

## **Radiocesium Concentration Change in Game Animals: Use of Food Monitoring Data – 13168**

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### **ABSTRACT**

Radionuclides were released into the environment in the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident. Radiocesium (Cs-134+137) concentrations in most agricultural products became lower than the detection limit ( $\sim 10 \text{ Bq kg}^{-1}$ ) from June 2011, and the concentrations have remained low. However, some wild food materials such as meat of game animals (e.g., bear and wild boar) caught in Fukushima and surrounding areas some times showed higher values than the detection limits. In this study, monitoring data on game animal meat were summarized to understand the amount of activities found in wild animals and the activity distribution in the contaminated areas.

Concentration data are available from monthly reports issued by the Ministry of Health, Labour and Welfare. Data were collected on wild boar (*Sus scrofa*), deer (*Cervus nippon*), Asian black bear (*Ursus thibetanus*), Japanese pheasant (*Phasianus versicolor*), and duck (e.g. *Anas poecilorhynch*). There is a tendency that the concentration decreases with distance from the FDNPP; in order to compare the Cs-137 concentrations among animals, one collection site was selected. The results showed that the concentration was in the following order within one year: Asian black bear > wild boar > deer > duck and Japanese pheasant. Bear and boar are omnivorous animals and their feeding pattern would affect the concentrations in their meats.

### **INTRODUCTION**

Soon after the Great East Japan Earthquake on 11 March 2011, four units at the TEPCO's Fukushima Daiichi Nuclear Power Plant (FDNPP) site were severely damaged by huge tsunami. The plant operators had to release radionuclides to the environment from three of the units to avoid further damage; fortunately, one unit had not been in operation at the time of the earthquake. After several intentional venting actions and hydrogen explosions in the middle of March, releases of small amounts of radionuclides were continuously observed during the remainder of the month; this series of release incidents is collectively referred to as the FDNPP accident in this paper. Due to the release of radionuclides, agricultural products were heavily contaminated in some areas in northeastern Japan. The Japanese government applied the guidance level of  $500 \text{ Bq kg}^{-1}$  in raw food materials for radiocesium; this is the sum of Cs-134 ( $T_{1/2}=2.06 \text{ y}$ ) and Cs-137 ( $T_{1/2}=30.17\text{y}$ ) activities considering the upper limit of effective dose from ingestion for a year is  $5 \text{ mSv}$  [1].

New government standard limits for radionuclides in food came into effect on 1 April 2012, and

the radiocesium concentration has been limited to 100 Bq kg<sup>-1</sup> in raw food materials, 50 Bq kg<sup>-1</sup> in milk and infants' foods, and 10 Bq L<sup>-1</sup> in drinking water [2]. Although radiocesium concentrations in most agricultural products and water have been lower than the detection limit, the radioactivity in some game animals, e.g., wild boar and bear, caught in Fukushima and surrounding areas some times showed higher values than the standard limit. The number of people who eat the meat of game animals is limited; however, to avoid unexpected intake of radiocesium, it is necessary to monitor radioactivity in their meat also. Additionally, for radiation protection of the environment, such data are important to know the amount of activities found in wild animals, and the activity distribution in the areas contaminated by the FDNPP accident. The information will be one of the important factors for considered in area remediation decision-making.

## **MATERIALS AND METHODS**

Concentration data are available from monthly reports issued by the Ministry of Health, Labour and Welfare [3]. Radiocesium concentration data in the edible part of wild boar (*Sus scrofa*), deer (*Cervus nippon*), Asian black bear (*Ursus thibetanus*), Japanese pheasant (*Phasianus versicolor*), and duck (e.g. *Anas poecilorhyncha* and *Anas platyrhynchos*) were selected. Data on Cs-137 were used because of its longer half-life than Cs-134; Cs-137 data do not need correction which allow the concentration change in the 18 months since the FDNPP accident to be seen easily.

Reported radioactivity values were of three types: total radiocesium (Cs-134+137), separately determined values (Cs-134 and Cs-137), or lower than the detection limit (D.L.). If only a total radiocesium concentration was listed for a sample, then Cs-137 was calculated by subtracting the Cs-134 contribution considering that the Cs-137: Cs-134 activity ratio was almost 1:1 at the time the nuclear power plants, reactor units were shut down, that is, 11 March 2011, and Cs-134 decays from that day. If the Cs-137 concentration was lower than the D.L., 10 Bq kg<sup>-1</sup> was used instead of the D.L. value because D.L. ranged from 1 to 20 Bq kg<sup>-1</sup>. In the food monitoring data reports, sampling dates were also listed together with the concentration data; thus, the numbers of days after 11 March 2012 was also calculated.

## **RESULTS AND DISCUSSION**

### **Time Dependence on Cs-137 Concentration in Wild Animals**

The Cs-137 concentrations in meat of game animals after 11 March 2011 are shown in Fig. 1 for wild boar, Asian black bear, deer, pheasant, and grey duck (*Anas poecilorhyncha*). All the reported data are plotted in these figures. Solid colored circles represent data other than from

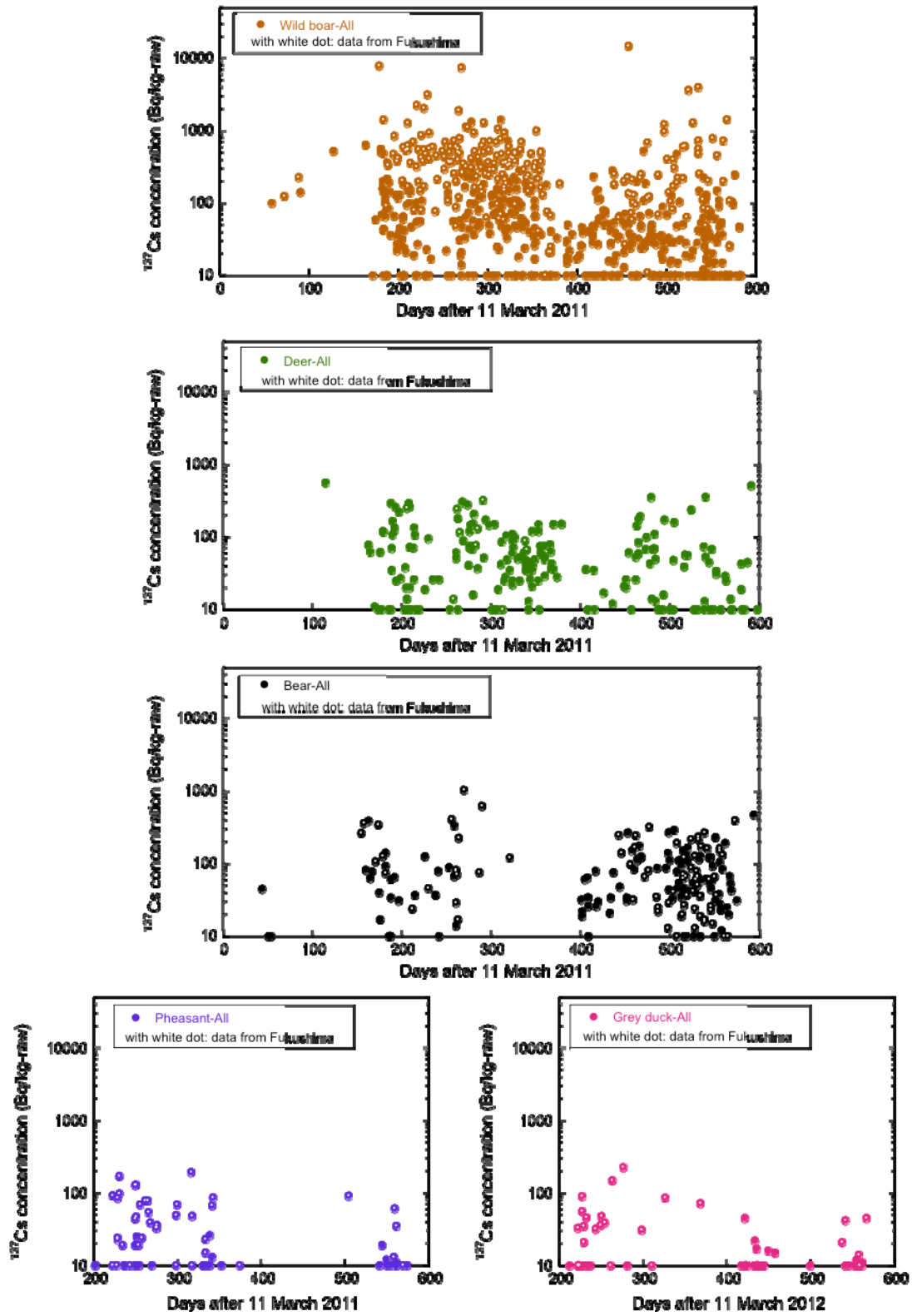


Fig. 1. Concentration of Cs-137 in meat of wild animals collected in Japan in 2011-2012. The solid circles with the center white dot plot values from Fukushima.

Fukushima and the solid circles with the center white dot plot values are from Fukushima; thus the tendency of the concentration change in Fukushima Prefecture was easily specified.

According to the data, the concentration tended to decrease for each type of animal before 500 days had passed (i.e. before the second mushroom growing season); however, statistically, no correlation between with time was observed during the 18-month period.

The geometric means of Cs-137 in wild animals collected in Fukushima within one year after the accident (sample collection period: 0 – 365 days) were: 336 (range: D.L. to 7854) Bq kg<sup>-1</sup>-raw for wild boar (n=151); 85 (range: D.L. to 322) Bq kg<sup>-1</sup>-raw for deer (n=10); 121 (range: 17–1031) Bq kg<sup>-1</sup>-raw for Asian black bear (n=19); 47 (D.L. to 408) Bq kg<sup>-1</sup>-raw for pheasant (n=46); and 26 (D.L. to 226) Bq kg<sup>-1</sup>-raw for grey duck (n=35). The Cs-137 concentration decreased in the following order: wild boar > Asian black bear > deer > pheasant > duck.

Wild boar showed the highest concentrations among the selected wild animals. However, the animal collection sites were not uniformly distributed in Fukushima Prefecture. It has already been reported that the radioactivity distribution was not uniform [4]; thus, one collection site, K city in Fukushima (FK-City), was selected to compare the concentrations among animals.

Geometric means were: 141 Bq kg<sup>-1</sup>-raw for wild boar (n=12), 99 Bq kg<sup>-1</sup>-raw for deer (n=3); 196 Bq kg<sup>-1</sup>-raw for Asian black bear (n=2); 21 Bq kg<sup>-1</sup>-raw for Japanese pheasant; and 32 Bq kg<sup>-1</sup>-raw for duck (n=3). The concentration decreased in the following order: Asian black bear > wild boar > deer > pheasant and duck. The tendency was similar to that for all Fukushima data for the smaller animals, but wild boar and bear were in reverse order.

The number of data for wild boar was more than for the other wild animals and their monitored area was wider; 34 municipalities provided three or more suitable data within one year after 11 March 2011. Therefore, geometric means for the wild boar data were calculated and plotted on a map in log scale to make a contour map (Fig.2). Although wild boar might migrate, the tendency was the same as that for the <sup>137</sup>Cs distribution on the ground [5].

Wild boar, Asian black bear, Japanese pheasant and duck are omnivorous animals (but most of their food consist of plant matter), while deer are a herbivorous animals. Because the foods of wild boars includes plant roots and small animals in the soil, occasionally, the boars will ingest contaminated soil particles; also they feed on mushrooms in the autumn. Asian black bears are the top predator in the Japanese forest food chain, and thus, their Cs-137 concentrations were higher as expected. Deer feeds on bark in the winter; the bark surface should have a high radiocesium concentration, which caused the high radiocesium concentration seen in deer meat. Pheasants and ducks had the lowest concentrations due to their different feeding habits.

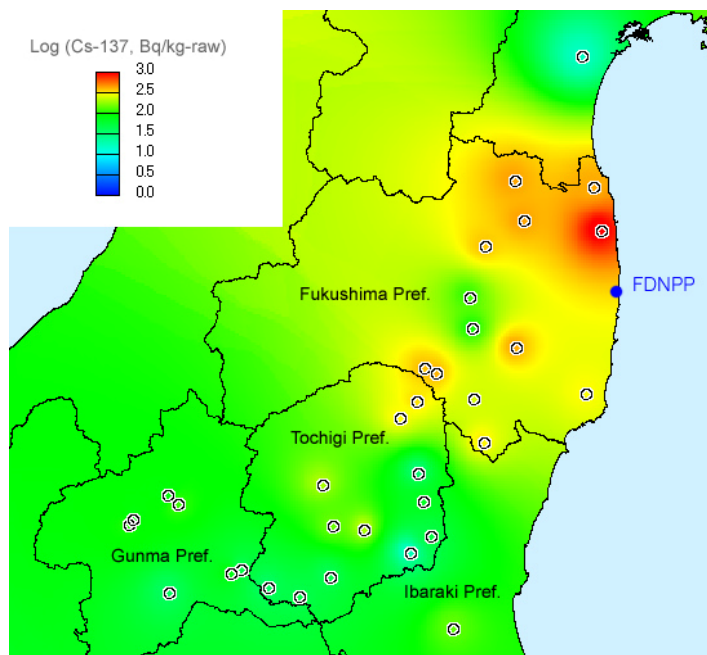


Fig. 2. Map of Cs-137 concentration (logarithm value) in wild boar meat collected within one year after the earthquake.

In the second year, between 366 – 600 days, wild boar and bear samples were available for FK-City. Based on the reported concentrations, the calculated geometric means were:  $101 \text{ Bq kg}^{-1}\text{-raw}$  ( $n=7$ ) for wild boar and  $86 \text{ Bq kg}^{-1}\text{-raw}$  ( $n=13$ ) for bear. The decreased order was reversed from that first seen in FK-City, becoming wild boar > Asian black bear. Another sampling site, N city in Fukushima (FN-City), also showed the same tendency and the geometric means of Cs-137 in wild boar were  $311 \text{ Bq kg}^{-1}\text{-raw}$  ( $n=17$ ) for wild boar and  $184 \text{ Bq kg}^{-1}\text{-raw}$  ( $n=6$ ) for bear.

Although the living habitats and available foods are different from the Japanese wild animals in this study, reindeer were reported to show a tendency for decreasing radiocesium concentration with time, although the concentration difference was large among individual animals [6]. To clarify the tendency in the present wild animals, wild boar data in FN-City, I city in Ibaraki Prefecture (II-City) and N city in Tochigi Prefecture (TN-City) were selected. Since FN-City had the highest value at 457 d, the data did not show any correlation with time; however, the data collected in II-City and TN-City had negative correlations with time with  $R=-0.47$  ( $p<0.01$ ) for II-City and  $R=-0.32$  ( $p<0.01$ ) for TN-City.

These were used to make a rough estimation of radiocesium retention time ( $T_{1/2}$ ) in wild boar; for the case of FN-City, the datum on 457th day was not used. The geometric mean was 204 d

(range: 122-334 d). According to these results, it was expected that the concentration of radiocesium in the body of wild animals would decrease with time; however, as was found from the 457th day datum of FN-City, prediction of the concentration for individual animals would be difficult; some would migrate from contaminated areas or would eat highly contaminated food like mushrooms in the case of wild boar.

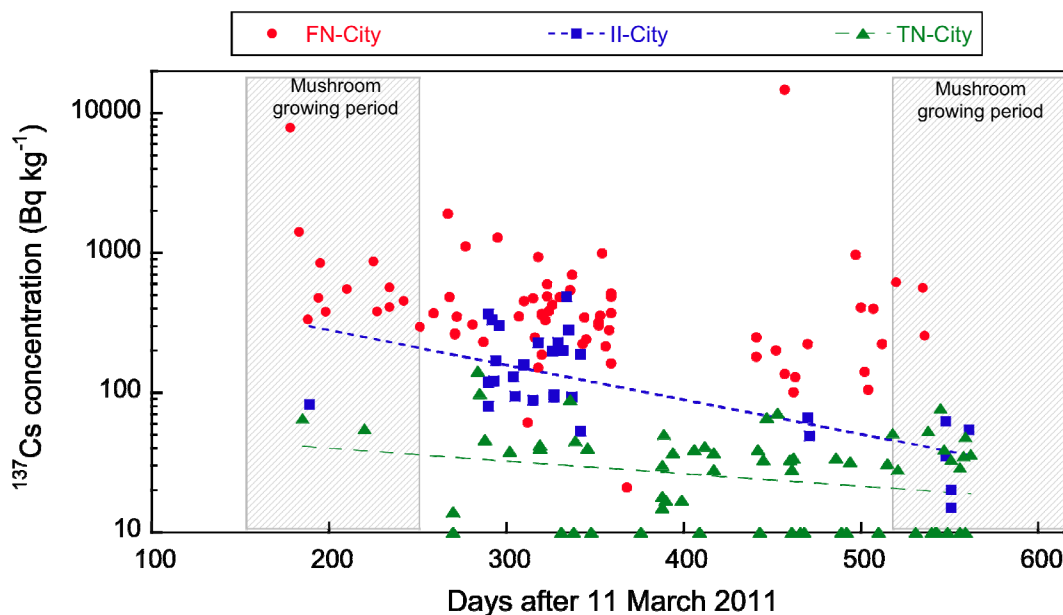


Fig. 3. Cs-137 concentration change in wild boar meat data collected in three cities.

### Concentrations of $^{137}\text{Cs}$ in Wild Mushrooms as an Indicator of Radiocesium Bioavailability in Forests

Wild mushrooms could be a source of mobile radiocesium fraction in forests, so wild mushroom data were also compiled and the results are shown in Table I. The data were classified by areas (*Aizu* and *Naka-dori*), fungi type (symbiotic and saprophytic), and year (2011 and 2012). *Aizu* is the western mountainous area of Fukushima and *Naka-dori* is located between *Aizu* and *Hama-dori* (east coastal area). The contamination level in the *Aizu* area was low; accordingly, geometric means of Cs-137 concentration in symbiotic and saprophytic fungi were lower than the standard limit level; however, the important point was that no clear difference was seen between the 2011 and 2012 results by ANOVA test, e.g. 13.8 and 21.1  $\text{Bq kg}^{-1}$ , respectively, for symbiotic fungi. In the southern part of the *Naka-dori* area, where the radiocesium concentration

level was higher than in the *Aizu* area, only symbiotic fungi results were available. In this area, the geometric mean rose in 2012.

Table I. Cs-137 concentrations in wild mushrooms collected in 2011 and 2012 in Fukushima Prefecture.

<i>Area</i> , Fungi type, year	N	<sup>137</sup> Cs concentration, Bq kg <sup>-1</sup> -raw		
		Geometric mean	Minimum	Maximum
<b><i>Aizu area</i></b>				
Symbiotic fungi, 2011	32	13.8	<D.L.	190
Symbiotic fungi, 2012	25	21.1	<D.L.	217
Saprophytic fungi, 2011	55	12.6	<D.L.	210
Saprophytic fungi, 2012	43	10.7	<D.L.	154
<b><i>Naka-dori area (southern part)</i></b>				
Symbiotic fungi 2011	10	59.2	15	1600
Symbiotic fungi 2012	4	1168	419	3340

D.L was about 5 Bq kg<sup>-1</sup>-raw.

It is highly probable that the dead leaves which fell at the end of 2011 were highly contaminated by direct deposition, and they were decomposed by microorganisms in 2012. It is known that organic matter decreases specific adsorption of radiocesium on clays [7], and radiocesium would bind to organic matter [8]; it was assumed that the mobility of radiocesium in litter and organic layers would be high. These results indicated that radiocesium in these layers is highly bioavailable and can be absorbed by mushrooms. Mushrooms are known as to be radiocesium accumulators [9]. Thus the radiocesium concentration did not decrease with time. Since wild boar feed on mushrooms which contain high levels of radiocesium, it can be assumed that the radiocesium concentration found in wild boar meat would not decrease rapidly.

## CONCLUSIONS

The concentrations of radiocesium in wild animals, i.e. wild boar, deer, Asian black bear, Japanese pheasant, and duck, were compiled in this study. It was found that the Cs-137

concentration decreased in the following order for the first year (11 March 2011 to 10 March 2012) after the FDNPP accident: Asian black bear > wild boar > deer > pheasant and duck. The wild boar data were used to make a contour map for Cs-137 concentration in wild boar meat in the first year. The distribution pattern was almost the same as that of the Cs-137 distribution on the ground, thus the concentration corresponded to the soil contamination levels. When the concentrations were plotted against time, they showed a decreasing tendency; however, this radiocesium is in a forest environment and animals will migrate to other places, so careful observations of wild animals are still necessary.

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