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THE EFFECT OF FRESHWATER INFLOW ON MACRO-BENTHOS IN THE LAVACA RIVER DELTA AND UPPER LAVACA BAY, TEXAS

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ABSTRACT

A two year study on the effects of freshwater inflow on macrobenthos at selected sites in the upper portion of the Lavaca River and Bay was conducted from November 1984 through August 1986. Lowest densities occurred in lakes, and highest densities occurred in creek deltas. Sediment grain size did not have a significant effect on spatial distributions. The first year of the study had higher inflow rates than the second year. Temporal changes of inflow had a larger effect on spatial variability, because freshwater species had extended ranges during the high-flow year. Temporal variation in the benthic community during the study was caused by population changes of low salinity species, and this was associated with high inflow rates during the first year. Freshwater inflow is apparently necessary to induce the recruitment of low salinity species in the upper bay. Chironomid larvae and the polychaete, *Hobsonia florida*, increased in density approximately 4 weeks after an inflow event. In contrast, the mollusks, *Mulinia lateralis* and *Macoma mitchelli*, had increased densities during the low inflow period resulting in high benthic biomass. *Streblospio benedicti*, a surface deposit-filter feeder, and *Mediomastus californiensis*, a burrowing deposit-feeder, were also positively correlated with increasing salinity during low inflow periods. Chlorophyll-*a* concentration in the surface water increased with inflow, indicating primary production was stimulated by inflow, and then decreased with increased salinity and increased filter feeder biomass. Non-molluskan benthic biomass was similar during wet and dry periods, and had a positive relationship with chlorophyll-*a* concentration. The amount, timing, and inter-annual variation of inflow influence both the spatial and temporal abundance and biomass of benthic macrofauna.

INTRODUCTION

The upper Lavaca Bay (Fig. 1), located at latitude 28° 41′ North and longitude 96° 36′ West, is part of one of the seven major estuaries along the Texas coast. Lavaca Bay is shallow with a maximum natural water depth of about 2.4 m and a surface area of about 16,576 ha. The perimeter of the upper bay shoreline is lined with patchy *Spartina alternifora* Lois. The surrounding low salinity marshes adjacent to the river are vegetated mainly with *Juncus*

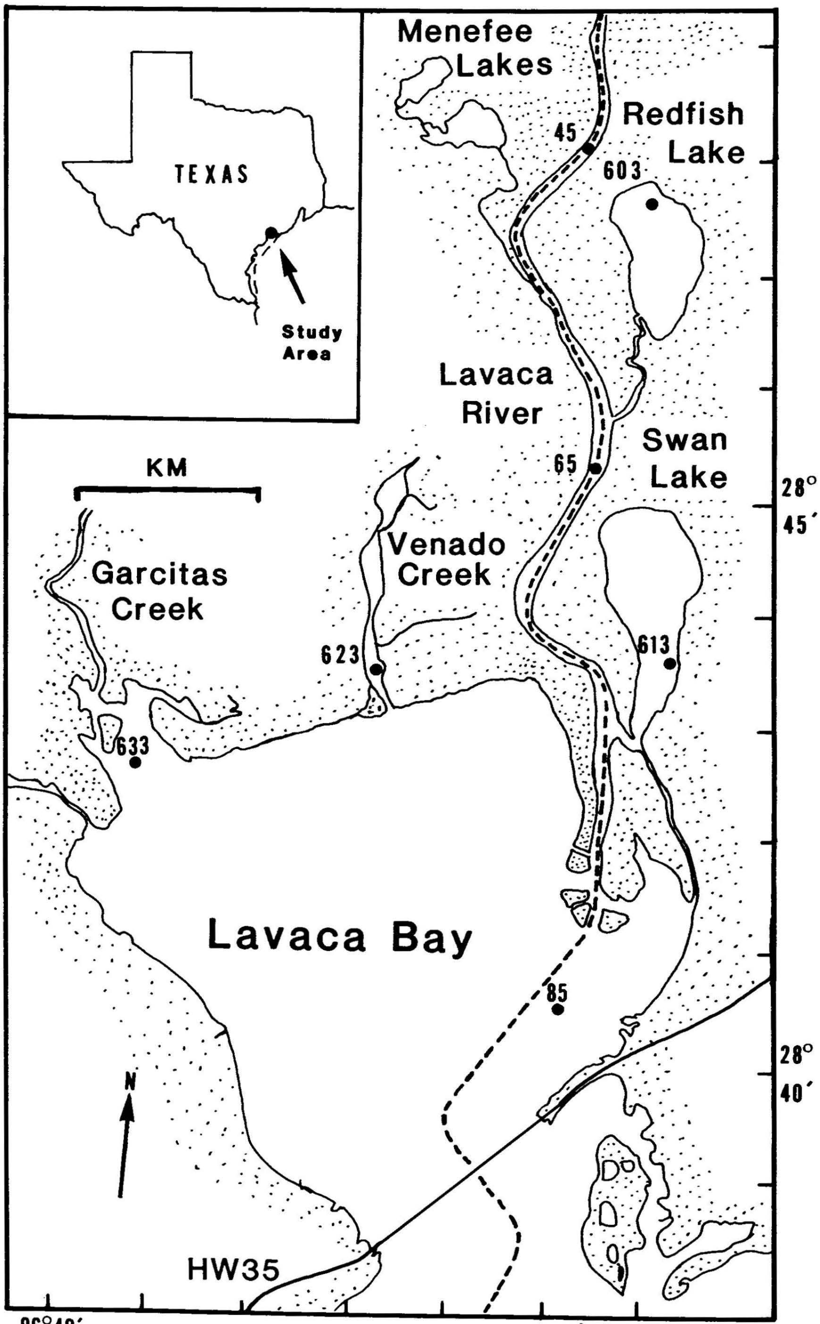

FIG. 1. Location of sample sites in Lavaca River, Delta and Bay.

roemerianus Scheele and *Phragmites communis* Trin. The majority of freshwater inflow into upper Lavaca Bay comes from the Lavaca and Navidad Rivers, while lesser contributions come from Venado, Garcitas and Placedo creeks. The Palmetto Bend Project, a dam, was constructed on the Navidad River in May 1980 to form Lake Texana. This reservoir was constructed to supply water for industrial and municipal use and was not intended for flood control. Major floods are allowed to pass through the flood gates and inundate the marsh system associated with the Lavaca-Navidad River delta. Circulation between the upper and lower bay is modified by the presence of State Highway 35 Causeway, (the remains of the old causeway that has been used as a fishing pier since its destruction by hurricane Carla in 1961) and the Causeway oyster reef which extends across the mouth of the upper bay. The Causeway Reef is a combination of Lap, Hole in the Wall, and Chicken Reefs (Munro 1961). Two tertiary bays or lakes are associated with the Lavaca River. Redfish Lake is approximately 4.8 km and Swan Lake is approximately 1.6 km north of Lavaca Bay (Fig. 1). The total area of Redfish Lake is about 194 ha and Swan Lake is about 259 ha. Both lakes are shallow with a maximum depth of about 1.2 m. The salinity of Redfish Lake is usually similar to the river's while the salinity in Swan Lake is more estuarine due to its proximity and connection with Lavaca Bay *via* Catfish Bayou. Sedimentation from the Lavaca River occurs in upper Lavaca Bay at a rate of 200,000 tons of silt annually. Only minimal amount of fill has occurred at the mouth of the Lavaca River with no appreciable extension of the river delta since 1870 (Shepard 1953).

Benthic studies in early 1900's in the Lavaca-Matagorda Bay area concentrated on oysters to determine their distribution, condition, and the possibility of the development and improvement of the oyster areas (Moore 1907; Moore and Danglade 1915; DeBogert 1913 in Munro 1961; Galtsoff 1931). These oyster bottom studies have described changes in oyster reef distribution over the years which have been attributed to natural and man-induced perturbations. The fluctuation of the area of oyster reefs directly affects the extent of soft bottom benthic communities in the estuary. The Texas Water Development Board (TWDB) was mandated by Senate Bill No. 137 (Schwartz, 64th Legislature, 1975) to conduct studies of the effects of freshwater inflow upon the bays and estuaries of Texas and to estimate the inflows necessary to maintain a suitable ecological environment (TDWR 1982). A number of studies have been conducted in the major estuaries on the Texas coast to measure the effect of freshwater inflow on salinity and nutrient gradients and the abundance and distribution of flora and fauna (Flint, Kalke and Rabalais 1981; Gilmore 1974; Gilmore, Matthews and Clements 1975; Gilmore, Dailey, Garcia, Hannebaum and Means 1976; Harper 1973; Hoese 1960; Holland, Maciolek and Oppenheimer 1973; Holland, Maciolek, Kalke and Oppenheimer 1974; Holland, Maciolek, Kalke, Mullins and Oppenheimer 1975; Jones, Cullen, Lane, Yoon, Rosson, Kalke, Holt and Arnold 1986; Mackin 1971; Matthews, Marcin and Clements 1974; Whitledge, Amos, Benner, Buskey, Dunton, Holt, Kalke, Montagna, Parker, Stockwell and Yoon 1989). Unlike earlier studies which concentrated on oyster reefs, most of the benthic work in Texas estuaries since the early 1970's have concentrated on the soft bottom benthic communities and their relationship to environmental variables *i.e.*, freshwater inflow, salinity, temperature and sediment type.

The objective of this study was to determine how environmental factors affected by freshwater inflow regulates macrobenthos population abundance, biomass and community structure in the upper Lavaca Bay. Spatial variability was assessed from samples taken in the river, tertiary bays (lakes), and delta. Temporal variability was assessed by sampling monthly and bimonthly over a two-year period. Biological responses were compared with salinity, river streamflow rates, and chlorophyll biomass to assess benthic response to freshwater inflow.

METHODS

The sampling sites included stations 45 and 65 (river sites), 603 and 613 (lake sites), 85 (river delta) and 623 and 633 (creek sites) (Fig. 1). The station locations and numerical designations were established by the TWDB (TDWR 1980). The Palmetto Dam is approximately 8.8 km above the up-river sampling site (Stn. 45) and approximately 24 km from Lavaca Bay.

Fourteen sampling trips were conducted during November, 1984, January, March, April, May, June, July, August, October and December, 1985 and February, March, June and August 1986. Year-1 of the study was from November 1984 through August 1985 and Year-2 was from October 1985 through August 1986.

Benthic core sampling was accomplished using SCUBA or snorkeling. Triplicate samples were collected at each site with 7.5 cm diameter, 30 cm long aluminum cores. The cores were sectioned horizontally by depth at 0-3, 3-10, and 10-20 cm. Sections were placed in a 1 liter jar and preserved with 10% formalin in seawater stained with rose bengal. In the lab, each sediment section was sieved through 0.5 mm mesh and the retained organisms were identified and counted. Wet weight biomass was measured on the numerically dominant individuals and on the remainder of the sample. All mollusk biomass data includes shell weight.

Sediment grain size analysis was performed using standard geologic procedures (Folk 1964; E.W. Behrens, personal communication). Percent contribution by weight was measured for four components: rubble (*e.g.* shell hash), sand, silt, and clay. A 20 cm^3 sediment sample was mixed with 50 ml of hydrogen peroxide and 75 ml of deionized water to digest organic material in the sample. The sample was wet sieved through a 62 μm mesh stainless steel screen using a vacuum pump and a Millipore Hydrosol SST filter holder to separate rubble and sand from silt and clay. After drying, the rubble and sand were separated on a 125 μm screen. The silt and clay fractions were measured using pipette analysis.

Inflow data was obtained from the TWDB. Gauged streamflow data is from a U.S. Geological Survey (USGS) gauge located near Edna, Texas on the Lavaca River. The effect of freshwater inflow of Lavaca Bay benthos was determined by correlating bay-wide abundance and biomass with physical parameters, *i.e.*, salinity, temperature, dissolved oxygen, chlorophyll-*a*, sediment grain size and streamflow. Lavaca River gauged inflow rates, averaged for 14 days prior to and including the first sampling day of each trip, gave the best correlation with mean salinity (Pearson correlation coefficients, $r = -0.55$; $P \leq 0.05$) and was used to assess the impact of recent flow regimes on the fauna. Lagged effects of flow were also examined. For example, salinity changes resulting from freshwater inflow can happen immediately, but effects on benthic reproduction and migration lags behind such changes. Therefore, a flow event may not result in measurable short term changes in the benthic community, but might be detectable later. Pearson correlation

coefficients (r) were calculated for benthos with salinity, temperature, mean 14-day flow and the mean 14-day lag flow. The lag flow was achieved by shifting the flow data forward by one sampling trip. Since 50 correlation tests were performed, it is prudent to take the Bonferroni approach and reject at $P \leq 0.001$ (*i.e.*, 0.05/50).

RESULTS

Historically, upper Lavaca Bay has been mainly supplied with freshwater from the Lavaca and Navidad Rivers. The 49-year daily flow average (1939-1987) for the Lavaca River is 9.4 m^3/s and the forty-year daily flow average for the Navidad River is 16 m^3/s (USGS 1980; Buckner, Carillo and Davidson 1987). Freshwater streamflow rates of the Lavaca River near Edna, Texas indicates that the average daily flow rate for Year 1 of this study was 10 m^3/s, 50% higher than the daily average of 5 m^3/s during Year 2. Since the closing of the dam on the Navidad River in May, 1980 the freshwater inflow pattern has been altered, although it has not deviated much from the historic flow rate of 16 m^3/s. Negligible input from the Navidad River occurred during initial filling of Lake Texana from May 1980 through December 1982. Freshwater releases beginning in December 1982 through December 1983 averaged approximately 35 $m^3/s/d$ on a monthly basis, which is above the 49-year average. The average monthly total inflow from January 1983 through 1986 demonstrates interannual cyclic inflow patterns (Fig. 2). Total inflow is the

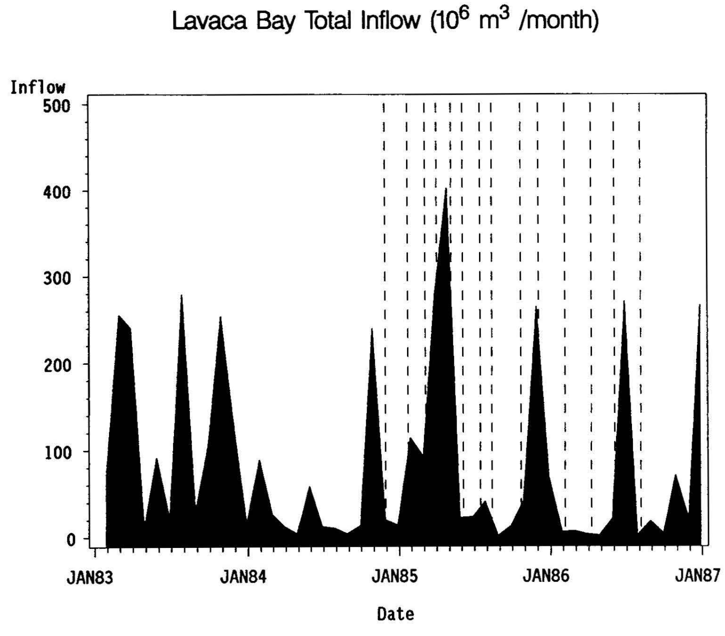

FIG. 2. Total freshwater monthly inflow into Lavaca Bay. Total inflow for each month from 1983-1986 is reported. Dashed vertical lines indicates sampling trips during this study.

sum of gauged inflow, modeled runoff, precipitation and return flows. A wet cycle occurred in 1983, followed by a dry year in 1984, prior to this study. Year-1 of this study was another wet year. Annual variation in total freshwater inflow can be demonstrated by comparing total inflow for September 1983 (722 x 10^6 m^3/mo), 1984 (1263 x 10^6 m^3/mo) and 1985 (722 x 10^6 m^3/mo). Low inflow in September 1983 and 1985 corresponds to dry years and high inflow in September 1984 corresponds to a wet year. Freshwater inflow declined in 1985-86 which resulted in a dry period during Year-2.

We compared stream inflow with salinity measured during sampling trips. We found that salinity correlated best with the average daily stream flow rates for 14-days prior to sampling (Fig. 3). We present this average 14-day inflow rate in Figs. 4-12 to compare inflow with benthic community response.

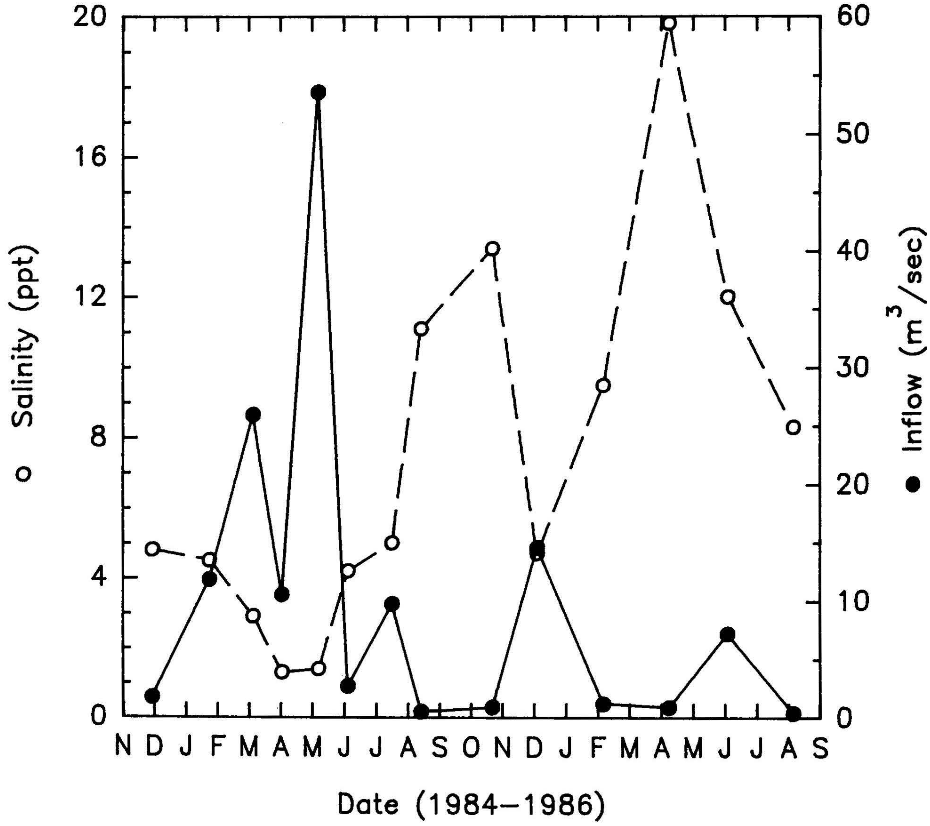

FIG. 3. Lavaca River streamflow 14-day average prior to each sampling trip and its relation to average salinity (dashed line) for all stations by month from November 1984 through August 1986. The 14-day average streamflows (solid line) corresponding with each sampling trip starting in October 1984 are as follows: 2, 12, 26, 11, 54, 3, 10, 0.5, 1, 15, 1, 1, 7, and 0.4 m^3/sec.

January 1984 through December 1985 was a drier period with sporadic daily discharges in January, May, and October 1984 averaging 9.5 m^3/s. From January 1985 through December 1985 increased inflow was noted with releases occurring every month except May, August and September 1985. The daily average flow rate for this period was 18.5 m^3/s. Flow rates were down from January 1986 through December 1986 with releases only in May, June and September, 1986, resulting in a daily average of 8 m^3/s.

The benthic community in upper Lavaca Bay during this study was typical of a low to moderate salinity estuary with only a few dominant species. The dominant species of the 52 taxa collected included the polychaetes, *Mediomastus californiensis, Streblospio benedicti, Laeonereis culveri,* and *Hobsonia florida*, oligochaetes, chironomid midge fly larvae, and the mollusks *Macoma mitchelli* and *Mulinia lateralis* whose combined total abundance comprised 90% of the total taxa abundance (Table 1). Chironomid larvae and *H. florida* were found at low salinity stations. The other dominant taxa: *M. californiensis, S. benedicti,* and *L. culveri* are estuarine species.

The overall average benthic standing crop was not significantly different between Year-1 (5, 505/m^2) and Year-2 (6, 959/m^2), (Table 2). The abundance of benthic fauna was highest in the winter and spring and lowest in the summer and fall (Fig. 4). No significant differences were found with faunal abundance among stations.

Stratification of both infauna abundance and biomass by sediment depth was similar at all stations. The highest concentration of organisms was found in the upper 3 centimeters and decreased with depth to the lowest abundance at the 10-20 cm sediment depth (Table 3). Average abundance by sediment depth was similar for both years at all stations. Distribution patterns of benthic biomass increased with sediment depth, which is opposite of abundance patterns (Table 3). The largest biomass occurred at the 10-20 cm depth zone.

Sediment composition was similar during all three sampling times, but there were station and vertical differences (Table 4). The uppermost river station (45) contained a lot of rubble, as did the surface sediment of the lower river station (65). The river stations were also sandy. Bay and Lake stations had finer sediments.

Biomass increases occurred from March through June 1985, in August 1985 and from February through August 1986 with the highest biomass occurring in Year-2 (Fig. 5). Benthic biomass was positively correlated with salinity, $r = 0.71$ (Table 5). Molluskan biomass dominated the total benthic biomass, so trends of total biomass were strongly influenced by the mollusks (Fig. 5). Mollusk biomass and total benthic biomass were correlated with salinity, $r = 0.73$ (Table 5).

Non-molluskan benthic biomass was comprised of mainly polychaetes, chironomids, rhynchocoels, and a few crustaceans (Table 6). These taxa, as a group, were not significantly correlated with salinity or freshwater inflow (Table 6). However, the main factors influencing total abundance and

TABLE 1
Lavaca Bay species distribution and *n* density/m^2 to a sediment depth of 20 cm by station from November, 1984 - August, 1985.

	Station						
Taxa	**45**	**603**	**65**	**613**	**85**	**623**	**633**
Platyhelminthes							
Turbellaria	0	0	0	0	0	897	0
Rhynchocoela	193	111	244	61	66	83	32
Mollusca							
Gastropoda							
Pyramidellidae							
Odostomia laevigata	0	6	61	11	0	6	26
Odostomia cf. gibbosa	0	6	6	0	11	0	13
Acteonidae							
Acteon punctostriatus	0	0	11	0	0	0	0
Pelecypoda	0	0	0	0	0	0	6
Solenidae							
Ensis minor	0	0	0	0	11	0	6
Tellinidae							
Macoma mitchelli	0	0	249	504	476	210	446
Macoma tenta	0	0	0	0	6	6	0
Mactridae							
Mulinia lateralis	28	6	94	44	194	55	355
Rangia cuneata	0	0	0	0	0	6	0
Solecurtidae							
Congeria leucophaeta	0	0	6	0	0	0	0
Tagelus plebeius	0	0	6	0	50	17	19
Annelida							
Polychaeta							
Phyllodicidae							
Eteone heteropoda	0	0	0	0	11	0	0
Pilargiidae	0	0	6	0	0	0	0
Sigambra tentaculata	0	0	0	0	17	0	0
Ancistrosyllis jonesi	0	0	0	0	11	17	0
Parandalia sp.	0	0	17	0	0	0	6
Hesionidae							
Gyptis vittata	0	0	6	28	11	6	0
Nereiidae	0	0	39	28	0	44	6
Laeonereis culveri	221	6	199	28	17	172	116
Neanthes succinea	0	0	33	0	0	0	0
Gonradidase							
Gycinde solitaria	0	6	6	0	78	17	90
Spionidae							
Polydora socialis	6	0	11	0	50	360	39
Streblospio benedicti	304	1954	1777	1854	1434	3122	1356
Scolelepis texana	0	0	0	0	6	0	0
Cossuridae							
Cossura delta	0	0	0	0	6	0	0
Orbinidae							
Haploscoloplos foliosus	0	0	0	0	6	0	0

Taxa	Station						
	45	603	65	613	85	623	633
Capitellidae							
Capitella capitata	0	0	22	39	55	55	19
Mediomastus californiensis	166	127	3089	620	4489	3875	2474
Heteromastus filiformis	0	0	0	0	0	11	0
Ampharetidae							
Hobsonia florida	277	61	61	28	55	210	32
Oligochaeta	769	587	603	277	66	642	349
Hirudinea	11	0	0	0	0	11	0
Crustacea							
Copepoda							
Cyclopoida	0	0	0	0	0	22	0
Hemicyclops sp.	0	0	22	0	0	0	226
Malacostraca							
Mysidacea							
Mysidopsis sp.	0	6	22	11	6	0	0
Mysidopsis almyra	0	17	22	0	0	0	0
Cumacea	0	0	0	0	0	6	0
Cyclaspis varians	0	0	6	0	17	0	6
Oxyurostylis smithi	0	0	5	0	0	0	0
Tanaidacea							
Leptochelia rapax	0	0	6	0	0	0	0
Isopoda							
Edotea montosa	6	0	17	0	28	6	0
Amphipoda							
Ampelisca abdita	0	0	0	6	44	0	0
Monoculodes sp.	0	0	0	11	17	28	78
Corophium louisianum	44	17	426	6	22	6	6
Microprotopus spp.	6	0	0	0	0	0	0
Decapoda							
Callianassa sp. juvenile	0	0	6	0	6	0	0
Callianassa latispina	0	0	17	0	0	0	0
Callinectes sapidus	0	6	0	0	0	0	0
Insecta							
Insecta larvae	0	0	6	0	0	0	0
Diptera							
Chironomidae	2762	614	548	288	22	194	90
Chironomid pupae	22	0	6	0	0	6	0
$\bar{x}$ Total n/m^2	4816	3526	7645	3842	7285	10086	5800

biomass were freshwater inflow and salinity (Table 6). There is a seasonal trend of increasing weight of mollusks in spring and summer. Few relationships with sediment grain size were found. Non-mollusk biomass was weakly correlated with increasing sand content and chlorophyll-*a* concentration.

TABLE 2

Benthos standing crop (n/m^2) to a depth of 20 cm at each station by sampling trip. Mean of 3 replicates.

	Month (1984-1986)										
Station	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
45	-	1320	-	10400	-	5120	6280	1470	10500	6120	3640
65	-	4340	-	4570	-	6820	5580	7910	9530	7750	5740
85	-	8760	-	8680	-	7830	6280	7750	8290	7670	6970
603	-	6050	-	2640	-	3640	7980	2480	5500	1400	1160
613	-	388	-	1090	-	2790	1630	1860	4340	4960	2950
623	-	5270	-	8060	-	13600	7980	11300	7750	6900	8530
633	-	-	-	-	-	5810	5350	1860	2250	1320	2870
45	1550	-	1090	-	6200	-	6050	-	22790	-	4880
65	5890	-	6280	-	11900	-	15100	-	12800	-	2790
85	3640	-	2170	-	6200	-	15000	-	7830	-	6000
603	1470	-	310	-	3100	-	7440	-	2170	-	930
613	2090	-	2090	-	11800	-	7980	-	7050	-	2790
623	18100	-	9300	-	17400	-	10200	-	9690	-	7051
633	698	-	5580	-	16000	-	14300	-	11000	-	2480

- station not sampled.

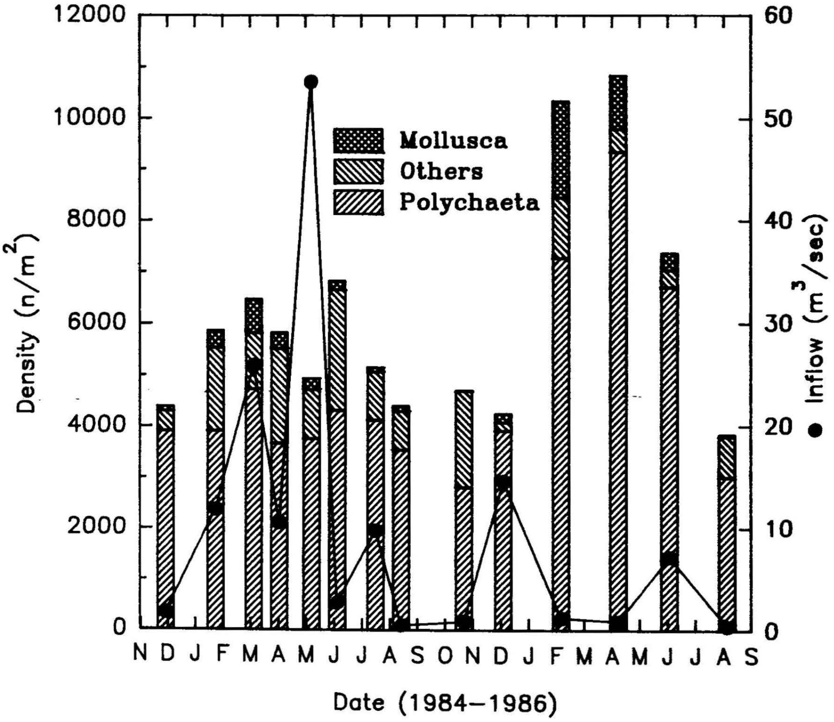

FIG. 4. Benthos standing crop average abundance (n/m^2) for all mollusks, polychaeta, and other taxa (bars) to a depth of 20 cm *vs.* 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

TABLE 3
Vertical distribution of macrofauna. Mean percent occurrence in each core for all stations and sampling trips.

Section	Abundance	Biomass
0 - 3 cm	70%	16%
3 - 10 cm	27%	31%
10 - 20 cm	3%	53%

TABLE 4
Lavaca Bay sediment grain size analysis (% composition). Mean and standard deviation (in parentheses) from 1 replicate taken in November 1984, August 1985, and August 1986.

Station	Depth (cm)	% Rubble	% Sand	% Silt	% Clay
45	0-3	23.0 (31.7)	68.9 (26.6)	3.3 (2.5)	4.7 (2.8)
45	3-10	20.9 (31.3)	70.8 (26.9)	4.1 (5.1)	4.2 (4.4)
45	10-20	29.2 (34.4)	56.8 (29.6)	6.3 (7.0)	7.6 (8.4)
65	0-3	17.9 (19.2)	67.2 (17.6)	6.8 (2.6)	8.1 (2.8)
65	3-10	8.1 (3.8)	47.1 (28.7)	16.1 (8.1)	28.6 (19.6)
65	10-20	2.7 (1.6)	24.0 (10.8)	22.7 (5.2)	50.6 (9.5)
85	0-3	4.0 (5.3)	65.1 (3.5)	13.2 (6.1)	17.6 (2.4)
85	3-10	1.2 (0.6)	59.4 (9.3)	20.0 (8.5)	19.4 (1.5)
85	10-20	0.9 (0.3)	38.8 (17.5)	25.4 (6.2)	34.9 (11.9)
603	0-3	3.4 (2.2)	43.0 (16.2)	14.5 (7.6)	39.2 (17.2)
603	3-10	2.6 (1.2)	38.8 (27.9)	11.2 (1.0)	47.4 (28.0)
603	10-20	2.4 (1.1)	33.9 (28.0)	11.1 (0.9)	52.6 (29.5)
613	0-3	1.3 (1.0)	39.5 (8.9)	19.8 (3.3)	39.4 (12.2)
613	3-10	3.1 (3.9)	47.9 (4.3)	15.7 (3.3)	33.3 (2.3)
613	10-20	0.9 (0.3)	54.5 (7.5)	15.0 (1.9)	29.6 (5.4)
623	0-3	0.5 (0.2)	67.6 (10.3)	16.7 (8.5)	15.2 (3.2)
623	3-10	1.1 (1.3)	62.8 (1.6)	18.5 (0.5)	17.7 (1.9)
623	10-20	0.9 (0.6)	52.8 (6.2)	24.0 (3.3)	22.3 (9.7)
633	0-3	0.4 (0.2)	72.6 (24.6)	14.2 (13.1)	12.8 (11.6)
633	3-10	30.5 (42.2)	42.2 (59.5)	14.6 (9.2)	12.6 (8.1)
633	10-20	0.8 (0.2)	71.5 (12.3)	16.3 (8.5)	11.4 (3.5)

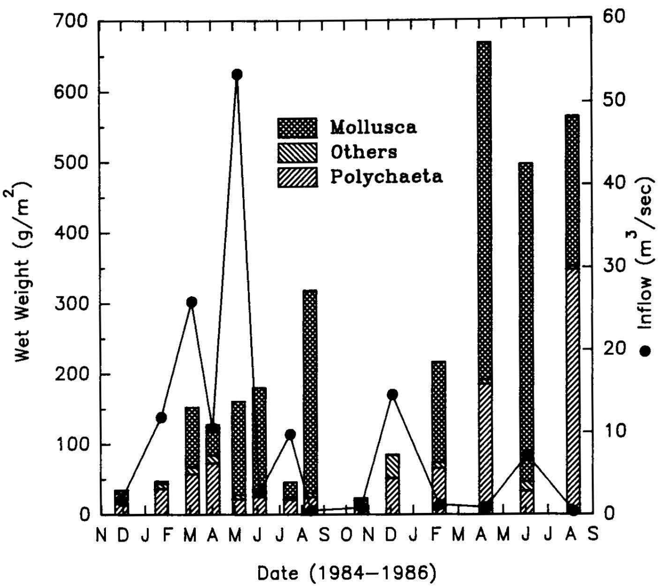

FIG. 5. Benthos average biomass (g/m^2) for all mollusca, polychaeta, and other taxa (bars) to a depth of 20 cm *vs.* 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

TABLE 5
Pearson correlation coefficients (r values) for Lavaca Bay benthos monthly means for all stations and sampling trips, r values without - indicates the correlation is not significant.

	Lavaca River $\bar{x}$ 14 day Stream Flow	$\bar{x}$ 14 day Lag Flow	$\bar{x}$ Salinity by Trip	$\bar{x}$ Temp. by Trip
Lag Flow	-0.05			
x Salinity	-0.55*	-0.39		
x Temperature	-0.14	0.18	0.35	
Standing crop	-0.18	0.11	0.51	0.11
Total Biomass	-0.19	-0.12	0.71**	0.41
Mollusk Biomass	-0.21	-0.11	-0.73**	0.47
Total Biomass minus Mollusk Biomass	0.10	-0.06	-0.10	-0.44
Chironomid Larvae	-0.03	0.84***	-0.48	0.08
Streblospio benedicti	-0.36	-0.39	0.75**	0.03
Mediomastus californiensis	-0.08	-0.15	0.56*	0.04
Mulinia lateralis	-0.09	0.04	0.34	-0.08
Macoma mitchelli	-0.12	-0.02	0.26	-0.21
Hobsonia florida	0.28	0.79***	-0.47	0.14
Laeonereis culveri	-0.30	-0.44	0.82**	0.27

- .05 $\leq P < 0.01$
-- 0.01 $\leq P < 0.001$
--- 0.001 $\leq P < 0.0001$

TABLE 6
Correlation between macrofauna and environmental factors. Chlorophyll-*a* data courtesy of John Cullen (in Jones, *et al.* 1987). Based on 98 sample pairs.

	Salinity	Temp.	D.O.	Chl-*a*	Inflow	Sand
Wet weight						
Mollusks	0.39****	0.24*	-	-	-	-
Others	-	0.28**	-	0.21*	-	0.23*
Total Net Weight	0.39****	0.21*	-	-	-	-
Abundance	0.20***	-	-	-	-	-
Chlorophyll-*a*	- 0.30**	0	0.22	-	0.29	-

- not significant
- 0.05 ≤ P < 0.01
-- 0.01 ≤ P < 0.001
--- 0.001 ≤ P < 0.0001
---- 0.0001

Chironomid midge fly larvae and *H. florida* had a positive response to freshwater inflow (Table 5, Figs. 6 and 7). When their abundance was correlated with streamflow, there was a strong lag response the month following an inflow event for chironomid larvae (r = 0.84) and *H. florida* (r = 0.79) (Table 5). Abundance distributions indicated that both species were surface dwellers in the upper 0-3 cm of sediment (Figs. 6 and 7). Their distribution was mainly restricted to the Lavaca River: stations 45 and 65, lakes: stations 603 and 613 and stations 623 and 633 which were associated with freshwater inflow from Venado and Garcitas Creeks (Table 1). High inflows during Year-1 extended the distribution of chironomid larvae (April-May, 1985) and *H. florida* (April-June 1985) into Lavaca Bay to station 85. Higher numbers and extended distributions in Year-1 were a result of high inflow during this period.

The polychaetes, *S. benedicti*, *M. californiensis* and *L. culveri* all increased in density during low inflow periods. (Figs. 8, 9 and 10). The lowest abundance of *S. benedicti* was during high inflow events and at station 45 upriver throughout the study. The abundance of *S. benedicti* was significantly correlated with salinity (r = 0.75, Table 5). *S. benedicti* was collected mainly from the surface sediments with only a few incidental occurrences in the 10-20 cm core sections (Fig. 8).

Mediomastus californiensis is a burrowing polychaete distributed through the sediment to at least a depth of 20 cm (Fig. 9). Highest densities were found in core sections 0-3 and 3-10 cm and declined below 10 cm. The abundance of *M. californiensis* was significantly correlated with salinity (r = 0.56, Table 5).

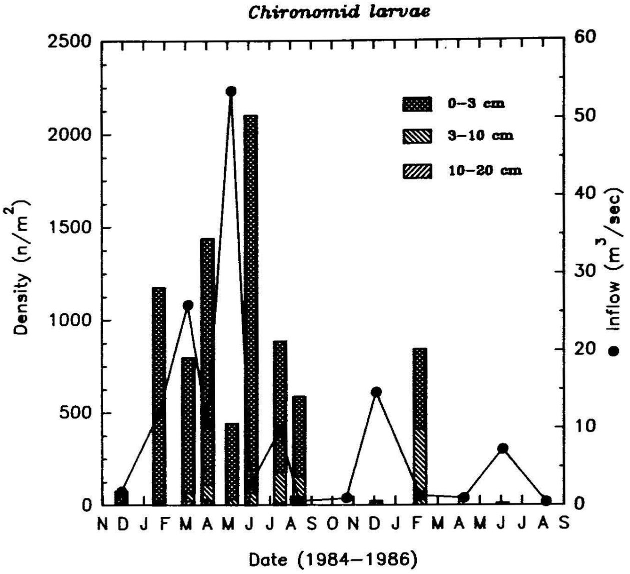

FIG. 6. Chironomid larvae average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

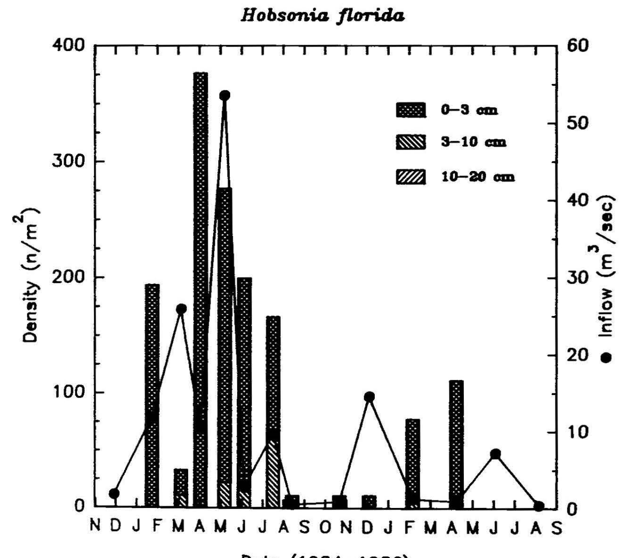

FIG. 7. *Hobsonia florida* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

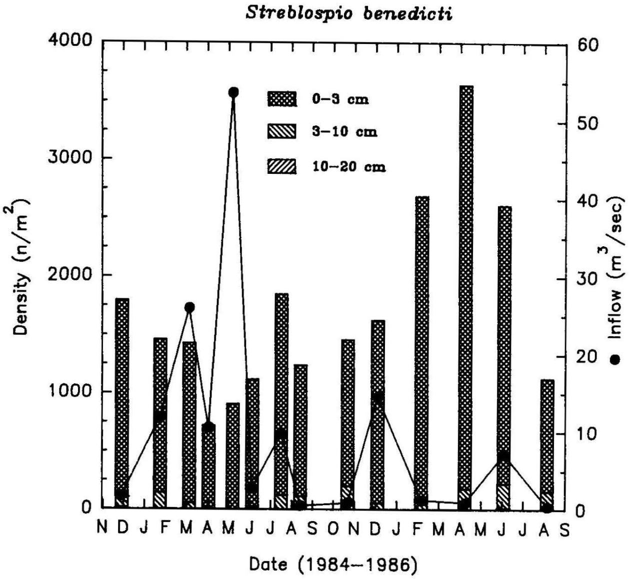

FIG. 8. *Streblospio benedicti* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

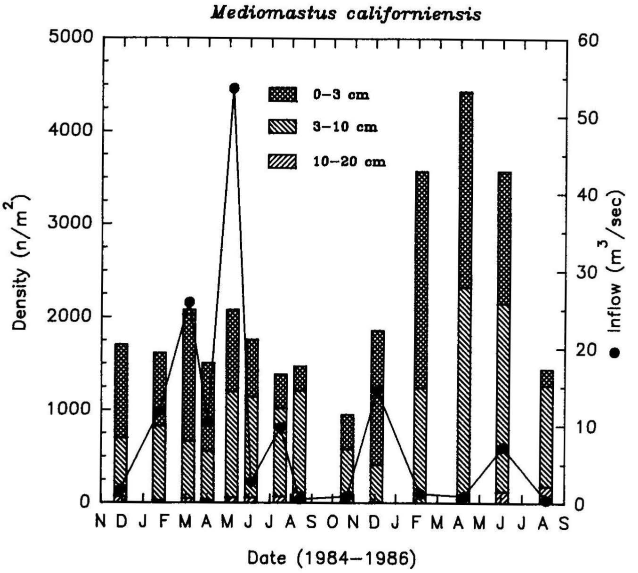

FIG. 9. *Mediomastus californiensis* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

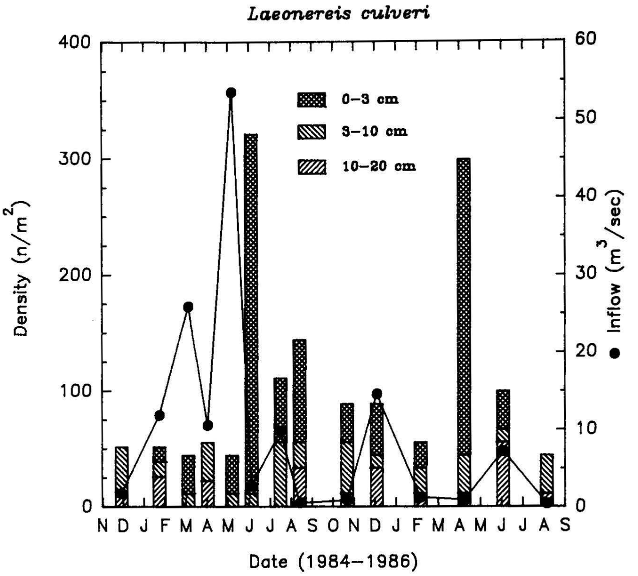

FIG. 10. *Laeonereis culveri* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

Laeonereis culveri was not numerically dominant but it was a much larger polychaete than *S. benedicti* and *M. californiensis*. *Laeonereis culveri* occurred at all depths sampled but occasionally it was collected from only the deep core sections (Fig. 10). The density of *L. culveri* was significantly correlated with salinity (r = 0.82, Table 5).

The two dominant mollusks, *M. lateralis* and *M. mitchelli* accounted for most of the benthic biomass. Both species occurred throughout the study and reached their highest density in February and March 1986. Although their peak density occurred during low inflow periods, there was no significant correlation with salinity or freshwater inflow and density (Table 5). *Mulinia lateralis* is a surface dweller which was collected predominantly in the upper 0-3 cm (Fig. 11). *Macoma mitchelli* inhabited sediments from the surface to 20 cm. When *M. mitchelli* first settled in the benthos it was found mainly in the surface sediments. In December 1985, the concentration of *M. Mitchelli* at the 0-3 cm sediment was juveniles (Fig. 12). As *M. Mitchelli* matured, larger specimens were found in the deeper sections in April and June 1986.

Stations 45, 65 and 85 form a salinity gradient from low to higher salinity in the Lavaca River (Fig. 1). In each trip the salinity was lowest at station 45, increased downstream at station 65 and was highest at station 85 (Fig. 13). The salinity from November 1984 through August 1985 was lower than the period from October 1985 through August 1986. The stations also formed a

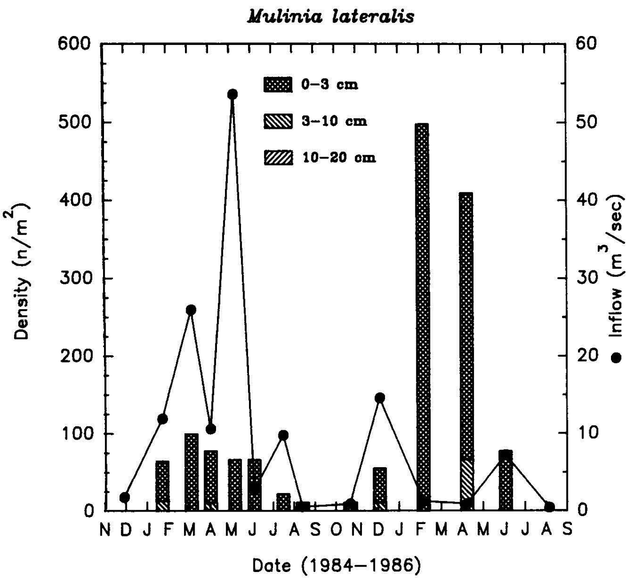

FIG. 11. *Mulinia lateralis* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

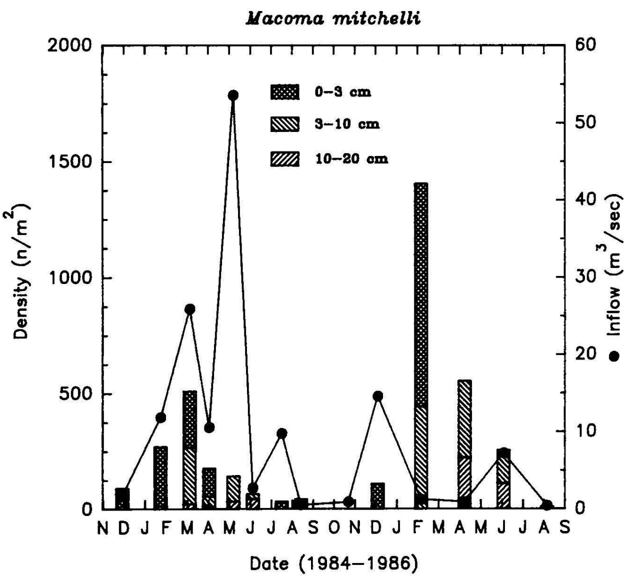

FIG. 12. *Macoma mitchelli* average abundance (n/m^2) at 0-3, 3-10, and 10-20 cm sediment depths and the 14-day average streamflow (solid line) by sampling trip from November, 1984 through August, 1986.

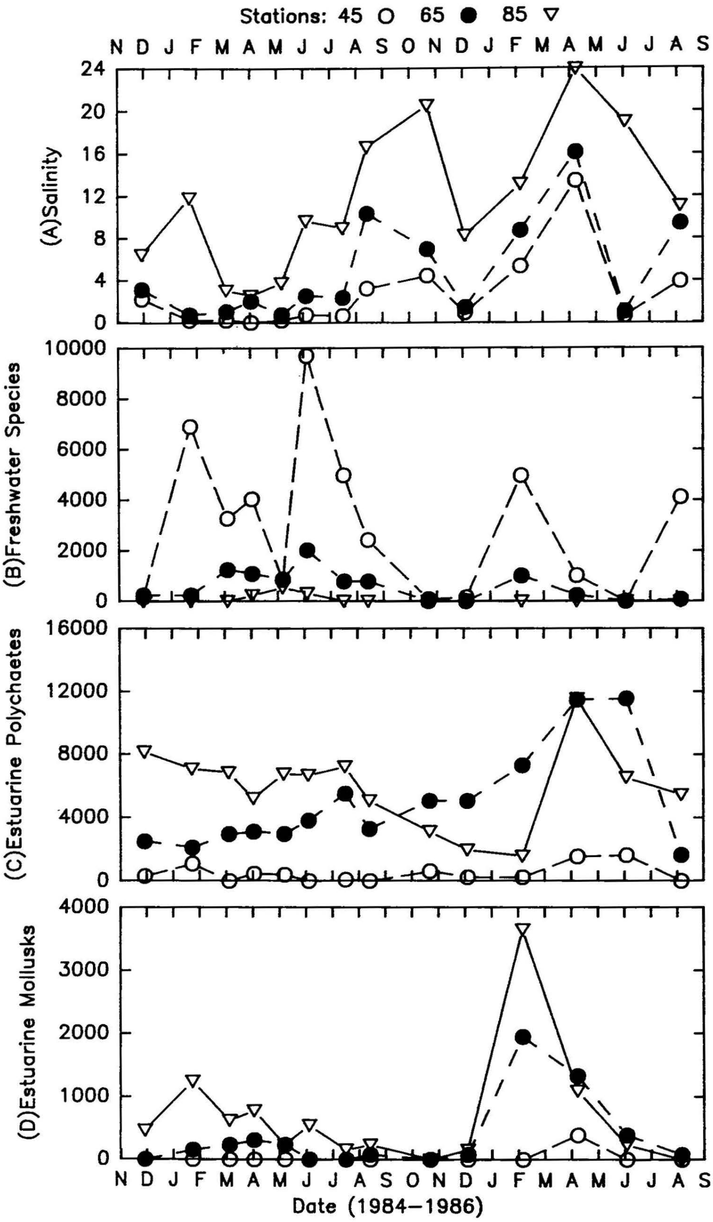

FIG. 13. Spatial and temporal response of species groups to salinity regimes. Salinity (‰) freshwater species (Chironomid larvae and *Hobsonia florida*), estuarine polychaetes (*Mediomastus californiensis, Streblospio benedicti* and *Laeonereis culveri*, and estuarine mollusks (*Mulinia lateralis* and *Macoma mitchelli*) abundance (n/m^2). Salinity gradient is from upstream to upper Lavaca Bay at stations 45, 65 and 85 for sampling trips from November, 1984 through August, 1986.

gradient of decreasing grain-size (Table 4). The dominant fauna at stations 45, 65 and 85 were freshwater and estuarine species. The freshwater or low salinity species were Chironomid larvae and *H. florida*. The estuarine species were the polychaetes: *S. benedicti*, *M. californiensis*, and *L. culveri* and the mollusks: *M. lateralis* and *M. mitchelli*. The average density of these species groups was compared with salinity changes to determine changes in areal distributions affected by fluctuation of freshwater inflow (Fig. 13). Freshwater species were abundant following the first sampling trip and remained abundant through August 1985. Because of high inflow, low salinity species were seen at station 85 in May 1985. Following August 1985, low salinity species were evident only in the river at stations 45 and 65 in February 1986 and at Station 45 in August 1986. Estuarine polychaetes and mollusks were most abundant at stations 65 and 85 and increased during Year 2. Estuarine species were present in low numbers or absent from station 45 until April and June, 1986 when the estuarine species briefly extended their range up river.

DISCUSSION

Low rainfall during the period from December, 1983 to September, 1984 caused drought conditions in the Lavaca Basin (Fig. 2). This resulted in an order from the Texas Water Commission on August 29, 1984 directing the Lavaca-Navidad River Authority to release 12 × 10^6 m^3 (10,000 acre-feet) of water from Lake Texana into the Lavaca Bay System (TDWR 1985). From August 31 through September 7, 1984 water was released at a rate of 21 m^3/s. Salinity decreased from 2 ‰ below Palmetto Bend Dam to 0 ‰ and from 15 ‰ near Redfish Bayou to 10 ‰. Lower Lavaca Delta and upper Lavaca Bay salinities decreased by only 1 ‰ immediately after the release (TDWR 1985). High Gulf of Mexico tides associated with tropical disturbances resulted in high tides from September 16 to 25 to push high salinity Gulf waters into the Lavaca-Tres Palacios Estuary raising salinities above those occurring prior to the release. In October 1984, a freshwater inflow event occurred which resulted in the beginning of a wet cycle which persisted throughout Year-1 of this study.

High freshwater inflow during Year-1 of this study resulted in an increase in the spatial distribution of low salinity benthic species and a decrease in estuarine and marine species in upper Lavaca Bay. The extensive distribution of chironomid larvae and *H. florida* in upper Lavaca Bay was indicative of flood conditions and increased spatial coverage of the freshwater zone.

Freshwater inflow decreased during Year-2 which reduced the freshwater influenced zone and increased the higher salinity estuarine zone. The distribution of low salinity species during Year-2 was restricted to the Lavaca River and lake stations and the stations close to Garcitas and Venado creeks. *Streblospio benedicti*, *M. californiensis*, and *L. culveri* all increased in abundance and areal distribution as a result of higher salinity during Year-2. Total increased abundance and biomass during Year-2 is attributed to benthic community response, not only to salinity increases, but also to primary production stimulated by nutrient input into the system the preceding high inflow year. Nitrate, nitrite, and phosphate were higher in the wet year (Jones, *et al.* 1986). Chlorophyll increased in Year-1 and decreased in Year-2.

Other studies have found similar relationships between benthos and inflow. Mackin (1971) reported an increase in total benthic abundance in Menefee Lake with increased salinity. Species diversity declined from the high salinity lower bay to the low salinity upper bay and Lavaca River (Gilmore, *et al.* 1976). Lavaca Bay freshwater-influenced benthic populations increased as salinity decreased and organic carbon increased during a 30 month freshwater inflow study from January 1973 through June 1975 (Gilmore 1974; Gilmore, *et al.* 1975, 1976).

The distribution of estuarine benthos in Texas estuaries has been partitioned into zones based on species salinity preferences along a salinity gradient from freshwater inflow to marine input in several studies (Flint, *et al.* 1981; Gilmore 1974; Gilmore, *et al.* 1975, 1976; Harper 1973; Hoese 1960; Mackin 1971; Matthews, *et al.* 1974; Ladd 1951; Parker 1955, 1959; Whitledge, *et al.* 1989). The present study indicates that these arbitrary zones are not constant but fluctuate up and down the bay system depending on freshwater inflow and marine input from the Gulf of Mexico (Fig. 13).

The mollusks, *Rangia cuneata* and *Littoridina sphinctostoma*, which have been reported as abundant in the freshwater influenced zone by Gilmore, *et al.* (1976) and White, Calnan, Morton, Kimble, Littleton, McGowen and Nance (1985) were rarely found in this study. Low density, or the absence of these species, may be attributed to patchy distribution or a slow response of these species to environmental fluctuation. For example, the year prior to this study was a drought year which may have limited the range of *R. cuneata* and *L. sphinctostoma* to areas upstream which were not sampled. In other Lavaca Bay studies chironomid larvae and/or *H. florida* were reported to be associated with low salinities (Blanton, Culpepper, Bischoff, Smith and Blanton 1971; Gilmore, *et al.* 1976; Mackin 1971). During Mackin's study the most upriver site in the upper Menefee Lake remained influenced by freshwater for the entire study while the lower Menefee Lake, Redfish Lake and lower river stations changed from a low salinity zone to a moderate salinity zone. The fauna changed from a freshwater community to a marine community at about the same rate the salinity increased (Mackin 1971).

Vertical sectioning of the core samples at 0-3, 3-10, and 10-20 cm enabled us to characterize benthic species by their preference for surface or sub-surface sediments. The numerically dominant surface dwelling species collected during this study were *S. benedicti*, *H. florida*, chironomid larvae, and *M. lateralis*. *Mediomastus californiensis*, *L. culveri* and *M. mitchelli* were occasionally abundant at the surface but had a preference for the deeper sediment. The mean percent abundance and biomass by depth indicated that most of the macrofauna abundance were found in the surface sediments and the greatest biomass occurred sub-surface at the 10-20 cm depth. Flint and Kalke (1986) found similar vertical distribution patterns for benthic macrofauna in Corpus Christi Bay. High densities of small organisms with a short turnover rate in the surface sediments in the long term make more biomass available to higher trophic levels, *i.e.*, finfish and shellfish. The deeper dwelling animals are less abundant larger animals which are not easily incorporated into the food chain because of their deep burrowing activities.

Although the biomass and abundance of the dominant mollusk species did not significantly correlate with inflow, they did increase with salinity (Table 5). Density and biomass of all mollusks increased significantly with increasing salinity (Table 6). Other environmental factors are also important. Total biomass increased with increasing temperature. Whereas, molluskan biomass increased with salinity, other macrofauna increased with increasing sand content and chlorophyll concentration in the overlying water (Table 6). Chlorophyll concentration increased with increasing inflow and decreased with increasing salinity. Considering the large increase of filter feeding mollusks with increasing salinity, the decrease in chlorophyll concentration could be due to increased consumption by the benthic community.

The variability in freshwater inflow results in predictable changes in the estuary. Flood conditions lower salinity and introduce nutrient rich waters into the estuary. This happens rapidly within 14 days. Within one month, the spatial extent of the low salinity fauna is increased. The freshwater fauna may even replace the estuarine fauna. High nutrient and chlorophyll levels correlate with high benthic productivity of predominantly low salinity and estuarine species. This community can deplete the surface water phytoplankton bloom since it is dominated by filter feeders. This can be followed by a transition to drought conditions and low inflow regimes resulting in higher salinities, lower nutrients, and higher densities of estuarine fauna. The results of benthic sampling programs depend on the inflow conditions existing prior and during the study. This indicates long-term studies are necessary to understand the relationship between freshwater inflow and benthic community structure and productivity.

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LITERATURE CITED

BLANTON, W.G., T.J., CULPEPPER, H.W. BISCHOFF, A.L. SMITH and C.J. BLANTON. 1971. A study of the total ecology of a secondary bay (Lavaca Bay). Report to the Aluminum Co. of America. Aluminum Co. of America, Point Comfort, Texas. 306 pp.

BUCKNER, H.D., E.R. CARILLO and H.J. DAVIDSON. 1987. Water resources data, Texas, water year 1987, Colorado River Basin, Lavaca River Basin, Guadalupe River Basin, Nueces River Basin, Rio Grande River Basin, and intervening coastal basins. Report to the U.S. Geological Survey Water Resources Division, TX-87-3. United States Geological Survey, Austin, Texas. 424 pp.

FLINT, R.W. and R.D. KALKE. 1986. Biological enhancement of estuarine benthic community structure. *Marine Ecology — Progress Series*. 31:23-33.

FLINT, R.W., R.D. KALKE, and S.C. RABALAIS. 1981. Quantification of extensive freshwater input to estuarine benthos. Report to the Texas Water Development Board. The University of Texas Marine Science Institute, Port Aransas, Texas. 55 pp.

FOLK, R.L. 1964. *Petrology of Sedimentary Rocks*. Hemphill's, Austin, Texas. 154 pp.

GALTSOFF, P.S. 1931. A survey of oyster bottoms in Texas. Bureau of Fisheries Investigational Report No. 6. Washington, DC. 30 pp.

GILMORE, G. 1974. An ecological study of benthic macro-invertebrates on Lavaca Bay, Texas. Report to the Texas Water Development Board. Texas Parks and Wildlife Department, Austin Texas. 26 pp.

GILMORE, G., G. MATTHEWS and G. CLEMENTS. 1975. An ecological study of the plankton and benthos in Lavaca Bay, Texas. Report to the Texas Water Development Board, September 1973 July 1974. Texas Parks and Wildlife Department, Austin Texas. 58 pp.

GILMORE, G., J. DAILEY, M. GARCIA, N. HANNEBAUM, and J. MEANS. 1976. A study of the effects of fresh water on plankton, benthos, and nekton assemblages of the Lavaca Bay system, Texas. Report to the Texas Water Development Board, January 1973-1975. Texas Parks and Wildlife Department, Austin Texas. 113 pp.

HARPER, D.E., Jr. 1973. The distribution of benthic and nektonic organisms in undredged control areas of San Antonio Bay, Texas. Report to the U.S. Army Engineer District. Texas A&M Research Foundation. College Station, Texas. 157 pp.

HOESE, H.D. 1960. Biotic changes in a bay associated with the end of a drought. *Limnology and Oceanography*. 5:326-336.

HOLLAND, J.S., N.J. MACIOLEK, and C.H. OPPENHEIMER. 1973. Galveston Bay benthic community structure as an indicator of water quality. *Contributions in Marine Science*. 17:169-188.

——————, ——————, R.D. KALKE and C.H. OPPENHEIMER. 1974. A benthos and plankton study of the Corpus Christi, Copano and Aransas Bay systems II. Report on data collected during the period July, 1973 and April, 1974. Report to the Texas Water Development Board. The University of Texas Marine Science Institute, Port Aransas Texas. 121 pp.

——————, ——————, ——————, L. MULLINS and C.H. OPPENHEIMER. 1975. A benthos and plankton study of the Corpus Christi, Copano and Aransas Bay systems and summary of the three-year project. Report to the Texas Water Development Board. III. Report on data collected 7/74-5/75. The University of Texas Marine Science Institute, Port Aransas, Texas. 174 pp.

JONES, R.S., J.J. CULLEN, R.G. LANE, W. YOON, R.A. ROSSON, R.D. KALKE, S.A. HOLT and C.R. ARNOLD. 1986. Studies of freshwater inflow effects on the Lavaca River Delta and Lavaca Bay, Texas. Report to the Texas Water Development Board. The University of Texas Marine Science Institute, Port Aransas, Texas. 423 pp.

LADD, H.S. 1951. Brackish water and marine assemblages of the Texas coast, with special reference to mollusks. *Publications of the Institute of Marine Science, The University of Texas*. 2:125-164.

MACKIN, J.G. 1971. A study of the effect of oilfield brine effluents on biotic communities in Texas estuaries. Report to the Humble Oil and Refining Co. and Amoco Production Co. Texaco Inc., Texas A&M Research Foundation, College Station, Texas. 73 pp.

MATTHEWS, G.A., C.A. MARCIN and G.L. CLEMENTS. 1974. A plankton and benthos survey of the San Antonio Bay system March 1972-July 1974. Report to the Texas Water Development Board. Texas Parks and Wildlife Department, Austin, Texas. 75 pp.

MOORE, H.F. 1907. Survey of oyster bottoms in Matagorda Bay, Texas. United States Bureau of Fisheries Document No. 610. 86 pp.

MOORE, H.F. and E. DANGLADE. 1915. Condition and extent of the natural oyster beds and barren bottoms of Lavaca Bay, Texas. Report of the U.S. Commissioner of Fisheries for 1914. Hugh H. Smith Commissioner. 45 pp.

MUNRO, G.J. 1961. General ecological survey of the Matagorda area, September 1, 1960 — December 31, 1961. Report for Project No. M-4-R-3, Job D-2, Texas Parks and Wildlife Department, Austin, Texas. 6 pp.

PARKER, R.H. 1955. Changes in the invertebrate fauna, apparently attributable to salinity changes in the bays of central Texas. *Journal of Paleontology*. 29:193-211.

PARKER, R.H. 1959. Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre. *Bulletin of the American Association of Petroleum Geologists*. 43:2100-2166.

SHEPARD, F.P. 1953. Sedimentation rates in Texas estuaries and lagoons. *Bulletin of the American Association of Petroleum Geologists*. 37:1919-1934.

TEXAS DEPARTMENT OF WATER RESOURCES (TDWR). 1980. Lavaca-Tres Palacios Estuary: a study of the influence of freshwater inflows. TDWR, Austin, Texas. LP-106.

TEXAS DEPARTMENT OF WATER RESOURCES (TDWR). 1982. The influence of freshwater inflows upon the major bays and estuaries of the Texas Gulf Coast: Executive Summary. TDWR, Austin, Texas. 53 pp. Appendices I-VI.

TEXAS DEPARTMENT OF WATER RESOURCES (TDWR). 1985. Investigation of the effects of releases of water from Lake Texana, Lavaca River Basin, on August 31 September 7, 1984. TDWR, Austin, Texas. 25 pp. Appendices A-D.

U.S. GEOLOGICAL SURVEY (USGS). 1980. Water resources data for Texas Colorado River Basin, Lavaca River Basin, Guadalupe River Basin, Nueces River Basin, Rio Grande Basin, and intervening coastal basins. USGS Water Data Report TX-80-3. USGS, Austin, Texas. 298 pp.

WHITE, W.A., T.R. CALNAN, R.A. MORTON, R.S. KIMBLE, T.G. LITTLETON, J.H. McGOWEN and H.S. NANCE. 1985. Submerged lands of Texas, Port Lavaca area: sediments, geochemistry, benthic macroinvertebrates and associated wetlands. Report by Bureau of Economic Geology, Austin, Texas. 309 pp.

WHITLEDGE, T.E., A. AMOS, R. BENNER, E. BUSKEY, K. DUNTON, S. HOLT, R. KALKE, P. MONTAGNA, P. PARKER, D. STOCKWELL and W.B. YOON. 1989. Final Report Nitrogen Process Studies (NIPS): The effect of freshwater inflow on benthos communities and dynamics. Report to the Texas Water Development Board. The University of Texas Marine Science Institute, Port Aransas, Texas. 370 pp.