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EFFECTS OF SALTWATER INTRUSION FROM THE INNER HARBOR NAVIGATION CANAL ON THE BENTHOS OF LAKE PONTCHARTRAIN, LOUISIANA

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ABSTRACT A study of the benthos of southern Lake Pontchartrain, Louisiana, was conducted from July 1976 to July 1978. Seven offshore stations and three stations in the New Orleans Marina complex were sampled seasonally. Offshore stations formed a transect from the Lake Pontchartrain Causeway to the Inner Harbor Navigation Canal (I.H.N.C.). A west to east gradient of increasing salinity and salinity stratification was evident.

Faunal differences among stations were assessed using indices of diversity, biological dominance, pollution, and station homogeneity. The fauna of the marina stations had a low species diversity and was dominated by annelids, indicative of a stressed environment. The fauna of stations near the I.H.N.C. were similar to the marina stations. Moving westward from the I.H.N.C., species diversity increased and the fauna became dominated by mollusks. Stressful conditions associated with the intrusion of water from the I.H.N.C. into Lake Pontchartrain appeared to be responsible for the faunal differences observed.

INTRODUCTION

The Lake Pontchartrain estuary has undergone numerous environmental changes associated with the activities of man. Among these changes are modifications in salinity regimes and increased levels of urban pollution.

The mean salinity of the southern sector of the estuary has increased since the construction of the Mississippi River Gulf Outlet (Figure 1). Furthermore, this saltier water has been shown to have high concentrations of heavy metals, pesticides and other pollutants (Perret et al. 1971, Costa et al. 1977). The Bonnet Carré Spillway (Figure 1), which connects the Mississippi River to Lake Pontchartrain, was opened in 1973, 1975, and 1979. Each time, the salinity of the southern sector of the lake was temporarily reduced to less than 0.5 ppt (Poirrier and Mulino 1975, 1977). Various industrial pollutants were introduced into the lake from the Mississippi River (Perret et al. 1971).

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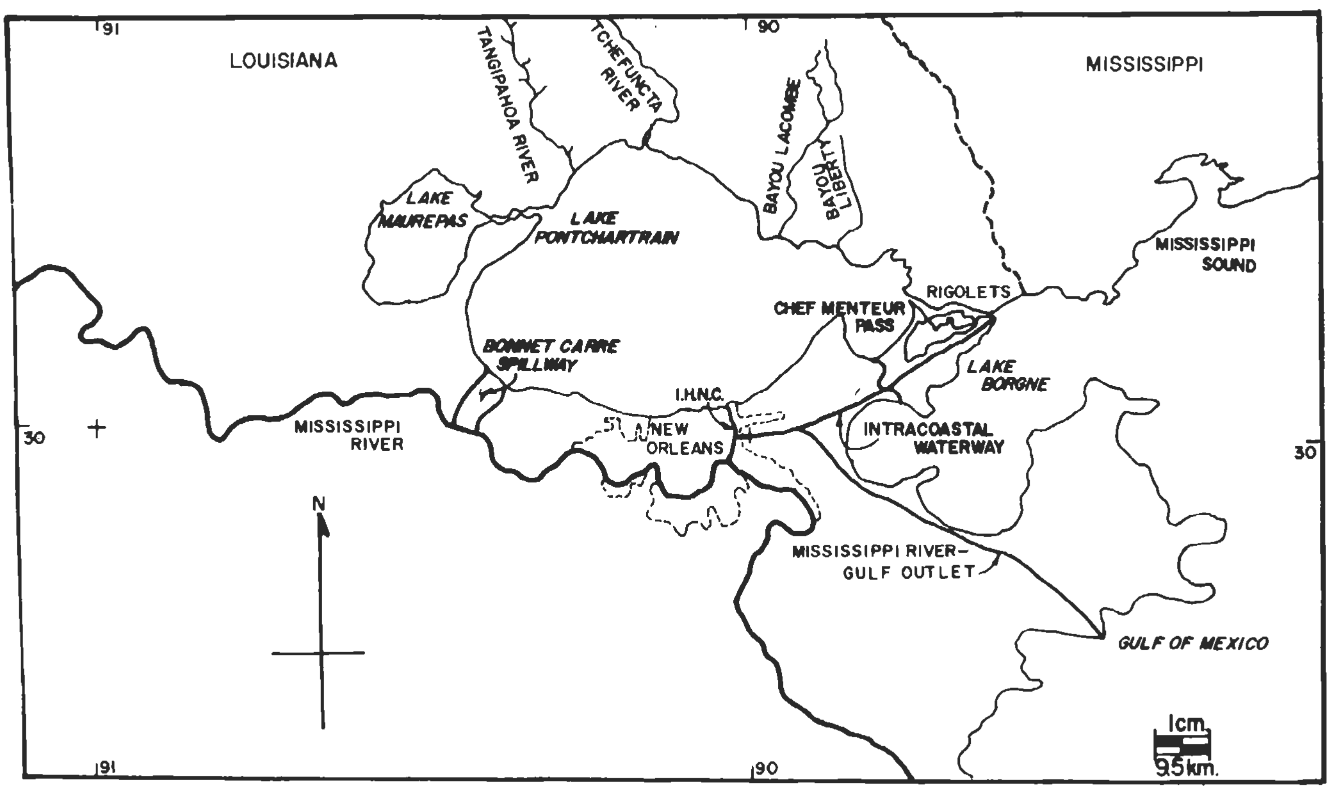

Figure 1. Map of Lake Pontchartrain, Louisiana, and vicinity.

Several studies (Stern and Atwell 1968, Stern and Stern 1969, Poirrier et al. 1975, Poirrier 1979a, Stone 1980) have established that storm water discharges into Lake Pontchartrain from the New Orleans Metropolitan Area result in high levels of total and fecal coliform bacteria, high concentrations of plant nutrients, and low dissolved oxygen (D.O.) values. Sikora and Sikora (1982) found a large area of bottom in southeastern Lake Pontchartrain to be defaunated.

The influence of the intrusion of water from the Inner Harbor Navigation Canal (I.H.N.C.) into Lake Pontchartrain was studied by Poirrier (1979b). He reported a west to east gradient of increasing salinity, salinity stratification, and decreasing bottom D.O. values. The present study was conducted to assess the impact of this non-mixing, higher salinity bottom water on the benthic community of southern Lake Pontchartrain. The marina complex was also sampled to provide information about the benthos of a highly stressed site. The effects of salinity stratification and resulting adverse water quality upon the benthos were evaluated by comparing sites along the salinity gradient to the marina sites.

MATERIALS AND METHODS

The areas sampled are shown in Figure 2. Stations were sampled seasonally from July 1976 to July 1978 using a $0.05 m^2$ Eckman dredge. The samples were immediately preserved in 10% formalin. The goal of the sampling strategy was to obtain representative seasonal samples from each offshore station. However, a complete seasonal study was not possible because all stations were not accessible at all seasons due to rough weather. Samples taken at offshore stations A through G in July 1976, December 1976, and April 1977 were passed through a 1.0 mm sieve. Marina stations H through J were established in October 1977 and used for comparison with the offshore stations. In preliminary samples in the marina, however, few individuals were retained on the 1.0 mm sieve; therefore, a 0.125 mm sieve was used in subsequent sampling. Three replicate samples were taken from each station. No significant differences were found among the three samples using a completely randomized analysis of variance. Since there were no statistical differences among the three replicates, they were treated as one set of faunal data per station. During October 1977, April 1978, and July 1978, an extra sample was taken at each station (except station G), fixed in 10% formalin and analyzed for sediment size composition (Folk 1968).

Salinity, temperature and dissolved oxygen (D.O.) were measured 0.3 m from the surface and 0.3 m from the bottom at each station. Salinity and temperature were measured using a Beckman RS5–3 salinometer and D.O. was measured

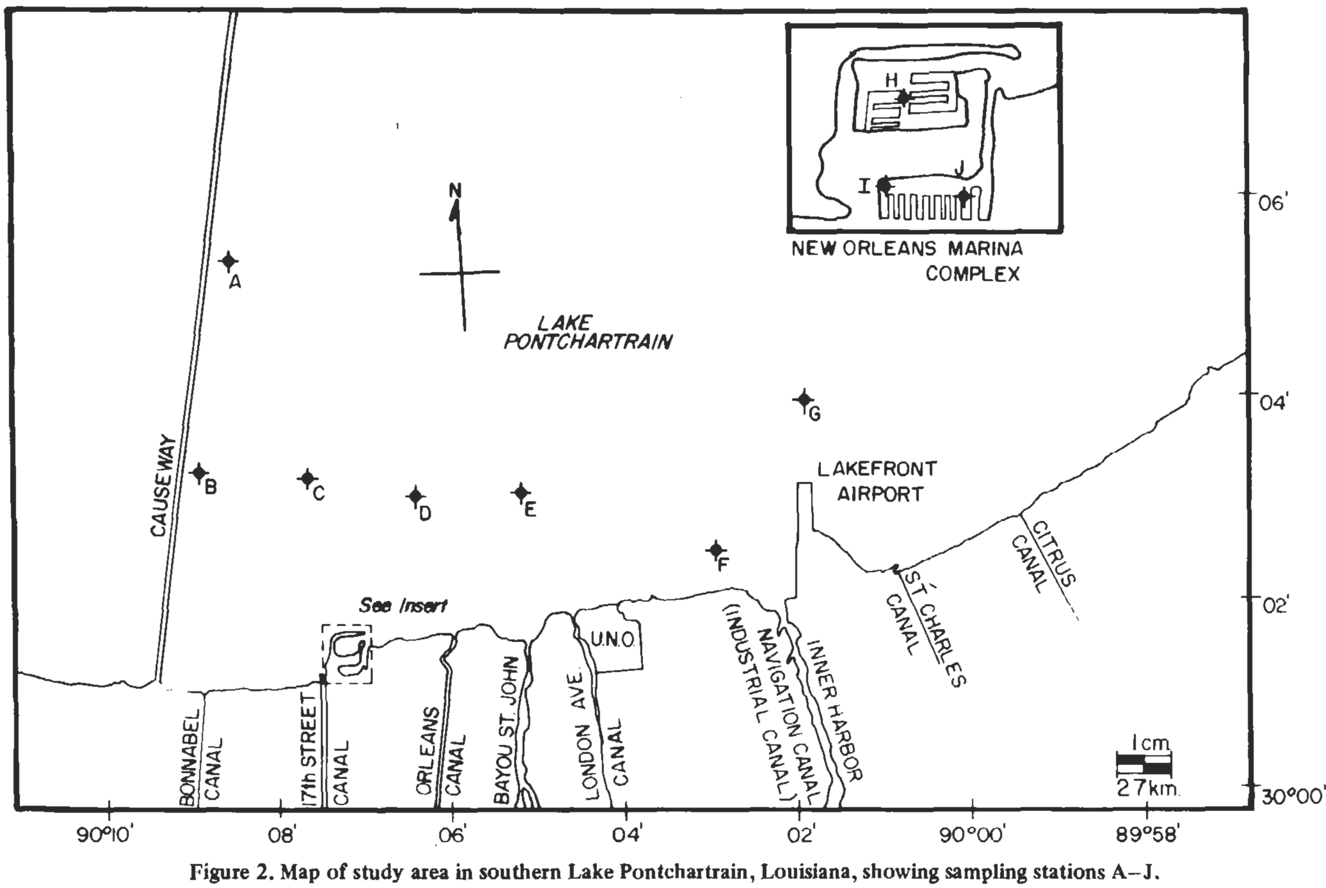

Figure 2. Map of study area in southern Lake Pontchartrain, Louisiana, showing sampling stations A–J.

with a YSI model 51A D.O. meter. Station depths were measured using a weighted chain marked in 1-m sections.

The faunal data was subjected to an analysis of species diversity, biological dominance, the degree of pollution based upon species abundance, and station homogeneity. Species diversity (H') was calculated using the Shannon-Weaver index (Shannon and Weaver 1962):

$$H' = -\Sigma(p_i \log_e p_i)$$

where p_i is the proportion of the ith species in each sample. An index of biological dominance (B.I.) was calculated by assigning the most numerous species in each sample five points, the next most numerous species four points, etc. These points were summed for all the samples and divided by the number of samples taken at each station (Fager 1957). Wass' pollution index (Wass 1967) assessed the degree of pollution at each station by measuring the ratio of stress-tolerant to stress-intolerant individuals at each station. Stress-tolerant species were considered to be those present in the marina complex, an area of poor water quality (Costa et al. 1977). Species abundances were also plotted against distance from the I.H.N.C. (Boesch 1971b). Sanders' index of faunal homogeneity (Sanders 1960), which is a measure of the percent of fauna common to a pair of stations, was calculated for all pairs of stations and arranged in a trellis diagram (McFayden 1963). Details of the sampling sites and methods employed are provided by Junot (1979).

RESULTS

Sediment composition at stations A through E was about 97% silt and clay. However, at station F the sediment was composed of 50% silt and clay, and 50% sand. Station F is near the I.H.N.C. in an area of swift currents. The marina stations H, I, and J had a high percentage (from 75 to 95%) of silt and clay, followed by sand.

Surface water salinity at offshore stations ranged from 2.5 ppt (Station C, April 1978) to 7.0 ppt (Station G, December 1976), with an overall mean of 4.2 ppt. Bottom water salinities at offshore stations varied from 2.5 ppt (Station B, April 1978) to 14.0 ppt (Stations E and F, October 1976), with an overall mean of 6.1 ppt. The average salinity in the marina complex was 3.5 ppt. The mean salinity profile (Figure 3) over the 2-year sampling period showed differences as large as 4.7 ppt between surface and bottom waters near the I.H.N.C. and negligible at the westernmost station. Thus, stratification of lighter, fresher water over the denser, saltier water introduced by the I.H.N.C. was most extreme at the eastern stations and decreased moving westward. Bottom water temperatures ranged from 10.7°C in December 1976 to 30.0°C in July 1976, with an overall mean of 22.3°C. Surface temperatures ranged from 11.2°C in December 1976 to 31.1°C in July 1976, with an overall mean of 23.1°C.

Surface D.O. values ranged from 4.3 ppm (Station J, July 1978) to 12.5 ppm (Station G, December 1976), with an overall mean of 9.3 ppm. Bottom D.O. values ranged from 0.5 ppm (Station C, July 1976) to 11.8 ppm (Station G, December 1976), with an overall mean of 6.9 ppm. The mean dissolved oxygen profile showed differences as large as 3.8 ppm between surface and bottom waters near the I.H.N.C. and as small as 0.8 ppm at unstratified stations (Table 1). Station depths ranged from 4.5 m (Stations A and B) to 10.5 m (Station F). Stations near the I.H.N.C. were deeper than stations near the Lake Pontchartrain Causeway (Figure 2).

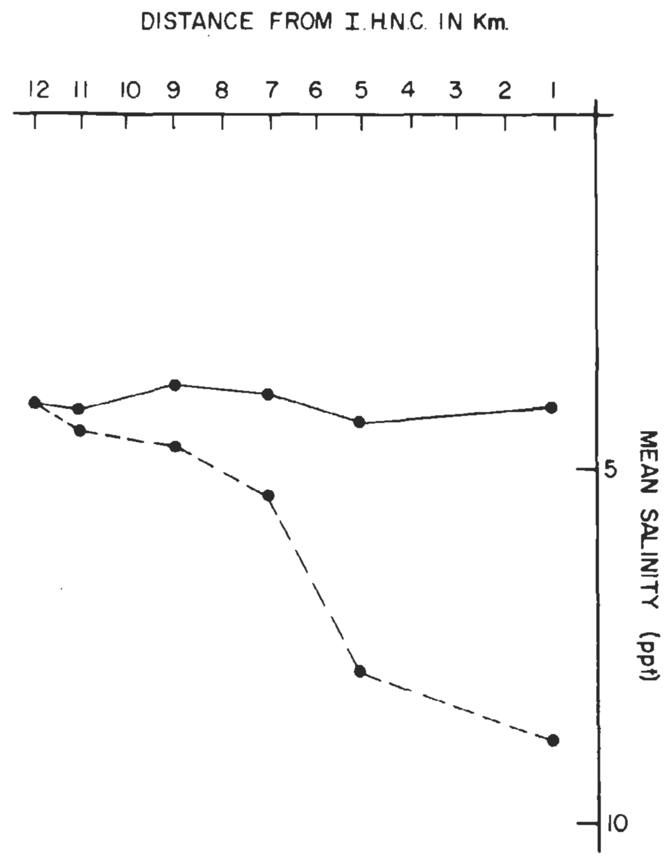

Figure 3. A graph of mean surface and bottom salinity values (ppt) versus distance from the I.H.N.C. (km) from stations A through F in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978. Surface salinity is represented by a solid line whereas bottom salinity is represented by a dashed line.

A total of 29,643 individuals representing 33 taxa were collected (Table 2). Shannon-Weaver diversity indices were calculated for each sample (Table 3). Mean diversity was higher at unstratified stations A and B than at stratified stations E and F. In general, the pattern was one of decreasing diversity in an easterly direction. However, station C had a lower overall mean diversity than did station D; also, station G showed a low mean diversity. The overall mean diversity of stations A through F (1.115) was significantly higher ($\alpha = 0.05$) than the overall mean diversity of marina stations H through J (0.624).

TABLE 1.

D.O. (ppm) of surface and bottom waters at stations A–J in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

Stations	July 76	Oct 76	Dec 76	Apr 77	Oct 77	Apr 78	July 78
A	* 8.0	––	––	––	9.6	8.5	7.9
	5.4	––	––	––	9.2	7.5	8.6
B	8.8	9.4	11.5	9.3	9.6	9.0	8.5
	6.4	6.2	11.3	8.9	9.6	1.0	8.5
C	8.2	9.2	11.3	9.7	––	8.5	8.3
	0.5	6.5	11.2	8.8	––	8.4	7.5
D	8.8	10.2	11.5	9.8	––	8.4	7.9
	4.4	3.2	11.5	7.7	––	7.8	7.5
E	9.6	11.0	11.8	10.2	9.4	––	8.1
	2.2	4.1	11.5	6.6	5.5	6.6	6.6
F	10.2	11.2	12.0	10.6	––	8.6	8.0
	6.1	7.8	11.2	6.3	––	5.4	6.4
G	9.6	10.8	12.5	10.7	––	––	––
	7.2	6.6	11.8	7.7	––	––	––
H	––	––	––	––	8.2	8.1	8.7
	––	––	––	––	8.0	6.3	5.8
I	––	––	––	––	9.3	8.3	5.0
	––	––	––	––	5.0	5.3	3.2
J	––	––	––	––	––	8.2	4.3
	––	––	––	––	––	6.0	2.2

*surface/bottom

TABLE 2.

Species list of benthic invertebrates from stations A–J in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

- Phylum Nematoda
- Phylum Annelida
  - Class Polychaeta
    - *Parandalia americana*
    - *Nereis occidentalis*
    - *Neanthes succinea*
    - *Laeonereis culveri*
    - *Pygospio elegans*
    - *Polydora websteri*
    - *Streblospio benedicti*
    - *Boccardia hamata*
    - *Ficopomatus miamiensis*
    - *Hobsonia florida*
    - Family Capitellidae
  - Class Oligochaeta
- Phylum Mollusca
  - Class Gastropoda
    - *Texadina sphinctostoma*
    - *Probythinella louisianae*
  - Class Pelecypoda
    - *Ischadium recurvum*
    - *Crassostrea virginica*
    - *Congeria leucophaeta*
    - *Mulinia pontchartrainensis*
    - *Rangia cuneata*
    - *Macoma mitchelli*
- Phylum Arthropoda
  - Class Crustacea
    - Subclass Cirripedia
      - *Balanus improvisus*
    - Subclass Copepoda
      - Order Calanoida
    - Subclass Malacostraca
      - Order Isopoda
        - *Edotea montosa*
      - Order Amphipoda
        - *Gitanopsis* sp.
        - *Melita* sp.
        - *Hyalella azteca*
      - Order Mysidacea
        - *Mysidopsis almyra*
      - Order Decapoda
        - *Rhithropanopeus harrisii*
  - Class Insecta
    - Order Diptera
      - Family Chironomidae
        - *Cryptochironomus* sp.
        - *Coelotanypus* sp.
        - *Dicrotendipes* sp.
        - Tribe Pentaneurini

TABLE 3.

Diversity, mean diversity for the first sampling period (X_1), mean diversity for the second sampling period (X_2), and overall mean diversity ($\bar{X}$) for stations A–J in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

Stations	July 76	Oct 76	Dec 76	Apr 77	X_1	Oct 77	Apr 78	July 78	X_2	$\bar{X}$
A	1.210	––	––	––	1.210	1.073	1.603	1.192	1.289	1.269
B	0.926	1.381	1.003	1.006	1.097	1.471	1.507	1.159	1.379	1.217
C	0.421	1.101	1.108	0.880	0.887	––	1.387	1.591	1.489	1.081
D	1.241	0.620	0.872	1.044	0.944	––	1.476	1.479	1.475	1.122
E	0.239	0.562	1.006	1.073	0.719	0.937	1.515	1.133	1.195	1.078
F	0.630	––	0.827	1.162	0.873	––	0.909	1.074	0.992	0.920
G	0.486	0.646	0.583	0.696	0.603	––	––	––	––	––
H	––	––	––	––	––	1.012	1.069	0.980	1.020	––
I	––	––	––	––	––	0.716	0.815	0.108	0.546	––
J	––	––	––	––	––	––	0.560	0.049	0.305	––

The abundance of dominate species graphed as function of distance from the I.H.N.C. is shown in Figure 4. Dominate species were considered to be those which had a B.I. greater than or equal to 1. Changes in the species composition of the benthic community are apparent. The mollusks *Texadina sphinctostoma, Rangia cuneata, Mulinia pontchartrainensis, Macoma mitchelli,* and *Probythinella louisianae* were more abundant at stations A and B, and decreased in importance with increasing salinity stratification near the I.H.N.C. The polychaetes *Streblospio benedicti, Hobsonia*

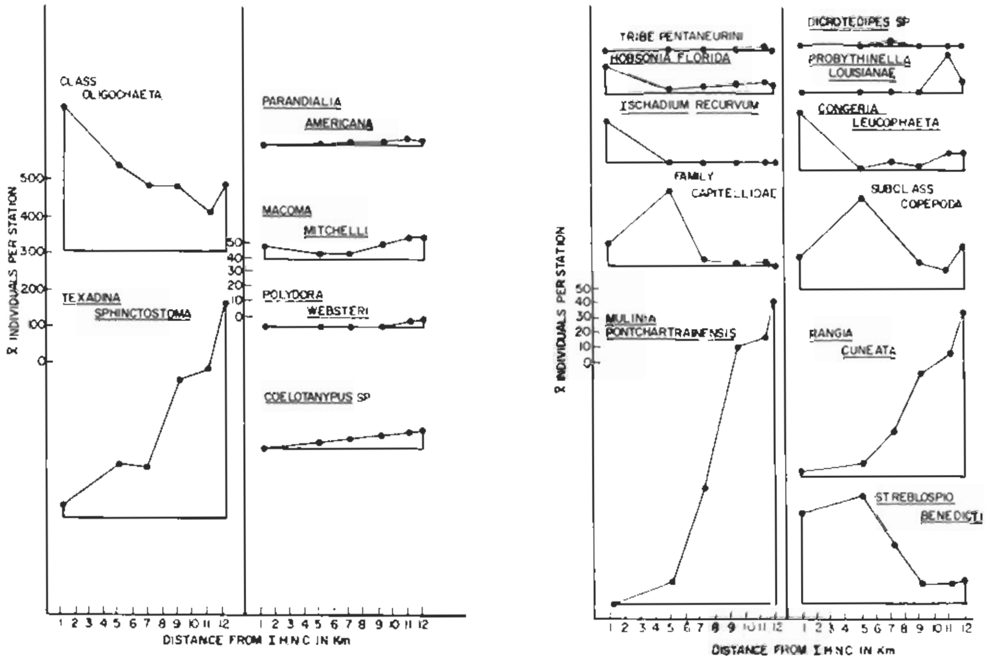

Figure 4. A graph of species abundance (as mean number of individuals per species per station) versus distance from the I.H.N.C. (in km) from stations A through F in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

	A	B	C	D	E	F	G	Marina
A								
B	92							
C	94	92						
D	71	67	72					
E	50	46	53	79				
F	25	21	27	49	57			
G	76	77	75	48	31	4		
Marina	21	26	23	49	62	72	0.40	

Figure 5. Trellis diagram of index of homogeneity. The percentage of species common to station pairs is presented numerically in the lower half, and schematically in the upper half of the diagram. Striped boxes indicate a >50% homogeneity; the stippled boxes indicate 30–50% homogeneity, whereas the clear boxes indicate <30% homogeneity. The diagram includes data from stations A through G and the combined marina stations (H, I, and J) in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

florida, capetellids, and oligochaetes were more abundant at stratified stations E and F and decreased in abundance with decreasing stratification westward.

Sanders' index of faunal homogeneity (Sanders 1960) reflected the degree of faunal change along the salinity gradient by measuring faunal similarity between pairs of stations in terms of species presence and abundance (Figure 5). Pairwise comparisons of unstratified stations A, B, and C showed high indices of similarity and a similar molluscan fauna. Only station F was highly distinct from the unstratified stations. Station F did, however, have affinities with stations D and E. Stations D, E, and F had a fauna either dominated by annelids or with a large annelid component. Stations D and E thus had affinities with the unstratified stations and with station F, whereas the fauna of station G was most like that found at the unstratified stations. The marina stations, which were characterized by poor water quality, showed the greatest degree of affinity with the stratified stations E and F. In terms of Wass' pollution index values (Table 4), stations A, B, and C constituted one group and stations D, E, and F constituted another. Stations D, E, and F showed a greater affinity to the polluted marina stations.

DISCUSSION

Salinity has been described as the major factor responsible for the distribution of estuarine organisms (Gunter 1961, Kinne 1966, Boesch 1977). Dissolved oxygen concentrations have also been found to affect the distribution and occurrence of benthic organisms, especially where stratification of the water column results in anoxic conditions in bottom waters (MacIntyre 1968, Coull 1969). Sanders (1960) found that sediment composition greatly influenced benthic distributions, but Muus (1967) felt that salinity and D.O. values were more important in determining the species composition of the benthos. In the present study, poor bottom water

TABLE 4.

Wass' pollution index for offshore stations A through F in southern Lake Pontchartrain, Louisiana, July 1976 to July 1978.

Station	Wass' Index
A	0.2854
B	0.2181
C	0.3201
D	1.0426
E	2.3707
F	4.7164

quality associated with salinity stratification appears to be a factor responsible for the distribution of benthic species.

Unstratified and marina stations had comparable salinity and substrate types, but their faunas were dissimilar. Unstratified stations had a fauna dominated by mollusks, whereas the marina stations had a fauna dominated by annelids. The stratified stations and the marina stations had different substrate types and different salinity values, yet they had a similar annelid fauna. Other studies have demonstrated that a shift from an estuarine fauna dominated by mollusks to one dominated by annelids occurs with increases in industrial and domestic pollution (Taylor et al. 1970, Crippen and Reish 1969, Pfitzenmeyer 1971, Richardson 1971, Boesch 1971a, 1971b). The change from a predominantly molluscan fauna at the westernmost stations to the predominantly annelid fauna at the easternmost stations indicates that stressful conditions were associated with salinity stratification.

Although a different mesh size (0.5 mm) was used in their sampling, the mean H′ of offshore stations A–G (H′ = 1.042) was similar to the mean H′ of all stations (H′ = 1.086) of Sikora and Sikora (1982). Station A (H′ = 1.269) and station B (H′ = 1.217) had higher H′ values than the midlake station (H′ = 1.031) of the Sikoras. Observed decreases in benthic diversity from west to east cannot be ascribed to a nearshore effect. Sikora and Sikora (1982) found higher diversity values at nearshore northwestern stations than at both their midlake station and their nearshore southern stations. Diversity values showed evidence of seasonal changes associated with salinity stratification and low D.O. concentrations. Summer and fall H′ values were generally lower than spring and winter values (Table 3). Poirrier (1979b) demonstrated that salinity stratification in southern Lake Pontchartrain can extend into the fall, decreases with distance from the I.H.N.C., and is associated with low bottom D.O. concentrations. In the present study, low bottom D.O. concentrations were often reflected in low H′ values. For example, stations C and E in July 1976 had low D.O. values and low H′ values; during July 1978, D.O. concentrations and H′ values were both higher. Dissolved oxygen concentrations on the bottom and in the sediments were probably lower than those measured since measurements were made 0.3 m from the bottom. Several studies (Gaufin and Tarzwell 1952, 1956, Wilhm and Dorris 1966, 1968, Cairns and Dickson 1971) have used decreases in diversity indices to indicate decreasing water quality.

In studies conducted by Remane and Schlieper (1971), the oligohaline zone (0.5 to 5.0 ppt) in an estuary contained the lowest number of species. Moving into more saline waters, the number of species increased. Since stations E and F had bottom salinities ranging from 5.7 to 14.0 ppt, they might be expected to support a more diverse fauna than other offshore stations which had lower salinities. This was not the case; the diversity indices of stations E and F were generally lower than those of other offshore stations (Table 3). However, expectations of greater benthic diversity at higher salinity are based upon concepts developed by benthic ecologists working on homiohaline or gradient estuaries in northwestern Europe (see Boesch 1977). Most of the benthic species found in Lake Pontchartrain are estuarine endemics which are characteristic of gradient estuaries. Thus, fluctuating salinities (as in poikilohaline or fluctuating estuaries) in the area influenced by stratification could, in itself, have an adverse impact upon these endemic forms.

Gulf coast populations of the clam *Rangia cuneata* are only maintained within a salinity range of 0–15 ppt (Hopkins et al. 1973). *Rangia* and the snail *Probythinella louisianae* were absent from the far eastern area of Lake Pontchartrain in 1967 to 1973 (Tarver and Dugas 1973, Dugas et al. 1974) but present in 1978–1980 (Sikora and Sikora 1982). Their distribution may have been restricted by high salinity conditions prior to the 1973, 1975, and 1979 Bonnet Carré Spillway openings. The barnacle *Balanus subalbidus,* which dominates the epifauna of Lake Pontchartrain, was found to be limited to gradient salinity conditions below 16 ppt by Poirrier and Partridge (1979). Recent studies (Downs 1983) demonstrate that it has physiological adaptations which restrict it to low salinity waters. Little is known about the ecological and physiological factors which limit the distribution of estuarine endemics to low-salinity waters. As a group they do not appear to be able to readily adapt to rapid salinity changes in the high-salinity zone.

The differences in benthic fauna between stratified and unstratified stations and the similarity between the fauna of stratified and marina stations indicate that salinity stratification resulting from flow of more saline water from the I.H.N.C. has an adverse impact on the benthos of Lake Pontchartrain. This impact is probably caused by low bottom D.O. concentrations, changes from the normal salinity regime, and possibly toxic substances which accumulate in the non-mixing bottom waters.

Mean dissolved oxygen values presented in this study and Poirrier (1979b) were not low enough to account for the changes observed. However, D.O. concentrations in the sediments were probably lower and values were probably lower at other times and exerted a limiting effect. The low H′ values associated with low D.O. values in July and October 1976 indicate that low D.O. values do affect the benthos.

Saltwater intrusion may be having a direct impact on the benthos. Since the opening of the Mississippi River Gulf Outlet, the salinity regime has shifted from stable oligohaline conditions to rapidly changing salinities with occasional values above 15 ppt (Poirrier 1979b). This changed salinity regime may have depressed populations of Lake Pontchartrain endemics which are not adapted to this altered salinity regime. The expected colonization by euryhaline opportunists has not occurred but instead the high-salinity, stratified areas are dominated by tolerant forms found in stressed environments. Recruitment of euryhaline opportunists is probably limited because the source of saltwater is not adjacent estuaries but navigation canals with poor water quality and unnatural depth, bottom and salinity conditions.

Lake Pontchartrain receives a variety of pollutants from diverse sources (Costa et al. 1977). Toxic substances originating from the I.H.N.C., outfall canals, and the Mississippi River may accumulate in the non-mixing bottom layer and cause changes in community structure. Under anoxic conditions toxic compounds may be released from the sediments and H_2S produced.

Low D.O. concentrations, salinity stress, and toxic substances probably all affect the benthos. Additional information is needed on the concentration of toxic substances, D.O. and salinity in bottom waters and sediments, and the biology of the benthos before definitive effects can be determined. However, the overall effect is caused by saltwater intrusion and salinity stratification. The impact on the benthos depends on the intensity, extent and duration of the stratification. This is dependent upon prevailing weather conditions. Stratification persists through summer and fall and is not disrupted by summer storms (Poirrier 1979b). The extent that D.O. is lowered depends on organic loading of the bottom layer. During years when plant nutrients and organic material are higher because of runoff and spillway openings, the D.O. concentration of the bottom layer will be lower. The extent of stratification depends upon the salinity of I.H.N.C. water and the movement of water from the I.H.N.C. into the lake. During periods of low flow, high salinity and temperatures, the I.H.N.C. probably becomes stratified and a bottom layer characterized by poor water quality develops. When this water enters the lake, an adverse impact on the benthos can be expected.

ACKNOWLEDGMENTS

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