Journal of Environmental Radioactivity 190–191 (2018) 97–104

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Transfer of radionuclides and dose assessment to ants and anthills in a Swedish forest ecosystem

K. Rosén[a,*], L. Lenoir[b], K. Stark[c], M. Vinichuk[d], S. Sundell-Bergman[a]

[a] Department of Soil and Environment, Swedish University of Agricultural Sciences, SLU, Box 7014, SE-750 07, Uppsala, Sweden
[b] Brunnvalla 401, SE-740 45, Tärnsjö, Sweden
[c] Swedish Radiation Safety Authority, SSM, SE-171 16, Stockholm, Sweden
[d] Department of Ecology, Zhytomyr State Technological University, 103 Chernyakhovsky Str., 10005, Zhytomyr, Ukraine

ABSTRACT

In forest ecosystems soil organisms are important for immobilization, translocation and recycling of radionuclides. Still, there is a lack of studies on the role of insects such as ants in the turnover of radionuclides and how radioactivity affects an ant community. In this study seven anthills were sampled in an area that was heavily contaminated after the fallout from the Chernobyl accident. Samples of ant and anthill materials were taken from different depths of the anthills as well as from the surrounding soil and the activity concentrations of ^{137}Cs were determined. In addition, a radiation dose assessment was performed for ants and anthills using the ERICA tool. The deposition of ^{137}Cs in 1986 in the study area was calculated back to be on average 110,500 Bq m^{-2}. The averaged data for all the seven locations investigated indicate that the level of ^{137}Cs activity concentrations in the anthill's material increased with depth of the anthill being highest at the depth 50–65 cm. The concentration in the upper layers (0–2 cm) and of the ants showed significant correlations with the deposition upon multivariate analysis.

The concentration ratio (CR) defined as the ratio between the mass activity for ^{137}Cs density in ants (Bq kg^{-1} d.w.) and mass activity density in soil (Bq kg^{-1} d.w.) was determined to be in the range of 0.04–0.14.

Also, the transfer factor (TF) defined as the ratio between the mass activity for ^{137}Cs density in ant (Bq kg^{-1} d.w.) and to the unit area activity density (in Bq m^{-2} d.w.) was determined for ^{137}Cs to be 0.0015 m^2 kg^{-1} d.w. The assessed radiation doses were found to be a 4.9 μGy h^{-1} which is below international reference levels for non-human biota.

1. Introduction

To understand the long-term consequences of nuclear fallout in the environment it is essential to have knowledge of the transfer and the fate of radionuclides in the affected ecosystems. In forest ecosystems soil organisms, can be important for immobilization, translocation and recycling of radionuclides. For example, the presence of soil organisms, such as fungi, in the upper organic rich forest soil layers enhances retention of ^{137}Cs within the soil profile and makes it available for uptake (Vinichuk et al., 2004). However, our understanding of the processes involved in the radionuclide interactions with living components of soil systems in forest is limited. There is a lack of notable studies on the role of insects such as ants in the turnover of radionuclides and its effect on the radionuclide availability in soil (Jarvis et al., 2010; IAEA, 2014). This low level of understanding of the interactions between the radionuclides and different components of natural ecosystems hampers the development of reliable models (Tamponnet et al., 2008).

The contribution of the ants to radionuclide recycling in forest soil is largely unknown. Though, it has been shown that the concentration of ^{137}Cs may be greater in *Pogonomyrmex salinus* nests than in adjacent reference soils (Blom and Johnson, 1991).

An ant colony can include one or more anthills, and the nests can look very different among species of ants. Some species have their nests under the ground surface, while others build large anthills above the ground. Even the lifespan of nests varies between species, ranging from one month to several years. *Formica rufa* anthills have been observed to be active for more than 30 years (Persson et al., 2007). The anthills of forest ants (genus *Formica*) are mostly based of conifer forest litter, twigs, branches, resin and soil particles. Each anthill is maintained at all times by worker ants by rearranging the different types of materials. Ants require heat to optimize their physiological functions (Hölldobler and Wilson, 1990) and they ants regulate the heat to a temperature of

* Corresponding author.
E-mail address: klas.rosen@slu.se (K. Rosén).

https://doi.org/10.1016/j.jenvrad.2018.05.003
Received 8 February 2018; Received in revised form 2 May 2018; Accepted 3 May 2018

about 20 °C. In general, the temperature in the nest depends on climate factors such as solar radiation, wind, temperature and humidity in the air and in the soil, but also the ants' population density and size of the anthill are of importance (Coenen-Stass et al., 1980).

Ants act as forest engineers and interaction occurs with different organisms, from fungi and bacteria to vertebrates and vascular plants. They can live in symbiosis with certain species and as parasites on others (Lach et al., 2010). Both the soil of the colony and the land around could potentially be affected by ant activities and the soil structure and its chemical content may change. Ants that mix and redistribute soil can have the potential to redistribute radionuclides in the soil profile (Persson et al., 2007). In addition, ants can constitute a dietary route of transfer of radionuclides to higher taxa in the ecosystem. Several animals like bear (*Ursus arctos*) and badger (*Meles meles*) and some bird species such as cub (*Picus viridis*) and wryneck (*Jynx torquilla*) consume ants. In spring, ants are an important food (protein source) for bears coming out of hibernation (Douwes et al., 2012). Ants affect the forest ecosystem also as predators as they can collect large amounts, up to millions of insects from the canopy (Petal, 1978).

The aim of the present study was to investigate the transfer of ^{137}Cs from the Chernobyl fallout in a spruce and pine forest to ants (*Formica rufa*) and anthills. Accordingly, the activity concentrations of ^{137}Cs in ants and in different parts of a number of anthills in the affected areas were measured as well as the surrounding soil. Furthermore, multivariate statistical modelling using the software SIMCA 14 (https://umetrics.com/) was used to see how well the activity concentrations in the ants and anthills correlated with the deposition. In addition, a radiation dose assessment to ants and anthills was performed using the ERICA tool (Brown et al., 2016). Finally, activity concentrations of ^{40}K and ^{214}Pb were measured in a subsample of the collected material.

2. Materials and methods

2.1. Study site description

Two separate locations, called A and B, near the Hille Lake, north of Gävle, Sweden (Fig. 1) were selected for the investigation. The average annual temperature and annual mean precipitation was respectively 5.2 °C and 618 mm. Weather data is measured at weather station in Gävle (close to Hille) with a normal mean for 30 years 1961–1990, Alexandersson and Eggertsson-Karlström (2001). The areas around the Hille Lake were heavily contaminated after fallout from the Chernobyl accident in 1986 and have been investigated in several studies concerning the transport of radionuclides in soils and plants (Rosén et al., 1999; Vinichuk et al., 2004; Matisoff et al., 2011). Other studies performed in the area are on redistribution of radionuclides in wetland areas (Stark et al., 2006) and radiation doses to frogs (Stark et al., 2004; Stark and Pettersson, 2008).

The distance between the two study sites (A and B) is about one kilometer. Location A; Coordinates (N 60°43.90′- E 17°11.94′) (Land Survey, 2001) was on a forest hillside, facing agricultural fields and pastures to the east and to the north (Fig. 1). The soil is classified as moraine soil with plenty of boulders. The forest is dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), with intermixture of deciduous trees, primarily birch (*Betula alba*).

Location B; (N 60°43.98′ E 17°12.75′) (Land Survey, 2001) was right next to a dirt road that was bordered by boreal forests on both sides (Fig. 1). Similarly, to location A, this forest consisted mainly of coniferous pine and spruce with intermixture of some deciduous trees.

Seven anthills were investigated and all except one (A2) were active with ants. The distances between the anthills for site A (A1-A5) varied between 12 and 180 m and for site B (B1 and B2) 110 m. Anthill A2 was a dead anthill that was wet and some grass was growing on the top, contradictory to the active anthills. Some of the anthills were built around a tree stump. A few of the anthills also contained a lot of stones. Around some of the anthills grasses, lingonberry (*Vaccinium vitis-idaea*) and blueberry (*Vaccinium myrtillus*) bushes were growing.

2.2. Sampling

2.2.1. Anthills

In spring 2011, twenty-five years after the Chernobyl accident samples of anthills were collected at the two study locations A and B. The sampling was performed in late April, i.e. after the Fukushima accident in Japan. The measurements of air filters done by the National Defense Institute in Sweden after the Fukushima accident showed very low levels of deposited cesium in the environment, about 100–200 µBq ^{137}Cs per m^3 (SSM, 2018). At site A we sampled five, and at site B two anthills. The diameter and the height of the anthills were measured. The distances between the anthills were also measured, as mentioned above, (Table 1). At both locations, materials from the top (0–2 cm), the middle (20–25 cm) and the bottom (40–50 cm) of the anthill were collected with a small shovel. About 0.5 L of material was collected from each level of the anthill. At some locations (A3 and B1) samples were also collected at about 65 cm depth. The core material in the center of the anthill, mainly consisting of small and very dry pine and spruce branches, was collected as well. In the middle of some of the anthills (A1, B6, B7) there was a tree stump which also was sampled. In Table 1, all the sampled materials are described for each anthill.

We collected the different parts of the anthills because the ants deposit needles, resin and coarse materials at different places in the stack. Coarse material is often deposited in the middle of the stack while needles and resins are on the outside because it provides good protection from rain. Fine fragmented organic material is often on the bottom of the anthills in the dry parts (Lenoir, 2002). Different parts of anthill can differ in pH, nitrogen content and mineralization rate, but differences depend also on the location of the anthill. The chemical composition and biochemical processes are thus different in different parts of the anthill according to Lenoir et al. (2001).

2.2.2. Ant

From all the anthills the same species of ants (*Formica rufa*) were collected. Ants from each anthill were aspirated with a small vacuum cleaner (Fig. 2). The ants were put in 70 percent ethanol in the field (Lenoir et al., 2001). Ants from each anthill and from each layer were sampled. No repetitions were made at the time of sampling. In Table 1, the different amounts of collected samples are described.

2.2.3. Soils

Soil samples were taken near the anthills at three points on the forest slope at site A and in two points in the forest at site B. The forest soil samples were taken within a circle with a diameter of 5 m (Fig. 3). A soil auger with 10 cm depth and a diameter of 5.7 cm was used. The five core samples were pooled together and homogeneously mixed to one samples. Totally five soil samples, three from A and two from B, were measured. The ground where the soil samples were taken was undisturbed since the Chernobyl fallout.

2.3. Samples preparation

All the samples were stored at room temperature for one day before the sample preparation began. Both the anthill and the soil samples were homogenized before measurement. Anthill samples taken from the top layer (0–2 cm) were sieved with a 2-mm sieve, resulting in a finer and a coarser sample. The fine material (< 2 mm) contained organic material from the trees, needle from pine and spruce, and some soil particles. The coarser material had its origin from pine and spruce, consisted mainly of needles and small branches. All samples, from the layers 0–2 cm ($Y_{2coarse}$ and Y_{2fine}), 20–25 cm (Y_{25}), 40–50 cm (Y_{50}), 65 cm (Y_{65}) and core materials, tree stumps and ants, were dried in aluminum trays at 35 °C for 4 days. Living ants that were found in the