Spatial and Temporal Variations of Foraminifers as an Indicator of Marine Pollution

Im Chul Shin and Hi-Il Yi

Korea Ocean Research and Development Institute (KORDI), Marine Geology and Geophysics Division, Ansan P.O. Box 29, Seoul 425-600, Korea

(Manuscript received 20 October, 1998)

Abstract

Sediment samples from five stations at the Shihwa Lake sewage outfall, west coast of Korea, were collected to evaluate the effect of the outfall on benthic foraminifers. Heavy metal (Cu and Zn) polluted the eastern part of the Shihwa Lake, adjacent to the Shihwa-Banwol Industrial Complexes, shows barren or nearly barren of benthic foraminifers, and the lowest number of species both at the core top and downcore. Excepting for the barren zone, pyritized benthic foraminifers abundantly occur both at the surface and downcore sediments in the western part of the Shihwa Lake, suggesting that foraminiferal disease by anoxic bacteria.

Recent intrusion of pollutants from the Shihwa-Banwol Industrial Complexes and adjacent six major streams severely polluted the Shihwa Lake as shown by the low abundance (number/10 g) of benthic foraminifers, low number of *Ammonia beccarii*, low species diversity, and absence of both *Elphidium* spp. and ostracodes at the surface sediments compared to the downcore. Except the barren zone, both pyritized and non-pyritized *Ammonia beccarii* occur dominantly in the surface sediments and downcore. *Elphidium* spp. (either pyritized or non-pyritized) do not occur in the surface sediments of whole stations. However, they occur from the entire downcore sediments except in the eastern part of Shihwa Lake. Arenaceous foraminifers do not inhabit in the heavily polluted areas as evidenced by the occurrence of relatively deep core depth (11-50 cm). Ostracodes occur at the downcore sediments, but they do not occur at the surface sediments. Ostracodes also do not occur at the heavily polluted areas in the eastern part of the Shihwa Lake both at the surface and downcore sediments, indicating that the abundance of ostracodes also can be used for a pollution indicator.

1. Introduction

The foraminifers are members of the Order Foraminiferida, Subclass Rhizopoda, Class Sarcodina, Phylum Protozoa, and Kingdom Protista. They constitute about 2.5% of all animals known from the Cambrian to the Recent (Boltovskoy and Wright, 1976). Foraminifers, which have a sand-sized test, are consist of calcium carbonate. There are two types of foraminifers based on their life mode. Planktonic foraminifers live in the surface water column (surface to down approximately 1000 m water column). Benthic foraminifers live in the bottom of the ocean, especially above carbonate compensation depth (CCD). Foraminifers inhabit from the tropical to Antarctic (also Arctic) surface and bottom water. Foraminifers also tolerate wide ranges of salinity conditions. They live 0.1 to 70‰ of salinity values. But foraminifers most commonly occur at normal marine salinity value (35‰). Many physical and chemical variables control the distribution and abundance of foraminifers. However, three major factors (temperature, salinity, and dissolved oxygen content) significantly control the distribution patterns of planktonic and benthic foraminifers. Therefore, the distribution patterns of foraminifers in the sediments (also rocks) can be used as paleoecology, paleodepth, paleooceanography, paleoclimatology indicators.

Recently, foraminifers are widely used as pollution indicator in different environmental settings (Bandy, 1963; Seiglie, 1968, 1973; Bates and Spencer, 1979; Ellison *et al.*, 1986; Sharifi *et al.*, 1991; Alve, 1991, 1995; Yanko *et al.*, 1994; Collins *et al.*, 1995; Culver and Buzas, 1995; Scott *et al.*, 1995). There are several advantages of pollution studies by foraminifers. These are: (1) ubiquitous in marine environments, (2) lives on and in the sediment, which receives and stores much of pollutants, (3) wide range of taxonomic diversity, (4) to posses hard shelled tests which can be well preserved, (5) to provide statistically significant populations and easily collectable, (6) very short reproductive cycles (month to year), and (7) inexpensive for study (Yanko *et al.*, 1994). To date, systematic studies of the influence of pollution upon foraminiferal populations have addressed: (1) industrial wastes, (2) agricultural and domestic waste, (3) paper processing, (4) effects of oil-gas seepages from sediments, and (5) effects of trace metal contaminated sediments (Yanko *et al.*, 1994).

The aim of this study is to document the effect of pollution on the benthic foraminifers in the Shihwa Lake. No previous foraminiferal studies in the study area have been published.

2. Hydrography of the Shihwa Lake

The Shihwa Lake is located in the eastern part of Yellow Sea (the western part of the Korea Peninsula) (Fig. 1). The Shihwa Lake is approximately 25 km long and 4 km wide.

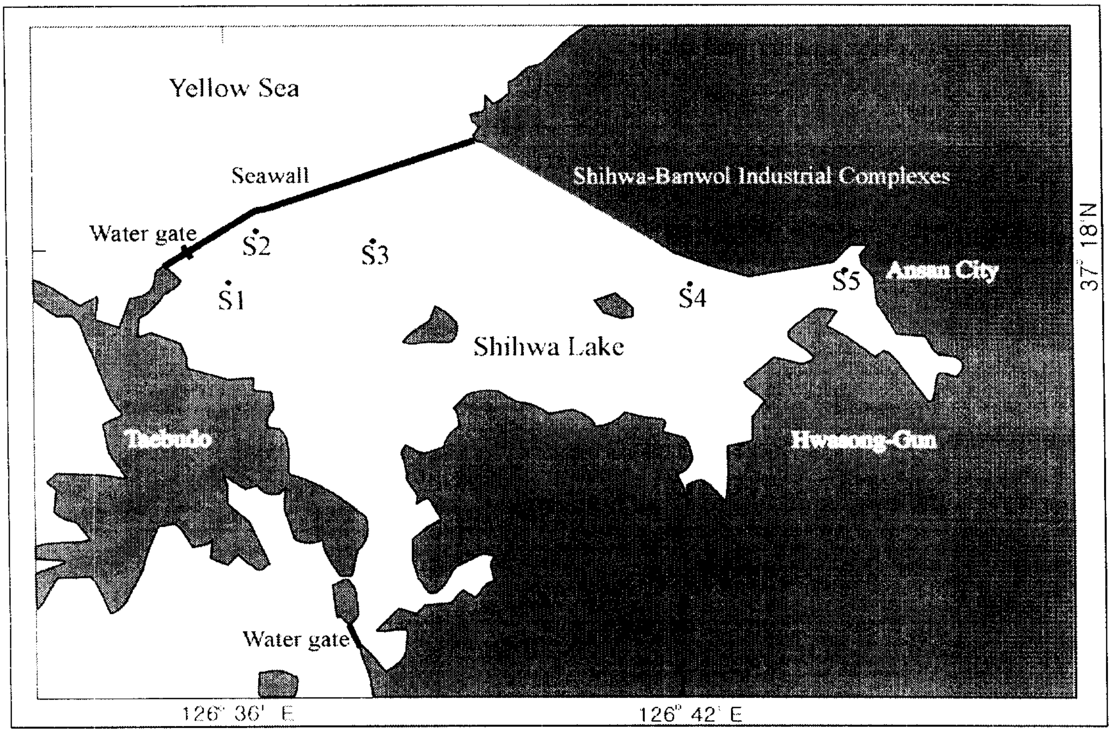

Fig. 1. Location map of study area.

The water depth ranges from 4 m to 18 m (Korea Ocean Research and Development Institute, 1998). The surface water temperature ranges from 3.0°C (December) to 29°C (August). The surface water salinity lies between 1.5‰ (September) and 24.8‰ (December) (KORDI, 1998). The bottom water temperature ranges between 20.9°C (August) and 3.0°C (December). The average salinity in bottom water in March, 1997 was 26.8‰ (KORDI, 1998).

The Shihwa Lake was an estuarine environment (called the Banwol tidal flat) before the Shihwa Seawall was completed in January, 1994. After the completion of the Shihwa Seawall, the Shihwa Lake has started a restricted circulation. As a result, the surface water (surface to approximately 5 m water depth) of the Shihwa Lake is brackish, while the bottom water contains saline water (Park *et al.*, 1997).

Marginal marine environments, especially estuaries, have conventionally served as recipients for domestic and industrial effluents (Alve, 1995). The Shihwa Lake receives an enormous amount of industrial pollutants from the neighboring Shihwa-Banwol Industrial Complexes, and almost untreated domestic sewage from the municipal areas enters the lake through six major streams (KORDI, 1997, 1998). The Shihwa-Banwol Industrial Complexes were built during the middle of 1980th.

These Industrial Complexes and six major streams release approximately 300 million tons of domestic and industrial waste into the Shihwa Lake per year (Park *et al.*, 1997). As a result, the water in the Shihwa Lake is heavily polluted (Huh and Oh, 1997) and the bottom water has an anoxic to hypoxic condition (Park *et al.*, 1997). Therefore, the Shihwa Lake is a good place to study the response of benthic foraminifers to the various pollutants. Sediments in the Shihwa Lake are mainly brownish- to dark-colored organic-rich mud and sandy mud (KORDI, 1998).

3. Materials and Methods

Sediments, approximately 10 cm sampling intervals, from five short piston cores, which were collected in August of 1997, are used for the benthic foraminiferal studies. Five stations are selected. Two stations (S4 and S5) are located near the sewage outfall of Shiwha-Banwol Industrial Complexes and streams from municipal areas. The other three stations (S1, S2, and S3) are located around the Seawall (Fig. 1). The water depths of stations S1, S2, S3, S4, and S5 are 7, 17, 9, 4, and 4 m, respectively (Table 1).

Table 1. Latitude, longitude, water depth, and core length in each station.

Station	Latitude	Longitude	Water Depth (m)	Core Length (cm)
S1	37°17.572' N	126°36.142' E	7	30
S2	37°18.349' N	126°36.723' E	17	57
S3	37°18.166' N	126°39.335' E	9	73
S4	37°17.390' N	126°45.888' E	4	78
S5	37°17.792' N	126°44.382' E	4	65

Approximately 2-4 g dried sediments were used for the study of benthic foraminifers. The coarse fraction content (>63 μm) in the sediment, abundance (number/10 g), species composition, and species number of benthic foraminifers, number of pyrite-filled foraminifers, and number of ostracodes are counted and identified (Tables 2 and 3). Benthic foraminifers are picked from greater than 63 (μm size fraction. Every sample contains less than 300 specimens of benthic foraminifers. Their raw counts are shown in Table 2 and converted value per 10 g sediments is shown in Table 3. The number of ostracodes greater than 63 μm size fraction is also counted.

4. Results and Discussion

4.1 Benthic foraminifers at the surface and downcore sediments

The eastern part of the Sihwa Lake (S4 and S5), which is located adjacent to the Shihwa-Banwol Industrial Complexes, contains barren or nearly barren of benthic foraminifers at the

Table 2. Raw counts of benthic foraminifers: The downcore depth, the original dry weight, the weight and relative percentage of coarse fraction content in the sediments, the number of ostracodes, and the number of benthic foraminiferal species are listed. Numbers without parenthesis denotes the raw counts of total (pyritized+non-pyritized) number of each species. Numbers with parenthesis denotes the raw counts of pyritized species.

Stations	S1	S1	S1	S1	S2	S2	S2	S2	S2	S2	S3	S3	S3	S3	S3	S4	S4	S4	S4	S4	S4	S4	S5	S5	S5	S5	S5	S5	S5
Core depth (cm)	0-1	10-11	20-21	29-30	0-1	5-6	11-12	29-30	41-42	45-46	0-1	10-11	29-30	50-51	70-71	0-1	5-6	12-13	20-21	29-30	50-51	70-71	0-1	10-11	20-21	29-30	40-41	50-51	60-61
Dry weight (g)	2.44	1.90	2.86	2.19	1.76	1.94	2.98	2.52	3.77	3.26	3.35	3.18	2.75	2.93	3.19	1.42	1.78	2.92	2.06	2.06	1.69	1.79	1.90	1.82	2.29	2.36	2.10	2.70	3.03
Coarse fraction (>63μm) (g)	0.04	0.17	0.96	0.89	0.26	0.14	1.02	0.93	1.93	1.32	1.57	0.71	0.49	0.48	1.22	0.01	0.01	0.05	0.38	0.02	0.02	0.02	0.04	0.04	0.02	0.16	0.05	0.40	0.20
Coarse fraction (%)	1.43	9.16	33.57	40.34	14.71	7.37	34.36	36.82	51.17	40.58	46.79	22.36	17.66	16.22	38.25	0.42	0.45	1.61	18.37	0.97	1.18	1.34	2.26	1.92	0.66	6.56	2.57	14.78	6.64
Ammonia beccarii	3 (1)	24 (9)	74 (14)	25 (9)	0	2 (1)	37 (9)	39 (18)	44 (25)	49 (27)	16 (6)	33 (28)	60 (60)	26 (26)	21 (21)	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Bolivina striata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B. sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buccella frigida	0	6	7 (1)	2	0	0	0	3 (1)	2	2	1 (1)	4	7 (7)	8 (2)	3 (2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides lobatulus	0	0	1 (1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium advena	0	12 (1)	23	7	0	1 (1)	11 (3)	6	13	4	0	12	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. excavatum	0	0	0	0	0	0	7 (1)	7 (3)	17 (7)	10 (2)	0	0	2 (1)	3 (2)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. kusiroense	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. subincertum	0	5 (1)	3 (2)	2 (2)	0	0	8	13 (3)	10 (5)	14 (4)	0	8 (4)	14 (10)	1	0	0	0	1(1)	0	0	0	0	0	0	0	0	0	0	0
E. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Helenina anderseni	0	0	0	0	0	0	0	0	0	0	1 (1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena laevis	0	0	1(1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oolona sp.	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia nipponica	0	0	0	2	0	0	5	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudononion grateloupi	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina elongata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q. fukushimaensis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q. seminumum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina bradyi	0	0	5 (2)	0	0	0	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. vilardeboana	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rotalinoides annectens	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triloculina laevigata	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina pacifica	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Triloculina rotunda	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostracode number	0	1	3	1	0	0	7	8	13	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total number of foraminifers	3 (1)	47 (11)	114 (21)	39 (11)	0	3 (2)	73 (13)	74 (25)	94 (37)	88 (33)	20 (8)	59 (32)	88 (78)	50 (30)	26 (23)	1	0	2(1)	1	0	0	0	0	0	0	0	0	1	0
Number of foram species	1	4	7	6	0	2	9	10	12	9	5	5	6	6	4	1	0	2	1	0	0	0	0	0	0	0	0	1	0

Table 3. Converted values (number/10 g sediments) of each species in each station: Raw counts are in Table 2.

Stations	S1	S1	S1	S1	S2	S2	S2	S2	S2	S2	S3	S3	S3	S3	S3
depth (cm)	0-1	10-11	20-21	29-30	0-1	5-6	11-12	29-30	41-42	45-46	0-1	10-11	29-30	50-51	70-71
Ammonia beccarii	12 (4)	126 (47)	258 (49)	114 (41)	0	10 (5)	124 (30)	155 (71)	117 (66)	150 (27)	48 (18)	104 (88)	218 (218)	89 (89)	66 (66)
Bolivina striata	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
B. sp.	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
Buccella frigida	0	32	24 (3)	9	0	0	0	12 (4)	5	6	3 (3)	13	25 (25)	27 (7)	9 (6)
Cibicides lobatulus	0	0	3 (3)	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium advena	0	63 (5)	80	32	0	5 (5)	37 (10)	24	34	12	0	38	15	34	0
E. excavatum	0	0	0	0	0	0	23 (3)	28 (12)	45 (19)	31 (6)	0	0	7 (4)	10 (7)	3
E. kusiroense	0	0	0	0	0	0	0	0	0	0	0	0	0	7	3
E. subincertum	0	26 (5)	10 (7)	9 (9)	0	0	27	52 (12)	27 (13)	43 (12)	0	25 (13)	51 (36)	3	0
E. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helenina anderseni	0	0	0	0	0	0	0	0	0	0	3 (3)	0	0	0	0
Lagena laevis	0	0	3 (3)	0	0	0	0	0	0	0	0	0	0	0	0
Oolina sp.	0	0	0	0	0	0	3	0	0	0	0	0	4	0	0
Pararotalia nipponica	0	0	0	9	0	0	17	8	5	6	3	0	0	0	0
Pseudononion grateloupi	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0
Quinqueloculina elongata	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Q. fukushimaensis	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Q. seminuinum	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Rosalina bradyi	0	0	17 (7)	0	0	0	0	4	3	12	0	0	0	0	0
R. vilardeboana	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Rotalinoides annectens	0	0	0	0	0	0	0	0	0	0	3	6	0	0	0
Triloculina laevigata	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Trochammina pacifica	0	0	0	0	0	0	3	4	3	0	0	0	0	0	0
Triloculina rotunda	0	0	0	0	0	0	10	4	0	0	0	0	0	0	0
Ostracode number/10 g	0	5	10	5	0	0	23	32	34	28	0	3	0	0	0
total number/10 g	12 (4)	247 (58)	398 (73)	178 (50)	0	15 (10)	245 (44)	293 (99)	249 (98)	270 (101)	60 (24)	186 (101)	320 (283)	170 (102)	81 (72)

Stations	S4	S4	S4	S4	S4	S4	S4	S5	S5	S5	S5	S5	S5	S5
depth (cm)	0-1	5-6	12-13	20-21	29-30	50-51	70-71	0-1	10-11	20-21	29-30	40-41	50-51	60-61
Ammonia beccarii	7	0	0	5	0	0	0	0	0	0	0	0	0	0
Bolivina striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buccella frigida	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides lobatulus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium advena	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. excavatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. kusiroense	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. subincertum	0	0	3 (3)	0	0	0	0	0	0	0	0	0	0	0
E. sp.	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Helenina anderseni	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena laevis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oolina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia nipponica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudononion grateloupi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina elongata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q. fukushimaensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q. seminuinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina bradyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. vilardeboana	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rotalinoides annectens	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triloculina laevigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina pacifica	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Triloculina rotunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostracode number/10 g	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total number/10 g	7	0	7 (3)	5	0	0	0	0	0	0	0	0	4	0

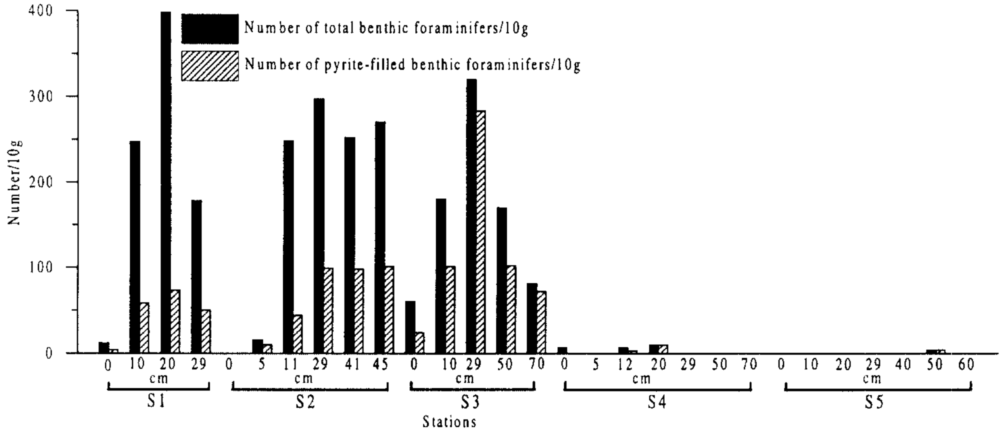

Fig. 2. Surface and downcore values of total and pyritized benthic foraminiferal abundance (number/10 g) in each station.

surface sediment samples compared to those of the western part (S1, S2, S3) (Figs. 1 and 2). Based on the report of the Korea Ocean Research and Development Institute (KORDI, 1997), the eastern part of the Shihwa Lake contains much higher heavy metals (Cu and Zn) compared with the western part. The eastern part contains 0 to 7 and the western part contains 0 to 60 specimens of benthic foraminifers per 10 g dried sediments (Fig. 2 and Table 3).

There are several possibilities for the absence or (nearly absence at station S4) of benthic foraminifers in the surface sediments of the eastern part of Shihwa Lake. Generally, the low number of benthic foraminifers can be found off the outfalls of streams due to the fresh water input (Polski, 1959; Waller, 1960). The monthly average salinity of Shihwa Lake bottom water in March, 1997 is 26.8±1.5‰ (KORDI, 1998). We believe that this salinity value is not a major reason for the absence of foraminifers at the eastern part of Shihwa Lake. Poorly-oxygenated nearshore water contains lower number of benthic foraminifers than the offshore (Blackwelder *et al.*, 1996). The dissolved oxygen (DO) content in the bottom water of Shihwa Lake in February, 1997 was 17.7±1.8 mg/L and in March, 1997 was 1.2±1.5 mg/L. The average DO content from March to August, 1998 was less than 5.0 mg/L (KORDI, 1998). These DO values negate the absence of foraminifers at these stations.

A low number of benthic foraminifers is also associated with high coarse fraction content (Sen Gupta, 1979). In contrary, the eastern part of Shihwa Lake (stations S4 and S5) contains low percentage of coarse fraction content (Fig. 3).

The number of benthic foraminifers increased farther from the sewage outfall areas (Bandy *et al.*, 1964; Bates and Spencer, 1979; Alve, 1991, 1995; Stott *et al.*, 1996). The presence of foraminifers "Dead Zone" with no living benthic foraminifers surrounding the outfall was reported by several previous workers (Bandy *et al.*, 1964; Alve, 1995; Stott *et al.*, 1996). This study shows that the low number (7 specimens/10 g) or barren of benthic foraminifers from the surface sediments occur in just vicinity of the sewage outfall areas (stations S4 and S5).

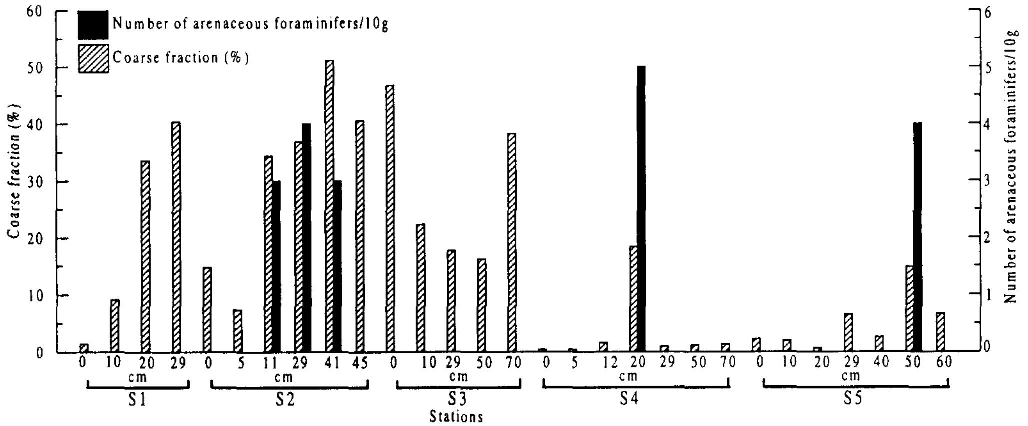

Fig. 3. Coarse fraction (>63 μm) content in sediments and number of arenaceous foraminifers/10 g. Notice the scale differences in y-axis both coarse fraction (%) and number of arenaceous foraminifers (number/10 g).

Surface sediment at station S2, the previous tidal channel located near the Shihwa Seawall, also shows barren of benthic foraminifers (Fig. 2). As shown in Table 1, the water depth of station 2 is 17 m. We do not have dissolved oxygen content at this depth. But, the dissolved oxygen content at 8 m water column, very close to the station 2, is 0.3 mg/L (Park *et al.*, 1997). However, the dissolved oxygen content at 5 m water column of station 1 is 6.5 mg/L and at 4 m water column at station 3 is 8.2 mg/L. Therefore, the absence of foraminifers in the surface sediment of station 2 is probably due to the low oxygen content of the bottom water.

The low number of foraminifers in the eastern part of Shihwa Lake (stations S4 and S5) is due to the heavily polluted nature. Particularly, stations S4 and S5 are located adjacent to the Sihhwa-Banwol Industrial Complexes, and lots of sewage and industrial pollutants are dumped through six major streams. Heavy metal (Cu and Zn) contents in the surface sediment of these stations are very high compared with those of the other stations (KORDI, 1997). These heavy metals prevent the foraminifers from surviving in the eastern part of Shihwa Lake. Increased heavy metal pollution causes not only impoverishment of foraminiferal fauna (Alve, 1991, 1995), but also local extinction (Culver and Buzas, 1995). Seiglie (1973) also showed that the poor in number of living foraminifers on or in the sediment of polluted areas. Therefore, absence of foraminifers at stations S4 and S5 is due to the proximity to the pollution sources

In the eastern part of the Shihwa Lake (stations S4 and S5), the downcore abundance of benthic foraminifers shows almost barren compared with that in the western part (stations S1, S2, and S3). This strongly suggests that the various pollutants severely affected to the bottom sediment in the eastern part of Shihwa Lake compared with those in the western part. Excepting the barren zone (stations S4 and S5), it is clear that the number of benthic foraminifers at the surface sediment shows significantly lower number compared with that of the downcore (Fig. 2). We do not know the sedimentation rate in this area. However, the significantly low number of benthic foraminifers at the surface sediment indicates that the recent input of pollutants in combination with the low salinity due to the Seawall construction in 1994 significantly affected the ecological system and sedimentary environment.

4.2 Pyrite-filled benthic foraminifers at the surface and sedimentary sequences

The total number of pyrite-filled benthic foraminifers per 10 g in the surface and downcore sediments is shown in Fig. 2. Except the barren zone due to the severe heavy metal pollution in the eastern part of the Shihwa Lake (stations S4 and S5), the sediments from the western part (stations S1, S2, and S3) contain pyrite-filled benthic foraminifers both at the surface and of downcore sediments (Fig. 2). Station S1 contains 4 among 12 specimens and station 3 contains 24 among 60 specimens of pyritized foraminifers in 10 g dried sediments (Fig. 2 and Table 3). The pyritization of foraminifers is controlled by localized environmental conditions (Seiglie, 1973). Pyrite is formed in anoxic environment mainly by bacterial activity (Seiglie, 1973; Berner, 1980). Pyritization by bacterial activity inside the foraminiferal test is due to the disease (Seiglie, 1973) and occurs in polluted areas (Seiglie, 1973; Alve 1991). Therefore, the presence of pyrite-filled benthic foraminifers also suggests that the study area be severely affected by pollutants. Hallock *et al.* (1995) reported that if foraminifers are affected by disease, the population densities are declined by 95%.

4.3 Benthic foraminifers assemblages in the surface and core sediments

Except for the barren zone (stations S4 and S5), *Ammonia beccarii* is the most abundant species in the surface and downcore of the Shihwa Lake (Fig. 4 and Table 3). In the surface

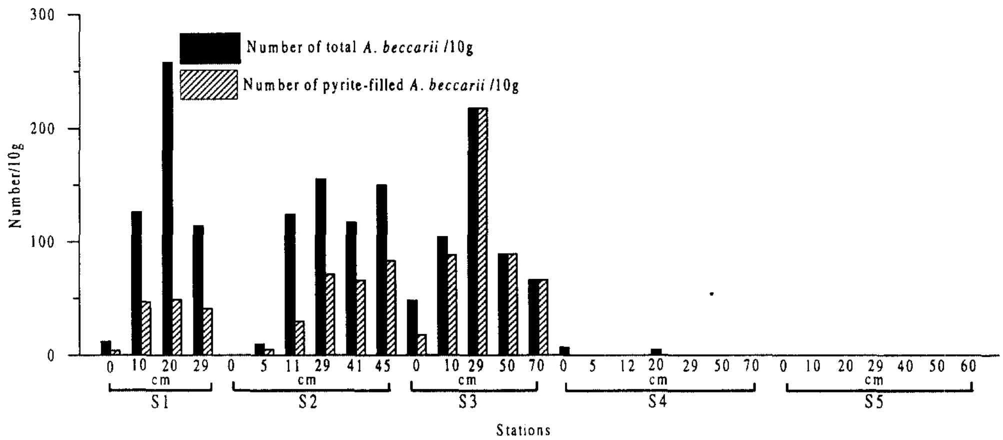

Fig. 4. Downcore abundance (number/10 g) of total and pyritized *Ammonia beccarii* in each station.

sediment, station S1 contains 12 specimens of *A. beccarii* per 10 g dried sediments and 4 of them (33%) are pyritized. Station S3 contains 48 specimens of *A. beccarii* per 10 g dried sediments and 18 of them (35%) are pyritized (Table 3). Alve (1995) reported that *A. beccarii* is abundant species in the most polluted areas. The significantly low number of this species in the surface sediments, compared with that in the downcore sediments, at the wastern part of Shihwa Lake (stations S1, S2, and S3) suggests that the relatively recent intrusion of pollutants modified the ecology of Shihwa Lake. Significant accumulation of pollutants into the lake is probably after the completion of the Shihwa Seawall construction in January of 1994.

It is very interesting to note that *Elphidium* spp. (*E. advena*, *E. excavatum*, and *E. subincertum*) do not occur in the surface sediments of the study area (Fig. 5). However, both

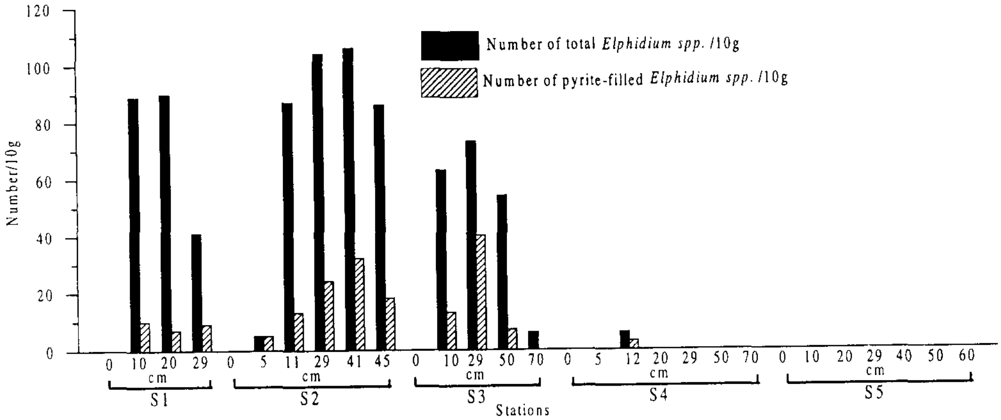

Fig. 5. Downcore abundance (number/10 g) of total and pyritized *Elphidium* spp. in each station.

non-pyritized and pyritized *Elphidium* spp. commonly occur at the downcore. *Elphidium advena* and *E. excavatum* commonly occur in continental shelf areas, which have a normal salinity (Waller, 1960; Streeter and Lavery, 1982; Oki and Yamamoto, 1992). The absence of *Elphidium* spp. in the surface sediment might be partly due to the fresh-waterized nature of the Shihwa Lake after the completion of Seawall.

4.4 Arenaceous foraminifers

In previous work, arenaceous foraminifers have been used as a dominant group near outfall areas (Zalesny, 1959; Watkins, 1961; Alve, 1995). However, in this study area, no arenaceous foraminifers are found in the surface sediments (Fig. 3). The highest concentration of arenaceous foraminifers also occurs in coarse substrate (Finger and Lipps, 1981; Blackwelder *et al.*, 1996) and brackish water (Bandy and Arnal, 1960). In this study, arenaceous foraminifers occur at 20 cm downcore depth at station S4 and 50 cm at station S5 (Fig. 3). These downcore depths contain relatively high amount of coarse fractions (Fig.

3). The occurrence of arenaceous foraminifers at 11, 29, and 41 cm of station S2 can also be explained by the high amount of coarse fraction contents in the sediments.

Stations S1 and S3 also contain high amount of coarse fractions but no arenaceous foraminifers. We do not know why station S2 contains arenaceous foraminifers, and stations S1 and S3 do not.

In this study, the arenaceous foraminifers do not occur in the surface sediments of all five stations (Fig. 3). The total absence of arenaceous foraminifers may be due to the heavily polluted nature of the surface sediments. Bandy *et al.* (1964) also reported that the lowest value of arenaceous foraminifers under the sewage field. The result of this study well agrees with that of Bandy *et al.* (1964).

4.5 Species diversity

The polluted Shihwa Lake contains a very low number of species in the surface sediments (Fig. 6). Only one species is found at stations S1 and S4, and 5 species at station S3. Stations

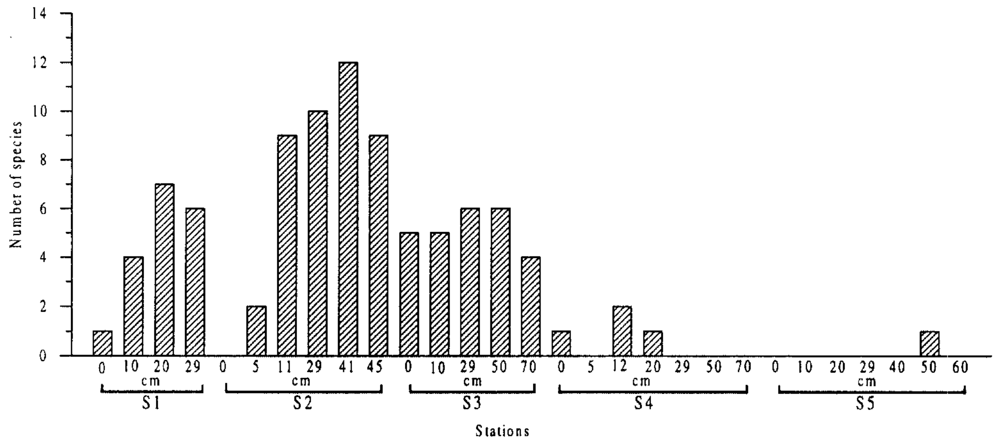

Fig. 6. Number of species in the surface and downcore sediments in each station.

S2 and S5 do not contain foraminifers. The lowest number of species also reported at various sewage outfall areas (Bates and Spencer, 1979; Yanko *et al.*, 1994; Alve, 1995). Bates and Spencer (1979) reported that the numbers of living benthic species and total benthic (living+dead) species are the lowest at the Chesapeake-Elizabeth sewage outfall, Virginia, USA. The lowest number of species is also observed near the Hadera Power Station, Israel, where a coal is the major source of pollution into the surface sediments (Yanko *et al.*, 1994). In the study area, the number of species in the surface sediments is very low (or almost absent) compared to that in the downcore sediments (Fig. 6). It is believed that this low value of species diversity at the surface sediment is affected by the recent input of pollutants.

4.6 Ostracodes

All five stations from the surface sediments do not contain ostracodes (Fig. 7). The eastern part of the heavily heavy metal polluted Shihwa Lake, which is adjacent to the Shihwa-

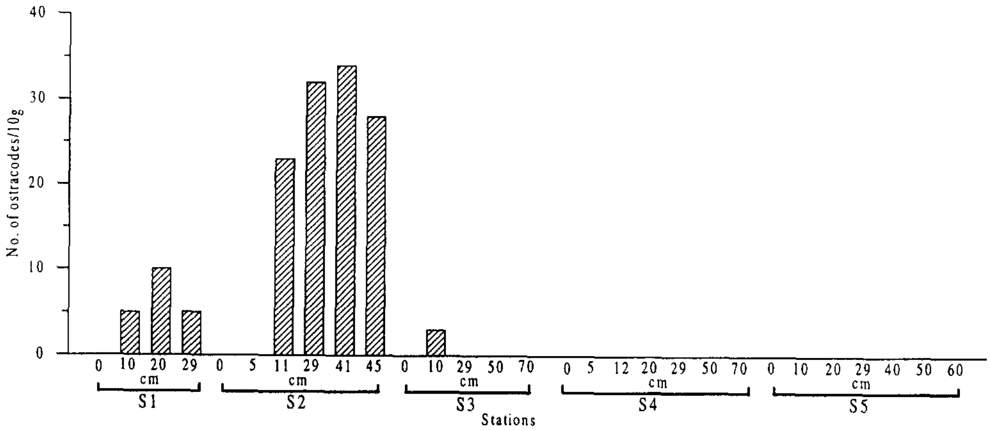

Fig. 7. Number of ostracodes/10 g in the surface and downcore sediments in each station.

Banwol Industrial complexes, does not contain any ostracodes even at the downcore. Schafer *et al.* (1975) pointed out that oastracodes seem to be one of the most sensitive biological indicators of environmental modification. We believe the absence of ostracodes in the surface sediments from all five stations is due to the polluted nature of the study area.

5. Conclusions

Based on benthic foraminiferal analysis of five sediment cores from the Shihwa Lake, the following conclusions can be drawn:

(1) The heavy metal (Cu and Zn) polluted eastern part of the Shihwa Lake shows barren or nearly barren zone of benthic foraminifers both at the surface and downcore sediments.

(2) Recent intrusion of pollutants after the construction of the Seawall in 1994 severely modified the Shihwa Lake environment as evidenced by the low number of benthic foraminifers, low number of *Ammonia beccarii*, low species diversity, and absence of *Elphidium* spp., and ostracodes in the surface sediment compared with those of the downcore sediments.

(3) Except the barren station (eastern part of Shihwa Lake), the western part contains pyritized benthic foraminifers both in the surface and downcore sediments, suggesting a foraminiferal disease by bacteria.

(4) Either pyritized or non-pyritized *Elphidium advena*, *E. excavatum*, and *E. subincertum*

do not occur in the surface sediments. But they are abundant in the downcore sediments. The absence of the above species in the surface sediments is due to probably a fresh-waterized nature of the Shihwa Lake after the completion of the Seawall in 1994.

(5) The surface sediments contain a low number of species compared with the downcore sediments, suggesting the relatively recent modification of the Shihwa Lake bottom water environment by pollutants.

(6) Ostracodes do not occur in the surface sediment of all five stations. Even, it is not found adjacent to the Shihwa-Banwol Industrial Complexes and outfalls of sewage both in the surface and downcore sediments, indicating that ostracodes can also be used as a sensitive pollution indicator.

Acknowledgements

Funding for this research was obtained through the Korea Ocean Research and Development Institute (KORDI) from the Ministry of Korea Maritime and Fishery Affairs (A Study on Environmental Changes in Shihwa Lake: Research Grant No BSPE 97610-00-1035-4). Thanks are extended to J.H Chun, K.S. Kim, S. Chang, and H.J. Choi who helped collecting and analyzing the core samples.

References

Alve, E., Benthic foraminifera in sediment cores reflecting heavy metal pollution in Sorfjord, western Norway, *J. Foraminiferal Res.*, 21, 1-19, 1991.

Alve, E., Benthic foraminiferal responses to estuarine pollution: A review, *J. Foraminiferal Res.*, 25, 190-203, 1995.

Bandy, O.L. Dominant paralic foraminifera of southern California and the Gulf of California, *Contributions Cushman Foundation Foraminiferal Res.*, XIV, 127-134, 1963.

Bandy, O.L. and Arnal, R.E., Concepts of foraminiferal paleoecology, *Am. Asso. Petrol. Geologists Bull.*, 44, 1921-1932, 1960.

Bandy, O.L., Ingle, Jr. J.C., and Resig, J.M., Foraminifera, Los Angeles county outfall area, California, *Limnology and Oceanography*, 9, 124-137, 1964.

Bates, J.M., and Spencer, R.S., Modification of foraminiferal trends by the Chesapeake-Elizabeth sewage outfall, Virginia beach, Virginia, *J. Foraminiferal Res.*, 9, 125-140, 1979.

Berner, R., Early diagenesis: Princeton University Press, Princeton, N.J., 241 pp, 1980.

Blackwelder, P., Hood, T., Alvarez-Zarikian, C., Nelsen, T.A., and McKee, B., Benthic foraminifera from the Necop study area impacted by the Mississippi River plume and seasonal hypoxia, *Quaternary International*, 31, 19-36, 1996.

Boltovskoy, E. and Wright, R., Recent Foraminifera. Dr. W. Junk b.v. Publishers, The Hague, 515 pp, 1976.

Collins, E.S., Scott, D.B., Paul, P.T., and Medioli, F.S., Foraminifera in Winyah Bay and north inlet marshes, south Carolina: Relationship to local pollution sources, *J. Foraminiferal Res.*, 25, 212-223, 1995.

Culver, S.J. and Buzas, M.A., The effects of Anthropogenic habitat disturbance, habitat destruction, and global warming on shallow marine benthic foraminifera, *J. Foraminiferal Res.*, 25, 204-211, 1995.

Ellison, R.L., Broomee, R., and Ogilvie, R., Foraminiferal response to trace metal contamination in the Patapssco River and Baltimore Harbour, Maryland, *Marine Pollution Bull.*, 17, 419-423, 1986.

Finger, K.L. and Lipps, J.H., Foraminiferal decimation and repopulation in an active volcanic caldera, Deception Island, Antarctica, *Micropaleontology*, 27, 111-139, 1981.

Huh, S.-H. and Oh, I.S., Ecological studies on the man-made Lake Shihwa and adjacent coastal area: Introduction, *J. Korean Soc. Oceanography*, 2, 49-52 (in Korean), 1997.

Hallock, P., Talge, H.K., Cockey, E.M., and Muller, R.G., A new disease in reef-dwelling foraminifera: Implications for coastal sedimentation, *J. Foraminiferal Res.*, 25, 280-286, 1995.

Korea Ocean Research and Development Institute (KORDI), A Study on Environmental changes in Shihwa Lake, BSPN 96325-985-4, 169 pp (in Korean), 1997.

Korea Ocean Research and Development Institute (KORDI), A study on environmental changes in Shihwa lake, BSPE 97610-00-1035-4, 230 pp, 1998.

Oki, K. and Yamamoto, H., Notes on marine Quaternary sediments newly found in the west coastal area of the Satsuma Peninsula, Kyushu, Japan, with special reference to the benthic foraminiferal assemblages. In: Ishizaki, K. and Saito, T., (eds.), *Contenary of Japanese Micropaleontology*, 189-205, 1992.

Park, Y.C., Park, J.K., Han, M.W., Son, S.K., Kim, M.K., and Huh, S.H., Biogeochemical study of dissolved organic and inorganic compounds under oxic/anoxic environment in Lake Shihwa, *J. Korean Soc. Oceanography*, 2, 53-68 (in Korean), 1997.

Polski, W., Foraminiferal biofacies off the north asiatic coast, *J. Paleontology*, 33, 569-587, 1959.

Scott, D.B., Schafer, C.T., Honig, C., and Younger, D.C., Temporal variations of benthic foraminiferal assemblages under or near aquaculture operations: Documentation of impact history, *J. Foraminiferal Res.*, 25, 224-235, 1995.

Schafer, C.T., Wagner, F.J., and Ferguson, C., Occurrence of foraminifera, molluscs and ostracods adjacent to the industrialized shoreline of Canso Strait, Nova Scotia, *Water,* *Air and Soil Pollution*, 5, 79-96, 1975.

Seiglie, G.A., Foraminiferal assemblages as indicators of high organic carbon content in sediments and of polluted waters, *Am. Asso. Petrol. Geologists Bull.*, 52, 2231-2241, 1968.

Seiglie, G.A., Pyritization in living foraminifers, *J. Foraminiferal Res.*, 3, 1-6, 1973.

Sen Gupta, B.K., Foraminifera of south Atlantic/Georgia Bight: South Atlantic Benchmark Program 1997 Report, 3, p. 341-396, Texas Instruments, Inc., Dallas, 1979.

Sharifi, A.R., Croudace, I.W., and Austin, R.L., Benthic foraminiferids as pollution indicators in Southampton Water, southern England, U.K. *J. Micropaleontology*, 10, 109-113, 1991.

Stott, L.D., Hayden, T.P., and Griffith, J., Benthic foraminifera at the Los Angeles County Whites Point outfall revisited, *J. Foraminiferal Res.*, 26, 357-368, 1996.

Streeter, S.S. and Lavery, S.A., Holocene and latest glacial benthic foraminifera from the slope and rise off eastern North America, *Geol. Soc. Am. Bull.*, 93, 190-199, 1982.

Waller, H.O., Foraminiferal biofacies off the south China coast, *J. Paleontology*, 34, 1164-1182, 1960.

Watkins, J.G., Foraminiferal ecology around the Orange County, California, ocean sewer outfall, *Micropaleontology*, 7, 199-206, 1961.

Yanko, V., Kronfeld, J., and Flexer, A., Response of benthic foraminifera to various pollution sources: Implications for pollution monitoring, *J. Foraminiferal Res.*, 24, 1-17, 1994.

Zalesny, E., Foraminiferal ecology of Santa Monica Bay, California, *Micropaleontology*, 5, 101-126, 1959.