Pteridophytes in the Hiroshima wide-area urban districts concentrate cadmium (Cd) in their leaf and stem

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ABSTRACT

To investigate the status of Cd in the soil available in the Hiroshima wide-area urban districts, pteridophytes have been collected from 5 districts. The concentrations of Cd were measured by the Atomic Absorption Spectrometer. The pteridophytes accumulated Cd depending on the soils they grew. The *Athyrium yokosense* and *Plagioria euphlebia* species contained more than 1.0 mg/kg, while the *Gleichenia japonica* and *Cyrtomium falcatum* species showed less than 0.5 mg/kg. The soil of the two former species was composed with the Jurassic stratum, and the latters of which was that with Cretaceous. Since the average Cd was high in the wildlife habituated there, present data supported the speculation that the accumulation of Cd in wildlife would be influenced by the soils, where the Cd has accumulated differently depending on the geological periods.

key words: cadmium, landscape, oyster, pteridophyta, wildlife

INTRODUCTION

Heavy metal contamination results from improper disposal, mining by-products or released specific chemicals in and around urban districts. Cd is one of the metals and possibly one of the non-essential elements for mammalian health, however high toxicities have been obvious for humans when expsed chronically[1–6].

Assessing the exposure to environmental pollutants has been provided by the aquatic and terrestrial organisms[7, 8]. Some birds accumulated heavy metals in their viscerous organs, and some other birds showed the reduction of reproductive success or physiological abnormalities.

In view point of the ecological landscape, the anthropogenic environmental activities to change the original vegetation in the target districts should be considered. Because fields, heavy metals and anthropogenic activities compose visible as well as invisible parts

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of the landscape, where the wildlife is one of the main elements of biodiversity.

The objective of this study was to measure location-specific metal concentrations in the Hiroshima wide-area urban districts through wildlife simbiotic with humans. Pteridophydes were provided to measure the concentrations of Cd in the soils of the distircts. Making the circulation of Cd in the target districts visible could be informative for the perspectives of biodiversity as well as health of the resident people.

MATERIALS AND METHODS

Ppteridophytes: Pteridophytes were collected from the 5 districts during the periods of routine hunt from November in 2017 to February in 2019 (Table 1). Leaf and stem parts of each pteridophyta were used for the Cd measurement.

Cd and Zn measurements: Samples were dried in a drying device (KM-300V, AS ONE, Osaka, Japan) overnight and ground by a stainless ball mill and stored at −20℃ until use. The drying ratio was 2.5 ± 0.7 (mean ± SD) for the 14 samples.

70% HNO_3 solution (reagent grade) was added to each sample to process microwave digestion. The sample solution was dried on a hot plate at 180℃ and then filled up to 10 ml with deionized water. Concentrations of Cd and Zn were determined by the Atomic Absorption Spectrometer (AA-6200, SHIMADZU, Kyoto, Japan). The limit of detection by the instrument was 0.01 mg/kg. The average value of the triplicated measurements was used as a representative for each sample. The values of the metals were shown per the wet weight of the samples.

Table 1 Geologic characteristics of the southern part of Hiroshima wide-area urban districts.

Districts*	Geologic age*	Hunting area**	Field area**	Oyster culturing area***	Self-growing pteridophytes				
					Athyrium yokoscense	*Plagiogyria euphlebia*	*Dicranopteris linearis*	*Cyrtomium fortunei*	*Gleichenia japonica*
1	Jurassic period	+	−	−	+	+	−	−	−
2		+	−	−	+	+	+	−	−
3	Cretaceous period	+	+	−	−	−	+	+	+
4		−	−	+	−	−	+	+	+
5		−	−	−	−	−	+	+	+

Characteristics applicable or not was shown as + or −, respectively. *: previously reported in the reference No. 9; **: previously reported in the reference No. 10; ***: previously reported in the reference No. 11.

Statistical analysis: Student's *t*-test and F-test were performed to compare the concentrations of Cd and Zn. Pearson's coefficient of correlation was used to examine the correlation between the values of Cd and Zn. The software, Mac multiple regression analysis, version 3 (ESUMI, Tokyo, Japan) and Kaleida Graph (HULINKS, Tokyo, Japan) were used[12].

RESULTS

Distribution of the pteridophytes in the Hiroshima wide-area urban districts was referenced to the previous reports[13, 14]. Investigating the pteridophyta vegetation in Yamaguchi prefecture, the field work was performed for the mapping (Fig. 1). *Athyrium yokosense, Plagioria euphlebia* and *Dicranopteris linearis* were observed in the districts of Jurassic strata, while *Gleichenia japonica, Cyrtomium falcatum* and *Dicranopteris linearis* were of the Cretaceous strata (Table 1).

The two species, *Athyrium yokosense* and *Plagioria euphlebia* contained Cd of more than 1.0 mg/kg (Fig. 2-A). While, the concentrations of Cd in the other two species, the *Gleichenia japonica* and *Cyrtomium falcatum* were less than 0.5 mg/kg. Correlation coefficient between the two metals for the 14 samples of all species of the pteridophytes exam-

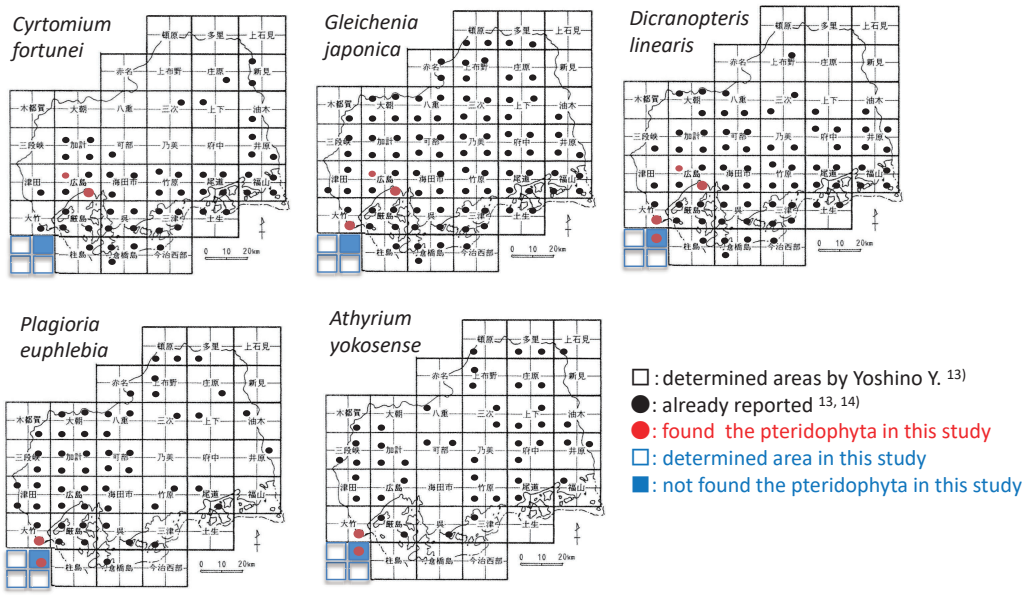

Figure 1. Distribution of the pteridophyta in the Hiroshima wide-area urban districts.
The mesh illustrations colored were referenced from the original illustration by Yoshino Y.[13].

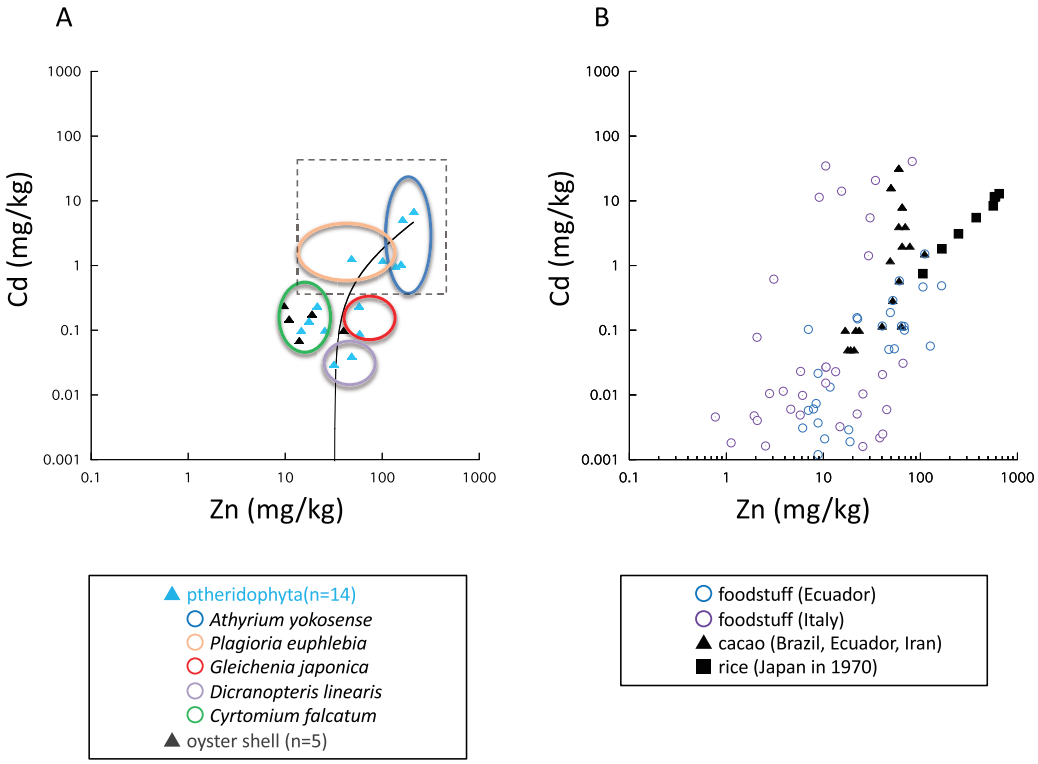

Figure 2. Concentrations of Cd in plants as a function of Zn.

A: Five species of the pteridophytes were collected from the districts in Table 1. Reggression curve for the pteridophytes was given by the equation of y = 0.027x −0.880 (R = 0.82, $p < 0.0002$). Values of Cd in oyster shells were overlaid[11]. Hatched square included the data of over 1.0 mg/kg. **B**: A meta-analysis of the Cd and Zn concentrations among the pteridophytes and foodstuffs. Values were overlaid [15–19].

ined was high (R = 0.817, $p < 0.0002$), no matter if their habituating districts had long distances in between.

Meta-analysis indicated that values of the pteridophytes from the Jurassic strata were as high as those of rice contaminated with Cd in 1970s and those in cacao beans (Fig. 2-B).

DISCUSSION

Plants absorb Cd from soil[20, 21]. Reported concentration of Cd in foods varied[15, 22–29]. When the risks of the heavy metal contamination for humans were assessed, foodstuffs are the main source of Cd exposure[30].

Since the sources of Cd in soils, such as Zn mining, battery production plants or

heavy metal smelters were not observed in the Hiroshima wide-area urban districts of this study, the phosphate fertilizers were the major inputs of Cd into the agricultural soils[31]. The previous reports indicated the contamination of Cd in wildlife and oyster shells[10, 11]. The accumulation of Cd in wildlife could be caused by the agricultural land, where the fertilizers blended with oyster shells were spread. The human activity to reuse oyster shells as one of the fertilizer components adds a burden of Cd on our sanitary environment.

The districts of Jurassic strata in the Hiroshima wide-area urban districts had 2 aboandoned manganase mines, where 2 streams of natural pathway unaffected by human activities flowed[9]. Plants growing in such a natural environment drop berries and leaves of their own to rot and return to the soil. Consequently, the mineral concentrations of the plants have been in equilibrium for a long time. The high concentrations of Cd in the pteridophytes in the districts indicated the Cd in the districts, where wildlife hunted[32, 33]. The accumulation of Cd in wildlife could be influenced by their home range, where the geological characteristics were inevitable.

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REFERENCES

1. Horiguchi H., Oguma E., Sasaki S., Okubo H., Murakami K., Miyamoto K., Hosoi Y., Murata K. and Kayama F. 2013. Age-relevant renal effects of cadmium exposure through consumption of home-harvested rice in female Japanese fielders. *Enviro Int.* 56: 1–9.
2. Ishizaki M., Suwazono Y., Kido T., Nishijo M., Honda R., Kobayashi E., Nogawa K. and Nakagawa H. 2015. Estimation of biological half-life of urinary cadmium in inhabitants after cessation of environmental cadmium pollution using a mixed linear model. *Food Addit. Contam. Part A.* 32: 1273–1276.
3. Järup L., Berglund M., Elinder C. G., Nordberg G. and Vahter M. 1998. Health effects of cad-

mium exposure–a review of the literature and a risk estimate. *Scand. J. Work. Environ. Health.* 24 (Suppl. 1): 1–51.
4. Järup L. and Akesson A. 2009. Current status of cadmium as an environmental health problem. *Toxicol. Appl. Pharmacol.* 238: 201–208.
5. Nishijo M., Nakagawa H., Suwazono Y., Nogawa K. and Kido T. 2017. Causes of death in patients with Itai-itai disease suffering from severe chronic cadmium poisoning: a nested case-control analysis of a follow-up study in Japan. *BMJ Open* 7: e015694.
6. Nogawa K., Yamada Y., Honda R., Ishizaki M., Tsuritani I., Kawano S. and Kato T. 1983. The relationship between Itai-Itai disease among inhabitants of the Jinzu River basin and cadmium in rice. *Toxicological Letter*. 17: 263–266.
7. Maurya P. K., Malik D. S., Yadav K. K., Kumar A., Kumar S., Kamyab H. 2019. Bioaccumulation and potential sources of heavy metal contamination in fish species in River Ganga basin: Possible human health risks evaluation. Toxicol. Rep. 29: 472–481.
8. Sow A. Y., Dee K. H., Lee S. W. and Eh Rak A. A. L. 2019. An Assessment of Heavy Metals Toxicity in Asian Clam, *Corbicula fluminea*, from Mekong River, Pa Sak River, and Lopburi River, Thailand. Scientific World J.: eCollection 2019.
9. Nishimura Y., Imaoka T., Kanaori Y and Kameya A., 2012. Geological map of Yamaguchi Prefecture, Third edition, (1:150 000) and its explanatory text. Geological Society of Yamaguchi pp1–167. (in Japansese).
10. Nitta Y. 2019. Evaluation of the contamination of cadmium in the wildlife of a western part of Japan. *Studies in the Health Sciences*, 2: 17–27.
11. Nitta Y. 2019. Oysters (*Crassostrea gigas*) in the Hiroshima wide-area urban districts concentrate cadmium (Cd) in their shells. *Studies in the Health Sciences*, 3: 1–8.
12. Nitta Y., Miki Y., Aoi S., Ikeda H., Iida T., Chikamura C., Tamura N., Nitta K., Miyaguchi H., Harada T and Ishizaki F. 2017. Age-dependent contributions of neck circumference to indices of obesity among female college students aged 18 to 20. *The Hiroshima J. Med. Sci.*, 66: 109–115.
13. Yoshino Y. 2016. Some notes of the pteridophyta in Hiroshima prefecture, Japan. *Bulletin of the Hiroshima Botanical Garden* 33: 1–6.
14. Matsumura M. and Inoue N. 2016. Distribution of the pteridophyta in Hiroshima prefecture. *Bulletin of the Hiroshima Botanical Garden* 33: 7–135.
15. Argullo D., Chavez E., Lauryssen F., Vanderscheren R., Smolders E and Montalve D. 2019. Soil properties and agronomic factors affecting cadmium concentrations in cacao beans: A nationwide survey in Ecuador. *Science of The Total Environment* 649: 120–127.
16. Filippini T., Cilloni S., Malavolti M., Violi F., Malagoli C., Tesauro M., Bottecchi I., Ferrari A., Vescovi L., Vinceti M. 2018. Dietary intake of cadmium, chromium, copper, manganese, selenium and zinc in a Northern Italy community. *J. Trace Elem. Med. Biol.* 50: 508–517.
17. Pereira de Araújo R., Furtado de Almeida A. A., Silva Pereira L., Mangabeira P. A. O., Olimpio Souza J., Pirovani C. P., Ahnert D. and Baligar V. C. 2017. Photosynthetic, antioxidative, molecular and ultrastructural responses of young cacao plants to Cd toxicity in the soil. *Ecotoxicol. Environ. Saf.* 144: 148–157.
18. Romero-Estévez D., Yánez-Jácome G. S., Simbaña-Farinango K. and Navarrete H. 2019. Distribution, Contents, and Health Risk Assessment of Cadmium, Lead, and Nickel in Bananas Produced in Ecuador. *Foods* doi: 10.3390/foods8080330.
19. Honna Y. and Hirata H. 1978. Noticeable increase in cadmium absorption by zinc deficient rice plants. *Soil Sci. Plant Nutr.* 24: 295–297.

20. Shan H., Su S., Liu R., Li S. 2016. Cadmium availability and uptake by radish (*Raphanus sativus*) grown in soils applied with wheat straw or composted pig manure. *Environ. Sci. Pollut. Res. Int.* 23: 15208–15217.
21. Kikuchi Y., Nomiyama T., Kumagai N., Uemura T. and Omae K. 2002. Cadmium Concentration in Current Japanese Foods and Beverages. *J. Occup. Health.* 44: 240–247.
22. Lane E. A., Canty M. J. and More S. J. 2015. Cadmium exposure and consequence for the health and productivity of fielded ruminants. *Res. Vet. Sci*. 101: 132–139.
23. López-Alonso M., Miranda M., Benedito J. L., Pereira V. and García-Vaquero M. 2016. Essential and toxic trace element concentrations in different commercial veal cuts in Spain. *Meat Sci.* 121: 47–52.
24. Marín S., Pardo O., Sánchez A., Sanchis Y., Vélez D., Devesa V., Font G. and Yusà V. 2018. Assessment of metal levels in foodstuffs from the region of Valencia (Spain). *Toxicol. Rep*. 5: 654–670.
25. Mulero R., Cano-Manuel J., Ráez-Bravo A., Pérez J. M., Espinosa J., Soriguer R., Fandos P., Granados J. E. and Romero D. 2016. Lead and cadmium in wild boar (*Sus scrofa*) in the Sierra Nevada Natural Space (southern Spain). *Environ. Sci. Pollut. Res. Int.* 23: 16598–16608.
26. Pastorelli A. A., Baldini M., Stacchini P., Baldini G., Morelli S., Sagratella E., Zaza S. and Ciardullo S. 2012. Human exposure to lead, cadmium and mercury through fish and seafood product consumption in Italy: a pilot evaluation. *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess.* 29:1913–1921.
27. Rudy M. 2010. Chemical composition of wild boar meat and relationship between age and bioaccumulation of heavy metals in muscle and liver tissue. *Food Addit. Contam. Part A*. 27: 464–472.
28. Danieli P. P., Serrani F., Primi R., Ponzetta M. P., Ronchi B. and Amici A. 2012. Cadmium, lead, and chromium in large game: a local-scale exposure assessment for hunters consuming meat and liver of wild boar. *Arch. Environ. Contam. Toxicol.* 63: 612–627.
29. Ferri M., Baldi L., Cavallo S., Pellicanò R. and Brambilla G. 2017. Wild game consumption habits among Italian shooters: relevance for intakes of cadmium, perfluorooctanesulfonic acid, and ^{137}cesium as priority contaminants. *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess*. 34: 832–841.
30. Hamid A., Riaz H., Akhtar S. and Ahmad S. R. 2016. Heavy Metal Contamination in Vegetables, Soil and Water and Potential Health Risk Assessment., *American-Eurasian J. Agric. & Environ. Sci.* 16: 786–794.
31. Roberts T. L. 2014. 2nd International Symposium on Innovation and Technology in the Phosphate Industry Cadmium and Phosphorous Fertilizers. *The Issues and the Science Procedia Engineering* 83: 52–59.
32. Chen Z., Sergawa M., Kang Y., Sakurai K., Aikawa Y and Iwasaki K 2009. Zinc and cadmium uptake from a metalliferous soil by a mixed culture of *Athyrium yokoscense* and *Arabis flagellosa*. *Soil Science and Plant Nutrition* 55: 315–324.
33. Yoshihara T, Suzui N, Ishii S, Kitazaki M, Yamazaki H, Kitazaki K, Kawachi N, Yin YG, Ito-Tanabata S, Hashida SN, Shoji K, Shimada H, Goto F, Fujimaki S. 2014. A kinetic analysis of cadmium accumulation in a Cd hyper-accumulator fern, *Athyrium yokoscense* and tobacco plants. Plant Cell Environ. 37: 1086–1096.

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広島広域都市圏のシダ植物が蓄積する重金属

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要　　約

カドミウム（Cd）は環境汚染物質で，慢性曝露はヒトへ健康影響を及ぼす。農水畜産物の Cd 含有の実態を調査して情報提供することは，消費者の Cd 摂取量低減に寄与する。著者は，広島広域都市圏のカキ（*Crassostrea gigas*）と野性動物とを定点観察し，Cd と亜鉛（Zn）の含有量を測定している。本稿では，シダ植物に含まれる Cd と Zn 量を測定した。土壌環境が生態系に及ぼす影響を見える化し，土壌から植物への Cd 移行を野生哺乳動物の体内 Cd 蓄積量との相関で考察するためのデータとした。**材料及び方法**：2017～2019年の狩猟期間中に採集したシダ類を用いた。茎と葉の Cd と Zn の濃度を原子吸光分析法で測定した。**成績**：①シダ植物は，地質年代の別に生育する種類が異なった。②ジュラ紀地層に生育したシダ植物は高濃度の，白亜紀地層に生育したシダ植物は中等度以下の濃度で Cd を蓄積していた。③ 2 種類の重金属濃度は，シダ植物において強く相関した（$R=0.82, p<0.0002$）。**考察**：広島広域都市圏の土壌はジュラ紀と白亜紀の地層から構成され，イノシシをはじめとする野生動物は，これらの土壌を行動圏として生息している。土壌中の Cd 量を，そこに生育するシダ植物の含有濃度として表記し，この生態系における Cd 循環を明らかにすることは，ヒトの公衆衛生環境への影響を考察するために必須の基礎資料となる。

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