한국환경분석학회지 제13권 (제1호) 1~10, 2010
J. of the Korea Society for Environmental Analysis

Distributions of Polycyclic Aromatic Hydrocarbons and Fecal Sterols in Sediment from Gamak Bay and Their Impact on Benthic Community

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Received January 25, 2010/Accepted March 13, 2010

Polycyclic aromatic hydrocarbons (PAHs) and fecal sterols were determined in the sediment from Gamak Bay in Korea, to investigate their distributions and impacts on benthic environment. Concentrations of 16 PAHs and 8 fecal sterols in Gamak Bay sediments ranged from 130 to 2,100 ng/g dry weight (mean 400 ng/g dry weight), and from 740 to 9,500 ng/g dry weight (mean 2,900 ng/g dry weight), respectively. Concentrations of coprostanol (Cop), which has been used as indicator of domestic pollution, ranged from 12 to 600 ng/g dry weight. Concentrations of PAHs and Cop in the sediment from Gamak Bay were similar to or lower than those reported for industrialized bays of Korea and other countries. No correlation between the levels of PAHs and fecal sterols was found in sediment from Gamak Bay, suggesting the differences of source and behavior for these chemicals in coastal environment. Diagnostic ratios and profiles of PAHs in Gamak Bay sediment showed a strong pyrolytic origin with a slight petrogenic contamination. The Cop/(Cop+cholestanol) and Cop/cholesterol showed that the organic pollution in Gamak Bay was attributed to biogenic source rather than sewage pollution. Spearman correlation analyses and non-parametric multidimensional scaling (MDS) technique showed that distribution of fecal sterols was associated with benthic community structure in sediment from Gamak Bay.

Key words: PAHs, Coprostanol, Domestic pollution, Multidimensional scaling (MDS), Benthic community

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are widespread contaminants in the environment.[1,2] PAHs are primarily generated from car combustion, coal and petroleum combustion, and fire accidents.[3] Because of their carcinogenicity and mutagenicity to humans as well as wildlife, they have been measured in various environmental compartments, such as air, soil, vegetable, sediment and biota.[4-9] The major sources of PAHs in marine environment are combustion process (pyrolytic origin) and oil contamination (petrogenic origin).[10] Fecal sterols, including coprostanol, coprostanone, epicholestanol, and epichprostanol, are produced in the digestive tract of humans by the enteric microbial reduction of cholesterol.[11,12] Because fecal sterols are persistent and highly associated with organic matter and sewage particles, they have been used as molecular marker to identify the sources and status of domestic pollution in marine environment.[11-13] In particular, Coprostanol (Cop) has been widely used as a marker of human activities, because of high proportions (40-60%) of Cop to the total fecal sterols in human feces.[14]

A number of organic contaminants generated from various sources are introduced into marine environ-

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ment through atmospheric deposition, riverine input, soil run off and direct discharge. Because of their hydrophobic character, organic contaminants are adsorbed with particles in water column and then deposited to the sediment in marine environment. Analysis of marine sediment can provide comprehensive information on the contamination status, pathways, sources and potential risks of toxic chemicals in marine environment. Some studies have reported that toxic chemicals in the sediments can affect the survival and community structure of benthic organisms.15) Thus, benthic organisms have been used as good bioindicators of the long-term environmental health of sediments contaminated by toxic organic chemicals, because of their intimate contact with sediments.16)

Gamak Bay, which is located on the south coast of Korea, is a semi-enclosed bay. The bay has shallow water depth, many scattered islands and aquaculture farms.17) Aquaculture farm activity such as feel and feces from organisms is environmental problem to affect the benthic ecosystem of Gamak Bay.18) Yeosu area has been developed as a commercial harbor of south coast in Korea and has been increasing the population with high loadings of domestic sewage to Gamak Bay.18-20) The objective of this study was to investigate distributions and sources of PAHs and fecal sterols in sediments. We also investigated the relationships between the chemical contamination and benthic community in sediments from Gamak Bay, Korea.

2. Materials and Methods

2.1. Sample collection

Surface sediments were collected at 22 stations from Gamak Bay using a van Veen grab sampler (0.05 m^2) on February, 2005 (Fig. 1). Three replicate grab samples were collected for the analyses of chemicals and benthic community. The collected sediment samples for chemical analysis were individually wrapped in aluminum foil and were immediately frozen at freezer in a research

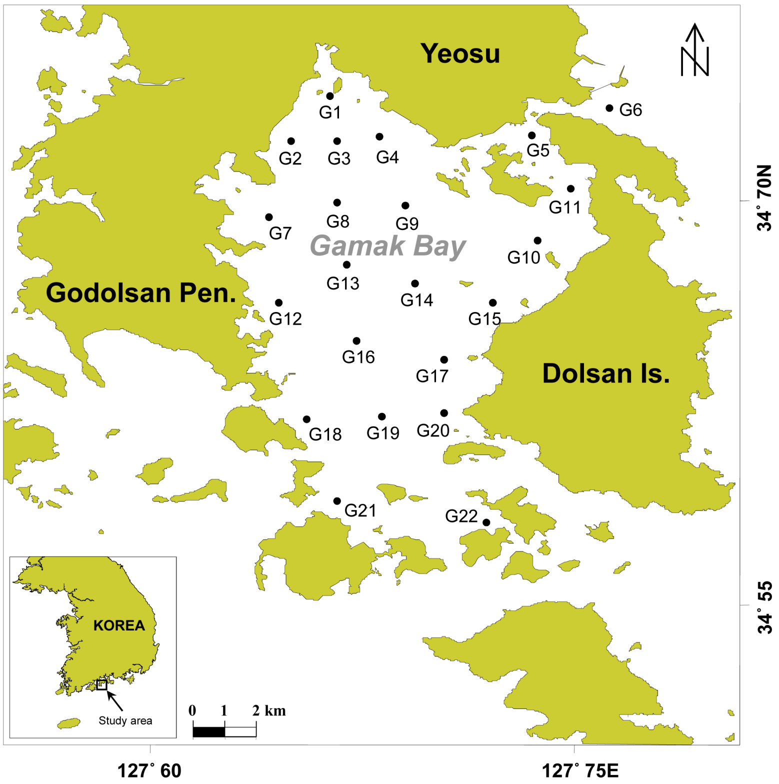

Fig. 1. Map showing the sampling locations of the sediments collected from Gamak Bay, Korea.

vessel. Sediment samples were transported to the laboratory and kept at 20°C in a refrigerator until further procedure. Macrofauna samples in sediments were sieved on a 1 mm round mesh. The retained fauna was fixed in 4% formalin and was identified to the lowest possible taxonomic level using a dissection microscope (Magnification 8-100, Discovery V12, Zeiss, Germany).

2.2. Sample preparation

Marine sediments were freeze-dried and sieved through a 2 mm mesh. PAHs in sediments were analyzed following the methods described elsewhere.[7,21] In brief, sediments were extracted in a Soxhlet apparatus using 200 mL of toluene (ultra residue analysis; J. T. Baker, Philipsburg, NJ, USA) for 16 h after spiking with 5 species of internal standards (napthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12} and perylene-d_{12}; 48902, Supelco, Bellefonte, PA, USA). The extracts were cleaned by passage through activated silica gel (neutral; 70-230 mesh; Merck, Darmstadt, Germany) column. The eluants were concentrated to approximately 1 mL. The residues were dissolved with 50 μL of *n*-nonane (pesticide analysis grade, Fluka, Buchs, Switzeland) for instrumental analysis.

Detailed methods for sterols analysis have been presented elsewhere.[16, 22, 23] Briefly, 5 g of freeze-dried sediment samples were placed in 50 mL Teflon centrifuge tube with a Teflon cap and then digested by mechanical shaking using 50% methlylene chloride (ultra residue analysis; J. T. Baker) 20 mL in chloroform (pesticide grade; Merck, Hohenbrum, Germany), after spiking surrogate internal standards 1-nonadecanol (Dr. Theodor Schuchardt & Co, Hohenbrum, Germany). The extract was reduced to 1 mL and then transferred to hexane (ultra residue analysis; J. T. Baker) and then, cleaned by passage through a florisil column and successive eluants with 40% hexane-methylene chloride 60 mL to eliminate the non-poral lipid and 40 mL of 20% methanol (ultra residue analysis; J. T. Baker)-chloroform. The eluents were concentrated and derivatized using bis(trimethylsilyl)trifluoroacetamide (BSTFA) (Sigma-Aldrich, St. Louis, MO, USA), for instrumental analysis.

2.3. Chemical analysis

Detailed conditions of instrumental analysis for PAHs and fecal sterols were presented elsewhere.[16, 22, 23] Identification and quantification of PAHs and fecal sterols were carried out using a gas chromatograph (Agilent 6890, Wilmington, DE, USA) coupled with mass spectrometer (Agilent 5973N). The capillary column used was a DB-5MS (30 m length, 0.25 mm inner diameter, 0.25 μm, J&W Scientific, Folsom, CA, USA). The mass spectrometer was operated under a selected ion monitoring mode using molecular ions of PAHs and fecal sterols. In this study, 16 non-alkylated PAHs recommended as priority pollutants by United Stated Environmental Protection Agency (US EPA). These include naphthalene (Nap), acenaphthylene (AcPy), acenaphthene (AcP), fluorene (Flu), phenanthrene (PhA), anthracene (AnT), fluoranthene (FluA), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-c,d] pyrene (InP), dibenzo[a,h]anthracene (DbA) and benzo [g,h,i]perylene (BghiP). Eight fecal sterols including coprostanol (Cop), cholesterol (Chst), cholestanol (Chsta), epicholestanol, epicoprostanol, brassicasterol, stigmasterol and sitosterol were analyzed.

Total organic carbon (TOC) contents in sediments were analyzed using a CHN elemental analyzer (Perkin Elmer, Model 2400; Boston, MA, USA), after removing the calcium carbonate with 1 N HCl. Grain size were analysis was performed using a particle size analyzer (Sympatec Windox4; Sympatec GmbH, Clausthal-Zellerfeld, Germany).

2.4. Quality assurance

All of the spiked internal and surrogate standards were detected with no interferences. The recoveries of spiked surrogate internal standards for PAHs and fecal sterols were 82 ± 22% (average ± standard deviation) and 77 ± 14%, respectively. Solvents injected before and after the injection of standards showed negligible contamination or carryover. Procedure blanks of sediments were processed in the same way as the samples. Blanks did not contain detectable amounts of target compounds. Limits of detection (LOD) were 1 ng/g dry weight for individual PAHs and from 5-15 ng/g dry weight for fecal sterols. In order to assess the quality of PAH determinations obtained by experimental procedure and instrumental analysis, certified reference sediment materials (1974a, NIST; Gaithersburg, MD, USA) were analyzed. The recoveries of total PAHs were 82 ± 11%.

2.5. Statistical analyses

Non-parametric multidimensional scaling (MDS) and cluster analysis were performed to characterize spatial variability of chemical distributions and the macrobenthic community at each sampling location using PRIMER software for Windows (PRIMER Version 5.2.9; Plymouth Marine Laboratories, Plymouth, UK). SPSS software (SPSS 12.0K for Windows) was used to perform the principal component analysis (PCA) and Spearman correlation analysis.

3. Results and Discussion

3.1. Contamination by PAHs and fecal sterols

The concentrations of PAHs and fecal sterols in sediments from Gamak Bay, Korea are summarized in Table 1. The concentrations of PAHs in sediments from Gamak Bay ranged from 130 to 2,100 ng/g dry weight with average 400 ng/g dry weight. The highest concentration of PAHs was found at Station G5, which is characterized by the location close to the outfall of the sewage treatment plant (STP) and Yeosu harbor. This result indicates the existence of local source of PAHs in Gamak Bay. Domestic sewage had been directly discharged to the northeast channel of Gamak Bay, before the establishment and operation of the sewage treatment plant (STP) on January 2005. The other stations, except G5 showed relatively uniform distribution of PAHs among stations with 320 ± 160 ng/g dry weight, suggesting that atmospheric deposition seems to be major source and pathway of PAHs in Gamak Bay.

The concentrations of total fecal sterols in the sediments from Gamak Bay ranged from 740 to 9,500 ng/g dry weight with average 2,900 ng/g dry weight. The concentrations of Cop in our study ranged from 13 to 600 ng/g dry weight. The highest concentrations of Cop was found at Stations G5 (560 ng/g dry weight) and G9 (600 ng/g dry weight), which are close to past and president outfalls of a STP in Yeosu. In particular, the Cop concentrations from Stations G5 and G9 exceeded the value (500 ng/g dry weight) influenced by sewage pollution.24) This result indicates that the STP is a major contamination source of fecal sterols in Gamak Bay.

Contamination of PAHs and Cop in sediments from Gamak Bay was compared to those reported for some locations from Korean coasts and other countries (Table 2). The concentrations of PAHs (130-2,100 ng/g dry weight) in Gamak Bay sediments were lower than those reported for Ulsan Bay (14-7,100 ng/g dry weight),8) Yeongil Bay (205-12,000 ng/g dry weight).7) The PAH concentrations in this study were higher than those measured in sediments from Kyeonggi Bay (10-1,400 ng/g dry weight) 25) and Mokpo Bay (5-510 ng/g dry weight) 26) in Korea. The contamination by PAHs in sediments from other countries such as Spain,27) USA28) and Tanzania9) was greater than those measured in this study. The overall PAH concentrations in Gamak Bay sediments were lower than the values of effects range low (ERL; 4,000 ng/g dry weight) and effects range median (ERM; 45,000 ng/g dry weight) of PAHs proposed by the National Oceanic and Atmospheric Administration (NOAA).28)

The concentrations of Cop (12-600 ng/g dry weight) in sediments from Gamak Bay were lower than those reported for those measured for industrialized bays of Korea such as Jinhae Bay (76-4,000),13) Mokpo Bay (94-7,600)30) and Ulsan Bay (140-8,300).31) The concentration of Cop in sediments from other locations/countries such as Vietnam,32) Black Sea,23) USA33) and Malaysia32) were one or two orders of magnitude higher than those measured in this study.

3.2. Sources of PAHs

The diagnostic ratios of PAH compounds have been

Table 1. Sedimentary characteristics, concentrations (ng/g dry weight) of PAHs and fecal sterols, and biotic indices in the sediments from Gamak Bay, Korea

Stations	Sediments										Benthic community			
			PAHs				Fecal sterols							
	TOC (%)	Grain size (μm)	PAH[a]	PhA/AnT[b]	FluA/Pyr[c]	LMW/HMW[d]	Sterol[e]	Cop[f]	Cop/(Cop+Chsta)[g]	Cop/Chst[h]	No. of species	Density (inds./m^2)	Individuals	Diversity (H')[i]
G1	1.3	4.7	290	3.1	0.8	1.1	2400	110	0.2	0.2	12	1050	105	1.1
G2	1.6	4.7	310	3.0	1.0	1.0	4400	150	0.1	0.2	7	300	30	1.5
G3	1.3	4.8	410	3.0	1.1	0.9	5100	420	0.3	0.3	8	990	99	0.6
G4	1.1	4.7	190	4.6	0.9	0.8	3300	110	0.1	0.2	17	1920	192	1.1
G5	0.6	5.2	2100	4.0	1.1	1.3	6500	560	0.4	0.2	na[j]	na	na	na
G6	0.6	5.8	200	5.8	0.8	1.8	740	20	0.1	0.1	na	na	na	na
G7	0.7	5.5	190	3.6	1.6	1.0	1500	75	0.2	0.3	8	250	25	1.9
G8	0.6	5.7	130	4.7	1.5	1.2	2200	52	0.1	0.1	9	190	19	1.9
G9	0.8	5.0	300	3.7	1.6	1.0	5800	600	0.3	0.4	19	3190	319	1.5
G10	0.7	5.4	360	4.0	1.4	1.0	2000	44	0.1	0.1	15	420	42	2.4
G11	1.7	5.2	450	3.9	1.4	0.8	9500	420	0.2	0.1	28	2960	296	1.9
G12	0.4	7.7	410	5.0	1.2	0.4	1900	20	0.1	0.03	22	1260	126	2.6
G13	0.4	9.0	510	4.7	1.3	0.6	2400	17	0.1	0.01	17	670	67	2.5
G14	0.4	7.6	320	11	0.9	0.4	1400	13	0.1	0.02	20	590	59	2.7
G15	0.3	6.0	150	6.5	1.1	1.2	2600	70	0.2	0.1	16	550	55	2.2
G16	0.3	7.4	700	4.1	1.6	0.5	2400	19	0.1	0.02	28	1620	162	2.8
G17	0.4	7.6	150	4.9	1.1	1.7	2500	41	0.1	0.1	28	650	65	3.1
G18	0.4	7.4	180	3.9	1.5	1.1	1100	12	0.1	0.03	23	650	65	2.8
G19	0.6	6.0	200	3.6	1.4	0.8	2200	28	0.1	0.04	12	210	21	2.4
G20	0.5	5.7	630	3.9	1.3	0.3	1700	19	0.1	0.03	20	670	67	2.6
G21	0.5	5.9	180	3.7	1.5	1.0	1600	17	0.1	0.03	12	220	22	2.3
G22	0.4	6.7	530	3.9	1.1	0.4	1500	18	0.1	0.03	21	710	71	2.5

[a] Sum of 16 PAHs by US EPA recommendation.

[b] Phenanthrene/Anthracene.

[c] Fluoranthene/Pyrene.

[d] LMW (lower-molecular-weight): sum of phenanthrene, anthracene, fluoranthene and pyrene; HMW (higher-molecular-weight): sum of benzo(a)anthrancene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno (1,2,3-c,d)pyrene, dibenzo(a,h)anthracene and benzo(g,h,i)perylene.

[e] Sum of 8 fecal sterols.

[f] Coprostanol.

[g] Coprostanol/(Coprostanol+Cholestanol).

[h] Coprostanol/Cholesterol.

[i] $H' = - pi \ln pi$; pi is the frequency of the species (i) present in the sample concerned.

[j] Not available.

used to identify contamination sources in marine sediments. The PhA/AnT > 10 and FluA/Pyr < 1 implies petrogenic origin and PhA/AnT < 10 and FluA/Pyr > 1 implies pyrolytic origin.[34)] In this study, almost of the sediment samples showed the values of PhA/AnT < 10 and FluA/Pyr > 1, indicating the predominance of pyrolytic origin in Gamak Bay. Besides, the ratios of lower-molecular-weight aromatics (LMW; sum of PhA, AnT, FluA and Pyr) versus higher-molecular-weight aromatics (HMW; sum of BaA, Chr, BbF, BkF, BaP, InP, DbA and BghiP) in sediments from Gamak Bay also indicated the predominance pyrolytic origin, like diagnostic ratios of PhA/AnT and FluA/Pyr.

To characterize the spatial variability of PAH profiles in sediments from Gamak Bay, we performed principal component analysis (PCA) using 16 PAH compounds (Fig. 2). Three groups were clustered with the distribution of PAH compounds. Group A (Stations G12-

Table 2. Comparison of the concentrations (ng/g dry weight) of PAHs and coprostanol in the sediments from Gamak Bay with those reported for Korean coasts and other countries/locations

Locations	Sampling year	n^a	Range
PAHs			
Gamak Bay, Korea	2005	16	130-2,100
Ulsan Bay, Korea[8)]	2000	16	14-7,100
Yeongil Bay, Korea[7)]	2000	16	210-12,000
Kyeonggi Bay, Korea[25)]	1995	23	10-1,400
Mokpo Bay, Korea[26)]	2006	16	5-510
Barcelona Harbor, Spain[27)]	2002	16	300-10,000
Casco Bay, USA[28)]	1991	16	12-6,200
Tanzania[9)]	2005	23	80-25,000
Coprostanol			
Gamak Bay, Korea	2005	-	12-600
Jinhae Bay, Korea[13)]	2004	-	76-4,000
Mokpo Bay, Korea[30)]	2006	-	94-7,600
Ulsan Bay, Korea[31)]	2003	-	140-8,300
Mekong Delta, Vietnam[32)]	2000	-	5-4,500
Black Sea[24)]	1995	-	1-5,400
Mississippi River, USA[33)]	1991-1992	-	100-7,500
Malaysia[32)]	1999	-	37-16,000

[a] Numbers of PAHs analyzed.

14, G16, G20, G22), located at middle part of the bay, was characterized by a dominance of HMW aromatics such as InP and BghiP. The PAH profiles in atmospheric deposition were governed by HMW PAHs associated with combustion processes.[21,35)] In contrast, Group B was characterized by a dominance of LMW aromatics such as FluA, Pyr and Chr, which seems to be affected by riverine discharge.[4)] The PAH profiles of Group C (Station G5), which have high level of PAHs, may have a specific source of PAHs like a discharge from the STP.

3.3. Sources of fecal sterols

The ratios of Cop and relative to fecal sterols in sediments can provide information on tracking the source of anthropogenic activities.[24, 36)] The Cop/(Cop + Chsta) > 0.7 represents a sewage pollution and Cop/(Cop + Chsta) < 0.3 represents a biogenic source in aquatic environment.[37)] In this study, almost of the sediment samples had the values of Cop/(Cop + Chsta) < 0.3, which indicates biogenic source of organic matter for Gamak Bay. Stations G3, G5 and G9, which were relatively high concentrations of Cop, were higher than 0.3, but did not exceed the value (0.7) influenced by

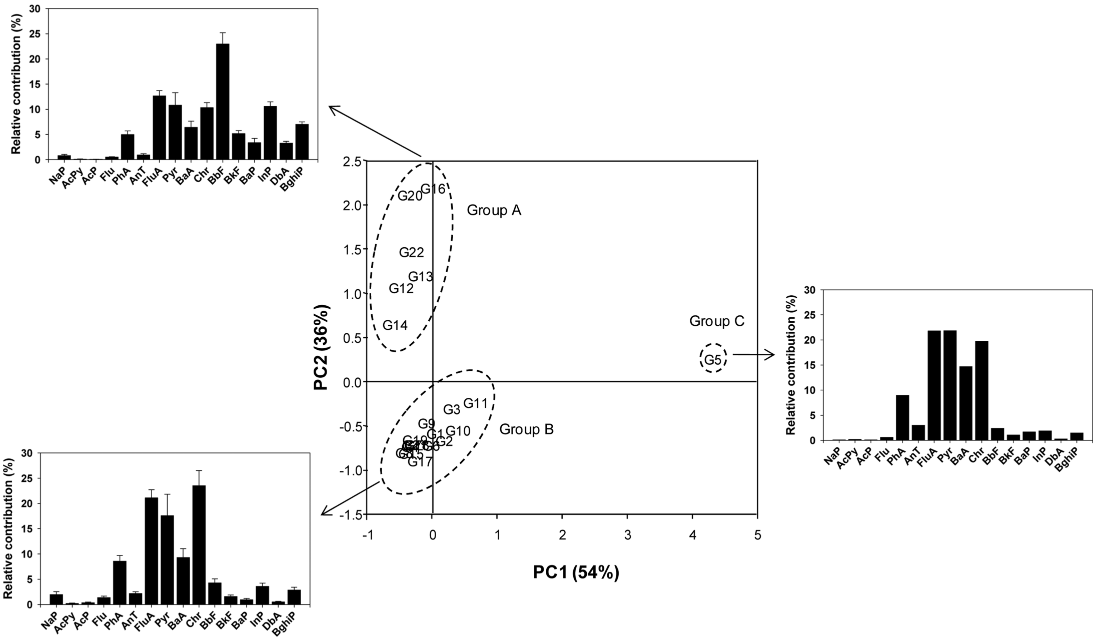

Fig. 2. Principal component analysis (PCA) of 16 PAH compounds in the sediment from Gamak Bay, Korea. Each group was clustered within near locations in the PCA results and normalized to the total concentrations of PAHs. Vertical lines represent standard deviations.

sewage pollution.

The Cop/Chst < 1 implies biogenic source and Cop/Chst > 1 implies sewage pollution.[24)] Although the values of Cop/Chst from Stations G3, G5 and G9 comparatively approached to 1, almost of the sediment samples showed the values less than 1. Our results suggest that sewage discharge is not contributable to the sediment contamination in the sediments from Gamak Bay.

3.4. Relationship between chemicals and benthic community

The main group of the benthic community at all stations was polychaete, which was generally recognized as an indicator of organic enrichment.[27)] Eighty polychaete species were found at all of the sampling stations. The dominant polychaete species were *Lumbrineris longifolia, Capitella capitata* and *Mediomastus californiensis*, which are highly resistant to organically contaminated sediments.[16,20)] Results of biotic indices such as the number of species, individual number, density and diversity of polychaetes are summarized in Table 1. Diversity (H') was calculated following the Shannon-Weaver diversity index. The number of species of polychaetes in all sampling stations was from 7 to 28 per 0.1 m^2. Diversity of polychaete species in the sediments from Gamak Bay was from 0.6 to 3.1. Individual numbers of polychaetes species were from 19 to 319 individuals/0.1 m^2.

Spearman correlation analysis was performed to investigate the relationship between the chemical and biotic data obtained in the sediments from Gamak Bay (Table 3). There was no significant correlation between the concentrations of PAHs and Cop was found ($r = 0.239$, $p = 0.021$) in the sediments from Gamak Bay, because they have different sources and behavior such as transport, mixing, deposition and degradation in coastal environment.[16)] No significant correlation between PAHs and TOC was found, whereas significant correlation ($r = 0.467$, $p = 0.029$) between Cop and TOC in the sediments from Gamak Bay. Our result indicates source and movement of TOC and fecal sterols are similar in coastal environment.

Number of species did not correlate with PAHs and fecal sterols. Density of polychaetes was positively correlated with PAHs and fecal sterols. Diversity in polychaetes was negatively correlated with the concentrations of TOC, fecal sterols and coprostanol, while there was no correlation between diversity and PAHs. Moon *et al.*[16)] reported that PAHs are little correlated with fecal sterols and, because unlike other chemical, PAHs has different sources such as combustion process and oil contamination. The dominant polychaete species, *L. longifolia, C. capitata* and *M. californiensis* had no significant correlations with PAHs and fecal sterols. Only TOC was positively correlated with *C. capitata*. Sediments from the northern part of Gamak Bay (G1-4) was governed by *C. capitata*, accounting for 99% to the

Table 3. Spearman correlation coefficients among chemical concentrations, biotic indices and dominant polychaete species in the sediments from Gamak Bay, Korea

	TOC	PAHs	Fecal sterols	Coprostanol	No. of species	Density	Diversity	*L. longifolia*	*C. capitata*
PAHs	0.026								
Fecal sterols	0.475*	0.015							
Coprostanol	0.758**	-0.123	0.811**						
No. of species	-0.490*	0.354	-0.088	-0.388					
Density	0.143	0.536*	0.452*	0.287	0.559*				
Diversity	-0.816**	0.196	-0.582**	-0.815**	0.689**	-0.105			
Lumbrineris longifolia	-0.241	0.256	0.341	0.099	0.515*	0.449*	0.184		
Capitella capitata	0.522*	0.098	0.335	0.418	-0.349	0.293	-0.607**	-0.406	
Mediomastus californiensis	-0.176	0.29	0.037	-0.079	0.417	0.322	0.215	0.576**	-0.449*

*$0.01 < p < 0.05$.

**$p < 0.01$

total individuals of *C. capitata*. Noh *et al.*[38] reported that the northern part of Gamak Bay are contaminated by aquaculture activities and sewage discharge from Yeosu area.

The results of non-parametric MDS ordination using chemical data and the benthic community at sampling locations are presented in Fig. 3. Non-parametric MDS showed two cluster groups of sampling locations by the distributions of PAHs, fecal sterols and benthic community, based on the confirmation of cluster analysis (figure not shown). The distributions of PAHs did not correspond to the distributions of other variables such as fecal sterols and benthic community. The cluster groups of sampling locations by fecal sterols were in accordance with those by benthic community, indicating that these are closely linked in deciding respective distributions in Gamak Bay. The first group (right circles) in (b) and (c) of Fig. 3 comprised of the stations (G1-4) of the northern part of Gamak Bay. As mentioned above, these sampling locations had relatively higher contents of organic matter, compared to other locations (left circles) in Gamak Bay. Consequently, comparatively high organic matters generated from biogenic and anthropogenic activities were primarily concentrated in the northern part of the bay and they were contributed to the benthic community structure in the sediments from Gamak Bay.

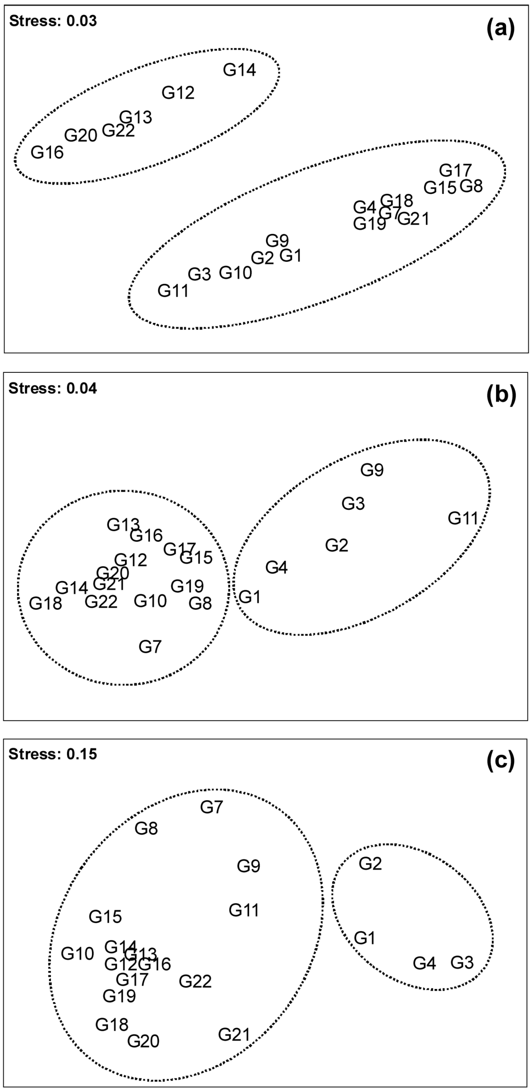

Fig. 3. Non-parametric multidimensional scaling (MDS) plots using (a) PAHs, (b) fecal sterols and (c) benthic community in the sediments from Gamak Bay, Korea.

4. Conclusion

Concentrations of PAHs and fecal sterols were measured in the sediments from Gamak Bay, Korea. No correlation between the levels of PAHs and fecal sterols was found at Gamak Bay sediments because of their different sources and behaviors in coastal environment. Contamination status of PAHs and Cop in Gamak Bay sediment was relatively low, compared to industrialized bays of Korea and other countries. Major source of PAHs were co-existence of predominantly combustions processes and oil contamination. The ratios of certain fecal sterols revealed biogenic source rather than sewage pollution for Gamak Bay. Multivariate statistical analyses showed that the distribution of fecal sterols was associated with benthic community structure in the sediments from Gamak Bay.

Acknowledgments

This study was funded by a grant from the National Fisheries Research and Development Institute (NFRDI-RP-ME-2010-007), Korea.

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