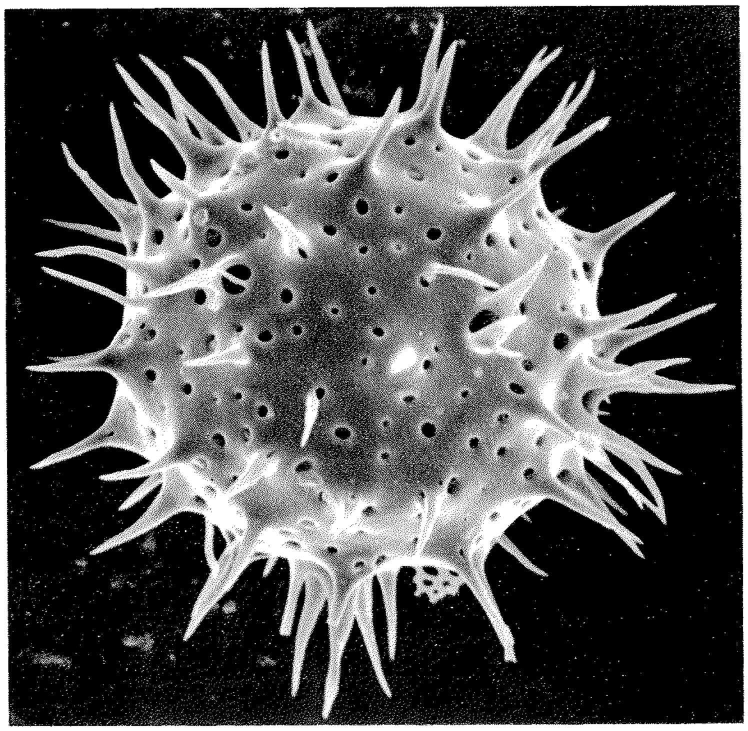
Radiolaria:
Flux, Ecology, and Taxonomy in the Pacific and Atlantic

Kozo Takahashi



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Explanation of Cover Photo: A scanning electron photomicrograph of *Acrosphaera spinosa* (Haeckel) *longispina* Takahashi collected at 4,280 m at PARFLUX sediment trap Station P_1 in the central tropical Pacific (see page 53 of text). *A. spinosa longispina* is a colonial radiolarian belonging to Suborder Spumellaria. The shell diameter of this specimen is 125 μm.

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Radiolaria:

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Abstract

Radiolarians settling through the oceanic water column were recovered from three stations (western tropical Atlantic, Station E; central tropical Pacific, Station P_1; and Panama Basin, Station PB) using PARFLUX sediment traps in moored arrays at several depths. The taxonomic diversity of the radiolarian assemblages in the sediment traps was very high. A total of 420 taxa (including 23 new taxa) were found at the three stations; of these 208 taxa were found at Station E. The polycystine radiolarians generally reach the sea floor with little change in abundance or species composition, although slight skeletal dissolution occurs during their descent through the water column. The phaeodarian radiolarians, on the other hand, are largely dissolved within the water column; only a few species reach the sea-floor and these dissolve rapidly at the sediment-water interface. Most radiolarian skeletons sink as individuals through deep water columns without being incorporated into large biogenic aggregates. Because significant numbers of nassellarian and phaeodarian species are deep-water dwelling forms, the diversity of radiolarians increases with increasing depth in the mesopelagic zone.

The vertical flux of the total radiolarians arriving at the trap depths (in $\times 10^3$ individuals $/m^2/day$) ranged from 16–24 at Station E, 0.6–17 at Station P_1, and 29–53 at Station PB. On the average 25% and 69% of the total radiolarian flux is transported by Spumellaria and Nassellaria, respectively, while 5% is carried by Phaeodaria. The supply of radiolarian silica (mg $SiO_2/m^2/day$) to each trap depth ranged from 2.5–4.0 at Station E, 0.9–3.2 at Station P_1, and 5.7–10.4 at Station PB. The Radiolaria appear to be a significantly large portion of the SiO_2 flux in the > 63 μm size fraction and thus play an important role in the silica cycle. When the radiolarian fluxes at the three stations are compared with Holocene radiolarian accumulation rates in the same areas it became apparent that several percent or less of the fluxes are preserved in the sediment in all cases and the rest must be dissolved on the sea-floor.

1 Introduction

Radiolaria are one of the major groups of marine planktonic protozoans belonging to the class Actinopoda. Their geometrically complex skeletons, where present, are composed of amorphous silica and are often aesthetically pleasing. Since Haeckel's (1887) time, modern Radiolaria have been known to represent quite diversified assemblages. About 200 radiolarian species, for instance, were reported from a single geographic area in the tropical Atlantic (Takahashi and Honjo, 1981). This is a remarkably high diversity in contrast with the total of about 40 present-day species of planktonic Foraminifera in the world oceans (Bé, 1977).

The highest standing stock of living Radiolaria is generally found in the vicinity of the thermocline (see e.g., Renz, 1976; Bishop et al., 1977, 1978; Takahashi and Ling, 1980). The major proportion of the population dwells in the upper several hundred meters of the pelagic realms, although there are some deep dwelling forms down to abyssal depths.

The quantitative world-wide distribution of living Radiolaria is not yet fully understood, however, the results of such biocoenosis can be seen in the underlain sediments (for example, as radiolarian oozes). The oozes generally occur more extensively in the equatorial siliceous belt of sediments than in other latitudinal regions, reflecting both siliceous productivity in the overlying water and carbonate dissolution on the sea-floor. In fact, Radiolaria are known to be the major siliceous component in suspension as well as in the sediments in the tropical regions (Lisitzin, 1971, 1972). High latitude siliceous belts are thought to be another major sink for radiolarian skeletons. However, Radiolaria are usually not present in high proportions in sediments because they are masked by diatoms.

There have been increasing numbers of recent studies concerning paleoenvironmental interpretations using radiolarian thanatocoenosis (e.g., Moore, 1978). Detailed studies of radiolarian production, sedimentation and preservation have only recently begun (e.g., Takahashi, 1981, 1983). The extent of preservation of radiolarians in marine sediments is known to be very small (e.g., Calvert, 1974; Heath, 1974; Takahashi and Honjo, 1981), and the thanatocoenosis is rarely proportional to the biocoenosis in the upper water layer (Renz, 1976). Preferential dissolution generally leaves only solution resistant taxa to be preserved. For this reason, estimating paleotemperatures, for instance, by using the thanatocoenosis without adequate information on preservation mechanisms may lead to inaccurate results.

Recent advancements in ocean experimental methods allow the deployment of large sediment traps for prolonged periods of time in pelagic environments (e.g., Wiebe et al., 1976; Honjo, 1978; Honjo et al., 1980). By studying sediment trap material collected over a three month period, Takahashi and Honjo (1981) documented the largest stock of radiolarian assemblages ever reported from the tropical Atlantic. Radiolarian samples collected by sediment traps are useful not only for a basic description of biocoenosis, but also for understanding the mechanisms of sedimentation, dissolution/preservation and silica cycling since the geochemistry of seawater is in part governed by particle-water interaction.

Despite many taxonomic works on fossil Radiolaria (e.g., Riedel, 1967a, 1971; Petrushevskaya, 1971d, 1981; Nigrini and Moore, 1979) the systematics of Recent Radiolaria is still in need of improvement. In this report Radiolarians from the PARFLUX sediment trap stations in the Atlantic and Pacific (Figure 1) were determined quantitatively and used for taxonomic emendations.

2 Samples and Methods

The sources of the samples used in this study are summarized in Table 1. Station E is located about 750 km from the Guyana Coast in a region where there is found very little seasonal variation in zooplankton productivity (e.g., Moore and Sander, 1977). The underlying Demerara Abyssal Plain has a gentle topography and is covered with silty clay. The North Equatorial Current flows in a northwesterly direction, but no deep current measurements have been reported in the study area. Station P_1 is located in the East Hawaii Abyssal Plain. The bottom sediment is consolidated clay with alternating thin ferro-manganese laminations (Honjo, 1980). Station PB, located in the Panama Basin, is characterized by high productivity and is relatively close to land (250 km from the nearest shoreline). Hydrography, geology, biology and physical oceanography are quite well known in this area

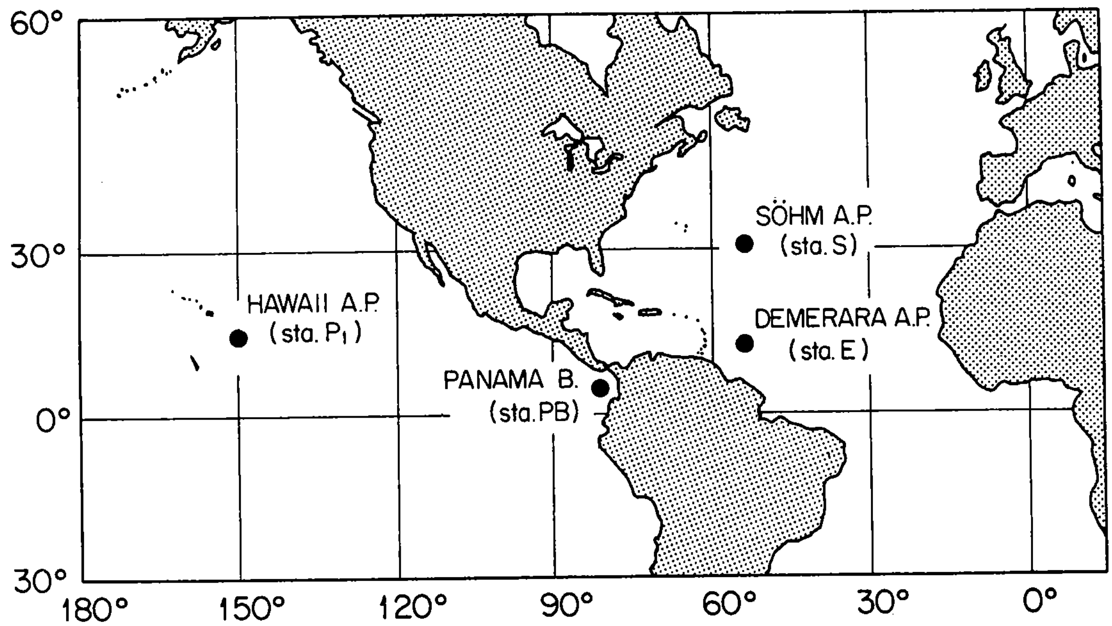

Figure 1: Locations of the PARFLUX sediment trap stations.

(e.g., Stevenson, 1970; van Andel, 1973; Kowsmann, 1973; Moore et al., 1973; Plank et al., 1973; Heath et al., 1974; Lonsdale, 1975, 1977; Swift, 1977; Swift and Wenkam, 1978).

The sediment trap arrays deployed at the above stations consisted of four or five PARFLUX Mark II traps with 1.5 m^2 opening (Honjo et al., 1980) (Table 1). The receiving cup was sealed by a time-controlled spring shutter prior to recovery.

The samples were wet sieved upon arrival in the laboratory with a 1 mm mesh screen and split into four aliquots by a Honjo-Erez precision rotary liquid splitter (Honjo, 1978). An aliquot of material finer than 1 mm was further split into several aliquots (Table 1). The resulting aliquot of the original sample was wet sieved through 250, 125 and 63 μm screens. When necessary the samples were split further into smaller aliquots prior to filtration (Table 2). Samples of less than 63 μm size fraction from Station E were separately prepared prior to establishment of the standard method: by diluting a 1/64 aliquot to 250 ml in a measuring flask using filtered seawater from the deep Sargasso Sea, and then a 2 ml aliquot was taken by using a pipet.

The above aliquots were filtered through a 47 mm type HA Millipore© grid filter with a nominal 0.45 μm pore size using a filtration funnel with a 19×42 mm rectangular opening. the residue was rinsed with distilled water, then dried at 50°C in an oven. Large foraminiferal and pteropod specimens in 1,000–250 μm and 250–125 μm size fractions were removed from the filter surface under a dissecting microscope. The dried filter sample was mounted on a standard glass slide after trimming off the excess margins. Drops of Cargile^R type B compound were applied to clear the sample filter. It took a few days for the bubbles to escape from all radiolarian shells prior to placing a cover glass over the sample area. Aliquot size and number of slides from the three stations which were used in this paper are summarized in Table 2.

Table 1: Summary of the sample sources from the PARFLUX sediment traps deployed in the Atlantic and Pacific.

	PARFLUX S_2	PARFLUX E	PARFLUX P_1	PARFLUX PB
Location	31°32.5′N, 55°55.4′W	13°30.2′N, 54°00.1′W	15°21.1′N, 151°28.5′W	5°21′N, 81°53′W
Ocean/Basin	Central Sargasso Sea/ Söhm Abyssal Plain	Tropical Atlantic/ Demerara Abyssal Plain	N. Central Pacific/ E. Hawaii Abyssal Plain	Tropical Pacific/ hemipelagic Panama Basin
Term	10/76–1/77	11/77–2/78	7/78–11/78	8/79–12/79
Duration	110 days	98 days	61 days	112 days
Trap Depth (m)	976 3,694	389 988 3,755 5,068	378 978 2,778 4,280 5,582	667 1,268 2,869 3,769 3,791
Anchor Depth	5,581 m	5,288 m	5,792 m	3,856 m

The slides were studied to identify radiolarian taxa and to count individuals to the species level under a transmission light microscope. Two or more of slides whose aliquot sizes are shown in Table 2 were used for the species identification. The number of slides used for counts is presented in Table 2. The counts were converted to the flux term; number of individual shells/m^2/day.

An abundant, medium sized radiolarian genus, *Pterocorys* (*P. campanula* Haeckel, Plate 42, figures 5–8, and *P. zancleus* (Miller), Plate 42, figures 1–4) was chosen in order to assess the range of errors induced during sample preparation, and the reproducibility of shell counting. The assessment was made by counting *Pterocorys* shells in a given slide. This taxon occurs mostly in 250–125 μm and 125–63 μm size fractions. The counting reproducibility by duplicate countings of an identical slide proved to be more than 90%. Statistical variability among four slides prepared from the coarse and medium size fractions is due to errors involving slide preparation including wet sieving and splitting. The standard deviation ranged from 0.14 to 0.26 at 95% confidence interval. The radiolarian species count applied in this paper is reproducible to better than 74%. All the microslides used for the present investigation are deposited permanently in the Sea-floor Sample Laboratory, Woods Hole Oceanographic Institution.

To prepare handpicked specimens for electron microscopy and dimension analyses, aliquots of 1/64 or 1/256 of wet samples from the sediment trap are sieved and desalted by the same method as above. Grid-imprinted, black-background, 47 mm HA Millipore© filters with a nominal 0.45 μm pore size are used to retain radiolarian samples. After drying, specimens of radiolarian taxa are handpicked using an ultrafine Japanese calligraphy brush. A portion of the picked specimens were mounted on an aluminum stub with a piece of

Table 2: Size of aliquot in each microslide relative to total sediment trap samples. Number of slides used for counts is shown in parentheses.

Station:	Depth (m)	Size Fraction 1000–250 (μm)	250–125 (μm)	125–63 (μm)	< 63 (μm)
E:	389	1/256 (1)	1/1024 (1)	1/1024 (1)	1/8000 (1)
	988	1/256 (1)	1/1024 (1)	1/1024 (1)	1/8000 (1)
	3755	1/256 (1)	1/1024 (1)	1/1024 (1)	1/8000 (1)
	5068	1/256 (1)	1/1024 (1)	1/1024 (1)	1/8000 (1)
		1/256[a] (1)	1/1024[a] (4)	1/1024[a] (4)	1/8000[a] (2)
PB:	667	1/4086 (2)	1/1024 (1)	1/1024 (1)	1/16384 (2)
	1268	1/1024 (1)	1/1024 (1)	1/1024 (1)	1/4096 (2)
	2869	1/4096 (2)	1/1024 (1)	1/1024 (1)	1/16384 (2)
	3769[b]	1/4096 (2)	1/4096 (2)	1/4096 (2)	1/16384 (2)
	3791	1/1024 (1)	1/1024 (1)	1/1024 (1)	1/16384 (2)

[a]For statistical assessment at each of the four depths at Station E.
[b]Studied only for Phaeodaria.

Station:	Depth (m)	Size Fraction 1000–250 (μm)	250–63 (μm)	< 63 (μm)
P_1:	378	1/256 (1)	1/256 (1)	1/256 (1)
	978	1/256 (1)	1/256 (1)	1/256 (1)
	2778	1/256 (1)	1/256 (1)	1/1024 (1)
	4280	1/256 (1)	1/256 (1)	1/1024 (1)
	5582	1/256 (1)	1/256 (1)	1/1024 (1)

double-sided adhesive tape and coated with carbon and then Pd-Au alloy film for scanning electron microscopy (SEM). Samples for transmission electron microscopy were prepared by the method described by Hurd et al. (1981).

Reflected light micrographs were taken at ×20 and ×40 magnification of a dissecting microscope for each taxa. The micrographs were converted to positive slides and projected onto an image digitizer (LW International) for measurements of length, width and maximum projected area.

After the photography, specimens were dried in a vacuum at 150°C for 2 days, then cooled in a desiccator for 10 minutes and quickly weighed. A Cahn 25 Automatic Electrobalance© was used in a room with humidity of less than 40%. The number of specimens needed for this varied significantly depending on weight/shell of different taxa. Details were reported elsewhere (Takahashi and Honjo, 1983).

3 Results and Discussion

3.1 Counts of Radiolarian Taxa

The majority of radiolarian specimens found in the slide samples were identified to the species level (Table 3, Section 6, Plates 1–63). A total of 420 taxa, including one new genus, 20 new species, and one new subspecies, were recognized from the three stations. Following are the total numbers of radiolarian taxa encountered at each trap station: Station E: 208; Station P_1: 217; Station PB: 225. The systematics of the taxa are given in a later section of this report. According to Casey (pers. comm., 1981), based on the published literature the best inference on total number of living radiolarian species in the world ocean is about 600. This report thus covers a majority of tropical radiolarian species.

Subclass Radiolaria are comprised of the following three suborders whose cumulative number of taxa encountered from all stations are shown in parenthesis: Spumellaria (175); Nassellaria (182); and Phaeodaria (63). The number of encountered taxa in Spumellaria, Nassellaria, and Phaeodaria in order are: Station P_1: 82, 113, 22; Station PB: 83, 111, 31 (for information on Station E, see Takahashi and Honjo, 1981). The number of taxa contained in the counting slides appeared to be less than that in slides used for species identification (Tables 2 and 3, Plates 1–63), due to the statistical discrepancy of using one or two slides for counting and one to four slides in each size fraction for species identification. When necessary (i.e., taxonomic division was not practical) several species were combined together as one group during census taking (Table 3). Spicules were not counted.

The radiolarian fluxes from the three stations were normalized to the number of individual shells/m^2/day for each taxon (Table 3). The size fractioned fluxes of radiolarian families from Stations P_1 and PB are presented in Table 4, and those from Station E are from Takahashi and Honjo (1981). Percentages of actual specimens counted in each slide are also given in Table 4. The fluxes of suborders are summarized in Table 5 and illustrated in Figure 2.

Table 3: The radiolarian (species) flux (number of shells/m^2/day) at three sediment trap stations. Data reported here include all size fractions from $< 63\ \mu m$ to 1mm–250 μm.

Sediment Trap Station	E				P_1					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Suborder SPUMELLARIA Ehrenberg													
Family COLLOSPHAERIDAE Müller													
Acrosphaera spinosa (Haeckel)	10	58	65	116	0	6	28	31	25	0	49	12	12
Acrosphaera murrayana (Haeckel)	0	0	0	0	0	0	0	6	0	12	43	104	67
Acrosphaera cyrtodon (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	0	0
Clathrosphaera arachnoides Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Collosphaera tuberosa Haeckel	19	9	31	29	0	8	53	34	31	98	37	110	61
Collosphaera confossa Takahashi, n. sp. and *C. armata* Brandt	0	0	0	0	0	0	19	8	31	30	6	24	43
Collosphaera huxleyi Müller	5	46	107	38	3	17	65	53	56	0	0	18	18
Collosphaera macropora Popofsky	0	0	0	0	39	36	81	107	123	55	37	98	73
Collosphaera polygona Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Disolenia collina (Haeckel)	0	0	0	0	6	0	17	0	8	0	0	0	0
Disolenia zanguebarica (Ehrenberg)	0	0	0	0	3	11	14	36	31	0	24	6	0
Disolenia quadrata (Ehrenberg)	0	0	0	0	0	14	34	45	22	0	0	0	0
Disolenia sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Disolenia sp. B	0	0	0	0	3	0	0	0	0	0	0	18	0
Otosphaera tenuissima (Hilmers)	0	0	0	0	0	0	0	0	0	0	0	0	0
Otosphaera polymorpha Haeckel	40	29	40	29	0	14	75	53	95	24	6	18	18
Otosphaera auriculata Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonosphaera magnisphaera Takahashi, n. sp.	0	0	0	0	6	0	8	11	14	18	0	0	6
Siphonosphaera sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonosphaera martensi Brandt	0	0	0	0	14	34	95	73	28	6	6	48	18
Siphonosphaera sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonosphaera sp. aff. *S. hippotis* (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonosphaera socialis Haeckel	19	15	19	26	6	11	34	22	31	0	12	6	6
Total COLLOSPHAERIDAE	88	111	155	200	80	151	523	479	495	243	220	462	322
Family SPHAEROZOIDAE Haeckel													
Rhaphidozoum pandora Haeckel***	86	71	63	12	0	0	0	0	0	12	0	0	0
Total SPHAEROZOIDAE	86	71	63	12	0	0	0	0	0	12	0	0	0
Family ETHMOSPHAERIDAE Haeckel													
Plegmosphaera pachypila Haeckel	74	74	162	143	0	0	0	0	0	0	0	0	0
Plegmosphaera coelopila Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Plegmosphaera sp. aff. *P. lepticali* Renz	0	0	0	0	0	0	0	0	0	48	49	79	73
Plegmosphaera sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Plegmosphaera sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3 (continued)

Sediment Trap Station	E				P_1					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Plegmosphaera entodictyon Haeckel	0	0	0	0	0	0	0	0	0	61	110	213	140
Plegmosphaera oblonga Takahashi, n. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Plegmosphaera lepticali Renz	21	0	15	18	0	0	20	17	8	0	0	0	0
Plegmosphaera pachyplegma Haeckel	0	0	0	0	0	0	0	0	0	0	18	12	0
Styptosphaera spongiacea Haeckel	0	0	0	0	0	0	3	28	20	24	30	91	134
Styptosphaera sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Styptosphaera sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Styptosphaera sp. C	0	0	0	0	0	0	0	0	0	0	0	0	0
Carposphaera capillacea Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Carposphaera sp. aff. *C. corypha* Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Total ETHMOSPHAERIDAE	95	74	177	161	0	0	23	45	28	133	207	395	347
Family ACTINOMMIDAE Haeckel emend. Riedel													
Subfamily ACTINOMMINAE Haeckel, emend. herein													
Centrocubus cladostylus Haeckel	3	0	3	14	0	0	0	0	0	0	0	0	0
Centrocubus octostylus Haeckel	0	0	0	0	0	0	11	0	3	0	0	0	0
Spongosphaera polycantha Müller	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongosphaera sp. aff. *S. helioides* Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongosphaera streptacantha Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongosphaera ? sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Lychnosphaera regina Haeckel	0	0	0	0	0	0	0	0	0	0	6	0	6
Actinomma archadophorum Haeckel	56	40	56	65	0	0	36	22	17	110	116	152	91
Actinomma capillaceum Haeckel	0	0	0	0	0	0	0	0	0	24	6	0	0
Actinomma sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Trilobatum ? *acuferum* Popofsky	238	58	673	437	3	112	213	196	171	201	262	256	274
Acanthosphaera actinota (Haeckel)	49	33	81	62	0	28	45	42	62	122	73	140	122
Acanthosphaera tunis Haeckel	0	0	0	0	0	0	0	0	0	12	0	0	0
Acanthosphaera castanea Haeckel	0	0	0	0	0	0	17	22	3	0	0	0	0
Heliosphaera radiata Popofsky	10	15	12	9	0	0	3	0	0	0	0	0	0
Cladococcus viminalis Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladococcus abietinus Haeckel	0	3	18	2	0	0	3	0	0	12	6	0	0
Cladococcus scoparius Haeckel	5	2	7	14	0	8	14	8	8	49	43	61	61
Cladococcus cervicornis Haeckel	0	0	0	0	0	3	31	22	3	238	238	360	256
Arachnosphaera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Arachnosphaera myriacantha Haeckel	21	12	37	23	0	3	3	3	3	49	55	110	104
Leptosphaera minuta ? Popofsky	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptosphaera sp. group	38	45	72	138	0	0	62	42	31	18	6	0	0

Table 3 (continued)

Sediment Trap Station	E				P$_1$					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Actinosphaera tenella (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	0	0
Actinosphaera acanthophora (Popofsky)	0	0	0	0	0	0	0	0	0	0	0	0	0
Actinosphaera capillacea (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	55	91
Haliomma ? sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Haliomma sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Haliomma castanea Haeckel	0	0	0	0	0	3	8	3	6	0	24	6	43
Heliosoma spp. aff. *radians* Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Elatomma penicillus Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Haeckeliella macrodoras (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	0	0
Astrosphaera hexagonalis Haeckel	5	5	16	0	0	0	20	14	0	164	152	268	305
Drymosphaera dendrophora Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeropyle mespilus ? Dreyer	0	0	0	0	0	0	0	0	0	0	0	0	0
Thecosphaera inermis (Haeckel)	251	58	409	194	0	6	6	59	8	0	18	12	6
Cromyomma villosum Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiphosphaera gaea Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiphosphaera tesseractis Dreyer	2	0	5	2	0	0	11	14	6	0	0	0	0
Staurolonche sp. A group	79	30	33	33	0	11	8	6	8	36	18	6	37
Staurolonche sp. B	2	16	19	14	0	0	0	3	0	12	0	0	6
Stauracontium sp.	9	0	0	0	0	0	0	0	0	0	12	43	12
Hexastylus triaxonius Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexastylus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexalonche sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexalonche spp. B	47	42	139	80	6	8	14	8	14	18	61	73	91
Hexalonche amphisiphon Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Centrolonche hexalonche Popofsky	0	3	5	5	0	3	25	8	11	0	0	0	0
Centracontarium hexacontarium Popofsky	21	23	16	12	0	0	0	0	0	0	0	0	0
Hexacontium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexacontium hostile Cleve	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexacontium arachnoidale Hollande and Enjumet	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexacontium axotrias Haeckel	22	33	71	21	3	67	131	156	112	153	134	134	177
Hexacontium sp. aff. *H. hostile* Cleve	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexacontium heracliti (Haeckel)	0	0	0	0	0	0	0	3	0	6	6	6	6
Hexacontium hystricina (Haeckel)	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexacromyum elegans Haeckel	0	16	5	7	0	0	3	0	0	0	6	0	30
Heterosphaera sp. A	0	0	0	0	8	17	47	22	36	0	37	55	73
Heterosphaera sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3 (continued)

Sediment Trap Station	E				P_1					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Cromyechinus sp. aff. *C. borealis* (Cleve)	0	3	0	0	0	0	0	0	0	0	0	0	0
Cromyechinus ? sp.	0	0	0	0	0	3	6	3	0	12	6	0	0
Cromyechinus borealis (Cleve)	0	0	0	0	0	3	0	6	3	0	0	0	0
Stomatosphaera sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Stomatosphaera sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Stomatosphaera sp. C	0	0	0	0	0	0	0	0	0	0	0	0	0
Stylacontarium bispiculum Popofsky	0	0	0	0	6	14	50	48	64	30	49	67	91
Stylosphaera ? sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Stylosphaera melpomene Haeckel	132	64	52	110	0	0	3	0	11	0	12	12	12
Stylosphaera ? sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Stylosphaera lithatractus Haeckel	0	7	89	166	0	3	28	6	6	0	61	91	79
Druppatractus ostracion Haeckel group	0	0	0	0	0	0	0	0	0	0	0	0	0
Ellipsoxiphium palliatum Haecker	0	0	0	0	0	0	0	0	6	0	0	0	0
Amphisphaera group	0	0	0	0	3	0	0	6	6	0	0	0	0
Axoprunum stauraxonium Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiphatractus pluto (Haeckel)	0	2	57	26	0	6	0	0	8	0	0	6	0
Xiphatractus sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiphatractus spp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Druppatractus ? sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Dorydruppa bensoni new name	0	0	0	0	0	0	0	8	3	0	12	43	18
Total ACTINOMMINAE	990	510	1875	1434	29	298	798	730	609	1266	1419	1956	1997
Subfamily SATURNALINAE Deflandre													
Saturnalis circularis Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	18
Total SATURNALINAE	0	0	0	0	0	0	0	0	0	0	0	0	18
Total ACTINOMMIDAE	990	526	1643	1401	29	292	815	716	629	1399	1608	2339	2356
Family COCCODISCIDAE Haeckel, emend. Sanfilippo and Riedel													
Subfamily ARTISCINAE Haeckel, emend. Riedel													
Didymocyrtis tetrathalamus tetrathalamus (Haeckel)	125	177	197	176	0	67	201	224	241	54	73	146	104
D. tetrathalamus tetrathalamus (Haeckel) juvenile form	-	-	-	-	6	25	107	44	93	0	6	12	6
Didymocyrtis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongoliva ellipsoides Popofsky	15	18	5	0	3	6	8	8	0	0	0	55	12
Total COCCODISCIDAE	140	185	202	176	9	98	316	276	334	54	79	213	122

Table 3 (continued)

Sediment Trap Station	E				P$_1$					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Family PORODISCIDAE Haeckel, emend. Petrushevskaya and Kozlova													
Euchitonia elegans (Ehrenberg)	26	39	68	57	3	22	50	48	45	55	55	189	177
Euchitonia cf. *furcata* Ehrenberg	106	32	128	46	0	0	36	50	48	0	6	0	0
Euchitonia sp.	0	0	0	0	0	8	22	28	45	0	0	0	0
Amphirhopalum ypsilon Haeckel	0	0	7	3	0	0	0	0	0	12	6	18	37
Amphirhopalum straussii (Haeckel)	0	0	0	0	0	0	0	0	3	0	0	0	0
Stylodictya validispina Jørgensen	0	0	0	0	0	0	0	0	0	0	0	0	0
Stylodictya ? sp.	0	0	0	0	3	81	218	293	280	397	433	689	615
Stylodictya multispina Haeckel	0	0	0	0	0	3	3	22	25	0	0	0	18
Circodiscus spp. group	0	0	36	16	0	3	0	0	0	6	24	0	18
Stylochlamydium venustum (Bailey)	0	0	0	0	0	0	0	0	0	0	0	0	0
Stylochlamydium asteriscus Haeckel	121	72	55	91	8	20	109	129	76	153	122	287	219
Porodiscus micromma (Harting)	76	160	257	114	0	0	34	39	64	18	55	103	140
Total PORODISCIDAE	329	303	551	327	14	137	472	609	586	641	701	1286	1224
Family SPONGODISCIDAE Haeckel, emend. Riedel, and Petrushevskaya & Kozlova													
Spongobrachium sp.	0	0	0	0	0	0	0	14	8	0	0	0	0
Dictyocoryne profunda Ehrenberg	81	72	126	102	0	8	31	22	70	6	61	30	79
Dictyocoryne truncatum (Ehrenberg)	0	0	0	0	0	3	3	11	6	24	37	0	30
Spongodiscus sp. A	0	0	0	0	0	0	14	17	0	24	43	30	67
Spongodiscus biconcavus Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongodiscus resurgens Ehrenberg	*	*	*	*	0	0	3	0	17	49	67	110	98
Spongodiscus spp. B group	808*	929*	1337*	1498*	11	159	590	554	450	2304	1475	2810	2176
Spongotrochus glacialis Popofsky	*	*	*	*	0	25	45	64	48	104	122	135	152
Spongotrochus sp. A	44	45	73	14	0	0	0	0	20	0	0	0	0
Spongotrochus sp. B	0	0	0	0	0	0	11	6	8	0	0	0	0
Stylospongia huxleyi Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongurus cylindricus Haeckel	23	5	22	7	0	0	17	28	34	61	67	42	85
Spongopyle setosa Dreyer	0	0	0	0	0	3	8	6	8	61	67	42	24
Spongopyle osculosa Dreyer	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongaster tetras tetras Ehrenberg	42	46	63	99	0	3	0	8	31	43	24	49	73
Spongaster pentas Riedel and Sanfilippo	0	0	0	0	0	0	6	39	36	0	0	6	30
Total SPONGODISCIDAE	998	1097	1621	1720	11	201	728	769	736	2676	1963	3254	2814

Table 3 (continued)

Sediment Trap Station	E				P_1					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Family MYELASTRIDAE Riedel													
Myelastrum quadrifolium Takahashi, n. sp.	0	0	0	0	0	0	0	0	0	0	0	0	6
Myelastrum trinibrachium Takahashi, n. sp.	0	0	0	0	0	0	0	0	0	0	0	24	24
Total MYELASTRIDAE	0	0	0	0	0	0	0	0	0	0	0	24	30
Family LARNACILLIDAE Haeckel													
Larnacalpis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Family PHACODISCIDAE Haeckel													
Heliodiscus ? sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Heliodiscus asteriscus Haeckel	3	2	2	13	6	3	11	6	14	67	24	79	49
Heliodiscus echiniscus Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Total PHACODISCIDAE	3	2	2	13	6	3	11	6	14	67	24	79	49
Family THOLONIIDAE Haeckel, emend. Campbell													
Tholoma metallasson Haeckel	0	0	0	0	0	0	0	0	0	6	67	0	0
Total THOLONIIDAE	0	0	0	0	0	0	0	0	0	6	67	0	0
Family PYLONIIDAE Haeckel													
Hexapyle dodecantha Haeckel	32	6	12	33	0	6	0	6	0	0	12	6	12
Hexapyle sp.	163	85	186	111	0	14	22	25	50	244	79	135	0
Octopyle stenozona Haeckel	53	56	72	37	0	6	31	34	73	323	171	91	134
Tetrapyle octacantha Müller	513	444	947	458	11	204	612	805	780	689	652	1280	1085
Total PYLONIIDAE	761	591	1217	639	11	230	665	870	903	1256	914	1512	1231
Family LITHELIIDAE Haeckel													
Larcopyle butschlii Dreyer	0	0	0	0	0	0	25	14	8	30	0	37	6
Larcopyle sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Larcopyle sp. B	0	0	0	0	0	0	0	0	0	0	0	0	0
Discopyle elliptica Haeckel	0	0	0	0	0	3	78	11	3	24	0	24	37
Tholospira cervicornis Haeckel group	191	365	176	371	25	260	1013	1180	1063	1024	1201	1494	1347
Tholospira dendrophora Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Tholospira ? sp.	0	0	0	0	0	11	31	14	14	0	0	54	98
Lithelius minor ? Jørgensen	0	0	0	0	0	0	0	0	0	0	0	0	0
Larcospira quadrangula Haeckel	2	0	9	3	0	0	8	22	25	12	24	12	37
Total LITHELIIDAE	193	365	185	374	25	274	1155	1241	1113	1090	1225	1621	1525
Spumellaria undetermined	-	-	-	-	20	73	98	92	92	377	134	652	543
Total SPUMELLARIA	3688	3355	6155	5094	205	1465	4789	5117	4910	7809	6953	11454	10204

Table 3 (continued)

Sediment Trap Station	E				P$_1$					PB			
Depth (m)	389	988	3755	5068	378	978	2778	4280	5582	667	1268	2869	3791
Suborder NASSELLARIA Ehrenberg													
Family PLAGIACANTHIDAE Hertwig, emend. Petrushevskaya													
Subfamily PLAGIACANTHINAE Hertwig, emend. Petrushevskaya													
Tetraplecta pinigera Haeckel	0	0	0	0	6	14	48	36	17	91	104	231	226
Tetraplecta plectaniscus Haeckel	0	0	0	0	0	0	3	6	0	12	0	0	12
Tetraplecta corynephorum ? Jørgensen	0	0	0	0	0	0	0	0	0	0	0	0	0
Archiscenium quadrispinum ? Haeckel	17	86	158	152	0	0	0	6	0	37	0	0	6
Plectanium sp.	5	18	0	5	0	0	3	0	6	0	0	0	6
Protoscenium ? sp.	0	0	0	0	0	3	6	0	0	0	0	0	0
Clathromitra pterophormis Haeckel	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladoscenium ancoratum Haeckel	123	320	267	419	22	162	235	330	243	1122	987	1865	1415
Semantis gracilis ? Popofsky	0	0	0	0	0	0	0	0	0	0	0	0	0
Deflandrella cladophora Jørgensen	0	0	0	0	0	6	20	25	17	0	0	0	0
Deflandrella sp.	75	239	129	83	0	17	25	28	25	0	0	0	0
Pseudocubus obeliscus Haeckel	83	131	167	113	0	20	20	34	45	311	165	213	140
Pseudocubus primordialis ? (Jørgensen)	0	0	0	0	0	0	0	0	0	0	0	0	0
Phormacantha hystrix (Jørgensen)	150	141	330	260	6	73	215	275	280	750	463	1578	701
Neosemantis distephanus Popofsky	39	43	19	98	3	11	34	39	36	79	91	147	110
Total PLAGIACANTHINAE	492	978	1070	1130	37	306	609	779	669	2402	1810	4034	2616
Subfamily LOPHOPHAENINAE Haeckel, emend. Petrushevskaya													
Acanthocorys cf. *variabilis* Popofsky	594	538	982	146	8	23	134	149	143	988	378	615	658
Lophophaena cf. *capito* Ehrenberg	21	17	36	28	3	109	632	495	498	1419	768	1292	743
Lophophaena decacantha (Haeckel) group	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophopaena circumtexta (Popofsky)	5	0	37	11	3	53	112	112	76	226	213	445	378
Lophophaena cylindrica (Cleve)	2445*	1283*	1925*	1570*	11	81	280	280	179	2681	1645	2907	2352
Peromelissa phalacra Haeckel	*	*	*	*	28	207	876	762	714	1097	762	1043	1012
Helotholus histricosa Jørgensen	313	251	238	120	0	0	14	0	14	0	0	115	61
Lithomelissa setosa Jørgensen	0	0	0	0	11	17	168	115	104	1907	926	1908	841
Peridium spinipes Haeckel	1251	2184	3114	2173	45	649	2314	2432	2046	7692	4468	7698	5517
Peridium sp.	6	96	41	47	3	14	39	50	72	0	30	116	73
Trisulcus triacanthus Popofsky	0	0	0	0	3	0	0	0	0	36	42	140	0
Total LOPHOPHAENINAE	4635	4369	6373	4095	115	1158	4569	4395	3846	16046	9232	16279	11635