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^{137}Cs in Finnish wild berries, mushrooms and game meat in 2000–2005

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Activity concentrations of ^{137}Cs in wild berries, mushrooms and game meat were measured in samples collected during 2000–2005 in areas with varying ^{137}Cs deposition levels in Finland. Depending on the ^{137}Cs deposition levels in the sampling areas, the areal-mean activity concentrations of ^{137}Cs were 10–230 Bq kg^{-1} in wild berries, 20–240 Bq kg^{-1} in moose meat and 10–3000 Bq kg^{-1} in all mushroom species. Compared with the ^{137}Cs level of samples collected in 1986 in the corresponding areas, the reduction in the ^{137}Cs level was about one third for wild berries, equal to the rate of radioactive decay of ^{137}Cs. More reduction was observed in the activity concentrations of ^{137}Cs in moose meat, on average up to 50% since 1986. The aggregated transfer coefficients from soil to wild berries showed no change since 1986–1988, while there was about one third reduction in those from soil to game meat.

Introduction

The rate of transfer of ^{137}Cs to food products is higher in forest than in agricultural environment, and the decrease of ^{137}Cs in forest environment is very slow. The consumption of forest products by general population is low, but there are groups like hunters, and berry and mushroom pickers consuming relatively large quantities of these products. In the mid-long term after deposition, consumption of forest products can form the major proportion of ingestion dose especially among the group of large-scale consumers of these products.

^{137}Cs in wild berries, mushrooms and game meat in Finland originates mainly from the fallout after the Chernobyl accident in 1986. The Chernobyl contamination in Finland was uneven with ^{137}Cs levels varying in different areas from 1 up to 78 kBq m^{-2} (1 Oct. 1987) (Arvela *et al*. 1990). The products from natural ecosystems, like wild berries, mushrooms and game meat, showed high radiocaesium concentrations in 1986 (Rantavaara 1987, Rantavaara *et al*. 1987). In forest ecosystems soluble radiocaesium is known to remain in the humus layer for years and to transfer easily to vegetation and mushrooms and to animals ingesting those (McGee *et al*. 2000, Strandberg 2004). In the present study, activity concentrations and aggregated transfer coefficients of ^{137}Cs in Finnish wild berries, mushrooms and game meat during 2000–2005 are presented. The reduction in ^{137}Cs levels and changes in aggregated transfer coefficients of forest products after 1986 are compared with the corresponding coefficients reported earlier (Johanson 1994, Rantavaara 1990).

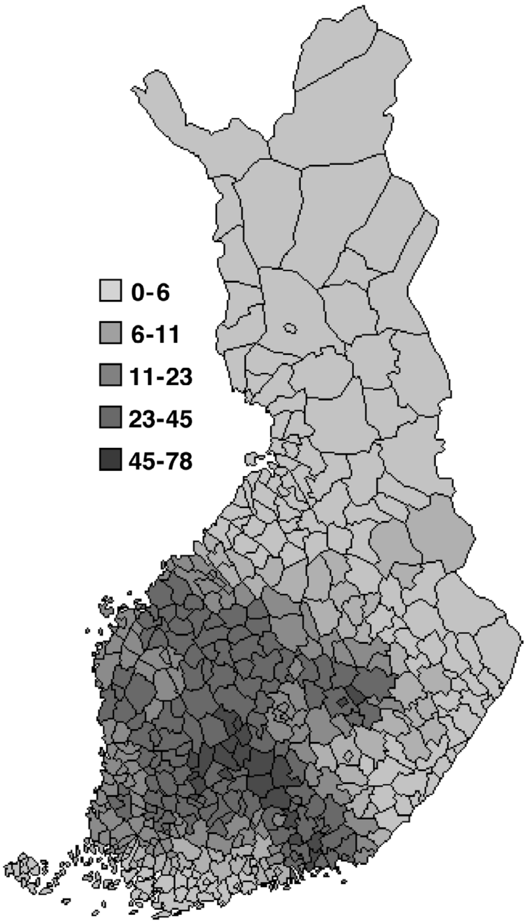

Fig. 1. Division of Finland in five categories according to the ^{137}Cs deposition level (kBq m^{-2}, 1 Oct.1987).

Material and methods

Sampling

Activity concentrations of ^{137}Cs in wild foodstuffs have been annually monitored in Finland since 1986. The monitoring program for the years 2000–2005 included about 1300 samples of wild berries, mushrooms and game meat. The main products sampled were lingonberry, blueberry, moose meat and widely consumed marketed mushroom species. The samples represented regions with different amounts of ^{137}Cs deposition. Samples of various species were taken at the same sampling sites to evaluate the variation in ^{137}Cs levels. Samples at the same sites in successive years were collected in order to find out the annual reduction in the activity concentrations of ^{137}Cs. Samples were collected by private persons. Each sampling site of berries and mushrooms represented an area that is normally used when picking berries or mushrooms for household use.

Sample treatment and measurements

The berry and mushroom samples were cleaned from soil and litter, and the mushroom and meat samples were chopped into small pieces. All the samples were dried in the oven (105 °C) until constant weight, and homogenised. The dry weight contents were determined. The ^{137}Cs concentrations on dried homogenised samples were determined by γ-spectrometry with high purity germanium detectors in cylindrical beakers with volumes of 30 or 110 ml. The counting times were chosen according to the activity of the samples in order to achieve measuring errors smaller than 5%.

Data treatment

For estimating the means and ranges of activity concentrations of ^{137}Cs in the different species, the data were divided into five groups (deposition areas, Fig. 1) according to the ^{137}Cs deposition levels (Arvela *et al.* 1990). The deposition was highest in the area 5 and lowest in the area 1. The activity concentrations of ^{137}Cs in berries, mushrooms and game meat were calculated per fresh weight. The aggregated transfer coefficients (Bq kg^{-1}/Bq m^{-2}) from mean regional deposition to products were calculated for all the samples, and the means, medians and ranges of the aggregated transfer coefficients for each species were calculated. The aggregated transfer coefficients for berries and game meat were calculated per fresh weight (f.w.), and for mushrooms per dry weight (d.w.).

Results

^{137}Cs in wild berries

The activity concentrations of ^{137}Cs were in accordance with the levels of deposition in the

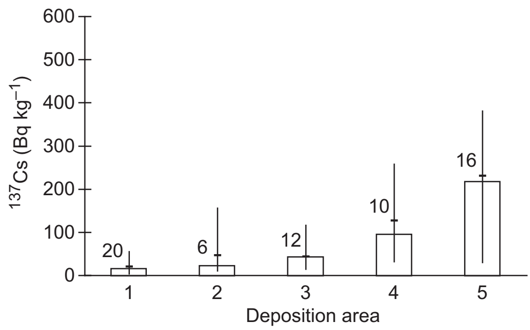

Fig. 2. Activity concentrations of ^{137}Cs (mean (–), median (column), range; Bq kg^{-1} f.w.) in blueberry in 2000–2005 in five deposition areas in Finland. Number of samples is given above the columns.

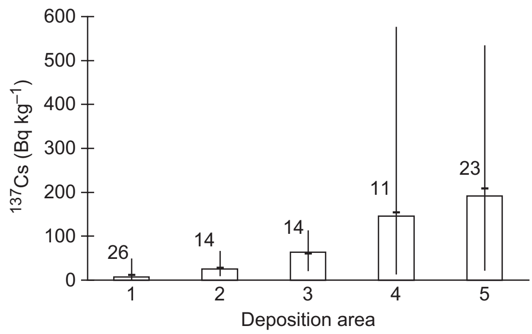

Fig. 3. Activity concentrations of ^{137}Cs (mean (–), median (column), range; Bq kg^{-1} f.w.) in lingonberry in 2000–2005 in five deposition areas in Finland. Number of samples is given above the columns.

sampling areas, being highest in areas 4 and 5 with maximum deposition levels (Figs. 2 and 3). The mean areal activity concentrations of ^{137}Cs for lingonberry (*Vaccinium vitis-idaea*) and blueberry (*Vaccinium myrtillus*) varied from 10 to 230 Bq kg^{-1} f.w. The activity concentrations of ^{137}Cs were highest in samples collected from poor lands and marshes. The variation inside each deposition area reflects different growing conditions at the sampling sites, including soil properties, nutrient content, pH, moisture and meteorological conditions. In addition, the deposition classification gives only the mean deposition over large areas, and local variation in deposition may be remarkable.

Compared with lingonberry and blueberry, other wild berries showed approximately the same ^{137}Cs levels for cranberries (*Vaccinium oxycoccus*) and crowberries (*Empretum nigrum*), and slightly higher levels for cloudberries (*Rubus chamaemorus*). The mean activity concentrations of ^{137}Cs were considerably lower in wild raspberries (*Rubus idaeus*), strawberries (*Fragaria vesca*) and rowan berries (*Sorbus aucuparia*).

^{137}Cs in wild mushrooms

During 2000–2005 more than 600 mushroom samples of circa 20 mushroom species were collected. Most of the samples were of the species that are widely consumed in Finland. The activity concentrations of ^{137}Cs in mushrooms were high relative to wild berries or game meat (Fig. 4). The variation in ^{137}Cs levels of different mushroom species sampled at the same site was at most tenfold. The range of the activity concentrations of ^{137}Cs was 10–9000 Bq kg^{-1} in all the samples collected in 2000–2005. The variation of the activity concentrations of ^{137}Cs in any given species sampled from the same site was at most two- to fivefold. The ^{137}Cs levels in the caps of mushrooms were 1.2–3.3 times higher than in the stems of the mushrooms. In widely consumed mushrooms, low activity concentrations of ^{137}Cs were found e.g. in *Leccinum* sp., *Gyromitra* sp., *Scutiger ovinus,* medium activity concentrations were found in *Boletus edulis, Cantharellus cibarius* and *Russula* sp., and high activity concentrations were observed in e.g. *Cantharellus tubaeformis*, *Craterellus cornucopioides*, *Lactarius* sp., *Hydnum* sp., *Suillus variegatus* and *Rozites caperatus.*

^{137}Cs in game meat

The mean activity concentrations of ^{137}Cs in the five deposition areas varied from 20 to 240 Bq kg^{-1} (f.w.) in moose meat samples (*Alces alces*) collected in 2000–2005 (Fig. 5). The concentrations for calves were 1.2-fold as compared with those in adult moose. In the samples of moose hunted near cultivated areas, the activity concentrations of ^{137}Cs were lower than in those hunted in large forest areas. The activity concentrations of ^{137}Cs were higher in moose kidneys than in moose meat, and lowest in liver samples

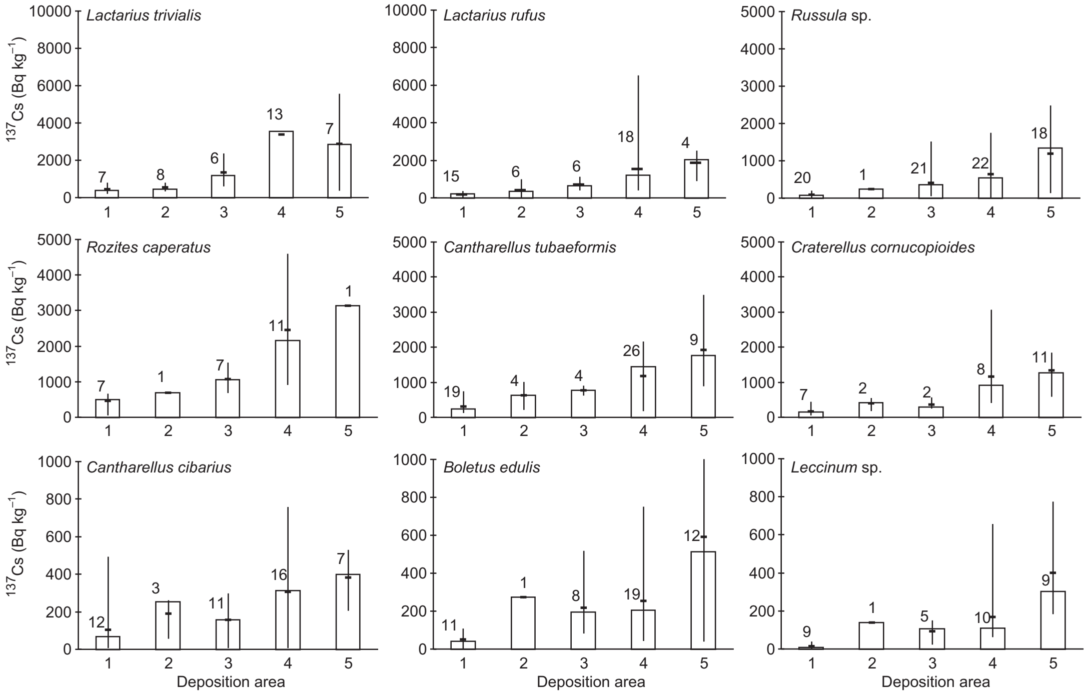

Fig. 4. Activity concentrations of ^{137}Cs (mean (–), median (column), range; Bq kg^{-1} f.w.) in mushroom species in 2000–2005 in five deposition areas in Finland. Number of samples is given above the columns.

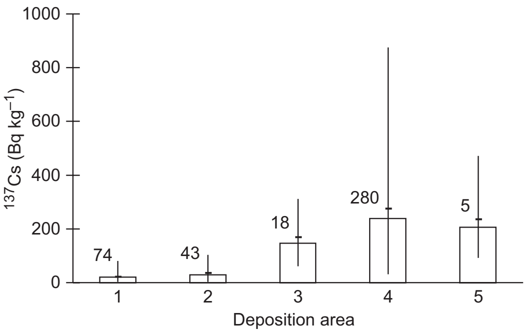

Fig. 5. Activity concentrations of ^{137}Cs (mean (–), median (column), range; Bq kg^{-1} f.w.) in moose meat in 2000–2005 in five deposition areas in Finland. Number of samples is given above the columns.

taken from the same animals. The ^{137}Cs levels in white-tailed deer (*Odocoileus virginianus*) samples were at the same level or a little higher than in the moose meat samples from the same areas. The highest activity concentrations of ^{137}Cs in the game meat were found in hare (*Lepus timidus*) samples, being about tenfold compared with those in moose meat. Considerably lower ^{137}Cs levels were found in brown hare (*Lepus europaeus*), reaching at most some tens Bq kg^{-1}.

Aggregated transfer coefficients

The efficiency of the ^{137}Cs transfer from soil to plants is described by an aggregated transfer coefficient T_{ag}, which is the ratio of ^{137}Cs concentration in the plant (Bq kg^{-1}) to that in the total soil deposition (Bq m^{-2}). The aggregated transfer coefficients were calculated for all the samples using the municipal mean deposition values corrected to the sampling dates (Tables 1 and 2). The mean aggregated transfer coefficients for moose meat were somewhat higher than those for lingonberry and blueberry. The aggregated transfer coefficients for mushrooms were multi-

Table 1. Aggregated transfer coefficients (T_{ag}, Bq kg^{-1} fresh weight/Bq m^{-2}) of ^{137}Cs for wild berries and moose meat in 2000–2005. Q_1 = 25th percentile, Q_3 = 75th percentile.

Species	*N*	Mean	Median	Q_1	Q_3
Blueberry	63	0.0055	0.0042	0.0030	0.0073
Lingonberry	83	0.0043	0.0035	0.0021	0.0057
Moose, adult	274	0.0071	0.0061	0.0040	0.0092
Moose, calf	146	0.010	0.0096	0.0065	0.014

fold as compared with those for wild berries and game meat. The transfer of ^{137}Cs from soil to mushrooms varied up to two orders of magnitude depending upon the species. The physiological differences among the mushroom species and host plants might be one of the reasons for the large variation in transfer of ^{137}Cs from soil to mushrooms (Tsukada *et al.* 1998).

Discussion

There is a lot of areal variation in the activity concentrations of ^{137}Cs in wild berries and mushrooms due to the very uneven deposition and different growing conditions. The variation in ^{137}Cs levels in game meat depends on — beside the deposition in the area — the fodder plants. Any seasonal variation in the ^{137}Cs level in moose meat due to consumption of mushrooms could not be detected due to the hunting of moose in late autumn (end of October–December) after the mushroom season (Avila *et al.* 1999). The variability of activity concentrations of ^{137}Cs in moose meat was higher within a year than between different years. The years with plenty of mushrooms showed no difference in activity concentrations compared with other years.

During the studied six-year period no significant reduction in the ^{137}Cs levels was observed in berries, mushrooms or game meat. The variabilities in ^{137}Cs levels between successive years even at the same sampling sites were so large that longer study periods are needed to detect the slow changes in activity concentrations of ^{137}Cs in forest environments. As compared with the measurements made in autumn 1986, the ^{137}Cs concentrations of wild berries showed an average reduction of about one third in the corresponding deposition areas. There was substantially more reduction in the ^{137}Cs contents in moose meat, on average up to 50% in all the deposition areas. This difference was also seen when comparing the transfer coefficients reported for the years 1986–1988 with those calculated for the years 2000–2005. No reduction was seen in the aggregated transfer coefficients for wild berries, while the reduction in T_{ag} for moose meat, both for calves and adults, was about one third. One reason for the more rapid decrease in the activity concentrations of ^{137}Cs in moose meat as compared with that in berries or mushrooms is the variability of fodder plants, including also components from cultivated areas where the reduction of ^{137}Cs levels was faster than in forests.

The temporal change in aggregated transfer coefficients for mushrooms is different for different species of mushrooms, which depends on the different depths of the mycelium location in the soil (Rühm *et al.* 1997, Mascanzoni

Table 2. Aggregated transfer coefficients (T_{ag}, Bq kg^{-1} dry weight/Bq m^{-2}) of ^{137}Cs for mushrooms in 2000–2005. Q_1 = 25th percentile, Q_3 = 75th percentile.

Species	*N*	Mean	Median	Q_1	Q_3
Hygrophoraceae	8	3.4	3.3	2.5	4.3
Rozites caperatus	27	1.5	1.4	1.2	2.0
Lactarius trivialis	42	1.2	1.1	0.96	1.4
Hydnum sp.	27	1.3	0.95	0.68	1.8
Suillus variegatus	16	0.8	0.62	0.28	1.3
Lactarius rufus	49	0.64	0.53	0.33	0.88
Cantharellus tubaeformis	58	0.55	0.51	0.39	0.66
Craterellus cornucopioides	30	0.58	0.51	0.36	0.71
Russula sp.	78	0.31	0.30	0.15	0.43
Suillus luteus	7	0.22	0.20	0.094	0.35
Cantharellus cibarius	46	0.19	0.17	0.093	0.22
Boletus edulis	49	0.15	0.14	0.072	0.22
Scutiger ovinus	25	0.078	0.073	0.054	0.096
Leccinum sp.	34	0.074	0.063	0.029	0.095
Gyromitra esculenta	11	0.067	0.055	0.044	0.099
Agaricus campestris	3	0.006	0.006	0.001	0.006

2001, Steiner *et al*. 2002, Strandberg 2004). For *Boletus edulis* the increase in the T_{ag} was remarkable as compared with the corresponding values measured in 1986–1988. This might be due to the migration of ^{137}Cs into deeper soil layers where it is available to mycelium of *Boletus edulis*. For other studied species of mushrooms there was a slight or no decrease in aggregated transfer coefficients since 1986.

The average consumption rates of forest products in Finland are 8 kg per year for berries, 1.5 kg per year for mushrooms and 1.2 kg per year for game meat (Markkula *et al*. 1997). The average radiation dose, caused by the consumption of wild berries, mushrooms and game meat was about 0.014 mSv per year in 1986 (Rantavaara 1987), and less than 0.01 mSv per year during 2000–2005 for an average consumer of wild products. Among the group of large-scale consumers, the doses can be more than tenfold compared with the average consumer.

Conclusions

In Finnish forest products large variations in the activity concentrations of ^{137}Cs resulting from the Chernobyl accident in 1986 still existed in 2000–2005, both among the species and areally, varying from 10 to 9000 Bq kg^{-1} f.w. and being highest in some mushroom species. No rapid reduction can be expected in the activity concentrations of ^{137}Cs in wild terrestrial products during the next years. The reduction rate is about 2%/year via radioactive decay of ^{137}Cs. Slight addition to the reduction is caused by the slow migration of ^{137}Cs into deeper soil layers. Long-term monitoring of the ^{137}Cs levels of forest products is important for assessing the radiation doses caused by consumption of these products.

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