Radiocaesium transfer to roe deer and moose – a comparative study

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Abstract. The paper describes the results of a comparative study of the seasonal and long-term dynamics of the levels of ^{137}Cs in roe deer and moose harvested in a relatively small area (100 km^2) of central Sweden. Samples of roe deer (N=1084) and moose (N=1922) were collected in 1988-1997 mainly during the hunting seasons. It is shown that the long-term decrease of ^{137}Cs levels in roe deer and moose is dominated by ^{137}Cs radioactive disintegration. Any other possible long-term trend of ^{137}Cs levels in these game animals is obscured by large and non-systematic between-years variations. A significant correlation between the levels in roe deer in August-September and the levels of ^{137}Cs in moose in October was observed. This correlation can explain 70 % of the between-years variation of the levels of ^{137}Cs in moose. The presented data indicate that there is a strong relationship between ingestion of fungi and the levels of ^{137}Cs levels in roe deer and moose during the summer-autumn period. This seems to be the main cause for the seasonal variations of ^{137}Cs levels in roe deer and the between-years variations in ^{137}Cs levels in roe deer in August-September and in moose in October observed in the study area. A significant correlation between the levels of ^{137}Cs in moose and the amount of rain in July-September was observed, which supports this conclusion. The number of fruit bodies of Suillus variegatus counted in six experimental plots located in the study area also confirms the important role of the ingestion of mushrooms. Estimations of the mushroom contribution to the total daily ingestion of food by roe deer and moose are provided.

1. INTRODUCTION

The work presented here is based on a long-term study of the levels of ^{137}Cs in roe deer and moose that has been carried out since the Chernobyl deposition in a relatively small area (100 km^2) of central Sweden. The results obtained in these studies up-to 1994 have been used in previous publications with various purposes [1, 2, 3, 4]. In this paper we present a comparative analysis of the whole data set of ^{137}Cs activity concentrations in roe deer and moose meat collected in this area from 1988 to 1997. The following main issues were addressed: (i) long-term trends of the levels of ^{137}Cs in roe deer and moose, (ii) between-years and seasonal variations of ^{137}Cs levels in roe deer and moose, (iii) correlation between the levels of ^{137}Cs in roe deer and moose. To interpret the results we also analysed data regarding ^{137}Cs levels in different a) sub-areas and b) sex and age categories of moose. Further the data was used for determining aggregated transfer factors. Another objective was to study the relationships between the abundance of fungi fruit bodies and the levels of ^{137}Cs in roe deer and moose.

2. MATERIALS AND METHODS

The research area is located in the central part of Sweden, 40-km Northwest of Uppsala. A description of the vegetation and fauna of this area can be found in [4]. The amount of rain in the research area was obtained from the meteorological station closest to this area (Harbo station). The Swedish Institute of Meteorology and Hydrology (SMHI) provided the data. The harvest of roe deer in this area is carried out in three hunting seasons: in spring (from May 1st to June 15th), in summer-early autumn (from August 16th to September 30th) and in late autumn-winter (from October 1st to January 31st of the next year). The hunting season of moose starts the second Monday of October and continues to the end of the year, although most moose are harvested in October.

The radiocaesium activity concentrations were measured in muscle samples of the animal foreleg. The majority of the samples came from roe deer and moose shot by hunters during the hunting seasons. A smaller number of samples were collected from animals killed outside the hunting season by special permission or from animals killed in car accidents. A total of 1084 samples of roe deer and 1922 samples of moose were collected during the study period. The samples were prepared and measured as described in [4].

To study the availability of mushrooms since 1994 we counted weakly the number of fruit bodies of Suillus variegatus in six experimental plots situated in the research area. We have chosen this fungal species because it is usually abundant in our research area and we have some indications that this species is eaten by game.

The statistical analysis of the results was carried out with the computer package STATISTICA (Stat Soft, Inc.). To test if the empirical distributions were normal (lognormal) distributed the Shapiro-Wilk's W test was applied. The statistical significance of between-groups differences (between-years differences, between-months differences, differences between hunting periods, differences between animals of different age and sex) was tested by Kruskal-Wallis ANOVA and Mann-Whitney U-tests. Spearman's correlation between the levels of ^{137}Cs in moose and roe deer and between the levels of ^{137}Cs in moose and the rain were computed. The results of the statistical tests that yield $p \leq 0.05$ were considered statistically significant.

3. RESULTS AND DISCUSSION

The ^{137}Cs activity concentrations measured in roe deer and moose during the studied period followed a lognormal distribution. The aggregated transfer factors (TF_{ag}) were approximately two times higher for roe deer than for moose (Table 1). The variability of the TF_{ag} was 1.5 times higher for roe deer than for moose. To some extent this is because the levels in roe deer were measured during all seasons of the year, while for moose all values were obtained in the autumn and winter, mainly in October. Another reason is that roe deer is a smaller animal than moose and thus it responds faster to changes of the levels of ^{137}Cs levels in the diet. One characteristics of the variability, common for both roe deer and moose, was the existence of correlation between the mean values and the standard deviations. One part of the variability observed in the data may depend on the biological characteristics of the animals. We studied the effect of age and sex on ^{137}Cs levels in moose and found a significant difference between calves (age ≤ 1 year) and adult moose, but did not found significant difference between animals of different sex.

Table 1. Aggregated transfer factors of Chernobyl ^{137}Cs, in units of Bq/kg fresh mass per Bq/m^2, for roe deer and moose.

Type of game	N	Mean	Geometric mean	5 % percentile	95 % percentile
Roe deer	1084	0.05	0.031	0.005	0.16
Moose	1922	0.02	0.016	0.005	0.05

There was a significant correlation between the levels of ^{137}Cs and ^{134}Cs in both moose and roe deer. The ratio ^{137}Cs to ^{134}Cs (after correction for decay) was constant during the whole study period and equal 1.776 ± 0.016 (mean value ± 1.96 standard error). This value is significantly higher than the average ratio in the Chernobyl deposition in Sweden (equal to 1.7 according to Mattson and Moberg, [5]). The difference is due to the contribution of pre-Chernobyl caesium and can be used to estimate pre-Chernobyl ^{137}Cs activity concentrations in moose and roe deer. The estimated values of ^{137}Cs levels in moose and roe deer just before the Chernobyl deposition were 34.5 and 85.4 Bq/kg (fresh weight) respectively. These values divided by the inventory of ^{137}Cs in this area before the Chernobyl deposition (about 3 kBq/m^2 [5]) yield mean TF_{ag} values for the pre-Chernobyl ^{137}Cs of 0.019 for moose and 0.047 for roe deer. These values are close to the TF_{ag} calculated for the Chernobyl ^{137}Cs (Table 1).

3.1 Yearly variations

There were significant between-years differences in the levels of ^{137}Cs in moose, but no trend with time was observed. The ecological half-life of ^{137}Cs in roe deer and moose, thus seems to be close to ^{137}Cs physical half-life (30.17 years). The ^{137}Cs activity concentrations in moose were lower in 1995 and 1996 than in other years (Fig. 1). The total number of fruit bodies of mushrooms counted in the six experimental plots situated in the area showed the same pattern, which suggests that there might be a correlation between the availability of mushrooms in August-September and the activity levels in moose in October. To study possible effects of the spatial variability on the between years variations the study area was divided into five sub-areas: Harbo, Huddunge, Runhällen, Tärnsjö and Östervåla. There were significant differences between the levels of ^{137}Cs in moose harvested in different sub-areas. The levels in Runhällen were the highest, while the levels in Tärnsjö were the lowest during the study period as a whole. The relationship between the areas changed from year to year, but the pattern of the between-years variation was the same for all areas. Thus, the factors that cause the difference between the years seem to operate in the whole study area.

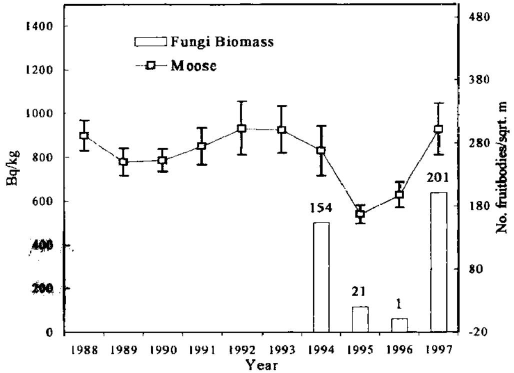

Figure 1. Mean values (confidence intervals) of ^{137}Cs activity concentrations in moose harvested in October in the research area and number of fruitbodies of Suillus variegatus found in six experimental plots situated in this area.

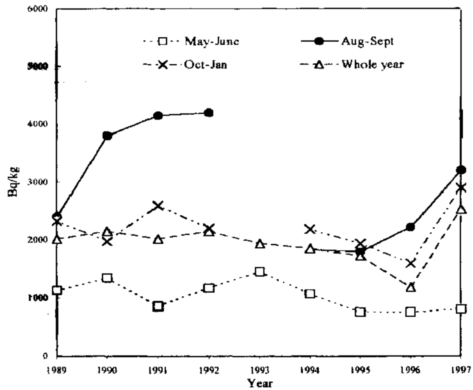

Figure 2. Yearly means and means in different hunting periods of ^{137}Cs activity concentrations in roe deer harvested in the research area.

When all measured values of ^{137}Cs activity concentrations in roe deer were pooled, it was not possible to demonstrate differences between the years. This is not surprising if we take into account that there are very large within-year variations of ^{137}Cs levels in roe deer [4]. The ^{137}Cs levels in roe deer during the spring (May-June) and late autumn-winter (October-January) hunting seasons were approximately constant during the whole study period (Fig. 2). At the same time, a significant variation between years in ^{137}Cs levels in roe deer harvested during August-September was observed As for moose, the levels in roe deer were significantly lower in 1995 than in other years.

In the study area mushrooms represent an important fraction of the daily ingestion of food by roe deer during summer and autumn. Mushrooms have higher ^{137}Cs levels (from 4 to 80 times higher) than other roe deer feeds. These two factors can quantitatively explain the seasonal dynamics and between-years variation of ^{137}Cs levels in roe deer observed in this area [4]. Using the model described therein it was possible to estimate that the average ingestion rate of mushrooms by roe deer during August-September was about 13 % of the total daily food ingestion. In a year with high mushroom abundance, like 1991, it could be as high as 20 % of the total daily ingestion of food, while in a year poor in mushrooms, like 1995, it was about 4.4 %. The biomass density (kg/ha) of mushrooms is usually many times lower than the biomass of other roe deer feeds and thus roe deer probably has a preference for mushrooms. At the same time, the availability of mushrooms can experience pronounced changes from year to year. This leads to between-years variations in the ingestion rate of mushrooms and consequently in the levels of ^{137}Cs in roe deer harvested in August-September (Fig. 2).

3.2 Seasonal variations

There was a significant difference between the levels of ^{137}Cs levels in roe deer harvested in different months when the whole data set was considered (dotted line in Fig. 3). The levels of ^{137}Cs in roe deer harvested in August, September and October were significantly higher than the levels of ^{137}Cs in roe deer harvested in other months. In each particular year a similar pattern was observed. In some years, however, there was not statistically significant difference between roe deer harvested in August (1995), September (1989,1990) or October (1990, 1993) and roe deer harvested in spring and winter months. In Fig. 3 the two years (1991 and 1995) with an extreme behaviour are presented. The curves for other years have a similar form and lie approximately between the curves of these two years.

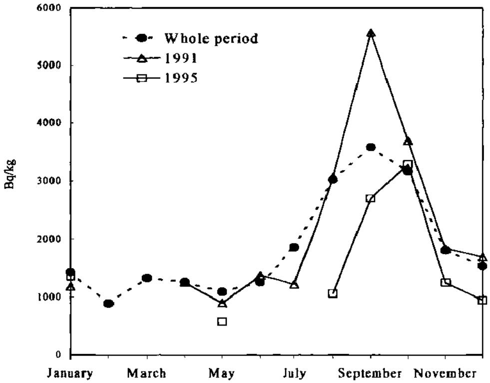

Figure 3. Monthly means of ^{137}Cs activity concentrations in roe deer harvested in the research area. Values for the whole studied period (1989-1997) and for a year with high (1991) and low (1995) mushroom abundance are presented.

The observed seasonal dynamics of ^{137}Cs levels in roe deer suggested that roe deer harvested in different hunting periods might show different ^{137}Cs levels. This was confirmed by the statistical analysis, which showed significant differences between the ^{137}Cs activity concentrations in roe deer harvested in the three hunting seasons for the whole period and for each particular year, except for 1995. There was no sufficient data available to compare the ^{137}Cs activity concentrations in roe deer harvested in different hunting periods during 1996. The mean ^{137}Cs levels in the summer hunting period are approximately three times higher than in the spring hunting period. This means that a shift of the hunting season from the summer to the spring might considerably reduce the radiation doses to people from consumption of roe deer meat.

3.3 Correlation between roe deer and moose

We examined the correlation between the levels of ^{137}Cs in roe deer in August-September and October-January and the levels of ^{137}Cs in moose in October. There was a significant correlation between the levels of ^{137}Cs in roe deer in August-September and the levels of ^{137}Cs in moose in October (Table 2). This correlation accounts for 70 % of the observed between-years variation of ^{137}Cs levels in moose. There was no correlation between the levels of ^{137}Cs in roe deer and moose in October. Neither were correlated the levels of ^{137}Cs in roe deer harvested in August-September and October-January.

Table 2. Spearmans rank correlation between the levels of ^{137}Cs in roe deer and moose

Compared groups	Correlation coefficient	Probability
Roe deer Aug/Sep – Moose October	0.85	0.023
Roe deer October - Moose October	0.5	0.39
Roe deer Aug/Sep - Roe deer Oct/Jan	0.7	0.18

The between-years difference in ^{137}Cs levels in roe deer during August-September, as pointed out above, is related to the rate of ingestion of mushrooms. At the same time there was a significant correlation between ^{137}Cs levels in roe deer in August-September and in moose in October. Thus, it is likely to be a correlation between ^{137}Cs levels in moose harvested in October and the ingestion rate of mushrooms by roe deer in August-September. A possible explanation for such correlation is that moose also eats mushrooms during August-September. Assuming that there is linear proportionality between the ingestion rate of mushrooms in August-September by moose and roe deer it was possible to estimate, using the model described in [4], that the ingestion of mushrooms by moose was between 0.25 % (1995) and 1.1 % (1991) of the total daily food intake. These values are reasonably close to values estimated from rumen content by Cederlund et al. [6] and by Johanson et al. [3]. Thus, it seems to be that in our study area the correlation between moose and roe deer is mostly due to ingestion of mushrooms in August-September by both types of game. This can explain 70 % of the observed between-years variation in moose. The remaining variation might be due to changes in the moose habitat or in the ingestion of other feeds.

3.4 Correlation with the weather

We studied the correlation between the rain in July-September and levels of ^{137}Cs in moose in October. The independent variables for the correlation study were the total amount of rain in (mm) and the number of days with rainfall above 2, 3, 4 and 6 mm. There was a significant correlation between the total amount of rain in July-September and the levels of ^{137}Cs in moose in October (Table 3). The observed correlation can explain 50 % of the between-years variation. The correlation was also a significant for the variable number of days with rainfall above 4 and the variable number of days with rainfall above 6 mm. No significant correlation was, however, observed between levels of ^{137}Cs in moose and the number of days with rain above 2 or 3 mm.

The observed correlation between ^{137}Cs levels in moose and the amount of rain in July-September is a confirmation of the important role of fungi ingestion. The amount of rain in summer is known to stimulate the production of mushroom fruit-bodies. The relationship between the number of fruit-bodies and the rain is, however, not simple. Other factors like the temperature, the spatial and temporal pattern of the rain, seem also to be important. In this study a better correlation was observed for the variable number of the days with rainfall above 6 mm than for the variables number of days with rainfall above 2, 3 and 4 mm. This suggests that the amount of rain under short periods might be important.

Table 3. Spearman's rank correlation between rain and the levels of ^{137}Cs in moose

Independent variable	Correlation Coefficient	Probability
Total rain in July-September, mm	0.73	0.024
Days with rainfall > 2 mm	0.61	0.081
Days with rainfall > 3 mm	0.61	0.084
Days with rainfall > 4 mm	0.67	0.05
Days with rainfall > 6 mm	0.72	0.026

4. CONCLUSIONS

This study shows that the levels of ^{137}Cs in roe deer and moose will decrease according to ^{137}Cs physical half-life. Any other possible long-term trend of ^{137}Cs levels in these game animals is obscured by large and non-systematic between-years variations. Evidence of a relationship between ingestion of fungi and the levels of ^{137}Cs in roe deer and moose during the summer-autumn period was found. This seems to be the factor governing the seasonal variations of the levels of ^{137}Cs in roe deer and the between-years variations of ^{137}Cs levels in roe deer and moose observed in our research area.

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