# Excerpt from *LOOP 14-YR Monitoring Program Synthesis Report* (Barry A. Vittor & Associates, Inc.)

Benthic samples were collected quarterly (winter, spring, summer, and fall seasons) by personnel of LDWF and processed in BVA's laboratories. Hydrographic and sediment data were also collected quarterly by LDWF and provided to BVA on an annual basis.

The raw data for this 14-year synthesis report were assembled and transferred to a digital spreadsheet format by BVA personnel. Selected data were graphically and statistically analyzed by both season and year. To assess differences between control and monitoring stations at the four sites, data for each season were combined over the 14 years. The seasonal summary data for total number of taxa and total density were first tested for normality (Shapiro-Wilk W; SAS Institute, 1994), and if normally distributed for homogeneity of variances (Bartlett's test; SAS Institute, 1994). Due to a consistent lack of normally distributed data with common data transformations, differences between all control/monitoring stations in total taxa and total densities for a given season were analyzed using non-parametric techniques (Wilcoxon/Kruskal-Wallis comparisons; SAS Institute, 1994). Correlations between variables on a yearly basis were calculated using non-parametric measures of association (Spearman Rho; SAS Institute, 1994).

## LOCATION OF MONITORING SITES

Two inland locations were selected to monitor impacts due to pipeline construction and operations associated with the Clovelly salt dome oil storage facility (salt dome excavation and oil transfer). Stations 461, 463, and 464 are located at the Clovelly salt dome and are the most inland sites with water depths of 2-3 m (Fig. 1, Table 1). Station 461 is a control station in Little Lake, while stations 463 and 464 are associated with the Clovelly facility and freshwater intake canal (Table 1). Stations 407 and 462 are located along the pipeline at Lake Jesse in water depths of 1 m (Fig. 1, Table 1). Station 407 is a control station located in Lake Jesse and station 462 is a monitoring station for the pipeline.

The brine diffuser is located approximately 6.4 km offshore at 10-11 m depth. Four stations were associated with the brine diffuser. Originally, monitoring stations were established to provide for adequate coverage in the direction of the prevailing westerly currents, and in areas predicted to experience elevated salinities based on brine dispersion models for the areas. Stations 473, 474, and 475 are located on a concentric ring 150 m from the diffuser (Fig. 2, Table 2). Station 435 is a control station located 3.2 km NE of the brine diffuser.



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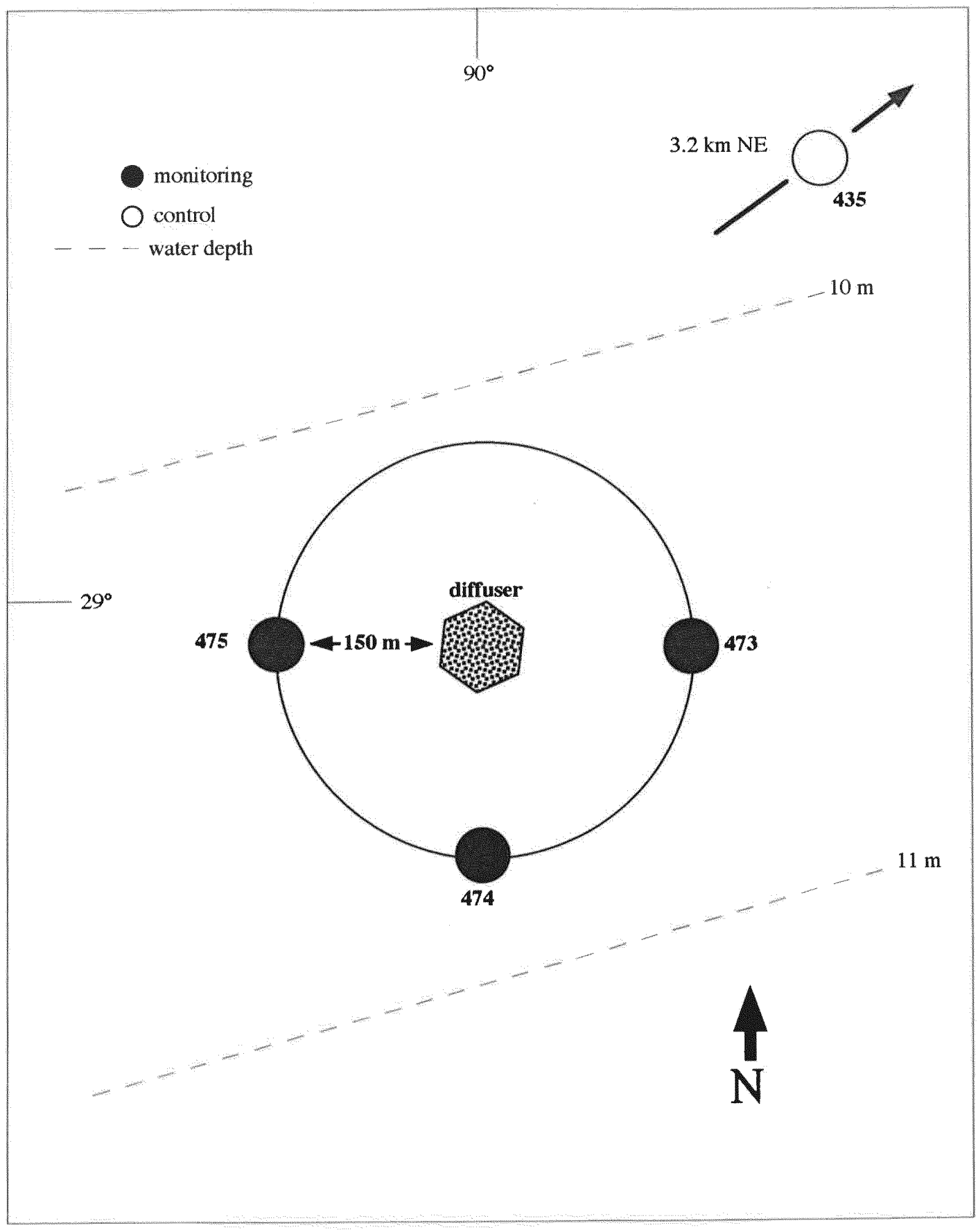


Figure 2. A schematic map of the LOOP brine diffuser control and monitoring stations.



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Table 2. Coordinates and site descriptions for the LOOP brine diffuser control and monitoring stations.

BRINE DISPOSAL AREA

| Station Number | Coordinates Latitude | Longitude | Loran W | Loran X | Location Description |
|---|---|---|---|---|---|
| 435 | 29°07'22" | 90°05'00" | 11722.1 | 28438.1 | Control, MS #35 46 m W of Hunt Platform 104-4-G124-5 at 10 m depth |
| 473 | 29°06'01' | 90°06'50" | 11713.75 | 28413.56 | 150 m E of diffuser at 10 m depth |
| 474 | 29°05'51" | 90°06'50" | 11713.56 | 28412.51 | 150 m S of diffuser at 10 m depth |
| 475 | 29°06'01" | 90°07'06" | 11712.61 | 28411.89 | 150 m W of diffuser at 9.5 m depth |

between stations, there were qualitative differences in abundance during a given season (Fig. 22). Both taxa exhibited variable year-to-year recruitment at each station.

## RESULTS III. BRINE DIFFUSER

### SEASONAL SUMMARY OF HYDROGRAPHY

A seasonal summary of hydrographic characteristics for the brine diffuser control station 435 and monitoring stations 473, 474, and 475 is given in Fig. 23. There was considerable spatial variation in the percentage of sand in the sediments at the three stations. The percentage of sand in the sediment varied from 10% at control station 435 in the winter to 23% at diffuser monitoring station 473 in the spring. The average percent sand was 12.0%, 17.4%, 19.9%, and 12.3% for stations 435, 473, 474, and 475, respectively. Diffuser stations 473 and 474 generally had a higher percentage of sand in the sediments than control station 435 and diffuser station 475 (Fig. 23). There were no spatial or temporal differences in interstitial salinity (Fig. 23). Interstitial salinity averaged 32 ppt for the four stations and ranged from 29 ppt in the spring at control station 435 to 35 ppt at diffuser station 473 during the fall (Fig. 23). There were no differences between stations in bottom dissolved oxygen for a given season. Bottom dissolved oxygen exhibited considerable temporal variability. DO levels observed during the winter and fall sampling periods were twice those measured during the spring and summer (Fig. 23). DO concentrations averaged 6.3, 2.9, 2.6, and 6.2 mg/l for the winter, spring, summer, and fall seasons, respectively. All stations had spring and summer DO levels approaching hypoxia.

### SEASONAL SUMMARY OF MACROINFAUNAL ASSEMBLAGE

A seasonal summary of the general characteristics of the macroinfauna assemblage for the brine diffuser control station 435 and monitoring stations 473, 474, and 475 is given in Fig. 24. There were no significant differences between average number of taxa collected and mean total density at the three stations for a given season (Table 6). The mean number of taxa collected was lowest during the summer and averaged 55.6, 55.7, 32.6, and 45.7 for the winter, spring, summer, and fall seasons, respectively (Fig. 24). Densities were highest during the spring months and lowest during the summer months. Densities averaged 4258.0, 6052.7, 2377.8, and 2859.9 individuals/$m^2$ for the winter, spring, summer, and fall seasons, respectively. There was no between station variation in diversity (H') and diversity averaged 2.3, 2.2, 1.7, and 2.1 for the winter, spring, summer, and fall seasons, respectively (Fig. 24).



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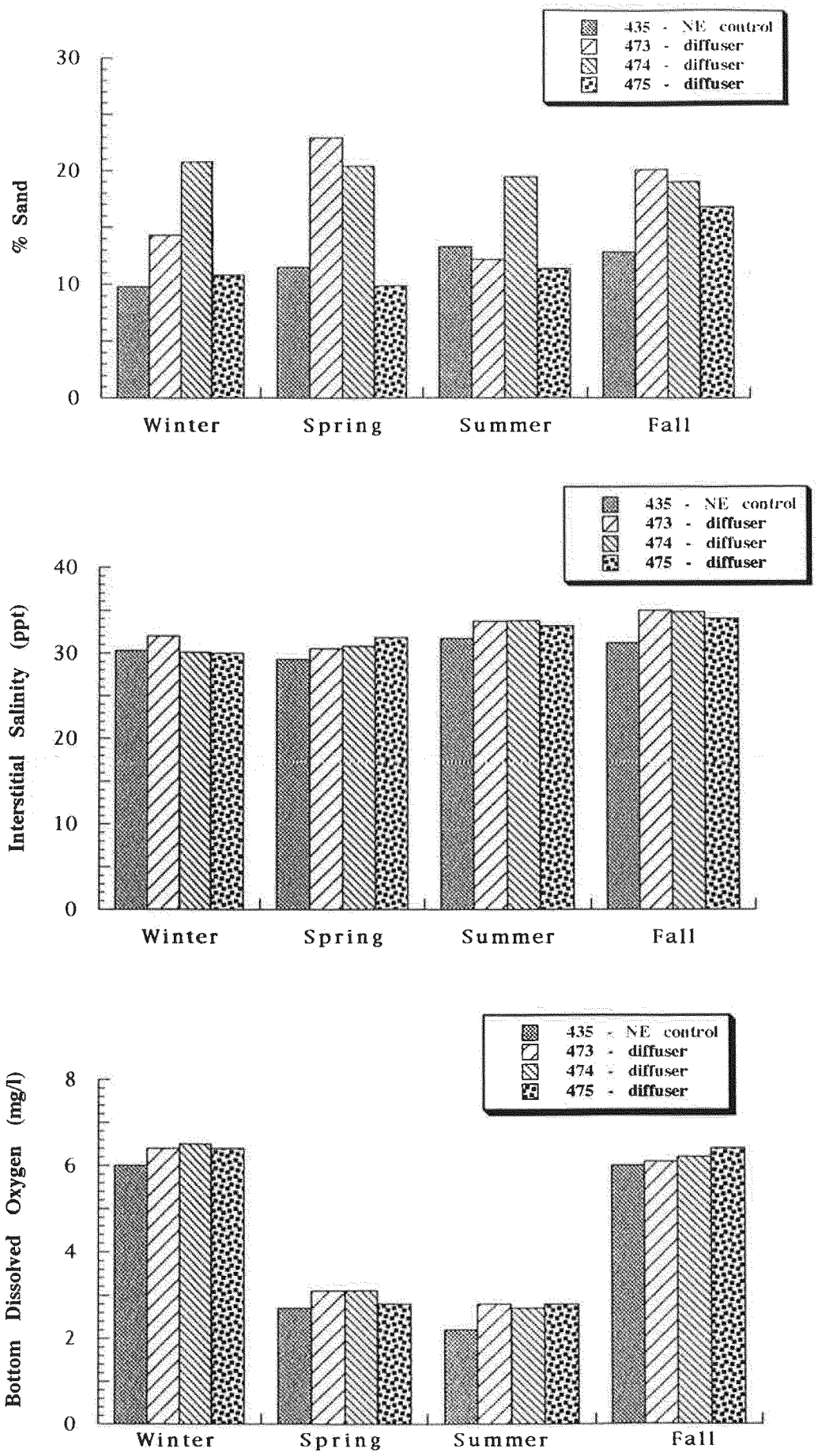
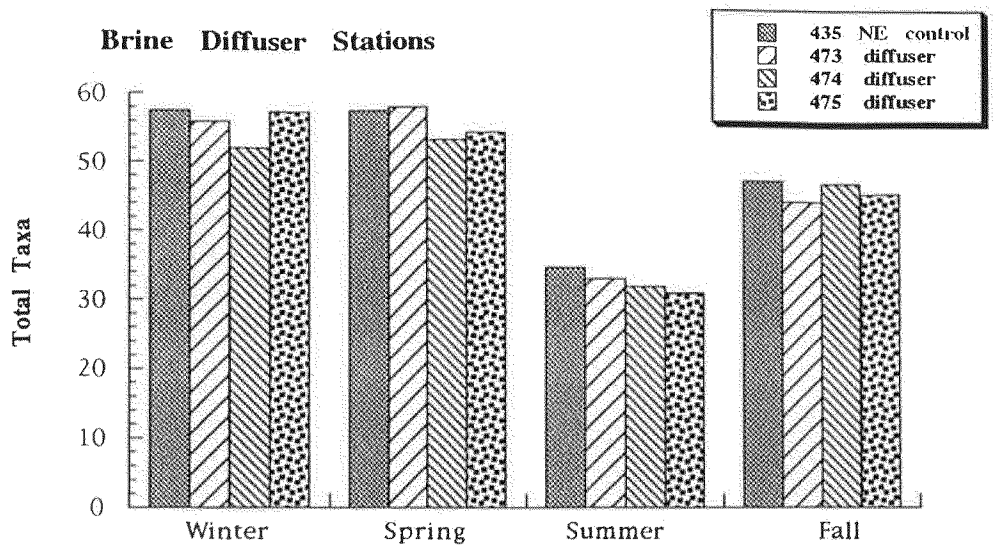
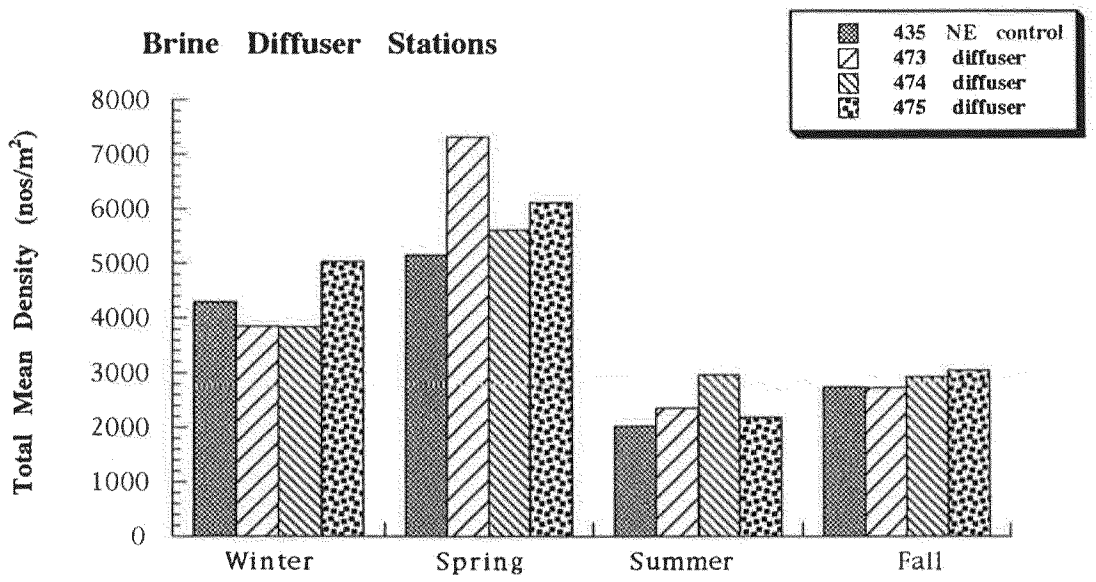



Figure 23. Seasonal summaries of hydrographic parameters over the 14-year LOOP monitoring program for the brine diffuser control and monitoring stations.



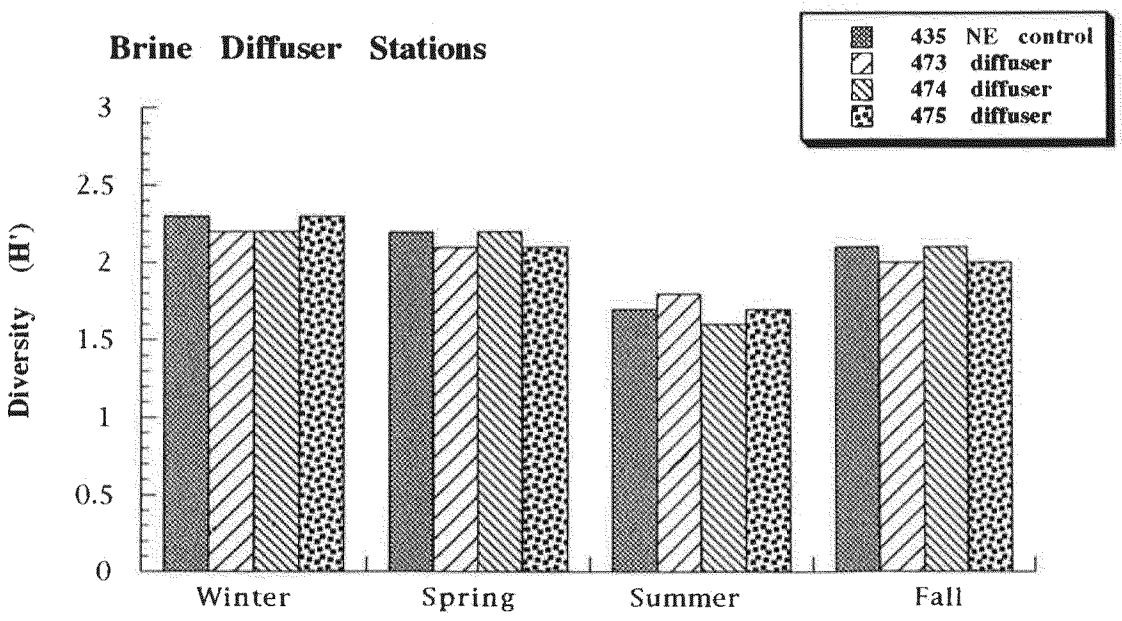




Figure 24. Seasonal summaries of characteristics of the macroinfaunal assemblage over the 14-year LOOP monitoring program for the brine diffuser control and monitoring stations.

Table 6. Results of various statistical analyses for the LOOP brine diffuser control and monitoring stations. The results of non-parametric Kruskal-Wallis comparisons of total number of taxa or mean density between stations for a given season are presented in Part A. The results of non-parametetric analyses for correlations between stations in major taxonomic groups is given in Part B. The results of non-parametetric analyses for correlations between stations in major taxa/species is given in Part C.

(A)

| Season | Mean Total Taxa Chi Square | Mean Total Taxa Prob > Chi Sq | Mean Density Chi Square | Mean Density Prob > Chi Sq |
|---|---|---|---|---|
| Winter | 1.550 | 0.671 | 1.978 | 0.577 |
| Spring | 1.059 | 0.787 | 0.182 | 0.981 |
| Summer | 0.357 | 0.949 | 0.473 | 0.925 |
| Fall | 1.376 | 0.711 | 1.754 | 0.625 |

(B)

| Station | Variable | by | Station | Variable | Spearman Rho | Prob > Rho |
|---|---|---|---|---|---|---|
| 435 | Mollusca | | 435 | Annelida | -0.9021 | 0.0000 |
| 435 | Arthropoda | | 435 | Annelida | -0.2415 | 0.0757 |
| 435 | Arthropoda | | 435 | Mollusca | 0.0491 | 0.7216 |
| 473 | Mollusca | | 473 | Annelida | -0.7073 | 0.0000 |
| 473 | Arthropoda | | 473 | Annelida | -0.2768 | 0.0408 |
| 473 | Arthropoda | | 473 | Mollusca | -0.1177 | 0.3920 |
| 474 | Mollusca | | 474 | Annelida | -0.7413 | 0.0000 |
| 474 | Arthropoda | | 474 | Annelida | -0.2621 | 0.0532 |
| 474 | Arthropoda | | 474 | Mollusca | -0.1486 | 0.2789 |
| 475 | Mollusca | | 475 | Annelida | -0.7809 | 0.0000 |
| 475 | Arthropoda | | 475 | Annelida | -0.1955 | 0.1526 |
| 475 | Arthropoda | | 475 | Mollusca | -0.1071 | 0.4365 |

(C)

| Station | Variable | by | Station | Variable | Spearman Rho | Prob > Rho |
|---|---|---|---|---|---|---|
| 473 | *Paraprionospio* | | 435 | *Paraprionospio* | 0.7196 | 0.0000 |
| 473 | *Mediomastus* | | 435 | *Mediomastus* | 0.8236 | 0.0000 |
| 473 | *Magelona* | | 435 | *Magelona* | 0.4835 | 0.0002 |
| 473 | Rhynchocoela | | 435 | Rhynchocoela | 0.7856 | 0.0000 |

## YEARLY SUMMARY OF HYDROGRAPHY

Yearly variation in hydrography for the brine diffuser control station 435 and monitoring stations 473, 474, and 475 is given in Fig. 25. There was considerable temporal variation in the percentage of sand in the sediments at all stations and ranged from near zero to 98%. The highest values for percent sand in the sediments were measured during the fall of 1985 which was less than one month after hurricane Juan moved through the monitoring area. There was little correlation between stations in the seasonal peaks in percentage of sand in the sediments (Fig. 25).

Interstitial salinities exhibited similar seasonal patterns between stations and generally varied between 20 ppt and 45 ppt (Fig. 25). In general, the brine diffuser monitoring stations had salinities which were similar to the control station. Low salinity events (< 20 ppt) occurred during 1983, 1984, 1987, and 1990 (Fig. 25).

Bottom dissolved oxygen (DO) levels showed considerable temporal variation at all stations and ranged from 0 to 10 mg/l (Fig. 25). All stations exhibited the same general pattern and magnitude of DO variation. Hypoxia and anoxia were observed at all stations (Fig. 25). The frequency and duration of hypoxia/anoxia varied considerably over the 14-year monitoring program. There were no measured hypoxic/anoxic events from the fall of 1982 to summer of 1986. From 1990 to 1993 hypoxic/anoxic events were measured during both the spring and summer seasons at all stations (Fig. 25).

## YEARLY SUMMARY OF MACROINFAUNA ASSEMBLAGE

Yearly variation in general characteristics of the macroinfaunal assemblage for the brine diffuser control station 435 and monitoring stations 473, 474, and 475 is given in Fig. 26. These stations exhibited the same general temporal patterns in total number of taxa, mean density, and mean diversity. Total taxa showed considerable seasonal and yearly variation and ranged from < 5 to 100. The total number of taxa was generally highest in the winter and spring months and lowest during the summer months. Mean densities varied three orders of magnitude between season and from year-to-year and ranged from < 100 to > 22,000 individuals/$m^2$ indicating differential recruitment success of the macroinfaunal assemblage (Fig. 18). Densities were generally highest during the spring months and lowest during the summer. The brine diffuser stations exhibited extremely high densities during 1982, 1985, and 1988. Taxa diversity ranged from 0.5 to > 3, and was highest in the winter and spring months and lowest during the summer. The lowest values for number of taxa, density, and taxa diversity generally occurred during periods of low DO, particularly during and following hypoxic and anoxic events (see Figs. 25 and 26).



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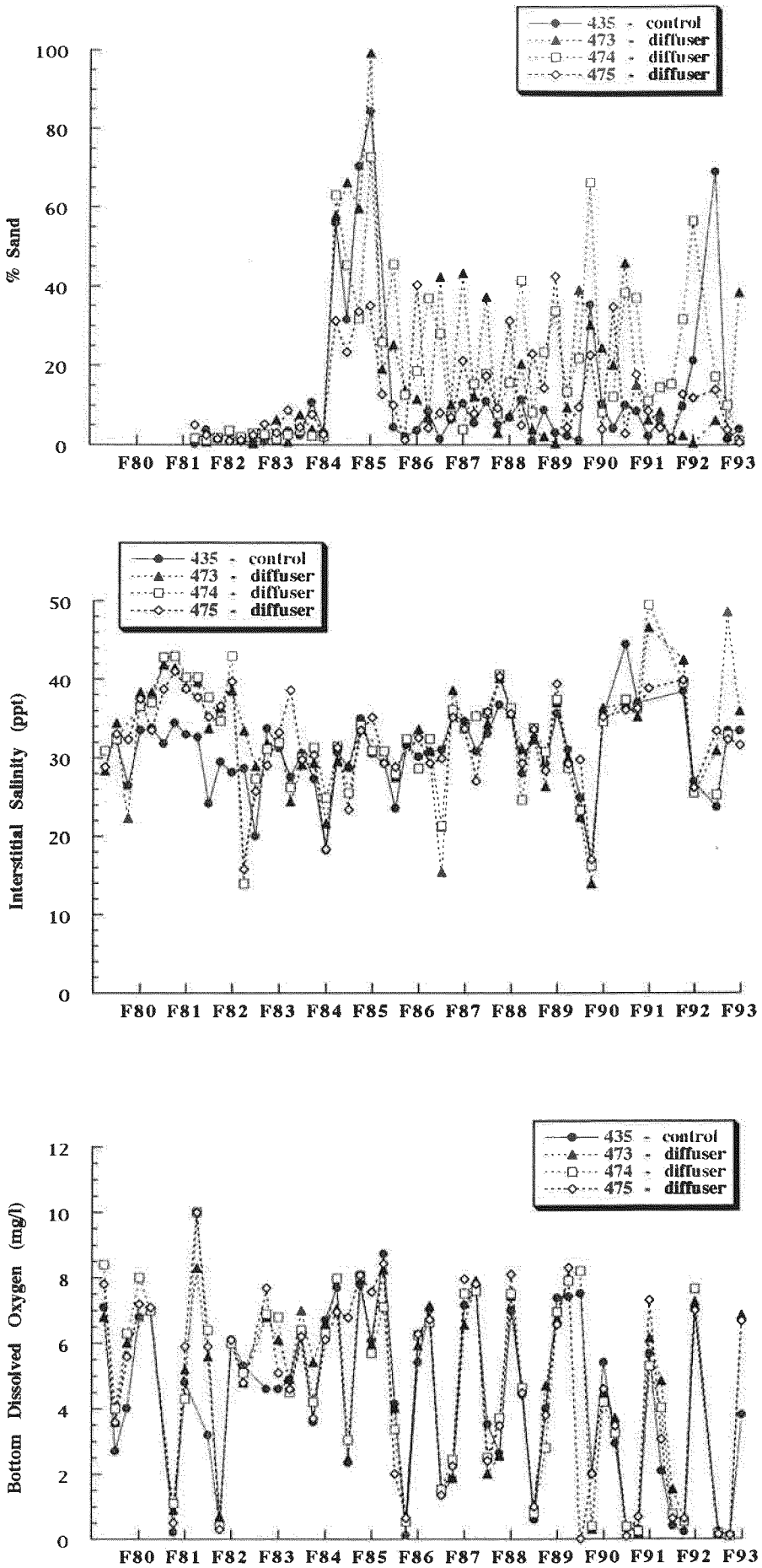


Figure 25. Yearly summaries of hydrographic parameters over the 14-year LOOP monitoring program for the brine diffuser control and monitoring stations.

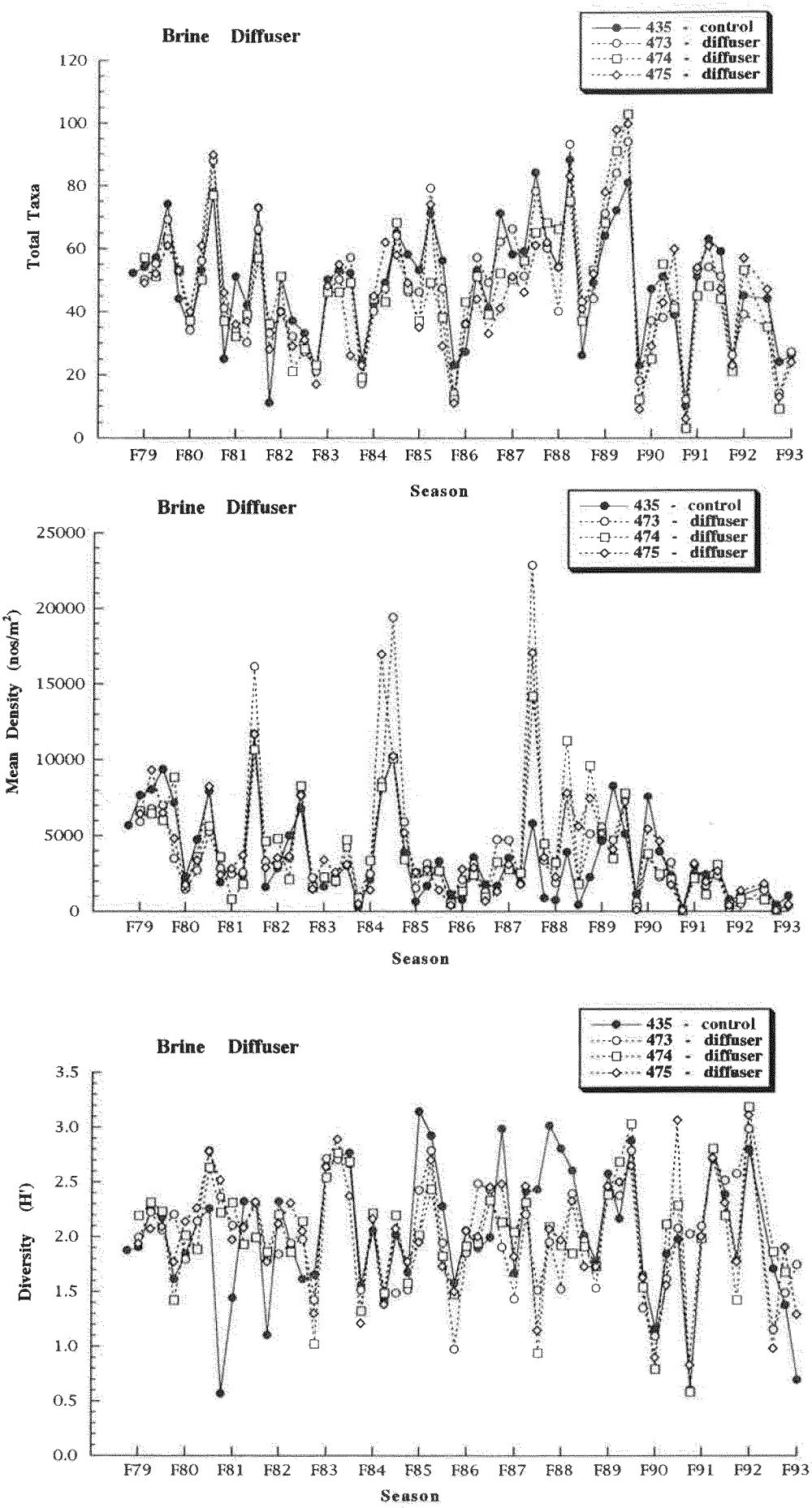


Figure 26. Yearly summaries of characteristics of the macroinfaunal assemblage over the 14-year LOOP monitoring program for the brine diffuser control and monitoring stations.

Yearly variation in abundance of the dominant taxonomic groups for the brine diffuser control station 435 and monitoring stations 473, 474, and 475 is given in Figs. 27 and 28. Polychaetes and bivalve molluscs made up > 90% of the total macroinfaunal assemblage during any given season. There were considerable seasonal differences in the percentage of the assemblage represented by these groups. In general, polychaetes dominated the assemblage at all stations. There were episodic increases in the percent abundance of bivalve molluscs resulting in shifts in dominance of the taxonomic groups during certain years (Fig. 27 and 28). There was a significant inverse correlation between the abundance of annelids and molluscs for all stations (Table 6). The increases in bivalve abundance usually occurred during the spring months and before hypoxic/anoxic events (Figs. 25, 27, and 28). Arthropods were much less abundant at these offshore stations when compared to the inland monitoring stations.

Yearly variation in abundance of dominant taxa for the brine diffuser control station 435 and monitoring station 473 is given in Figs. 29, 30, 31, and 32. The taxa/species chosen for each plot were dominant members of the macroinfaunal assemblage at these sites over the 14-year sampling effort. Taxa/species plotted were the polychaetes *Paraprionospio*, *Magelona*, *Mediomastus*, and *Sigambra*, the bivalve mollusc, *Mulinia* and the arthropods, *Corophium* and *Pinnixa* and the Rhynchocoela. There was considerable temporal variation in densities of the dominant taxa/species at these stations (Figs. 29-32). The taxa/species exhibited season-to-season and year-to-year variation in recruitment at both stations. Additionally, there was differential recruitment success for a given taxa on a yearly basis; densities often varied an order of magnitude on an annual basis. The bivalve, *Mulinia* was commonly present in very low abundance, but experienced episodic density increases and dominated the macroinfaunal assemblage during certain seasons (Figs. 29 and 31). There was no apparent correlation between density increases and season for the taxa/species, although the abundance of the bivalve, *Mulinia* was inversely related to the abundance of the polychaete, *Paraprionospio*.

Comparisons of densities of the polychaetes, *Paraprionospio*, *Magelona*, and *Mediomastus* and the Rhynchocoela for brine diffuser control station 435 and monitoring station 473 are given in Figs. 33 and 34. There was a significant positive correlation in the densities of these taxa between stations 435 and 473 (Table 6). While the patterns of taxa abundance were similar between stations, there were qualitative differences in abundance during a given season (Figs. 33 and 34). For these taxa, densities varied an order of magnitude between seasons. *Mediomastus*, and to some extent *Paraprionospio*, demonstrated consistent peaks in abundance during each year of the monitoring program. It is interesting to note that the densities for these four taxa exhibited less variation and consistently lower



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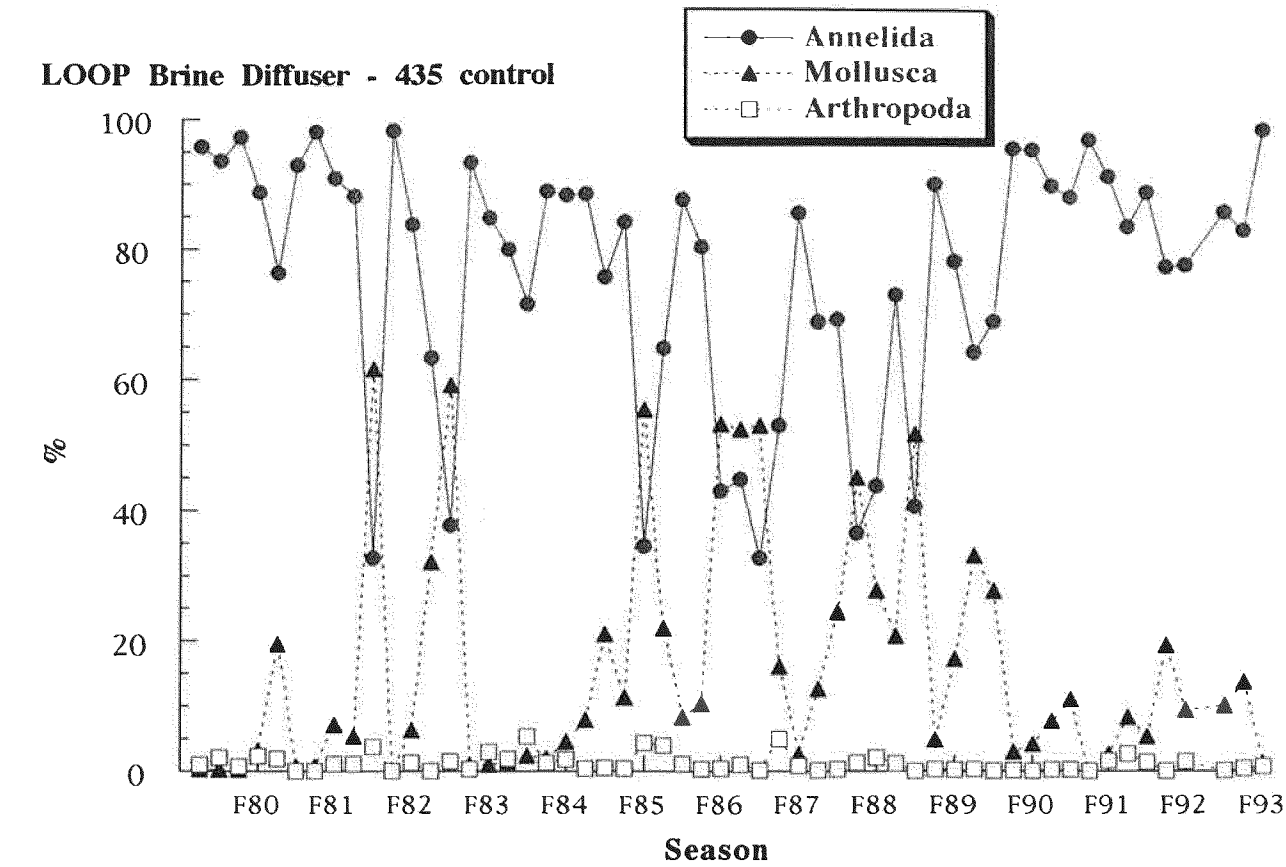


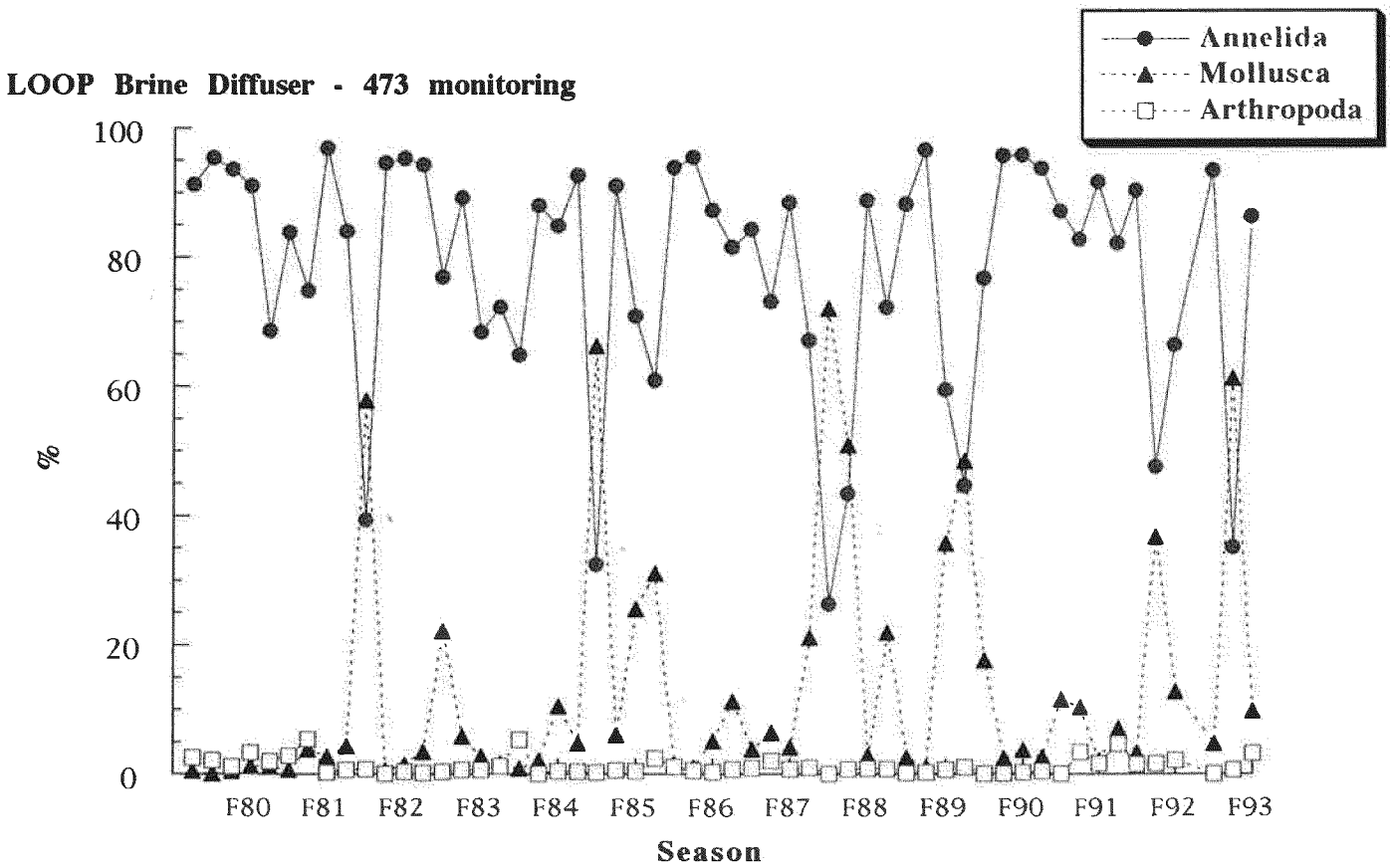


Figure 27. Yearly summaries for the percentage of the total macroinfauna assemblage represented by the major taxonomic groups, Annelida, Mollusca, and Arthropoda over the 14-year LOOP monitoring program for the brine diffuser control station 435 and monitoring station 473.



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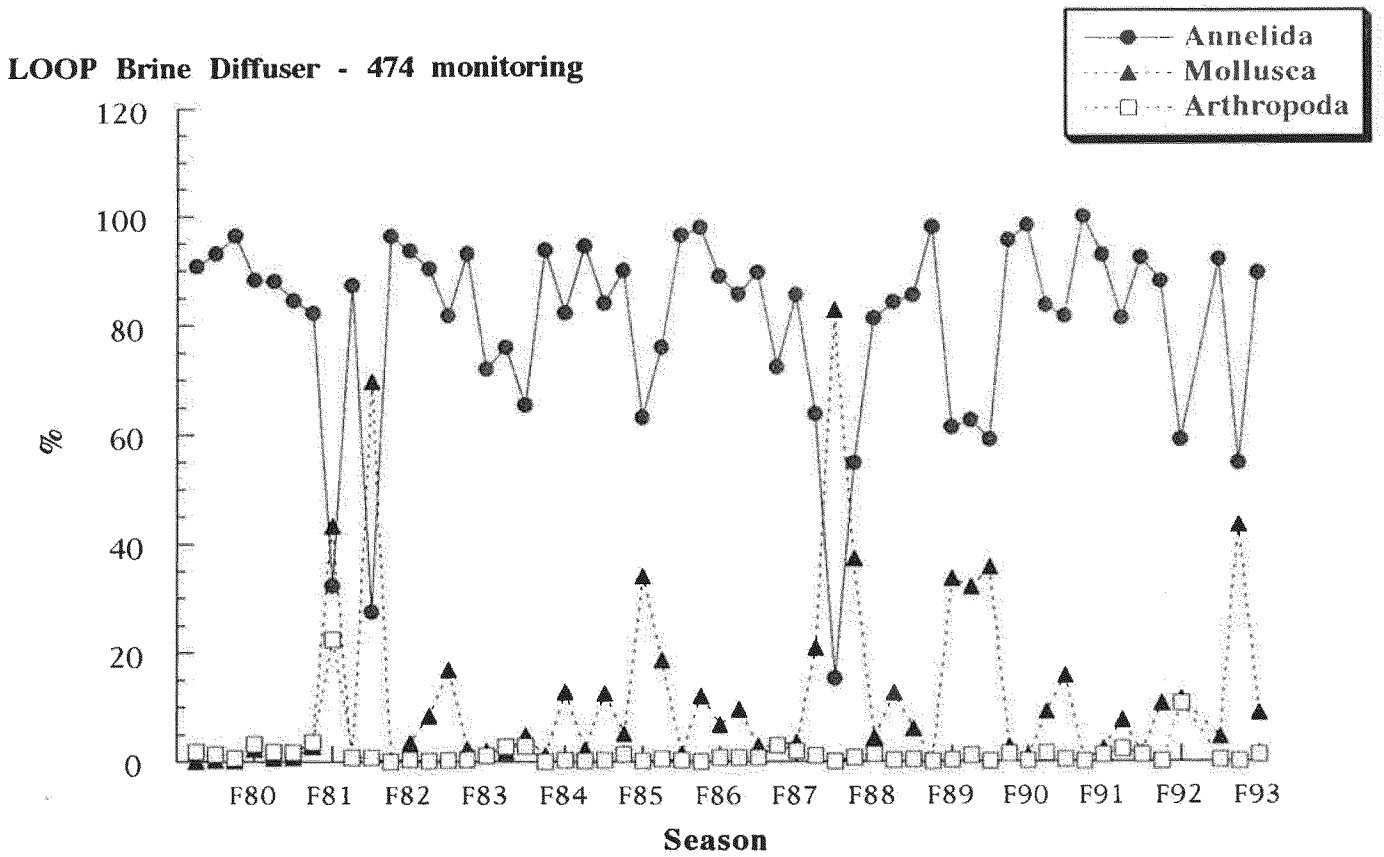


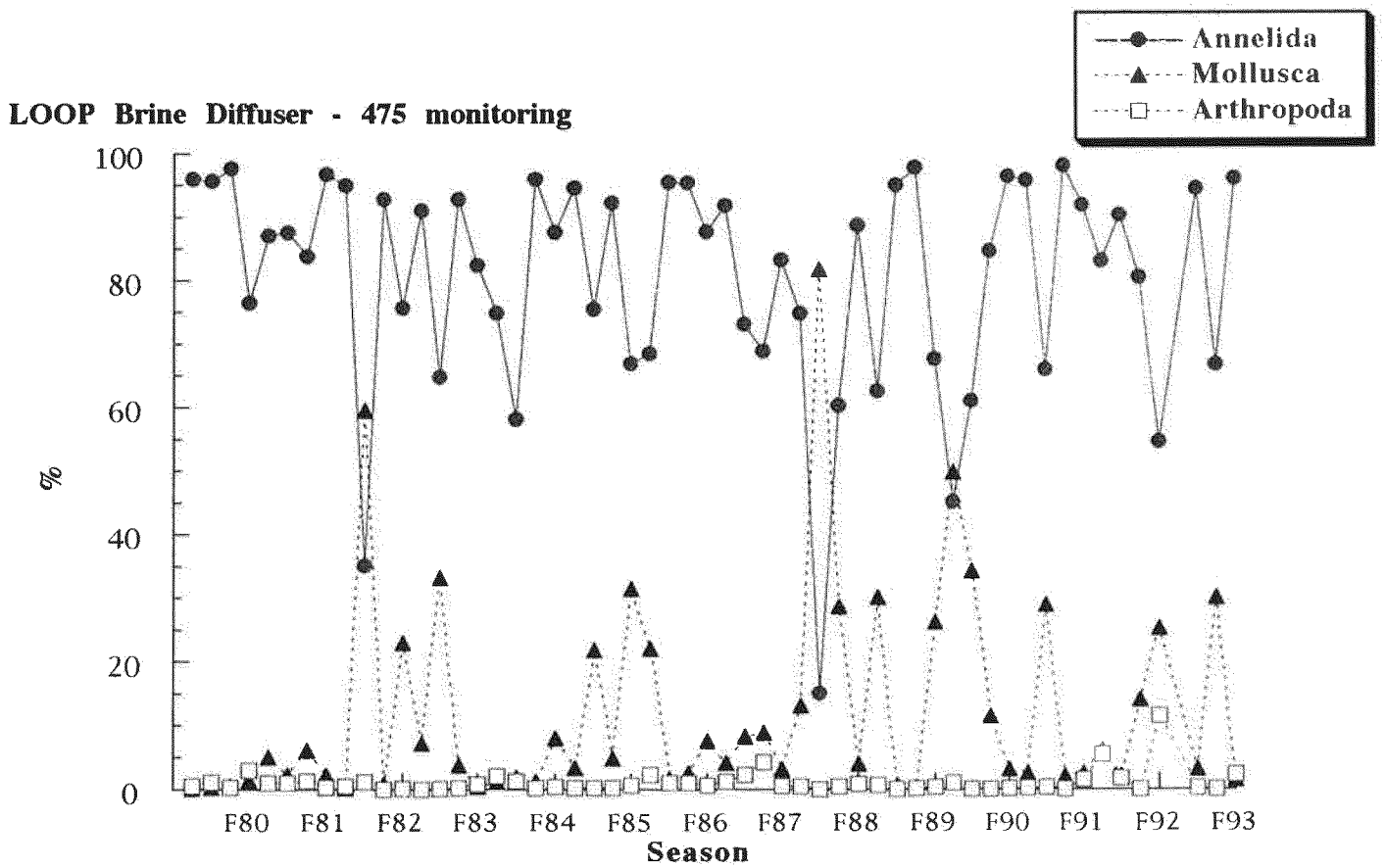


Figure 28. Yearly summaries for the percentage of the total macroinfauna assemblage represented by the major taxonomic groups, Annelida, Mollusca, and Arthropoda over the 14-year LOOP monitoring program for the brine diffuser monitoring stations 474 and 475.



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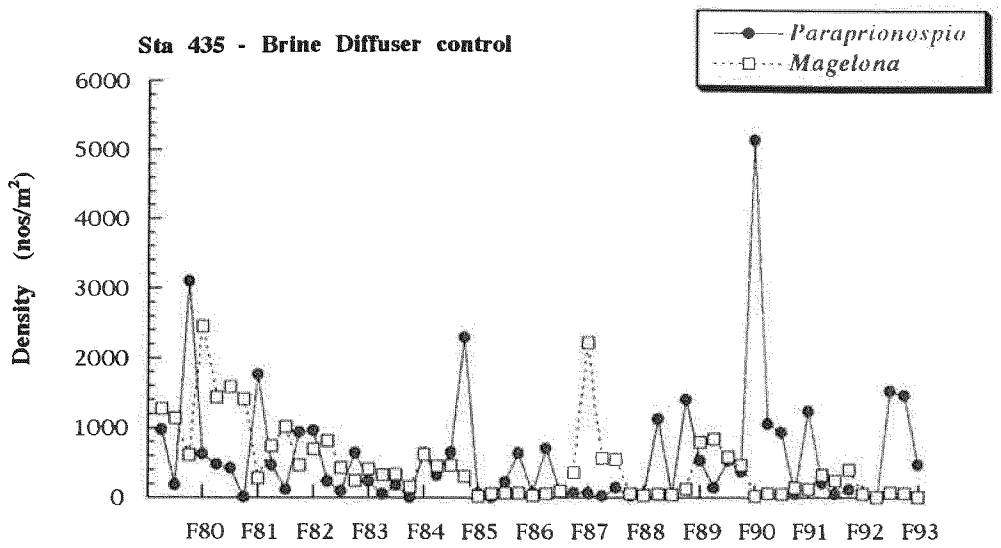
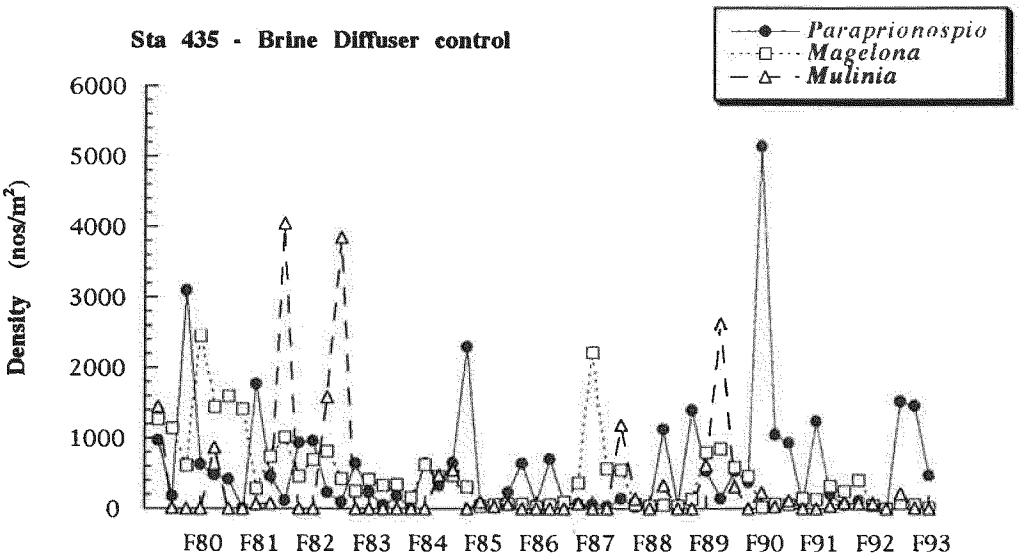


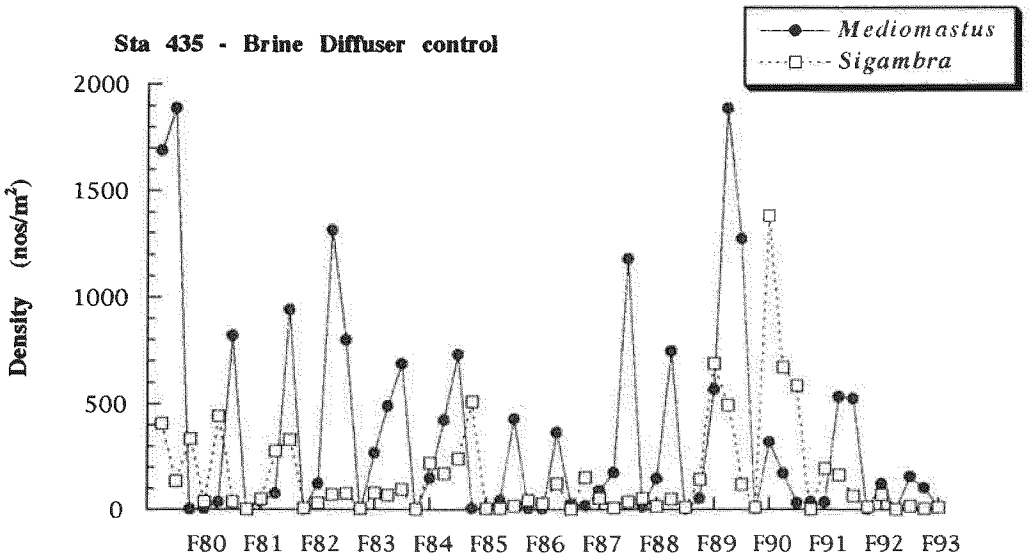
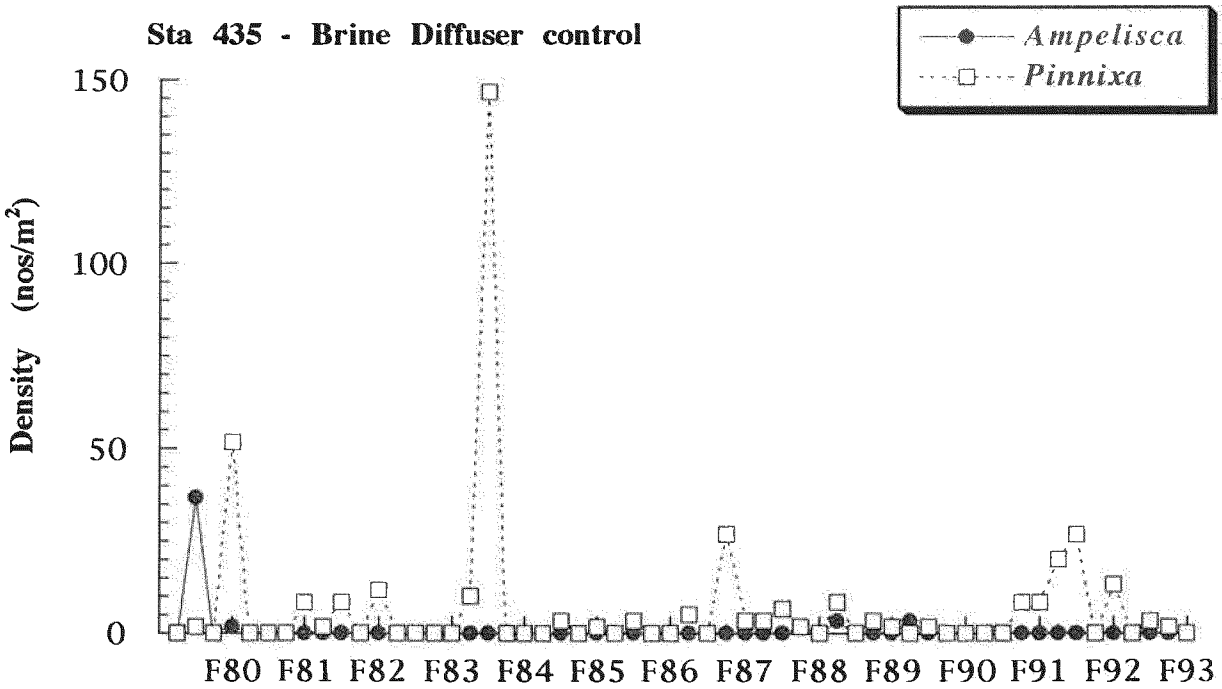




Figure 29. Yearly density summaries of the polychaetes, *Paraprionospio, Magelona, Mediomastus,* and *Sigambra*, and the bivalve mollusc, *Mulinia* for the brine diffuser control station 435.



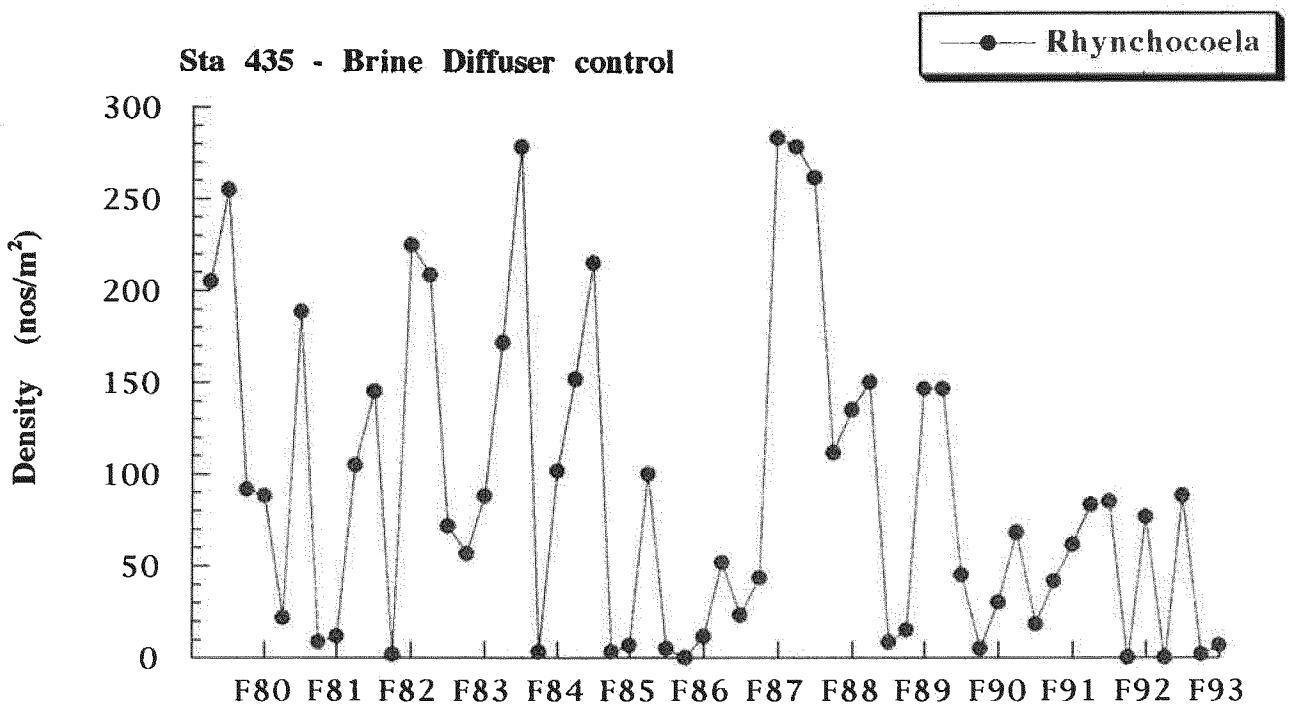




Figure 30. Yearly density summaries of the arthropods, *Ampelisca* and *Pinnixa*, and the Rhynchocoela for the brine diffuser control station 473.

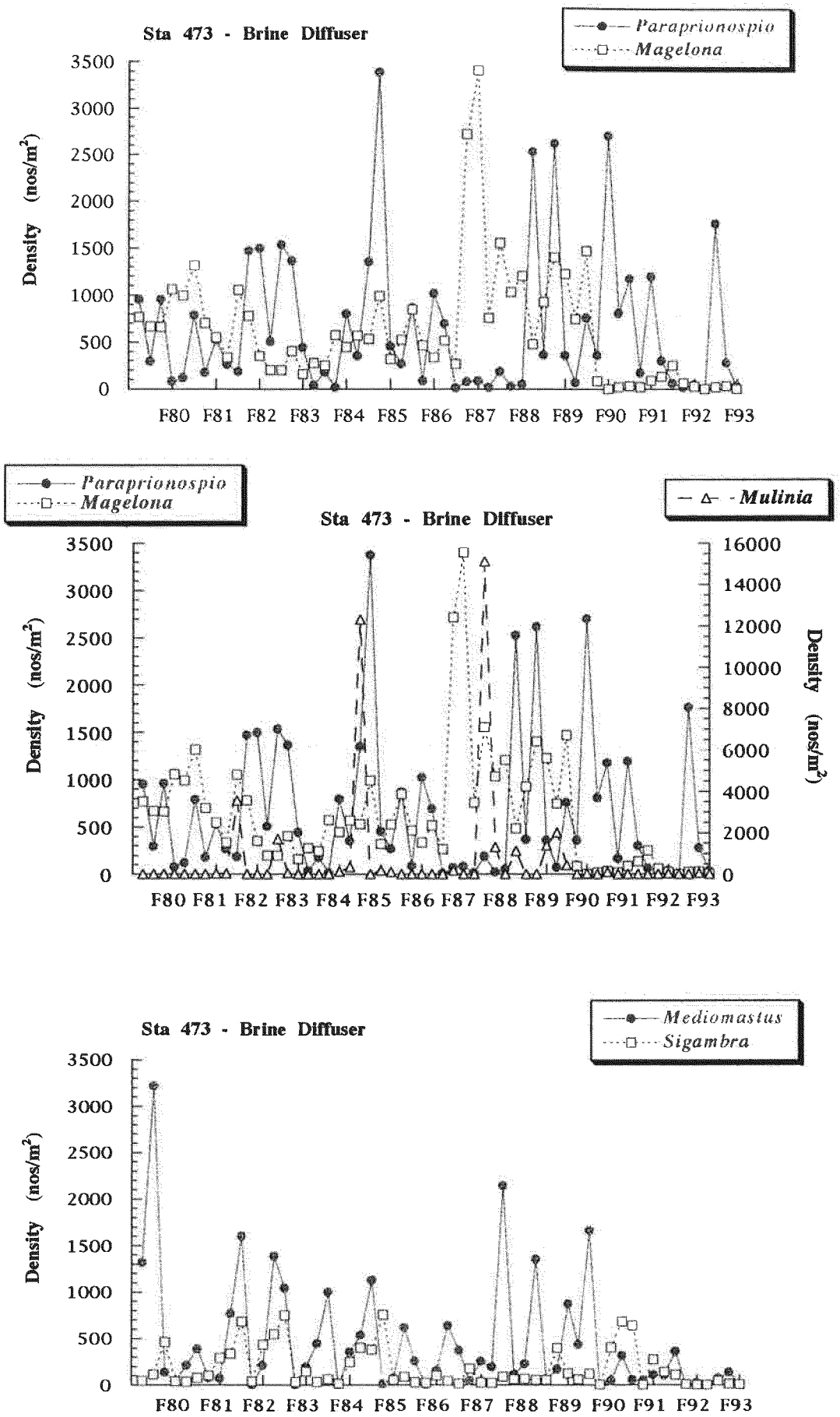
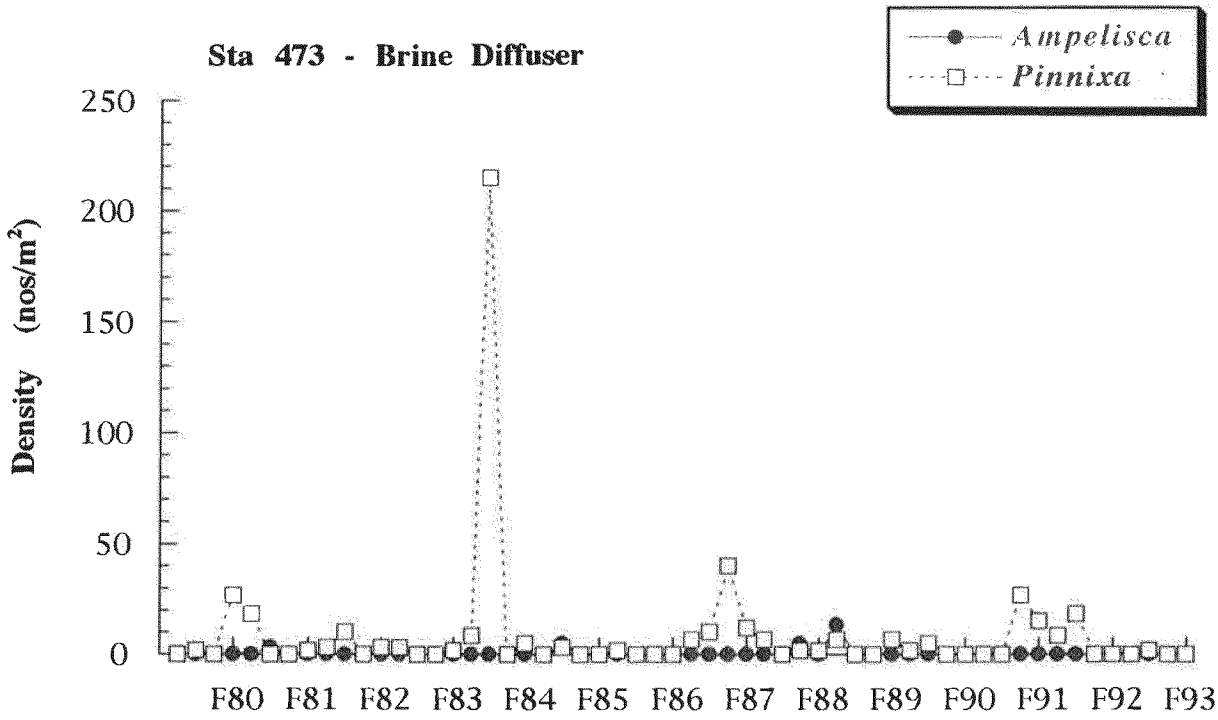



Figure 31. Yearly density summaries of the polychaetes, *Paraprionospio, Magelona, Mediomastus,* and *Sigambra,* and the bivalve mollusc, *Mulinia* for the brine diffuser control station 473.



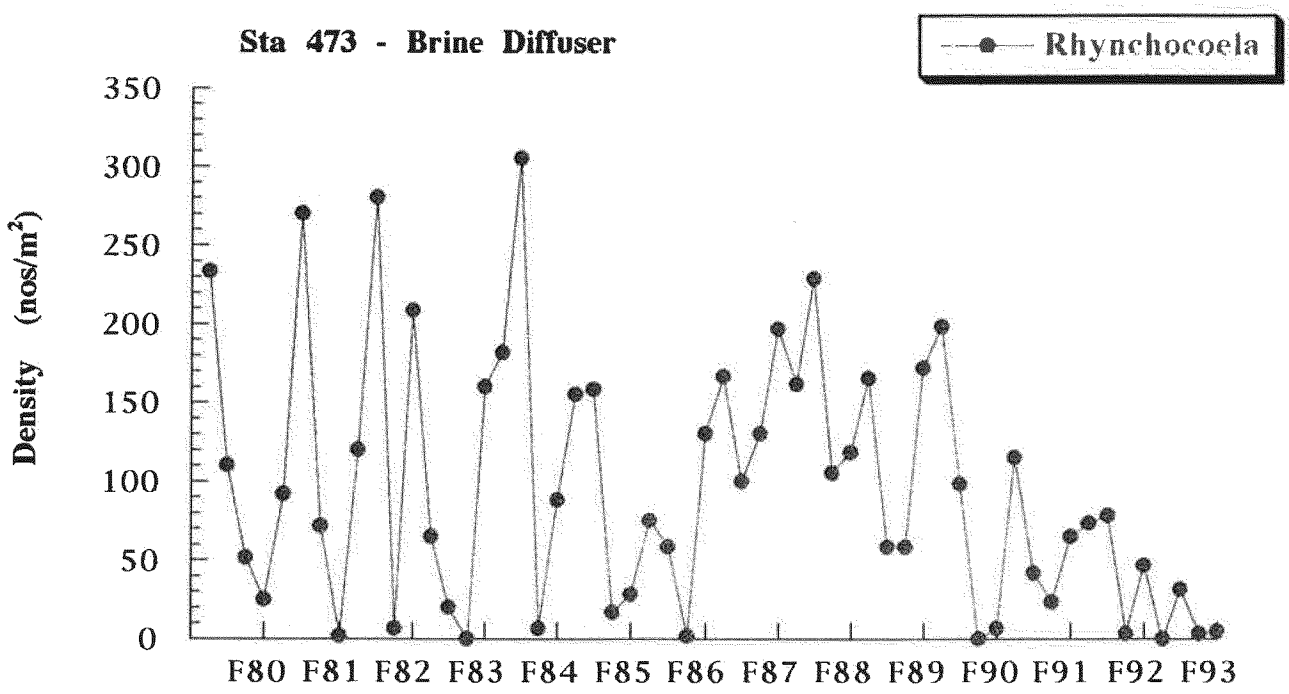




Figure 32. Yearly density summaries of the arthropods, *Ampelisca* and *Pinnixa*, and the Rhynchocoela for the brine diffuser control station 473.



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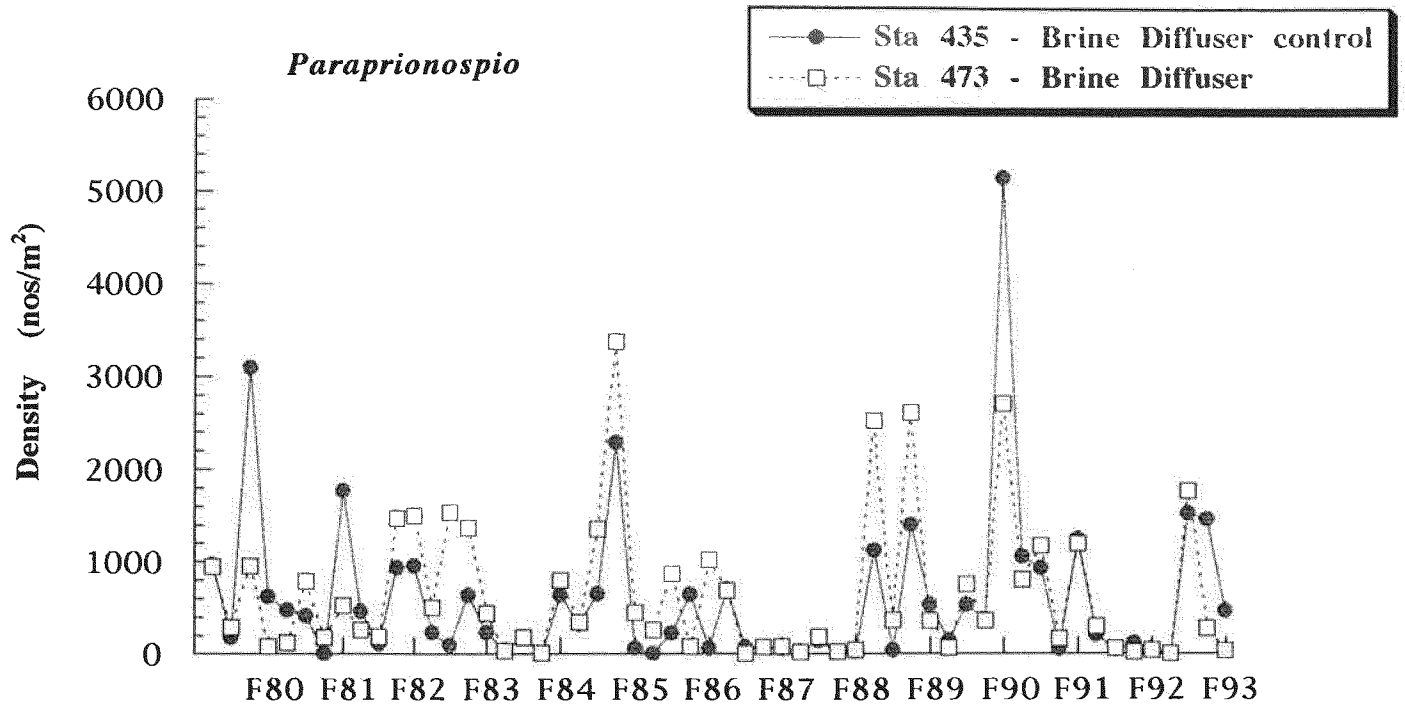


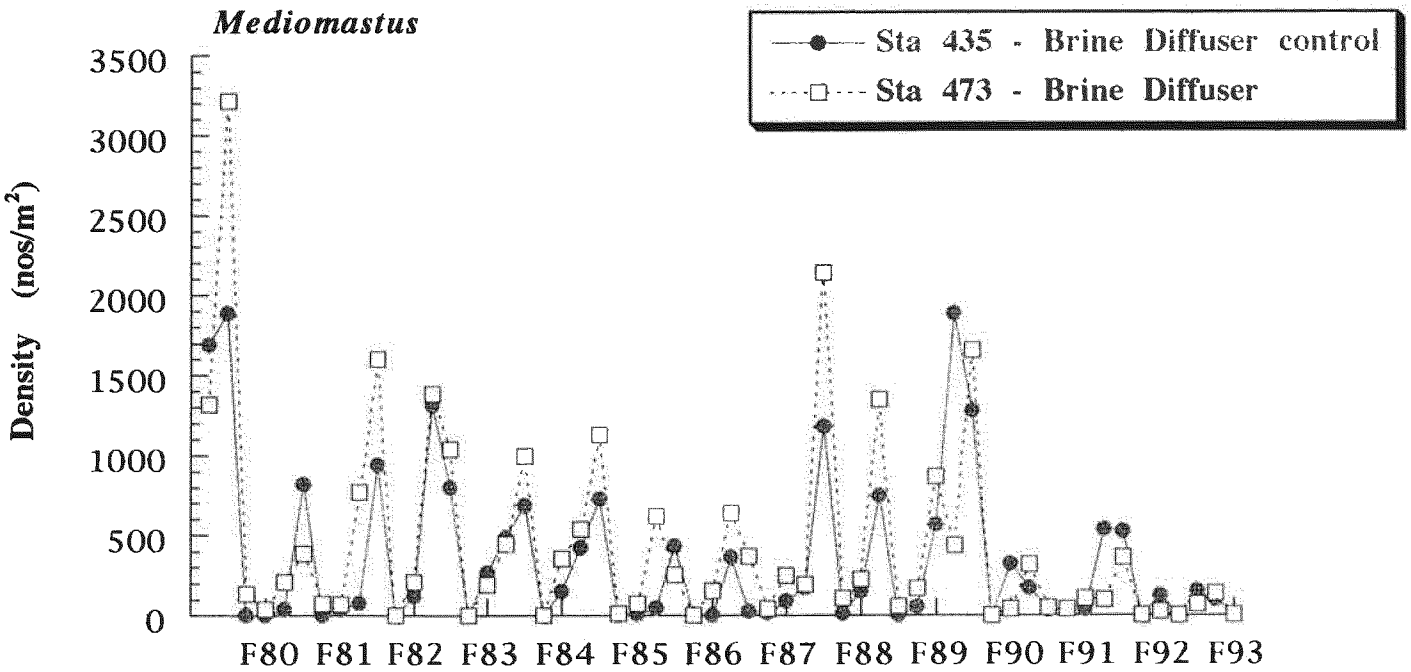


Figure 33. A comparison of yearly densities of the polychaetes, *Paraprionospio* and *Mediomastus* for control station 435 and the brine diffuser station 473.



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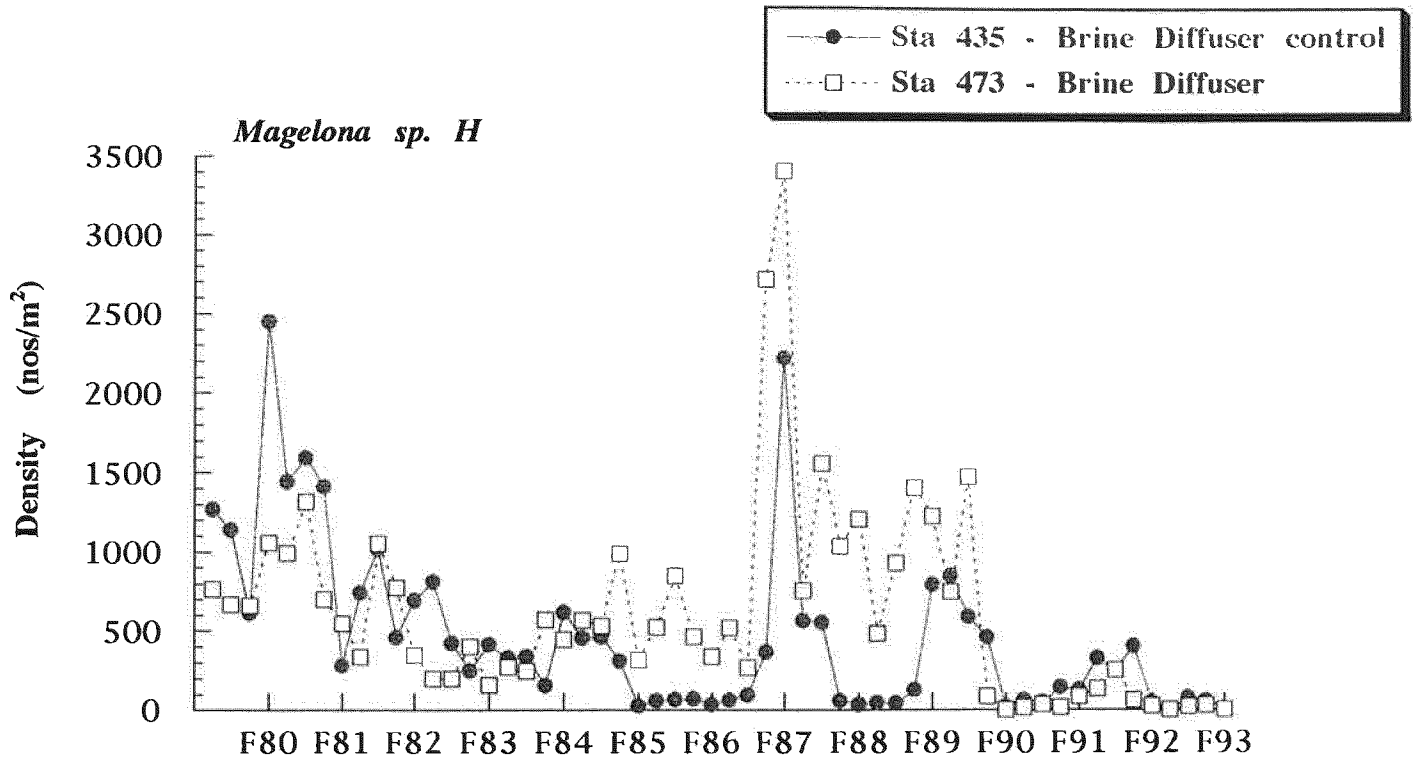


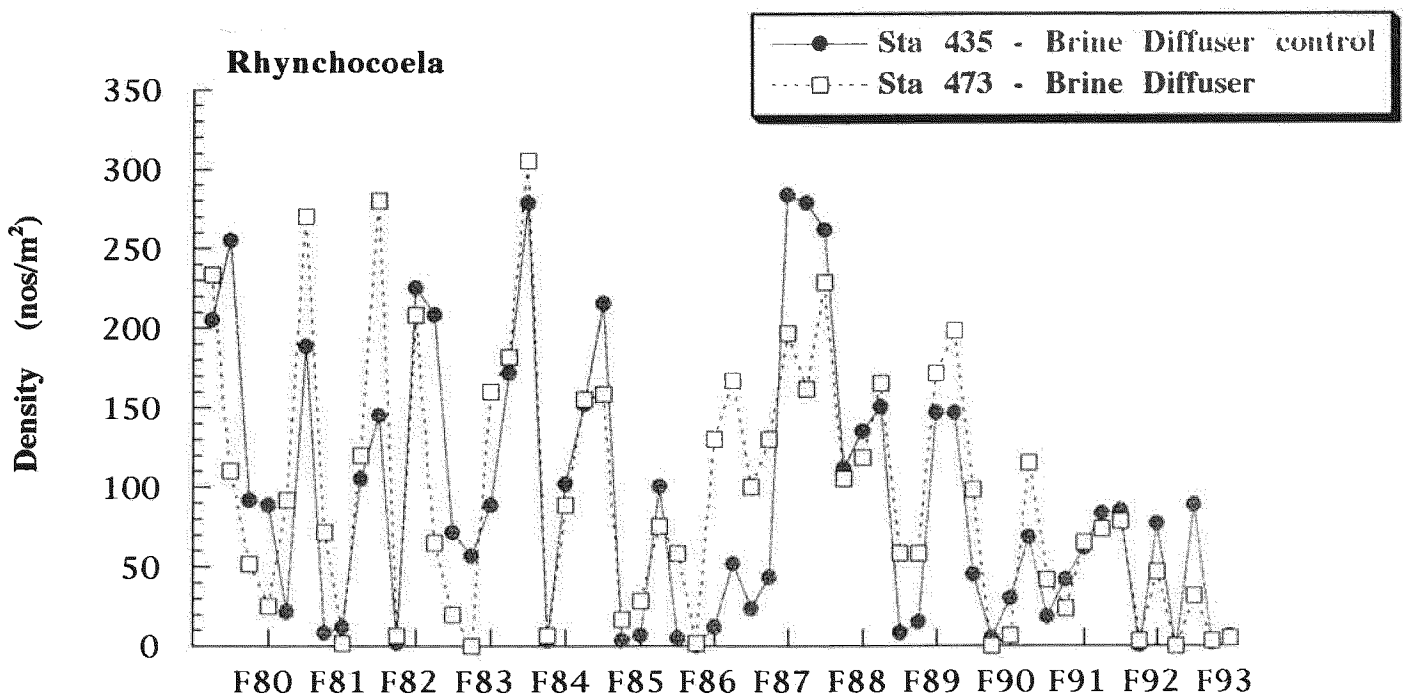


Figure 34. A comparison of yearly densities of the polychaete, *Magelona* and the Rhynchocoela for control station 435 and the brine diffuser station 473.



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densities from 1991-1993. These years had hypoxic/anoxic events which were present during two consecutive sampling seasons (see Fig. 25).

## RESULTS IV. OFFSHORE PUMPING STATION COMPLEX AND SPM

### SEASONAL SUMMARY OF HYDROGRAPHY

A seasonal summary of hydrographic characteristics for control stations 482 and 484 and the offshore pumping station and SPM complex station 481 is given in Fig. 35. Stations 481 and 484 had, on average, four times as much sand in the sediment as station 482. The average percent sand was 27.2%, 6.4%, and 24.2% for stations 481, 482, and 484, respectively (Fig. 35). There were no spatial or temporal differences in interstitial salinity (Fig. 23). Interstitial salinity was similar at all stations during all seasons and averaged 35.4 ppt (Fig. 23). There were no differences between stations in bottom dissolved oxygen for a given season. Bottom DO exhibited considerable temporal variability. DO levels observed during the winter and spring were greater than those measured during the spring and summer (Fig. 23). DO concentrations averaged 5.5, 6.0, 4.0, and 3.2 mg/l for the winter, spring, summer and fall seasons, respectively.

### SEASONAL SUMMARY OF MACROINFAUNAL ASSEMBLAGE

A seasonal summary of the general characteristics of the macroinfauna assemblage for control stations 482 and 484 and the offshore pumping station and SPM complex station 481 is given in Fig. 36. There were significant differences between average number of taxa collected during a given season (Table 7). For all seasons the number of taxa collected from control station 482 was significantly less than the number of taxa collected from stations 481 and 484. The average number of taxa collected for each station across seasons was 67.8, 39.4, and 54.0 for stations 481, 482 and 484, respectively (Fig. 36). There were significant differences between average macroinfaunal densities for a given season (Table 7). For each season, the average densities for station 481 were significantly higher than those of station 482, but not significantly different from station 484 densities. Densities ranged from 461.8 individuals/$m^2$ at station 482 in the winter to 2088.6 individuals/$m^2$ at station 481 (Fig. 36). There was minimal between station variation in diversity (H') and H' averaged 2.9, 3.1, 2.7, and 2.7 for the winter, spring, summer, and fall seasons, respectively (Fig. 36).



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## DISCUSSION

The LOOP monitoring program comprises four ecologically distinct habitat types which are arrayed along a salinity gradient ranging from 4 ppt at the most inland stations to 35 ppt at the offshore stations. Each of these habitats exhibited seasonal and year-to-year fluctuations in hydrography and macroinfaunal assemblages over the 14 years of sampling. The macroinfaunal assemblages at each site exhibited seasonal and annual variation in the number of taxa collected, total macroinfaunal densities, numerically dominant taxa, and long-term changes in assemblage composition. Physical processes (sediment texture, salinity, dissolved oxygen availability, riverine discharge) and regional climatological patterns (tropical storms, hurricanes) influenced the structuring of benthic assemblages at these sites. However, the relative effect of the various physical factors varied considerably among the sites. The inland stations (pipeline monitoring and Clovelly/freshwater intake) were primarily influenced by riverine discharge which determined seasonal salinity levels, and to some extent, sediment texture. The nearshore brine diffuser and the offshore pumping station complex/SPM stations were primarily influenced by seasonal shifts in dissolved oxygen availability, particularly hypoxic and anoxic events.

There were no significant differences in total number of taxa and total densities between control and monitoring stations at the inland pipeline monitoring site, the Clovelly/freshwater intake site, or the brine diffuser site on a seasonal basis. There were significant differences between the total number of taxa and total densities at the offshore site. These differences were due to the fact that control station 482 had different sediment characteristics when compared to control station 484 and monitoring station 481. However, total number of taxa and total densities at monitoring station 481 and control station 484 were not significantly different. There were also significant correlations at stations from each site between hydrographic and macroinfauna characteristics over the 14-year monitoring period. The data also indicated consistently similar patterns in abundances of major taxonomic groups, dominant taxa, and changes in macroinfauna assemblage composition. It is interesting to note that many of the patterns seen in the LOOP dataset were apparent only when considering multiple years of information. Any given one- or two-year period exhibited dramatically different hydrographic and macroinfaunal assemblage characteristics.

The macroinfaunal assemblages seen at the four LOOP sites were similar in structure to other North American marine benthic communities in similar habitat types. The hydrographic patterns and macroinfaunal assemblages were similar in function to estuarine and offshore benthic communities described from the northern Gulf of Mexico. The dynamics of benthic communities in the northern Gulf of Mexico are dominated by two unique interacting physical



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burrowing polychaetes were more tolerant. Defaunated bottoms were rapidly recolonized after hypoxia by the polychaete, *Paraprionospio pinnata.*

Harper *et al.* (1991) studied the recovery of a benthic community at 15 m and 21 m depths to a hypoxic event during 1979 in the northwestern Gulf of Mexico. Before the hypoxic event, dominance by the polychaete, *Paraprionospio pinnata*, was declining and abundance of the amphipod, *Ampelisca* was increasing. However, the hypoxic event eliminated *Ampelisca* and there were irregular post-hypoxia eruptions of *P. pinnata* which briefly dominated the benthos. Recovery at the two sites to the hypoxic event was different: 1) the deeper water assemblage stabilized within a year - polychaetes that were dominants before the hypoxic event quickly returned to dominance and there was little evidence of succession of different species during recovery; and 2) the shallower water assemblage underwent a more complex recovery - polychaete dominance (primarily *P. pinnata*) was greatly reduced after the event and there was a successional dominance which involved several species in different taxa - each species underwent a bloom and was numerically dominant for 1-3 months, declined, and was replaced by another species bloom - polychaetes eventually regained numerical dominance two years after the hypoxic event. Generally, the macroinfaunal assemblage of hypoxia-stressed habitats in the northern Gulf of Mexico have shifted to a dominance by younger, smaller, and shorter-lived species.

Gaston and Edds (1994) analyzed the effects of brine discharge from an offshore diffuser in Louisiana on benthic macroinfaunal from 1981-1989. Brine impacts were minimal because fine sediments around brine diffuser were numerically dominated by opportunistic species (primarily estuarine polychaetes) that exhibited natural temporal and spatial fluctuations in abundance. The fluctuations in species abundance resulted from summer hypoxia and anoxia and not from brine effects. Hypoxia eliminated some taxa and severely reduced the abundance of most benthic species. They found that the only significant differences between benthic assemblages near the diffuser and those outside the influence of the discharged brine resulted from water column mixing by the discharged brine which oxygenated waters around the diffuser and stabilized the salinity of the bottom water at stations near the diffuser. This enhanced benthic diversity around the diffuser and resulted in more abundant populations during some seasons. Gaston and Edds (1994) reported that the dominant species throughout study were the polychaetes, *Paraprionospio pinnata*, and *Magelona* sp. Other species, including several polychaetes and a phoronid, were dominant during the early years of the study but densities declined to near zero during the later years. Other opportunistic species increased in abundance over the course of the study. Shifts in dominant taxa are common in many continental shelf



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To our knowledge, the LOOP monitoring program represents one of the longest and most continuous hydrographic and benthic macroinfaunal datasets collected from the northern Gulf of Mexico. This dataset will be useful for determining the long-term effects of physical and anthropogenic influences on hydrography and macroinfaunal assemblages from an array of inland, nearshore, and offshore habitats. This dataset will also provide insights into the ecological properties of benthic communities and more general questions of ecosystem stability and resiliency. The dataset permitted an evaluation of impacts of LOOP activities in relation to natural background variation in physical and biological variables. There were no significant impacts due to LOOP's operations at any of the four sites. Both control and monitoring stations at these sites exhibited seasonal and year-to-year fluctuations in hydrography, species abundance, and assemblage composition that were typical of marine communities in the Gulf of Mexico. The complex interactions and annual variation in riverine discharge, climatological patterns, and hypoxia/anoxia in the northern Gulf of Mexico contribute to the variability seen at the four LOOP study sites.



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