect zooplankton abundance. The use of such regressions is common in limnology (Peters 1986) and has yielded useful results. For instance, McCauley and Kalff (1981) used data from 13 lakes to show that phytoplankton biomass was a good predictor of zooplankton biomass, and Canfield and Watkins (1984) found that different zooplankton groups (copepods, cladocerans, rotifers) were positively correlated with chlorophyll a concentrations in Florida lakes. In the Sacramento-San Joaquin Estuary, Knutson and Orsi (1983) found tht Eurytemora abundance and Chipps Island electrical conductivity were useful predictors of Neomysis population size during the July-October period. Orsi and Mecum (1986) showed that temperature and chlorophyll a were significantly correlated with several zooplankton taxa in the Delta.

Independent Variables Used in the Analysis and How They May Affect Zooplankton Abundance

Many environmental variables potentially affect zooplankton and thus serve as regulators of zooplankton population size. These variables may influence birth and death rates or may cause a net immigration or emigration to or from the study area.

Perhaps the most fundamental variable is river flow. This determines the location of the entrapment zone (a region of long water residence times located between 2,000 and 10,000 umhos surface electrical conductivity) and the degree of salinity intrusion and hence, the location of the various zooplankton populations. High flow can lower temperature in spring as occurred in April 1982 or retard the normal rise of temperature as happened in the springs of 1983 and 1986. Lower than normal temperature at this time of year can prolong the life span of large Neomysis that normally start dying off in spring. Since birth rates are positively temperature dependent, lower temperature will reduce them.

High flow can also scour freshwater zooplankton out of Delta channels and push it as far downstream as Carquinez Strait where the freshwater plankton will lie above the brackish water fauna in the more saline bottom layer. High rates of water movement whether from natural flows or from cross-delta flow to the pumps can limit zooplankton population size by moving the zooplankton along faster than it can reproduce (Ketchum 1954). However, in the Delta net flow velocity has not correlated significantly with zooplankton abundance partly because of the wide variations in abundance along the San Joaquin River where net velocities are quite uniform (Orsi and Mecum 1986).

Temperature not only affects birth rates by regulating egg development time but by controlling the size of crustacean plankton at maturity. High temperature results in smaller adults which produce fewer eggs than large ones (McLaren 1965, Warren et al. 1986). But the positive effect of high temperature on egg development time more than outweighs its negative effect on fecundity.

Food supply also affects fecundity. Inadequate or inappropriate food has reduced zooplankton fecundity in laboratory experiments (Harris 1977, Ambler 1985).

Numerous vertebrate and invertebrate predators exist in the estuary. The large caridean shrimp Crangon and Palaemon feed on Neomysis (Sitts and Knight 1979). Many species of fish eat zooplankton and Neomysis (Stevens 1966, Turner 1966).

DESCRIPTION OF THE ENVIRONMENT

Chlorophyll a

From 1969 to 1985, chlorophyll a annual averages (March to November) were highest in the upper San Joaquin River (upstream from the mouth of Old River) (Figure 3). Suisun Bay had a slightly lower mean concentration and a much smaller range than the upper San Joaquin River. The lowest mean and the smallest range was in the Sacramento River (Collinsville to Rio Vista).

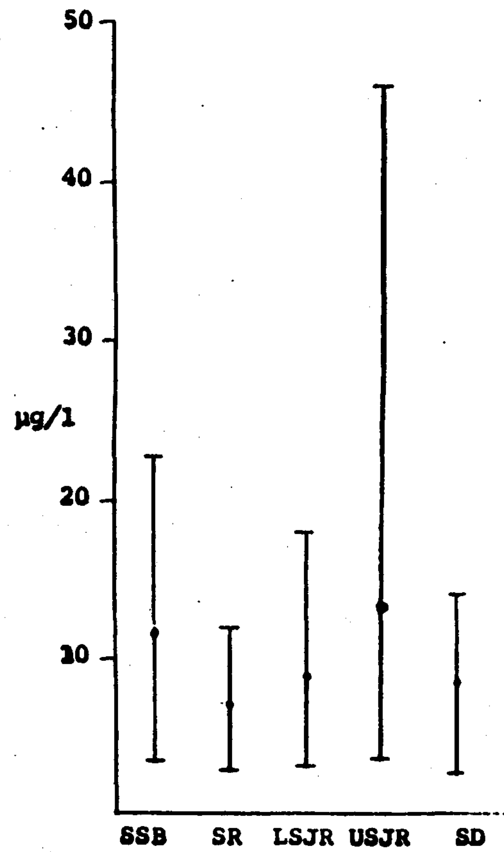


Fig. 3 . March-November means and ranges of chlorophyll a by area, 1969-1985. Areas are SSB - Suisun Bay, SR - Sacramento River, LSJR - lower San Joaquin River, USJR - upper San Joaquin River, SD - south delta.

Long-term trends showed a decline in the Delta from 1970-1971 to 1978 (Figure 4. After that there was a partial recovery due largely to Melosira blooms in 1981, 1984 and 1985.

In Suisun Bay, chlorophyll a was highest from 1970 to 1973, declined sharply to 1977, then experienced a recovery from 1978 to 1981, followed by a further decline (Figure 5). Melosira blooms did not extend into Suisun Bay.

When annual averages are calculated for the pre-drought (1969-1975) and post-drought (1978-1985) periods the decline was greatest in the upper San Joaquin River and least in the South Delta (Figure 6). The area with the highest average chlorophyll a concentrations changed from the upper San Joaquin River in pre-drought years to Suisun Bay in post-drought ones. In the Delta, post-drought concentrations differed little from area to area. The range was only about 2 ug/l.

Note: The use of pre-drought and post-drought periods does not imply causation. The drought simply provides a convenient benchmark at which to separate data from the early nineteen seventies when the striped bass population was still high from later years when the bass population was low. The process of zooplankton decline has been previously shown to have begun before the drought (Orsi and Mecum 1986).

Temperature

From 1972 to 1985 (1969-1971 data is unreliable) mean annual temperature was highest in the upper San Joaquin River and lowest

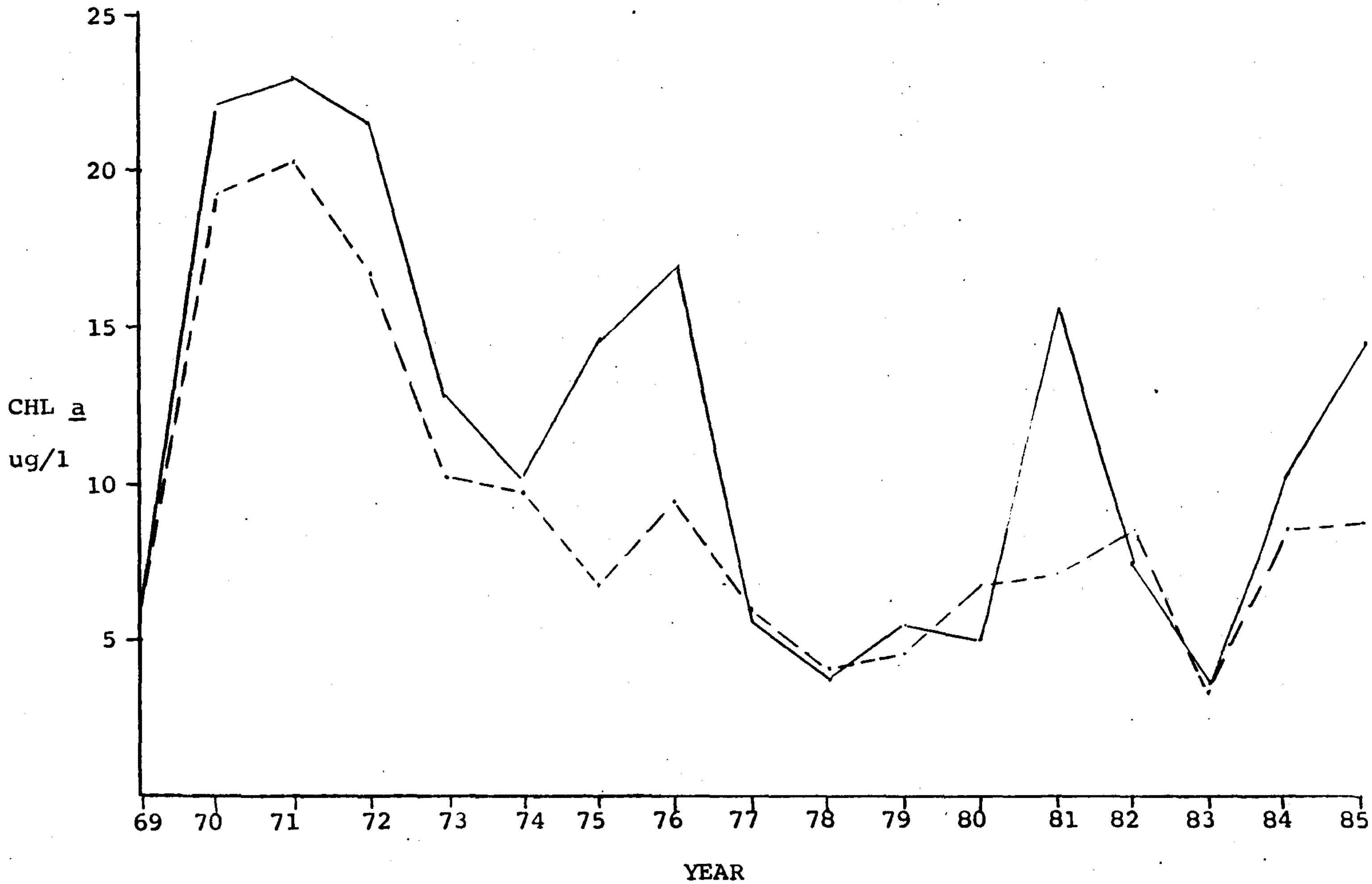


FIg. 4. Trends in chlorophyll a from 1969 to 1985 in the delta. March-November means (——) and April to June means (- - -).

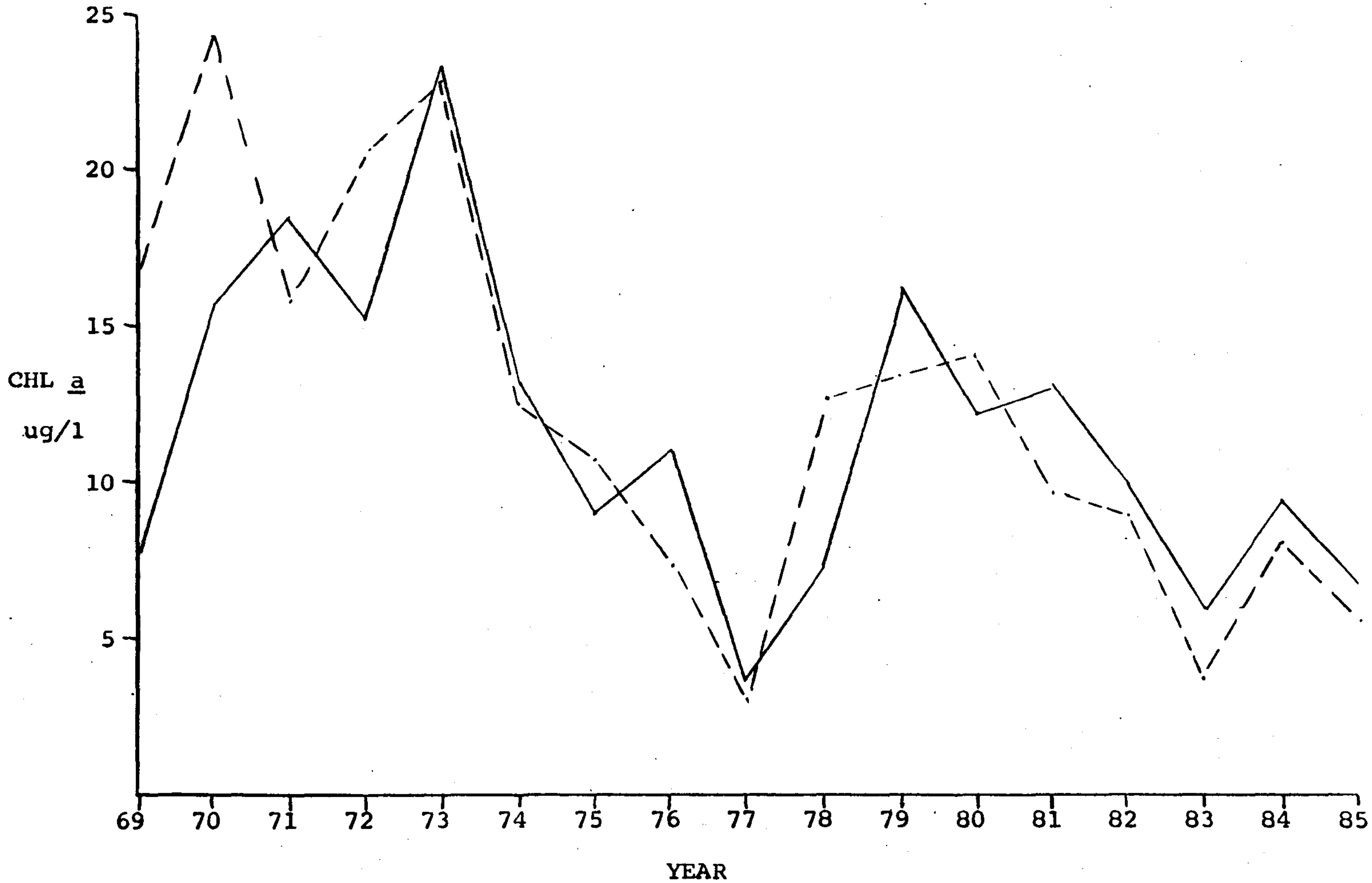


Fig. 5 . Trends in chlorophyll a from 1969 to 1985 in Suisun Bay. March-November means (——) and April-June means (- - -).

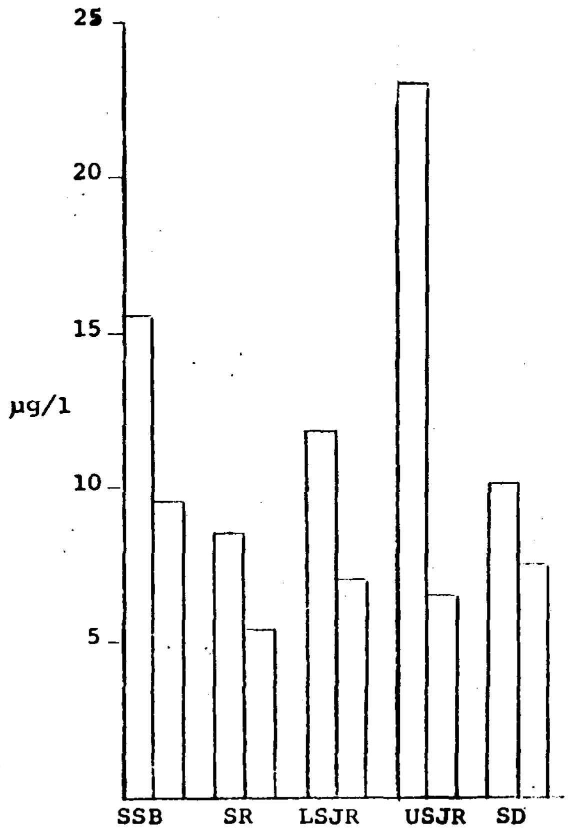


Fig. 6. Mean March-November pre-drought (left bar) and post-drought (right bar) chlorophyll *a* by area. South delta pre-drought years are 1972-1975. For other areas the years are 1969-1975. Post-drought years are 1978-1985 in all areas.

in Suisun Bay and the Sacramento River (Figure 7). Suisun Bay also had the smallest temperature range. The variation in the means was 2.2 C between Suisun Bay and the upper San Joaquin River.

Long-term temperature trends were not examined because pre-drought and post-drought temperature means for each area were similar (Figure 8). The differences were only 0.2 to 0.4 C depending on area, decreasing in some areas, increasing in others.

Outflow, Salinity (EC) and Exports

Mean March-November Delta outflow varied from ~3,000 to 85,000 cfs from 1969 to 1985 (Figure 9). The mean pre-drought outflow (1969-1975) was 24,600 cfs compared to a mean of 28,400 cfs in post-drought years (Table 1). However, the post-drought mean was raised by the extraordinary 1983 outflow of 85,000 cfs which was almost three times greater than the mean for all post-drought years. Without the 1983 flow, the post-drought mean drops to 20,300 cfs, which is 82% of the pre-drought average.

This is reflected in the higher post-drought March-November mean EC at Chipps Island of 3,545 umhos compared to the pre-drought mean of 2,120 uhmos (Table 1). Electrical conductivity is, of course, a negative function of outflow but it is not a straight-line function, rather an exponential one (Figure 10). A small change in outflow at levels <10,000 cfs can result in large EC differences. Conversely, Chipps Island EC is consistently low at outflows ranging from 25,000 to 85,000 cfs.

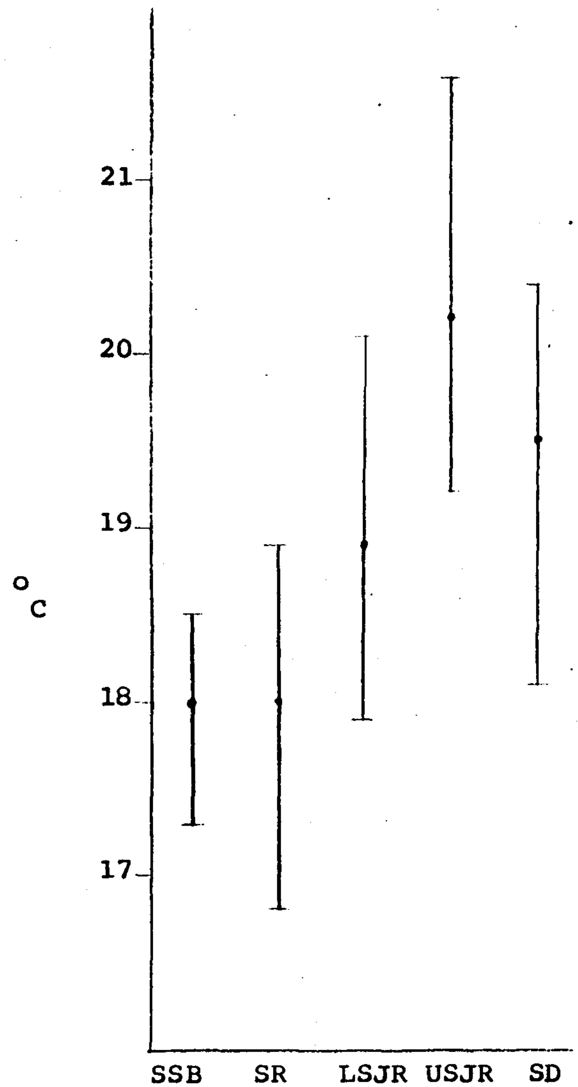


Fig. 7. March-November means and ranges of temperature by area.

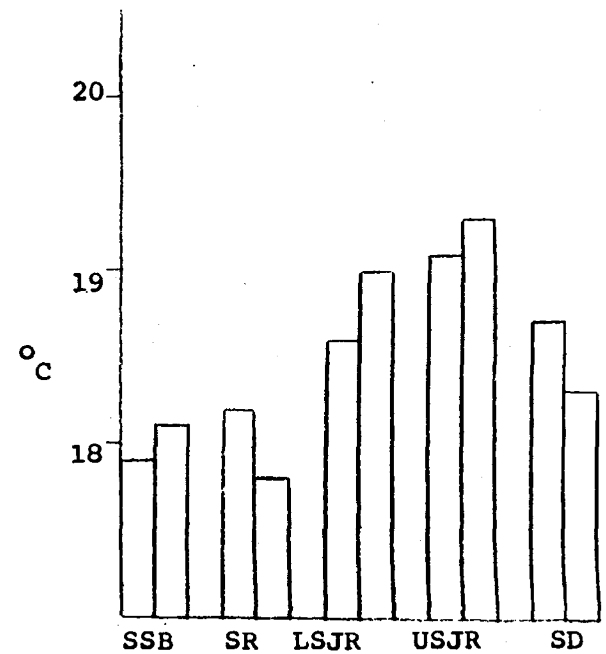


Fig. 8. Mean March-November pre-drought (left bar) and post-drought (right bar) temperature by area.

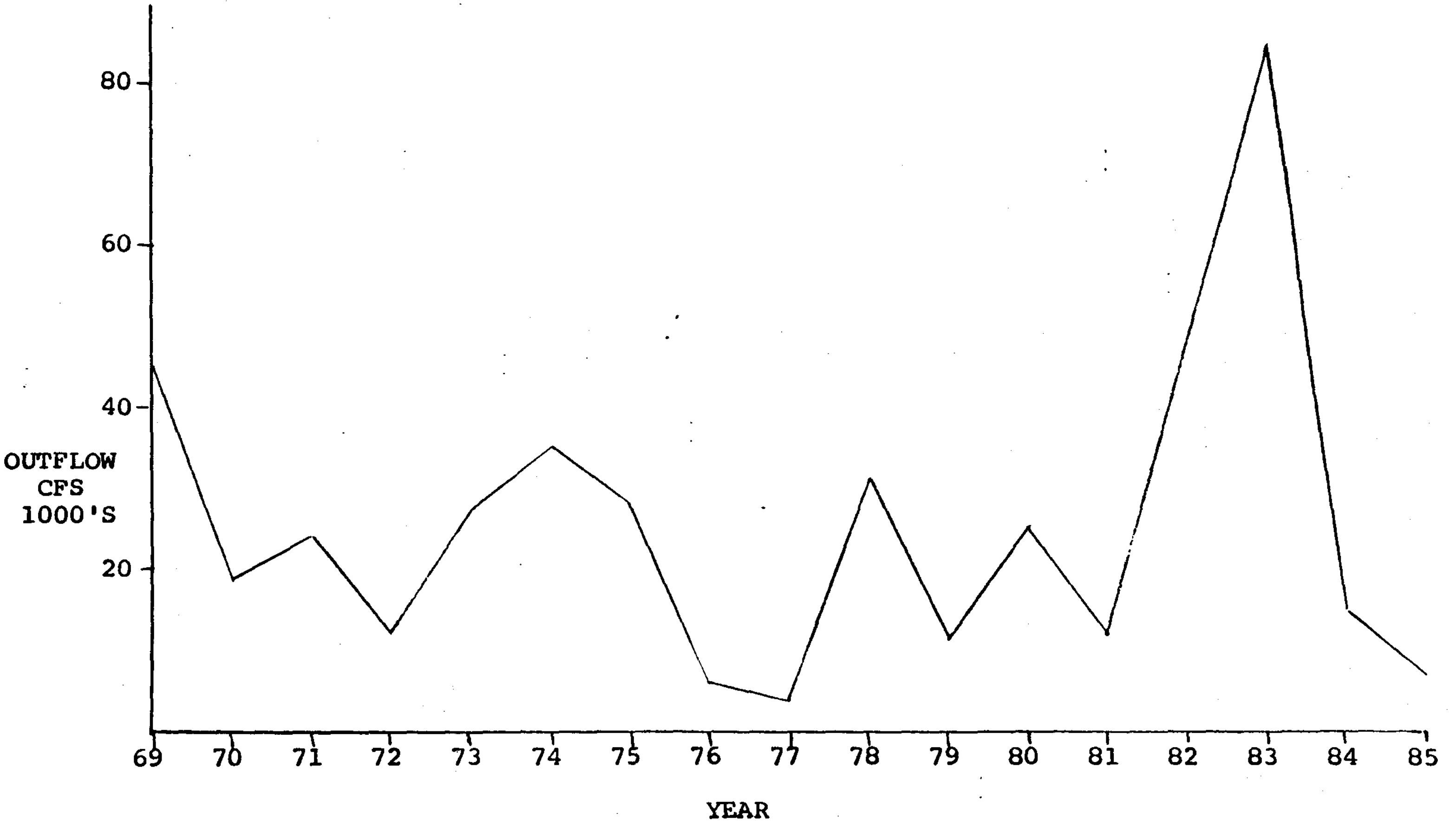


Fig. 9. March-November mean delta outflow measured at Chipps Island from 1969 to 1985.

Table 1. Summary of pre-drought (1969-1975 or 1972-1975) and post-drought (1978-1985) environmental conditions and zooplankton abundance.

Variable	Pre-Drought (1969-1975)	Pre-Drought (1972-1975)	Post-Drought (1978-1985)
Delta Outflow (cfs)	24,600	23,500	28,400
Delta Outflow (less 1983)			20,300
Exports (cfs)	5,810	6,620	7,115
Chipps EC (umhos)	2,120	2,673	3,545

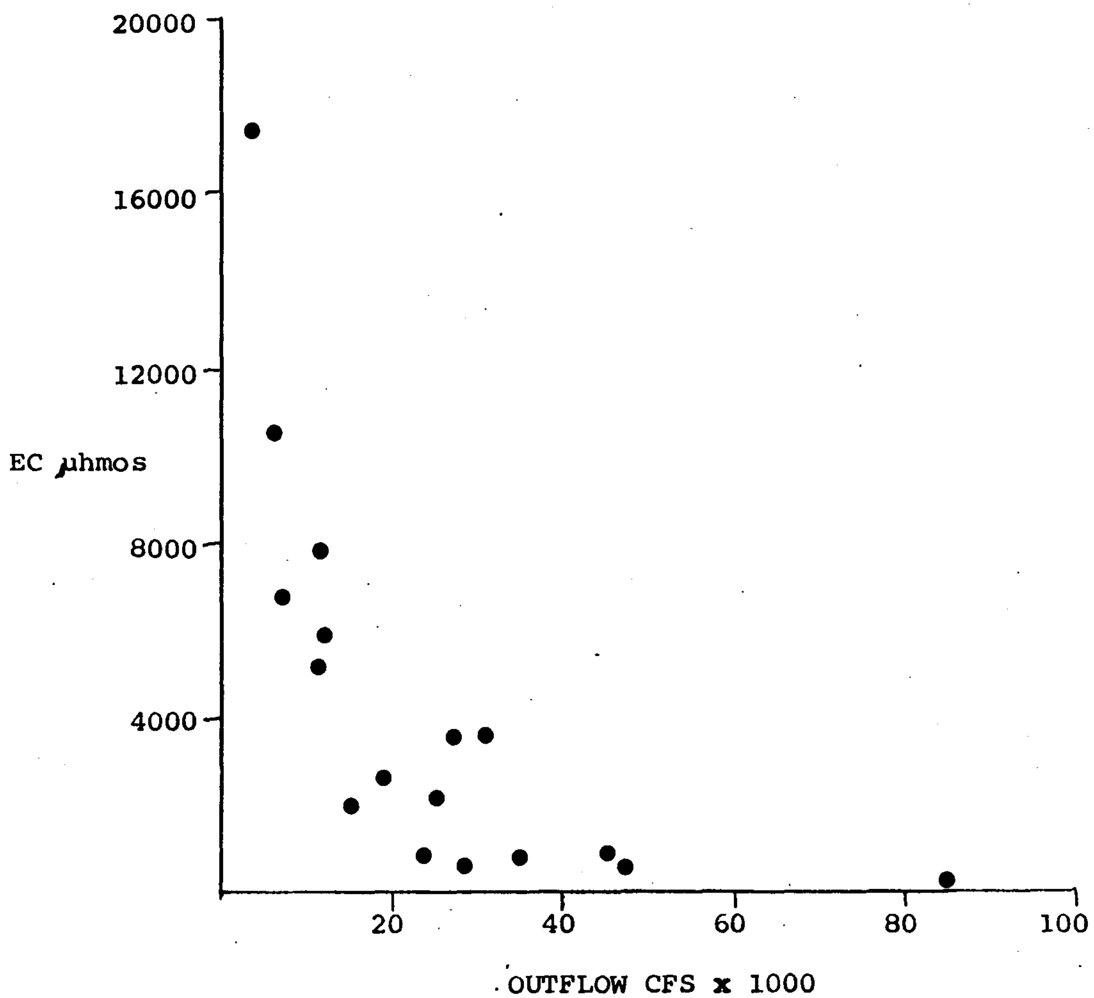


Fig. 10. Relationship between delta outflow as measured at Chipps Island from Dayflow Model and Chipps Island EC. The points are March to November means for 1969-1985.

CVP-SWP export pumping in the South Delta plays an important role in regulating salinity by reducing freshwater outflow. In the post-drought years export levels were 20% greater than in the pre-drought period (Table 1).

TAXONOMIC COMPOSITION OF THE CALANOID COPEPOD FAUNA IN SUISUN BAY AND THE DELTA

Calanoid copepods are important food items for young striped bass (Miller 1986). Four major genera and several species of calanoids are present in Suisun Bay and the Delta (Orsi and Mecum 1986). In order of declining salinity tolerance these are *Acartia* (two species), *Eurytemora affinis*, *Sinocalanus doerrii* and several *Diaptomus* species.

In Suisun Bay, prior to the establishment of *Sinocalanus* in 1979, *Eurytemora* and *Acartia* were the important genera. Relative abundance of each was related to salinity intrusion and hence to outflow (Figure 11). *Eurytemora* was dominant in both wet and dry years but *Acartia* was dominant only in the drought years, 1976 and 1977. *Diaptomus* was never abundant. This pattern did not change with the arrival of *Sinocalanus* but this species constituted an important part of the fauna in wet post-drought years and apparently displaced *Diaptomus* after 1980.

In the Delta *Eurytemora* dominated the fauna in all years before *Sinocalanus* became established (Figure 12). *Acartia* entered the Delta only during low outflows in 1977 and 1981.

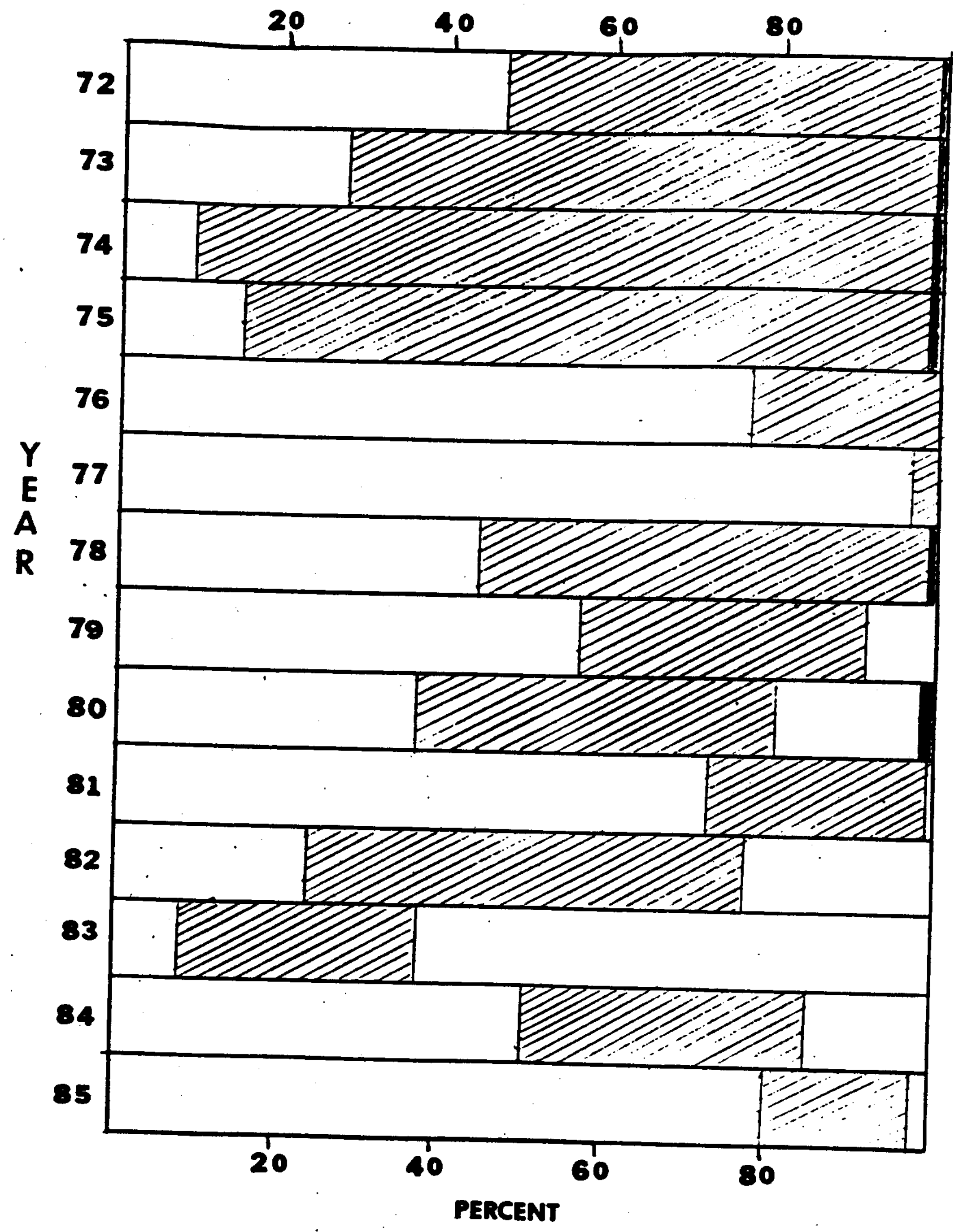
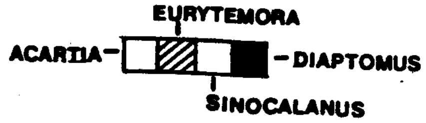


Fig. 11. PERCENT COMPOSITION OF CALANOID COPEPODS IN SUISUN BAY

MARCH–NOVEMBER MEANS



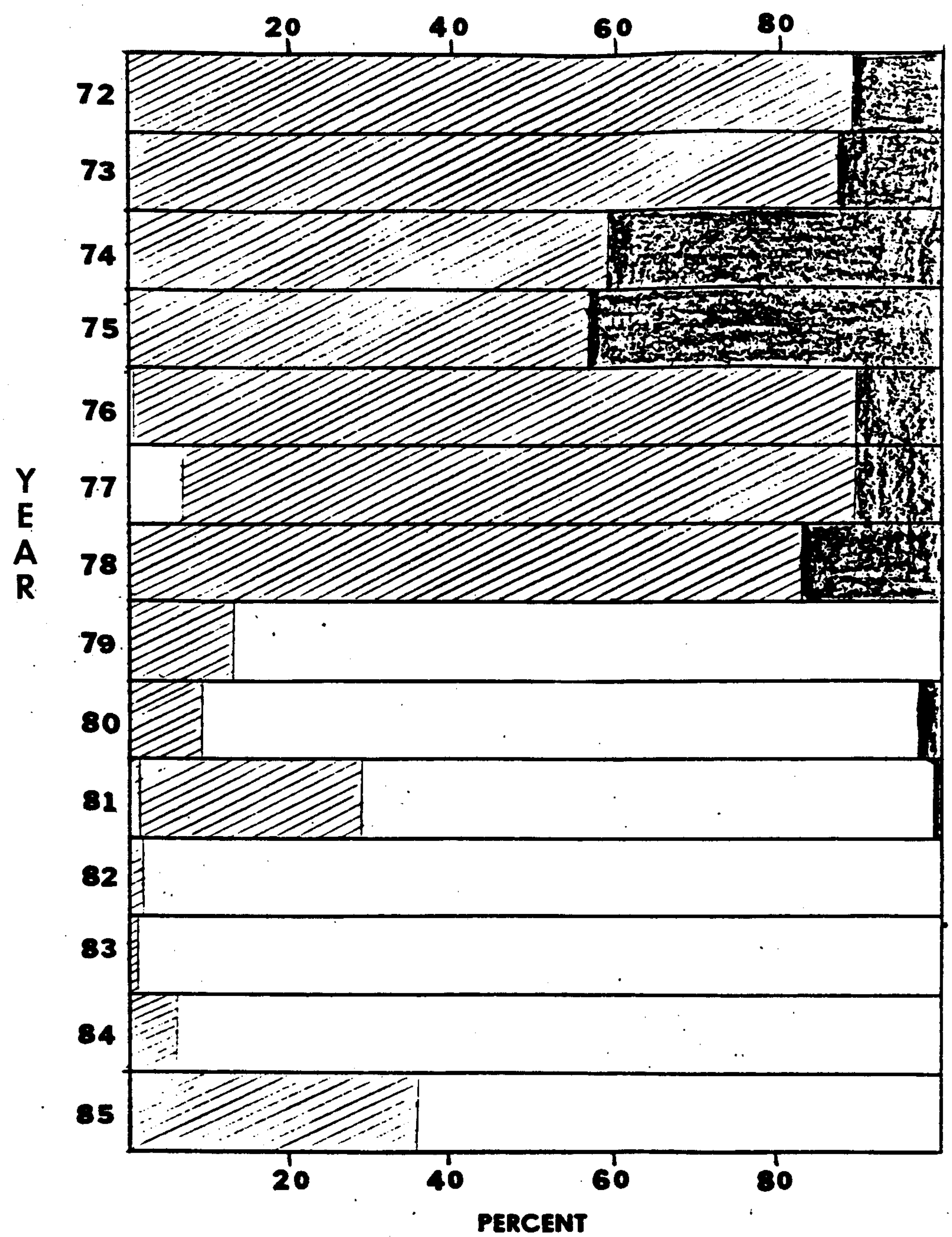
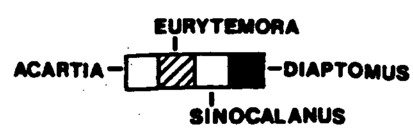


Fig. 12. PERCENT COMPOSITION OF CALANOID COPEPODS IN THE DELTA

MARCH-NOVEMBER MEANS



Sinocalanus apparently displaced Eurytemora downstream in 1979 and has dominated the Delta fauna in all years from then to 1985. Diaptomus has been present only in trace numbers since 1981.

Long-Term Trends in Abundance

All Calanoid Copepods

Calanoid copepod abundance was much higher in Suisun Bay than in any other area. The range in abundance was also greatest there (Figure 13). In the Delta, calanoids were most abundant in the Sacramento River and least abundant in the upper San Joaquin River (the San Joaquin upstream from the mouth of Old River). This pattern reflects the close association between Eurytemora and the entrapment zone and its progressively reduced densities upstream from that zone in the Delta channels.

Total calanoid abundance varied considerably in Suisun Bay (Figure 14). The years of highest abundance were 1972, 1977 and 1985 because these were dry years and allowed the marine genus Acartia to penetrate the bay in large numbers (Figure 11). The two years with the lowest abundance, 1975 and 1983, were characterized by high Delta outflows.

In the Delta,the peak years were 1972, 1977 and 1979. The first two were dry years when Eurytemora came into the Delta with the entrapment zone and raised total calanoid abundance. In 1979, Sinocalanus became very abundant and brought total numbers up. Low years were wet ones, 1974, 1975, 1978 and 1983, when high flows transported the copepods into Suisun Bay or even further

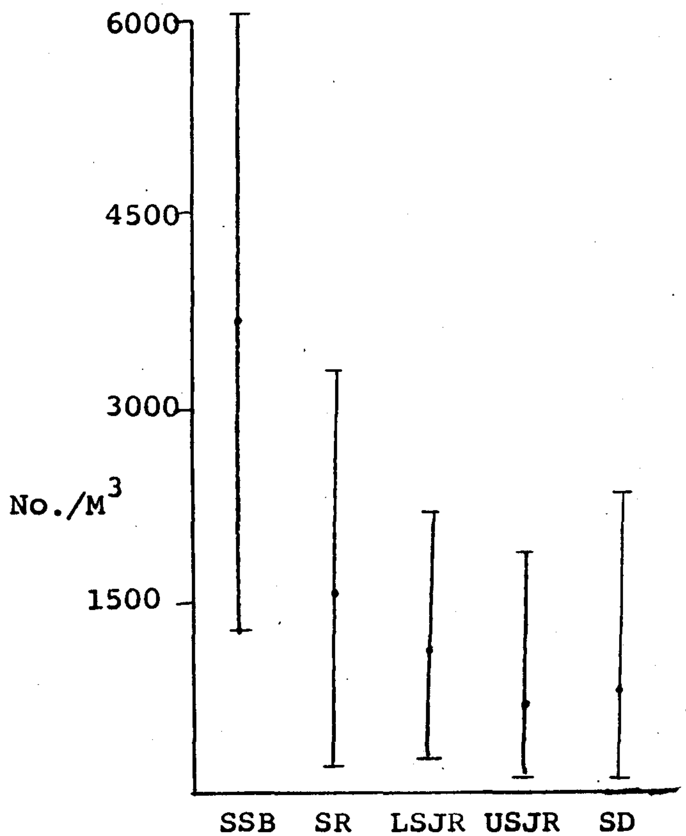


Fig. 13. Means and ranges of all calanoid copepod abundance, 1972-1985.

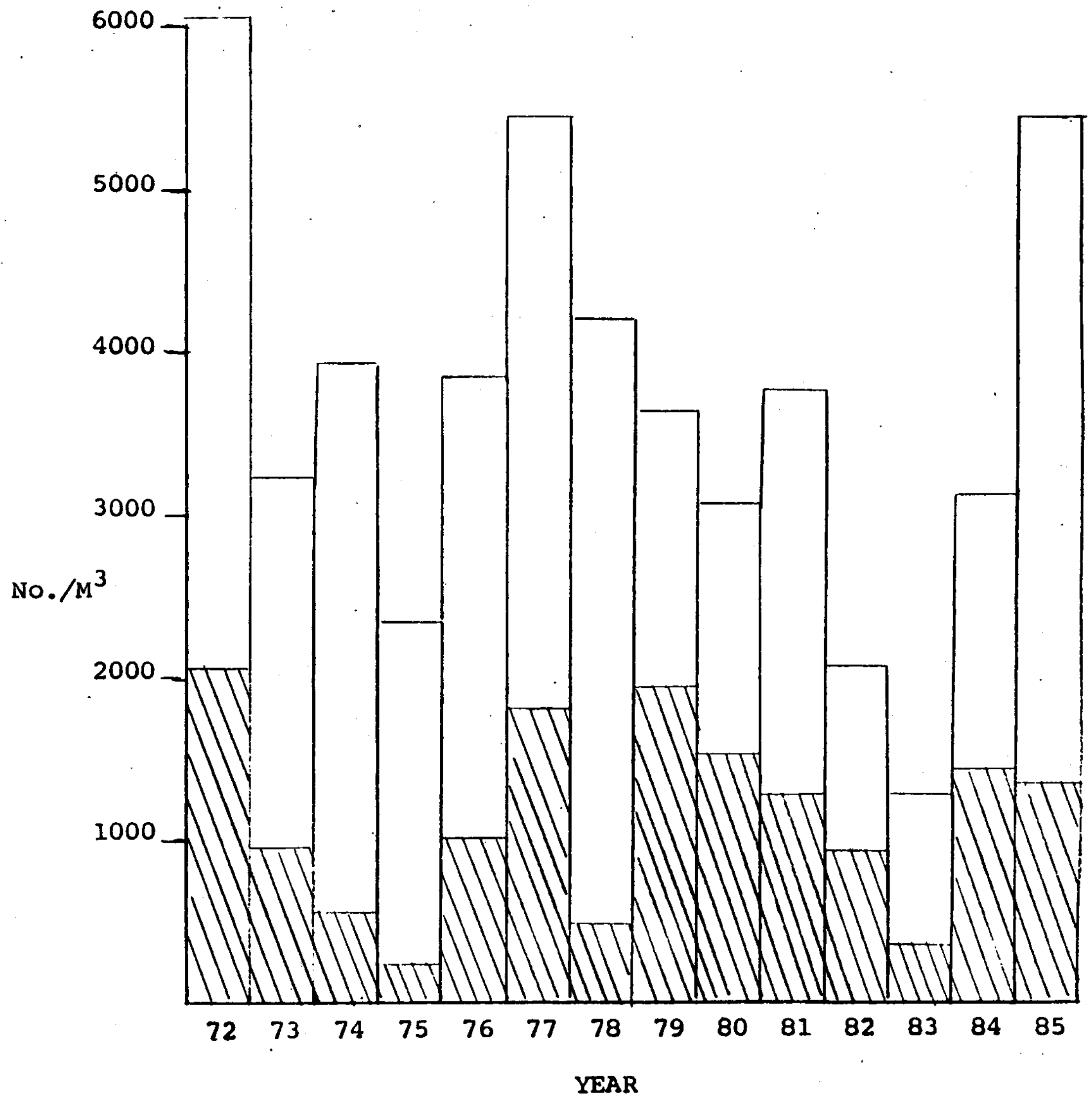


Fig. 14. Mean March to November abundance of all calanoid copepods (Acartia, Eurytemora, Diaptomus, Sinocalanus) in Suisun Bay (clear bar) and in the delta (shaded bar).

downstream. In 1974 and 1975 Diaptomus reached its greatest percent abundance, but because Diaptomus never has achieved high densities, total abundance was low. It's not clear what factors caused the low 1978 calanoid population size. In 1983, flood conditions held Eurytemora downsteam from the Delta and also kept Sinocalanus density down.

Important Zooplankton Species or Groups

Eurytemora affinis

This major calanoid copepod was almost equally abundant in Suisun Bay and the Sacramento River during the 14 year sampling period (Figure 15). In the Delta, the population tended to be highest in the Sacramento River and next most abundant in the lower San Joaquin River. Densities were lowest in the upper San Joaquin River, the area farthest from this species center of abundance in the entrapment zone.

When all areas are considered, Eurytemora underwent a long-term decline which started before the drought (Figure 16). Years of highest abundance were 1972 and 1974, a dry and a wet year. The low year was 1983, a result of flood flows keeping Eurytemora seaward of Suisun Bay in the early part of that year. A negative impact of competition is possibly reflected in the reduced Eurytemora abundance since 1979 but the Eurytemora downtrend actually began before that year.

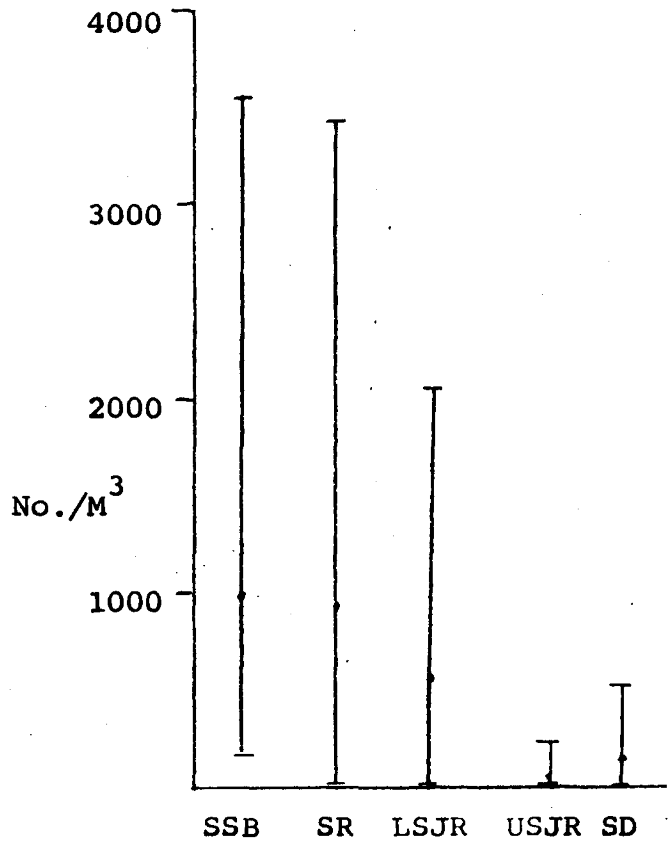


Fig. 15. Means and ranges of Eurytemora by area 1972-1985.

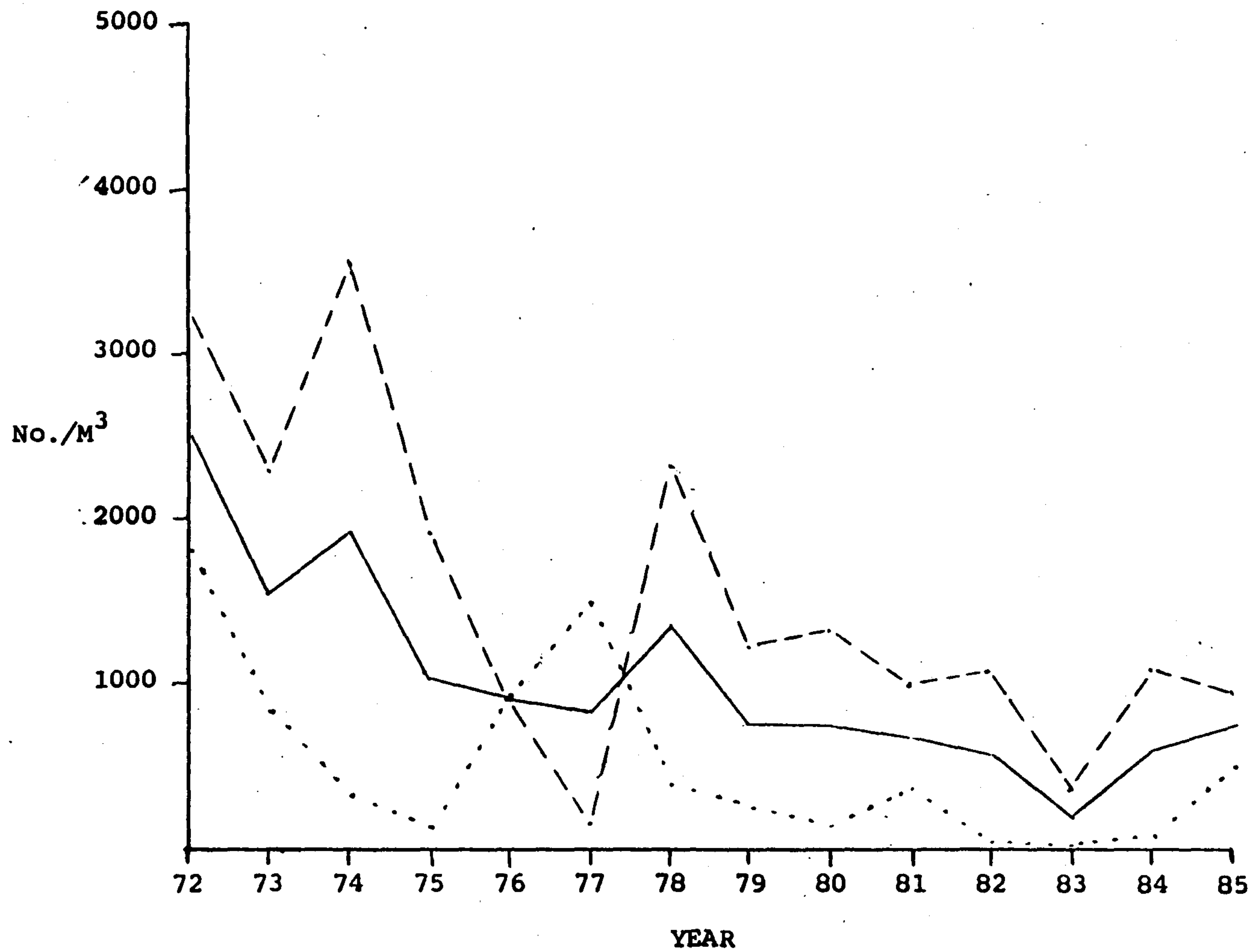


Fig. 16. Mean March to November Eurytemora abundance in all areas (——), Suisun Bay (- - -) and the delta (· · ·).

Sinocalanus doerrii

Sinocalanus was most abundant in the Sacramento River and least abundant in Suisun Bay (Figure 17). The south Delta was the area of second highest concentrations.

This species first appeared in 1978 and became abundant in the following year, which was also the year of its greatest population size (Figure 18). As with the native species, river outflow affects Sinocalanus. If flow is very high as in 1983, it will be moved into Suisun Bay or even farther downstream. This flood year was the only one in which abundance was greater in Suisun Bay than in the Delta.

In 1973, before the introduction of Sinocalanus, the stretch of Bay and Delta between the entrapment zone where Eurytemora abundance peaked and the Stockton area of the San Joaquin River where Diaptomus was abundant, contained relatively few calanoid copepods. Now Sinocalanus is abundant in that stretch (Figure 19). Although Diaptomus extended into the entrapment zone in very low numbers it was abundant only near Stockton. Eurytemora was dominant throughout most of the Delta especially during extensive salinity intrusion as occurred in July of 1973.

In 1979. Sinocalanus established itself in the Delta and extended downstream past the entrapment zone into the range of Acartia, although its abundance began to decline progressively seaward from the upstream edge of the entrapment zone (Figure 19). Since slinity intrusion was similar in July of 1973 and 1979, the marked decine of Eurytemora abundance in the Delta in the latter year is unlikely to have been caused by salinity, instead it may

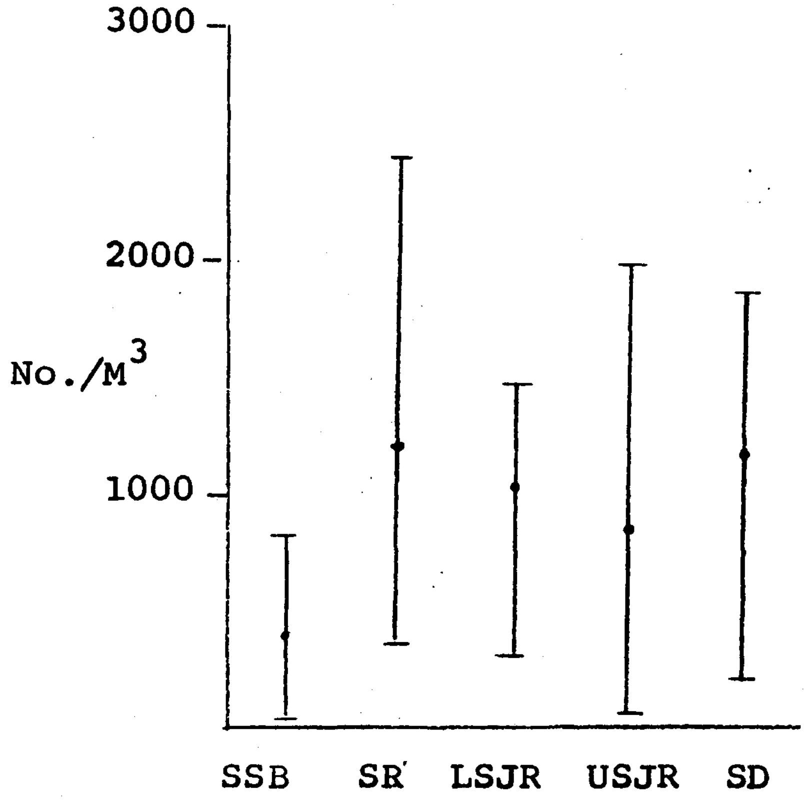


Fig. 17. Means and ranges of Sinocalanus abundance by area, 1979-1985.

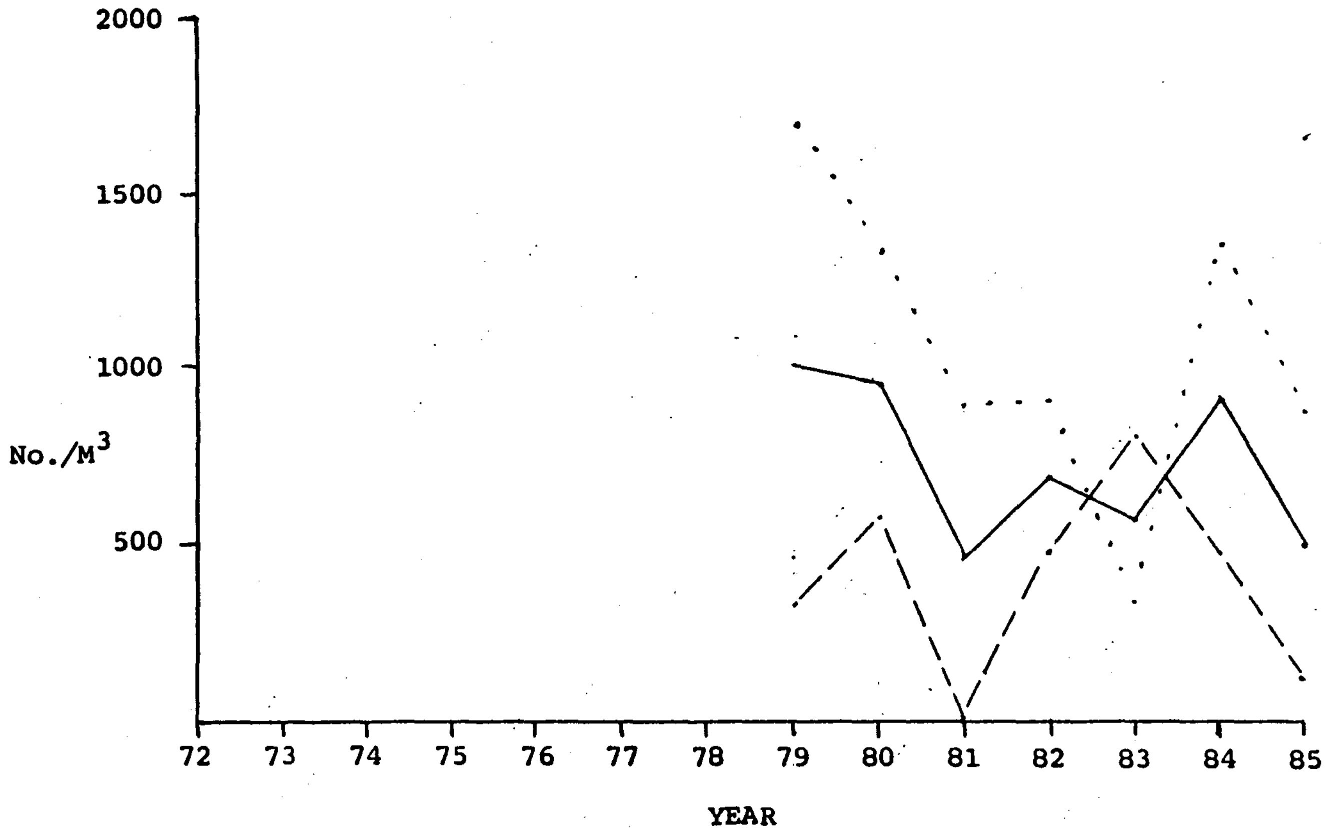


Fig. 18. Mean March to November Sinocalanus doerrii abundance in Suisun Bay (- - -) and the delta (· · ·) and all areas (——).

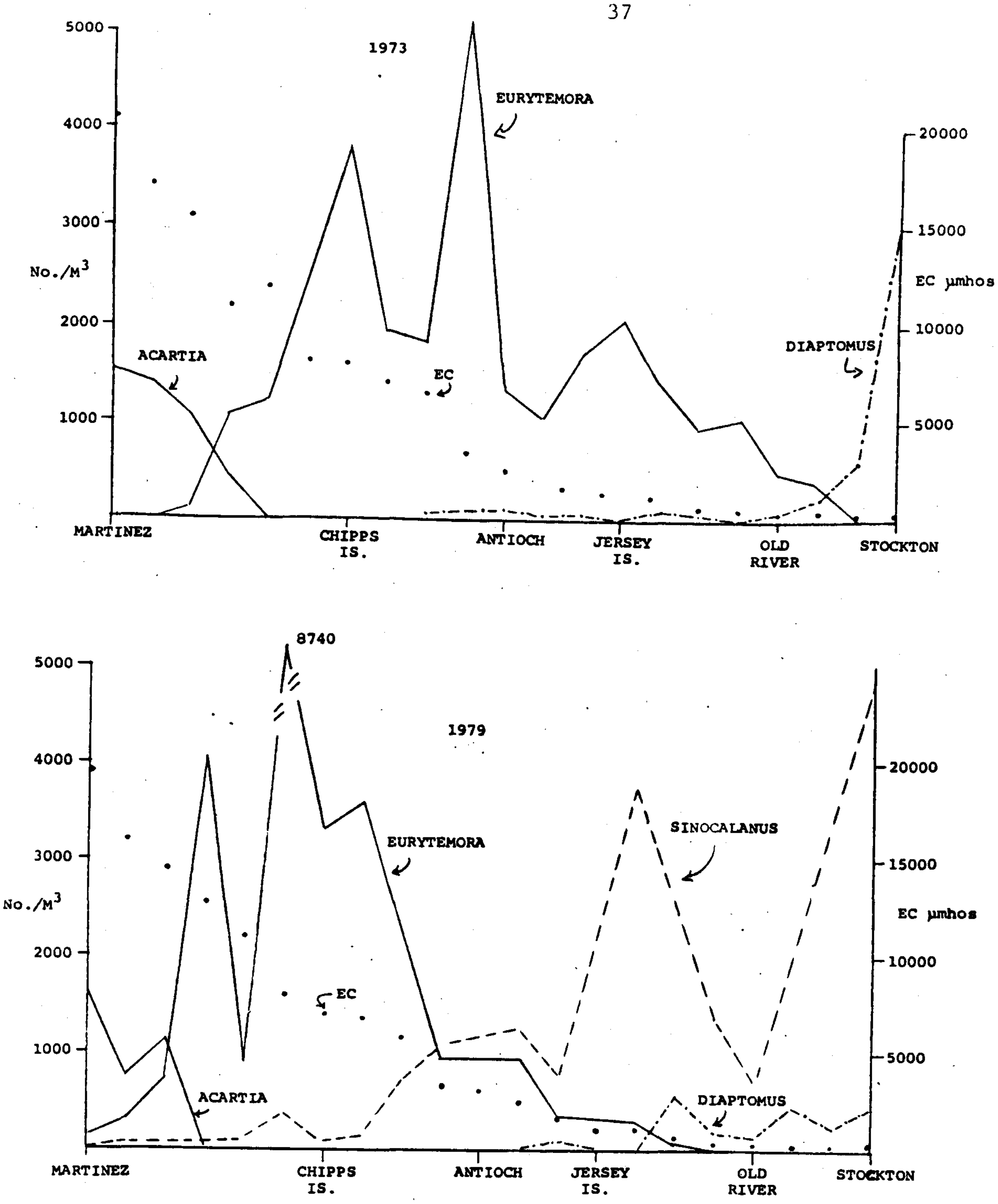


Fig. 19 . Abundance of calanoid copepods by genera and EC along the axis of the estuary from near Martinez, through Suisun Bay and up the San Joaquin River to Stockton in July of 1973 and 1979. Entrapment zone was located from Antioch to Chipps Island. Figure is not to scale.

be the result of some type of competition between the two species.

Diaptomus suffered a very large decline in 1979 where *Sinocalanus* peaked near Stockton although in most of the San Joaquin River it was actually more abundant than in 1973.

Diaptomus spp.

The three *Diaptomus* species were strongly localized in the upper San Joaquin River (Figure 20). Suisun Bay and the Sacramento River contained very low numbers.

Diaptomus showed no sustained trend from 1972 to 1977 (Figure 21). Abundance was much reduced however from 1979 to 1981 after the introduction of *Sinocalanus*, and from 1982 to 1985 only trace numbers of *Diaptomus* were found, except during early spring before *Sinocalanus* develops large populations and in areas such as the Sacramento River at Hood and in the Mokelumne River above its forks where *Sinocalanus* does not reach.

Acartia

Acartia abundance fluctuated widely but showed no long-term trend (Figure 22) Its abundance was a function of salinity and it was generally located too far downstream to be an important young striped bass food. The genus has predatory or omnivorious habits, so it is probably not as dependent on phytoplankton as the other cdlanoids are. It was most abundant in Suisun Bay and entered the Delta only in dry years.

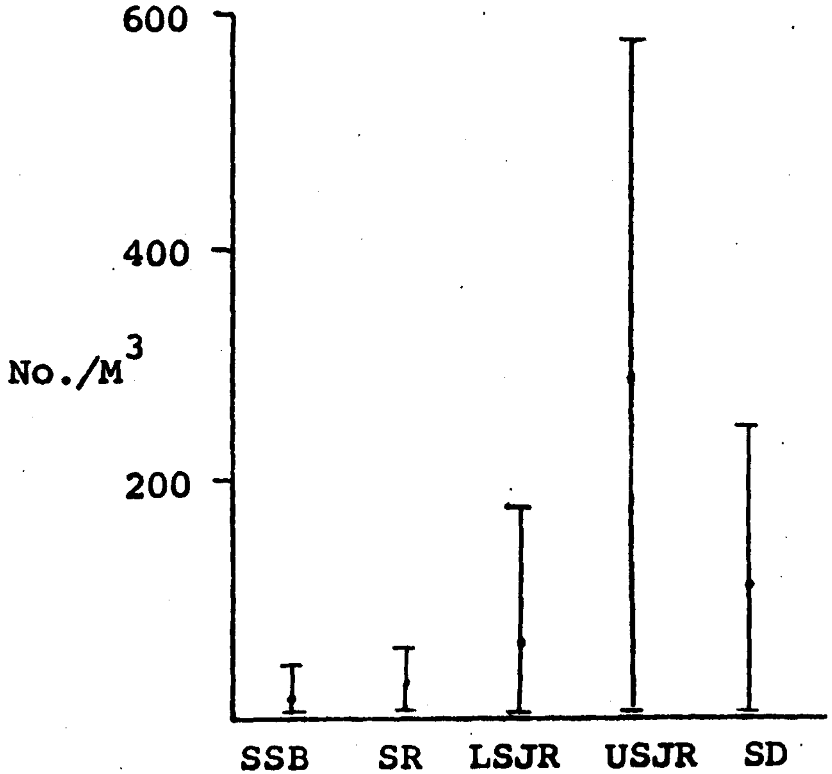


Fig. 20. Means and ranges of <u>Diaptomus</u> abundance by area, 1972-1981.

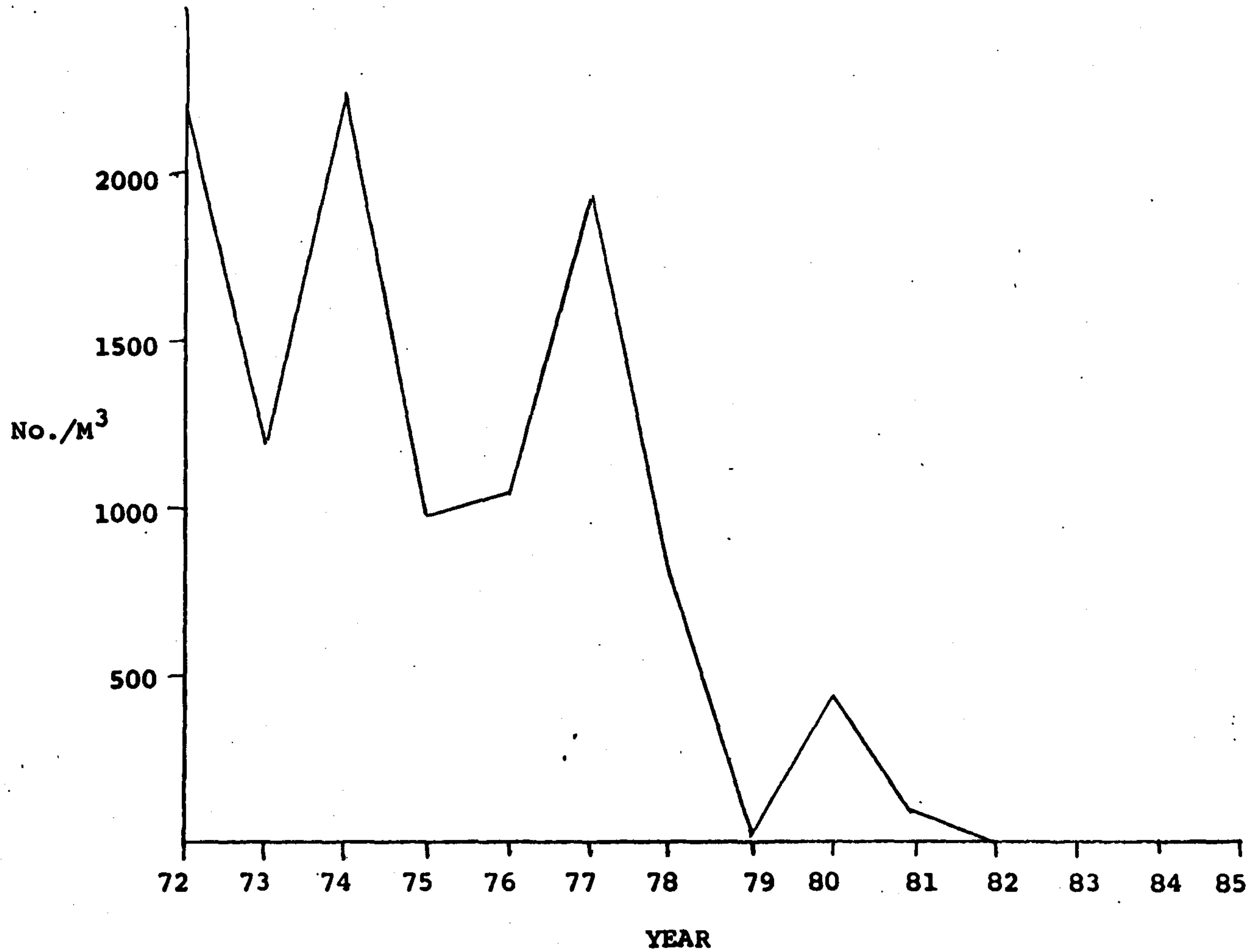


Fig. 21 . Mean March to November Diaptomus abundance in the delta.

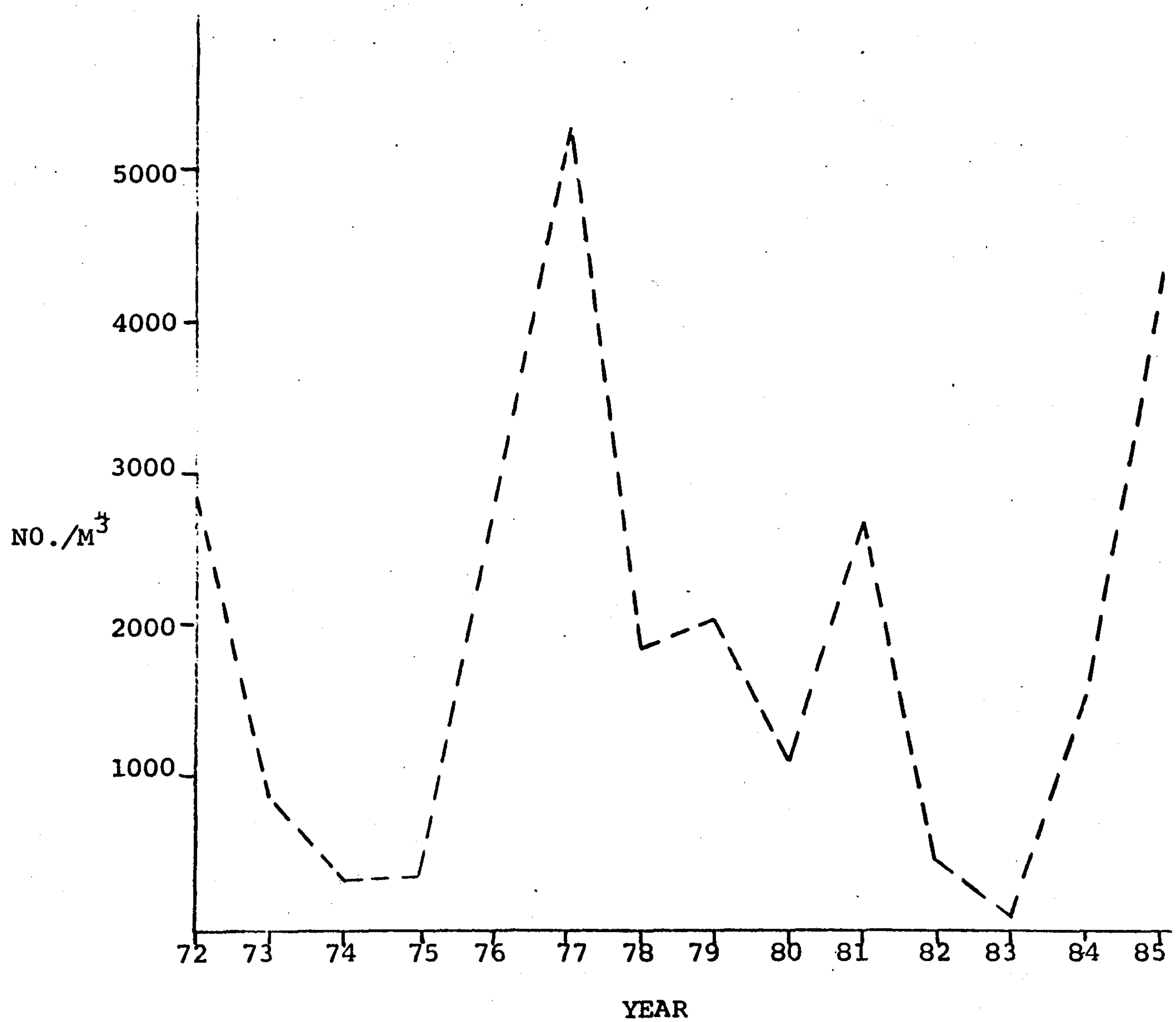


Fig. 22 . Mean March to November abundance of Acartia in Suisun Bay.

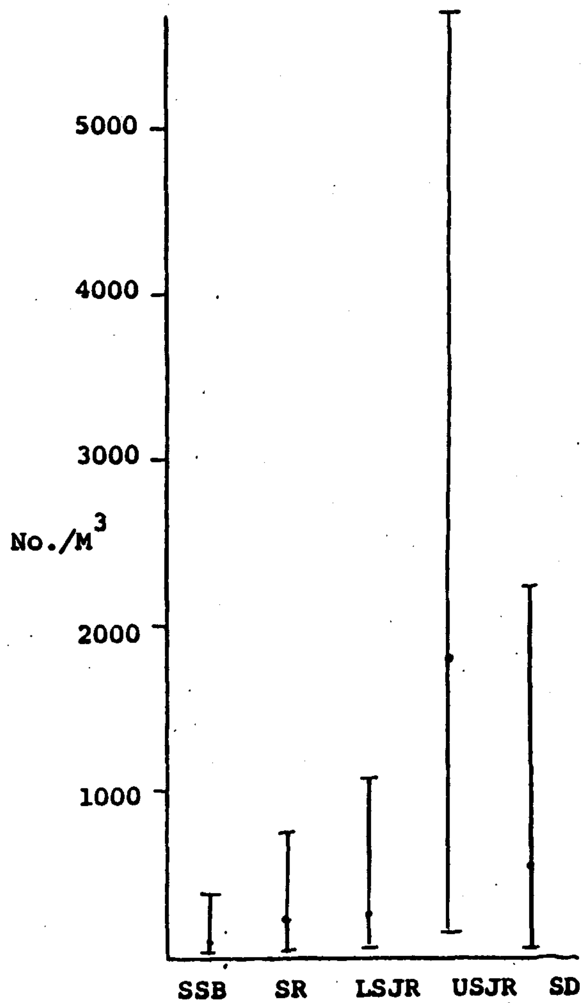


Fig. 23 . Means and ranges of native cyclopoid abundance by area, 1972-1985.

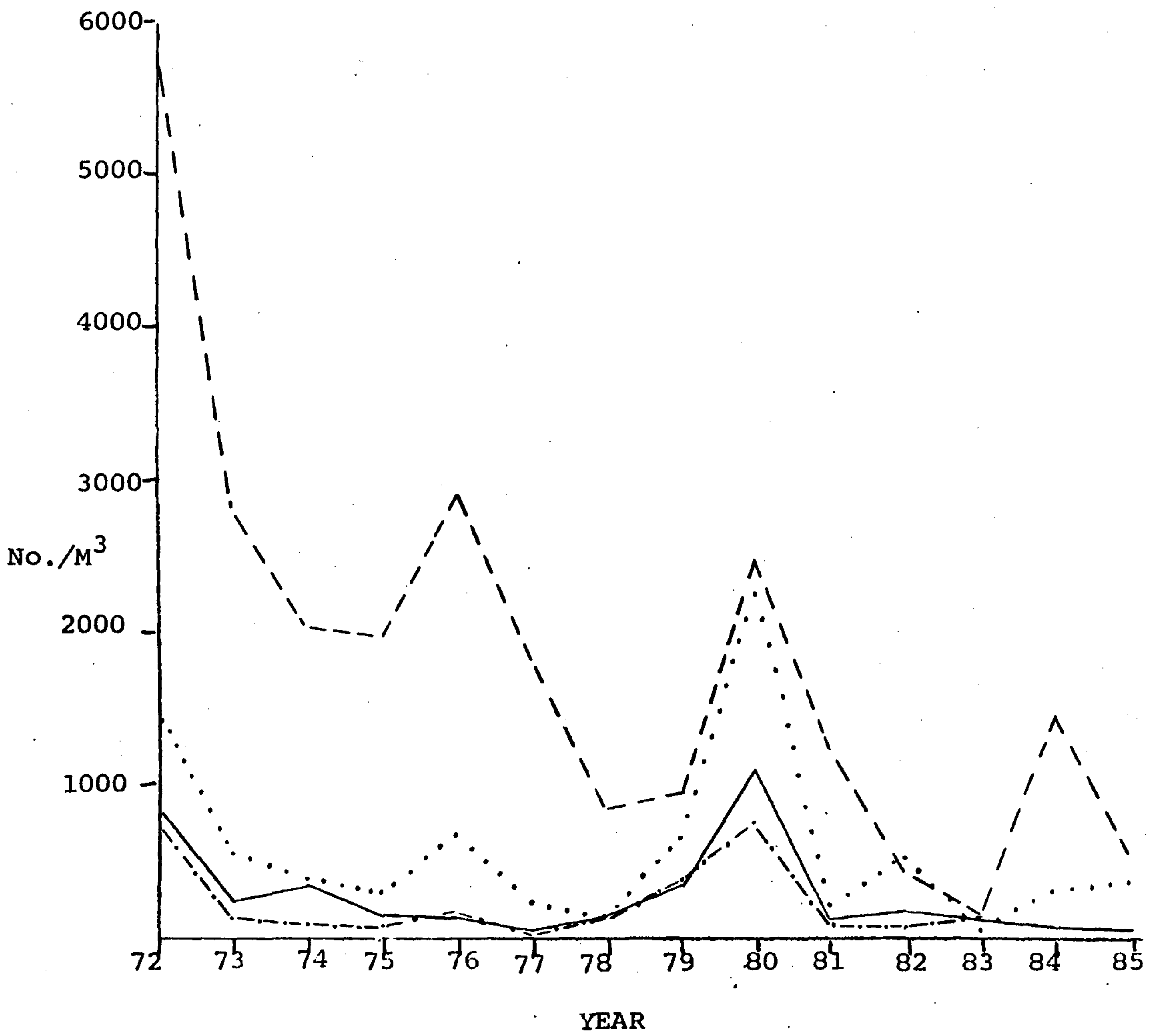


Fig. 24. Mean March to November abundance of native cyclopoids in the lower San Joaquin River (——), the upper San Joaquin River (- - -), the south delta (· · ·) and the Sacrament :iver (·-·--·).

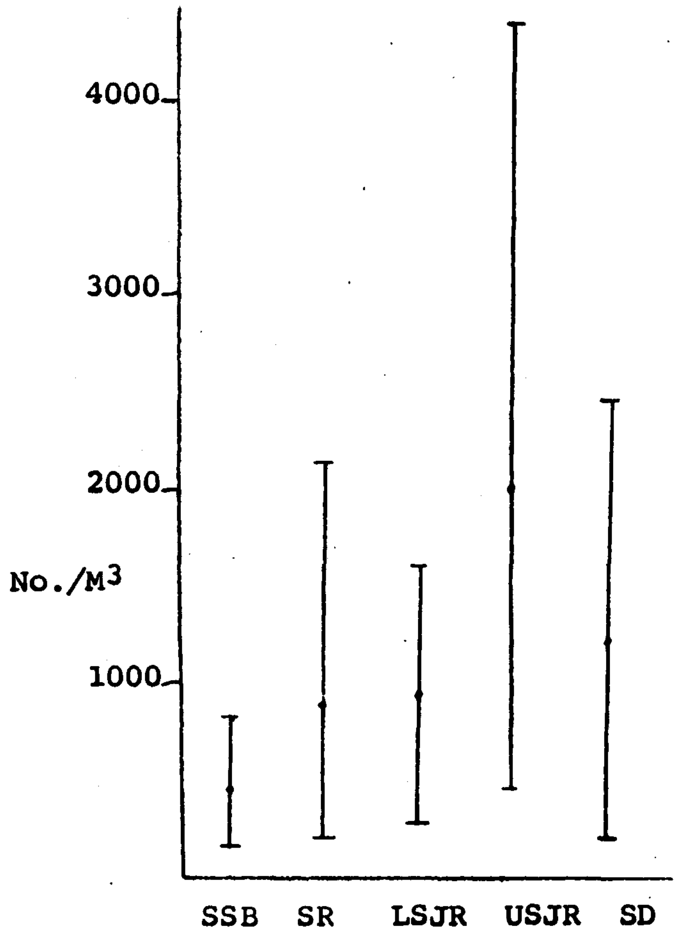


Fig. 25. Means and ranges of <u>Limnoithona</u> abundance by area, 1980-1985.

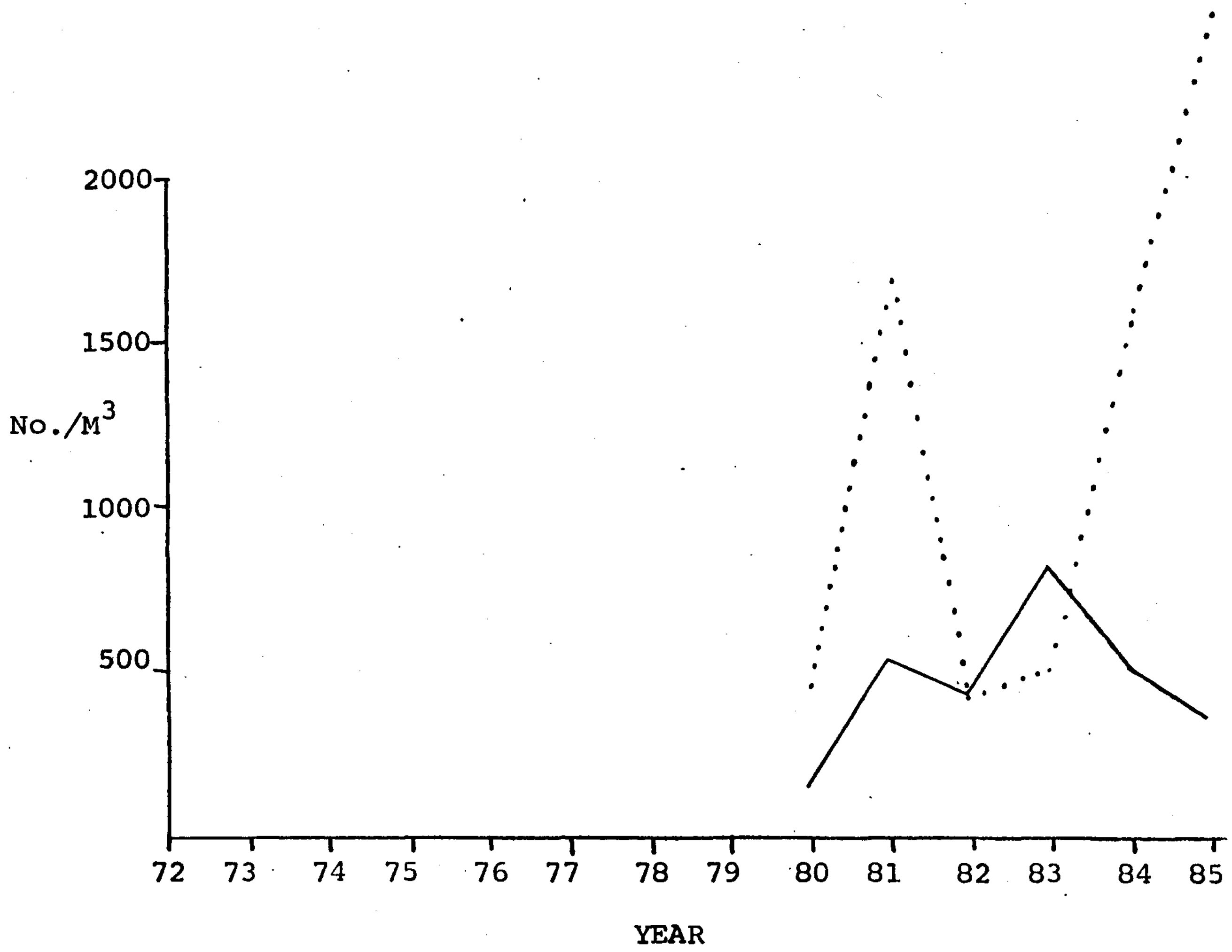


Fig. 26. Mean March to November abundance of <u>Limnoithona sinensis</u> in Suisun Bay (——) and the delta (···).

or *O. similis*, a coastal species that occasionally appears in our sampling area. *Oithona davisae* was first detected in 1979, became abundant in 1980 and has increased almost exponentially since then (Figure 27). It is most abundant in Suisun Bay and currently does not extend into the upper San Joaquin River (Figure 28). Members of the genus *Oithona* tend to be predatory but the food habits of this species have not been studied.

Cladocerans

Cladocerans are freshwater organisms and as for *Diaptomus*, *Limnoithona* and native cyclopoids, they weere most abundant in the upper San Joquin River (Figure 29). They were also quite abundant in the south Delta but were scarce in the lower San Joaquin and Sacramento rivers.

They have suffered a long-term decline including a precipitous drop in 1977 particularly in the upper San Joaquin River (Figure 30). The high 1983 flows kept cladocerans from reaching high abundance in the Delta and made them more numerous in Suisun Bay than in any other year (Figure 31).

Neomysis mercedis

On the average, the opossum shrimp, *Neomysis*, was most abundant in Suisun Bay and only slightly less abundant in the Sacramento River (Figure 32). Densities were much less in the lower and upper San Joaquin River,and the south Delta contained very small numbers of *Neomysis*.

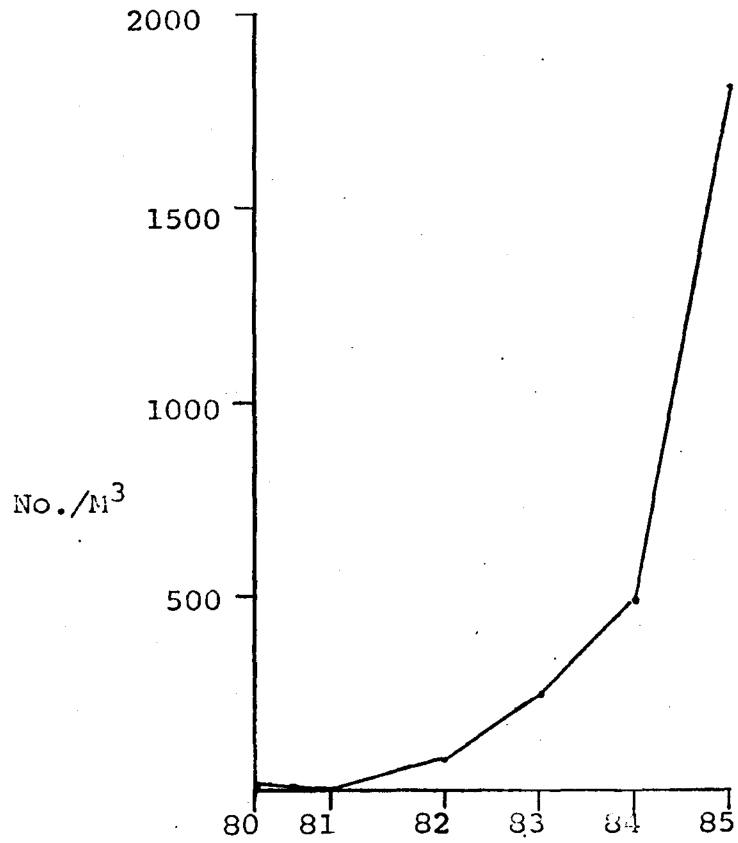


Fig. 27. Mean March to November abundance of *Oithona davisae* in Suisun Bay.

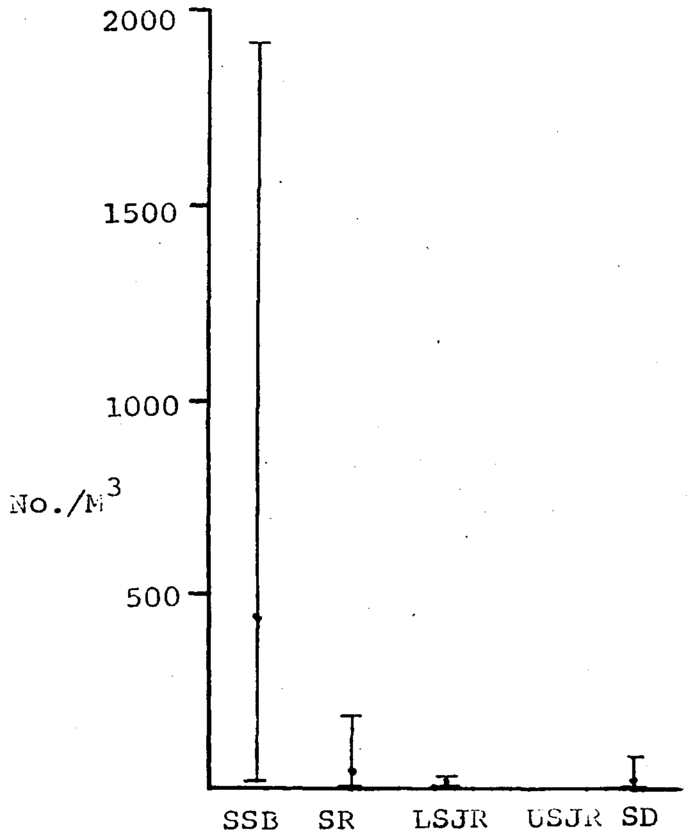


Fig. 28. Means and ranges of <u>Oithona</u> abundance by area, 1980-1985. None were found in the upper San Joaquin River.

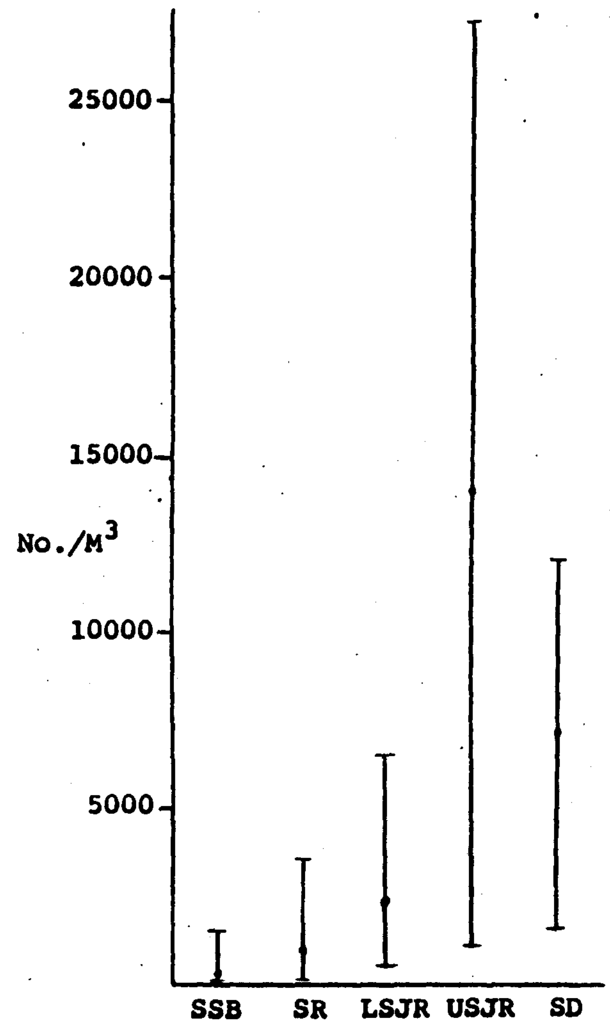


Fig. 29 . March-November means and ranges of cladocerans by area, 1972-1985.

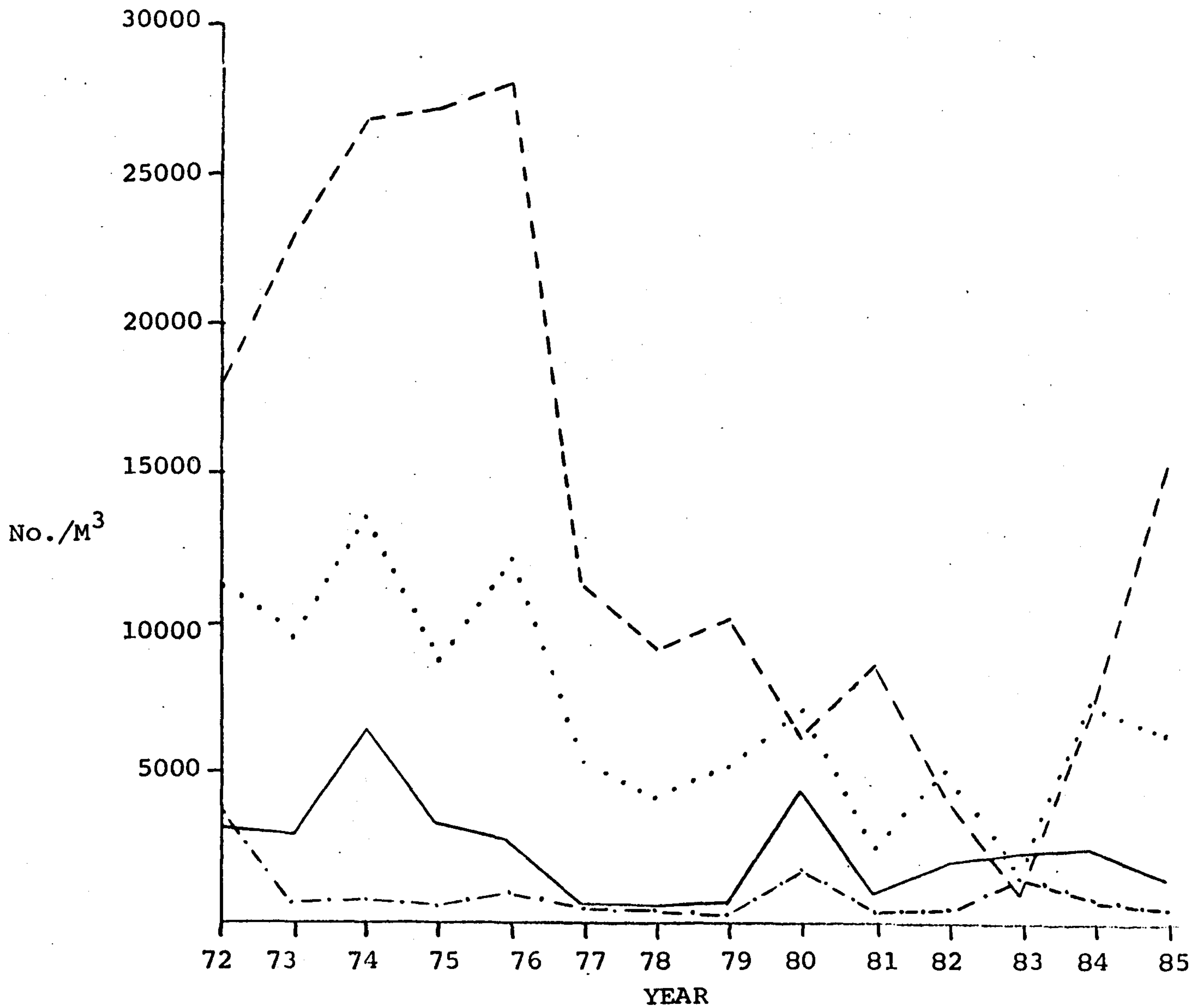


Fig. 30. Mean March to November cladoceran abundance in the lower San Joaquin River (——), the upper San Joaquin River (- - -), the south delta (· · ·), and the Sacramento River (·–·–·).

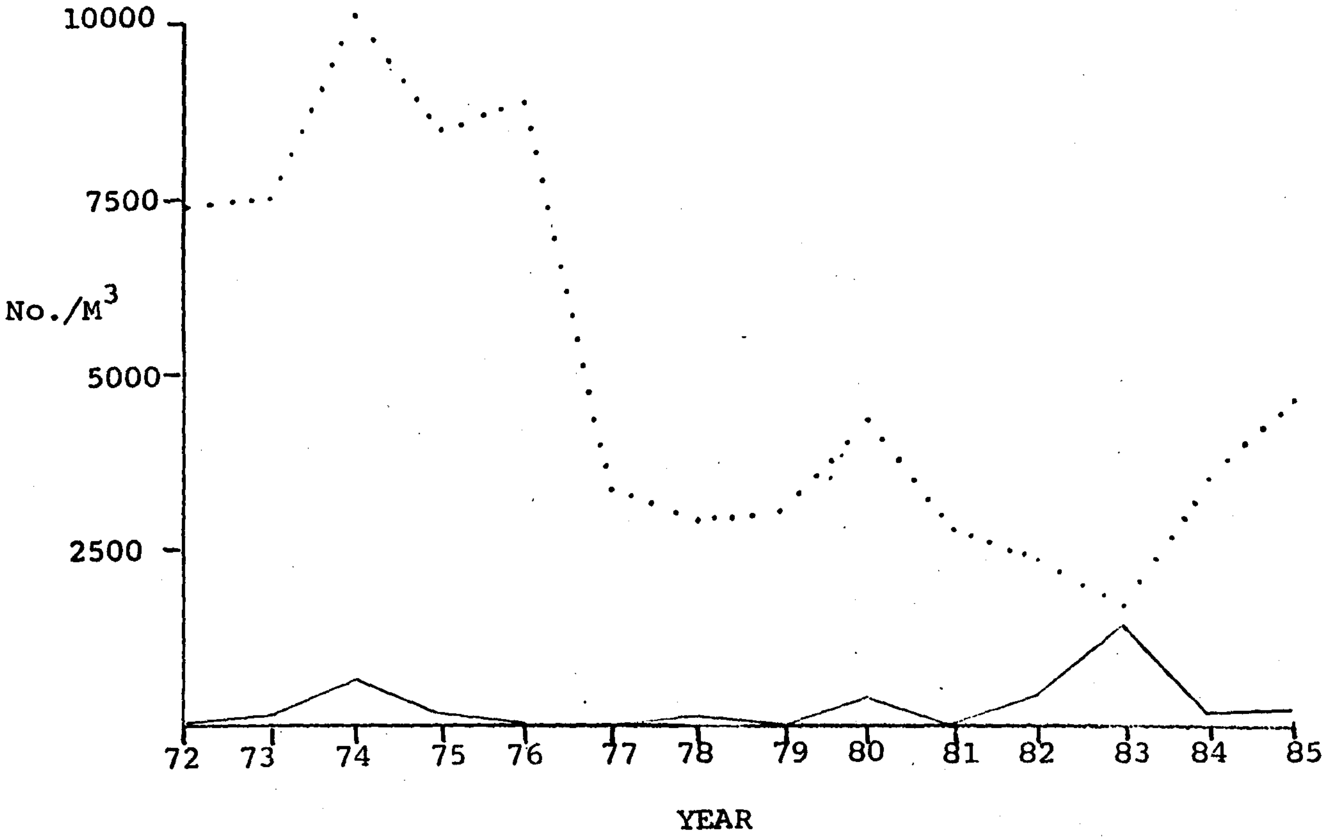


Fig. 31. Mean March to November cladoceran abundance in Suisun Bay (——) and the delta (· · ·).

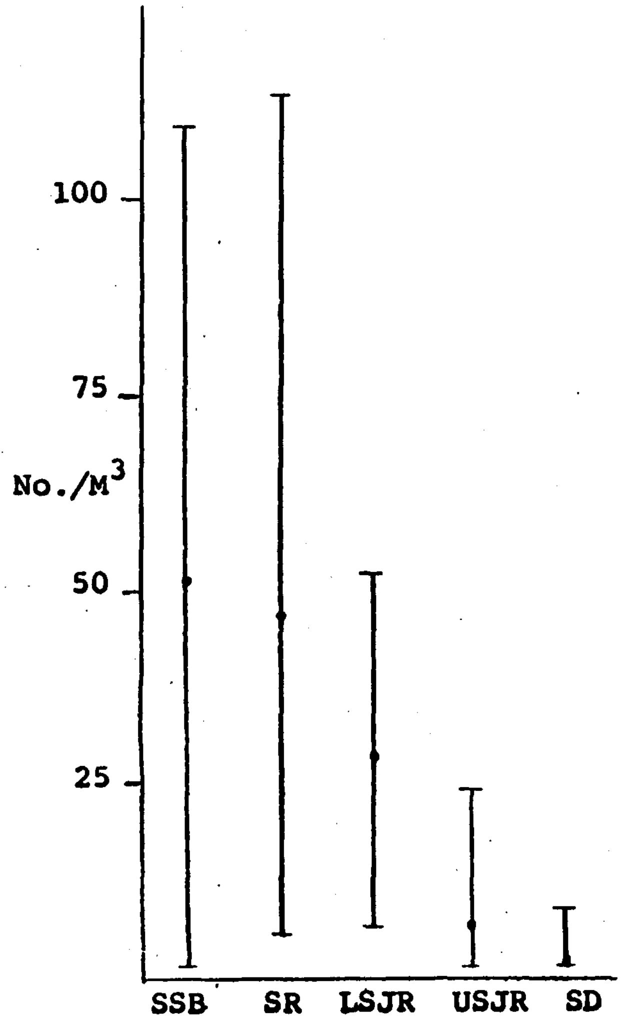


Fig.32 . Means and ranges of *Neomysis* abundance by area, 1969-1985.

When Suisun Bay, the Sacramento River and the lower San Joaquin River combined are considered, abundance rose from moderate levels from 1969 to 1972 to a peak in 1973 and then declined without interruption to 1977 (Figure 33). Thereafter, abundance has fluctuated widely from year to year; however it has been at pre-drought levels only in 1980 and 1982, both wet years.

Rotifers

The rotifers considered here are all freshwater forms. As with other freshwater zooplankton they were most abundant in the upper San Joaquin River (Figure 34). They were only slightly more abundant in the Sacramento River than in Suisun Bay and were not very common in the lower San Joaquin River.

In the Delta they suffered a decline of an order of magnitude from 1972 to 1979 (Figure 35). A small recovery occurred in 1980 but abundance from 1979 to 1985 has remained at very low levels. The downtrend was particularly severe in the lower San Joaquin River and in the Sacramento River in 1979 (Figure 36).

Synchaeta bicornis

Synchaeta bicornis is a euryhaline rotifer that extends from the entrapment zone well into freshwater. It was most abundant in Suisun Bay, aut equally abundant in the Sacramento and lower San Joaquin Rivers and least abundant in the upper San Joquin River and the south Delta (Figure 37).

This rotifer was not identified properly during part of 1972 so abundance in that year was disregarded (Figure 38). The

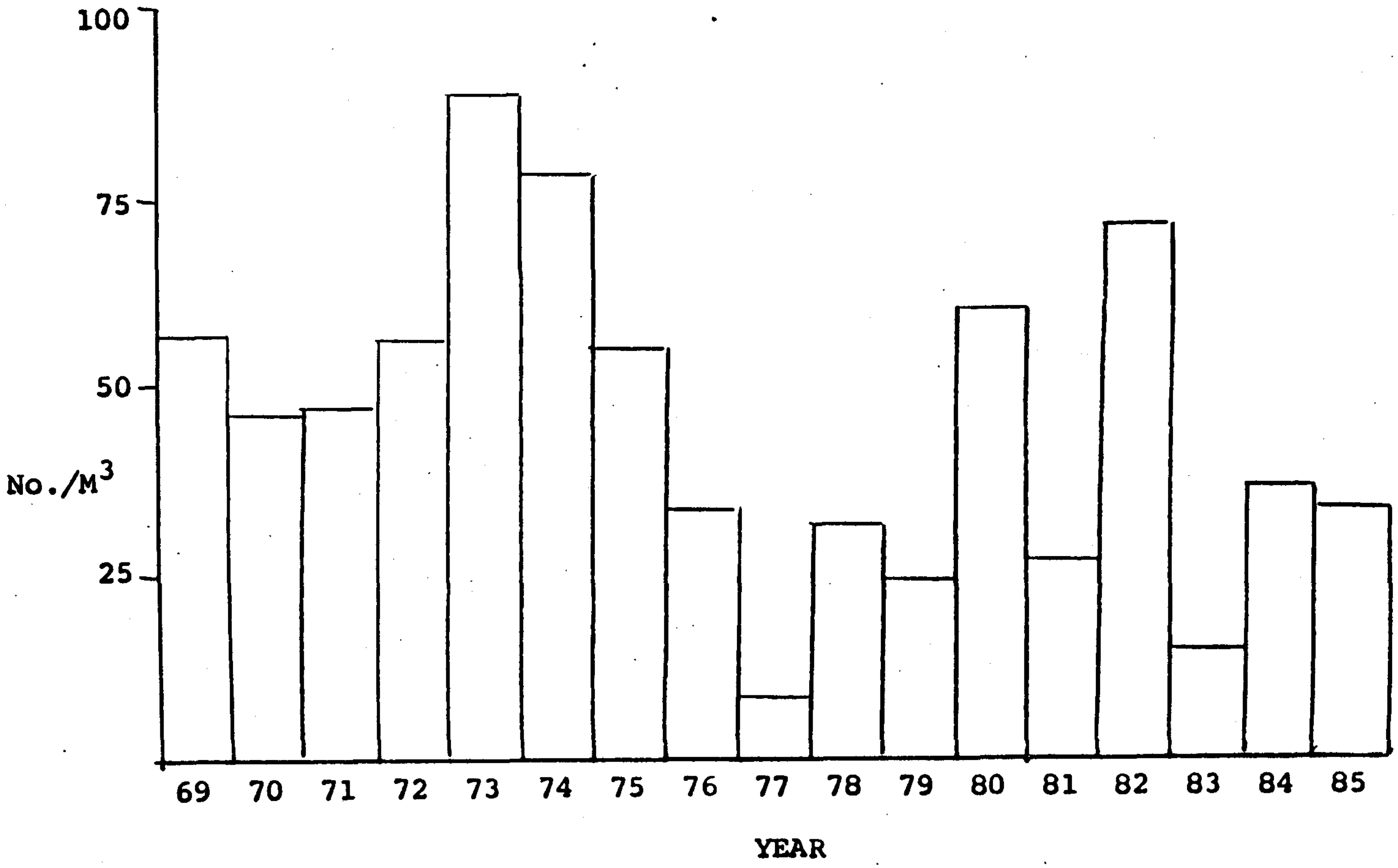


Fig. 33. Mean Neomysis (≥4 mm) abundance from western Suisun Bay to Rio Vista on the Sacramento River and to the mouth of Old River on the San Joaquin River. These are March-November means for each year 1969 to 1985.

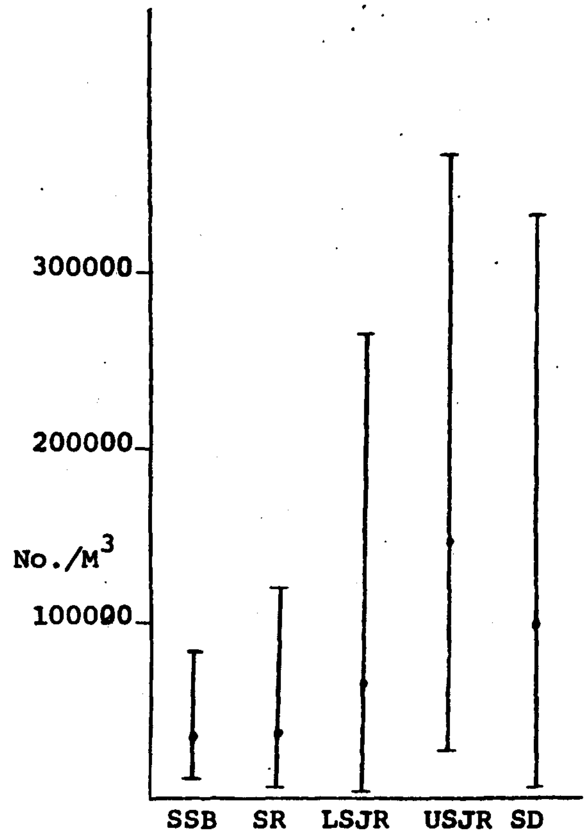


Fig. 34 . March-November means and ranges of rotifers by area, 1972-1985.

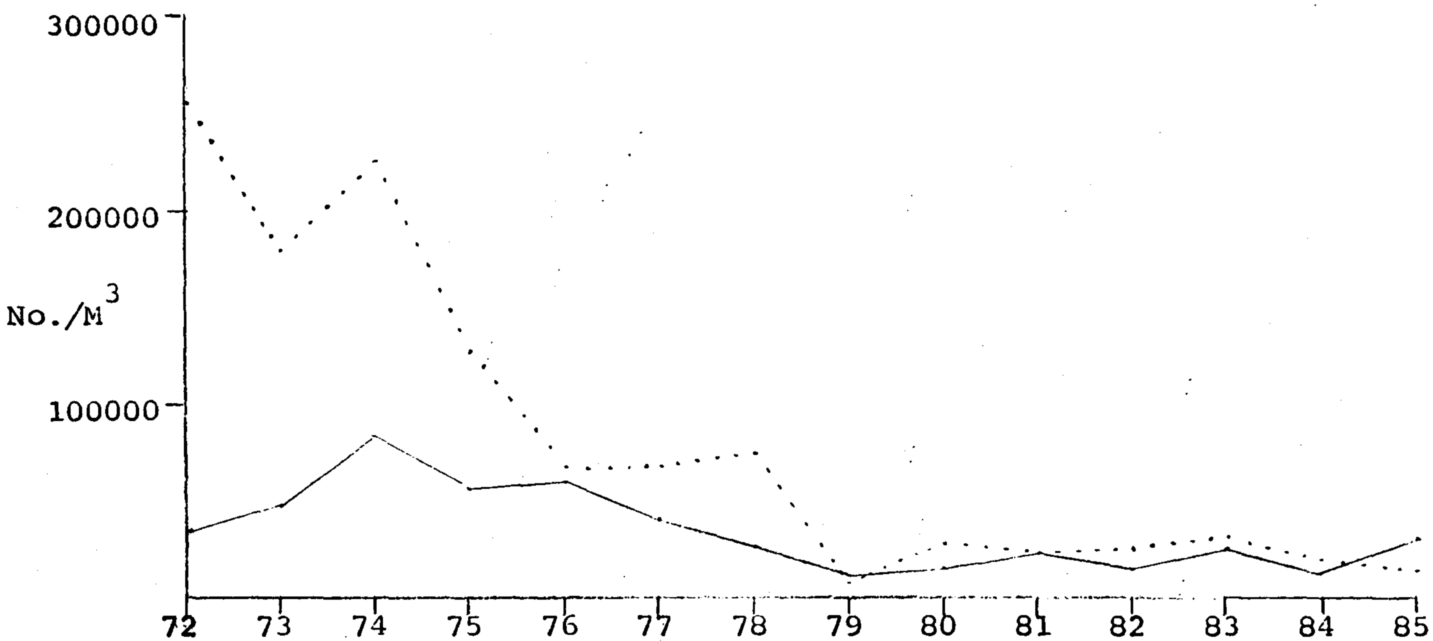


Fig. 35. Mean March to November rotifer abundance in Suisun Bay (___) and and the Delta (· · ·).

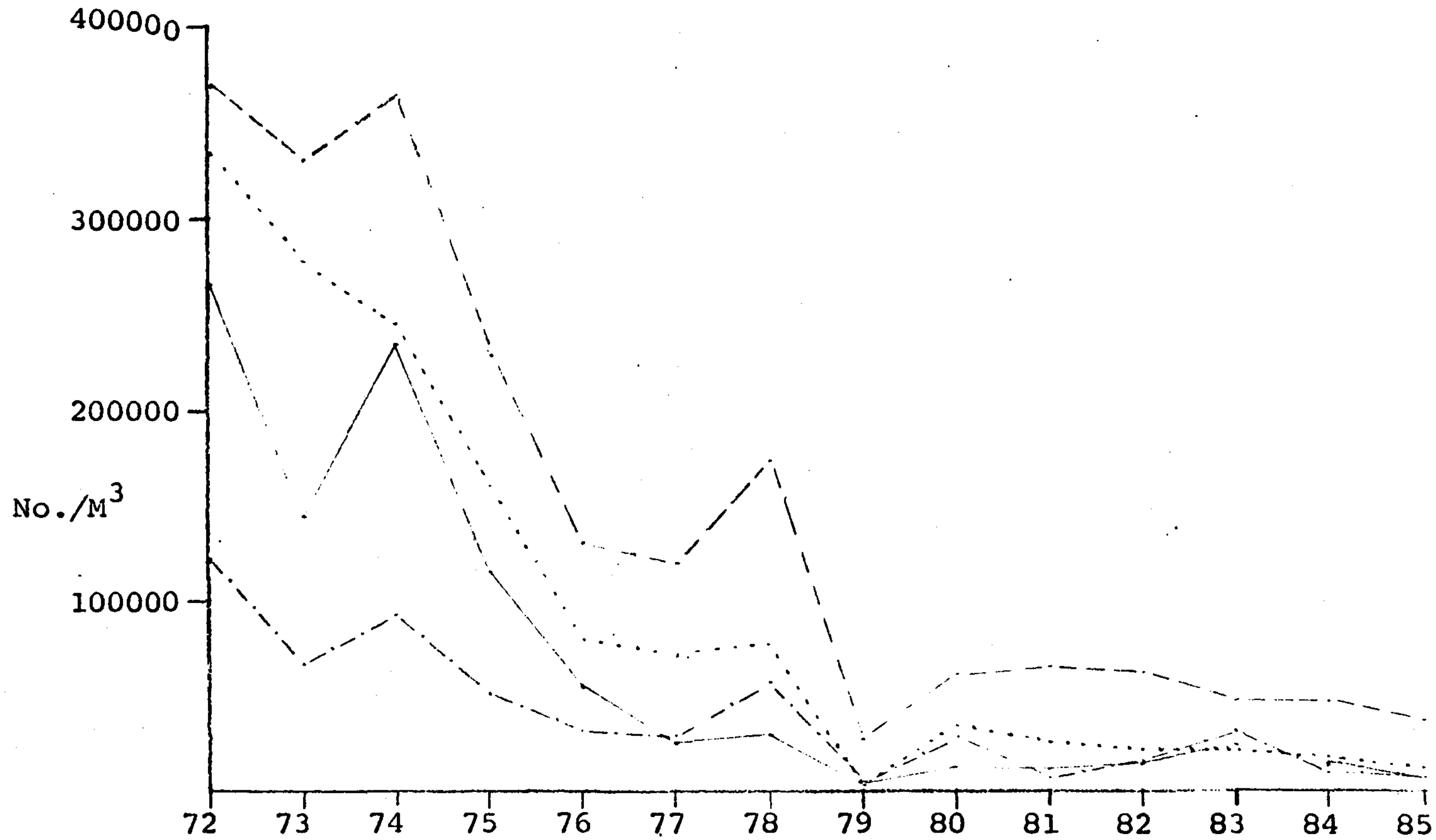


Fig. 36. Mean March to November rotifer abundance in the lower San Joaquin River (____), upper San Joaquin River (---), south delta (. . .), and Sacramento River (._._.).

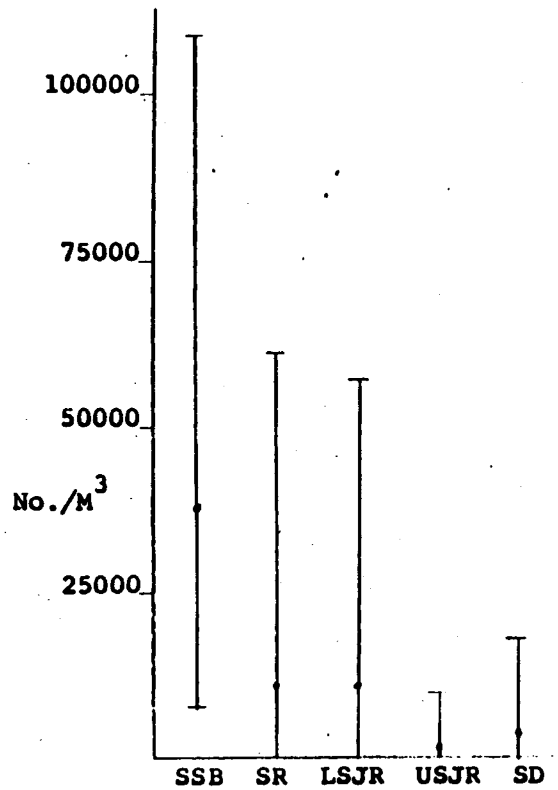


Fig. 37. March-November means and ranges of *Synchaeta bicornis* by area, 1973-1985.

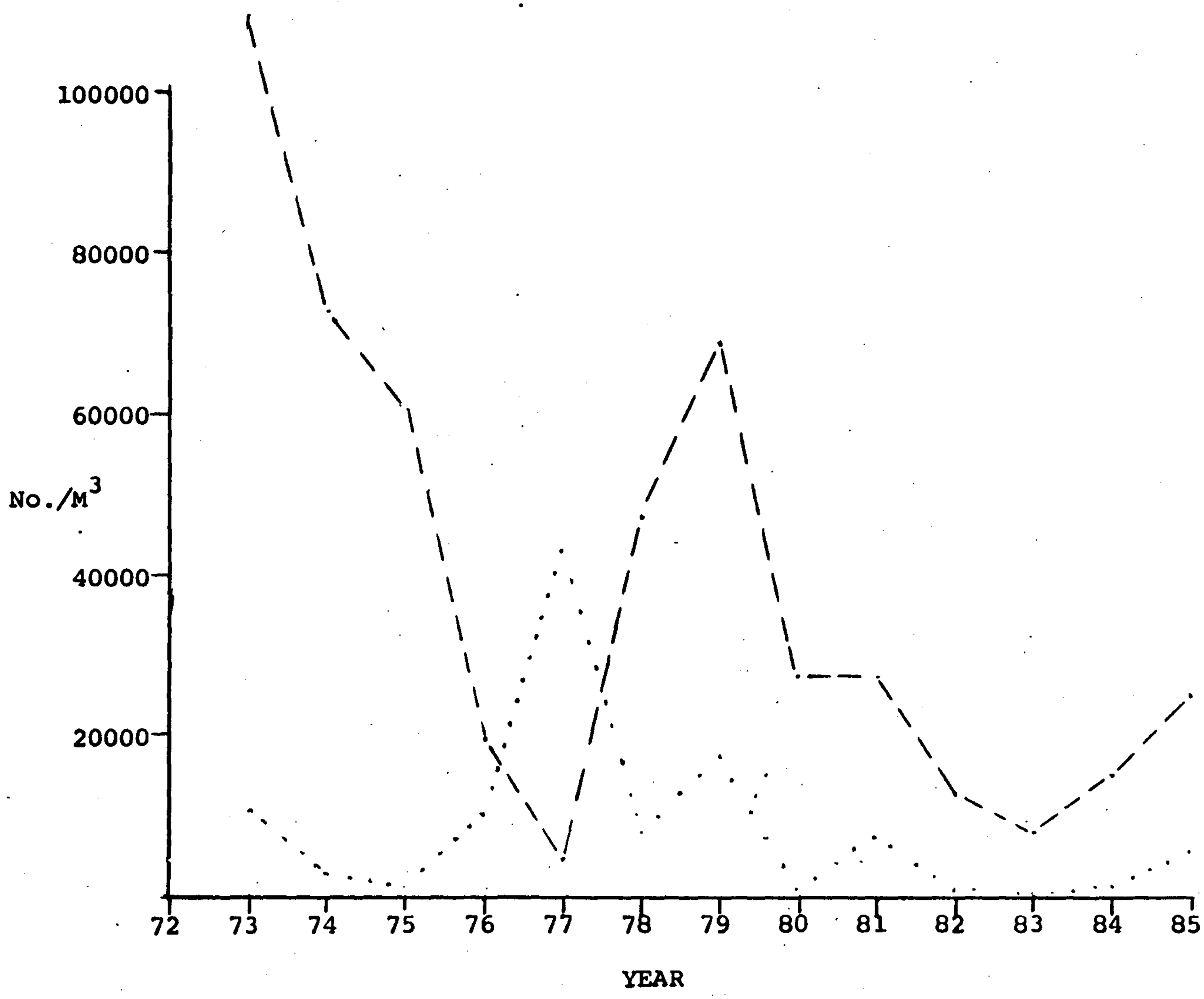


Fig. 38. Mean March to November abundance of <u>Synchaeta bicornis</u> in Suisun Bay (- - -) and the delta (· · ·).

long-term trend was sharply downward from 1973 to 1976 with a partial recovery in 1977 when *Synchaeta* entered the Delta along with the entrapment zone. The recovery lasted until 1979 only to be followed by another decline continuing until 1983.

Summary

Of the native species only *Acartia* and *Neomysis* did not undergo a long-term decline. Yet, *Neomysis* was abundant only in two years after the drought, 1980 and 1982. Both of these years were characterized by high outflows in the spring. *Rotifers* and *Diaptomus* were the taxa most reduced in abundance. The introduction of *Sinocalanus*, *Limnoithona* and *Oithona* helped maintain the total abundance of calanoid and cyclopoid copepods. *Sinocalanus*. However, is a possible cause of the reduction of *Diaptomus* and may have affected *Eurytemora* as well. The evidence is circumstantial because our data is not of the proper kind to show just how these species interact. Some of the annual fluctuations in abundance and shifts of population between Suisun Bay and the Delta can be attributed to variations in Delta outflow which regulate water residence times, the position of the entrapment zone and salinity gradient, and hence the distribution of all zooplankton species.

Regression Results

Stepwise multiple regressions were run for the important zooplankton taxa in their areas of greatest abundance against chlorophyll *a*, salinity (specific conductance (EC)) at Chipps Island, temperature, and CVP-SWP export pumping rates as independent variables. For *Neomysis*, an omnivorous species, the total abundance of *Eurytemora* and *Sinocalanus*, an additional measure of their food supply, was also used. For cladocerans, *Neomysis* was an additional independent variable because Orsi and Mecum (1986) found that *Bosmina*, an important cladoceran, was significantly and negatively correlated with *Neomysis* in the Delta.

Chlorophyll *a* was the independent variable that acheieved significance most often (Table 2). It had significant and positive t ratios with all taxa except *Limnoithona*. Plots of abundance vs. chlorophyll *a* (Figures 39 to 47) showed that for most taxa the relationship was linear but for *Neomysis* and rotifers the relationship appeared to be curvilinear (Figures 42 and 46). The non-linear plots suggest that at high chlorophyll *a* concentrations the food supply is supporting the maximum numbers of organisms it can, given the other environmental conditions. In many cases the range in abundance at a particular chlorophyll *a* concentration is large, indicating that other factors also greatly affect the populations.

Chipps Island EC had significant and negative t ratios with *Neomysis* in both Suisun Bay and in all areas combined (Table 2). Rotifers in the upper San Joaquin River also had a significant negative t ratio with EC. This is likely to be a spurious relationship since salinity does not intrude that far upstream.

Table 2. Results of stepwise multiple regressions by taxon and time period. Only variables that achieved significance are listed.

Taxon	Time Period	Area	Independent Variables	t Ratio	P	R^2	df
Eurytemora	March-Nov.	Suisun Bay	Chlorophyll *a*	3.63	>.01	61.56	8
		All Areas	Chlorophyll *a*	4.93	>.01	66.96	8
Sinocalanus	March-Nov.	Delta	None				
		All Areas	Chlorophyll *a*	3.40	>.05	83.26	3
Diaptomus	March-Nov	Upper San Joaquin R.	Chlorophyll *a*	5.94	>.01	81.53	6
Neomysis	March-Nov.	Suisun Bay	Chlorophyll *a*	2.41	>.05	58.06	8
			Chipps EC	-2.29	>.05		
		All Areas	Chlorophyll *a*	2.40	>.05	63.27	8
			Chipps EC	-2.84	>.05		
Native Cyclopoids	March-Nov.	Upper San Joaquin R.	Chlorophyll *a*	6.54	>.01	78.08	10
		Delta	Chlorophyll *a*	3.40	>.01	49.03	9
Limnoithona	March-Nov.	Delta	None				
		All Areas	None				
Cladocera	March-Nov.	Upper San Joaquin R.	Chlorophyll *a*	2.45	>.05	33.36	9
		Delta	Chlorophyll *a*	2.50	>.05	34.21	11

Table 2 (cont.)

Taxon	Time Period	Area	Independent Variables	t Ratio	P	R^2	df	
Rotifers	March-Nov.	Upper San Joaquin R.	Chlorophyll *a*	5.47	>.01	79.30	9	
			Exports	-2.40	>.05			
			Chipps EC	-2.39	>.05			
		Delta	Chlorophyll *a*	3.65	>.01	56.28	9	
			Exports	-2.42	>.05			
Synchaeta bicornis	March-Nov.	Suisun Bay	Chlorophyll *a*	5.92	>.01	76.11	13	9
		All Areas	Chlorophyll *a*	3.44	>.01	51.77	13	9

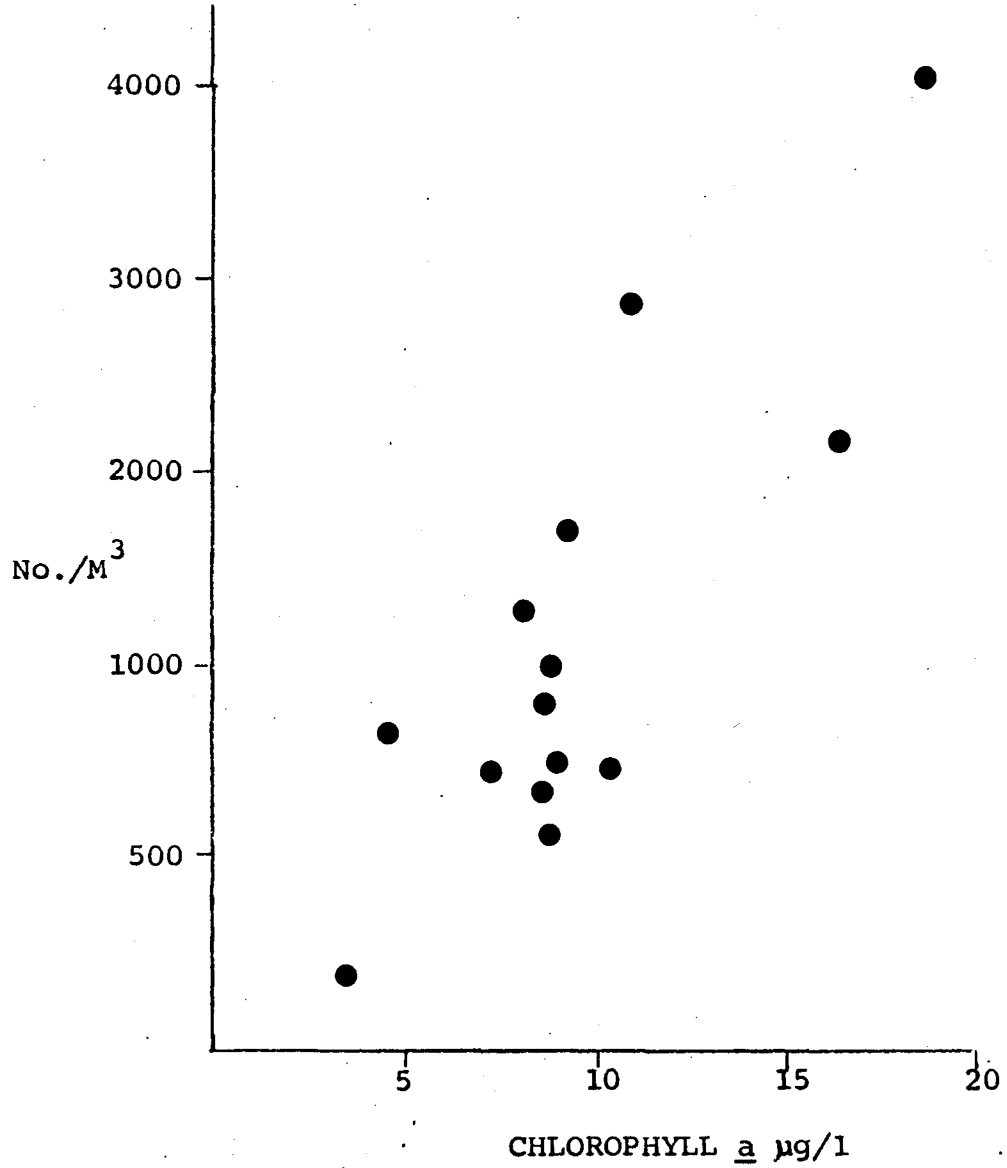


Fig. 39 . Eurytemora abundance vs. chlorophyll a concentrations in all areas combined, March-November means 1972-1985.

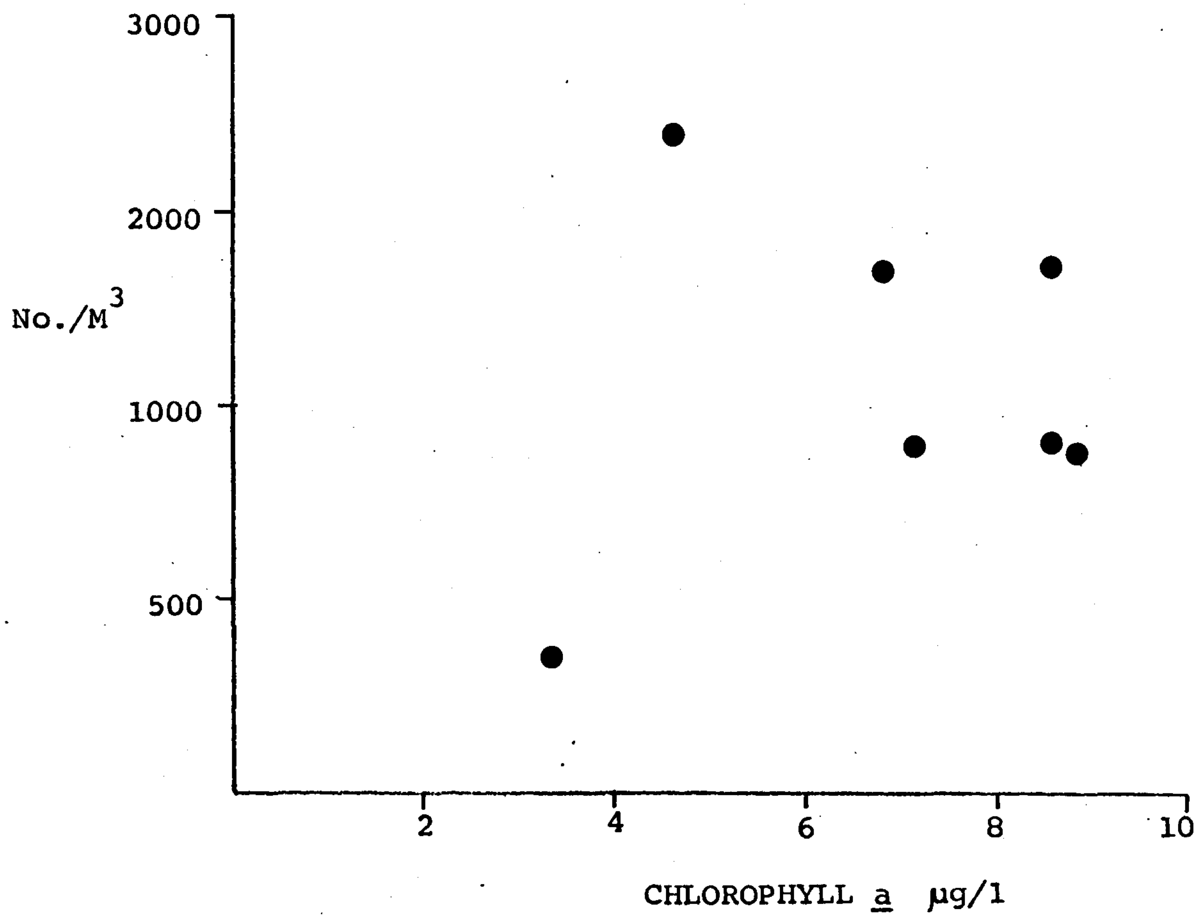


Fig. 40. Sinocalanus abundance vs. chlorophyll a concentrations in the delta, March-November means 1979-1985.

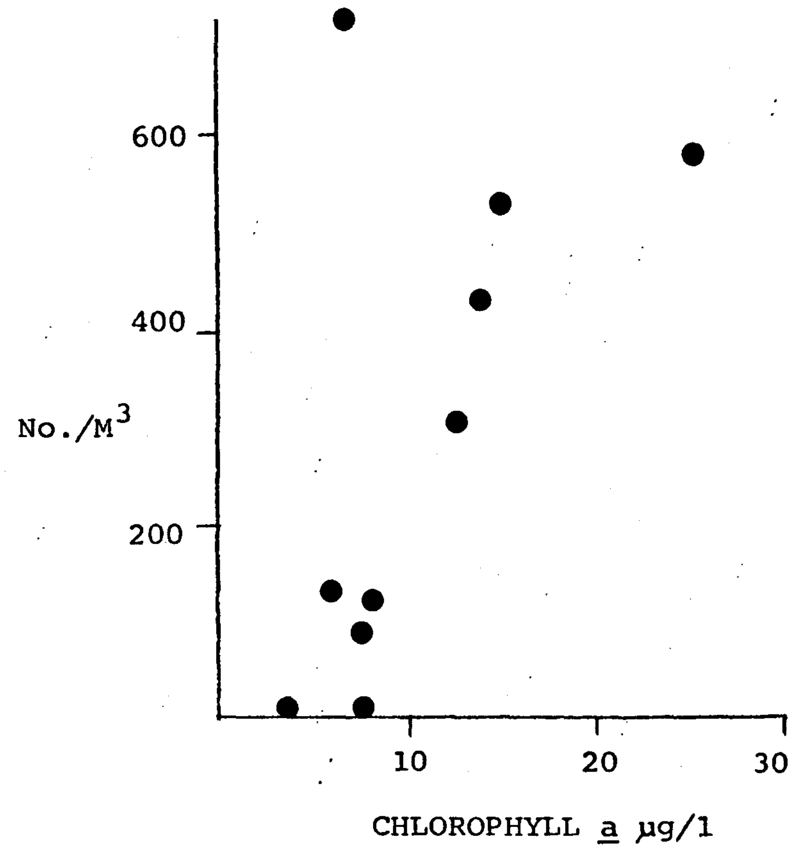


Fig. 41. *Diaptomus* abundance vs. chlorophyll *a* concentrations in the upper San Joaquin River, March-November means, 1972-1985.

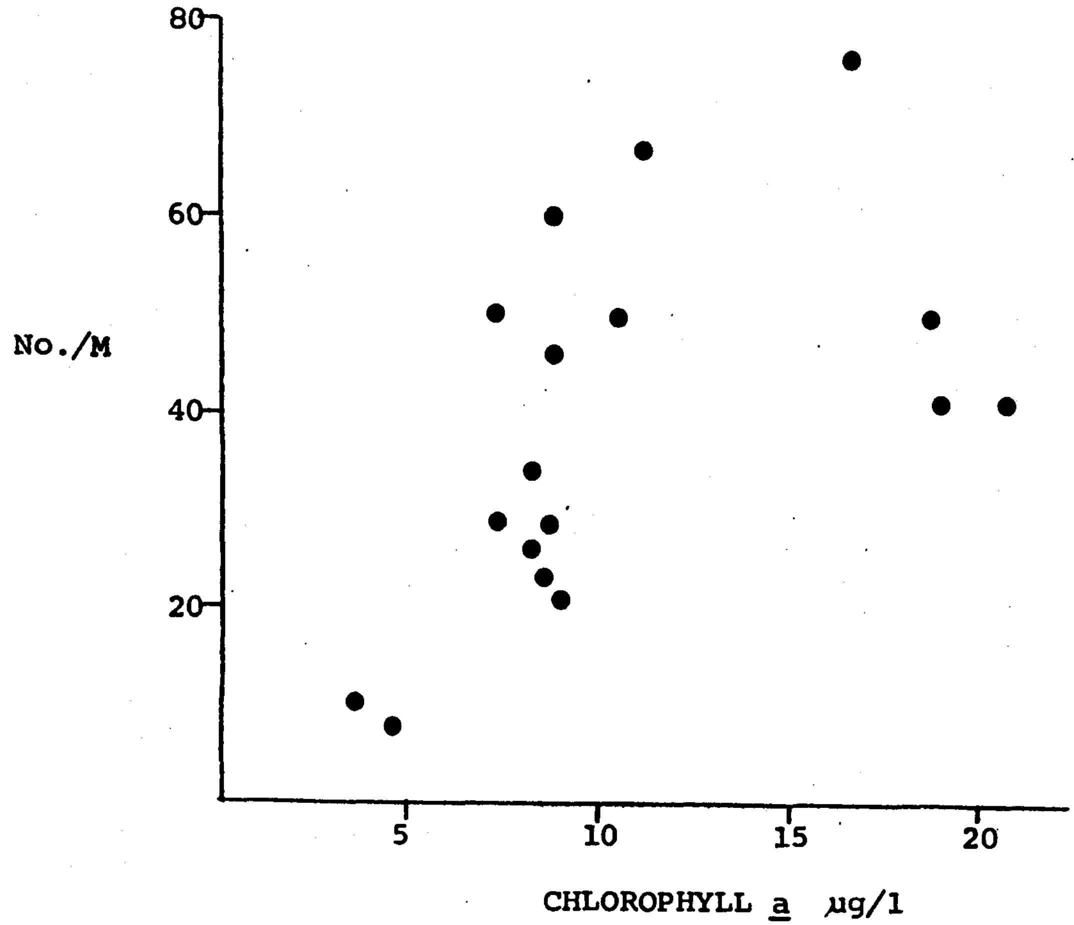


Fig. 42. *Neomysis* abundance vs. chlorophyll *a* concentrations in all areas combined, March-November means 1969-1985.

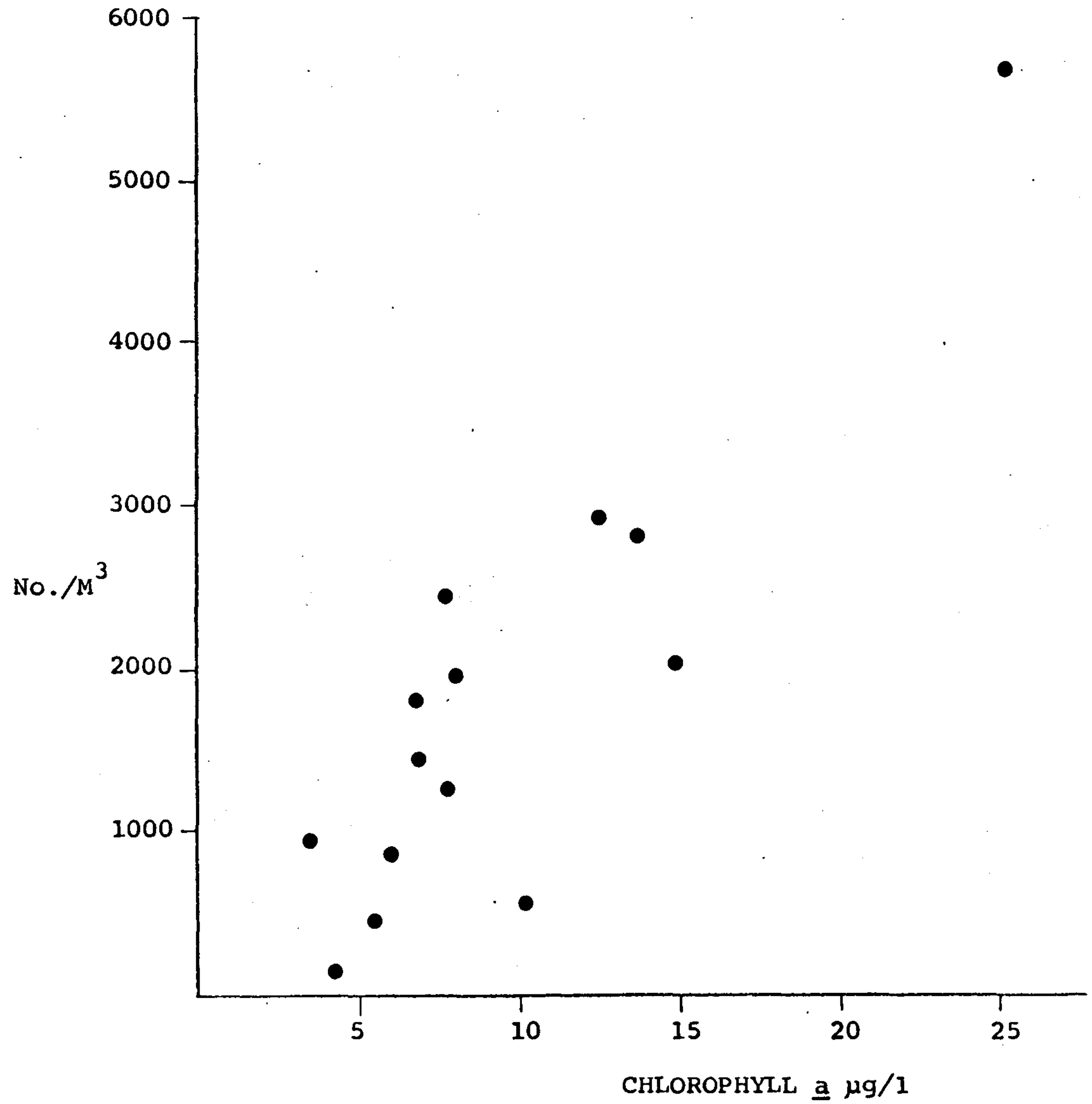


Fig. 43. Abundance of native cyclopoid copepods vs. chlorophyll a in the upper San Joaquin River, March-November means 1972-1985.

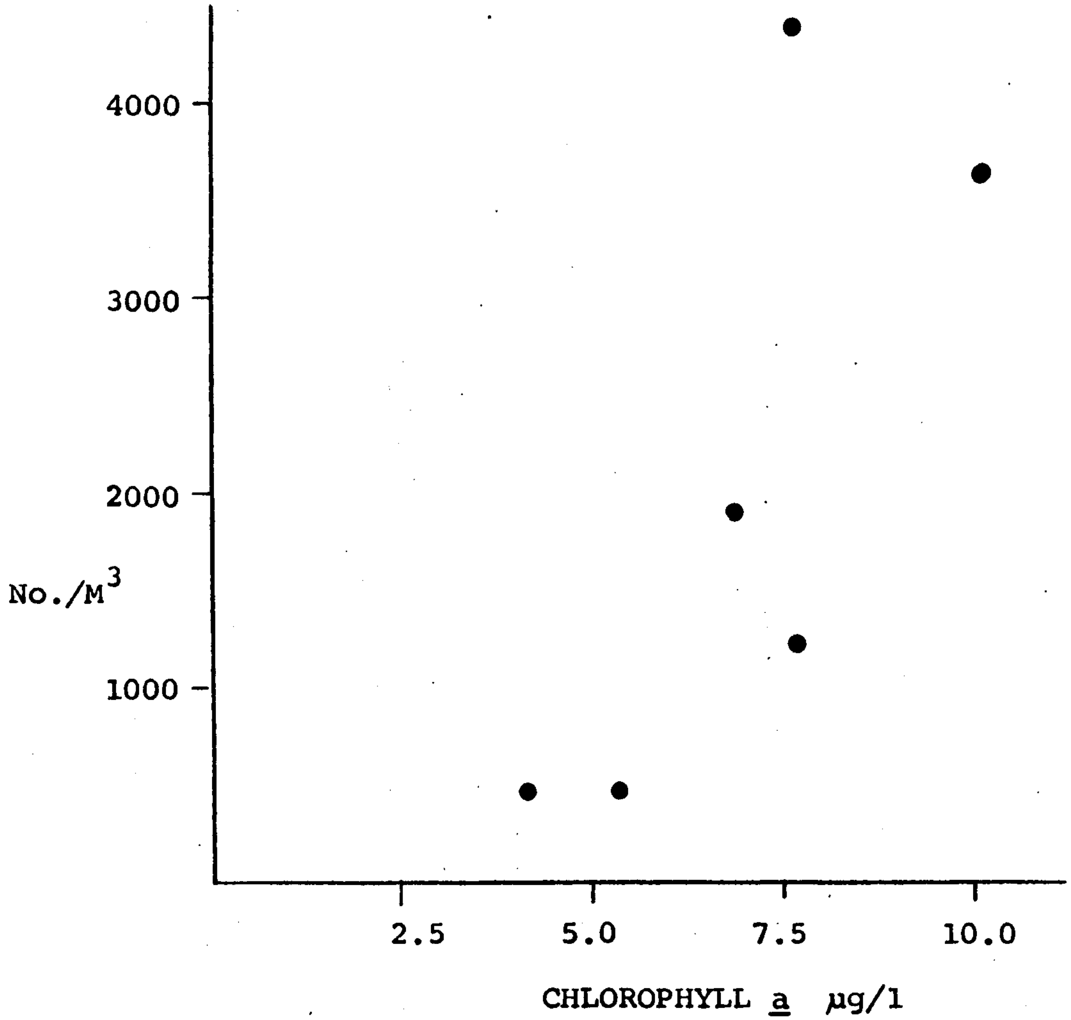


Fig. 44. *Limnoithona* abundance vs. chlorophyll *a* concentrations in the upper San Joaquin River, March-November means 1980-1985.

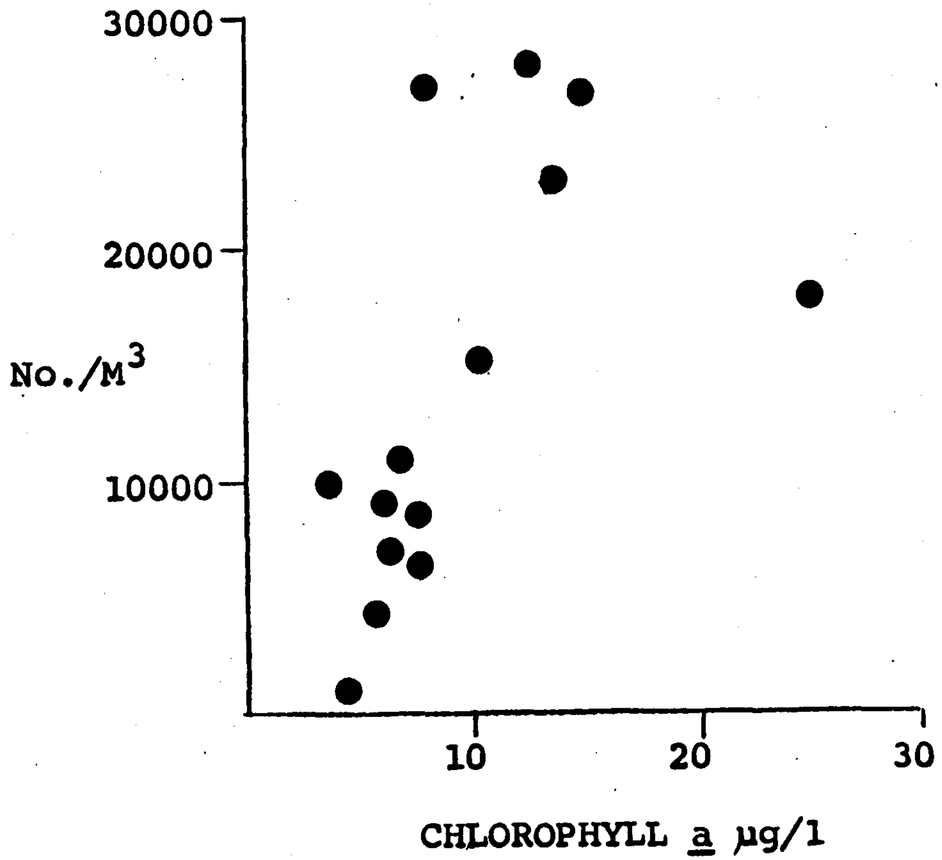


Fig. 45 . Cladoceran abundance in the upper San Joaquin River vs. chlorophyll a concentrations, March-Novmeber means 1972-1985

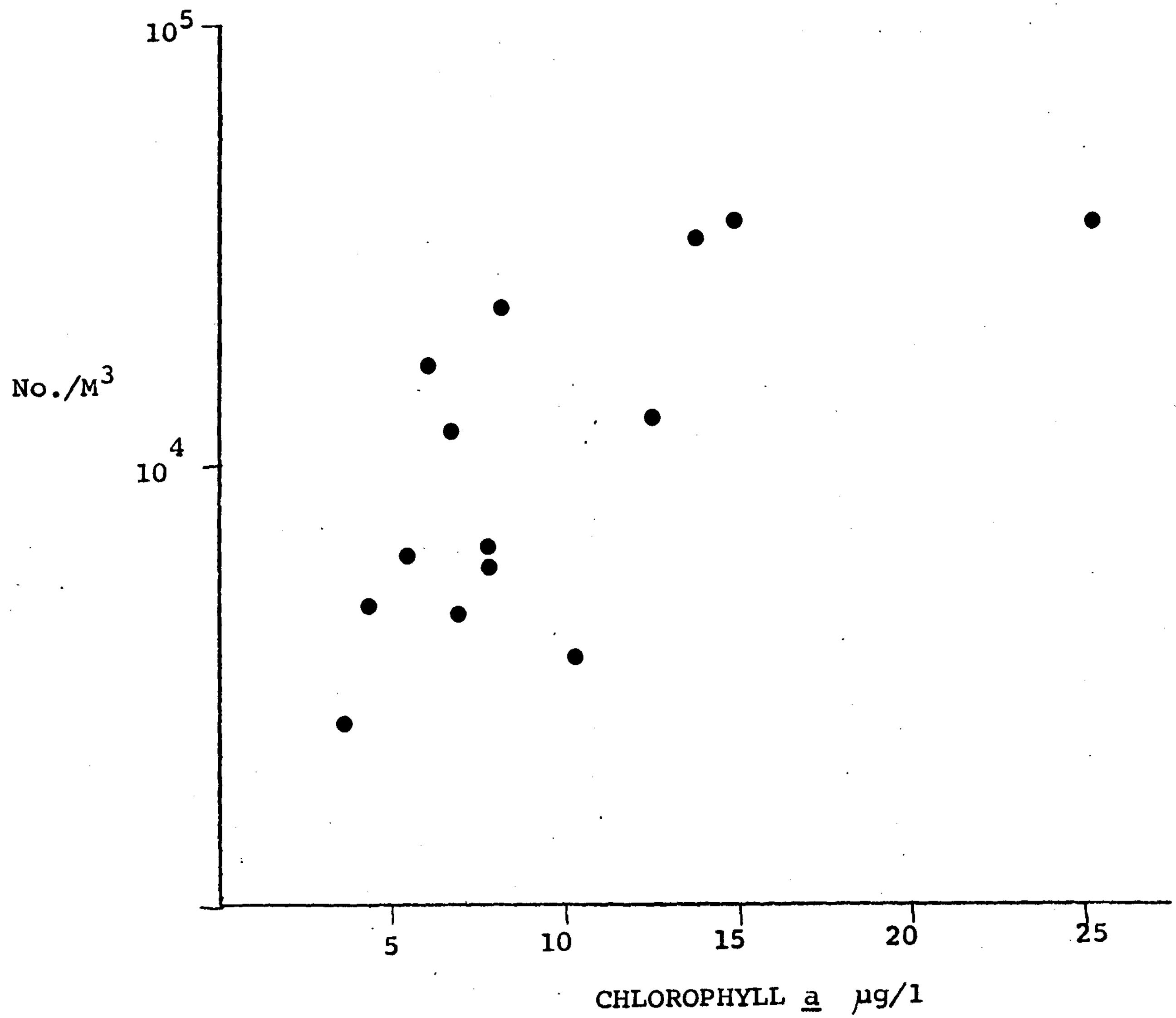


Fig. 46. Rotifer abundance in the upper San Joaquin River vs. chlorophyll a concentrations, March-November means 1972-1985.

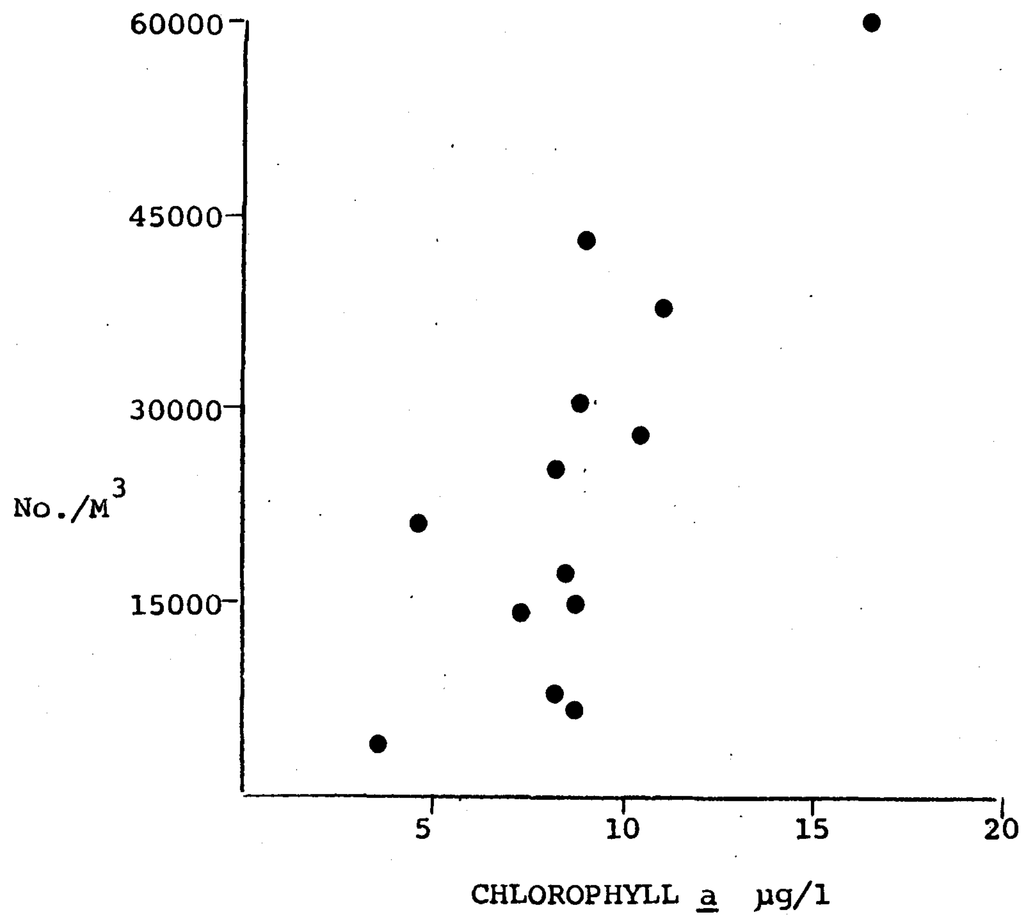


Fig. 47 . *Synchaeta bicornis* abundance vs. chlorophyll *a* in all areas combined, March-November means 1973-1985.

Rotifers also had a significant negative t ratio with water export. It was the only taxon to achieve significance with this variable.

The significant relationship between Neomysis and EC reflects a similar relationship between Neomysis and Delta outflow (Figure 48). A plot of abundance vs. outflow showed that this relationship was almost linear except low concentrations were associated with the flood level 1983 outflow. A regression using outflow, square of outflow and chlorophyll a as independent variables vs. Neomysis density in all areas combined yielded highly significant t ratios for outflow (+4.086, $p<.01$), outflow squared (-3.703, $p<.01$) and chlorophyll a (+2.412, $p<.05$).

Salinity intrusion not only affects Neomysis population size, but also the portion of the population located in Suisun Bay or the Delta. The percent of the population in the Delta ranged from less than 20 when Chipps Island EC was at its lowest to almost 100 percent at a mean March-November EC of 17,000 uhmos (Figure 49). The highest EC was recorded in 1977.

Reverse Flows

During summer and fall very high export rates at the CVP-SWP pumping plants in the southern Delta draw Sacramento River water around the tip of Sherman Island and into the San Joaquin. Under these conditions flow direction in the San Joaquin River reverses and the river flows upstream to the mouth of Old River and then to the pumps. To examine the effects of reverse flow on zooplankton in the San Joaquin River, the abundance of three major zooplankton

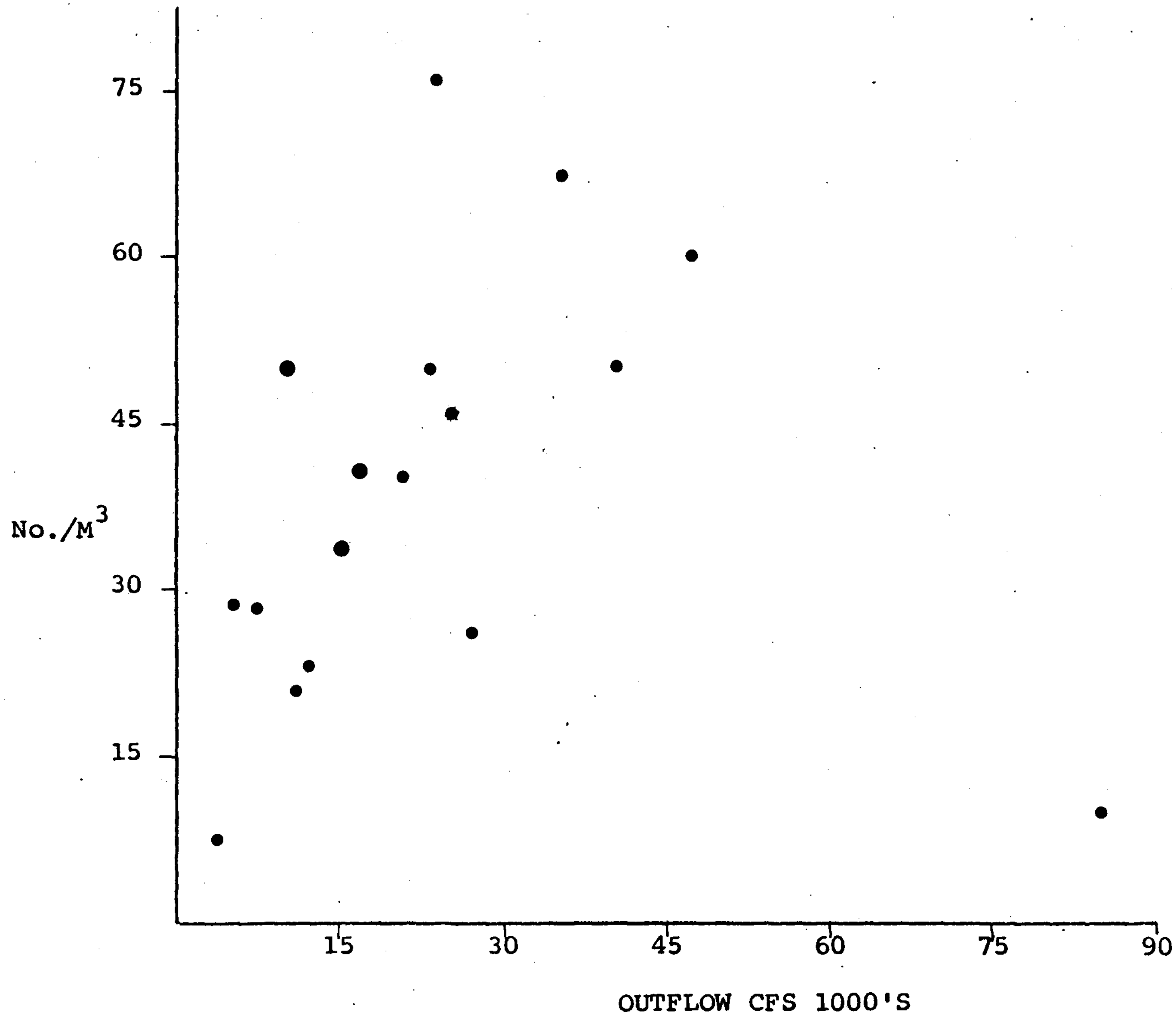


Fig. 48. Neomysis abundance in all areas combined vs. delta outflow as measured at Chipps Island , March-November means 1969-1985.

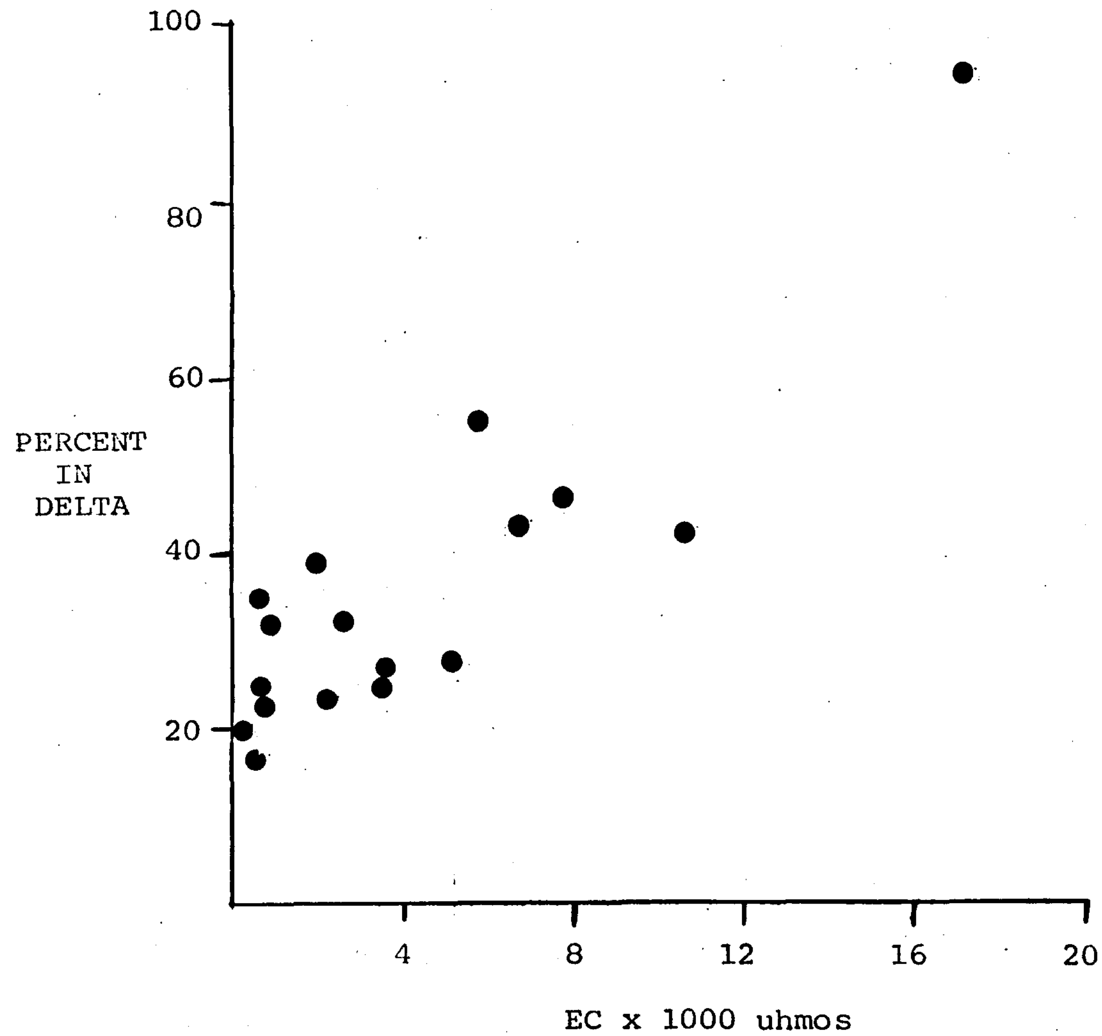


Fig. 49. Percent of the mean March-November Neomysis population in the delta in each year in relation to mean Chipps Island electrical conductivity.

groups: calanoid copepods, cladocerans, and rotifers was calculated for San Joaquin River stations during normal and reverse flows. July and August data from four years were used. Two of the years, 1979 and 1981, were dry years with reverse flows in these months. The other two, 1982 and 1983, were wet years with normal flow direction.

No clear-cut differences in abundance between the two groups of years could be detected (Figure 50). For cladocerans, abundance was much higher at all stations downstream from the mouth of Old River in the wet years. But this is probably due to lower salinities during these years. Calanoid copepods include the euryhaline Eurytemora as well as the fresh water genera Sinocalanus and Diaptomus so regardless of flow abundance was highest at the farthest downstream stations where both Eurytemora and Sinocalanus were present and declined moving upstream as Eurytemora became less numerous.

Rotifers were extremely abundant in the wettest year, 1983, but abundance in the other three years was similar. Abundance increased moving upstream in these years but in 1983 peak abundance was at Jersey Island.

Thus, no relationship can be discerned between zooplankton abundance and flow direction. Only the effects of salinity intrusion were apparent. We could not determine if low freshwater zooplankton densities at the farthest downstream stations were caused by the entrance of zooplankton deficient Sacramento River water or simply by high salinities which would exist in dry years even in the absence of reverse flow.

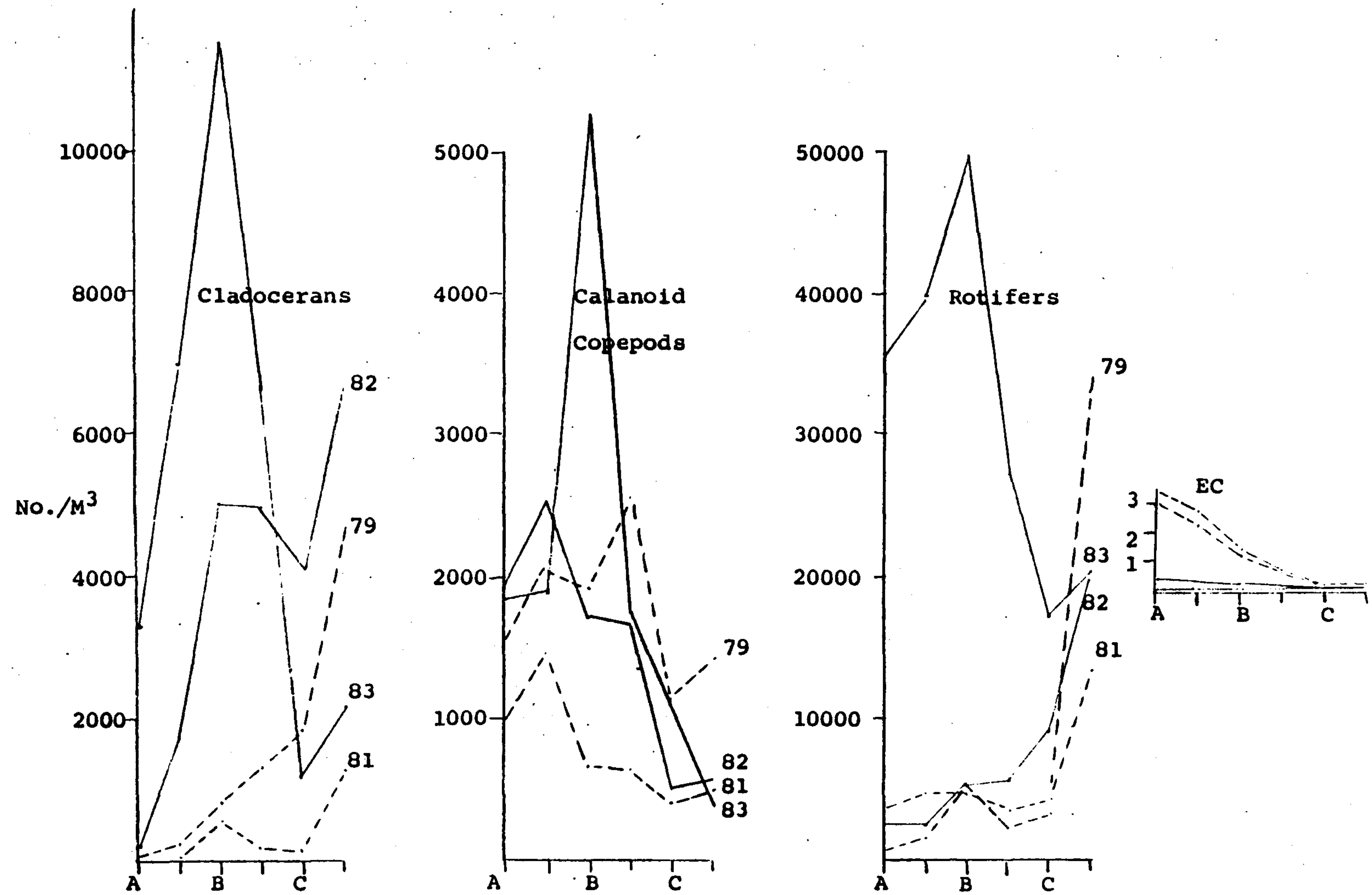


Fig. 50. Abundance of cladocerans, calanoid copepods and rotifers in the San Joaquin River during normal downstream flow direction (1982 and 1983) and during reverse flow direction (1979 and 1981). Values are July and August means at each sampling station. A is the location of Antioch, B is Jersey Island, and C is the mouth of Old River. EC is measured in umhos. Reverse flow years are dashed lines. Normal flow years are solid lines.

Effects of Cross-Delta Flow on Zooplankton Abundance in Old River

Cross-Delta flow to the south Delta pumps brings large volumes of Sacramento River water into Old River via the Mokelumne River. This could cause changes in the abundance of zooplankton in Old River because the Sacramento River at the Delta cross-channel has very low zooplankton concentrations (Orsi and Mecum 1986). In addition, as export pumping in the south Delta increases, residence time in Old River decreases and this may hold down zooplankton abundance in Old River by reducing the amount of time available for reproduction before the water reaches the pumps.

To examine the effects of export pumping on abundance in Old River mean numbers per cubic meter of cladocerans, calanoid copepods and rotifers during July and August of each year from 1979 to 1984 were compared with mean monthly export rates from the Federal and State pumps combined. The zooplankton data came from the Old River sampling station near Rock Slough. No relationship existed between abundance of any zooplankton group and export rates ranging from 3,500 to 9,500 cfs (Figure 51).

However, cross-Delta flow may reduce zooplankton abundance in the San Joaquin River at the mouth of Old River (Figure 50). Abundance of cladocerans was sharply lower in 1981, 1982 and 1983 at the sampling station in the path of the cross-Delta flow. A strong reduction of calanoid copepods was visible in 1979 and lesser effects are suggested in 1981 and 1982. Rotifers, showed a decline at this location only in 1983.

DISCUSSION

The patterns of zooplankton distribution and abundance in the Delta from 1972 to 1978 reported by Orsi and Mecum (1986) have not changed. Chlorophyll a concentrations in the upper San Joaquin River have declined drastically but freshwater zooplankton abundance is still higher there than elsewhere in the Delta. High temperature in this area is a factor favoring high zooplankton birth rates and hence abundance. This is also the area of the Delta least affected by the entrance of zooplankton deficient Sacramento River water from cross-delta and reverse flows.

The long-term downtrends observed for most native zooplankton taxa are, for the most part, statistically related to chlorophyll a which has also experienced a decline. Since all of the zooplankton studies in this report with the possible exception of Limnoithona, feed at least in part on phytoplankton there is strong reason to believe that the relationship is an effect of food supply on zooplankton abundance.

Only Neomysis appeared to have its abundance affected by the position of the salinity gradient but all species will have their distribution affected by it. The exact mechanism by which the position of the salinity gradient affects Neomysis abundance is not clear. It can impact the population either by reducing habitat or as when the entrapment zone enters the Delta by reducing phytoplankton concentrations.

Export rates were significant only for rotifers.

The temperature range from 1972 to 1985 was 1.3 C in the Delta and 1.5 C in Suisun Bay. This should be large enough to have some effect on birth rates but apparently not enough to be detected by statistical tests. In the Delta, temperature had a significant partial correlation coefficient with several zooplankton taxa during the 1972-1978 period when data for each station was individually entered into the correlations (Orsi and Mecum 1986). The temperature range between coolest and warmest stations was 3 C, twice the range in these regressions.

Effects of cross-Delta flow rate were not apparent in Old River but were detectable in the San Joaquin River at the mouth of Old River where they caused a reduction in zooplankton abundance. Rate of water movement is an important factor that can regulate zooplankton population size (Ketchum 1954). In order for population size to rise or at least remain stable the reproductive rate must be high enough to counterbalance emigration from flow transport. The higher the flow the higher the reproductive rate must be. Changes in pumping rates from 3,500 to 9,500 cfs as occurred during July and August of 1979 to 1984 should have caused large changes in net velocities in Old River, yet there was no perceptible effect on zooplankton densities. This may be because net velocities even at 3,500 cfs are so high that no significant reproduction can occur between the entrance of the water at the Delta cross-channel and the sampling station near Rock Slough. In that case zooplankton abundance in Old River may simply reflect its abundance wherever the water originates. This will not be solely from the Sacramento River at the cross-channel but also from a variety of channels in the interior Delta. Judging from the much greater zooplankton abundance in the south Delta as compared to the Sacramento River at Hood (Orsi and Mecum 1986), much of the zooplankton in Old River must originate within the Delta as shown by the reduced zooplankton abundance in the San Joaquin River at the mouth of Old River.

The sharp reduction in Sinocalanus abundance in the San Joaquin River at the mouth of Old River suggests that this copepod is drawn into Old River by the cross-delta flow (Figure 21). Other zooplankton taxa are likely to be pulled into the cross-delta flow but since the other freshwater zooplankton species are most abundant in the San Joaquin upstream from Old River it is not possible to demonstrate this as easily as for Sinocalanus.

Increased salinity in the drier years reduces the habitat available to Neomysis. This shrimp can be regarded as being in a box, the sides of which expand and contract with the volume of river outflow. The location of the box also moves, oscillating up and downstream with the tides and with river outflow. Tides cause minor daily displacements; changes in river outflow bring about major movements.

Basically, Neomysis tends to be most abundant in the entrapment zone and immediately upstream from there (Knutson and Orsi 1983)). This appears to be due to the diel vertical migration of the mysids interacting with two-layered estuarine flow (Orsi 1986). The high outflows of wet and normal winters and springs push the entrapment zone and Neomysis seawards into Carquinez Strait and even San Pablo Bay. Shrimp located in the main Delta channels are scoured out by these flows. By late spring, outflow has diminished and the entrapment zone has been pushed into Suisun Bay by intruding marine water. Once again, the mysids move with the zone and begin to appear in increasing numbers in the Delta.

Their upstream extent in the Delta and in the rivers that feed it is limited by high net velocities, light penetration to the bottom, high temperature, especially in combination with low dissolved oxygen (Heubach 1969, Orsi and Knutson 1979) and cross-delta flow to the export pumps in the south Delta.

In general, mysids are not abundant in the Sacramento River upstream from its junction with Steamboat Slough, in the Mokelumne River, and in the San Joaquin River upstream from the mouth of Old River. In the first two streams high net velocities and flow direction that may not reverse on the flood tide plus light penetration to the bottom are inhibiting factors (Heubach 1969, Delta Study, unpublished). In the San Joaquin the cross-delta flow appears to divert mysids into the south Delta, and in addition, high temperature in combination with low dissolved oxygen during late summer and fall depresses mysid abundance in the Stockton area of the San Joaquin River (Heubach 1969, Orsi and Knutson 1979).

Movement of the entrapment zone into the Delta not only reduces the area of suitable habitat but also cause a reduction in the phytoplankton concentration in this productive zone (Arthur and Ball 1979). Neomysis feeds on phytoplankton (Kost and Knight 1975) although zooplankton may be a more important food (Siegfried and Kopache 1980). Zooplankton, however, feed heavily on phytoplankton (Orsi 1987) so phytoplankton is important to Neomysis either directly or indirectly. Food supply is known to affect crustacean size at maturity and fecundity (Ambler 1986, Beckman and Peterson 1986, Deevey 1960, Warren et al. 1986). Hence, anything that causes a reduction in phytoplankton should also act to reduce Neomysis abindance.

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DFG Exhibit 28a

Exhibit 28a, entered by the California Department of Fish and Game for the State Water Resources Contol Board 1987 Water Quality/ Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta.

Effects of Export Pumping from Federal and State Pumps on Neomysis Abundance in the San Joaquin River

The Federal and State Pumping Plants draw water out of the Sacramento River at Walnut Grove through the Delta Cross Channel and Georgiana Slough. The water passes through the Mokelumne River, across the San Joaquin River and up Old and Middle rivers to the pump intakes in the south Delta (cross-Delta flow). Additional Sacramento River water may be pulled around Sherman Island and up the San Joaquin to the mouth of Old River and then to the pumps (reverse flow). _Neomysis_ may be entrained by either cross-Delta or reverse flows and brought to the pumps and thus removed from the Delta.

A major question is what effects do the entrainment losses have on the _Neomysis_ population size? Ecological Analysts (EA), a private consulting firm, attempted to estimate loss rates to the pumps (Ecological Analysts 1981). It's calculations of the estimated percent reduction of the total population of 4-17 mm mysids ranged from 3.3% in 1979 to 74% in 1970. The reduction estimates were highest from 1970 to 1972 and then showed a large, statistically significant decline to lower levels.

EA emphasized that the true reduction was less than the calculated levels because of compensation, that is, reduced natural mortality at lower population levels. However, EA was unable to quantifiy the compensation effect. Nevertheless, these calculations indicate that pumping can have a significant impact on _Neomysis_ abundance.

Subsequently, Turner (1982) noted that between 1970 and 1980, a period of rising pumping rates, chlorophyll _a_ and _Neomysis_ declined more in the San Joaquin River than in the Sacramento

River. Since the San Joaquin River is closer to the pumps the greater decline in that river suggests that pumping was reducing the population size.

The DFG recently performed a more extensive analysis of this problem as follows: ratios of Neomysis density in the San Joaquin River to density in the Sacramento River were calculated for the March-November period of each year 1969-1985. For the pre-drought years (1969-1975) the ratios averaged 0.74 and for the post-drought period the average ratio was 0.55. This means that post-drought abundance decreased in the San Joaquin relative to the Sacramento River. The ratios were less than unity for all years except 1971, 1977 and 1983.

Mean March-November Neomysis abundance at each station along the San Joaquin River was calculated and plotted for each year to determine where and when the losses were occurring (Figure 1). The decline was greatest in the section of the river most affected by cross-Delta flow and somewhat downstream from there and began in 1975.

Ratios of abundance at the three farthest downstream stations (72, 74, 76) to abundance at the three stations in the path of cross-Delta flow (84, 86, 88) were then calculated for each year and plotted against mean March-November pumping rates from Federal and State pumps combined (Figure 2). The results indicate that average pumping rates > 6000 cfs are asociated with high ratios, i.e., reduced abundance in the path of cross-Delta flow relative to abundance further downstream.

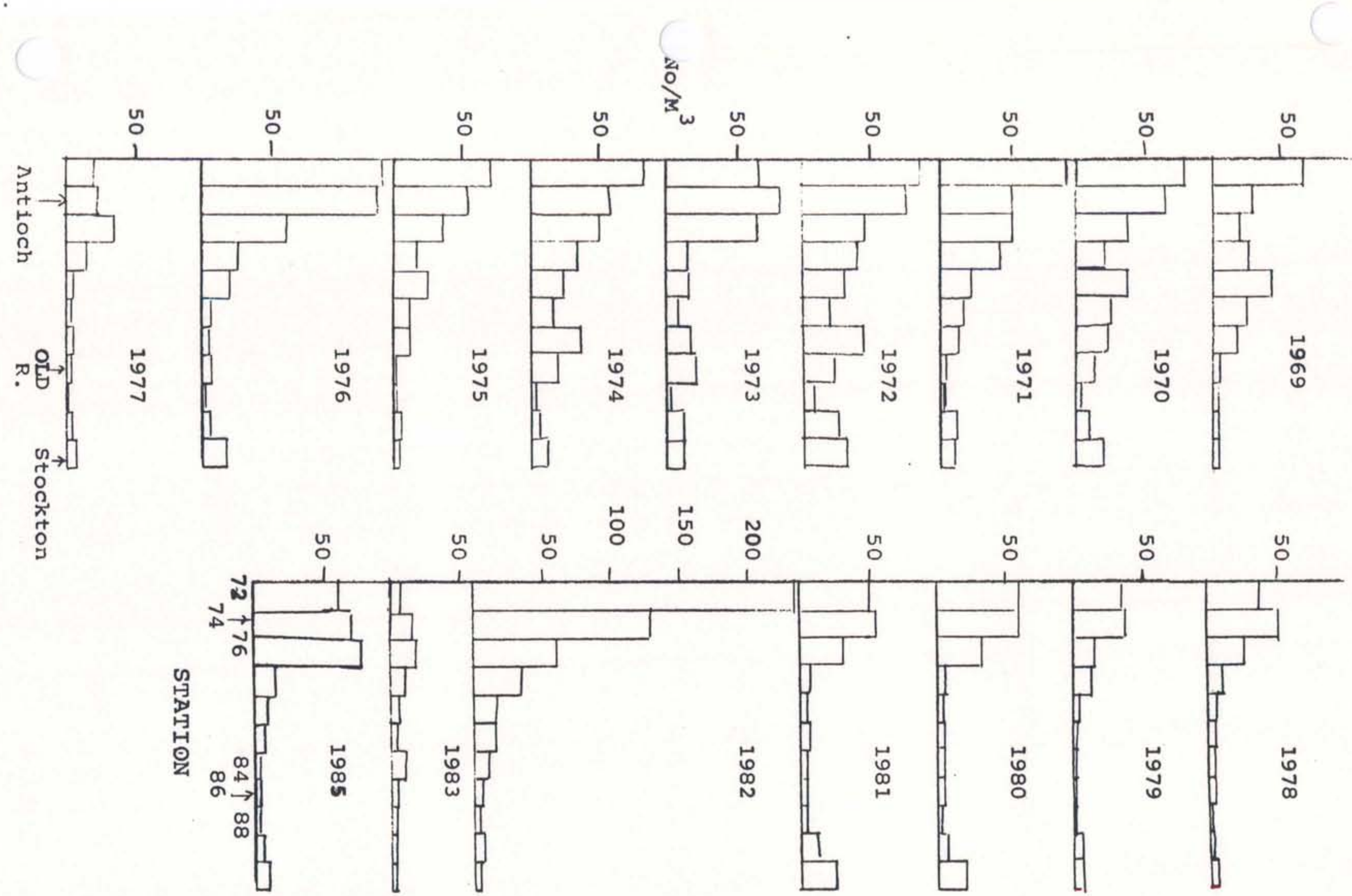

Fig. 1. Mean March-November Neomysis abundance (all sizes) at each sampling station along the San Joaquin River from 1969 to 1985. Data for 1984 is not presented because catches were seriously biassed by a Melosira bloom. Total abundance should not be compared between years because different net mesh sizes were used during 1969-1973 and 1974-1985.

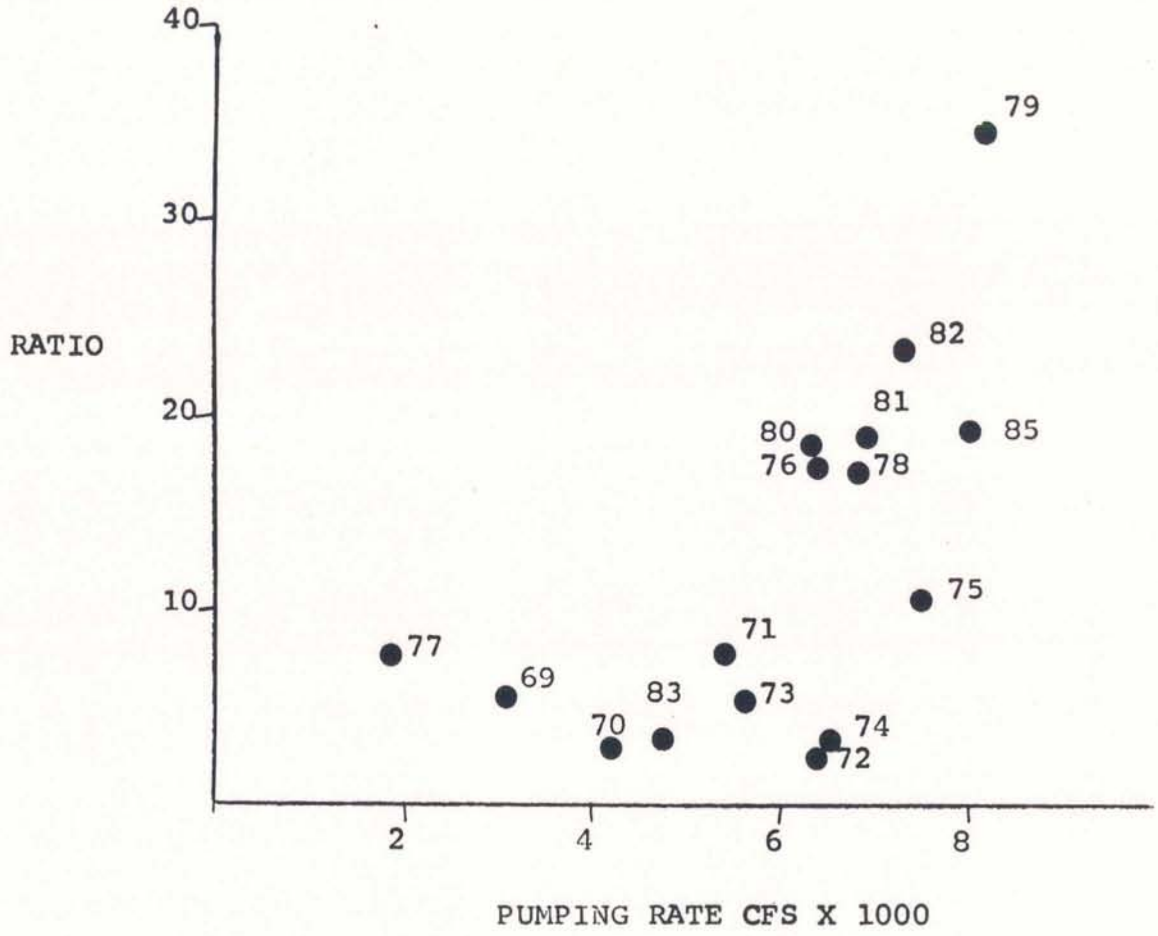

Fig. 2. Ratios of <u>Neomysis</u> abundance (March-November means) at farthest downstream San Joaquin River stations (72,74,76) to abundance at stations in path of cross-delta flow (84,86,88) vs. mean pumping rates from Federal and State pumps combined. Numbers next to the points are the years. Data for 1984 is omitted because catches in the San Joaquin River in that year were seriously biassed by a <u>Melosira</u> bloom.

The years 1972 and 1974 are exceptions to this but overall the relationship indicates a connection between pumping rates and *Neomysis* abundance in the central part of the San Joaquin River.

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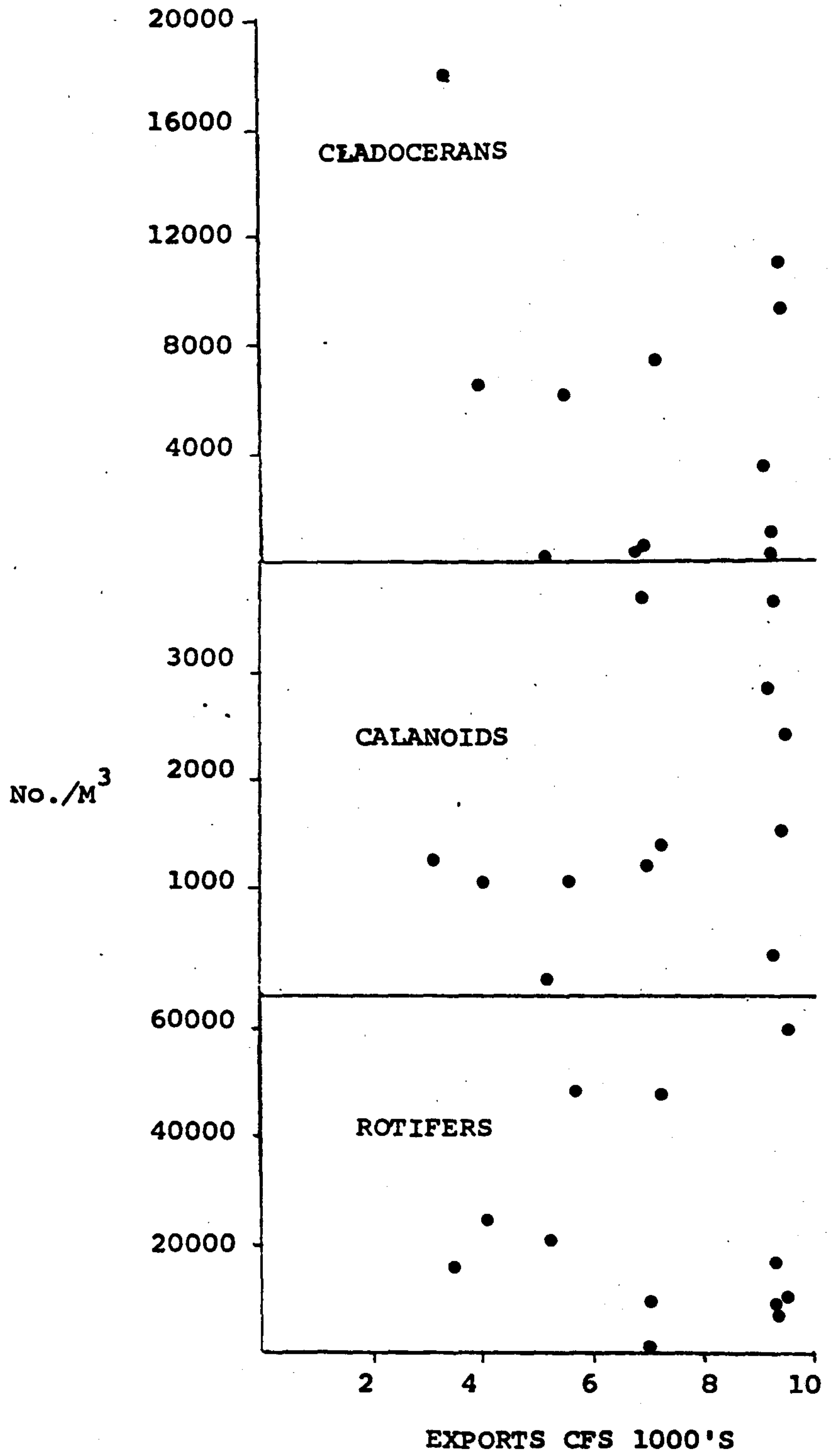

Fig. 51. Abundance of cladocerans, calanoid copepods and rotifers in Old RIver in July and August of each year 1979 to 1984 versus total monthly exports from the State and Federal pumping plants.