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Paleoecological perspectives of anthropogenic impact in Seocheon, on the west coast of the Korean Peninsula

서천에서 고생태학적 연구를 통해 본 최근 인간 활동의 역사

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Abstract

Paleoecological study was conducted in the Yonghwasil-mot to reconstruct human activities in Seocheon, Korea. Yonghwasil-mot is a reservoir constructed for the purpose of irrigating paddies. Sediment core was collected and dated using the ^{210}Pb method. The average dry mass accumulation rates from 1863 to 2011 was 1.80 kg m^{-2} yr^{-1}. The ^{210}Pb flux rate of the study area was 42.4 mBq cm^{-2} yr^{-1} and seemed to be affected by wind from China. There was a big increase in the accumulation rate in 1956 and the amount of organic matter, total carbon, nitrogen and phosphorus also increased. This indicates significant input of soil and organic particles into the Yonghwasil-mot and a less decomposed state because of increased water levels. The concentrations of Pb, Cu, As, Cd, and Zn reflect the influences of the Janghang smelter located around 6 km away and Janghang station located around 300 m away. The concentrations of As, Cu, and Pb have decreased slowly since the mid-1990s and the decrease of lead contents is attributed to the government policy banning the sale of leaded gasoline. Pollen analysis revealed that Gramineae and *Pinus* spp. were high in this area. *Alnus* spp. dominated below 44 cm depth and abruptly decreased around 1894. This may be related to the expansion of farmland around the study area. Relationship between human activities and changes of water level of Younghwasil-mot was reconstructed through pollen, LOI, C/N stratigraphy. Also, influence of Janghang smelter, Janghang station and the industrialization of Korea on environment was able to identified using heavy metal contents. The ^{210}Pb flux rate suggests that Seocheon is affected by dust from China because of westerlies.

Key words: Paleoecology, Anthropogenic impact, ^{210}Pb dating, ^{210}Pb flux, Pollen analysis, Heavy metals

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1. Introduction

1.1 Study background

Wetlands accumulate various detrital elements and materials. Sediments, nutrients and metals are transported by not only natural processes but also via the effects of anthropogenic activities in wetlands (Mackereth 1966; Bradbury and Van Metre 1997; Kim 2001). Trapped elements accumulate in the sediment over time and the sediment becomes a historical archive of various watershed information that help with discerning changes related to human activities and inferring likely future scenarios (Smol 1992). Furthermore, industrialization, urbanization, and related human activities from the last century leave traces in the sediment. Therefore sediment can act as an archive of past contamination history (Yu et al. 2011).

Unsupported ^{210}Pb is broadly distributed on the earth's surface by dry and wet precipitation and can be found in both soil and water (Preiss et al. 1996). With a half-life of 22.3 years and well-defined source functions, ^{210}Pb is the most commonly used chronometer for estimating sedimentation rates in environments (Appleby and Oldfield 1992). Accurate measurements of sediment accumulation rates are crucial for the determination of sediment budget, flux of chemicals, and changes in chemical composition in the sedimentary column (Hong et al. 1997). The Korean Peninsula is affected by wind from China that transports dust including pollutants and radioactive substances to Korea (Choi et al. 1989). Therefore, ^{210}Pb flux rate in the west coast of the Korean Peninsula can be an indicator of the degree and direction of air pollution from China to Korea.

Full industrialization began in the 1960's and was mainly focused on the coastal area in South Korea (Kim 2005). Seocheon is located in the vicinity of the west sea and was industrialized relatively early. In 1920~1930, the Japanese Government-General of Korea constructed the Chungnam line (it later became the Janghang line) and Janghang port for effective plunder of cereals. Furthermore, Janghang smelter was opened in 1936 for the purpose of smelting gold, which was used to purchase war materials (Kim 2014). Therefore, Seocheon is a reasonable region to assess the impact of early industrialization in Korea on the surrounding ecosystems. Furthermore, paleoeological studies focused on the border of the industrial era in Korea are rare and were mainly conducted in the eastern and southeastern parts of Korea (Kim 2005; Kim and Kim 2010; Cho et al. 2015). Although there was a study on the west coast of Korea, it focused on the period after 1970 and mainly investigated pollution through water (Ra et al. 2011). Hence, this study conducted in the west coast of Korea and focused on human activities at the beginning of the industrial era including pollution via air could uncover valuable data documented in the sediment.

This study will provide direct historical data of human activities in the Seocheon area on the west coast of the Korean Peninsula and determine the influence of China and industrial development on the ecosystems. The specific objectives of this study were to determine the ^{210}Pb flux rate and source as well as to reveal physical and chemical properties of the sediment for the assessment of recent human activities in Seocheon, Korea.

1.2 Study site

Seocheon is located in the southwest part of the Korean Peninsula (E 126° 52′ ~ 126° 30′, N 35° 59′ ~ 36° 11), in the vicinity of the west sea to the west and Geum river to the south (Fig. 1). Yonghwasil-mot (or Yonghwasil reservoir, and, even earlier, Deogam reservoir), which is located in the south part of Seocheon and has an area of 27,000 m^2, is a reservoir built for the purpose of irrigating paddies. The study area contains a hilly plain under 100 m.a.s.l. and marine alluvial deposits due to land reclamation. Bedrock around the reservoir consists mainly of Precambrian granite gneiss (Song et al. 2008). Janghang smelter was located around 6 km away from the reservoir and the reservoir was expected to reflect the change in heavy metal accumulation rate over time. Janghang smelter was established in 1936 by the Japanese Government-General of Korea for the purpose of refining gold. It was active until 1989 smelting copper, lead, and tin and completely ceased operation in 2008.

According to the Public health research conducted by the Ministry of environment in 2008, blood and urine concentrations of Cd, Pb, Cu, Ni, and As in the investigation group were significantly higher than in the control group (National Institute of Environmental Research 2008). In July 31, 2009, the Korean government announced an integrated solution for improving soil contamination in the region around the (former) Janghang smelter and decided to purify the area. Yonghwasil-mot is located at the northern end of the National Institution of Ecology (NIE) at present and was dredged during the construction of NIE.

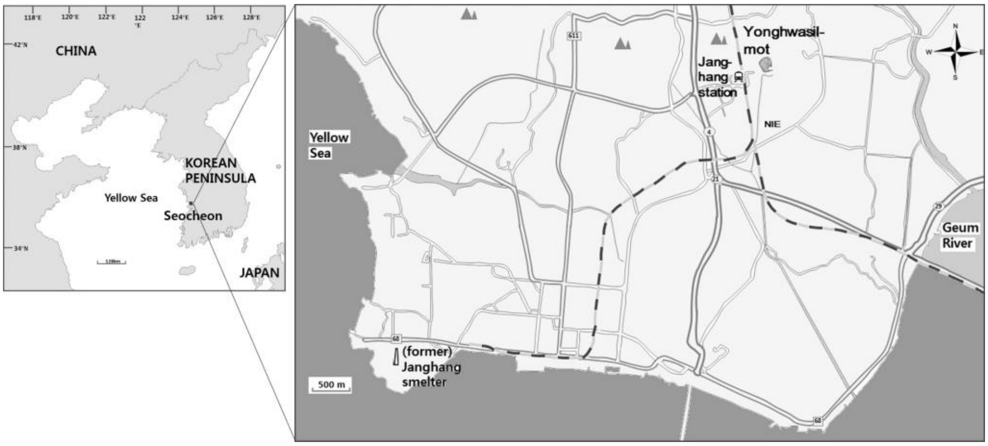

Fig. 1 Location of study site

2. Materials and Methods

2.1 Sample collection and analyses

In March 2011, a double sediment core of 60cm in depth was collected by driving a 5.5-cm-diameter plastic open-end sampler into the Yonghwasil-mot when the reservoir was drained for dredging. The core was immediately transported to the lab in a cooler and kept in a freezer. The frozen core was sectioned into 1 cm samples and about 1 g of wet soil was subsampled for pollen analysis. The remaining samples were dried at 60℃ and ground with ball-mill (FRITSCH, pulverisette 23) for physical and chemical analyses.

2.2 ^{210}Pb dating

^{210}Pb activity (alpha spectrometry) was measured at the Korea Basic Science Institute (KBSI). Subsamples from 1 to 40 cm depth were analyzed at intervals of 2 cm for ^{210}Pb activity. ^{210}Pb activities for non–analyzed intervals were interpolated. The ages of the sediments were calculated from the unsupported ^{210}Pb activity using the Constant Rate of Supply (CRS) model (Binford 1990). Supported ^{210}Pb activity was estimated using the assumption that the background activity of total ^{210}Pb in the bottom portion of the cores represented supported ^{210}Pb (Binford 1990; Kim et al. 2001).

2.3 Pollen analysis

Pollen analysis was conducted at 1 cm intervals throughout the 60 cm sediment core with a modification of the standard method (Faegri and Iverson 1989) that included KOH treatment, $ZnCl_2$ flotation, dehydration, and acetolysis. Two tablets of *Lycopodium* (batch 938934, Dept. of Quaternary Geology, Lund University) were added to each sample as an exotic tracer (Kim et al. 2001; Kim 2003). Pollens were counted up to 300 grains or 100 *Lycopodium* spores per sample. Pollen taxa were identified at the magnification of 400x by referring to a pictorial book of Korean pollen (Chang and Lim 1979; Chang 1986). Identified pollen taxa were divided into three groups: arboreal, herbs, and aquatic/wetland. The percentages of the arboreal and herb pollen were calculated by dividing each group sum by the sum of the arboreal and herb pollen. Aquatic taxa percentages were calculated based on terrestrial and aquatic taxa sum (Faegri and Iverson 1989). Pollen counts were converted to concentrations based on *Lycopodium* spores and sample amount (Kim et al. 2001; Kim 2003). Some observed rare herbaceous plant taxa were omitted from the pollen diagram.

2.4 Physical and chemical stratigraphy

Bulk density was calculated as dry weight per wet volume. Fresh wet sediment was weighed immediately and then dried for over 24 h at 105℃ to measure the dry mass. Organic matter content was determined with Loss On Ignition by combustion in a muffle furnace at 550 ° C for 4 h (Dean 1974). Total carbon and total nitrogen were determined with an Elemental (C, N, S) Analyzer at The National Instrumentation Center for Environmental Management (NICEM) of Seoul National University. To determine the concentrations of heavy metals (As, Cd, Cr, Cu, Ni, Pb, Zn) and Total phosphorus (P), 0.50 g sediment samples were digested with 10 ml of 70% nitric acid (trace metal grade, Fisher Scientific) in a closed microwave digestion system (MarsXpress, CEM, Program no. EPA 3051-24-Xpress) following the EPA 3051 method. Total phosphorus and heavy metal contents were measured with Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at NICEM.

2.5 Statistical analysis

Soil element data for the Yonghwasil-mot were analyzed by Principal Components Analysis (PCA) using variable-reduction in

SPSS ver. 20. A total of 12 variables were used and components with Eigenvalues of 1 or above were extracted.

3. Results

3.1 Radioisotope dating and sediment accumulation rate

The ^{210}Pb profile showed relatively constant activity in the top 20 cm of the core and an abrupt decline in activity was observed at 23 cm (Fig. 2a). Below 23 cm, total ^{210}Pb activity declined with a little fluctuation and reached supported levels at 41 cm. Supported ^{210}Pb activity in the Yonghwasil-mot was approximately 2.36 ± 0.15 dpm g^{-1}. The unsupported ^{210}Pb inventory was 81.60 dpm cm^{-2}, yielding a ^{210}Pb flux of 2.54 dpm cm^{-2} yr^{-1} (42.4 mBq cm^{-2} yr^{-1}). The sediment at 40 cm depth was dated to 1863 (Fig. 2b).

The calculation of the sedimentation and accumulation rate of the sediment core was based on the change in unsupported ^{210}Pb activities with depth. In the Yonghwasil-mot, the overall sedimentation rate at the top 40 cm was 4.05 mm yr^{-1}, ranging from 0.91 to 8.88 mm yr^{-1}. The average mass sediment accumulation (MSA) rate in the Yonghwasil-mot was 2.01 kg m^{-2} yr^{-1}, ranging from 0.79 to 4.27 kg m^{-2} yr^{-1} since 1863 (Fig. 3).

The MSA rate increased with relatively large fluctuation in the late 1930s and mid-1950s. The average organic matter accumulation (OMA) rate was 0.30 kg m^{-2} yr^{-1}, ranging from 0.10

to 0.59 kg m^{-2} yr^{-1} since 1863. In the 1940s and mid 1950s (at the peaks of MSA rate), the OMA rate slightly increased as well.

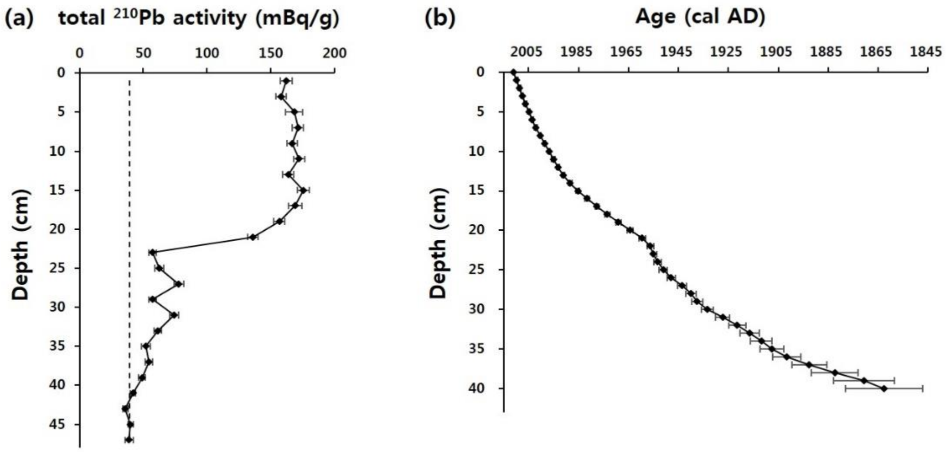

Fig. 2 Total ^{210}Pb activity with depth (a), and ^{210}Pb dates with depth profiles (b) of the Yonghwasil-mot sediment core

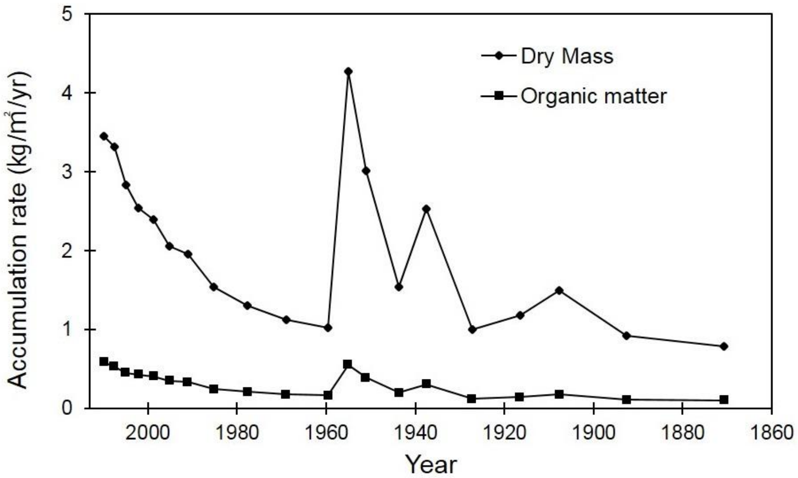

Fig. 3 Sediment accumulation rate and ^{210}Pb dates of the Yonghwasil-mot sediment core

3.2 Pollen stratigraphy

The alteration in total pollen concentration was remarkably influenced by the change in pine pollen concentration and displayed similar deposition patterns (Fig. 4). Between 44 and 60 cm depth, the percentage of *Alnus* pollen decreased gradually and that of *Pinus* pollen increased. Accumulated pollen concentration in this period was relatively low, with an average of 2.24×10^5 grains g^{-1}. Between 22 and 44 cm depth, the pollen concentration of *Pinus* started to predominate and total pollen concentration increased slightly, with an average of 5.61×10^5 grains g^{-1}. Above 22 cm depth, pollen concentrations abruptly exceeded 100×10^5 grains g^{-1} and pollen deposition remained relatively high until recent years. Pine pollen consistently predominated over total and arboreal pollen.

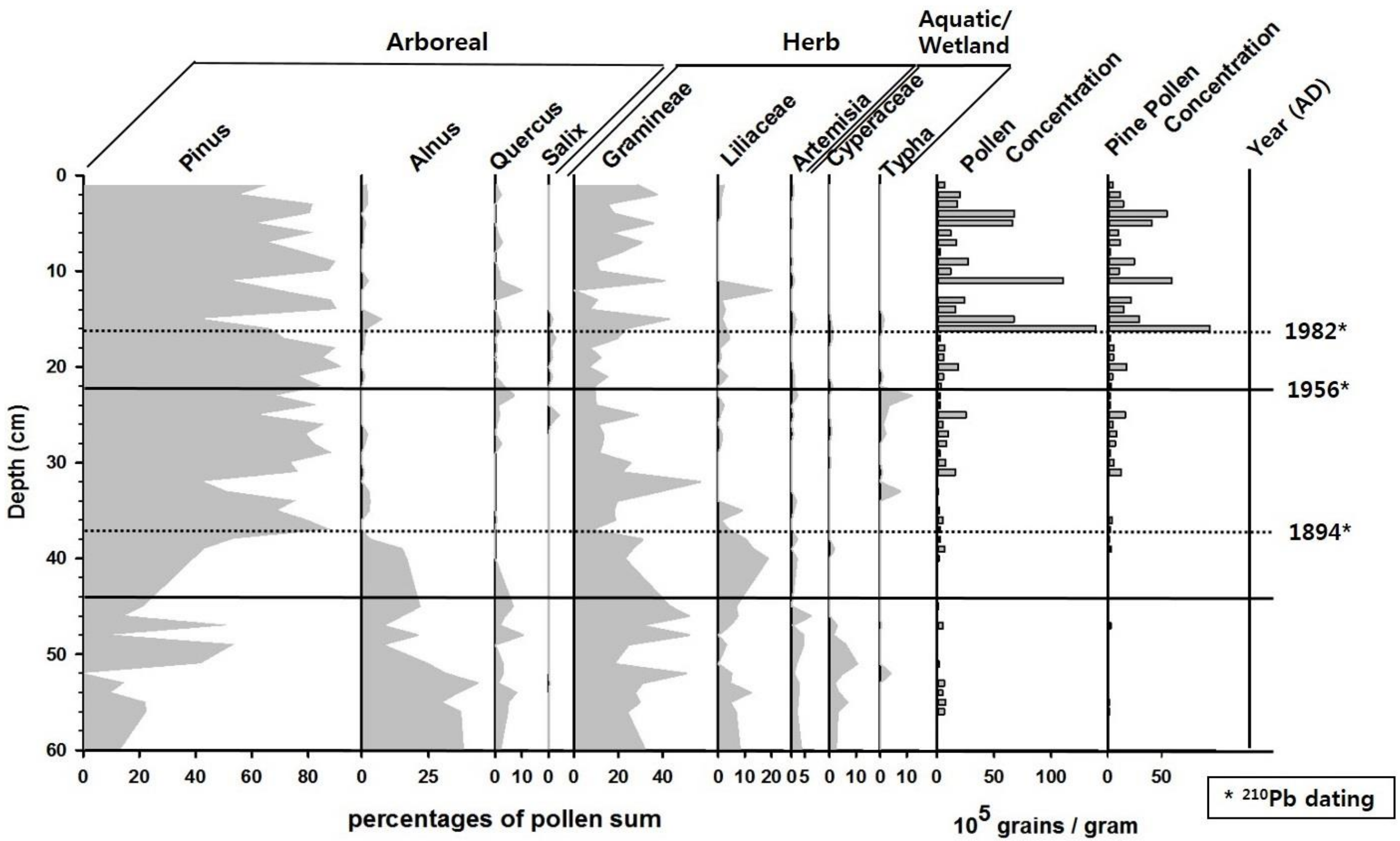

Fig. 4 Pollen percentage profiles of the Yonghwasil–mot sediment core. Horizontal lines indicate ^{210}Pb derived sediment dates

3.3 Biogeochemical properties

The Yonghwasil–mot core mostly consisted of brownish/gray clay sediment. Although the highest bulk density was 1.01 at 47 cm depth, the average bulk density was 0.61 g/cm^3, which was the value of the organic sediment (Fig. 5). There was a dramatic increase in the accumulation rate in 1956 (Fig. 3) and the amount of organic matter (LOI), total carbon, nitrogen and phosphorus also increased. The average organic matter content was 13.6%. LOI was 12.1% before the year 1956 and increased after 1956 with a mean value of 16.4%.

Total carbon and nitrogen concentration maintained similar stratigraphic patterns and the values increased above 22 cm, similar to the organic matter content. The C/N ratio above 44 cm depth displayed stable value from 9.0 to 11.3. Below 44 cm depth, C/N values fluctuated but generally decreased over time, with the highest value of 16.03.

Total phosphorus concentration remained fairly constant between 22 and 44 cm depth (average 19.0 mg/kg). However, the value increased at 22 cm depth, with an average of 51.4 mg/kg.

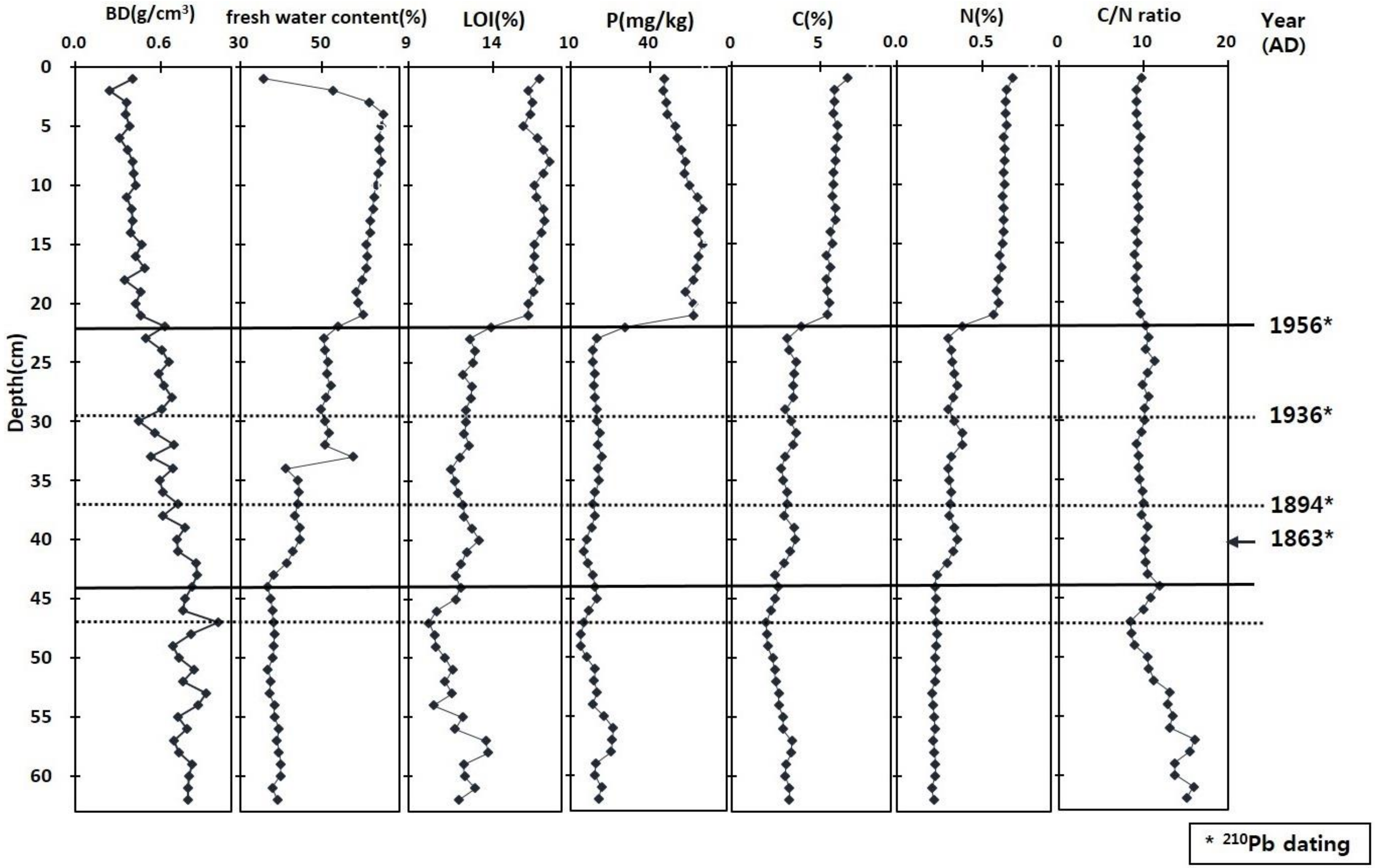

Fig. 5 Physical and chemical variables in the Yonghwasil−mot sediment core

3.4 Heavy metal profiles

The concentrations of most heavy metals changed in three stages (Fig. 6). The metal concentrations in the sediments below 44 cm depth indicated the natural background level. Subsequently, metal concentrations other than Ni and Cr increased in two stages, one at 44 cm depth, and the other at 22 cm. Ni and Cr had the highest concentrations at 40 cm depth and varied in similar patterns, unlike the other heavy metal profiles. At 26 – 28 cm and 31 – 33 cm depth, peaks were observed in the profiles of As, Pb, Cd, and Cu. Since 1989, heavy metals such as As, Pb and Cu in the study area gradually decreased in concentration.

3.5 Principal Component Analysis of the element in the sediment

Principle component analysis on the physico-chemical variables in the Yonghwasil-mot sediment core resulted in two variable groupings. One group included sediment organic material (LOI) related variables. Fresh water contents (WC), total carbon (TC), total nitrogen (TN), Zn, P, Cd, Pb, Cu, and As were placed in this group. The other group included Cr and Ni (Fig. 7).

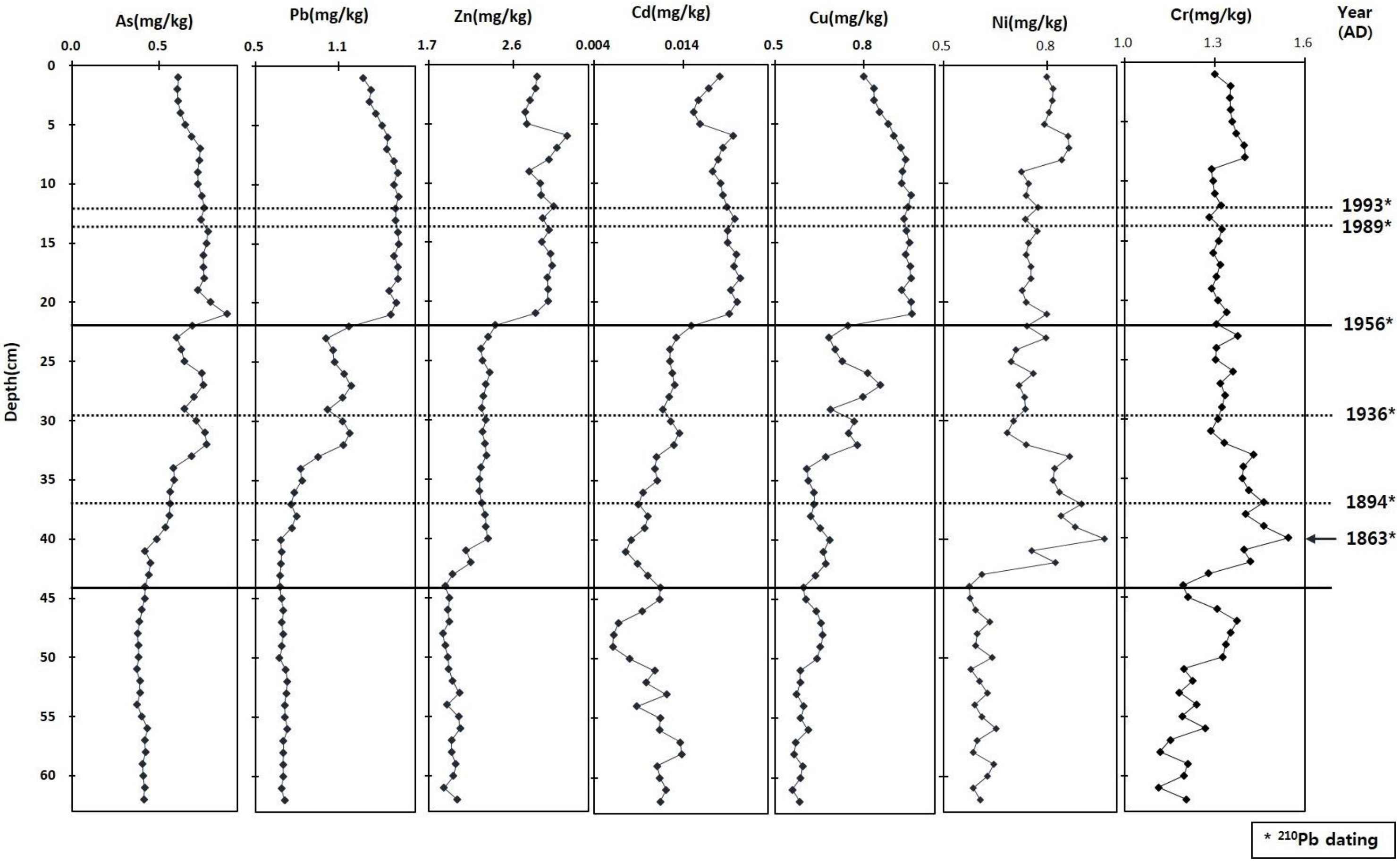

Fig. 6 Major heavy metal concentrations in the Yonghwasil−mot sediment core

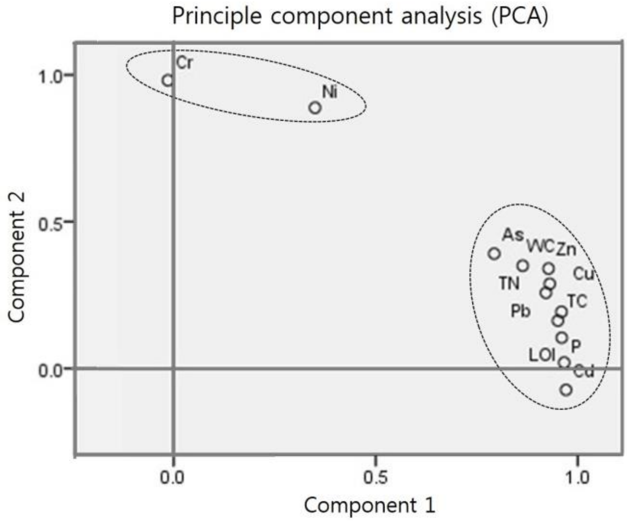

Fig. 7 PCA Component plot in rotated space showing relationships among physico−chemical variables in sediment

4. Discussion

4.1 Excess ^{210}Pb flux in Seocheon

Fallout ^{210}Pb is distributed on the earth' s surface by dry and wet precipitation, and is derived from decay of the noble gas ^{222}Rn introduced into the atmosphere from sediment (Preiss et al. 1996). The amount of ^{210}Pb fallout varies from location to location according to factors such as geographical position and rainfall (Binford et al. 1993).

The unsupported ^{210}Pb inventory in Seochoen was 81.60 dpm cm^{-2}, yielding a ^{210}Pb flux of 2.54 dpm cm^{-2} yr^{-1} (42.4 mBq cm^{-2} yr^{-1}). The global average in 1993 was 18.33 mBq cm^{-2} yr^{-1} (Binford et al. 1993). ^{210}Pb flux rate in the study area was much more than the global average. It was also much higher than at the Ulsan Sanggae reservoir (19.24 mBq cm^{-2} yr^{-1}) (Kim 2005) and Changnyeong Upo Wetland (10.73 mBq cm^{-2} yr^{-1}) (Kim and Kim. 2010) in the eastern part of the Korean Peninsula.

The higher ^{210}Pb flux rate in Seocheon compared to Ulsan and Changnyeong may be due to differences in bed rock composition and geographical location. Ulsan and Changnyeong are located in Kyongnam where the bedrock is composed of sedimentary and volcanic rock, while the bedrock around Seocheon (Chungnam) consists mainly of Precambrian granite gneiss. It is known that granite rocks have a high concentration of Uranium and higher radon emanation than any other rock type (Barretto et al. 1972).

Ulsan and Changnyeong are blocked by the Taebaek and Sobaek mountains to their respective northwests, which block the wind blowing from the west side, leading to precipitation on the northwest slope of the mountains and causing low ^{210}Pb flux rate. On the other hand, Seocheon is located on the west coast and no mountains block this region. Therefore, the ^{210}Pb flux rate in Seocheon is higher than in Ulsan and Changnyeong. In the same vein, the higher ^{210}Pb flux rate of Seocheon might be because of the wind passing through China. According to Kim et al. (1997), in all seasons except summer, most air mass reach Korea via China. In summer, furthermore, the majority of the air mass passes through southeastern China on the course to Korea. The study that investigated the fallout deposition of ^{210}Pb also support the hypothesis that the ^{210}Pb flux rate of Seocheon was affected by China (Lee et al. 1995).

4.2 Sedimentology

The average mass sediment accumulation (MSA) rate and the average organic matter accumulation (OMA) rate in the Yonghwasil-mot were much higher than in Mujechi-neup but similar to the Sanggae reservoir in Ulsan (Table 1). Because of their locations, Mujechi-neup has been affected less by human activities than the Sanggae reservoir (Kim 2005). Similar to the Sanggae reservoir, the high MSA and OMA rates in the Yonghwasil-mot reflect the human impact on the reservoir. The recently increased MSA rate in the Yonghwasil-mot might also be related to human activities, such as road or building construction,

Table 1 Comparison of sedimentation rates (SR) and element accumulation rates

Region	SR ($mm\ yr^{-1}$)	Dry Mass ($kg\ m^{-2}\ yr^{-1}$)	Organic Carbon ($kg\ m^{-2}\ yr^{-1}$)	P ($g\ m^{-2}\ yr^{-1}$)	Source
Yonghwasil-mot	0.91-8.88	0.79-4.27	0.10-0.59	1.4-15.2	this study
Sanggae reservoir	-	2.1-6.0	0.01-0.8	-	Kim (2005)
Mujechi-neup	0.10-0.12	0.2-0.4	0.09-0.3	-	Kim (2005)
Upo wetland	0.4-10	0.7-2.3	-	-	Kim et al. (2010)
Anderson Marsh	4.1-5.2	1.07-1.38	0.11-0.16	1.17-1.32	Kim et al. (2003)
Everglades	1.6-4.0	0.14-0.36	0.005-0.010	0.06-0.14	Craft and Richardson (1993); Kim et al. (2003)

around that area (Kim and Kim 2010). The phosphorus rate in the Yonghwasil-mot was much higher than at Anderson Marsh and the enriched areas of the Everglades (Kim 2003). This indicates that nutrient input into the Yonghwasil-mot was relatively high.

4.3 Water level change of Yonghwasil-mot

The water level of Yonghwasil-mot was likely to change at three stages. Below 44 cm depth was characterized by a low water table. *Alnus* was the dominant vegetation below 44 cm depth, which indicates wet conditions. At this depth, pollen density was very low (Fig. 4). Recurrent wetting and drying of sediment due to low water levels can cause the destruction of pollen grains and low pollen density. The presence of few pollen grains generally indicates a harsh depositional environment (Bradbury and Van Metre 1997). Also, LOI content fluctuated compared to the upper part of the core (Fig. 5). Average C/N ratio below 44 cm depth was 12.28 and the highest value was 16.03, though C/N ratio decreased over time. C/N ratios of 13-14 for sediments suggest a sub-equal mixture of algal and vascular plant contributions (Meyers 2001). Because of the low water level, land-derived material can be introduced into wetlands easily during this period, and this could be the reason for the high and fluctuating organic matter content and C/N ratio.

The second stage for water level was observed at a depth of 44 cm to 22 cm. A gradual rise in pollen concentration at 32 cm depth (1920 AD) suggested that the preservation and depositional environment for pollen improved, indicating that the water level rose and the depositional condition stabilized. At 37 cm depth (1894

AD), the pollen percentage of *Alnus* diminished abruptly and the *Pinus* pollen percentage increased. The decrease of *Alnus* pollen percentage and the increase of *Pinus* may be because most wetlands in the study area were reclaimed for agricultural land (Park 2012). That is, Yonghwasil-mot' s water storage capacity had to be increased for irrigation to the reclaimed agricultural land. Increased organic matter and stable C/N ratio of around 10 may support the increase of water level and the stabilized depositional condition. The C/N ratio of around 6 – 12 in sediments indicates planktonic algae and other autochthonous organic matter (Meyers et al. 1998; Olsson et al. 1997) and a decrease in land-derived nutrients.

The last stage for water level at Yonghwasil-mot was above 22 and featured the highest water level. At 22 cm depth (1956 AD), organic matter, phosphorous, carbon and nitrogen contents showed considerable increases. The relatively high phosphorous content of these sediments may indicate a significant input of soil particles from the watershed and a less decomposed state because of high, stable water level (Kim 2001). Since 1982, *Pinus* pollen concentration increased dramatically in the study area (Fig. 4). This concentration change also supports a highly increased water level. Furthermore, it could be related to the reforestation movement in the 1970' s in Korea. The Korean government encouraged people to plant trees and tried to manage forests. Small trees were cut and *Pinus* was planted in most mountains (Kim 2002).

4.4 History of pollution

The concentrations of most heavy metals changed in three stages (Fig. 6). The metal concentrations in the sediments below 44 cm depth indicate changes driven by natural processes in the preindustrial period. Subsequently, the metal concentrations increased in two stages; one at 44 cm depth, and the other at 22 cm (1956 AD). These increases were because of human activities (Engstrom and Wright 1994; Kim 2005). Prominent anthropogenic activities augmented the transport of soluble and particulate forms of nutrients and heavy metals from the watershed and the atmosphere (Boynton et al. 1995; Carpenter et al. 1998; Kim 2003) and these were recorded in the sediment.

In 1936, Janghang smelter was built by the Japanese Government-General of Korea for the purpose of refining gold. It remained in operation until 1989 smelting copper, lead, and tin and completely ceased operations in 2008. In the course of smelting, pollutants such as sulfuric acid gas, cadmium, arsenic, and lead were fumed through its 90m smokestack (Kim 2014). Janghang smelter was located around 6 km to the west of the core site. Heavy metal concentrations in the core of Yonghwasil-mot showed a slight increase since 1936 and this is probably due to the smelter and the direction of the wind (Bremner 1981). Janghang smelter was located west of the study area and the wind blows mainly from the west to the east in Seocheon. Janghang smelter was active until 1989, and heavy metal concentrations were recorded due to the effect of industrialization around the study area. Since the smelter ceased operations in 1989, heavy metals in the study area gradually decreased in concentration.

Other peaks were observed in the profile of As, Pb, Cd, and Cu around 1920 – 1930 (31 – 33 cm depth). This seems to be related to the construction of a railroad (Janghang line) and station (Janghang station) around 300 m from the core site. The Janghang line, formerly Chungnam line, was opened in 1922 and Janghang station is its last station, in operation since 1930.

In the 1990' s, most heavy metal concentrations decreased except for zinc and cadmium. Lead was used as an anti-knock agent in gasoline until 1993 in Korea, so lead contents in sediments can reflect the usage of leaded gasoline (Kim 2005). Because the Korean government banned the usage of leaded gasoline in 1993, a recent decline in lead contents (Kim 2001; Kim 2005; Murray 1997) in the study area seems reasonable.

4.5 The relationships of each element in the study area

Principle component analysis about physico-chemical variables in the Yonghwasil-mot sediment core showed variables grouped with each other. One group includes sediment organic material (LOI) related variables: fresh water contents (WC), total carbon (TC), total nitrogen (TN), Zn, P, Cd, Pb, Cu, and As. Ni and Cr were placed in the other group (Fig. 7). Anthropogenic metals are less soluble and selectively associate with the organic matter fractions of sediments (Jacobs et al. 1985). Component one may represent elements bound to the allogenic nutrient fraction. Component two may also represent the fraction from the allochthonous elemental group. The differences between component one and two might be due to the differences in the source area or in the physical and chemical properties of various elements. Even though their source area would be the same, differences in the size of elements can change the transportation route (Choi et al. 1989). Furthermore, the LOI related group may represent the influx of heavy metals on the wind coming off the countries located to the west and north of the Korean Peninsula because there is no plausible source of polluted water flowing into the Yonghwasil-mot. Countries such as China with arid deserts supply huge amounts of atmospheric particulates that include heavy metals to neighborhood areas (Choi et al. 1989).

5. Reconstructed history of human activities in Seocheon

This paleoecological study provides a good description of the relationship between natural processes and human activities on the west coast of the Korean Peninsula. ^{210}Pb flux rate was 42.4 mBq cm^{-2} yr^{-1} and reflects the influence of bedrock and wind blowing from China over the Yellow sea as well as recent urbanization and industrialization. Dry mass and phosphorous accumulation rates indicate significant nutrient input to the Yonghwasil-mot by human activities as well as a rise in the water level history of the Yonghwasil-mot. Based on physical and chemical properties, Yonghwasil-mot displays the increased water level in two steps. Below 44 cm depth, Yonghwasil-mot was a low water leveled wetland. Total pollen concentration at this depth reflects a harsh environment for the preservation and deposition of pollen. C/N value at this time was 13–14, which suggests easy introduction of land-derived material into the wetland. Around 1860, Yonghwasil-mot appears to have become a pond, based on features such as rising water contents, increased pollen deposition, and C/N ratio of 9–10. In this period, *Alnus* spp. decreased and *Pinus* spp. increased. This might be due to the cutting of *Alnus* spp. trees for the expansion of farmland. Around 1955, all elements increased abruptly because of elemental input from different sources, implicating human activities in the rise of the water level of Yonghwasil into the reservoir. In the 1970s, the Korean government implemented afforestation and the effort was reflected in the greatly increased *Pinus* spp. pollen density.

The influence of industrialization began to appear in the late 1890s in the study area. The Janghang line and station were constructed in 1920 – 1930 and Janghang smelter was founded in 1936. These events were visible in the sediment as heavy metal concentrations. Also, the Pb profile indicated changes in the consumption of leaded gasoline. Therefore, this paleoecological study reconstructed human activities well; 1) Changes in the scale of Yonghwasil-mot, 2) influences from China as well as from recent urbanization and industrialization through the ^{210}Pb flux rate, 3) the records of industrialization and results of Korean government policies such as banning the use of leaded gasoline in the study area (Table 2).

Table 2 Reconstructed major events and supporting evidence in the study site

Depth of the core (cm)	Major Event	Core Evidence
0 – 22	Extended catchment to reservoir scale	Greatly stabilized pollen deposition, substantially increased element contents around 22 cm depth
	Influence of closing of Janghang smelter	Slowly decreased As contents
	Result of prohibition of sale of leaded gasoline	Slowly decreased lead contents
22 – 44	Catchment became pond scale	Improved environment for pollen deposition, C/N of 9 – 10
	Influence of operation of Janghang smelter	Increased As contents
	Expansion of farmland	Decreased concentration of *Alnus* spp.
44 – 60	Low water level wetland	Harsh environment for pollen deposition, C/N of 15–16, reversed ^{14}C dates due to the introduction of old carbon
	Background heavy metal level (preindustrial period)	Low and stable heavy metal content

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국문 초록

서천에서 고생태학적 연구를 통해 본 인간 활동의 역사

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서천지역 생태계에 대한 인간의 영향을 알아보기 위해 용화실못을 대상으로 고생태학적 연구를 수행하였다. 용화실못은 농수를 대기 위한 목적으로 조성된 저수지이다. 약 60cm 길이의 퇴적토를 채취하여, ^{210}Pb 를 이용하여 연대를 추정하였다. AD 1863 ~ 2011 년의 평균 건량 축적률은 1.80 kg m^{-2} yr^{-1} 이었다. 연구 지역의 ^{210}Pb flux rate 는 42.4 mBq cm^{-2} yr^{-} 이었으며, 이 수치는 중국으로부터 불어오는 바람의 의한 영향을 보여준다. 1956 년경 토양 축적률이 큰 변화를 보였으며, 이때 유기물, 총 탄소, 총 질소와 총 인의 함량도 급격히 증가하였다. 이는 증가한 수위로 인해 용화실못으로 상당량의 토양과 유기물 입자가 유입되었으며 분해가 저해된 상태임을 보여준다. 납, 구리, 비소, 카드뮴, 아연의 농도에서 연구지역으로부터 서쪽으로 6 km 거리에 있는 (구)장항 제련소와 약 300 m 거리에 있는 장항역의 영향을 찾아볼 수 있다. 비소, 구리, 납은 1990 년대 중반부터 농도가 서서히 감소하였다. 이 중 특히 납의 감소 농도는 1989 년 시행된 정부의 유연 휘발유의 판매 금지 정책과 관련이 있다. 용화실못 퇴적토의 화분분석 결과 전반적으로 소나무속 (*Pinus* spp.)과 벼과(Gramineae)가 우세하였다. 깊이 44 cm 이하에서는 오리나무속 (*Alnus* spp.)의 화분이

우세하였으나 1894 년경 화분의 밀도가 갑자기 감소하였다. 오리나무속 화분밀도의 급속한 감소는 연구 지역 주변의 농경지 확대에 의한 결과로 보인다. 화분 기록, LOI, C/N 비율을 통하여 용화실못이 수위가 낮은 습지에서 연못 크기로, 그리고 증축을 거쳐 저수지로 변화한 것을 복원할 수 있었다. 또한 중금속의 농도를 통해 장항 제련소의 가동과 장항역의 건설, 그리고 한국 산업화가 환경에 미친 영향을 볼 수 있었다. ^{210}Pb flux rate 는 한국이 편서풍 지대에 있기 때문에 중국으로부터 불어오는 바람이 서해안에 영향을 주는 것을 보여준다.

핵심 용어: 고생태학, 인간의 영향, ^{210}Pb dating, ^{210}Pb flux, 화분 분석, 중금속

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