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Effects of radionuclide contamination on leaf litter decomposition in the Chernobyl exclusion zone

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HIGHLIGHTS

- The effects of radioactivity on ecosystem processes are largely unknown.
- Leaf litter decomposition was studied in Chernobyl exclusion zone.
- Litter mass loss increased with decomposer organisms' total dose rate.
- Ecosystem processes may recover faster from radioactive pollution than populations.

GRAPHICAL ABSTRACT

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ABSTRACT

The effects of radioactive contamination on ecosystem processes such as litter decomposition remain largely unknown. Because radionuclides accumulated in soil and plant biomass can be harmful for organisms, the functioning of ecosystems may be altered by radioactive contamination. Here, we tested the hypothesis that decomposition is impaired by increasing levels of radioactivity in the environment by exposing uncontaminated leaf litter from silver birch and black alder at (i) eleven distant forest sites differing in ambient radiation levels (0.22–15 μGy h^{-1}) and (ii) along a short distance gradient of radioactive contamination (1.2–29 μGy h^{-1}) within a single forest in the Chernobyl exclusion zone. In addition to measuring ambient external dose rates, we estimated the average total dose rates (ATDRs) absorbed by decomposers for an accurate estimate of dose-induced ecological consequences of radioactive pollution. Taking into account potential confounding factors (soil pH, moisture, texture, and organic carbon content), the results from the eleven distant forest sites, and from the single forest, showed increased litter mass loss with increasing ATDRs from 0.3 to 150 μGy h^{-1}. This unexpected result may be due to (i) overcompensation of decomposer organisms exposed to radionuclides leading to a higher decomposer abundance (hormetic effect), and/or (ii) from preferred feeding by decomposers on the uncontaminated leaf litter used for our experiment compared to locally produced, contaminated leaf litter. Our data

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indicate that radio-contamination of forest ecosystems over more than two decades does not necessarily have detrimental effects on organic matter decay. However, further studies are needed to unravel the underlying mechanisms of the results reported here, in order to draw firmer conclusions on how radio-contamination affects decomposition and associated ecosystem processes.

1. Introduction

The major nuclear accident at the Chernobyl Nuclear Power Plant (ChNPP) in 1986 led to a total release of fission products (ignoring inert radioactive gases) into the atmosphere estimated at about 14×10^{18} Bq (IAEA, 2006). This release and subsequent deposits resulted in a large-scale but heterogeneous radioactive contamination of territories according to the trajectories of the radioactive plume. The most affected natural and agricultural ecosystems are located within an area of about 4300 km^2 around the damaged power plant known as the Chernobyl exclusion zone (CEZ).

Numerous studies have investigated the effects of ionizing radiation on wildlife from subcellular to community levels around the ChNPP (e.g. Møller and Mousseau, 2006; Geras'kin et al., 2008, 2013). However, the consequences of increased ionizing radiation levels on ecosystem processes such as plant production, the degradation of dead organic matter, and elemental cycling have received very little attention so far. The only existing study evaluating the influence of radioactive contamination on plant litter decomposition in the CEZ and adjacent areas reported decreased rates of leaf litter decomposition, resulting in an increasing thickness of the litter layer with increasing levels of ambient radiation (Mousseau et al., 2014). These results suggest a slower turnover of organic matter in response to higher levels of radioactivity, possibly due to negative impacts on the decomposer community.

Leaf litter decomposition plays a major role in ecosystem carbon and nutrient cycling (Swift et al., 1979; Cadish and Giller, 1997). Nutrients released during litter decomposition are estimated to account for 68 to 87% of the total annual requirement of essential elements for forest plant growth (Waring and Schlesinger, 1985). Decomposition is driven by a vast diversity of soil organisms including microorganisms and detritivorous invertebrates (e.g. Bardgett, 2005; Gessner et al., 2010). Depending on the quantity and quality of radionuclides accumulated in soil and litter, the resulting absorbed radiological dose (or dose rate) by soil organisms during their entire life and across generations may drive direct and/or indirect changes in various biological and ecological processes, including leaf litter decomposition (Geras'kin et al., 2008; Zaitsev et al., 2014). Indeed, within 2 months after the Chernobyl accident, 90% of soil invertebrate species had perished at a distance of 2 to 7 km from the ChNPP (Krivolutsky, 2000). In the first year after the accident, the total abundance of soil invertebrates in the forest litter was 45% of that of a reference site (Krivolutsky, 1996). However, the soil mesofauna communities were almost completely restored in terms of abundance and diversity 2.5 years after the accident, with the exception of the most severely contaminated sites (Krivolutsky, 1996, 2000). In contrast, Maksimova (2002) reported a diminished density and biomass of Diplopoda in forests exhibiting high contamination levels in the Gomel region (Belarus), 30 km North-East from the ChNPP, compared to control areas between 1986 and 1996. Very little data has been reported on the impact of the Chernobyl nuclear catastrophe on soil microbial community structure or biomass. For example, Romanovskaya et al. (1998) showed that the abundance and diversity of cellulolytic, nitrifying, and sulphate-reducing bacteria were 1 or 2 orders of magnitude lower in contaminated soils within a 10 km zone around the ChNPP compared to control soils, 7 to 9 years after the accident. Moreover, fungal community data collected around the ChNPP between 1990 and 2005 indicated that the fungi species richness declined with increasing ambient radiation level (see Dighton et al., 2008 for a review). In contrast, Chapon et al. (2012) showed that soil contaminated with radionuclides in the CEZ, exhibiting ^{137}Cs activities ranging from 61 to 750 Bq g^{-1}, hosted a wide diversity of bacteria similar to that observed in nearby control soils with ^{137}Cs activities ranging from 0.35 to 1.5 Bq g^{-1}, 25 years after the nuclear accident, suggesting recovery of bacterial communities.

Data on the consequences of radioactive contamination on soil organisms being scarce, it is presently difficult to predict how decomposition as a key process of ecosystem functioning may be affected by radionuclides in the environment. In the present study, we investigated the effects of radionuclide contamination in the CEZ on the decomposition of leaf litter from two tree species, silver birch (*Betula pendula*) and black alder (*Alnus glutinosa*) that are both highly abundant in the forests of the CEZ. The forested area has actually increased considerably since the establishment of the CEZ. Only 15 years after the nuclear disaster and the evacuation of residents, the forested area covered 70% of the total CEZ compared to 53% before the nuclear disaster (IAEA, 2001). Much of this forested area is covered by the early successional species silver birch and black alder. We exposed leaf litter collected in uncontaminated sites from uncontaminated trees to different levels of soil radioactive contamination. In addition, we estimated the average total dose rates (ATDRs) absorbed by decomposer communities based on soil radioactivity measurements. We hypothesized that leaf litter mass-loss decreases with increasing ATDRs, due to an impact on the decomposer communities.

2. Materials and methods

2.1. Study sites

A total of 11 deciduous forest sites were selected within the Chernobyl exclusion zone (CEZ; see materials and methods in the Supplementary text for detailed description) with distances among sites ranging between 1 and 50 km (=sites 1 to 11; Fig. 1). The dominant tree species at all sites were silver birch and black alder. The sites were chosen based on a similar vegetation cover and a gradient of ambient dose rates (Table 1). We established a second gradient of soil contamination along a short distance transect (site T, Fig. 1) within one single forest (approximately 300 m between two successive sampling points), in order to further reduce the variability of potential environmental confounding variables such as vegetation cover or soil characteristics (Fig. 1). This second gradient covered a range of radioactive contamination similar to the first gradient, with a total of 6 sampling points (A, B, C, D, E, and F; Table 2). The dominant tree species at this site T were scots pine (*Pinus sylvestris*), sessile oak (*Quercus petraea*), and European hornbeam (*Carpinus betulus*), with sweet cherry (*Prunus avium*) and silver birch at lower abundances.

2.2. Leaf litter decomposition experiment

In October 2010, leaf litters of silver birch and black alder were collected outside the CEZ, near Slavutych town (i.e. 55 km East from Chernobyl) in uncontaminated sites. The leaves were collected at the time of abscission by shaking numerous trees and intercepting falling leaf on sheets of fabric (3×4 m). Leaves were dried at 35 °C during 72 h, and stored at 20–25 °C until use. They were thoroughly mixed within species, after the selection of only clean and intact leaves.

At the eleven different forest sites and at site T, custom-made microcosms and litter bags with leaf litter were installed, respectively. Both