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LONG-TERM TRENDS IN ABUNDANCE OF NATIVE ZOOPLANKTON IN RELATION TO DELTA OUTFLOW IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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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 fish. Zooplankton range from less than a millimeter to 16 mm in length. They feed on phytoplankton, detritus and each other. Some migrate vertically or stratify their vertical distribution in the water column in response to light or other stimuli. This behavior helps them to maintain their horizontal position where two-layered estuarine flow exists (Orsi 1986, unpublished MS).

The Department of Fish and Game (DFG) has sampled zooplankton continuously since 1972 in the Delta and Suisun Bay. During this period several zooplankton species from Asia were accidentally introduced to the estuary in ship ballast water (Orsi et al. 1983, Ferrari and Orsi 1984, Orsi and Walter 1991). The DFG presented testimony (Exhibit 28) at the State Board Hearings of 1987 regarding the long-term trends in abundance of all zooplankton species. The present report focuses solely on native crustacean zooplankton, updates the abundance trends to 1990, uses a different statistical method to detect trends (anomaly method), and examines the trends in relation to Delta outflow and San Joaquin River flow at Jersey Point only. A complete report on abundance trends of all zooplankton taxa from 1972 to 1988 has been published as IESP Technical Report 32 (Obrebski et al. 1992). The zooplankton investigated here are the opossum shrimp, Neomysis mercedis, the estuarine copepod Eurytemora affinis, the freshwater copepods, Cyclops and Diaptomus, and the freshwater cladocerans Daphnia and Bosmina.

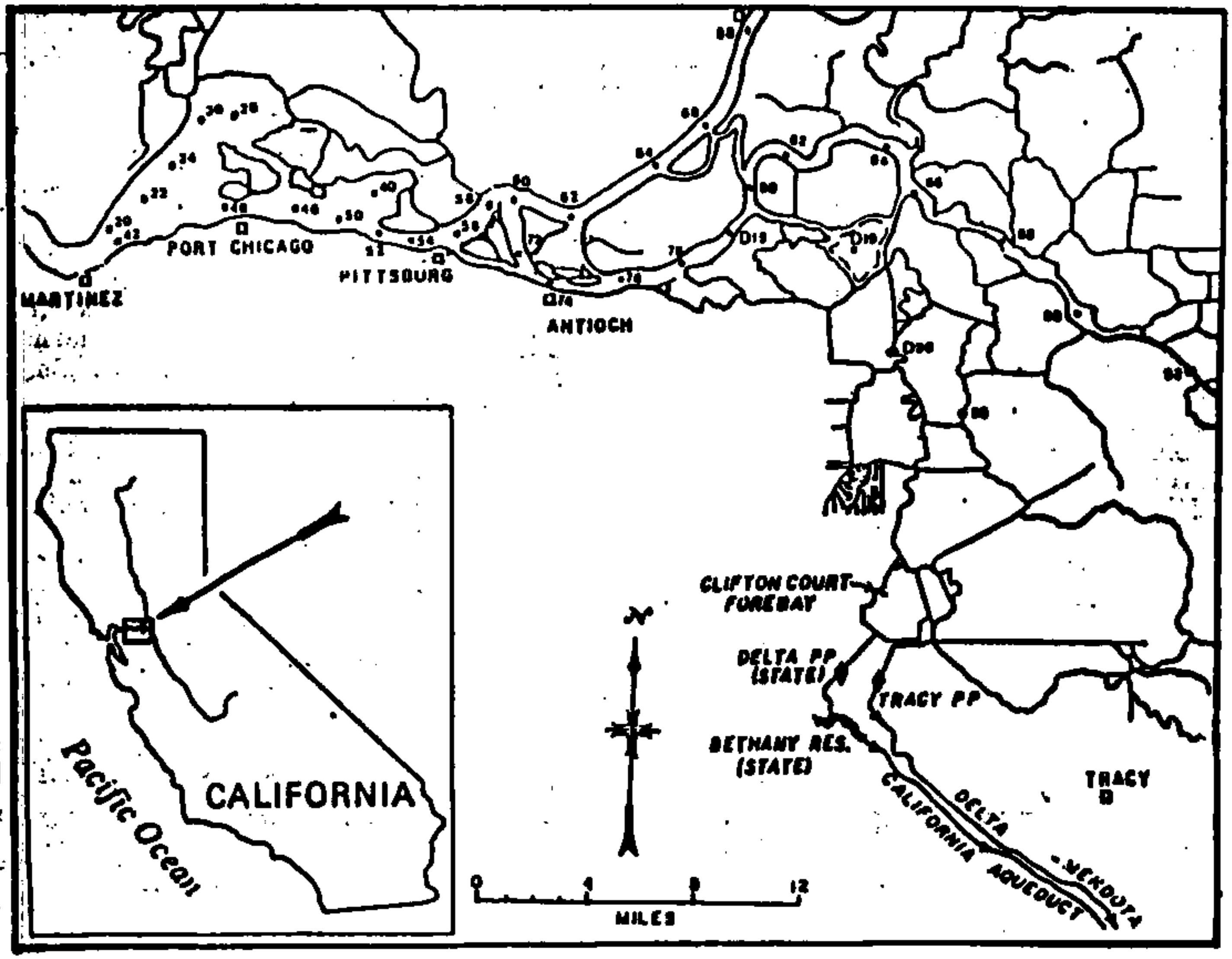
STATISTICAL METHODS

The analysis is based on data from stations sampled continuously from 1972 to 1990 and is restricted to the months April to July when larval striped bass feed on zooplankton. For Neomysis, the period August to November is also analyzed as larger young-of-the-year striped bass feed on it in those months. The stations used are 20, 22, 24, 28, 32 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, D15, D19, and D28 (Figure 1).

Calculated abundance per cubic meter was log transformed to log10 (Z+1) values to reduce the influence of infrequent extreme values on the means. To correct for the effects of salinity and month on abundance, anomaly values were calculated. Anomalies represent abundance after the average effects of salinity (electrical conductivity) and month are removed and may be regarded as the differences between actual observations and the over-all means. Anomalies can be positive or negative. Positive anomalies indicate higher than average abundance and negative ones lower than average abundance. For a complete explanation of this procedure

Figure 1

SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN BAY SAMPLING STATIONS USED IN THE ANALYSIS



see Obrebski et al. 1992. The anomalies were then correlated with Delta outflow at Chipps Island (Dayflow).

RESULTS

Neomysis abundance anomalies were highest in the early 1970's for both April-July and August-November (Figures 2 and 3). Abundance declined during the 1976-77 drought, then rose and stabilized at an intermediate level during the April-July period and finally declined again during the 1987-90 drought years. During the August-November period the recovery after 1976-77 was less marked (Fig. 3). Abundance anomalies had significant linear and curvilinear correlation coefficients with Delta outflow for both time periods (Table 1 and Figures 4 and 5).

Eurytemora abundance anomalies declined gradually from the early 1970's to 1985, then rose in 1986 and 1987 (Figure 6). From 1988 to 1990 the anomalies were very low due presumably to predation from the introduced Asian clam, Potamocorbula. The correlations between the anomalies and Delta outflow were not significant (Table 1 and Figure 7). Even if 1988, 1989 and 1990 are omitted from the plot a relationship with outflow does not become apparent.

Cyclops (cyclopoid) anomalies were generally higher from 1972 to 1980 and lower from 1987 to 1990 (Figure 8). Correlations were not significant (Table 1) but this was due to the high anomalies in 1972, 1976 and 1977. Without these years a significant curvilinear

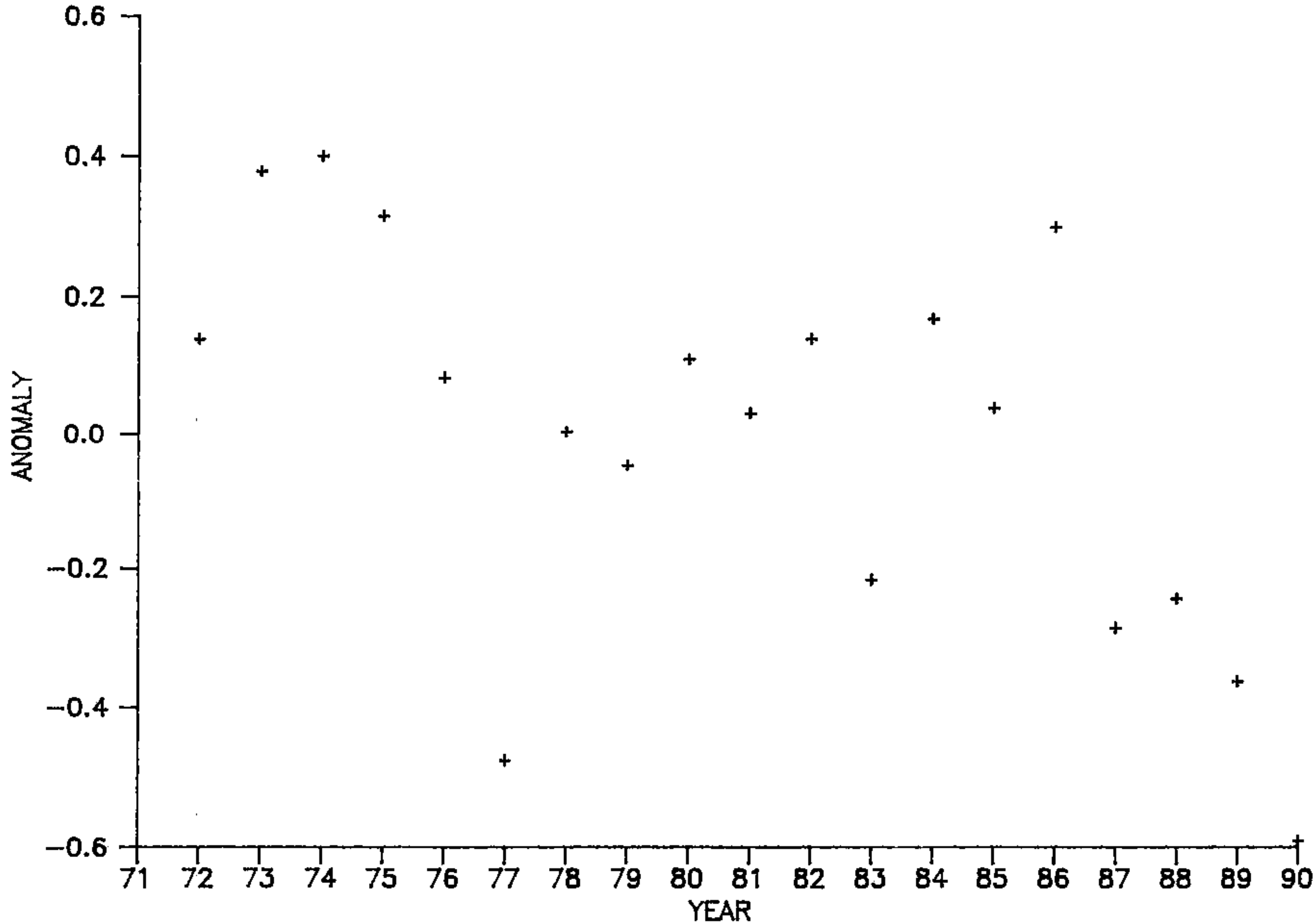


Figure 2 NEOMYSIS POPULATION ANOMALIES vs YEAR
April through July means, 1972 to 1990

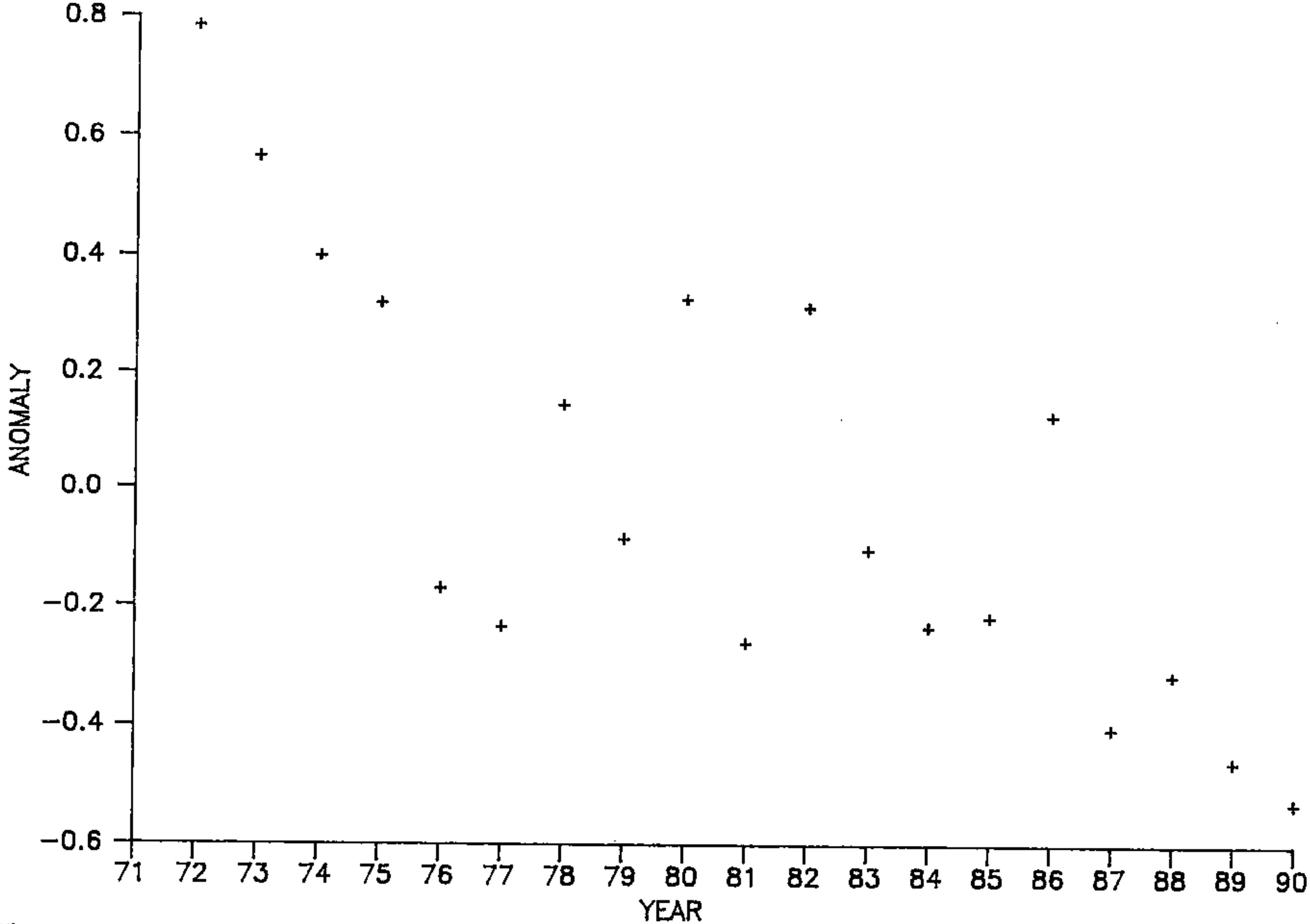


Figure 3

NEOMYSIS POPULATION ANOMALIES vs YEAR
August through November means, 1972 to 1990

Table 1. Significance of linear and quadratic (curvilinear) correlation coefficients for zooplankton abundance anomalies and log of Delta outflow 1972-1990, and percent of variance in anomalies explained by the correlations (R2).

Zooplankton taxon	Linear	R2	Quadratic	R2
Neomysis (April-July)	ns	0.181	<0.01	0.546
Neomysis (Aug.-Nov.)	<0.01	0.415	<0.01	0.563
Eurytemora	ns	0.013	ns	0.044
Eurytemora (1972-87)	ns	0.086	ns	0.136
Cyclops (less 1972, 1976, 1977)	<0.025	0.370	<0.025	0.512
Cyclops	ns	0.074	ns	0.097
Diaptomus	ns	0.070	ns	0.021
Daphnia	ns	0.137	ns	0.198
Bosmina	<0.01	0.341	<0.01	0.393

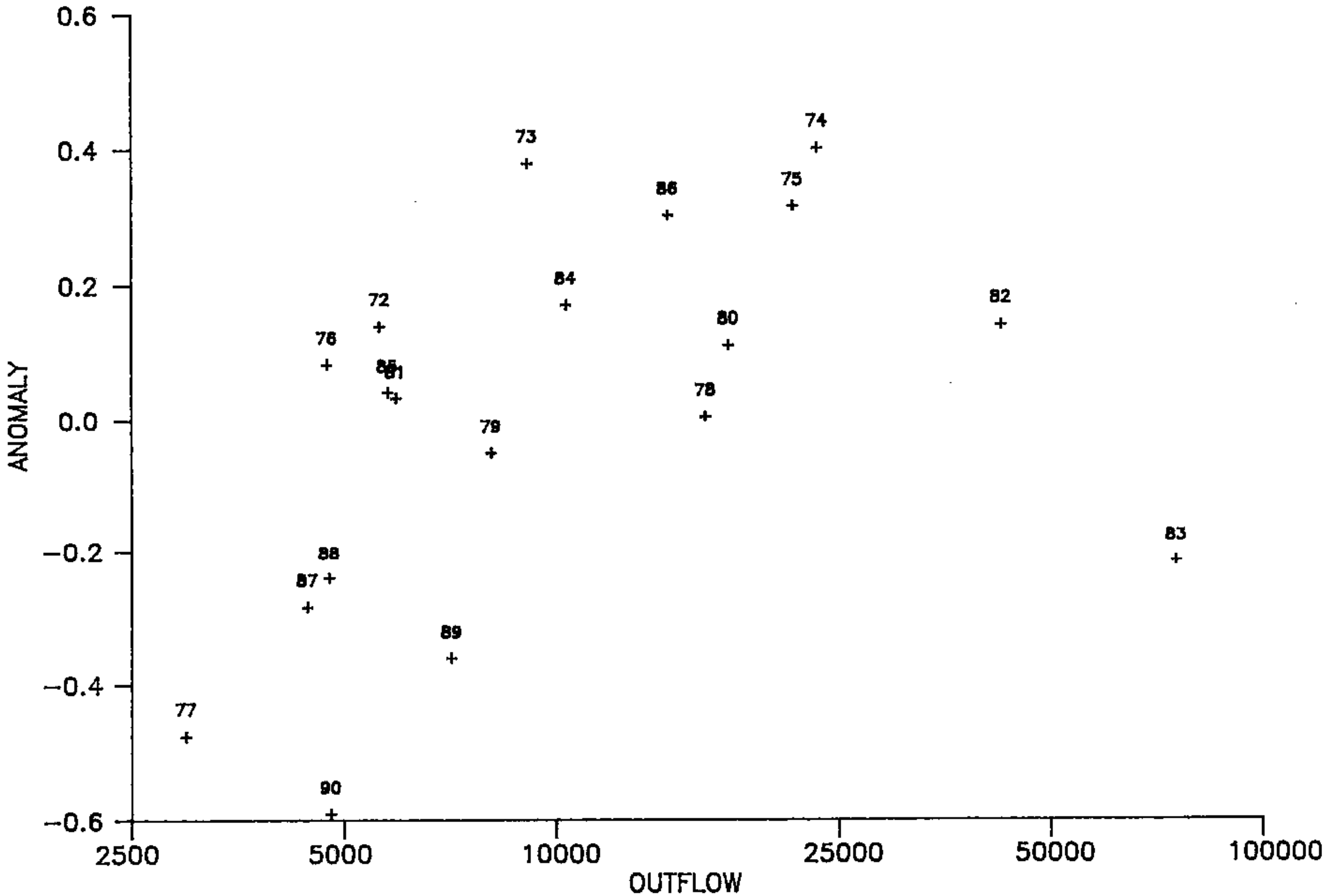


Fig. 4 NEOMYSIS POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 to 1990

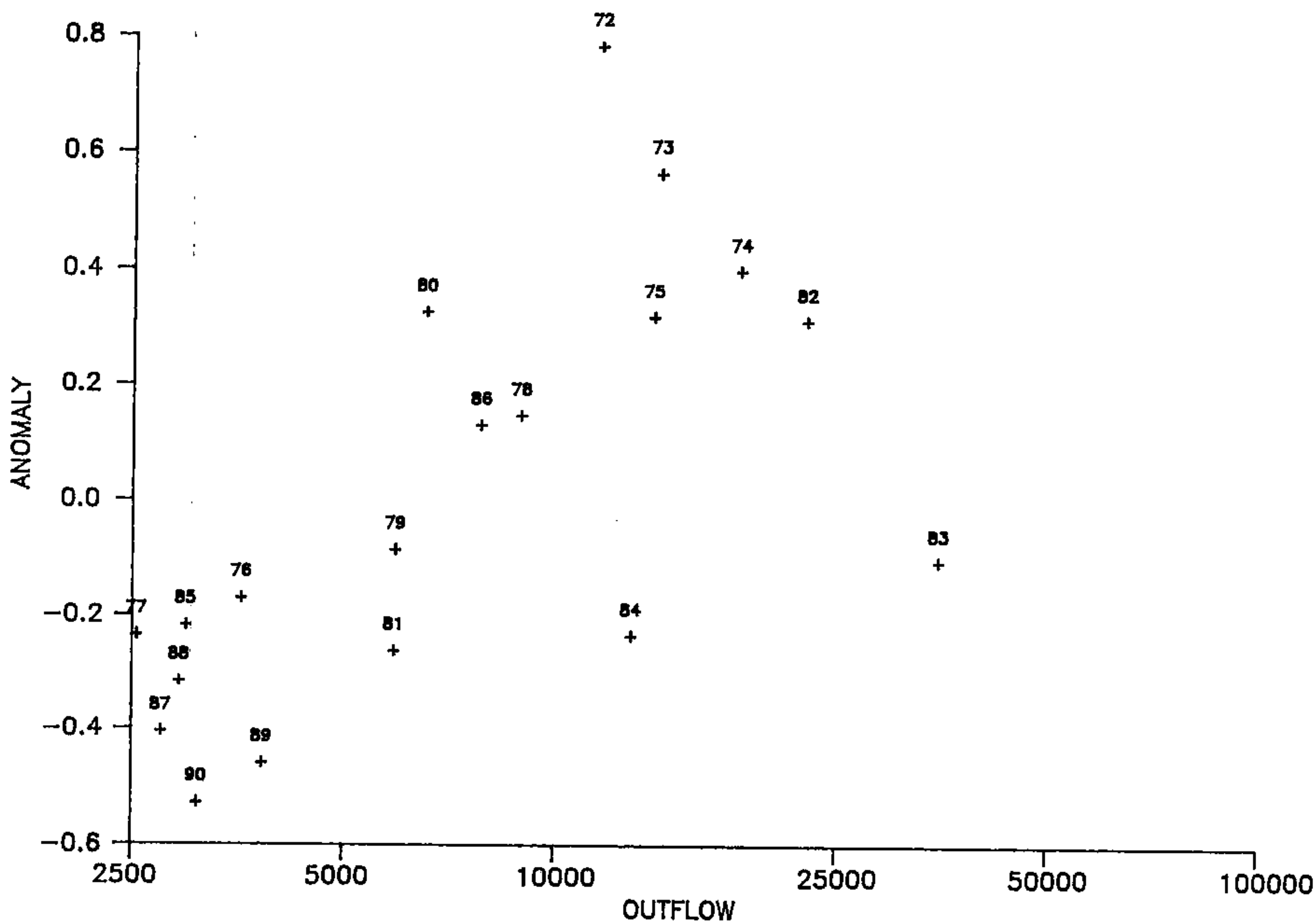


Fig. 5 NEOMYSIS POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
August through November means, 1972 to 1990

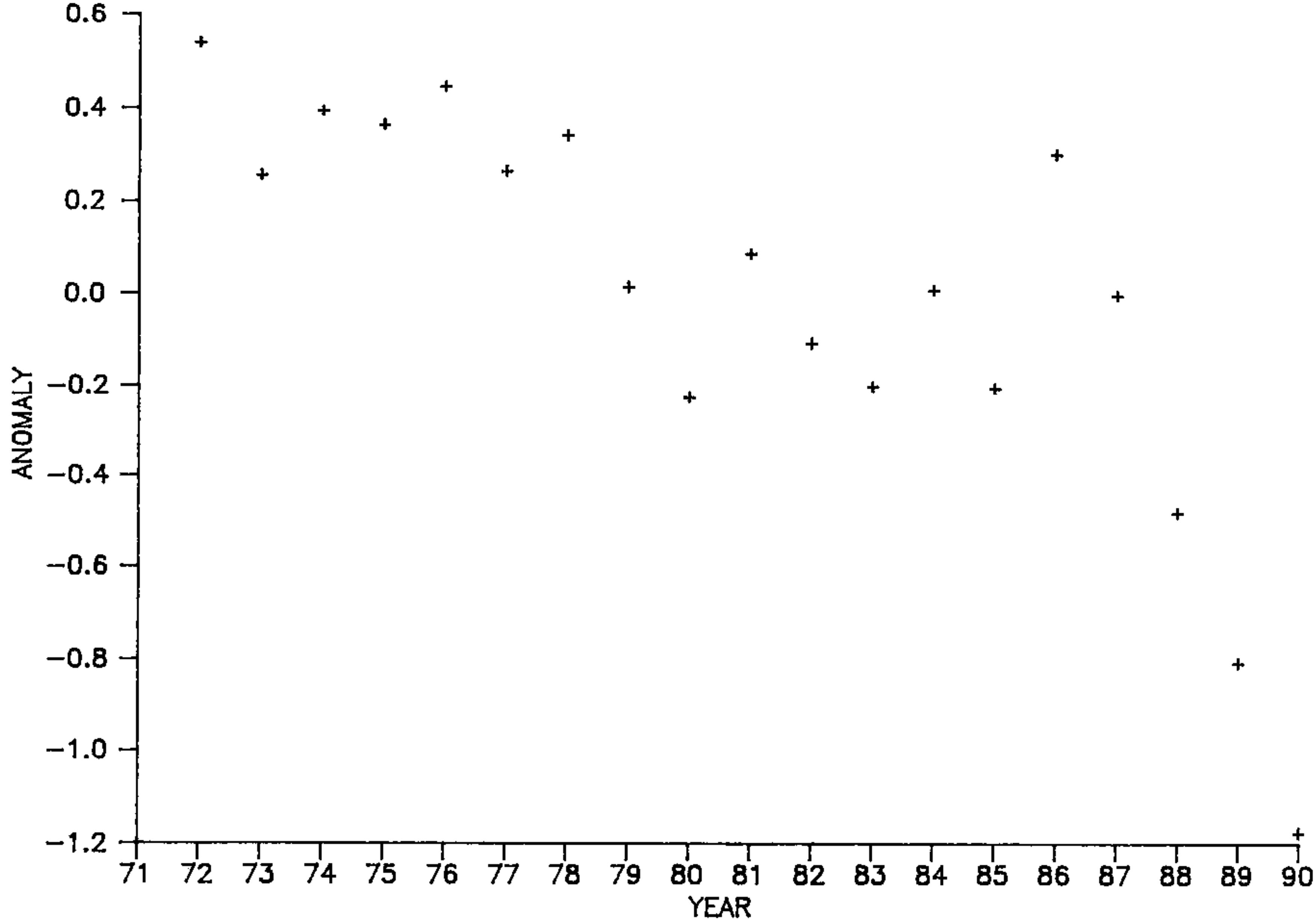


Figure 6

EURYTEMORA POPULATION ANOMALIES vs YEAR
April through July means, 1972 TO 1990

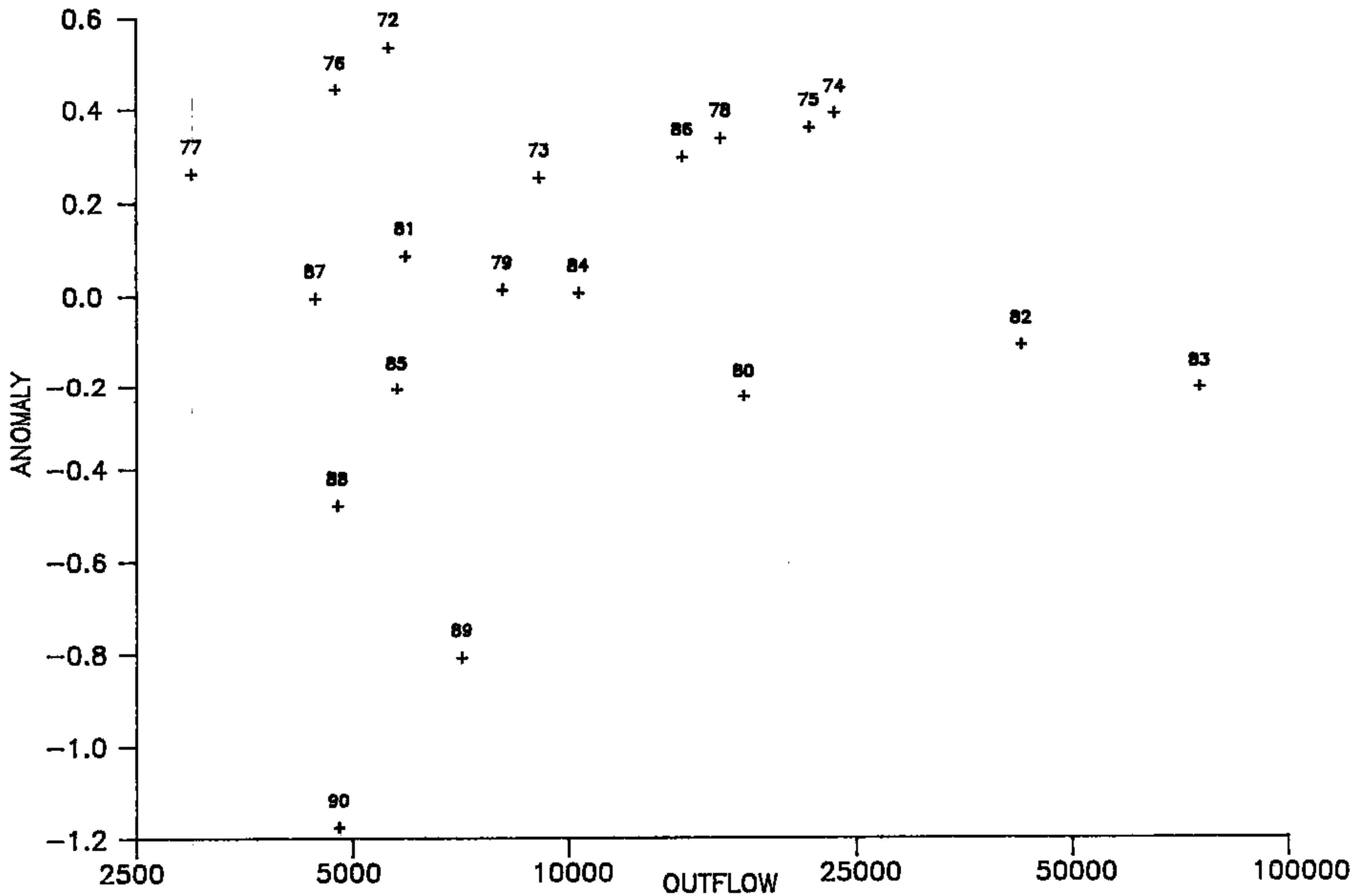


Fig. 7 EURYTEMORA POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 TO 1990

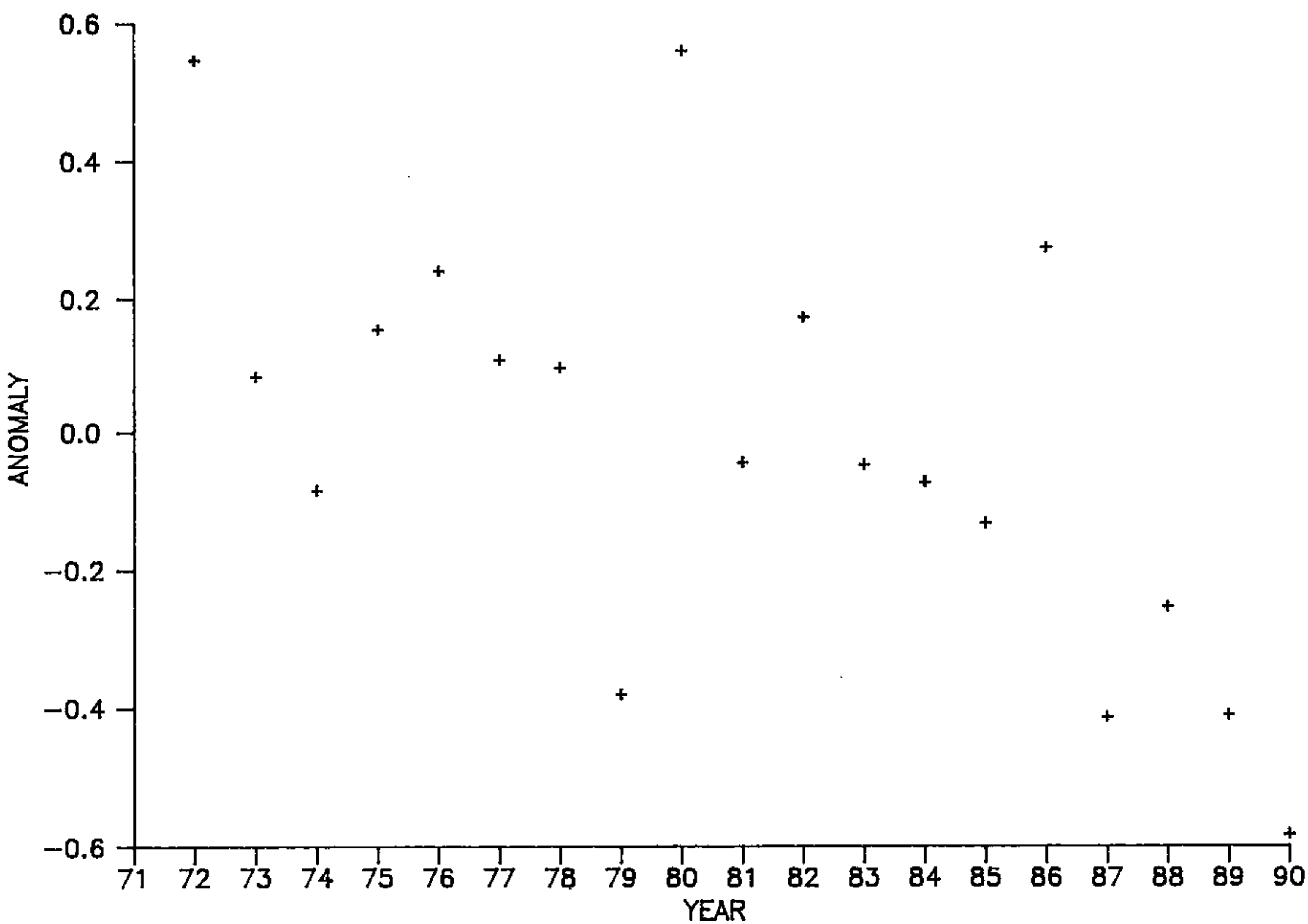


Fig. 8 CYCLOPOID POPULATION ANOMALIES vs YEAR
April through July means, 1972 to 1990

relationship would exist (Table 1 and Figure 9).

Diaptomus anomalies were high from 1972 to 1978 and showed an abrupt collapse in 1979 when the introduced copepod Sinocalanus became abundant (Figure 10). With the exception of 1980 and 1986 the anomalies remained very low thereafter. The correlations with outflow were not significant (Table 1 and Figure 11).

Daphnia anomalies showed a gradual long-term downtrend but 1982 and 1983 were the lowest years (Figure 12). The correlations with outflow were not significant but the two years with the highest outflows had the lowest anomalies (Table 1 and Figure 13).

Bosmina anomalies failed to show a long-term trend (Figure 14) but had significant and negative linear and curvilinear correlations with Delta outflow (Table 1 and Figure 15).

DISCUSSION

Rate of water flow affects estuarine and freshwater zooplankton in different ways. In an estuary freshwater moves to the ocean on the surface while salt water moves upstream on the bottom, creating a two-layered circulation cell. The greater the volume of freshwater flowing out on the surface, the stronger the bottom flow will be. Estuarine plankton can utilize the bottom current to avoid being moved out to the ocean. Early life stages of Eurytemora, for example, tend to be found in the surface layer and should experience a net downstream movement. Older life stages are located in the bottom layer and should move upstream (DFG unpublished).

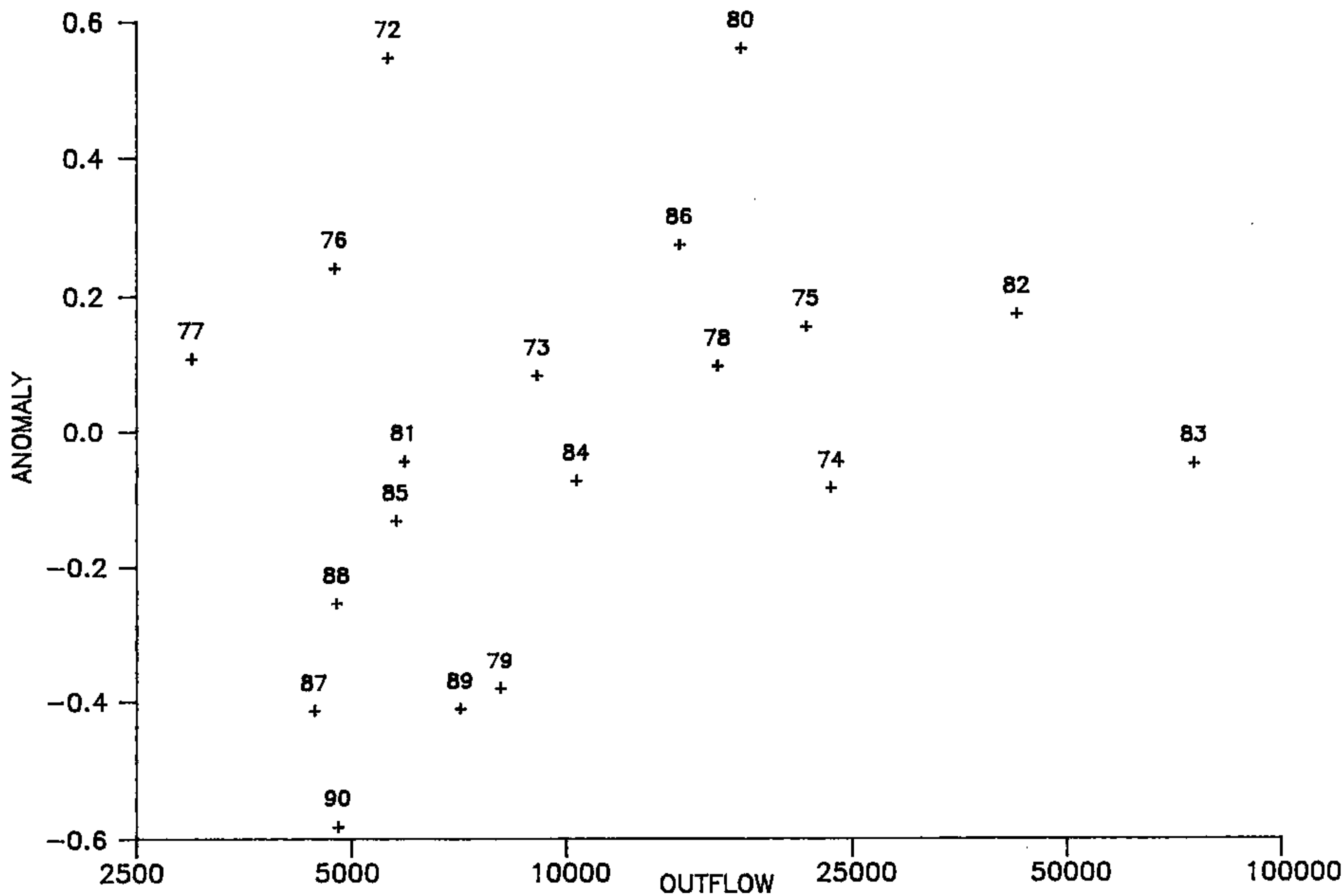


Fig. 9 CYCLOPOID POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 to 1990

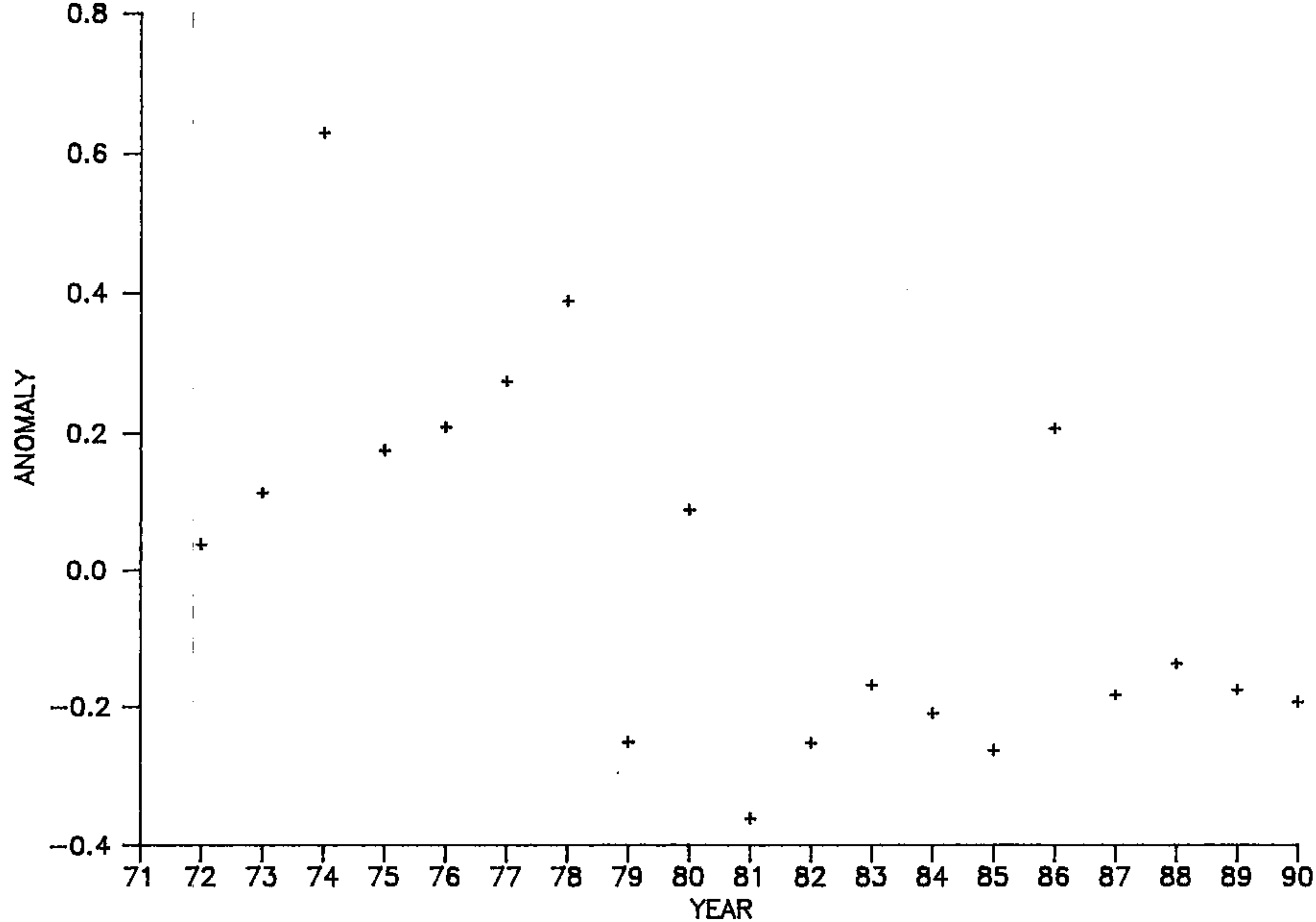


Fig. 10 DIAPTOMUS POPULATION ANOMALIES vs YEAR
April through July means, 1972 to 1990

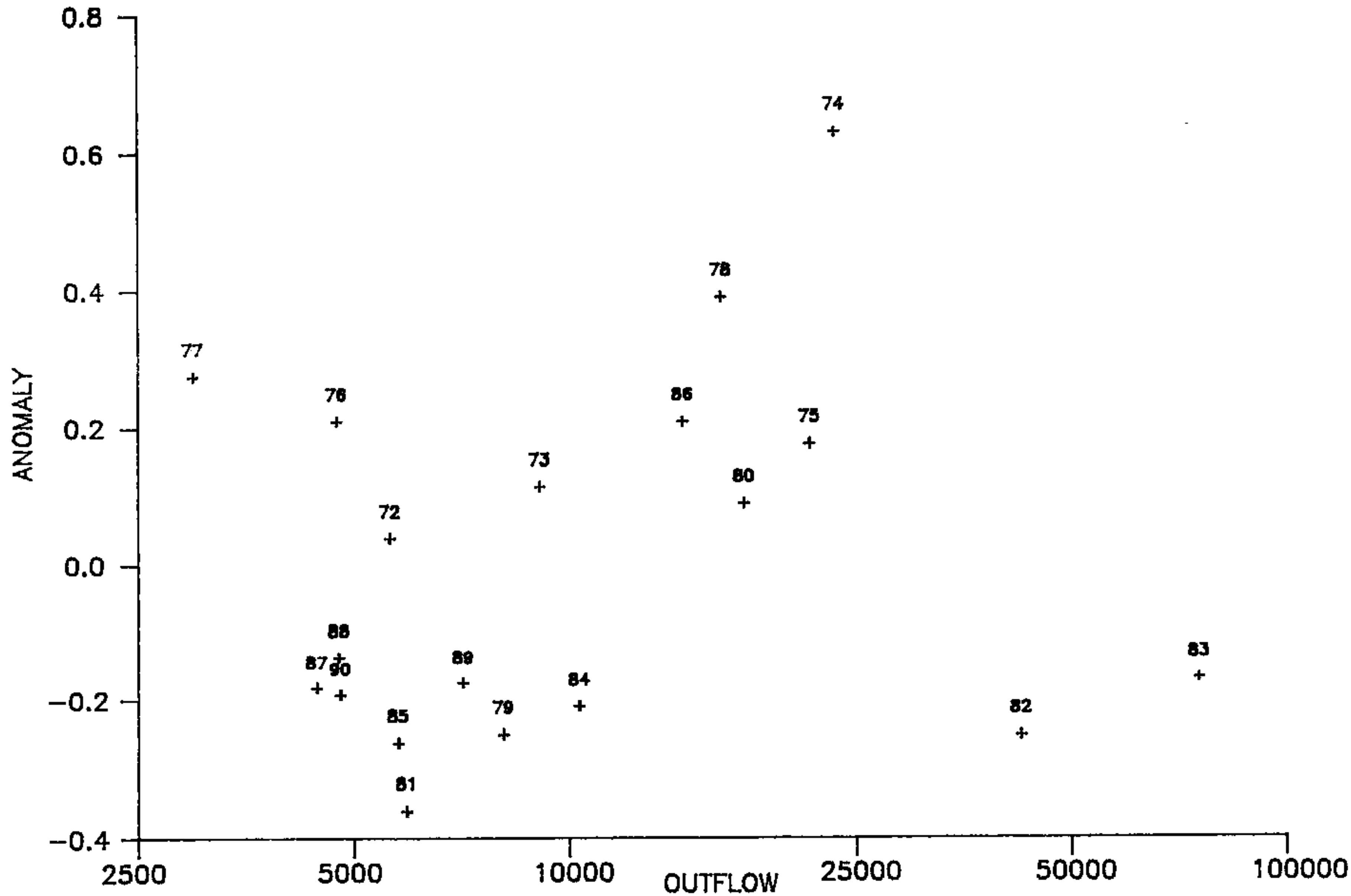


Fig. 11 DIAPTOMUS POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 to 1990

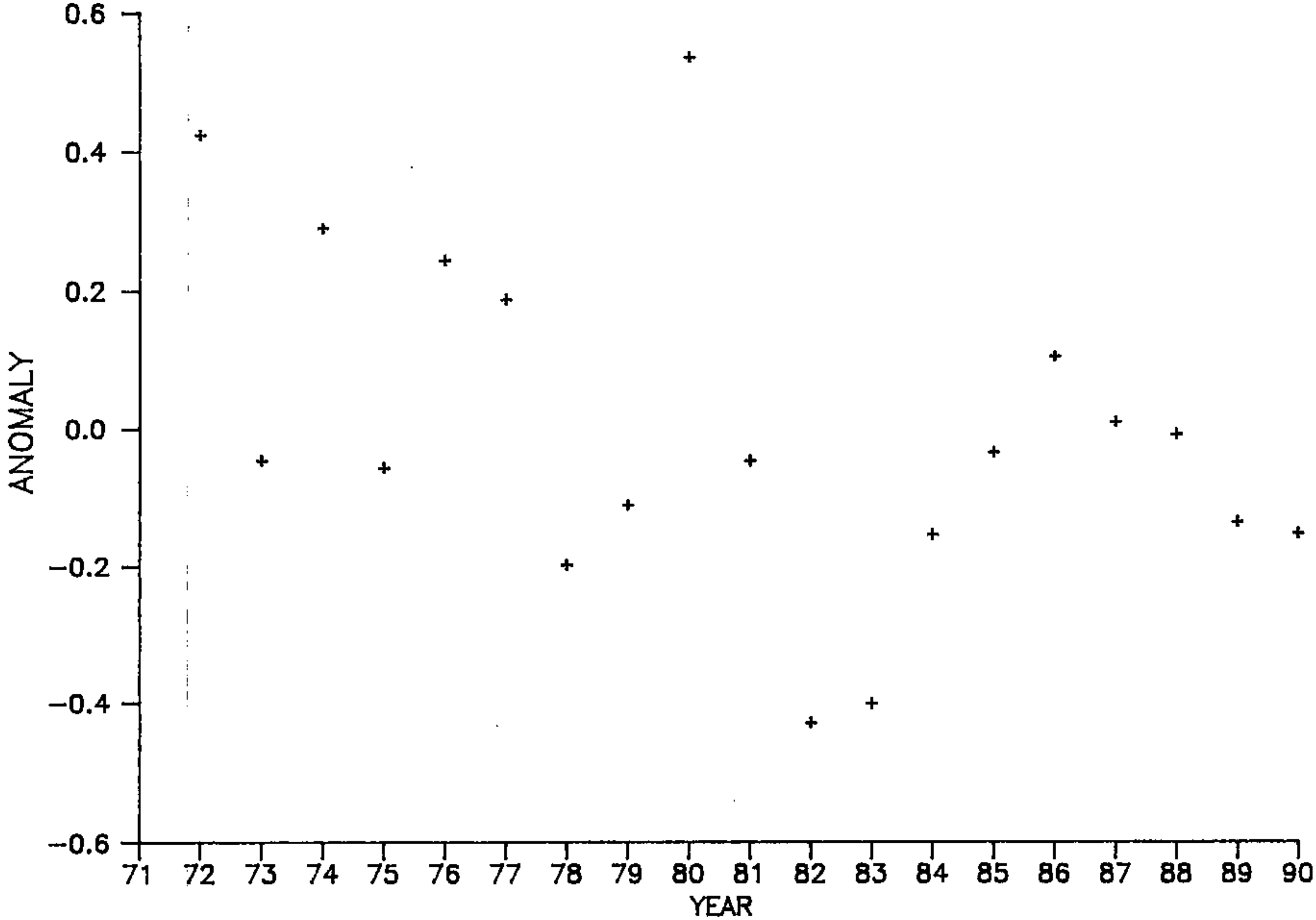


Fig. 12 DAPHNIA POPULATION ANOMALIES vs YEAR
April through July means, 1972 to 1990

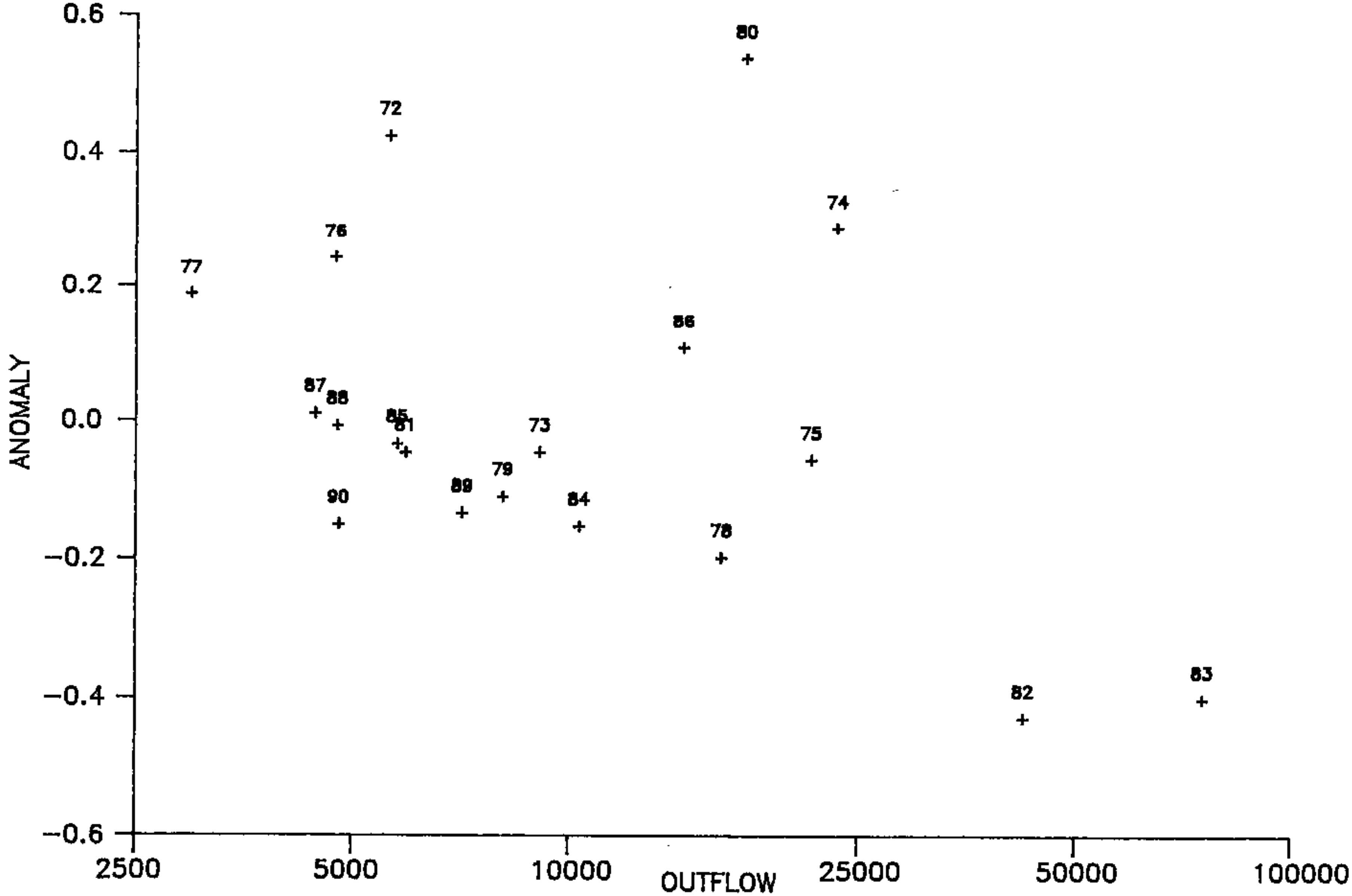


Fig. 13 DAPHNIA POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 to 1990

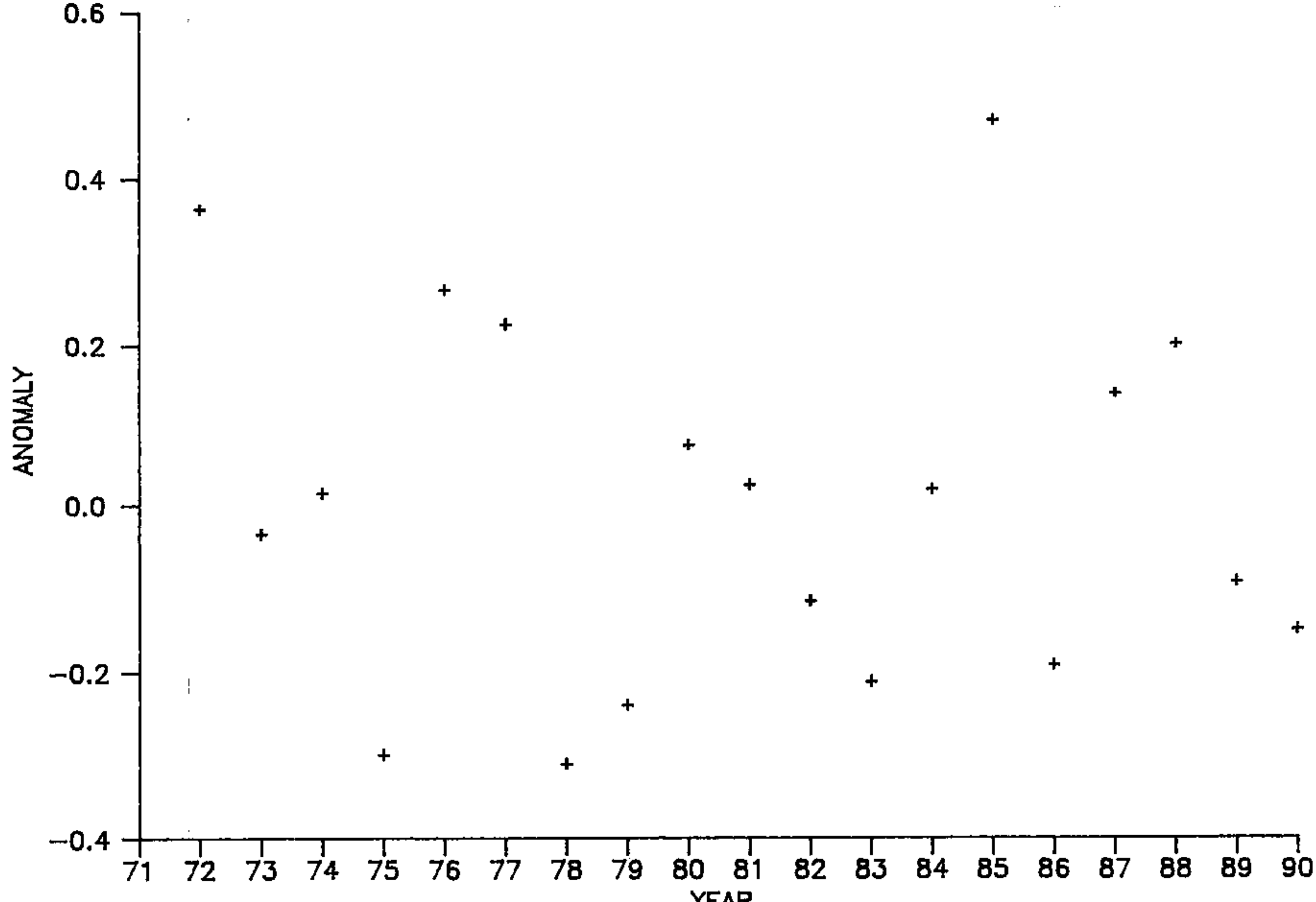


Fig. 14 BOSMINA POPULATION ANOMALIES vs YEAR
April through July means, 1972 to 1990

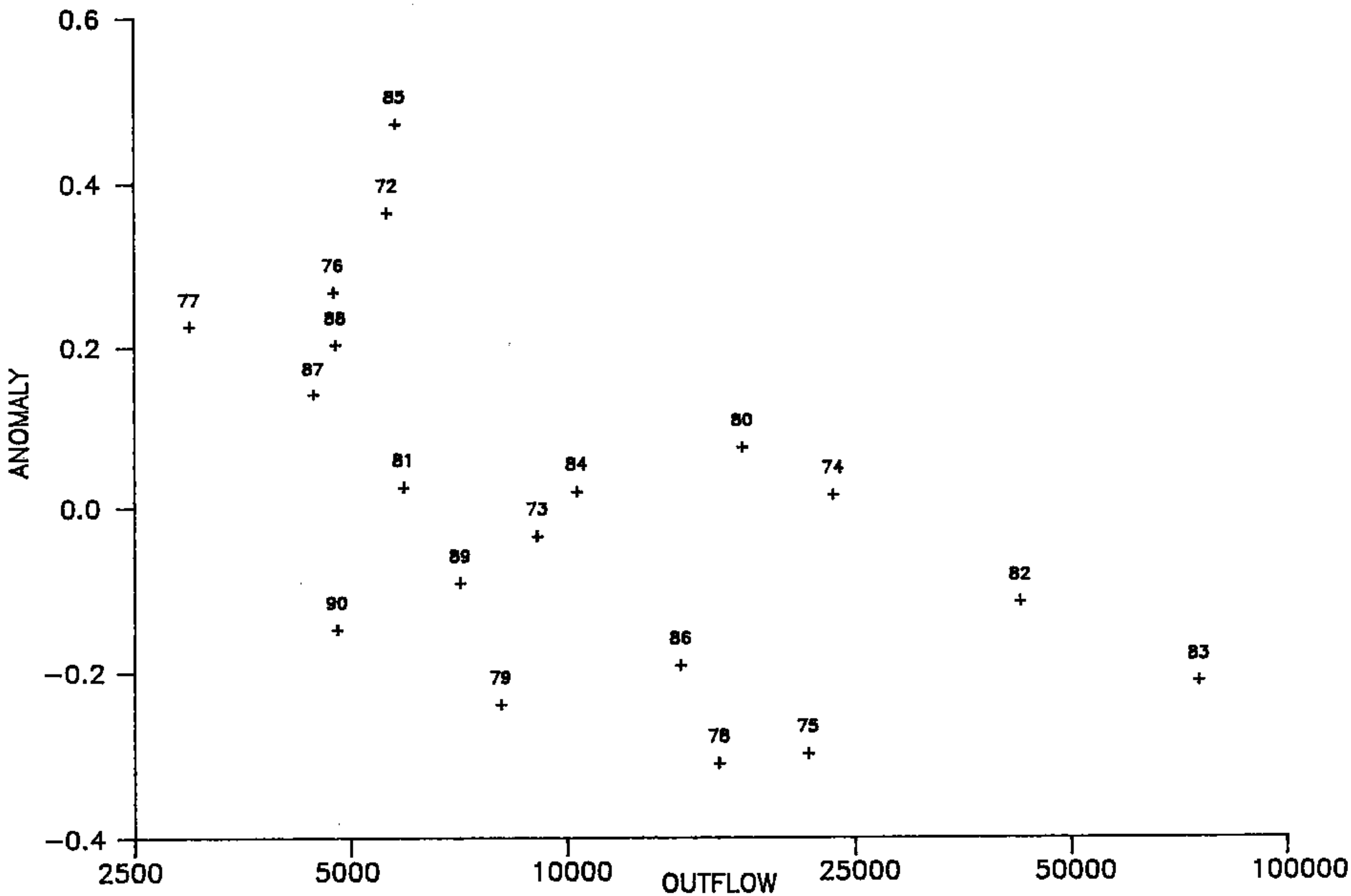


Fig. 15 BOSMINA POPULATION ANOMALIES vs LOG of OUTFLOW (cfs) at CHIPS ISLAND
April through July means, 1972 to 1990

The result should be a concentration of organisms at certain salinities and hence high abundance at them when outflow is high. During exceptionally strong outflow this concentration might not occur either because the water column is so strongly stratified from surface to bottom that the young stages are inhibited from moving into the surface layer or because the young are transported so far downstream that they do not return when they become adults.

Where the water column is fresh from surface to bottom two-layered flow does not exist. The entire water column moves downstream (or upstream where and when reverse flow to the Delta export pumps occurs). Freshwater zooplankton will tend to move at the same velocity as the water mass it inhabits. Therefore, high outflow should be inimical to the development of large freshwater zooplankton populations. To develop high populations in Delta channels, zooplankton must reproduce faster than it is transported either to Suisun Bay or to the export pumps. Sloughs where net flow velocities are low may serve as "incubators" for plankton, which gradually move into the main river channels. Transport of zooplankton into the Delta from the rivers that feed it appears to be minimal judging from zooplankton abundance at Hood on the Sacaramento River and in the Mokelumne River (Orsi and Mecum 1986).

Of the six groups of native zooplankton only two, _Neomysis_ and _Bosmina_, had a significant relationship with Delta outflow for the April-July period. _Neomysis_ also had a significant outflow relationship for the August-November period. The plots (Figures 3 and 5) suggest that at very high outflows _Neomysis_ abundance is reduced. At intermediate outflows abundance should be high because strong two-layered flow interacting with the vertical migration pattern of the shrimp should concentrate them in the entrapment zone. At low outflows this concentration would not take place.

The Bosmina correlations were negative; abundance tended to fall as outflow rose. High outflow would tend to transport Bosmina downstream into more saline water where osmotic stress would cause mortality. This process should also have affected Daphnia. The Daphnia anomalies for the two highest outflow years, 1982 and 1983, are indeed the lowest (Figure 13) but the other years fail to demonstrate a trend. Several Daphnia species are found in the Delta as compared to only one Bosmina. Differences in vertical migration patterns or reproductive rates between species might give one or several species an advantage over the others in different years depending upon environmental conditions including outflow. The shifts in species composition might account for the absence of a relationship with outflow.

The two freshwater copepod genera, Diaptomus and Cyclops also lacked significant correlations with outflow. Diaptomus appears to have been severely impacted by the introduction of the Asian copepod, Sinocalanus, as it experienced a sharp decline in 1979, the year Sinocalanus became abundant, and subsequently was numerous only in spring before Sinocalanus populations developed (DFG unpublished). Hence, any relationship between Diaptomus and outflow would be obscured by the interference of Sinocalanus.

Cyclops shows a positive linear or a curvilinear relationship with outflow if the years, 1972, 1976 and 1977 are ignored. These three dry years were characterized by very high population densities in the San Joaquin River at Stockton and low abundance elsewhere. The concentrations at Stockton apparently brought the anomalies up relative to other years and rendered the correlations non-significant.

The percent of the variance explained by the significant correlations was never very high, indicating that other unexamined factors must play an important role in the regulation of zooplankton population size. Nevertheless, the volume of outflow is very important for Neomysis because it depends on two-layered estuarine flow to concentrate it in the entrapment zone. The other estuarine organism, Eurytemora, fails to show a significant correlation with outflow even when the analysis is restricted to the years prior to the introduction of Potamocorbula. The impact of the introduced Sinocalanus may account for this as the anomalies for the years 1979 to 1987 are all lower (with the exception of 1986) than those for the pre-introduction years (Figure 6). Sinocalanus adults could prey on the young of Eurytemora or could compete with it for algal food. A separate analysis (Kimmerer and Orsi, unpublished) shows that in fall Eurytemora abundance was greater when Delta outflow positioned the entrapment zone in Suisun Bay than when lower outflows located the entrapment zone in Delta channels. In spring the relationship between Eurytemora abundance and entrapment zone position was ambiguous and in summer it was not significant.

In summary, the results show that moderately high Delta outflows from approximately 10,000 to 35,000 cfs are associated with the highest annual April-July abundance of Neomysis, Bosmina and possibly Cyclops, of which, Neomysis and Cyclops, are important striped bass food organisms (Miller 1987). One other important bass food organism, Daphnia and one unimportant organism, Diaptomus, showed no association with outflow. The relationship between Eurytemora and outflow during April-July is unclear, possibly because of the impacts of introduced organisms.

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