THE EFFECTS OF FLOODS ON THE ZOOPLANKTON ASSEMBLAGE OF SAN ANTONIO BAY, TEXAS DURING 1972 AND 1973

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ABSTRACT

Plankton tows and hydrographic measurements were taken encompassing a single flood in 1972, and three floods in 1973 in San Antonio Bay. The shallow bay was rapidly flushed by influx of flood waters as was indicated by reductions in salinity and in the densities of the dominant species, Acartia tonsa. Floods replaced the typical estuarine zooplankter (Balanus sp. nauplii, Oithona colcarva, Paracalanus crassirostris, Oikopleura spp., and the cyphonautes larvae of Membranipora sp.) with the freshwater ones (Diaptomus spp., Cyclops spp., Arcella discoides, Moina sp., Diaphanosoma sp. and other cladocerans). During the 1972 flood, total zooplankton densities fell from $10,800/m^3$ before the flood to $3,400/m^3$ after the flood, but they increased rapidly when the river flow returned to base level. After the three floods in 1973, a cumulative decrease in total density of over two orders of magnitude was found. There had been insufficient time to reestablish preflood densities between each flood. The rapidity with which densities were re-established and the areas in which these increases were first found indicates the majority of the density changes were due to influx of zooplankton-rich bay water from Espiritu Santo Bay, rather than from population explosion by surviving refuge populations. It is important to note that the seasonal occurrence of a flood may severely reduce the survival of a bay's annual recruitment of economically important species whose larval stages are members of the zooplankton or which depend on zooplankton as food. It is also important to note the interdependency of these estuaries as currents flow carrying life from one into the next.

INTRODUCTION

Most estuarine plants and animals depend in some manner on fresh water from rivers and streams for their survival. The variability in quality and quantity of the freshwater inflow during a year and through several years can lead to dramatic environmental changes in an estuary, and thus in the organisms living there. With the increasing use of estuaries for various economic purposes it has become essential to know what to expect when certain environmental factors change. The objective of this paper is to describe the effects of floods on the zooplankton of a shallow estuary, San Antonio Bay, Texas.

MATERIALS AND METHODS

STUDY AREA

San Antonio Bay covers an area of about 305 km^2 and is located in the middle of the Texas coastline at latitude 28°20' North and longitude 96°45' West. It is a shallow bar-built estuary with an average natural depth of 1.5 m and contains many shallower oyster reefs and few places as deep as 3 m, however, recent shell dredging in the middle bay area has increased the depth in about 20 percent of this section to 4 m. Matagorda Island isolates San Antonio Bay from the Gulf of Mexico, and most salt water must flow into Matagorda Bay and through Expiritu Santo Bay before reaching San Antonio Bay. Fresh water from the combined flows of the San Antonio and Guadalupe Bay flow into upper San Antonio Bay (Figure 1). Annual evaporation slightly exceeds annual rainfall in normal years.

SAMPLING REGIME

Eleven sites were selected to represent the bay (Figure 2). To facilitate biological analyses with respect to salinity, these sites were partitioned into: Zone 1 = the upper bay, Zone 2 = the middle bay, and Zone 3 = the lower bay. Zooplankton was collected at each site twice per month by making a one-minute oblique tow with a #10 mesh (150 micron pore width) conical Nitex net which had a mouth diameter of 0.5 m and a length of 1.3 m. A flowmeter mounted in the net mouth measured the amount of water filtered on each tow. After each tow, the net was washed and the bucket's contents were preserved in 5 to 10 percent Formalin. Water temperature and salinity were taken immediately following the tow.

DATA COLLECTION

River flow rates were obtained for the rivers and creek from the U.S. Geological Survey annual records. Ten-day average river flow rates were calculated for each sampling time. Each average was based on the sum of the daily flow rates of each of the three tributaries for the day of sampling plus the nine previous days, i.e. the summation of 30 values divided by 10.

SAMPLE ANALYSIS

Methods similar to those used by Hopkins (1966) were used to analyze each zooplankton sample. A subsample taken with a Hensen-Stemple pipet and containing between 200 and 1,000 organisms was examined from each tow. Each organism was identified to the lowest taxon possible--usually to genus or species. Counts from the subsample were converted to numbers per cubic meter of bay water.

RESULTS AND DISCUSSION

THE SINGLE FLOOD OF 1972

Collections on May 4, before the flood, showed fairly high densities of zooplankton in Zone 1 and moderate levels in Zones 2 and 3 (Table 1). The composition of the zooplankton was typically estuarine for all zones at this time. Just before the flood there was a freshet which introduced sufficient fresh water to reduce the

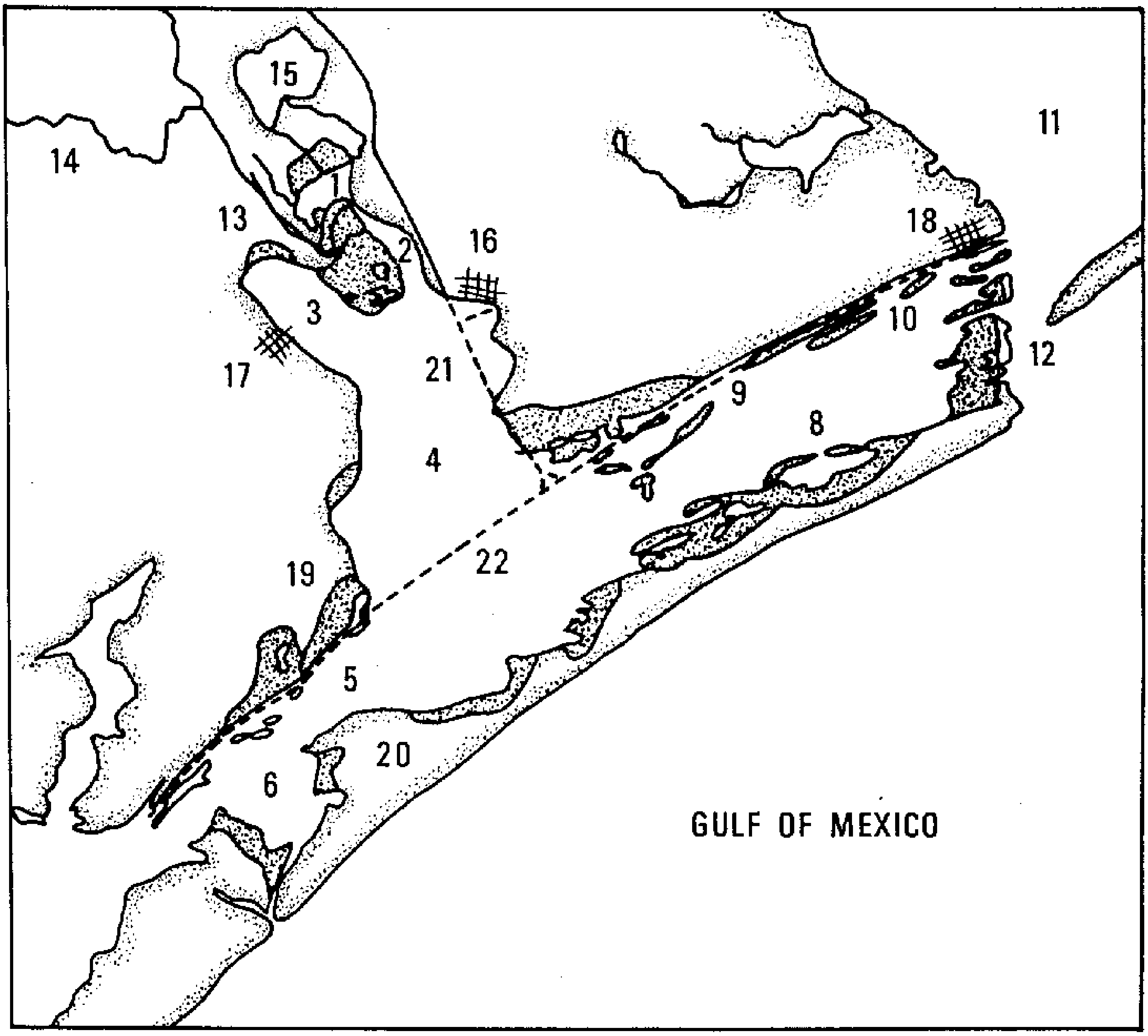

Figure 1. Components of San Antonio Bay System and vicinity. (1) Mission Lake (2) Guadalupe Bay (3) Hynes Bay (4) San Antonio Bay (5) Ayers Bay (6) Mesquite Bay (7) Cedar Bayou (8) Espiritu Santo Bay (9) Shoalwater Bay (10) Barroom Bay (11) Matagorda Bay (12) Pass Cavallo (13) Guadalupe River (14) San Antonio River (15) Green Lake (16) Seadrift, Texas (17) Austwell, Texas (18) Port O'Connor, Texas (19) Aransas Wildlife Refuge (20) Matagorda Island (21) Victoria Barge Canal (22) Intracoastal Waterway.

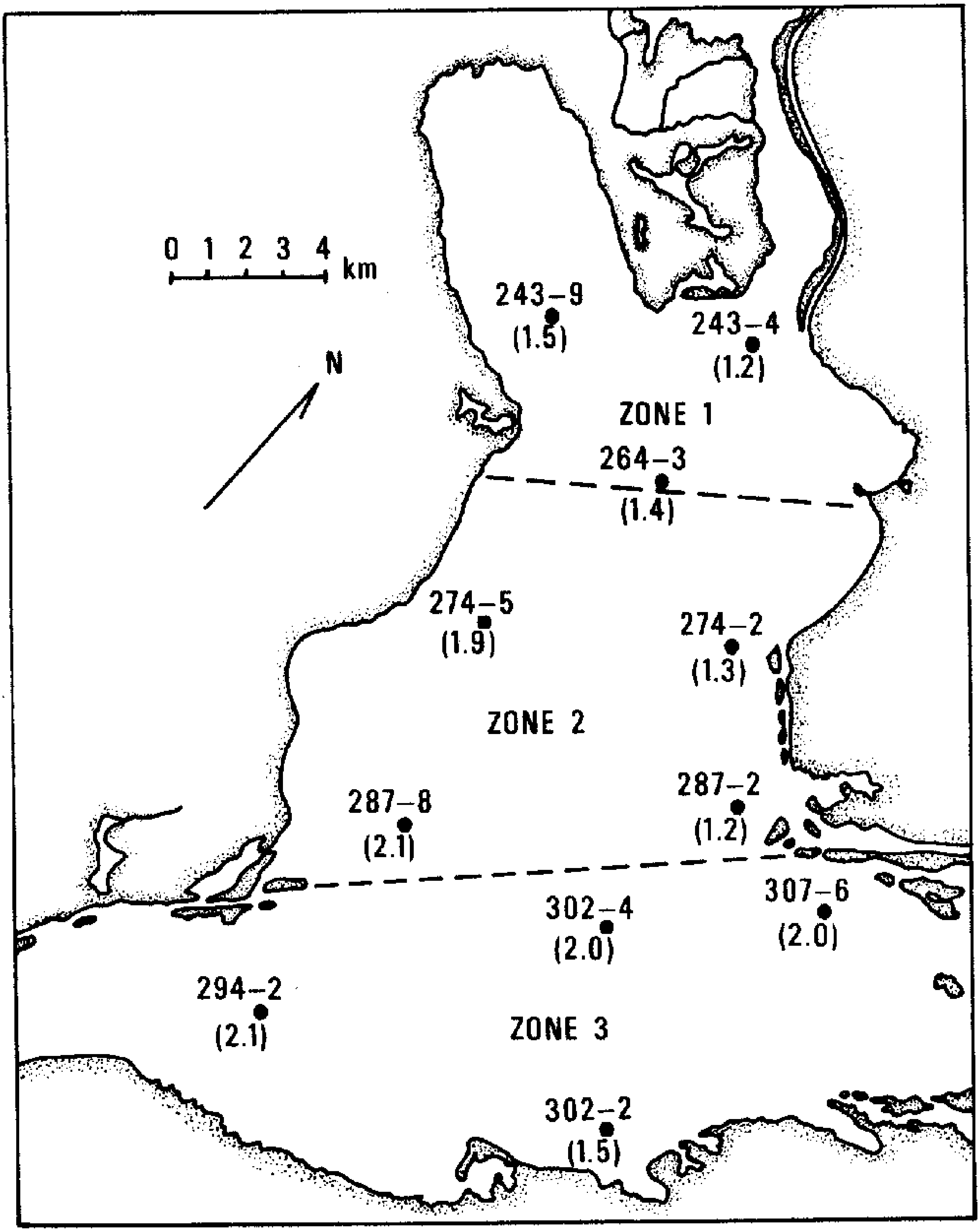

Figure 2. Collection sites in San Antonio Bay, Texas. Depths are given in meters in parenthesis.

Table 1. Zooplankton densities (individuals/m^3) before and after flood of May 1972 in San Antonio Bay, Texas. The contribution of freshwater taxa are delineated.

Date	ZONE 1			ZONE 2			ZONE 3		
	Total	Freshwater (No.)	Freshwater (%)	Total	Freshwater (No.)	Freshwater (%)	Total	Freshwater (No.)	Freshwater (%)
19 April	17611	7	0.0	10505	0	0.0	24300	0	0.0
4 May	19527	263	1.3	6122	0	0.0	6859	0	0.0
FLOOD............									
23 May	3882	2116	54.5	4475	758	16.9	1757	757	43.1
7 June	851	66	7.8	11563	42	0.4	8460	74	0.9
22 June	584	344	58.9	21768	11	0.1	20390	0	0.0
6 July	5691	150	2.6	25211	136	0.5	34995	+	0.0
20 July	20001	35	0.2	12798	0	0.0	14093	0	0.0

average salinity in Zone 1 to about 7 parts per thousand. Total zooplankton density in Zone 1 increased slightly over its value at the previous sampling (19 April), but it decreased in both Zones 2 and 3. A few common freshwater zooplankters such as Cyclops sp., Diaptomus sp., and cladocerans were introduced into Zone 1, but no freshwater-related changes in diversities were found in the zooplankton of Zones 2 and 3 at this time (4 May).

The flood began on May 8, peaked on May 16, and had decreased to a freshet level by the sampling trip on May 23. Salinities in all zones had fallen to between 1 and 4 parts per thousand. Several changes had occurred in the zooplankton, and total zooplankton densities in Zones 1-3 had decreased to 20, 73, and 26 percent, respectively, of what they had been 19 days earlier. The percent of the total density contributed by taxa of freshwater origin had increased from 1.3 to 54.5 percent in Zone 1, and from 0 to 17 percent and 43 percent for Zones 2 and 3, and most of the dominant taxa in all three zones were of freshwater origin (Table 2).

By the collection time of June 7, the river flow rate had decreased to only 5 percent of the maximum flood flow rate, but the river rate was still slightly elevated above base flow rate. Salinity remained depressed in Zone 1 and increased only very slightly in Zones 2 and 3. Zooplankton densities were now even lower in Zone 1, but they had doubled in Zone 2 and had quadrupled in Zone 3. Contributions by taxa of freshwater origin to these densities were down to 7.4, 0.4, and 0.9 percent for Zones 1 to 3, respectively, and only in Zone 1 were they representing about half of the dominant taxa (Table 3). Diversities in all zones were lower than during the previous sampling. The percent of the diversity contributed by freshwater taxa was also lower, but it was still between 44 and 18 percent.

Freshwater inflow increased to freshet levels again on June 19, just a few days prior to sampling. Salinity remained at about 1.5 parts per thousand in Zone 1, but slight increases in salinities to about 6 and 10 parts per thousand were found in Zones 2 and 3 respectively. Densities reached a low in Zone 1 at $584/m^3$, but increased in Zones 2 and 3 to above $20{,}000/m^3$. Freshwater taxa accounted for virtually nothing in Zones 2 and 3. Diversity increased in Zones 1 and 2 but not in Zone 3. Freshwater taxa accounted for 54 percent and 12 percent of the diversity in Zones 1 and 2 respectively; none was found in Zone 3. All of the dominants in Zone 1 were of freshwater origin except Acartia tonsa.

River flow rate continued to decrease after the spike in late June, and salinity in Zone 1 finally increased to 2.5 parts per thousand at the time of the sampling on July 6, but it remained unchanged in Zones 2 and 3. Zooplankton densities increased an order of magnitude in Zone 1 and also increased again in Zones 2 and 3. Contributions by freshwater taxa to the density in Zone 1 decreased to about 3 percent and they increased in Zone 2 to 0.5 percent. Diversity decreased by almost half in Zone 1, just slightly in Zone 2, and

Table 2. Zooplankton diversities (number of taxa) before and after flood of May 1972 in San Antonio Bay, Texas. The contribution of freshwater taxa are delineated.

Date	ZONE 1			ZONE 2			ZONE 3		
	Total	Freshwater		Total	Freshwater		Total	Freshwater	
		(No.)	(%)		(No.)	(%)		(No.)	(%)
19 April	39	3	7.7	51	0	0.0	56	0	0.0
4 May	33	8	24.2	39	0	0.0	30	0	0.0
FLOOD..........									
23 May	51	34	66.7	40	20	50.0	48	18	37.5
7 June	32	14	43.8	26	8	30.8	34	6	17.6
22 June	44	24	54.5	40	5	12.5	31	0	0.0
6 July	26	4	15.4	35	6	16.7	31	1	3.2
20 July	38	7	18.4	32	0	0.0	25	0	0.0

Table 3. Composition of the zooplankton community in each zone before, during, and after the May 1972 flood in San Antonio Bay, Texas. Each zone's composition is represented by its 12 most abundant taxa. * indicates taxa of freshwater origin. Surface and bottom salinities (o/oo) are given for each zone on each date.

	ZONE 1	ZONE 2	ZONE 3
Date: 7 June 1972			
Surface:	1.5	4.7	5.8
Bottom :	1.7	5.3	6.1
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Asplanchna sp.	Balanus sp. nauplii	Balanus sp. nauplii
	Gastropod veligers	Paracalanus crassirostris	Pseudodiaptomus coronatus
	*Cyclops sp.	Cyphonautes larva *A	Paracalanus crassirostris
	*Sinocephalus sp.	Copepod nauplii	Cyphonautes larva *A
	Harpacticoids	Oithona colcarva	Oithona colcarva
	*Diaptomus spp.	*Cyclops sp.	Copepod nauplii
	*Arcella discoides	Polychaete larvae	Spionid larvae
	*Perissocytheridea sp.	Asplanchna sp.	Fish eggs
	Copepod nauplii	Epistylis sp.	Polychaete larvae
	Ergasilus sp.	Ergasilus sp.	*Brachionus quadridentatus
	Ostracods	*Brachionus quadridentatus	Bivalve veligers
Date: 22 June 1972			
Surface:	1.5	5.8	9.3
Bottom :	1.7	6.5	10.0
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	*Ilyocryptus spinifera	Balanus sp. nauplii	Balanus sp. nauplii
	*Cyclopoids	Gastropod veligers	Spionid larvae
	*Ephemeropteran larva	Oithona colcarva	Copepod nauplii
	*Diaptomus spp.	Copepod nauplii	Pseudodiaptomus coronatus
	*Tropocyclops prasinus	Hemicyclops sp. copepodids	Gastropod veligers
	*Diaphanosoma sp.	Neopanope texana zoea	Oithona colcarva
	Brachionus plicatilis	Halicyclops fosteri	Bivalve veligers
	*Apocyclops panamensis	Spionid larvae	Callianassa sp. #1 zoea
	*Arcella discoides	Ergasilus sp.	Halicyclops fosteri
	*Rhabdocoel worm	Callianassa sp. #1 zoea	Gobiosoma bosci larvae
	*Moina micrura	*Ostracods, Cyprididae	Rithropanopeus harrisii zoea
Date: 6 July 1972			
Surface:	2.6	6.6	9.4
Bottom :	2.8	6.6	9.5
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Balanus sp. nauplii	Balanus sp. nauplii	Balanus sp. nauplii
	*Cyclops sp.	Copepod nauplii	Pseudodiaptomus coronatus
	Copepod nauplii	Paracalanus crassirostris	Tintinnopsis sp.
	Paracalanus crassirostris	Pseudodiaptomus coronatus	Oithona colcarva
	Gastropod veligers	Gastropod veligers	Copepod nauplii
	*Ostracods	Polychaete larvae	Fish eggs
	Pseudodiaptomus coronatus	Oithona colcarva	Bivalve veligers
	Asplanchna sp.	Ergasilus sp.	Gastropod veligers
	Harpacticoids	*Platyias quadricornis	Anchoa mitchilli larvae
	Ergasilus sp.	*Eucyclops sp.	Spionid larvae
	*Cyclopoids	Brachyuran zoea	Cyphonautes larva *A
Date: 20 July 1972			
Surface:	2.8	8.1	9.5
Bottom :	3.0	8.2	11.8
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Balanus sp. nauplii	Balanus sp. nauplii	Balanus sp. nauplii
	Gastropod veligers	Copepod nauplii	Oithona colcarva
	Copepod nauplii	Brachionus plicatilis	Copepod nauplii
	Spionid larvae	Mnemiopsis mccradyi	Cyphonautes larva *A
	*Arcella discoides	Gastropod veligers	Pseudodiaptomus coronatus
	Halicyclops fosteri	Favella panamensis	Balanus sp. cypris
	Bivalve veligers	Balanus sp. cypris	Mnemiopsis mccradyi
	Pseudodiaptomus coronatus	Cyphonautes larva *A	Spionid larvae
	Tintinnopsis sp.	Bivalve veligers	Paracalanus crassirostris
	Balanus sp. cypris	Pseudodiaptomus coronatus	Neopanope texana zoea
	Oithona colcarva	Paracalanus crassirostris	Brachionus plicatilis

Table 3. Concluded.

	ZONE 1	ZONE 2	ZONE 3
Date: 19 April 1972			
Surface:	12.2	15.2	19.6
Bottom :	12.0	15.6	19.6
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Gastropod veligers	Balanus sp. nauplii	Oithona colcarva
	Balanus sp. nauplii	Oithona colcarva	Pseudodiaptomus coronatus
	Bivalve veligers	Uca sp. zoea	Oikopleura sp.
	*Ostracod #2	Tintinnopsis sp.	Paracalanus crassirostris
	Tintinnopsis sp.	Pseudodiaptomus coronatus	Fish eggs
	Balanus sp. cypris	Gastropod veligers	Cyphonautes larva #A
	Copepod nauplii	Bivalve veligers	Copepod nauplii
	Oithona colcarva	Balanus sp. cypris	Ophiopluteus larvae
	Spionid larvae	Spionid larvae	Balanus sp. nauplii
	Pseudodiaptomus coronatus	Paracalanus crassirostris	Balanus sp. cypris
	Paracalanus crassirostris	Copepod nauplii	Anchoa mitchilli larvae
Date: 4 May 1972			
Surface:	6.7	19.7	23.6
Bottom :	7.0	20.1	23.9
	Acartia tonsa	Acartia tonsa	Balanus sp. nauplii
	Gastropod veligers	Balanus sp. nauplii	Oikopleura sp.
	*Cyclops sp.	Paracalanus crassirostris	Acartia tonsa
	Balanus sp. nauplii	Cyphonautes larva #A	Ophiopluteus larvae
	Bivalve veligers	Oithona colcarva	Cyphonautes larva
	*Cladocerans	Bivalve veligers	Oithona colcarva
	*Diaptomus spp.	Gastropod veligers	Copepod nauplii
	Copepod nauplii	Brachyuran zoea	Fish eggs
	Ergasilus sp.	Oikopleura sp.	Paracalanus crassirostris
	Paracalanus crassirostris	Copepod nauplii	Bougainvillia sp.
	Cyphonautes larva #A	Harpacticoids	Bivalve veligers
	Balanus sp. cypris	Balanus sp. cypris	Polychaete larvae
Date: 23 May 1972			
Surface:	1.1	1.8	3.9
Bottom :	1.8	2.0	4.2
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	*Cladocerans	*Cyclopoids	*Cyclopoids
	*Cyclopoids	*Diaptomus spp.	Oithona colcarva
	*Cyclops vernalis	*Calanoid (freshwater)	*Eurytemora affinis
	*Arcella discoides	*Arcella discoides	*Eurytemora sp.
	*Apocyclops panamensis	*Microcyclops sp.	*Arcella discoides
	*Diaptomus spp.	*Moina sp.	*Diaptomus sp.
	*Eurytemora sp.	*Diaphanosoma sp.	*Moina micrura
	*Brachionus quadridentatus	*Cladocerans	Gastropod veligers
	Tintinnids	*Cyclops sp.	Nematodes
	Copepod nauplii	Harpacticoids	*Diaphanosoma sp.
	*Ceriodaphnia sp.	*Cyclops vernalis	Balanus sp. nauplii

remained unchanged in Zone 3. Freshwater taxa accounted for only 15 percent of the diversity in Zone 1, 16 percent in Zone 2, and 3 percent in Zone 3. The zooplankton throughout the bay was returning to its estuarine dominants with few exceptions.

Salinities were slightly higher in all three zones during the sampling on July 20, but river flow rate had not decreased from the previous sampling date. Zooplankton density had increased substantially in Zone 1, but had decreased by half in both Zones 2 and 3. A few freshwater taxa contributed to the zooplankton only in Zone 1. Diversity had increased only in Zone 1, and had fallen slightly in Zones 2 and 3. Arcella discoides was the only freshwater species to reach the dominance list, and it was in Zone 1. The ctenophore, Mnemiopsis mccradyi, reached the dominance list in both Zones 2 and 3, and should be considered as a possible cause for the decrease in zooplankton densities in these two zones.

The species and taxa which most characterize the estuarine zooplankton community were also most often found in the dominance tables because they contributed greatly to the densities in each zone and particularly to those in Zones 2 and 3. These species and taxa forming the estuarine zooplankton community in San Antonio Bay are Acartia tonsa, Balanus sp. nauplii, Oithona colcarva, Pseudodiaptomus coronatus, Paracalanus crassirostris, cyphonautes larvae of Membranipora sp., spionid larvae, polychaete larvae, and gastropod veligers. Acartia tonsa was usually very abundant, and is known to tolerate very low salinities (Conover 1956). Even the flood could not displace it from being the dominant zooplankter. Only during the winter and spring with salinities above 20 parts per thousand was A. tonsa often replaced as the dominant taxon by Balanus sp. nauplii.

Many of the typically estuarine species were replaced by species and taxa of freshwater origin during the flood (Table 3). The most characteristic of these freshwater taxa were the freshwater calanoids Eurytemora affinis and several species of Diaptomus; the freshwater cyclopoids Cyclops sp., Eucyclops sp., Apocyclops panamensis and Microcyclops sp.; the cladocerans Moina micrura and Diaphanosoma brachyurum; the rotifers Brachionus quadridentatus, B. Calyciflorus and Platyias quadricornis; and the protozoan Arcella discoides. There were many other taxa of freshwater rotifers, cladocerans, copepods, and insect larvae that entered the bay with floods and freshets, but most were found in low densities and frequencies.

Most of these freshwater species are characteristic of backwater areas (Ward and Whipple 1959; Cooper 1967) rather than the open river itself. These freshwater species' populations may have been dense locally, but when they were washed into the bay by the floods their densities were considerably lower than those of the estuarine zooplankters inhabiting the bay. The dilution and displacement of bay water by the fresh water of a flood creates a natural dilution of the estuarine zooplankton, and when the diluting water has relatively few zooplankters the result is a reduction in the total zooplankton density in the bay. This is what happened during the May flood.

Diversity, however, was increased in the bay because of the influx of freshwater species. The myriad of backwater localities along the tributaries allowed for many different species' populations to flourish, and during the flood they were washed down the rivers and into the bay. Initially, more freshwater species and taxa were added to the sampling sites than estuarine species were displaced or killed. Diversity declined after this initial increase probably because most of the freshwater zooplankton had already been carried down the river, and because flow rates declined so that fewer remaining plankters were carried into the bay.

It is evident that the zooplankton community in the bay was greatly changed by the flood and that the changes occurred within two weeks of the start of the flood, and probably much sooner. Re-establishment of the typical estuarine zooplankton community depends substantially on the reduction of river flow rates, and after flow rates fall below freshet levels, it can still take two months to re-establish the estuarine species in the upper bay. Only about one month was required to re-establish it in the lower and middle bay areas. In this specific case the east side of the bay was first supplied with higher salinity water from Espiritu Santo Bay which was rich in estuarine zooplankton. Many tidal cycles and their attendant circulation patterns were required to re-establish the estuarine zooplankton along the west side of the bay.

MULTIPLE FLOODS OF 1973

The species composition of the freshwater zooplankton that entered the bay with the river inflow was very much the same as found during the May 1972 flood. Diversity appeared to be regulated considerably by the amounts and rates of river inflow (Figure 3). During the first four months the diversity trend followed the river flow rate but was one sampling delayed (time lag effect). From the beginning of the June flood through the October flood, this relationship was no longer found. In spite of the decrease in river flow rate during the last of the year, diversity in all zones also decreased. Much of this decrease was due to the cold weather when many meroplankters are no longer found in bay waters.

The percentage of the diversity of each zone, contributed by taxa of freshwater origin, was greatly increased by the June and October floods (Figure 4), and these percentages were much higher for Zone 1 than for Zones 2 and 3. Percentages contributed by freshwater taxa in Zones 2 and 3 were similar and they varied together more closely than with that of Zone 1 during the entire year.

The total zooplankton density decreased an order of magnitude from the start of the year to the end, but it also decreased much lower at times between these end points (Figure 5). Total density showed an inverse relationship to river flow rate. The June and October floods each caused a decline in total density of nearly two orders of magnitude which was never completely regained through the rest of the year. The recovery time, or time required for the density of a zone to re-establish its preflood level, appeared to be between two weeks and a month, i.e. between one and two sampling trips. The recovery time depended on tides, circulation patterns, spawning rates and periods, and temperature.

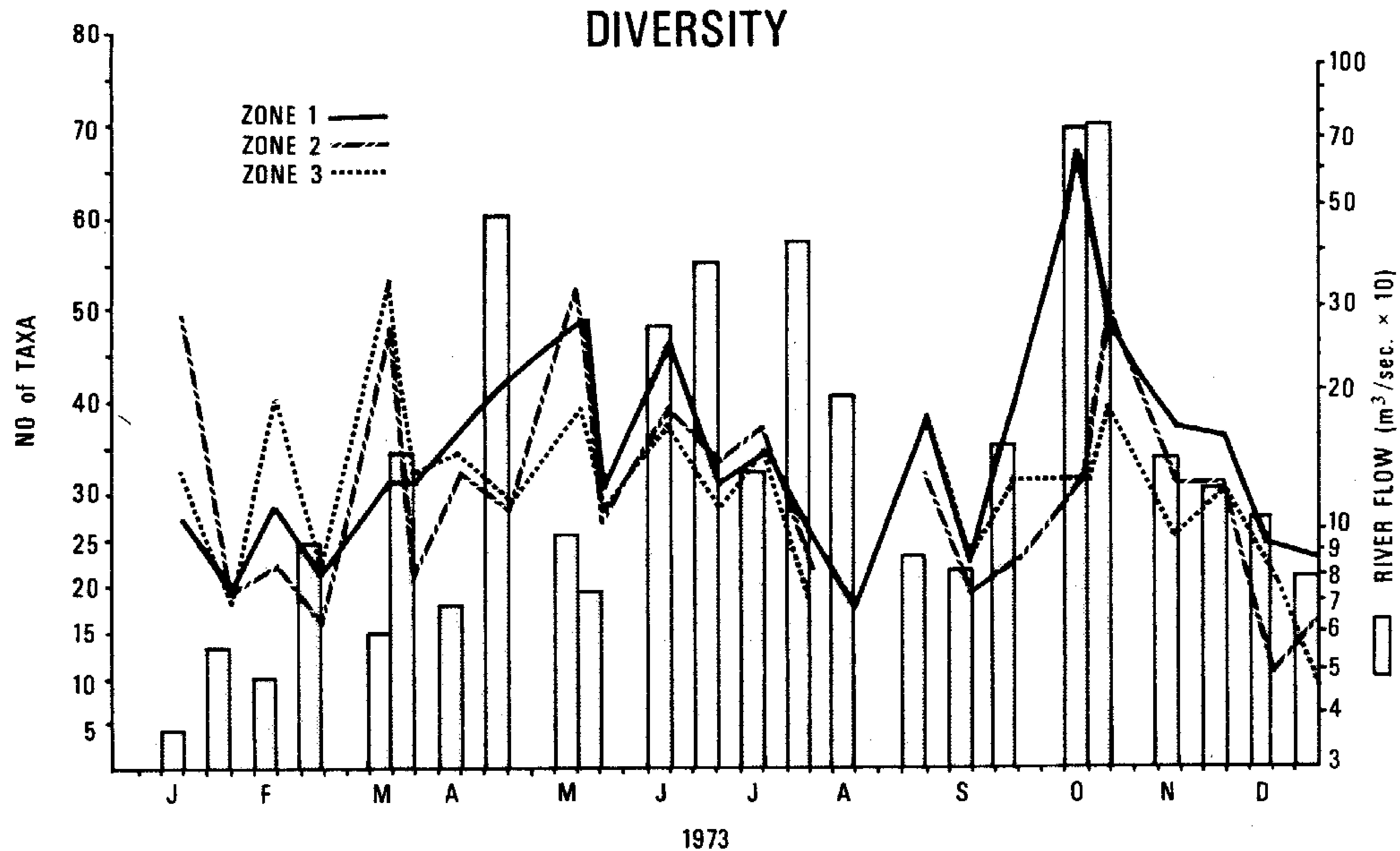

Figure 3. Zooplankton diversities for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

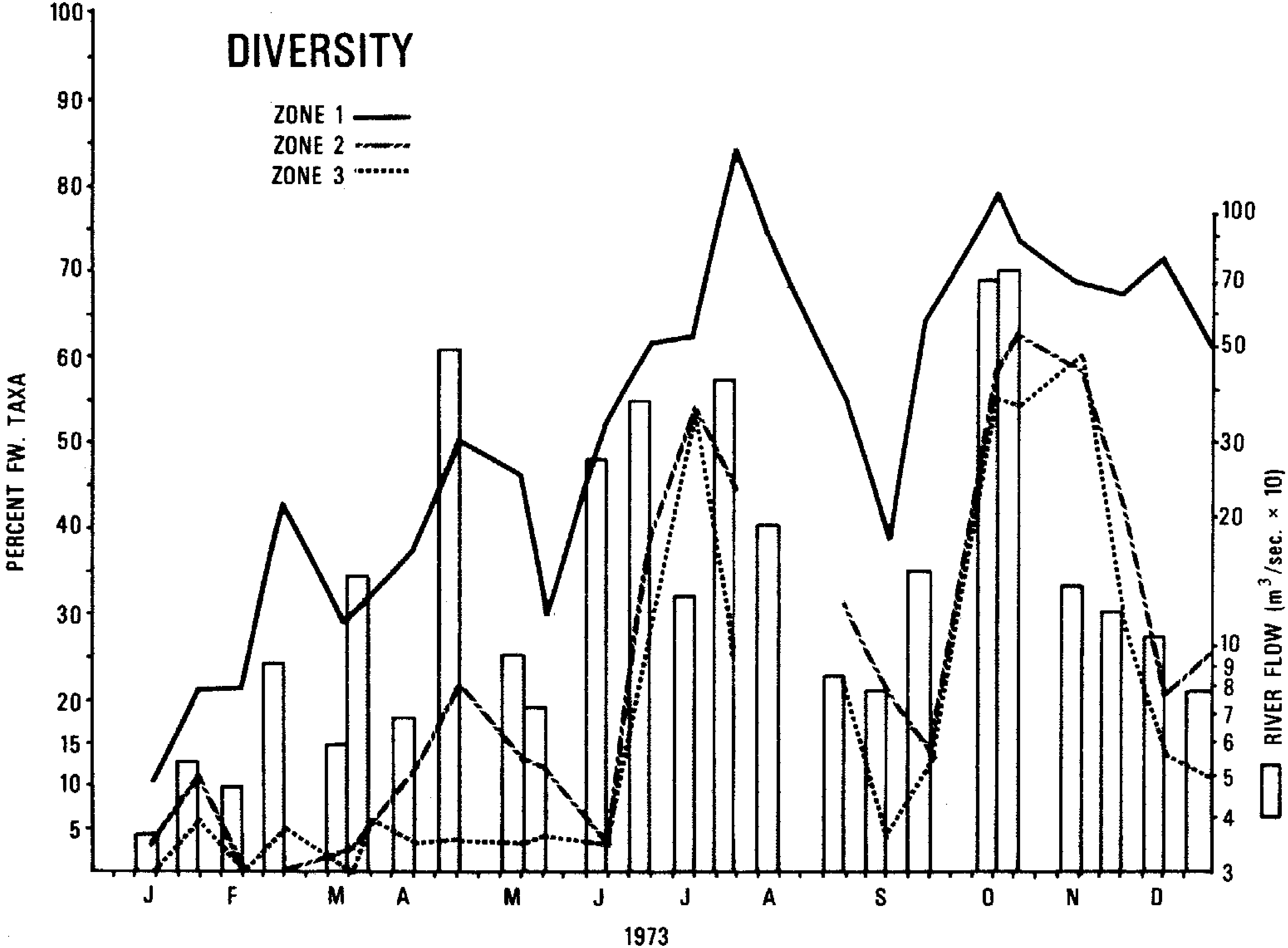

Figure 4. Percentages contributed by freshwater taxa to the diversity of zooplankton in each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

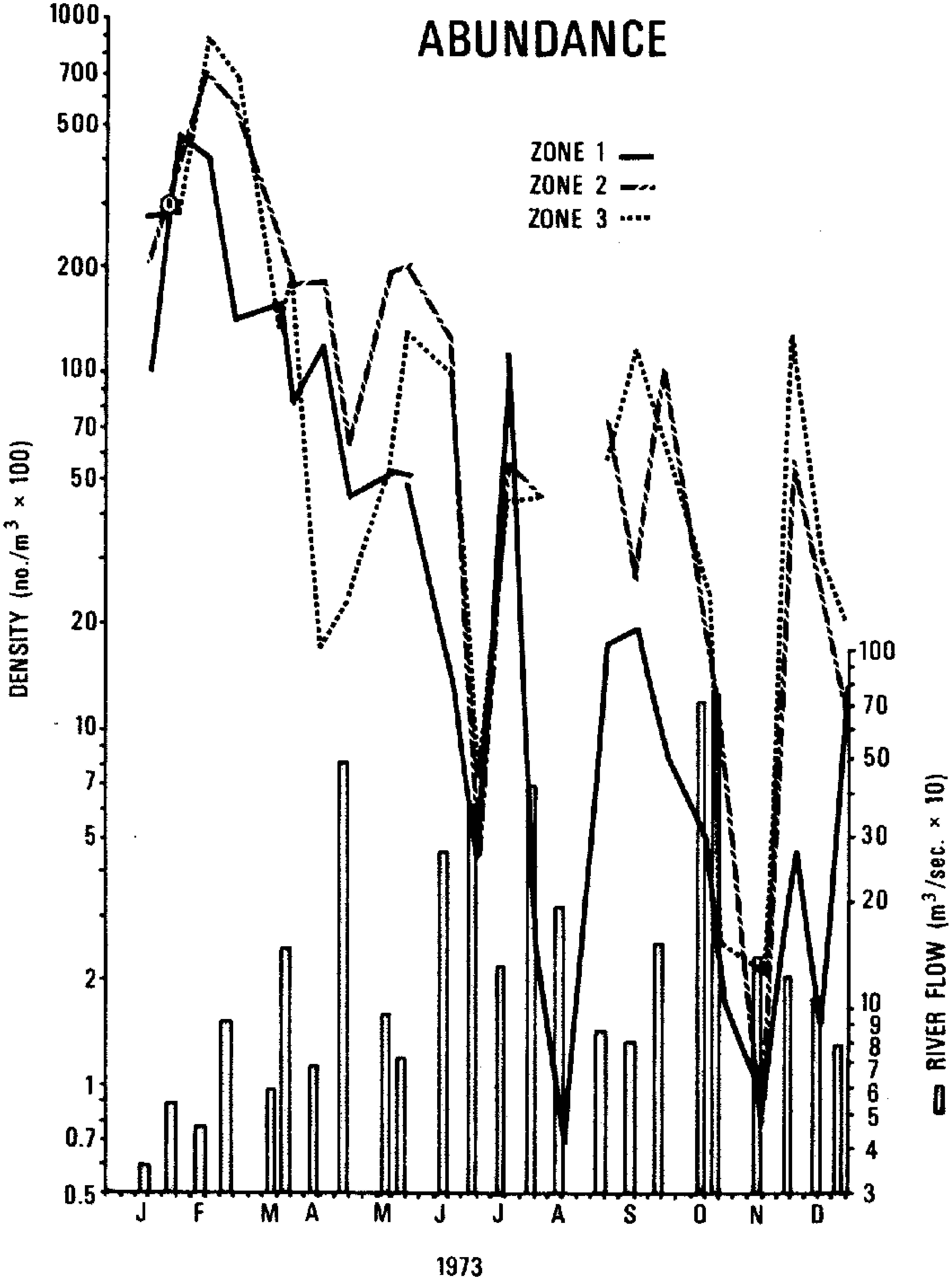

Figure 5. Total zooplankton densities averaged for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

After each flood the zooplankton did recover, but in each case the recovery was incomplete. Densities were $10,000/m^3$ to $20,000/m^3$ before the April flood, decreased to $2,000/m^3$ to $6,000/m^3$ during the flood and recovered to $4,000/m^3$ to $20,000/m^3$ afterwards. The June flood arrived soon after this recovery, and densities declined again, this time to $400/m^3$ to $800/m^3$. Recovery to $4,000/m^3$ to $12,000/m^3$ occurred between the two major flow periods of this flood, and much of these densities were due to moderate populations of freshwater zooplankters. Zooplankton density in Zone 1 fell to only $64/m^3$ after this second pulse of flood water. Equipment failure prevented sampling the other zones. After the flood, the densities recovered again to $1,800/m^3$ to $11,000/m^3$, just slightly lower than the preflood values. At the start of the October flood the densities were about $850/m^3$ to $9,500/m^3$, and they declined to $70/m^3$ at the end of the flood. Recovery after the flood was delayed in Zone 1, but it was rapid in Zones 2 and 3 with preflood densities being attained within a month.

Zooplankton of freshwater origin contributed greatly to the total density of each zone during these floods. Their contributions during the April flood were relatively minor, reaching only 33 percent of the total density in Zone 1 and much less for those in Zones 2 and 3 (Figure 6). Their contributions during the June flood were much greater, reaching 97 percent for Zone 1 near the middle of the flood, and 68 percent and 35 percent for Zones 2 and 3 respectively. Similar levels of contribution were found for each zone during the October flood. During all three floods, the freshwater taxa contributed a greater percentage to Zone 1 sooner and for a longer time than for the other zones which is reasonable considering Zone 1 is closest to the river mouth.

The cumulative effects of the floods during 1973 appear to be those of temporarily increasing diversity and decreasing density. Increased diversity in the bay as a whole is logical with the addition of freshwater taxa to those taxa already existing in the bay. Much of the decrease in density can be attributable to the relatively low densities of Balanus sp. nauplii in December 1973 versus the same time the previous year. This is a result of stressing or killing the adult barnacles with the very low salinities which existed in the bay for such an extended period. Matthews et al. (1975) noted relatively low standing crops of phytoplankton from early October through December 1973 as compared with the other periods. This paucity of food could have resulted in the poor spawn among the surviving barnacles, and thus the lower densities after the floods.

CONCLUSIONS AND RECOMMENDATIONS

Prolonged exposure of an estuary to fresh water such as was found during the floods in San Antonio Bay in 1973 may be considered damaging to the zooplankton and other fauna of the area on a temporary basis. Typical estuarine fauna are replaced by freshwater fauna and total zooplankton densities are usually greatly reduced during each flood. Because the 1973 type of flooding occurs once in 100 years or less, and because its effects are rapidly erased by influx of organisms and zooplankton from neighboring

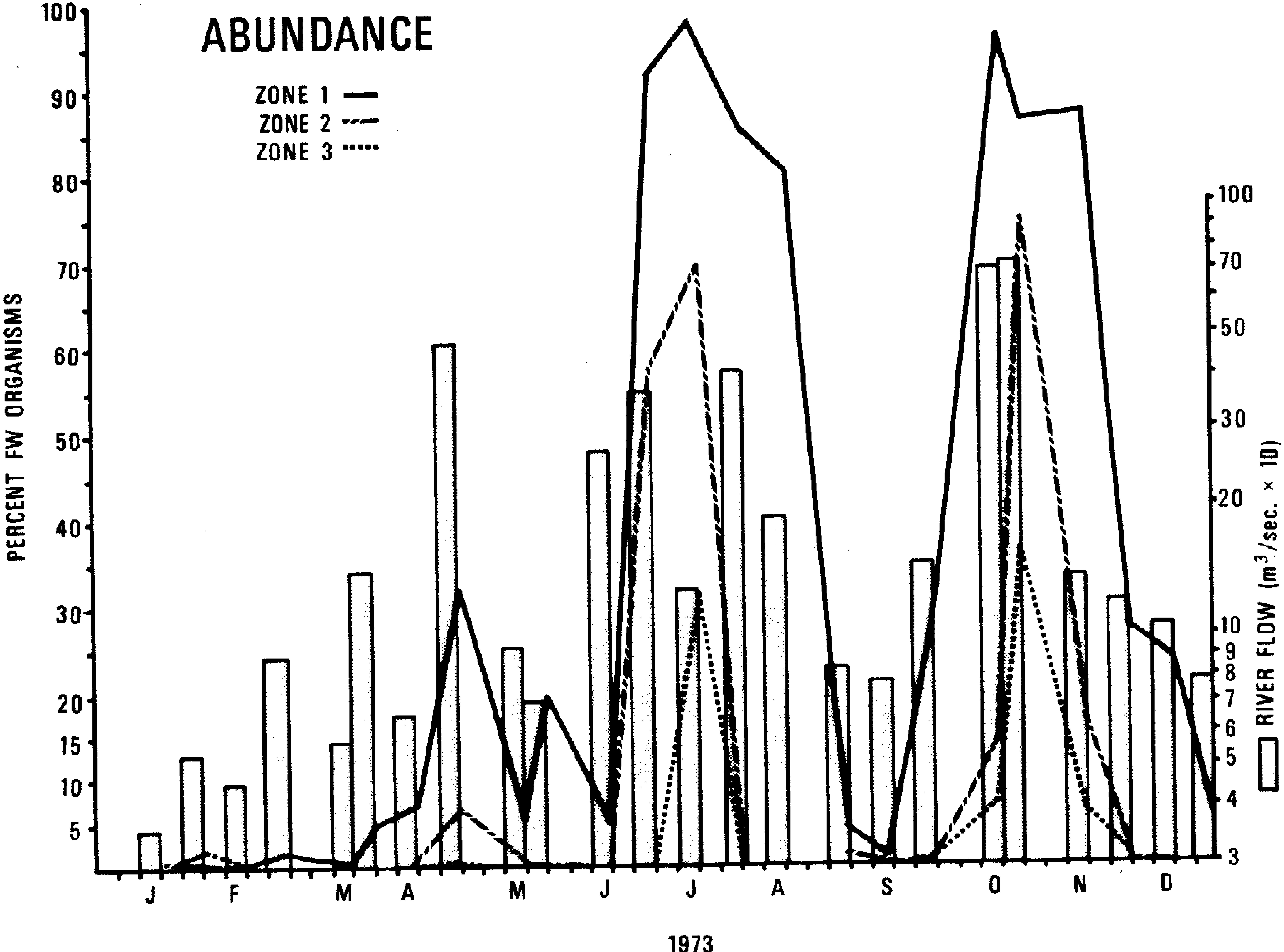

Figure 6. Percentages contributed by freshwater taxa to the total zooplankton densities averaged for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

bays, there is no need to take preventive action.

The seasonal timing of floods can have important consequences. The occurrence of a flood when larvae of economically important species are in the zooplankton could significantly reduce future harvests in the bay by displacing or killing these larvae. At this time the importance of the influx of organisms and zooplankton from neighboring bays can not be overstated. Recruitment from these bays can assist in re-establishing these economically important species. Thus, it is necessary to define the circulation patterns between estuaries and to realize their interdependence so as not to delude ourselves into relinquishing one estuarine area to pollution as though it were an entity unto itself.

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