J. Ecol. Field Biol. 29 (4): 389~398, 2006

Physical and Chemical Characteristics of Sediments at Bam Islands in Seoul, Korea

Han, Miehie and Jae Geun Kim*

Department of Biology Education, Seoul National University, Seoul 151-742, Korea

ABSTRACT: To examine sediment characteristics and find anthropogenic effects on riverine wetland ecosystems, paleoecological study was carried out at Bam islands in Seoul. Three hundred cm deep sediment cores were retrieved and dated with the lamination analysis method until 36 cm depth (1986). Sediments were divided into three zones based on the depth profiles of physico-chemical variables: below 160 cm depth (before 1968), between 160 and 40 cm depths and above 40cm depth (after 1986). Physico-chemical characteristics were very variable between 160 and 40 cm depths and this indicates unstable sedimentation environment. Even though heavy metal concentrations were relatively low, Cd and As contents have increased continuously. Dry mass accumulation rates during 1968~1986 and 1987~2003 were 140 and 21 kg m^{-2} yr^{-1}, respectively. This was related to flooding intensity and duration. Bulk density, water content, loss on ignition, N, C, C/N ratio were very similar to other river delta but Ca, Na and K contents were 2 to 4 times higher than others. Heavy metal contents except Pb were lower or similar to those in other studied marshes in Korea. Heavy metal and Mg contents were correlated with each other and this suggests that the source of heavy metals be parent rock. From ^{13}C dating dates of organic materials in sediment, it is suggested that organic matter originated from the watershed and flooding intensity in the watershed might be responsible for the source of sediments. This study provides reference data for the comparison of sediment characteristics at islands in river and for the management of Bam islands.

Key words: Flood, History of Bam islands, Nutrient analyses, Pollen density, Sedimentation rate

INTRODUCTION

One important function of wetlands is to remove organic and inorganic materials from the water through sedimentation. When any material precipitates in the bottom, the sediment represents environmental changes in wetlands and watersheds, such as changes in nutrient and heavy metal concentrations and sedimentation rates (Mitsch and Gosselink 1999, Kim et al. 2001, Kim 2003). Paleoecological studies have been used to find any clue on environmental changes from the sediment and have been used to estimate and track the natural and anthropogenic disturbances of watersheds (Craft and Richardson 1993, Brenner et al. 1996, Kim and Rejmankova 2001, Kim 2005). Past history of ecosystem and cause-effect relationship, which were revealed by paleoecological studies, are useful to forecast future changes in ecosystems (Smol 1992).

To forecast future changes in ecosystems, it is necessary to understand the inherent background levels of natural process, the history of human activity, and paleoecological data. Paleoecological studies, combined with the history of human activities in the watershed provide a useful retrospective view of human impacts on wetlands beyond the time scale of any existing monitoring program (Wieder et al. 1994, Bartow et al. 1996, Bradbury and Van Metre 1997). However, there was no information available on the sediment characteristics at river islands in Korea.

Bam islands located in the middle of Seoul City and in the Han river, are ecologically important in Seoul and give a good scenery in Han river (Seoul City 2004). The islands consist of the upper island and lower island (Fig. 1). In the past, people lived in Bam islands. Original Bam islands were destroyed in 1968 to get soil and rock for the development of Yeoeu-do. At that time, there were around 10 of small islands (Seoul City 2004). There was a sand mining around Bam islands in 1980s and northern and southern parts of upper Bam island were used for sand deposit and loading place (aerial photographs from Seoul City). Han river development project was completed in 1986 and river water level increased. Present shape of Bam islands was formed in 1986 and area of Bam islands has been increased continuously. These islands were designated as an ecosystem conservation area in August 10, 1999 by Korean Ministry of Environment and Seoul City is in charge of monitoring and management of this ecosystem.

This study examines 1) recent sedimentation rates in Bam islands

---

* Corresponding author; Phone: +82-2-880-7896, e-mail: jaegkim@snu.ac.kr

by the lamination analysis method, 2) physical and chemical characteristics of sediments, 3) the effects of flooding on sediment characteristics and sedimentation rates, and 4) the source of sediments. This study provides reference data for the comparison of sediment characteristics at islands in river.

METHODS

Sampling Area

Bam islands (N 37°32', E 126°55') are consisted of upper and lower Bam islands in Han river in the middle of Seoul (Fig. 1). Total area has been expanding continuously at the average rate of 0.32 ha/year between 1985 and 2002 and became 24.9 ha in 2002. Height above river water level was an average of 4 m in 1998 and is slowly increasing by sedimentation during floods. Bam islands are dominated by *Salix* spp., *Artemisia selengensis, Miscanthus sacchariflorus*, and *Phragmites communis* (Seoul City 2004). *Humulus japonicus* community develops in summer and 46 plant families and 194 taxa were reported in 2004. *Salix* trees were used as nest-sites of Black-crowned Night Heron (*Nycticorax nycticorax*) and herbaceous plant communities were used as nest-sites of Spot-billed Duck (*Anas poecilorhyncha*) from the end of April to June.

Sampling was conducted from a small marsh of Lower Bam Island (N 37°32'12", E 126°55'41"), where *Alopecurus aequalis* var. *amurensis*, *Typha angustata*, and *Veronica arvensis* were dominated and *Salix* trees were extending into the marsh from edges. The marsh was round-type and diameter was around 32 m. Only the center of the marsh was covered with shallow water (lower than 5 cm from the soil surface).

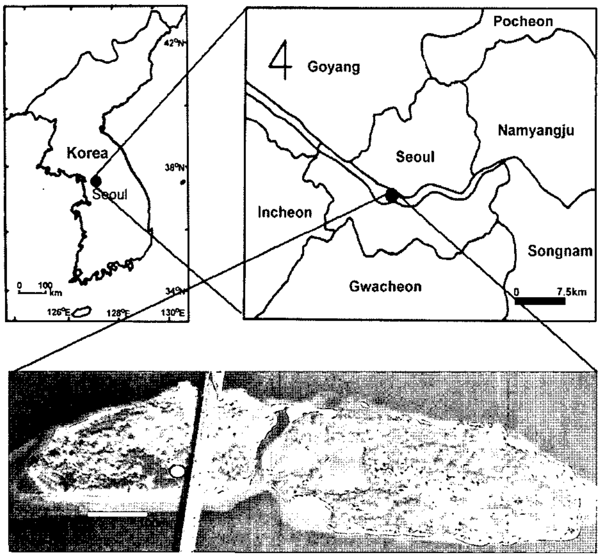

Fig. 1. Sampling area at Bam islands in Seoul. White circle in the bottom photograph indicates sampling area.

According to Korean Weather Bureau, there were high annual precipitation in 1987, 1990, 1998, and 2002 and precipitation is concentrated in the summer. In general, high river water level of Han river is related to the heavy rain in the watershed during rainy season and typhoon. Fig. 2 shows the duration of river water level above 4 m at Han bridge in summer and Bam islands were started to submerge above 4 m water level and all *Salix* trees were submerged at 9 m at Han bridge. There were big floods in 1987, 1990, 1995, 1998, 1999, and 2002. Figure 3 shows the effect of flood, e.g. high sedimentation and increase of the area of upper Bam island.

Sample Collection and Analyses

One sediment core (#1) was taken from the center of the marsh in March 2004 to a depth of 300 cm by a plastic open-end sampler (to 100 cm) and a soil augur (from 100 cm to 300 cm) and another core (#2) by driving a plastic open-end sampler (5.6 cm diameter) to a depth of 50 cm. Cores were transported to the lab in a cooler and then kept in a freezer. Frozen core #1 was later sectioned into 10-cm thick segments and another core #2 was sectioned into 1-cm thick segments. About 1 g of a wet sub-sample was taken for pollen analysis, and one or two tablets of the *Lycopodium* tracer (batch 938934, Dept. of Quaternary Geology, Lund University) were added to the sub-sample. Ten cm^3 of a wet-sample was taken from 40 cm of the core #1 for bulk density. The remaining samples were air-dried. Pollen analysis was performed at 1 cm intervals of core #2 with modifications of the standard method (Faegri and Iverson 1989) that included KOH treatment, sieving, $ZnCl_2$ flotation, and acetolysis. More than 300 grains of pollen or 100 grains of *Lycopodium* spore were counted under a light microscope (× 400).

Air-dried samples were ground with a mortar and a pestle and were sieved with a standard #60 sieve (mesh size 250 μm). The dry weight was determined after drying the sample at 105 ℃ for 24 hrs (Kim et al. 2004). Bulk density was calculated as dry weight per wet volume, and loss on ignition (LOI) was determined by the combustion in a muffle furnace at 550 ℃ for 4 hrs (Dean 1974, Boyle 2004). Total amounts of carbon (C) and nitrogen (N) were determined on an elemental analyzer (CE instrument, Model 1110). Total amount of phosphorus (P), sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) were determined by ICP-AES (Perkin-Elmer, Model OPTIMA 4300DV) and total amount of lead (Pb), copper (Cu), nickel (Ni) and cadmium (Cd) were determined by ICP-MS (Perkin-Elmer, Model ELAN 6100) at the National Center for Inter-University Research Facilities, Seoul National University.

Carbon dating of organic materials at 17 cm, 36 cm, 175 cm, and 296 cm of the core #1 was done at AMS laboratory of the

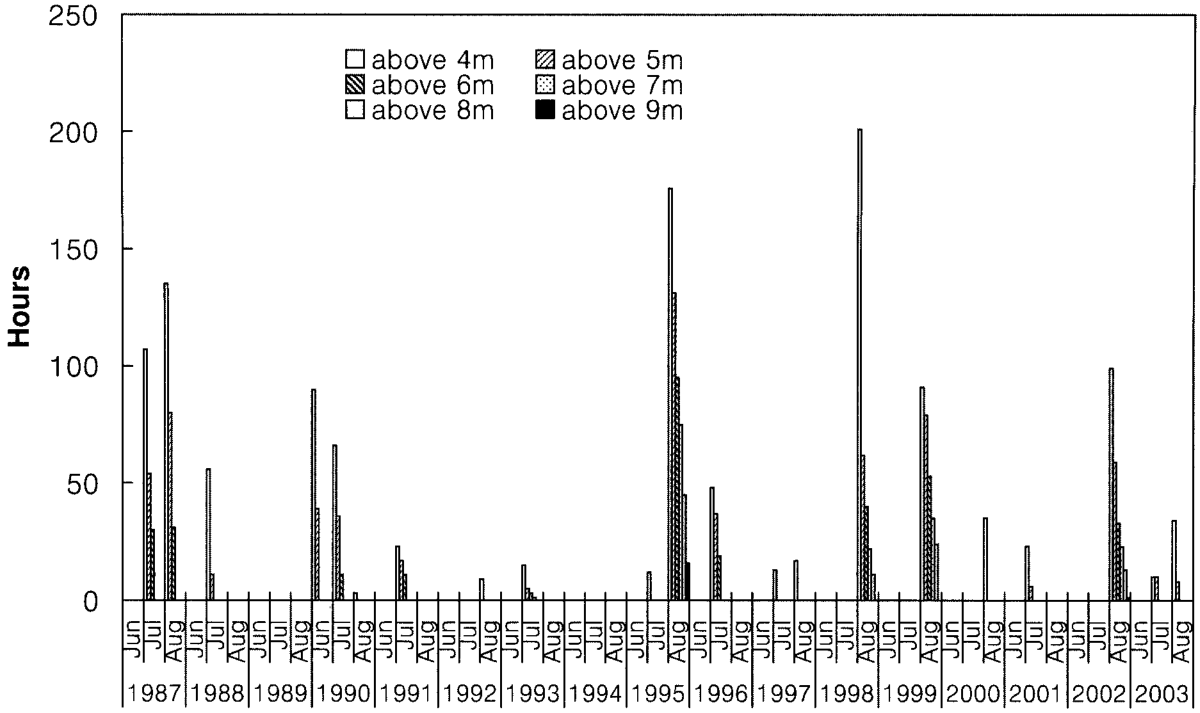

Fig. 2. Duration of river water level at Han bridge, indicating flooding level and duration of Bam islands. Bam islands started to flood at river water level 4 m. (Data from Water Resources Management Information System, http://www.wamis.go.kr/).

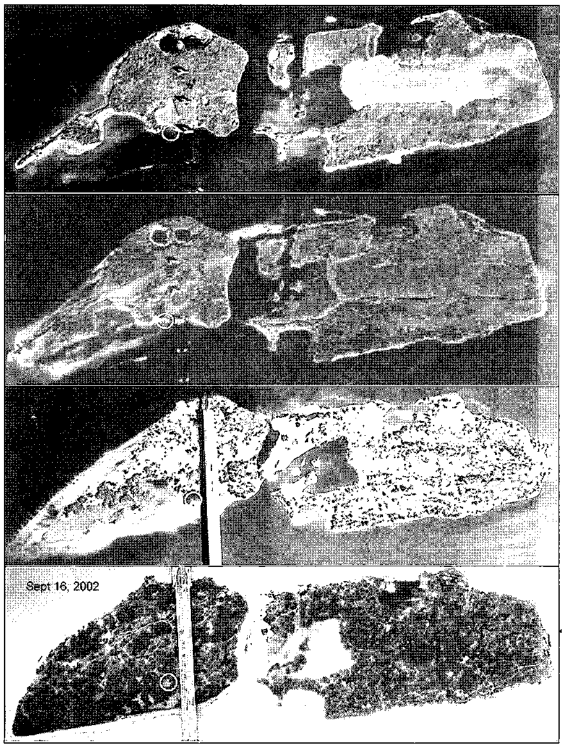

Fig. 3. Time sequential aerial photographs of Bam islands from 1987 to 2002. White circle indicates the sampling site.

National Center for Inter-University Research Facilities, Seoul National University. Sediment dating between 0 to 40 cm was done with the lamination analysis method, which compares water level change, physical and chemical characteristics of sediment, and pollen density (Saarnisto 1986). StatView for Windows (Abacus Concepts, Version 4.57) was used for statistical analysis.

RESULTS AND DISCUSSION

Temporal Changes of Physico-Chemical Characteristics and Dating of Sediment

300 cm sediment was divided into three zones based on physical and chemical characteristics (Fig. 4). Zone I is below 160 cm depth and has stable characteristics of sediment. Loss on ignition, C/N ratio and H content were relatively low and N content and bulk density were relatively high. This zone might have stable sedimentation environment under water, e.g. before destruction of Bam islands in 1968 (Seoul City 2004). Zone II is from 40 cm to 160 cm depth. Physical and chemical characteristics were variable meaning unstable sedimentation environment. The Han river development project was completed in 1986 and the river water level increased since then (Seoul City 2004). This zone might have been formed between 1968 and 1986, when sands were mined around

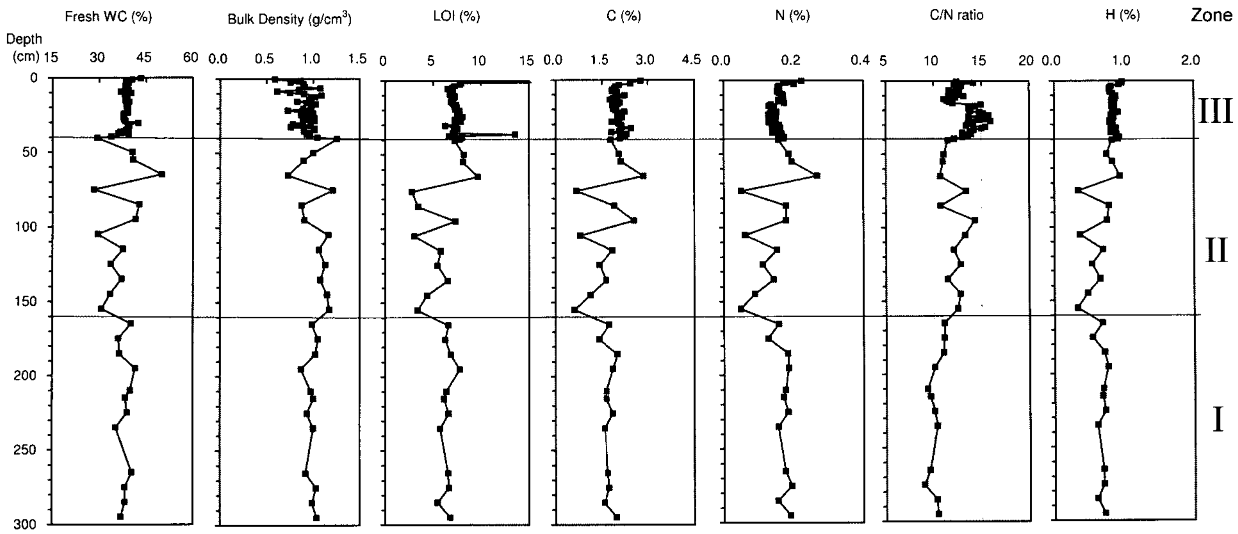

Fig. 4. Depth distribution of physical and chemical variables in the soil core #1 (10 cm intervals until 300 cm) and #2 (1 cm intervals until 40 cm depth). Horizontal lines indicate sediment zone.

sampling area.

Lamination analysis indicated four dates at the core #2; 1988, 1990, 1996, 2002 flooding events at depths of 37, 32, 17, 7~3 cm, respectively. Aerial photograph in 1987 shows that sampling area was shallow river and it was closed by sediment in the photograph of 1991 (Fig. 3). Organic content and pollen density are high in aquatic environment in general and high organic content and pollen density (Fig. 5) support this fact. There was a huge flood in 1996 and the area of Bam islands abruptly increased (Seoul City 2004) and the storm water might flush old organic materials in the soil of the watershed. This was recorded in the sediment at the depth of 17 cm as low C/N ratio (Fig. 5). Fresh water content, loss-on-ignition, total C and N increased recently in the result of growing vascular plant in the marsh and input of plant debris from the surrounding environment. Increased percentage of total N since 1996 coincides with the increase of *Humulus japonicus* (Seoul City 2004) which is an indicator species of nutrient pollution (Mun 1977). This might come from the increase of organic material input into the islands during floods (Seoul City 2004).

Heavy metal profiles indicate that Cd content has increased continuously from 0.25 ppm in 1988 to 0.30 ppm in 2004 and increased concentration of As has continued since 1990 (Fig. 6). Pb and Cu contents increased recently. A source of Cd is automobile tire and traffic increases since Seogang bridge was constructed. This might be resulted from the increase of traffic on Seogang bridge which across lower Bam island (Seoul City 1998). Even though some heavy metals increased recently, increasing levels were low. This may be the due to the steady state of population in Seoul and deep concerns of citizens on their environment.

Sediment Accumulation Rate

Zone Ⅱ was formed between 1968 and 1986 and sedimentation environment might have been very turbulent (Fig. 4). Zone Ⅲ was formed in the period of relatively stable water flow except flooding. Sediment accumulation rate in zone Ⅱ was much higher than in Zone Ⅲ. The difference in sediment accumulation rate must come from the different sedimentation environment such as water flow rate, flooding intensity and duration, etc. This high dry mass accumulation has not been recorded even in river systems (Kim 2003).

Dry mass accumulation rate in Zone Ⅲ was about 21 kg m^{-2} yr^{-1} and can be converted to 2.7 cm/yr (Table 1). If this sedimentation rate applied to all area of the islands, altitude might be increased 16 cm since 1997 measured by Seoul City.

Accumulation rates of total N, C and H, which were related to organic material, were less than 1/10 in other marshes in Korea and North America (Kim 2003, Kim 2005, Kim and Lee 2005). However, much higher accumulation rates of heavy metals compared to accumulation rate of total P was similar to other marshes in Korea (Kim 2005, Kim and Lee 2005). This means that heavy metals and some portion of total P were brought with other inorganic matter to the islands.

Dry mass accumulation rate since 1986 changed dramatically with flooding events (Figs. 2 and 7). There were severe floods in 1990, 1995, 1998, and 2002 (Fig. 2) and dry mass accumulation rates were 36.6, 38.9, 24.8, and 45.4 kg m^{-2} yr^{-1}, respectively.

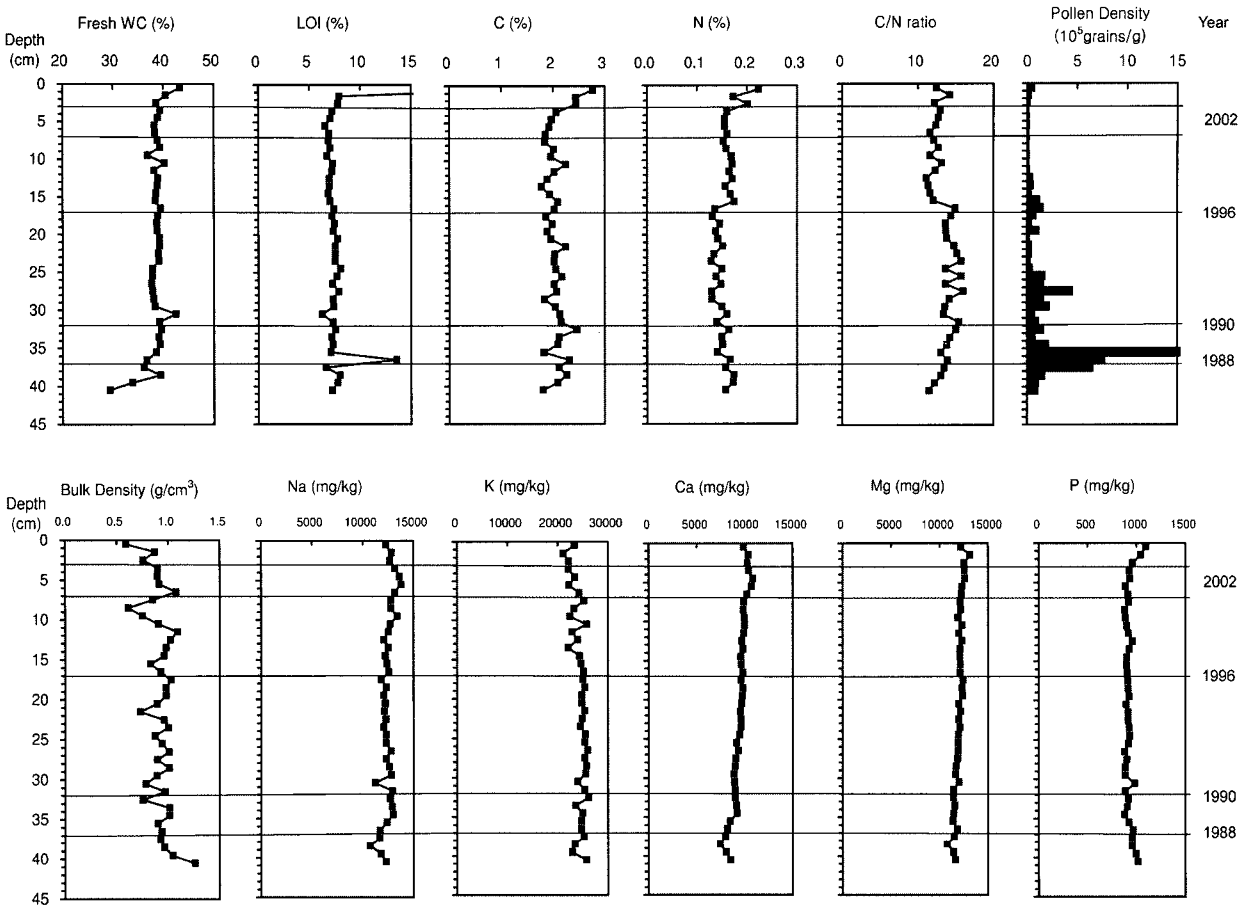

Fig. 5. Depth distribution of physical, chemical and biological variables in the soil core #2. Horizontal lines indicate lamination-derived sediment dates.

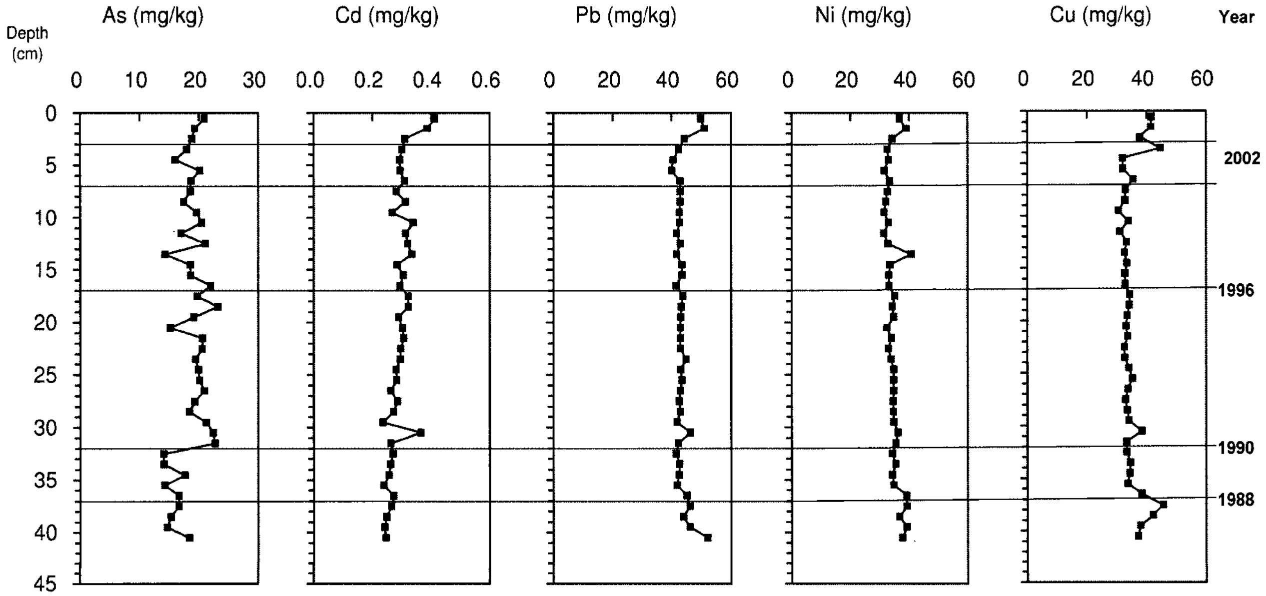

Fig. 6. Depth distribution of heavy metals in the sediment core #2. Horizontal lines indicate lamination-derived sediment dates.

There was no flood in 1994 and little flood in 2001 (Fig. 2) and dry mass accumulation rates were very low. These indicate that sediment accumulation rate in Bam islands is determined by the flooding intensity and duration and these depend on discharge at Paldang-dam.

Table 1. Element accumulation rates (g m^{-2} yr^{-1}) in Bam islands.

Period (AD)	Total N	Total C	Total H	Dry mass	
1987~2003	0.003	0.043	0.018	20,950	
1968~1986	0.023	0.260	0.096	139,766	
	Total Na	Total K	Total Mg	Total Ca	Total P
1987~2003	261.3	510.7	251.0	197.6	19.42
	Total Cd	Total Pb	Total As	Total Ni	Total Cu
1987~2003	0.006	0.914	0.390	0.73	0.73

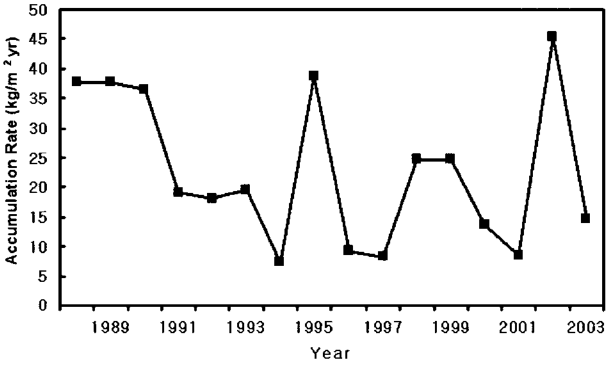

Fig. 7. Annual change of dry mass accumulation rate in Bam islands since 1986.

Physico-Chemical Characteristics of Sediment

1) Concentrations of Physico-Chemical Variables in Sediments

The major components of sediment in Bam islands were sand and silt and average of bulk density was 0.9 g/cm^3. Bulk density in Bam islands was higher than organic sediment (around 0.5 g/cm^3) but lower than sand, sand-peat, silty clay (around 1.5 g/cm^3) at marshes in Ulsan, Korea (Kim 2005). Pb content was much higher than in Mujechi-neup and Sanggae reservoir in Ulsan (Kim 2005). Heavy metal content were much lower than the minimum contents in heavy metal polluted area suggested by Korean Law for Soil Environment Conservation (Korean Law No. 7459).

Bulk density, water content, LOI, N, C, and C/N ratio were very similar at Rodman Slough in California where sedimentation environment was similar (Kim 2003). However, Ca, Na and K contents were 2 to 4 times higher than those in Rodman Slough. Pb content was much higher than 22 mg/kg at Rodman Slough and this high content might be resulted from air pollution and different parent rock type in the watershed.

2) Relationships among Physico-chemical Variables in Sediments

Correlation analysis among physico-chemical variables in sediments shows that many variables were correlated with each others (Table 2). Physico-chemical variables can be divided into three groups. The first group includes organic material related variables: C, H, N, P, LOI, Bulk Density, Water Content (Fig. 8). Bulk Density was negatively correlated with N and LOI and P, N, and LOI were positively correlated. The second group includes mineral and heavy metals: Na, Ca, Mg, Cd, Cu, Ni, Pb (Fig. 9). Mg was positively correlated but Ca and Na were negatively correlated with heavy metals. Correlation analysis showed the strong positive correlations

Table 2. Average and standard deviation of physical and chemical characteristics of sediments

	BD (g/cm^3)	FWC (%)	LOI (%)	H (%)	N (%)	C (%)
Average	0.953	38.3	7.27	0.78	0.16	1.93
1SD	0.128	3.3	3.11	0.14	0.03	0.40
	C/N ratio	Na (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	P (mg/kg)
Average	12.6	12478	24344	9458	11994	928
1SD	1.7	588	1296	733	424	46
	As (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	
Average	18.6	43.6	0.29	34.7	35.1	
1SD	2.5	2.5	0.04	2.3	3.6	

SD: standard deviation, BD: bulk density, FWC: fresh water content, LOI: loss on ignition.

among heavy metals. This suggests that heavy metals came from the parent rock materials (Schlesinger 1997) and Mg can be a candidate for heavy metal indicators of parent materials.

The other group includes P, Ni, Cu, Pb, N, and LOI (Fig. 10). Phosphorus was strongly related with other variables in this group (Table 3). The major portion of phosphorus in sediments is typically bound to caly or soil particles (Murray and Gottgens 1997, Schleginser 1999). The relatively high phosphorus content in these sediments may indicate a significant input of soil particles from the watershed (Murray and Gottgens 1997). The relationships in the third group support that Mg and heavy metals originated from the parent materials in the watershed.

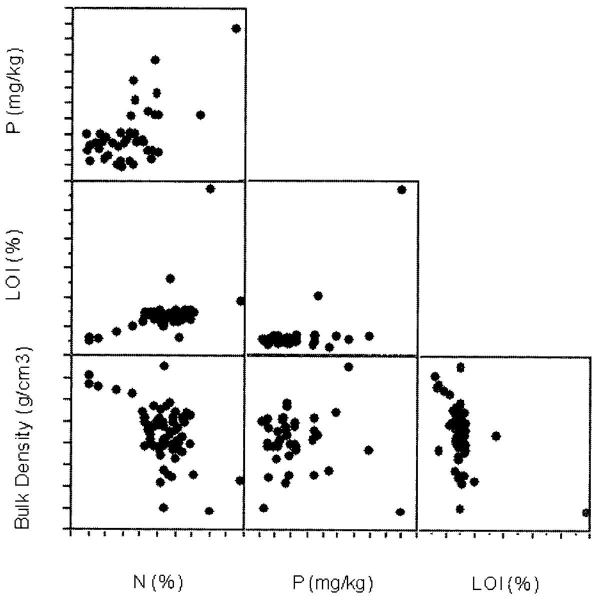

Fig. 8. Scattered plots showing relationships among P, N, LOI, and bulk density.

Carbon Sources Deduced from ^{13}C Dating of Sediment

^{13}C dates of organic materials in sediment were much older than those examined with the lamination analysis method. The 17, 36, and 160 cm depths dated with lamination analysis method were 1999, 1988, and 1968, respectively. However, dates with ^{13}C dating method at corresponding depths were 430, 390, and about 370 years BP (Table 4). Also ^{13}C dates were reversed with depth even though

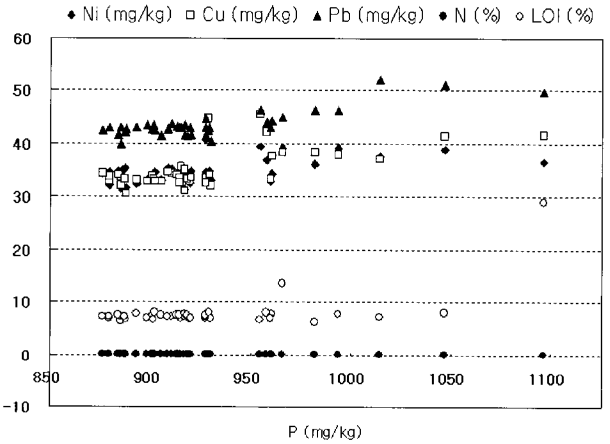

Fig. 10. Scattered plots showing relationships between P and Ni, Cu, Pb, N and LOI.

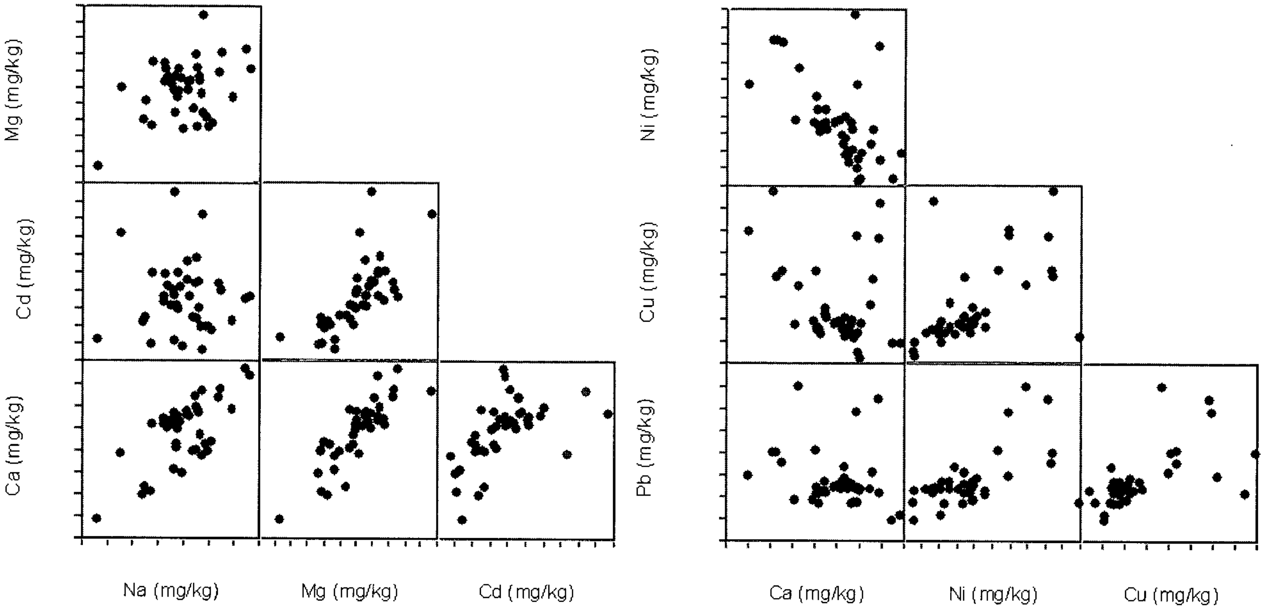

Fig. 9. Scattered plots showing relationships among selected mineral and heavy metals.

Table 3. Correlation matrix of physical and chemical characteristics of sediments

	BD	WC	LOI	N	C	H	C/N	P	Na	Mg	K	Ca	Ni	Cu	As	Cd	Pb
WC	−0.695***																
LOI	−0.500***	0.392**															
N	−0.570***	0.746***	0.478***														
C	−0.688***	0.736***	0.584***	0.778***													
H	−0.625***	0.624***	0.511***	0.665**	0.908***												
C/N	−0.105	−0.072	−0.094	−0.421**	0.234	0.268											
P	−0.104	0.001	0.614***	0.61***	0.521**	0.658***	−0.217										
Na	−0.083	0.023	−0.133	−0.029	−0.157	−0.459**	−0.134	−0.372*									
Mg	−0.210	0.292	0.038	0.140	0.020	−0.001	−0.145	0.158	0.356*								
K	0.194	−0.174	−0.093	−0.490**	−0.141	−0.203	0.459**	−0.346*	−0.209	−0.381*							
Ca	−0.242	0.365*	−0.006	0.104	−0.081	−0.234	−0.200	−0.131	0.687***	0.842***	−0.387*						
Ni	0.182	−0.237	0.241	0.172	0.244	0.418**	0.020	0.586***	−0.471**	−0.241	−0.080	−0.560***					
Cu	−0.075	0.012	0.335*	0.430**	0.479**	0.542**	−0.059	0.648***	−0.394*	−0.048	−0.251	−0.342*	0.564***				
As	−0.101	0.227	0.099	−0.085	0.063	−0.05	0.202	−0.028	0.049	0.361*	0.243	0.289	−0.266	−0.108			
Cd	−0.407**	0.616***	0.445**	0.411**	0.378*	0.351*	−0.107	0.467**	−0.025	0.701***	−0.383*	0.556**	0.013	0.164	0.342*		
Pb	0.047	−0.240	0.425**	0.403*	0.374*	0.506**	−0.111	0.831***	−0.388*	0.089	−0.121	−0.247	0.582***	0.599***	0.087	0.319*	
Depth	0.320**	−0.135	−0.260	0.037	−0.430**	−0.590***	0.366*	−0.069	−0.507**	−0.828***	0.534**	−0.906***	0.450**	0.117	−0.255	−0.671***	0.106

Table 4. ^{13}C contents and ^{13}C-derived dates

Sample ID	Lab No.	^{13}C (‰)	Depth (cm)	Dates (years BP)
Bamsum 17	SNU 04-777	-22.79	17	430 ± 40
Bamsum 36	SNU 04-778	-23.18	36	390 ± 40
Bamsum 175	SNU 04-779	-21.81	175	370 ± 40
Bamsum 296	SNU 04-780	-21.69	296	170 ± 40

deeper part was deposited earlier than lower part in general. If carbon in sediments came from the near-surroundings of the sampling site and there was no disturbance in the sediment column, ^{13}C dates in upper part must be younger than in lower part in general. This means that most organic materials in sediment originated from the watershed and transported by water. Flooding intensity in the watershed might be responsible for the source of sediments and flooding event in Han river (Fig. 2) is well correspond to the ^{13}C dates; intense flood flushes old materials in relatively deep soil.

CONCLUSION

This study revealed the physico-chemical characteristics of sediments and sediment accumulation rates in Bam islands. Dry mass accumulation rate since 1968 was much higher than other inland wetlands studied in Korea and North America. This high dry mass accumulation rate came from the hydrological characteristics of Han river and geological setting of Bam islands due to human activities: flooding event and excavation of soil and rock. Major cation concentrations were much higher but C and N were much lower than other inland wetlands studied in Korea. Heavy metal contents except Pb were lower than in other inland wetland studied in Korea. The age of carbon in the sediment of 1986 was 400 year BP and there were strong corelation among heavy metal and Mg concentrations. From this result, the major source of heavy metal and C in the sediment was organic materials and parent rock in the watershed. This study provides reference data for the comparison of sediment characteristics of islands in the river and for the management of Bam islands.

ACKNOWLEDGEMENT

We thank YW Lee for helping sampling and sample pre-treatment for analyses and HM Kang, HJ Lee, JY Hu in Seoul Science High School for helping sample pre-treatment for analyses. We thank Seoul City for allowing us to sample sediment in Bam islands. This work was supported by Research and Education Program from Korea Science and Engineering Foundation funded by Korean Government in 2004.

LITERATURE CITED

Bartow SM, Craft CB, Richardson CJ. 1996. Reconstructing historical changes in Everglades plant community composition using pollen distributions in peat. Lake Res Mgmt 12: 313-322.

Bradbury JP, Van Metre PC. 1997. A land-use and water-quality history of White Rock Lake reservoir, Dallas, Texas, based on paleolimnological analysis. J Paleolimn 17: 227-237.

Brenner M, Whitemore TJ, Schelske CL. 1996. Paleolimnological evaluation of historical trophic state conditions in hypereutrophic Lake Thonotosassa, Florida, USA. Hydrobiologia 331: 143-152.

Craft CB, Richardson CJ. 1998. Recent and long-term organic soil accretion and nutrient accumulation in the Everglades. Soil Sci Soc Am J 62: 834-843.

Dean WE Jr. 1974. Determination of carbonates and organic matter in calcareous sediment and sedimentary rocks by loss on ignition: Comparison with other methods. J Sed Petrol 44: 242-248.

Boyle J. 2004. A comparison of two methods for estimating the organic matter content of sediments. J Paleolimn 31: 125-127.

Faegri K, Iverson J. 1989. Textbook of Pollen Analysis. John Wiley and Sons. New York.

Kim JG, Lee YW. 2005. Recent vegetation history and environmental changes in Wangdeungjae moor of Mt. Jiri. Korean J Ecol 28: 121-127.

Kim JG. 2003. Response of sediment chemistry and accumulation rates to recent environmental canges in the Clear lake watershed, California, USA. Wetlands 23: 95-103.

Kim JG. 2005. Assessment of recent industrialization in wetlands near Ulsan, Korea. J Paleolimn 33: 433-444.

Kim JG, Park JH, Choi BJ, Shim JH, Kwon KJ, Lee BA, Lee YW, Joo WJ. 2004. Method in ecology. Bomundang, Seoul, p 285. (in Korean)

Kim JG, Rejmankova E. 2001. The paleoecological record of human disturbance in wetlands of the Lake Tahoe basin. J Paleolimn 25: 437-454.

Kim JG, Rejmankova E, Spanglet HJ. 2001. Implications of a sediment-chemistry study on subalpine marsh conservation in the Lake Tahoe basin, USA. Wetlands 21: 379-394.

Mitsch WJ, Gosselink JG. 1999. Wetlands, 3rd ed. John Wiley & Sons, Inc. New York, p 919.

Mun H-T. 1997. Effects of colony nesting of *Adrea cinerea* and *Egretta alba modesta* on soil properties and herb layer composition in a *Pinus densiflora* forest. Plant Soil 197: 55-59.

Murray TE, Gottgens JF. 1997. Historical changes in phosphorus accumulation in a small lake. Hydrobiologia 345: 39-44.

Saarnisto M. 1986. Annually laminated lake sediments. In: Handbook of Holocene Palaeoecology and Palaeohydrology (Berglund BE, ed). John Wiley & Sons Ltd., New Jersey, pp 343-370.

Schlesinger WH. 1999. Biogeochemistry: An analysis of global change. Academic Press, New York, p 588.

Seoul City. 1998. Survey Research in Han river Ecosystem. (in Korean)

Seoul City. 2004. Ecological Monitoring and Management Plan in Bam

Islands Ecosystem Conservation Area. (in Korean)

Smol JP. 1992. Paleolimnology: an important tool for effective ecosystem management. Journal of Aquatic Ecosystem Health 1: 49-58.

Wieder RK, Novak M, Schell WR, Rhodes T. 1994. Rates of peat accumulation over the past 200 years in five Sphagnum dominated peatlands in the United States. J Paleolimn 12: 35-47.

(Received August 1, 2006; Accepted August 18, 2006)