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RESPONSE OF BENTHIC FORAMINIFERA TO VARIOUS POLLUTION SOURCES: IMPLICATIONS FOR POLLUTION MONITORING

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ABSTRACT

A detailed study of foraminiferal populations was carried out at three contaminated sites along the Mediterranean coast of Israel. The unpolluted coast of Nitzanim provided the first natural base line to be determined for the region.

A total of 158 species of benthic foraminifera from 36 families were identified along the shallow (6–50 m) parts of the Mediterranean coast of Israel. *Ammonia tepida* (Cushman), *Porosononion subgranosus mediterranicus* Yanko, and *Triloculina marioni* Schlumberger were the dominant species everywhere, whereas the accessory species varied.

At Palmahim (domestic sewage) the species diversity and population density was greatest. Here the largest foraminiferal test sizes and the highest percentage of agglutinated foraminifera were found. In contrast, the lowest species diversity and population density occurred near the Hadera power station, where coal was the major source of pollution in the sediment.

Part of Haifa Bay is currently being contaminated by a variety of heavy metals. In the contaminated site the foraminiferal tests were smaller, often stunted and frequently pyritized. Abberant tests was another more noticable response. At least 16 species exhibited abnormal tests. The degree of deformation ranged from mild to extreme. Benthic foraminifera have been demonstrated to be sensitive *in situ* monitors or coastal pollution.

INTRODUCTION

With the increasing worldwide awakening to the problems of the environment ways to detect and monitor pollution inputs over time are continuously being sought. It is the shallow near–shore environment that generally is subjected to frequent and abundant industrial and sewage outfalls. The use of shallow water benthic foraminifera would appear attractive as continuous *in situ,* biological monitors of this ecological zone. Among the factors that favor their use are: (1) They are ubiquitous in marine environments, (2) They live on and in the sediment, which receives and stores much of the pollutants. Consequently, they can be affected to a greater degree than plankton or nekton, (3) They have a wide range of taxonomic diversity, (4) Foraminifera possess hard shelled tests which can be well preserved. Their tests can record evidence of environmental stresses through time and provide "a priori" data when no previous baseline information existed before, (5) They are small enough, compared to other abundant but larger hard-shelled taxa (such as the mollusks), to provide statistically significant populations with small, easily collectable, samples; (6) Their very short reproductive cycles (month to year) [Walton 1964] and species specificity to ecological constraints make them sensitive to rapid environmental changes. Corliss and Silva [in prep.] suggest that the rapid growth of foraminifera (some of which have a meroplanktic stage) will preserve within each test a continuous record of the environmental conditions covering a short time span (approximately 3 months).

To date, systematic studies of the influence of pollution upon benthic foraminiferal populations have been directed to a single specific pollutant. Although some foraminiferal researchers have studied the effect of industrial wastes, most studies have addressed: (1) agricultural and domestic waste (Alve, 1991a, b; Alve and Nagy, 1986; Bandy and others, 1964a, b; 1965a, b; Banerji, 1973, 1989; Bates and Spencer, 1979; Bhalla and Nigam, 1986; Buckley and others, 1974; Dermitzakis and Alafousou, 1987; Ellison and others, 1986; Kameswara Rao and Satyanarayana Rao, 1979; Nagy and Alve, 1987; Schafer, 1970, 1973; Schafer and Cole, 1974; Seiglie, 1968; Setty, 1976, 1982; Setty and Nigam, 1984; Varshney and others, 1988; Watkins, 1961; Yanko and Flexer, 1991, 1992; Yanko and others, 1992a), (2) paper processing (Buckley and others, 1974; Schafer, 1970, 1973; Seiglie, 1975) as well as (3) the effects of oil-gas seepages from the sediments (Seiglie, 1968; Yanko, 1974; Yanko and Flexer, 1991, 1992; Jones, in press). Only recently (Alve, 1991a, Sharifi and others, 1991, Yanko and others, 1992a) have the effects of trace metal contaminated sediments upon the associated benthic foraminifera been investigated. Boltovskoy and others (1991) summarized the effects of a wide range of environmental parameters, including pollution, as they may lead to morphological changes.

Until now, no systematic taxonomic base line study of shallow-water benthic foraminifera has been prepared for the eastern Mediterranean, though some preliminary work has been presented for the Israeli coast (Reiss and others, 1961; Perath, 1966; Yanko and others, 1992a, b), the Nile delta (Abdou and others, 1991) and the coast of Lebanon, Moncharmont Zei, 1968). To date the introductory study of Parker (1958) represents the most detailed reference on the eastern Mediterranean.

AREA DESCRIPTION

The coast of Israel is an ideal place to study near-shore marine pollution. The pollution inputs are clearly defined. Ecological variables can be readily related to the geologic and oceanographic conditions which are also well known and change in a consistent manner along the coast. These include: (1) The coastline of Israel runs practically as a straight line from the southern border to the embayment at Haifa (Fig. 1), (2) In general the currents follow the

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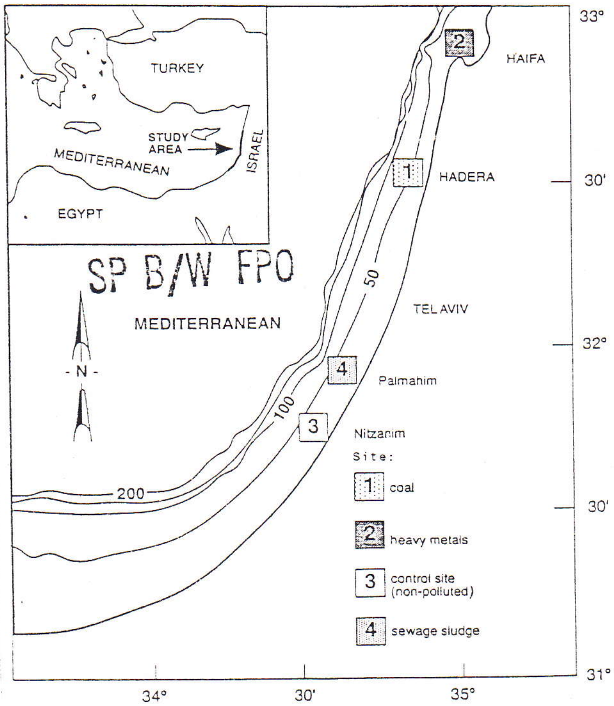

FIGURE 1. Location map defining the areas studied and the type of pollution that is dominant.

bathymetry and exhibit a strong northward component (Rozentroub and Brenner, 1989), (3) Fresh water inputs along the coast are sparse. The salinity of the near shore bottom water is approximately 39‰, (4) The dominant sediment source is the Nile River. The sediment is brought northward by the prevailing longshore current. The composition of the sediments has been well studied (Emery and Neev, 1960; Nir, 1973, 1980). In general the nearshore sediments are mainly clastic, predominantly metal-poor quartz sands that grade northwards into metal-poor carbonates in the Haifa region. A small biologic component is present. The clay mineralogy is predominantly smectite (60–80%), with abundant kaolinite (20–40%), and some illite (trace to 15%) (Nir and Nathan, 1972). (5) The pollutant inputs are well known and of relatively recent origin, having increased since independence of the state in 1948. Along the coast there are three major sites of pollution. These sites were investigated and the results compared to a non-polluted control area. The contaminated areas studied were:

Site #1, (8 stations located at water depths ranging from 17.5 m to 0.4 m), is near a coal based power station situated along the coast of Hadera. The coal unloading quay currently is a focus for coal pollution.

Site #2, (two stations located at water depth of 6 m and 12 m) is within Haifa Bay. This bay is the industrial heart of Israel. A considerable number of heavy industries are concentrated around the bay. They include a chlor-alkali plant, an oil refinery, a petrochemical and fertilizer plant, and various other chemical and metallurgical factories that discharge their effluents into the bay, either directly or through the Qishon River. As a result, the Qishon River is polluted by organic compounds, sulfides and a large variety of heavy metals (Hornung and others, 1981, 199; Kronfeld and others, 1974; Kronfeld and Navrot, 1974; 1975; Navrot and others, 1973). This site was divided into two areas. One station, 27/91, is near the mouth of the Qishon river. Therefore, this station is liable to receive high inputs of trace metal contaminated sediments. The other station (19/90) is situated to the north. In the initial project, from which we received the sediment samples, this station was believed to be sufficiently far removed from the Qishon mouth as to be considered to be non-polluted.

Site #4, (7 stations located at water depths ranging from 20 m to 50 m), was located approximately three miles off of the coast of Palmahim. A pipe, fitted with a diffuser at this end, disposes of 1400 m^3/day of domestic sewage (water depth 38 m). The activated sludge (after secondary treatment) is composed of 95% water and 5% solids. In addition to the stable biomass, it may contain pathogenic bacteria, inorganic nutrients, and synthetic organic compounds (Kress and Hornung, 1992). Stations P4, P5, and P6 were located in front of the distal end of the pipeline. Stations P20 and P35 were situated on the north side of the pipeline, while station P50 was located north-west of the sewage outfall (Kress and Hornung, 1992; Fig. 1).

Site #3 (4 stations located in water depth from 20 m to 50 m) provides a natural base-line for comparative purposes. This was a clean coast off Nitzanim which has never suffered from pollution.

Much information is available from previous work on the grain size distribution and chemistry of the sediment and the chemistry of the associated water (Cavari and others, 1983; Golik, 1986; Hornung and Kress, 1991; Kress and Hornung, 1992). We make use of this information. The reported concentrations of selected trace metals in the sediments are presented in Table 1. The sediment type for each site is found to be:

Site #1. The sediment at this site was primarily composed of sand, which can reach up to 99% (by weight). Coal was found down to the 250 μm sized fraction at stations H1, H2, H3, H5. Station H4 was composed entirely of coal fragments. Site #3. The sediment was composed of 93% sand (>63 μm) at the near shore station N20. The sand percentage decreased to less than 20% at 50 m depth (station N50). The trace metal concentration in the sample shows a sympathetic increase with the rise in the percentage of the clay component which follows a concomitant decrease in the quartz sand component (Kress, oral communication, 1993).

Site #4. The sediment composition was comparable to that of Site #3.

The water depth of each of the stations sampled is presented in Table 1. All sediments were collected under normal conditions for eastern Mediterranean bottom water (pH = 8.1–8.3; salinity 39‰; dissolved O_2 = 6–8.5 ppm).

SAMPLING

This study was primarily based on 71 samples of surface marine sediment that had been collected during a prior geochemical study using the research vessel Shikmona. We received four types of samples: (1) 7 samples from Palmahim, and 4 samples from Nitzanim collected in September

TABLE 1. Water depth of sampling stations and reported concentrations of selected heavy metals in the sediments (Golik, 1986; Kress and others, 1991; Hornung and Kress, 1991; Hornung, oral communication, 24 January, 1993).

Site	Station	Water depth (m)	Elements					
			Fe %	Cd ppm	Cu ppm	Zn ppm	Pb ppm	Hg ppm
1	Hadera (power station)							
	H1/86	24.0	**	0.19	2.11	5.48	3.99	BDL*
	H2/86	24.0	**	0.20	2.17	5.47	4.35	0.007
	H3/86	24.0	**	0.19	1.92	5.15	3.85	0.008
	H4/86	24.0	**		----- area covered with coal -----			
	H5/86	24.0	**	0.20	2.53	10.20	4.43	0.019
	H6/86	24.0	**	0.21	2.52	5.73	5.55	0.014
	H5c/86	30.4	**	0.21	4.30	11.33	5.26	0.016
	H11c/86	17.5	**	0.19	2.01	6.17	4.37	0.005
2	Haifa Bay (industrial pollution)							
	27/86	12.0	1.01	1.00	27.30	102.00	31.00	0.35
	27/87	12.0	0.98	1.00	24.70	77.00	23.30	0.31
	27/89	12.0	1.24	1.80	43.10	133.00	33.10	0.31
	27/90	12.0	1.39	1.34	31.60	102.00	33.50	0.27
	27/91	12.0	1.48	1.39	33.80	116.00	36.00	0.32
	19/90	6.0	0.28	0.15	2.90	14.30	10.40	0.12
3	Nitzanim (non-polluted)							
	N1	33.0	4.68	0.05	27.32	78.41	16.10	0.04
	N2	34.0	5.50	0.09	41.81	80.77	16.70	0.05
	N20	20.0	0.55	0.11	2.92	12.43	6.24	BDL
	N50	50.0	5.52	0.13	30.67	84.68	18.18	0.03
4	Palmahim (domestic waste)							
	P4	38.0	4.35	0.04	29.02	93.23	15.81	0.04
	P5	35.5	3.71	0.02	23.72	67.73	14.00	0.04
	P6	38.4	5.88	0.21	40.11	79.75	16.95	0.01
	P7	34.5	2.61	0.03	15.53	45.60	11.89	0.02
	P20	20.0	0.56	0.10	2.45	12.08	5.04	BDL
	P35	35.0	2.32	0.11	13.52	42.71	10.44	0.07
	P50	50.0	5.65	0.14	35.49	92.01	18.50	0.01

* BDL-Below detection limit.
** Fe was not measured during the 1986 sampling.

1991, as well as one sample from Station 27 in Haifa Bay taken in July 1991, that were preserved in a 4% formalin-sea-water solution buffered with sodium borate, (2) one frozen sample from Station 19 in Haifa Bay taken in December 1990, (3) 8 total sediment samples from the Hadera coast, taken in May 1986, and stored at room temperature, (4) Supplementing the non-sieved material, we also received the <250 μm size sediment fraction of 50 samples that had been lyophilized and stored at room temperature.

METHODS

Foraminifera were studied by standard methods (Feyling-Hanssen, 1983; Yanko and Troitskaja, 1987). Rose Bengal stain (Walton, 1952) was added to the fresh samples taken in 1991 to identify organisms living at the time of collection. The potential limitations of the Rose Bengal stain method have been discussed (Boltovskoy and Wright, 1976; Walker and others, 1974). Recently, Corliss and Emerson (1990) have demonstrated that the effectiveness of the method has been understated. The Rose Bengal stain was preferred for this study, over the Sudan Black B stain, for the response is more easily seen. The pollution itself, such as coal, can darken the tests, and mask the Sudan Black B stain. The samples were sieved at the 125 μm mesh size and microscopically analyzed in the laboratory. In retrospect, in light of the results that we obtained, it is suggested that future analysis start at the >63 μm fraction to investigate the possibility that there might have been a down-sizing response to the pollution. All the foraminiferal parameters were normalized against a 5 g dry sediment mass. When possible, 300 specimens of foraminifera from the >125 μm fraction were counted for each sample for population statistics. The foraminifera were separated from the sediment by hand picking. Flotation by CCl_4 was not carried out because some tests were significantly pyritized. The foraminifera were divided, for statistical purposes, into three size groups: >590 μm, 590–250 μm, <250 μm. Each group was weighted and the size-percentage calculated. Living and non-living foraminifera were used for taxonomic purposes, while living foraminifera were used to evaluate the degree of pyritization. The non-living foraminifera were used for statistical purposes as they provided a larger data base. There appeared to be no obvious differences in the population parameters between the living and the non-living foraminifera, in agreement with the observations of Scott and Medioli (1980).

An estimation of the species diversity was performed using the following parameters: (1) Number of species, (2) Number of specimens, (3) Shannon-Wiener index (H') (Shannon and Weaver, 1949), (4) Evenness (E) (Pielou, 1966), (5) Percentage of agglutinated species, and (6) Percentage of megalospheric generation of *Ammonia tepida*. The test morphology as well as the assessment of the extent of pyritization of the tests was studied using the SEM (Joel JSM-840 with attached energy dispersive spectrometer Link

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Analytical AN 10 000) in conjunction with the standard binocular microscope.

The foraminifera were statistically analyzed using a Q-mode factor analysis with the program CABFAC (Klovan and Imbrie, 1971). One of the statistical problems was that a few species overwhelmingly dominated while the majority of the species were represented by only 1 or 2 individuals per sample. Therefore, small changes could lead to large percentage errors for this latter group. It was decided that this statistical treatment was not suitable for the population distributions found here.

The taxonomic identification was carried out by direct comparison with the original collections of the Museum of Natural History, Paris which included those of d'Orbigny, Schlumberger, and Le Calvez. The taxonomic collection of the eastern Mediterranean foraminifera prepared for this study is now stored there as well as at the Faculty of Life Sciences at Tel Aviv University. The classification of Loeblich and Tappan (1988) has been adopted for use in this research for identification at the supraspecific level.

RESULTS OF THE FORAMINIFERAL ANALYSIS

Structure and Composition of Foraminiferal Assemblages

A total of 158 foraminiferal species from 36 families were identified (see Appendix 2). Agglutinated foraminifera, belonging to 6 families, were represented by 13 species, with *Eggerella bradyi, Textularia bocki* and *Lagenammina fusiformis* being the most abundant. Calcareous foraminifera were represented by 30 families and 145 species.

Site 1, (Hadera), was characterized by a total of 42 species (Appendix 1). The number of specimens ranged from 12 to 305 per 5 g sediment. Six stations (H1, H2, H3, H4, H5, and H6) were located at the same (24 m) water depth. The foraminiferal density and diversity differs from station to station: (1) Foraminifera were not found at station H4 where the seabottom was covered by coal, (2) At stations H1, H3, and H6 coal was a considerable but variable contaminant. These sites had the most impoverished foraminiferal assemblages studied (H′ = 0.30–65; E = 0.,44–0.21) (Fig. 2). Stations H2 and H5 (with a lower concentration of coal particles in the sediment) were characterized by a higher species diversity (H′ = 0.93–1.07). Many species were represented by one or two individuals (E = 0.15). Station H5c exhibited a similar diversity (H′ = 0.93; E = 0.11) but obtained a slightly larger number of species (22), and a greater population density (299 individuals per 5 g sediment). About 50% of all the species were represented by only one or two individuals. This station was located furthest away from the coal-loading quay. The amount of coal in the sediment at this statin was greatly reduced. At station H11c near to station H5c, though in shallower water (17,5 m) and with a coarser substrate, the diversity was reduced (H′ = 0.69, E = 0.15). Approximately 35% of the tests were greater than 590 μm at station H5c. Almost 95% of the tests were between 590–250 μm at station H1 (Fig. 3). The test sizes at the rest of stations were smaller than 250 μm. Agglutinated foraminifera did not comprise more than 3% of the total population. *Adelosina cliarensis* was highly dominant everywhere, with the exception of station H5c. *Ammonia tepida* and *Triloculina marioni* were the next most abundant species. *Porosononion subgranosus mediterranicus, Eponides repandus, Quinqueloculina viennensis,* and *Triloculina earlandi* were generally abundant. The megalospheric forms of *Ammonia tepida* ranged from 10 to 12%.

Site 2, (Haifa Bay) contained a total of 55 species (Appendix 1); station 27/91, 44 species, and station 19/90, 28 species. The foraminiferal density ranged from 1,520–1,720 individuals per 5 g sediment. The diversity was slightly higher at station 19/90 (H′ = 0.93) than at station 27/91 (H ′ = 0.81). The sediment was coarser at the shallower station. Agglutinated foraminifera (4 species) comprised between 0.33 and 1.0% of the assemblages. The most abundant calcareous species was *Ammonia tepida.* Its abundance significantly decreased from station 27/91 to station 19/90. The percentage of megalospheric forms of *Ammonia tepida* reached almost 95% at station 27/91. It was 45% at station 19/90. About 60% of the remaining species were represented by one or two individuals at each station. Therefore, the Evenness parameter was very low, ranging from 0.05 to 0.09. Several species were represented by empty tests only. Species such as *Adelosina cliarensis, Eponides repandus, Porosononion subgranosus mediterranicus, Quinqueloculina berthelotiana, Q. stelligera,* were more abundant at station 19/90. The species *Peneroplis planatus* was found only there. The percentage of *Adelosina cliarensis* increased from station 27/91 (0.67%) to station 19/90 (11%). Approximately 70% of the foraminiferal tests were smaller than 250 μm. The remainder of the tests fell in the range between 590 μm and 250 μm. There were no tests greater than 590 μm (Fig. 3).

Site 4, off the Palmahim coast, exhibited the largest number of species (93) and a high diversity (H′ = 1.1) (Appendix 1). Once again the majority of species was represented by only a few individuals (E = 0.07–0.12). The highest diversity (H′ = 1.45) and the greatest number of species (61) were present at station P50. The highest number of individuals, 8,290 per 5 g, was found at station P35. The lowest population density, 2,500 per 5 g, occurred at station P4. No foraminifera were found at station P20. The substrate was coarsest here, similar to that of station N20. Nine agglutinated species made up to 20% of the total population. With the exception of a higher amount of ribbed *Adelosina, Quinqueloculina,* and *Triloculina,* the rest of the population parameters were similar to those for Site 3. The size of the tests, for the majority of the species was much greater than for the other areas (Fig. 3).

Site 3, the non-polluted, Nitzanim control area, exhibited 71 species (Appendix 1). The diversity was marginally higher than at the previous sites (H′ = 0.95–1.19). At the same time, the majority of species were represented by a few number of individuals (E = 0.07–0.11). Stations N1 and N2 (water depth 33 m and 34 m, respectively) were characterized by the highest number of individuals, (5,000–6,390 per 5 g). The lowest number of individuals (161 per 5 g) was found at station N20, where the sediment substrate was the coarsest. The number of individuals at the deepest station, N50, was 756 per 5 g sediment. This deeper water site was characterized by an elevated number of species, 26, as well as a higher percentage (18%) of agglutinated fora-

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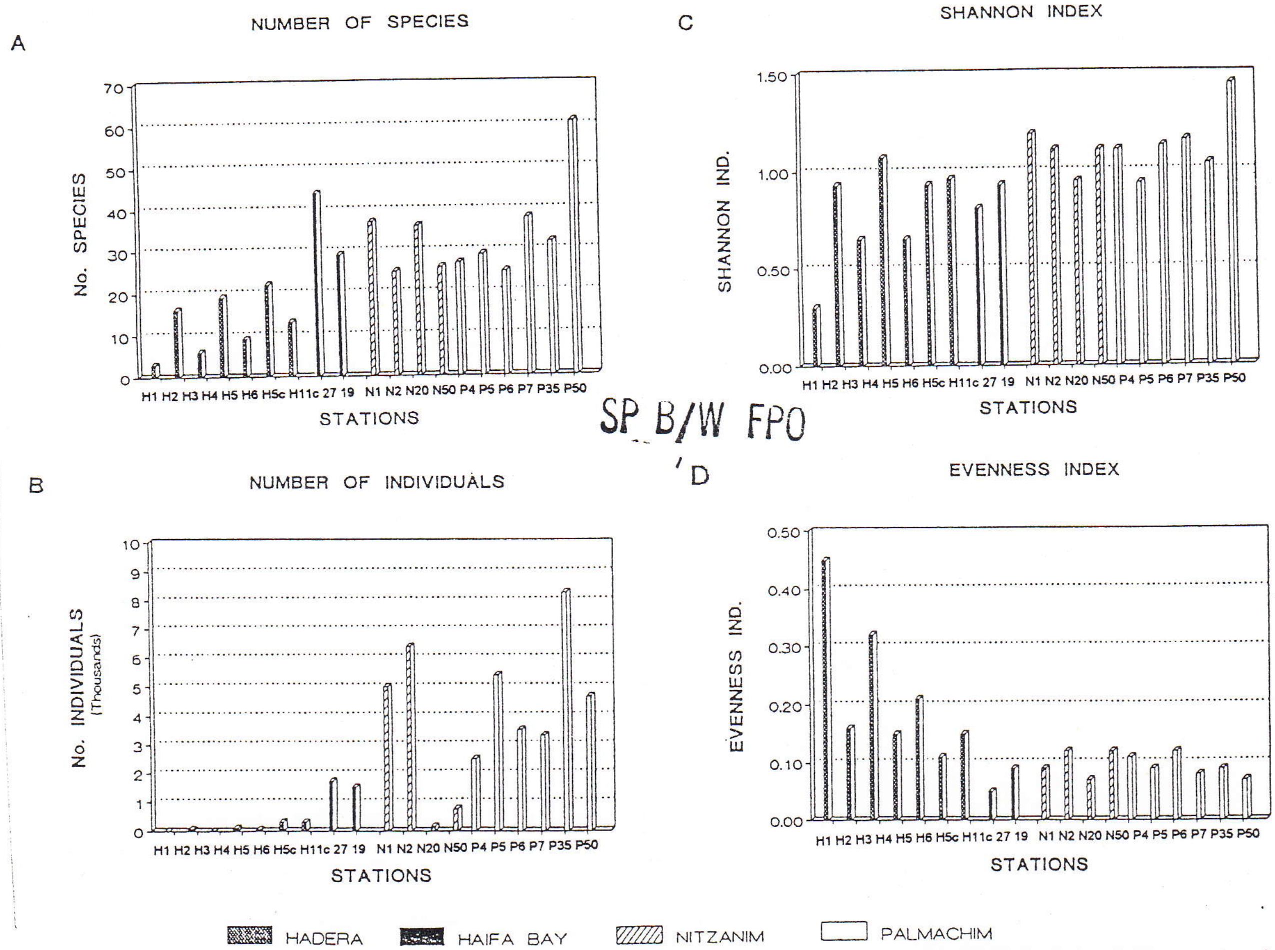

FIGURE 2. Statistical parameters used to relate the foraminiferal populations to the environment studied: a) Species diversity, b) Population density, c) Shannon-index, and d) Evenness-index.

minifera. The dominant agglutinated species were *Textularia bocki* and *Eggerella bradyi.* The abundance of the former sharply decreased with depth. The abundance of the latter, as well as *Lagenammina fusiformis,* increased with depth. Epifaunal species made up almost the entire foraminiferal assemblage. The dominant calcareous species were the same as at Site 1. All of them showed a tendency to decrease in abundance with depth. The percentage of *Ammonia tepida* was the highest (about 50%) at the shallowest station N20. The megalospheric forms of *Ammonia tepida* ranged between 10–15%. The assemblage at the 50 m, station N50, also included deep-dwelling species such as *Lenticulina cultrata, L. gibba,* and *Guttulina lactea.* Approximately 70% of the tests were between 590–250 μm in size. Almost 5% of the tests were greater than 590 μm (Fig. 3).

PYRITIZATION

Spot pyritization was mainly found in both living and non-living individuals of *Ammonia tepida* and *Porosononion subgranosus mediterranicus;* though, it was not exclusively confined to these two species. However, this phenomena is confined to station 27/91. Approximately one quarter of the foraminiferal tests in all samples were spot pyritized. No pyritization was evident for the tests from the Sites 1, 3, and 4, or from station 19/90.

MORPHOLOGICAL ABNORMALITIES

Morphological abnormalities of the foraminiferal tests were restricted to the Haifa Bay site (station 27/91). At least 16 species, including both agglutinated and calcareous forms exhibited morphological deformation (Pl. 1–3). Deformed tests comprised up to 2–3% of the total assemblage. The test abnormalities ranged from mild to the bizarre. Sometimes the deformation was so extreme that taxonomic identification was very difficult (Pl. 1, Fig. 10 and 12). For *Ammonia tepida,* the morphological deformation was manifest as additional chamber development, the appearance of protuberances, the deformation of the shape of the chamber, twisting of the last whorl or twisting of the entire side (Pl. 3). Test deformities of *Triloculina marioni* (Pl. 1) included a strong distortion of the chambers. Abnormalities were also readily noticeable in other species (Pl. 2) including *Ammonia compacta, Brizalina spathulata, Cycloforina villafranca, Cycloforina sp. 2, Eggerella bradyi, Eponides*

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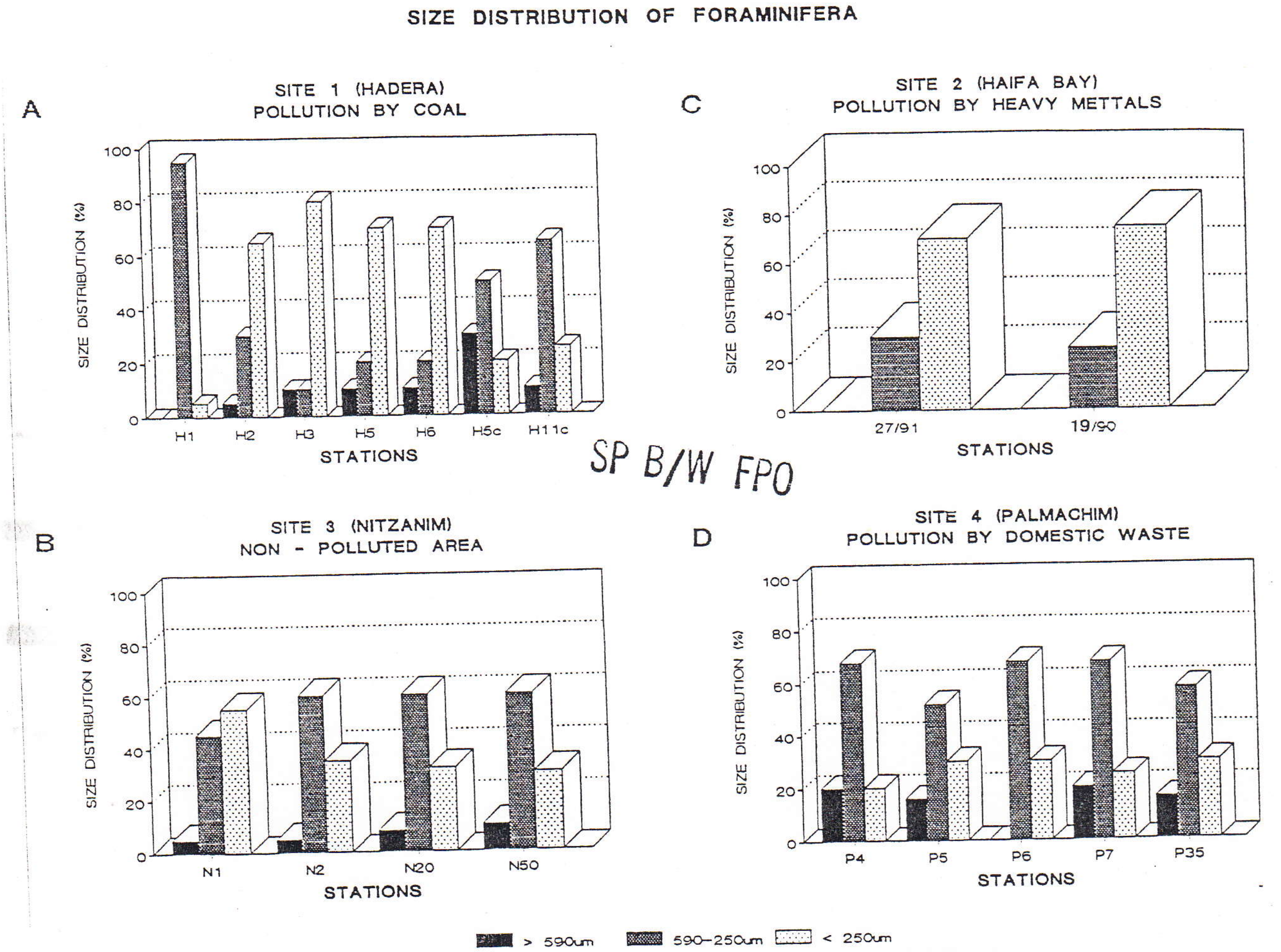

FIGURE 3. The size distribution of the foraminiferal populations found at each site.

repandus, Lobatula lobatula, Nonionella atlantica, Peneroplis complanatus, Planorbulina mediterranensis, Quinqueloculina disparalis, Quinqueloculina phoenicia, Quinqueloculina sp. 1, Triloculina earlandi. The test abnormalities were found to be present in all of the supplementary samples of Haifa Bay Station 27 from 1986–1990. There did not appear to be obvious differences in any of the measured foraminiferal parameters over this period of time. However, this station exhibited high amounts of heavy metals, especially Pb, which was significantly higher than at any other station.

DISCUSSION

The sediment samples were not all collected at the same time. For the same substrate, foraminiferal assemblages should be most robust and flourishing during the spring, when nutrient enrichment occurs. This is the time of planktic blooms. Despite the fact that Hadera was sampled in the spring, when water-nutrient conditions should be high, this site yielded the most impoverished assemblage, even compared with station 19/90 which was sampled during the winter. The most impoverished foraminiferal population was found in the vicinity of the local loading quay where coal and coal waste products were abundant in the sediment. The biological effects of the coal have not been studied. There was a marked negative population response to the presence of coal. The extent to which the population was found to be impoverished corresponded to the degree to which the sediment was contaminated. There were no apparent differences in the sediment or water composition; therefore it was inferred that the presence of coal was the variable responsible for the adverse population response. Possibly this type of contaminated substrate may not be a favorable growth site, perhaps due to a poor release of nutrients. This aspect will be studied in a following report. Nitzanim and Palmahim were both sampled during the summer. Their substrate was the same. The only difference between them was the input of domestic sewage to Palmahim. Here the foraminifera responded favorably to the domestic sewage input. This type of sewage included organic material and did not include toxins. The foraminiferal population was most diverse and dense. It contained a large percentage of very robust forms (Fig. 3). Such a positive response to domestic sewage has been recorded before (Watkins, 1961). Station 27/91 of Haifa Bay also showed an impoverished assemblage compared to Nitzanim and

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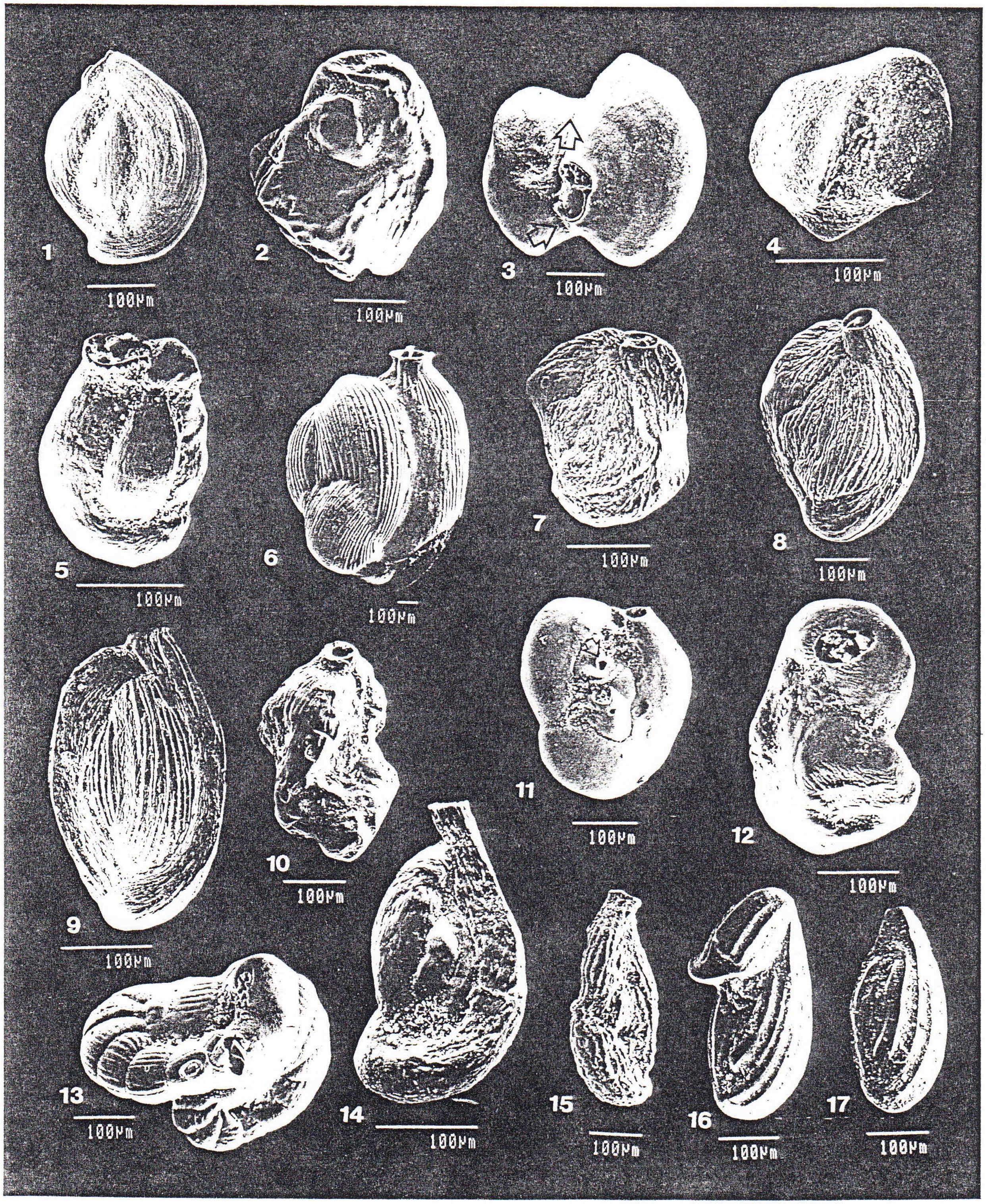

PLATE 1

Examples of test abnormalities in living foraminifera of the order *Miliolida* found at station 27 in Haifa Bay. **1–5** *Triloculina marioni* Schlumberger, specimens, representative of a non-deformed specimen (1) compared to seriously deformed specimens (2–4), arrows on fig. 3 point to deformation; aberrant chamber shape (5). **6.** *Quinqueloculina phoenicia* Colom, twisted chamber arrangement. **7, 8** *Quinqueloculina disparalis* d'Orbigny, stunted and deformed (7) versus normal (8) specimen. **9, 10** *Cycloforina villafranca* (Le Calvez, J. et Y.), normal (9) versus highly deformed (10) specimen. **11.** *Quinqueloculina* sp. 1, distorted chamber arrangement, with two additional apertures (arrows). **12.** Specimen exhibiting very great deformation possibly *Adelosina cliarensis* (Heron-Allen et Earland). **13.** *Peneroplis planatus* (Fichtel et Moll), twinning. **14, 15.** *Cycloforina* sp. 2, distorted chamber arrangement (14), and aberrant chamber shape. **16, 17.** *Triloculina earlandi* Cushman, specimen with additional chamber (16) versus normal specimen (17).

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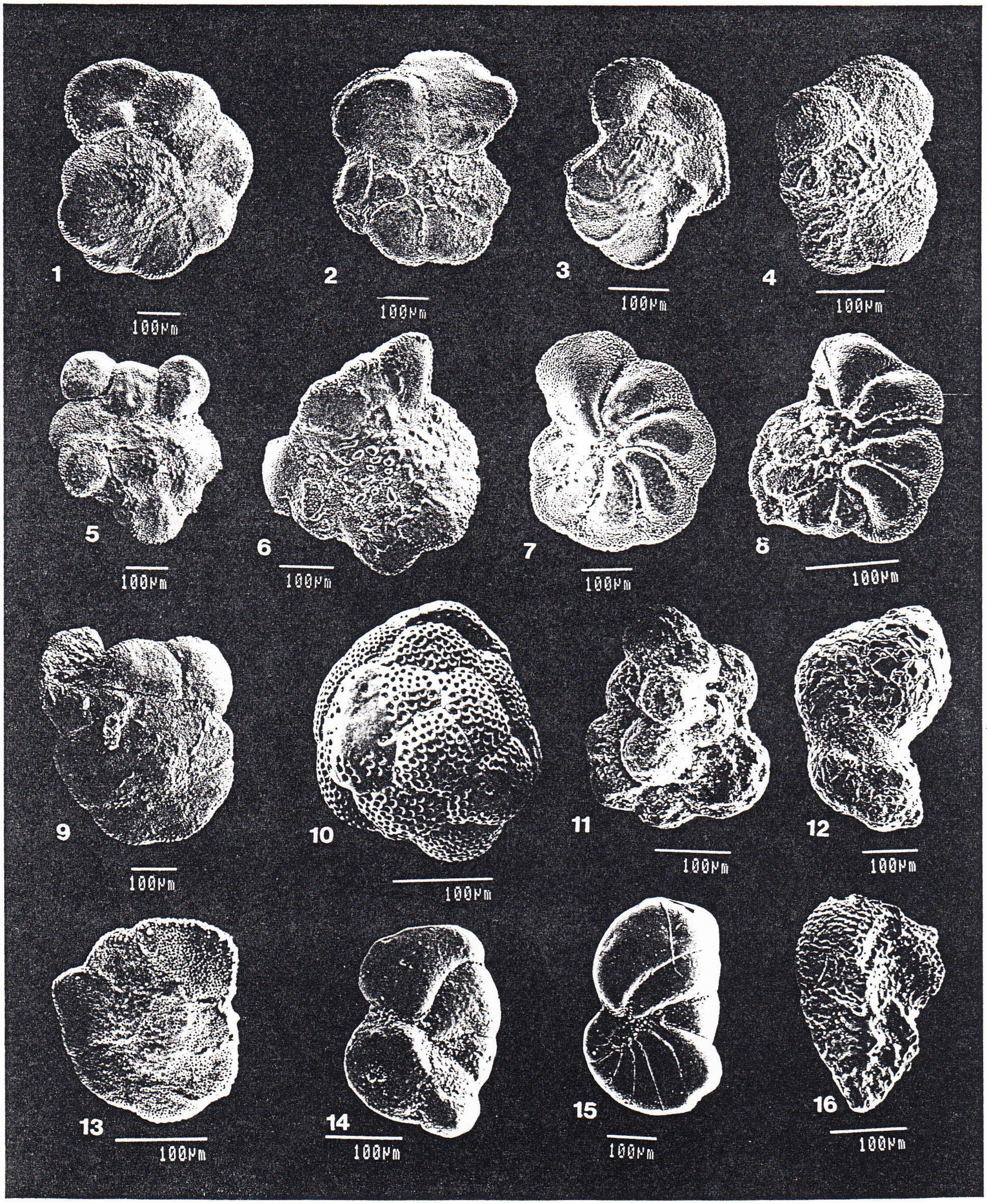

PLATE 2

Examples of test abnormalities in living foraminifera found at station 27 in Haifa Bay. **1–9.** *Eponides repandus* Fichtel et Moll, normal specimen (1 - dorsal side, 7 - ventral side) versus non-developed (2–4, 8), distorted chamber arrangement (5), and additional chamber (6 and 9). **10, 11** *Planorbulina mediterranensis* d'Orbigny, normal specimen (10) versus specimen with distorted chamber arrangement (11). **12** *Eggerella bradyi* (Cushman), distorted chamber arrangement. **13, 14** *Lobatula lobatula* (Walker et Jacob), specimen with one aberrant chamber shape on dorsal side (13), and additional chamber on ventral side (14). **15** *Nonionella atlantica* Cushman, specimen with two chambers of aberrant chape. **16** *Brizalina* sp. 1, specimen with distorted right side of the test.

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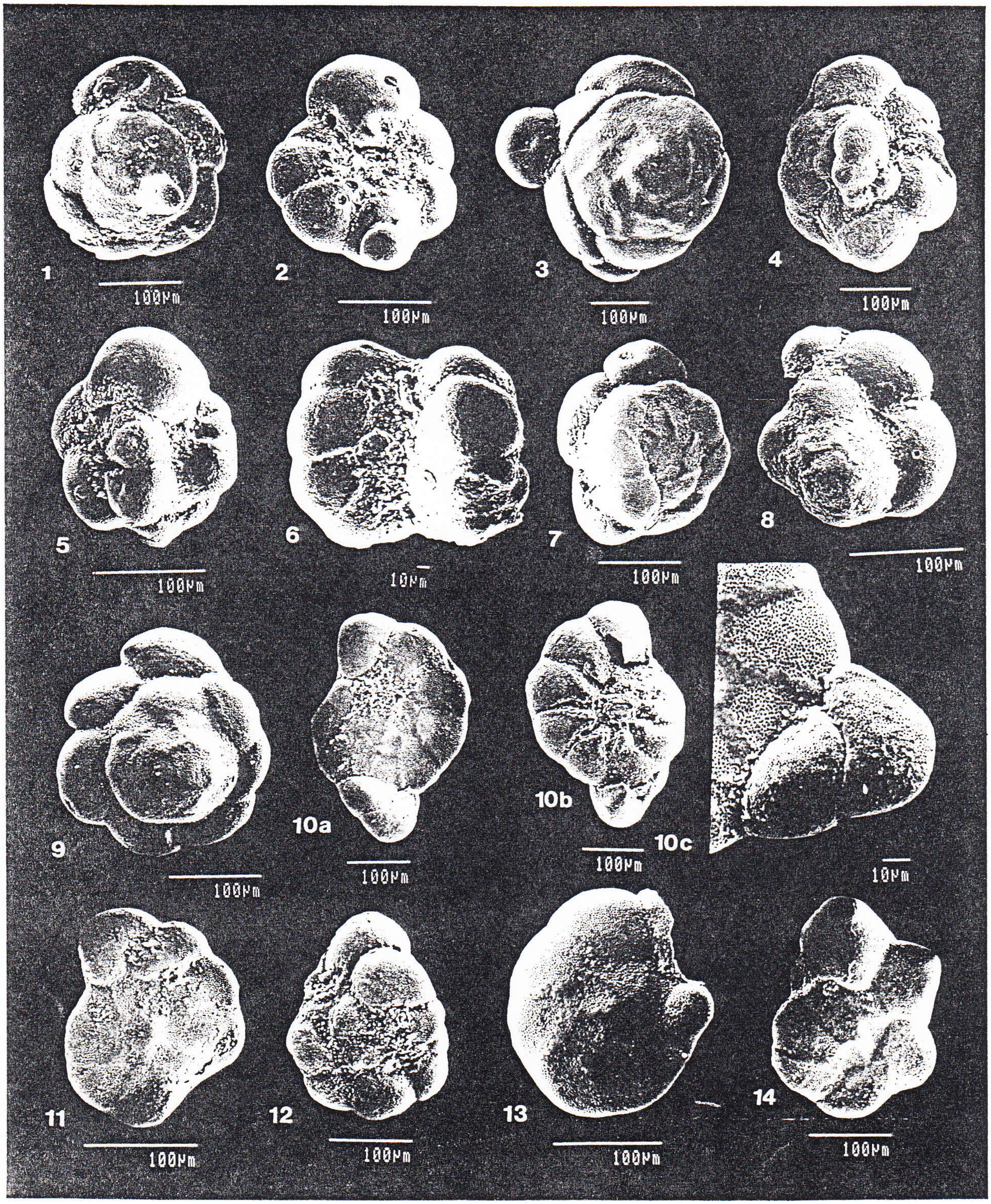

PLATE 3

Examples of test abnormalities in living foraminifera of *Ammonia* found at station 27 in Haifa Bay. **1–9** *Ammonia tepida* (Cushman), specimens with anomalous protuberance (1-dorsal side, 2-ventral side), additional chamber on the dorsal side (3), twisting on the entire side (4 and 7), twisting of the last whorl (5), twins (6), non-developed test (8), and aberrant shape of the last two chambers (9). **10–14.** *Ammonia compacta* Hofker, additional chambers (10a and 10c - dorsal side, 10b - ventral side), non-developed test (11), twisting of the test (12), protuberance on dorsal side (13), aberrant shape of the last three chambers (14).

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Palmahim, though it was sampled during the same season. Station 19/90 suffered less serious pollution than did station 27/91. It did not exhibit pyritization nor abnormalities as did station 27/91, though the total number of species encountered was fewer. Part of this may be because it was sampled during the winter. Yet, Station 19/90 is responding to stress conditions as indicated by stunted forms and a high percentage of megalospheric forms. The most stunted foraminiferal tests were characteristic of the area contaminated by heavy metals.

Agglutinated foraminifera were more abundant at Site 4 (domestic waste) compared to the other sites. In no case did agglutinated foraminifera dominate. It has been suggested that the wide distribution of the more primitive agglutinated foraminifera may be related to their higher tolerance to environmental stress. The dominant role of agglutinated foraminifera at pollution sites in cold water was noted previously (Watkins, 1961; Bandy and others, 1964a, b; 1965a, b; Schafer, 1970; Resig and others, 1980; Resig, 1981; Mayer, 1980; Nagy and Alve, 1987; Alve, 1991a, b). However, other studies, which have been carried out in warm water, notably investigations near the Ionian Islands (Dermitzakis & Alapousou, 1987) and offshore Trivandrum (Kameswara Rao & Satyanarayana Rao, 1979) did not find any dominance of agglutinated foraminifera. Likewise in our study, we did not find that either.

Pyritization

Spot pyritization was characteristic of the trace metal contaminated site. Under anoxic conditions, where H_2S was present, pyrite formation would be expected. In anoxic environments such as found in the Black Sea, pyrite formation in and upon foraminiferal tests is common (Yanko and Kravchuk, 1992). However, in Haifa Bay anoxic condition did not prevail (Cavari and others, 1983). The pyritized tests were collected from the uppermost surface sediment, so that oxygen depletion due to burial should not be expected. Explanations for spot pyritization in oxygenated waters have been reviewed by Alve (1991a). Referring to the work of Seiglie (1975) she has proposed an explanation for the presence of pyritization in living foraminifera in Sorfjord, which also appears to be applicable to Haifa Bay. This is not an anoxic fjord, but one that is very highly polluted by trace metals. It was proposed that this was biologically stressful to the organism, enabling bacteria to attack their cytoplasm. Though the marine environment provides sufficient oxygen for foraminiferal life functions, the bacteria sets up a reducing microenvironment in the bacterially invaded portions of the organism. That the trace metals do weaken the foraminifera within Haifa Bay was readily apparent by the stunting of the test size and the morphological deformations. Reactive iron is available in the Bay. Therefore, it appears that spot pyritization upon living foraminifera may denote incipient disease brought upon by environmental poisoning.

Morphological Abnormalities

Alve (1991a) and Sharifi and co-workers (1991) working in areas polluted by trace metals have similarly encountered test abnormalities. They have correlated the abnormalities to the high levels of trace metals pollutants. They worked in cold water environments, while the present study was carried out in the warm Mediterranean Sea. This demonstrates that the phenomenon occurs independently of temperature. The type of deformities found in the present study, were not entirely identical to those reported by Alve. A wider range of anomalies was encountered here. Sharifi (1991) and his group on the basis of a culture experiment using Cu concluded that: "it can be inferred with confidence that foraminiferal species can be used as indicators for heavy metal pollution. . .". We concur with this observation, although we are aware that morphological abnormalities can also be caused by other pollutants such as crude petroleum (Venec-Peyre, 1981) or organic matter (Caralp, 1989). Boltovskoy and others (1991) found that abnormalities may be a result of multiple affects and that it would be very difficult to isolate any single specific cause. Only controlled laboratory culture experiments (as are being currently carried out at Tel Aviv University) can resolve the morphological reaction of the foraminiferal test to specific degrees and types of pollution.

Foraminiferal assemblages at all stations are dominated by shallow water species from the families *Rotaliidae, Elphidiidae, Spiroloculinidae,* and *Hauerinidae.* Abundant species such as *Ammonia tepida* and *Triloculina marioni* appear to be the most resistant to pollutants. Others species (*Adelosina cliarensis, Quinqueloculina williamsoni, Q. Viennensis*) appear to be somewhat tolerant to coal pollution. In general, those species that are frequently represented by only a few individuals are opportunistic species. However, even these species are found to exhibit test abnormalities in the area polluted by heavy metals.

The most severe response to pollution was found near the Qishon Harbor of Haifa Bay (Station 27/91). In this region a whole suite of biologically active trace metals were added by industrial pollution, much transported by the Qishon river (Kronfeld and Navrot, 1975). The sediments in which the foraminifera were recovered exhibited high concentrations of trace metals. The uptake of these trace metals by the foraminifera that feed off of the sediment, can explain the spot pyritization, stunting of the test, and the test abnormalities.

Preliminary chemical comparisons between deformed and non-deformed varieties of various species has suggested that the deformed specimens incorporated higher concentrations of Mg, S and, perhaps other elements from the sea water into their tests (Yanko and Kronfeld, 1992, 1993; Yanko and others, 1992a) compared to non-deformed varieties. This will be reported later.

Percentage of Megalospheric Tests

Foraminifera can reproduce by sexual and asexual modes. The asexual cycle leads to the generation of megalospheric forms. Furssenko (1978) has suggested that under stressed conditions the asexual cycle is preferred. The causes of stress can be multiple and include for example a decrease in salinity (Yanko, 1989, 1990), and decreased nutrients (Furssenko, 1978). Trace metal pollution might also stress the foraminifera by causing cellular injury. An injured cell may exhibit a variety of responses to the injury.

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In sum this may lead to a decrease in the efficiency of its energy metabolism and protein synthesis (Ganote and Vander Heide, 1987). Life-support systems then function at a reduced level (Baserga, 1985). Therefore, meiosis may be considered a luxury (Effrussi and Farber, 1975) compared to mitosis. In the present study, it was found that megalospheric forms of *Ammonia tepida* were entirely dominant at station 27/91 where the toxic trace metal pollution was prevalent. The high percentage of megalospheric forms appears to be characteristic of stressed environments in our local study area. Culture experiments should be carried out to work out the actual reproductive cycles to test if this is a universal feature.

CONCLUSIONS

The differences in foraminiferal response noted at the various polluted sites was due to contamination of the environment and not due to seasonal or oceanographic conditions. The present study supports the feasibility of studying benthic foraminifera as a technique for the *in situ* continuous monitoring of near shore marine pollution. Industrial pollution, especially by coal and heavy metals, has a deleterious effect upon the foraminifera. This is denoted by a reduced population diversity and density. Stunting of the tests, pyritization, and the presence of anomalous morphologies is strictly related to a trace metal contaminated environment. On the other hand, the foraminifera responded positively to the presence of domestic sewage. Apparently they accept it as a nutrient source. The Mediterranean has been considered as a nutrient deficient sea (Berman and others, 1984; Krom and others, 1991). The added nutrient supply enables the foraminifera, feeding off of the organic waste, to realize their full growth potential. If this is indeed so, the inference may be drawn that benthic foraminifera may be useful not only for detecting anthropogenic pollution, but also natural organic pollution as well. Anomalously large test sizes and species abundance may potentially indicate the presence of naturally occurring organic material. Such may be the case where natural gas seepages occur in the shallow marine environment (Yanko and Flexer, 1991). Therefore, the study of shallow water benthic foraminifera has a wide, as yet not completely realized, potential in a variety of fields where the monitoring of the present marine environment or analysis of the paleomarine section is required.

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APPENDIX 1.

Distribution of foraminifera along Israeli cost of the eastern Mediterranean. See Appendix 2 for explanation of taxon name abbreviations.

Sampling station	H1	H2	H3	H4	H5	H6	H5c	H11c	27/91	19/90
Month/year				05.1986					09.91	01.90
Water depth (m)	24.0	24.0	24.0	24.0	24.0	24.0	30.4	17.5	12.0	6.0
Species	Species percentage (calculated for non-living population)									
EGADV	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.3	0.0
EGBRA	0.0	1.4	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0
EGsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HAPCA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LABSU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAGAT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 1. Continued.

Sampling station	H1	H2	H3	H4	H5	H6	H5c	H11c	27/91	19/90
Month/year				05.1986					09.91	01.90
Water depth (m)	24.0	24.0	24.0	24.0	24.0	24.0	30.4	17.5	12.0	6.0
LAGFU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
REOSC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEXAG	0.0	0.0	0.0	0.0	0.0	2.0	0.3	0.0	0.0	0.0
TEXBO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
TEXCO	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.0
TEXsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TROINF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ADECL	78.0	4.3	21.4	0.0	33.6	29.0	6.7	0.0	0.7	10.7
ADEDU	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
ADEDUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ADEINT	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
ADEME	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
ADEPU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
AMBEC	0.0	0.0	21.4	0.0	1.0	0.0	6.7	0.0	0.0	0.0
AMCOM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AMPAR	11.0	0.0	0.0	0.0	0.0	0.0	6.7	0.6	0.0	0.0
AMTEP	0.0	36.2	0.0	0.0	6.5	28.0	36.4	29.8	65.0	45.7
AMPSC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARTALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARTsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARTsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
ASMAM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
ASTSTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AUBPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOLDA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
BOLDO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
BOLVA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.7	0.0
BRIZST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
BRsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BUCFRI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BUCGRA	0.0	1.4	7.1	0.0	1.0	0.0	1.3	0.0	0.0	0.7
BULEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BULMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3
CAPAR	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	3.0	0.0
CIBADV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.7
CORINV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CORsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
CRITRA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRIsp.1	0.0	0.0	7.1	0.0	3.7	0.0	1.7	0.6	0.0	0.0
CRIsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
CRIPOE	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	1.3
CYCTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CYCVIL	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CYCsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0
CYCsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
DENsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DENsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EDECU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EDsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELADV	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.7
ELCRI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELJEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELMAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
ELMAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
ELSTP	0.0	1.4	0.0	0.0	3.7	0.0	1.3	0.0	0.0	0.0
EPCON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EPORE	0.0	4.3	0.0	0.0	2.0	5.8	5.0	15.1	1.4	6.0
EPsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ESsp.1	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FISsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FURAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GAVPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GLOGI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
GLOsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GRIPIR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GUTLA	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
GUTPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HAYAN	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.3	0.3
HAYDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.3
HAYsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
HETsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYAGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAGDO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAGINT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAGsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LENCU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LENGIB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 1. Continued.

Sampling station	H1	H2	H3	H4	H5	H6	H5c	H11c	27/91	19/90
Month/year				05.1986					09.91	01.90
Water depth (m)	24.0	24.0	24.0	24.0	24.0	24.0	30.4	17.5	12.0	6.0
LENsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LOBLO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MASSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MILEL	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	4.5	0.0
NEOTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
NOATL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.3
NOOPI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOTUR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
NODAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
NODsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NONMA	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.3	0.0	0.0
NONsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NONsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NONsp.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NUMsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOLGL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ORTsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PENPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
PLLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLMED	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.3
PLsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
POLsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POLsp.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POLsp.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POSUM	11.0	13.2	14.0	0.0	2.4	0.0	3.3	2.6	0.3	4.3
PROPU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
PSTOB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUBER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	6.3
QUBOS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
QUCAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUCOS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUDISP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
QUERIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
QUKER	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QULAE	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
QUPAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUPHO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUPOL	0.0	0.0	0.0	0.0	0.0	2.0	0.3	0.0	0.0	0.0
QURAD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUSAG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
QUSEM	0.0	0.0	29.0	0.0	5.6	0.0	0.0	40.6	0.0	0.0
QUSTE	0.0	0.0	0.0	0.0	7.5	0.0	4.0	0.0	1.0	5.3
QUVIE	0.0	14.5	0.0	0.0	0.0	15.4	15.0	0.0	0.0	0.0
QUVUL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUWIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
RECEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
REUSP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROSBR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	1.0
ROSGL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROSMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
SIGED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIPHAG	0.0	5.8	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
SIPHRE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIPHAS	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
SIPHsp.1	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIPHORE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPICYM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.0
SPIDIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPIORN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPIROS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRADR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRBUL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
TREAR	0.0	0.0	0.0	0.0	0.0	10.0	0.7	2.4	0.3	0.3
TRMAR	0.0	5.8	0.0	0.0	10.0	5.8	7.0	2.5	1.3	2.0
TRROT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRSHR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRWIL	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	1.5	0.0
TRsp.2	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
TRsp.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRICsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
VALBRA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VERST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WEBHE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No species	3	16	6	0	19	9	22	13	44	28
No individuals	12	69	21	0	107	52	299	305	1,720	1,520

APPENDIX 1. Continued.

Sampling station	H1	H2	H3	H4	H5	H6	H5c	H11c	27/91	19/90
Month/year				05.1986					09.91	01.90
Water depth (m)	24.0	24.0	24.0	24.0	24.0	24.0	30.4	17.5	12.0	6.0
S-W index (H')	0.30	0.93	0.65	0	1.07	0.65	0.93	0.69	0.81	0.93
Evenness (E)	0.44	0.16	0.32	0	0.15	0.21	0.11	0.15	0.05	0.09

Sampling station	N1	N2	N20	N50	P20	P4	P5	P6	P7	P35	P50
Month/year					September 1991						
Water depth (m)	33.0	34.0	20.0	50.0	20.0	38.0	36.5	38.4	34.5	35.0	50.0
Species	Species percentage (calculated for non-living population)										
EGADV	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EGBRA	1.3	1.3	1.3	18.0	0.0	4.7	2.0	2.0	1.0	1.0	7.7
EGsp.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HAPCA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
LABSU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LAGAT	0.3	0.0	0.0	0.0	0.0	0.3	1.0	0.0	1.0	0.3	0.0
LAGFU	1.7	1.3	0.0	15.0	0.0	0.0	1.0	1.0	1.0	1.4	7.0
REOSC	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7
TEXAG	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEXBO	10.0	7.3	0.3	3.7	0.0	6.0	8.7	11.0	10.0	4.3	4.0
TEXCO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEXsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
TROINF	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.3	0.7
ADECL	6.7	7.3	3.5	0.3	0.0	5.0	14.0	12.0	2.3	3.0	0.7
ADEDU	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ADEDUT	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0
ADEINT	0.0	2.3	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
ADEME	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	7.3	8.0	5.0
ADEPU	0.3	0.3	0.0	0.0	0.0	0.7	0.0	0.0	0.0	1.0	0.3
AMBEC	3.3	1.3	0.0	0.0	0.0	10.3	6.7	0.0	1.3	2.3	0.0
AMCOM	0.0	0.0	0.0	5.7	0.0	0.0	0.0	6.7	0.0	0.0	1.3
AMPAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AMTEP	19.8	20.7	46.7	16.0	0.0	20.7	24.3	16.7	25.1	26.4	10.1
AMPSC	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.7	0.7
ARTALT	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARTsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
ARTsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ASMAM	1.7	3.0	0.0	3.3	0.0	2.3	2.7	3.0	0.7	0.7	1.0
ASTSTE	0.0	0.0	0.0	0.3	0.0	2.7	1.3	0.0	0.0	0.0	2.0
AUBPE	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
BOLDA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOLDO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOLVA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BRIZST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BRsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
BUCFRI	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BUCGRA	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.7	0.7	0.7
BULEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
BULMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CAPAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CIBADV	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
CORINV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
CORsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRITRA	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRIPOE	1.7	0.0	0.0	7.3	0.0	2.3	1.0	4.0	1.0	0.3	6.0
CRIsp.1	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
CRIsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CYCTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
CYCVIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CYCsp.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CYCsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DENsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
DEsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
EDECU	0.7	2.0	2.7	2.7	0.0	0.0	0.0	0.3	0.3	1.7	0.3
EDsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
ELADV	0.3	0.0	0.0	0.0	0.0	1.0	0.3	0.0	1.0	0.3	0.7
ELCRI	0.3	1.5	0.0	0.0	0.0	0.7	2.0	1.0	0.0	0.0	0.7
ELJEN	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
ELMAC	0.3	0.0	0.0	0.3	0.0	1.0	0.0	0.0	1.3	0.7	0.0
ELMAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELSTP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EPCON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
EPORE	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EPsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
ESsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FISsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
FURAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
GAVPR	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.0	0.0	0.0	0.0
GLOGI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GLOsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3

APPENDIX 1. Continued.

Sampling station	N1	N2	N20	N50	P20	P4	P5	P6	P7	P35	P50
Month/year	September 1991										
Water depth (m)	33.0	34.0	20.0	50.0	20.0	38.0	36.5	38.4	34.5	35.0	50.0
GRIPIR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
GUTLA	0.3	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.7	0.0	1.7
GUTPR	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
HAYAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HAYDE	1.3	0.0	0.3	2.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3
HAYsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HETsp.1	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0
HYAGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LAGDO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LAGINT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LAGsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LENCU	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LENGIB	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
LENsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
LOBLO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
MASSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
MILEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NEOTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOATL	0.3	0.0	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.7	0.0
NOOPI	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3
NOTUR	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	1.0
NOsp.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NODAN	0.3	0.0	0.0	1.0	0.0	0.0	0.0	0.3	1.0	1.0	1.0
NODsp.1	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NONMA	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	1.0	0.0	0.3
NONsp.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NONsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
NONsp.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
NUMsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
OOLGL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
ORTsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
PENPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLLAR	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.7
PLMED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POLsp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
POLsp.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
POLsp.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POSUM	13.0	10.0	8.3	9.3	0.0	18.4	11.3	6.0	4.0	13.3	7.0
PROPU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PSTOB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
QUBER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUBOS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUCAN	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUCOS	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUDISP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 1. Continued.

Sampling station	N1	N2	N20	N50	P20	P4	P5	P6	P7	P35	P50
Month/year	September 1991										
Water depth (m)	33.0	34.0	20.0	50.0	20.0	38.0	36.5	38.4	34.5	35.0	50.0
QUERIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
QUKER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QULAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUPAR	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUPHO	0.0	3.3	0.7	0.0	0.0	0.0	3.0	3.3	1.0	10.0	0.3
QUPOL	0.7	0.0	0.3	0.7	0.0	0.0	0.0	0.3	0.0	0.0	0.3
QURAD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
QUSAG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUSEM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUSTE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUVIE	4.4	3.7	10.3	0.0	0.0	2.0	3.0	3.3	1.3	1.7	0.0
QUVUL	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QUWIL	4.0	8.3	1.3	1.7	0.0	2.3	1.0	3.3	0.0	0.0	0.0
QUsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RECEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
REUSP	1.0	0.3	0.0	0.3	0.0	1.3	0.7	1.0	1.7	0.0	0.3
ROSBR	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROSGL	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7
ROSMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIGED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
SIPHAG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIPHRE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIPHsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
SIPHORE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
SPICYM	1.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
SPIDIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0
SPIORN	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.3	3.3
SPIROS	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0
TRADR	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRBUL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TREAR	3.0	0.3	1.7	0.0	0.0	0.0	1.7	0.0	0.7	0.0	0.3
TRMAR	14.3	18.3	7.3	5.0	0.0	12.3	7.3	15.1	15.3	10.7	8.0
TRROT	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRSHR	3.3	3.3	1.3	0.0	0.0	2.0	2.9	6.6	10.0	6.0	6.0
TRWIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRsp.2	0.7	0.0	0.0	0.0	0.0	1.5	0.0	0.7	1.7	0.0	1.0
TRsp.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRICsp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VALBRA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
VERST	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WEBHE	0.0	0.0	1.7	0.8	0.0	0.0	0.0	0.5	0.0	0.0	0.0
No species	37	25	36	26	0	27	29	25	38	32	61
No individuals	5,000	6,390	161	756	0	2,500	5,400	3,529	3,333	8,290	4,670
S-W index (H')	1.19	1.11	0.95	1.11	0	1.11	0.94	1.13	1.16	1.04	1.45
Evenness (E)	0.09	0.12	0.07	0.11	0	0.11	0.09	0.12	0.08	0.09	0.0

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