Journal of Environmental Radioactivity 100 (2009) 241–249

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Seasonality of ^{137}Cs in roe deer from Austria and Germany

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ARTICLE INFO

Article history:
Received 26 April 2007
Received in revised form
14 September 2008
Accepted 15 December 2008
Available online 21 January 2009

Keywords:
Radiocaesium
Roe deer
Mushroom
Chernobyl
Modelling
Seasonality

ABSTRACT

Empirical data on the ^{137}Cs activity concentration in meat of roe deer (*Capreolus capreolus*) roaming in 3 spruce forest areas and one peat bog area are presented and compared. They cover time series of nearly 20 years after a spike contamination in 1986 originating from Chernobyl. A model is presented which considers three soil compartments to describe the change of the availability of ^{137}Cs with time.

The time-dependency of the ^{137}Cs activity concentration in meat of roe deer is a combination of two components: (1) an exponential decay and (2) a peak in the second half of each year during the mushroom season. The exponential decay over the years can be described by a sum of two exponential functions. The additional transfer of ^{137}Cs into roe deer during the mushroom season depends on precipitation. On the peat bog the ^{137}Cs activity concentration in roe deer is higher and more persistent than in spruce forest.

1. Introduction

The contamination of the meat of roe deer (*Capreolus capreolus*) with ^{137}Cs and its seasonality has been reported by several authors recently (Avila et al., 1999; Fielitz, 2005; Strebl and Tataruch, 2007; Zibold et al., 2001, 2005). Relevant characteristics of roe deer biology and some general information on size and use of habitat are given in these publications and references therein. In Germany adult roe deer are quite sedentary, with home range sizes scarcely over a couple of hundred hectares (Ellenberg, 1978). Their diet varies with the seasons and includes leaves of deciduous trees and shrubs, buds, herbs, ferns, heather, grasses and fungal fruitbodies (Cederlund et al., 1980). The idea of the present publication is to give an overview of the existing data sets for complete time series available and to compare the different sites. In addition to model the seasonality of ^{137}Cs contamination in roe deer and interpret the site-specific differences with respect to the following parameters: ecosystem, e.g. spruce forest versus peat bog, different fixation rates of ^{137}Cs in the soils and, therefore, different ecological half-lives for the sites, and influence of precipitation on mushroom growth and roe deer contamination. The same dynamic model is used for the 4 data sets presented. Characteristic features of the areas studied are given in Table 1.

2. Materials and methods

2.1. Study area

2.1.1. Weinsberger Forest, Austria

The investigation area Weinsberger Forest extends to 6500 ha. The typical highland landscape encompasses altitudes between 700 m and 1041 m. It is situated north of the river Danube, in the south-western part of Waldviertel which belongs to the Crystalline Bohemian Massif (e.g. Gutenbrunn, 48° 22′ N, 15° 07′ E, WGS 84; altitude 868 m).

2.1.1.1. Geology and soils. The geological underground consists of Weinsberger Granite, and partly gneiss. The investigation area is dominated by loamy brown-earth soils (Dystric cambisol). The high permeability and the cool-humid climate favour podsolization; therefore, all stages from brown-earth and podsolic brown-earth to semipodsols can be found. The soils are carbonate-free, soil reaction is acidic to very acidic. In valleys due to slope-parallel waterflow one can find gley-podsols, and peaty soils as well as holo-organic sphagnum soils. Mean values of soil parameters in B-horizons of forest soils: pH ($CaCl_2$): 3.8; texture (sand:silt:clay in %): 41:34:25; C_{org} (%): 6.3; CEC (meq/kg): 205 (Strebl et al., 1999).

2.1.1.2. Hydrology. On average 100 days a year the Weinsberger Forest is covered by snow. The long-term annual mean of precipitation amounts to 914 mm.

The hydrologic situation of the area especially the groundwater level is not uniform, depending on the thickness of the sand and gravel layers. This leads to a high infiltration velocity of precipitation (locally more than 30 mm per hour). During dry periods the water content of A and B soil horizons can decrease to less

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doi:10.1016/j.jenvrad.2008.12.005

Table 1
Characteristic data of the forest districts studied as given by the local forest authorities.

Forest district	Bodenmais, Germany	Weinsberger Forest, Austria	Ochsenhausen, Germany	Pfrunger Ried, Germany
Population of roe deer uncertainty 10%	2200	1900	600	200
Forest area in km^2	75	65	16	5
^{137}Cs soil inventory at 1.05.86 in kBq/m^2 (geo mean and range)	47 ± 57% ($n = 59$)	52.2 ± 27% ($n = 218$)	39 ± 79% ($n = 18$)	21 ± 5% ($n = 4$)
Annual bag; uncertainty ≈ 10%	80	<177	200	60
Mean live-mass of roe deer (kg)	18	18	17	17
Hunting season male	1.05–15.10	1.06–15.10	15.05–15.10	
1 year old male	–	1.05–15.10	–	
Female	1.09–15.01	16.08–31.12	1.09–31.01	
1 year old female	1.09–15.01	May and 16.08–31.12	1.09–28.02	

than 20%. On hill-foots wet areas with high groundwater level between 0.3 and 0.8 m are found.

2.1.1.3. Vegetation. The climax vegetation has developed as mixed forest (spruce–beech–fir). Due to timber production the actual vegetation is dominated by spruce. The species composition of the understorey is dependent on the small scale (position on the slope of hills) hydrologic and light conditions. The most abundant understorey species are (^{137}Cs median values from 1996). *Vaccinium myrtillus* (leaves, n=17: 900 Bq kg^{-1} F.M.), *Oxalis acetosella* (n=7: 200 Bq kg^{-1} F.M.), *Calamogrostis sp.*,(n=8: 350 Bq kg^{-1} F.M.), *Dryopteris dilatata*, (n=17: 5000 Bq kg^{-1} F.M.), *Polytrichum sp.* (n=8: 900 Bq kg^{-1} F.M.) and other mosses (F.M. derived from Strebl et al. 1999).

In meadow sites within the forest the most abundant species, besides grasses, are: *Alchemilla vulgaris* (n=6: 120 Bq kg^{-1} F.M.), *Trifolium sp.*, (n=6: 100 Bq kg^{-1} F.M.), *Rumex sp.* and *Ranunculus acris* (n=6: 40 Bq kg^{-1} F.M.) (F.M. derived from data in Belli, 2000).

Radiocaesium content of mushrooms is very variable, e.g. in 1993 *Xerocomus badius* contained 3700 Bq kg^{-1} F.M. median, n = 5 (Strebl et al., 2000).

2.1.2. Bodenmais, Germany

The study area is a mountain forest ecosystem in South-East Bavaria, near the small tourist village Bodenmais (49° 04′ N, 13° 06′, WGS 84; altitude 654 m).

2.1.2.1. Geology and soils. The soil is a podsolic Braun earth soil with a 4 cm thick humus layer. The pH ($CaCl_2$) is 3.4, and the CEC is 144 meq/kg in the upper 0–5 cm mineral soil layer (Fielitz, 2001).

2.1.2.2. Hydrology. The mean annual precipitation is about 1200 mm, the mean annual temperature is 5 °C. In winter the snow often is deeper than 1 m.

2.1.2.3. Vegetation. The dominating trees are Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*). The ground vegetation is sparse and the main species are *V. myrtillus*, *Dryopteris carthusiana*, *Athyrium felix-femina*, *Rubus fruticosus* and *Polytrichum* sp. Since 1988, within the scope of several research projects, in about 10 000 samples of soil, plants, fungal fruitbodies and game from the forest ecosystems, the ^{137}Cs activity concentration had been measured, in order to investigate the dynamics of this nuclide (Fielitz, 1994, 2001). Unfavourable location conditions cause a relative high transfer of ^{137}Cs into plants and game. All soil and plant samples are taken exclusively from 100 × 100 m^2 permanent study plots. All examined plant types showed a pronounced decrease of the ^{137}Cs activity from 1987 until 2004. The deceleration of the decrease, which can be observed since 1995 for most plant types, continues. The mean ^{137}Cs activity of many plant types is below 1000 Bq kg^{-1} in the fresh mass (FM). Only few plant types, such as the spinulose woodfern (*D. carthusiana*) and bilberry (*V. myrtillus*), showed higher activities. The contamination of above ground fungal fruitbodies varies from 24 Bq kg^{-1} FM (*Macrolepiota procera*) to 2800 Bq kg^{-1} FM (*X. badius*). In 2005, with an average of 26 800 Bq kg^{-1} (FM) the contamination of deer truffles (*Elaphomyces granulatus*) is more than an order of magnitude greater than the contamination of all other potential food types of the considered roe deer (Fielitz, 2005).

2.1.3. Ochsenhausen, Germany

The study area is located north of Lake Constance in the south of Germany and is characterized in detail in Zibold et al. (2001).

State forest district Ochsenhausen (48° 04′ N, 09° 57′ E, WGS 84; altitude 577 m), situated near the city of Biberach, comprises 16 km^2 of forest populated by about 600 roe deer. Since 1987 about 200 roe deer are shot per year, and more than 50% of those are younger than 1 year. The dominant tree of the region is spruce, *P. abies*, with a fraction of about 80%. The mean tree age is about 100 years.

2.1.3.1. Geology and soils. The main type of soil is Stagnosol, and Luvisol belonging to the soil family mottled loam. The geology of the bedrock is mainly moraine. At a typical site the humus deposit has a thickness of 5.5 cm and is of mor type. The grain size distribution is (17–30) % clay, (40–50) % silt, and (0–33) % of sand. The pH value of O_f, O_h, and A_h ranges between 2.9 and 2.5 ($CaCl_2$ method).

2.1.3.2. Hydrology. At weather station Bad Schussenried, situated about half-way between Pfrunger Ried and Ochsenhausen, the following average values for the years 1980–2005 were recorded: maximum temperature: 17.8 °C in July, minimum temperature: −1.1 °C in January, maximum precipitation: 116 mm in July, minimum precipitation: 49 mm in February, and a mean precipitation of 916 mm per year. The annual precipitation varies locally between 700 and 1400 mm.

2.1.3.3. Vegetation. The time-dependency of the aggregated transfer factor T_{ag} soil-plant has been studied for the prevailing plant species in the neighbourhood of areas mentioned and results were published (Klemt et al., 1999; Pröhl et al., 2006) showing, that since 1992 for the grazing plant spinulose woodfern, *D. carthusiana*, and other plants ecological half-lives between 2 and 11 years were observed. Smaller contamination values and a longer ecological half-life are measured in mixed forest as compared to spruce forest (Drissner et al., 1998).

Geometric means of aggregated transfer factor of samples of *X. badius* from Ochsenhausen and surrounding forests as measured for each year after 1987–2002 decrease with an ecological half-life of about 4 years (Pröhl et al., 2006). Since 1987 in about 1058 samples of various fungi species from Ochsenhausen, Pfrunger Ried, and surrounding forests the ^{137}Cs activity concentration has been determined, prevailing species determined and those with highest contaminations are *Lactarius*, *Paxillus involutus*, and *X. badius*. The contamination of these fungi is decreasing with an ecological half-life of 9.3 ± 1.4 years, Klemt and Zibold (2005).

2.1.4. Pfrunger Ried, Germany

The study area is located north of Lake Constance in the south of Germany and is characterized in more detail in Zibold et al. (2001). Pfrunger Ried (47° 54′ N, 09° 23′ E, WGS 84; altitude 610 m) situated about 45 km south west of Ochsenhausen is a peat bog of about 5.2 km^2 populated by about 200 roe deer.

2.1.4.1. Geology and soils. Pfrunger Ried comprises about 1.3 km^2 of high moor dominated by pine, *Pinus mugo*, enclosing about 0.3 km^2 of low and intermediate moor. The high moor is surrounded by boggy forest (about 3.6 km^2), lakes (1 km^2) and agricultural land (20 km^2). The geology of the bedrock is mainly moraine.

2.2. Model to describe the time-dependency of the roe deer ^{137}Cs activity concentrations

First order processes, where the change of a compartment with time is proportional to the contents of the model compartments, lead to a set of first order common differential equations for the compartments. The equations were implemented in Model Maker (AP Benson Ltd., UK).

The main idea of our model is the following: the time-dependency of our data (Figs. 3–6) is interpreted as a sum of two exponential functions. This means that three different soil compartments are necessary in order to describe the time-dependency of the roe deer activity concentration with different time constants for fixation and redissolution processes between two different soil compartments [soil 1] and [soil 2] and final fixation in a third compartment [soil 3] including migration out of the rooting zone. The sum of the three soil compartments represents the total inventory in the soil.

In Fig. 1 the outline of the model is shown. The compartments [soil 1], [soil 2], [soil 3], and [deer] contain the average activity of the whole forest soil and the activity of the whole roe deer population, respectively, in Bq. The activity concentration of roe deer in Bq kg^{-1} is obtained by dividing the compartment [deer] by the number of roe deer in the forest and by the average weight of the roe deer as given in Table 1. In the model, hunting of roe deer (about one third of the population per year) is assumed to lead to negligible loss of activity from the forest ecosystem.