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Reduced colonization by soil invertebrates to irradiated decomposing wood in Chernobyl

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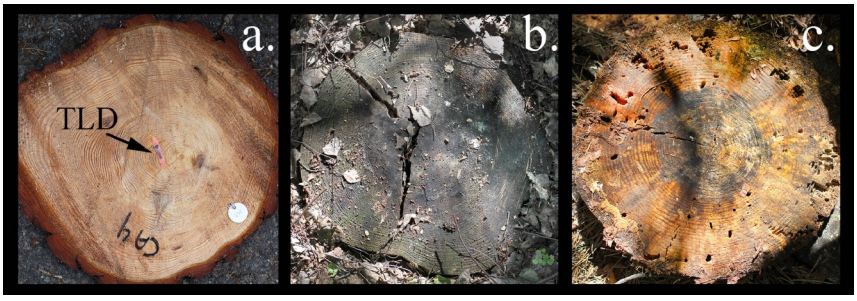
HIGHLIGHTS

- Wood quality and ambient radiation were used to test for deficient defenses against decomposers.
- Abundance of soil invertebrates extracted with mustard powder decreased with ambient radiation.
- There were more soil invertebrates under uncontaminated than contaminated wood.
- There was a temporal increase in abundance of soil invertebrates under wood slices.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil is inhabited by a range of microbes, invertebrates and vertebrates that disintegrate and decompose dead wood and leaf litter. These communities can be perturbed by ionizing radiation from natural radiation sources or from radiation originating from nuclear accidents such as those at Chernobyl, Fukushima and Three Mile Island. We used experimental manipulations of wood quality due to differences in exposure to ionizing radiation among tree trunks and ambient radiation levels of the soil to test the hypothesis that radioactively contaminated wood would result in a negative correlation between the abundance of soil invertebrates colonizing slices of wood and level of radioactive contamination. We extracted soil invertebrates underneath decomposing wood using mustard powder diluted in water. The abundance of soil invertebrates extracted was highly repeatable at study sites and decreased with increasing ambient radiation and total dose measured with thermoluminescent dosimeters (TLDs). Four 10 cm thick slices of ca. 70-year old Scots pines (*Pinus sylvestris*) were deposited at 20 sites and the invertebrate taxa and their colonization and their abundance was assessed annually during 2014–2017. There were more soil invertebrates under uncontaminated than contaminated slices of wood. In addition, there were more soil invertebrates in areas with less ambient radioactivity, and there was an interaction effect between contamination of wood and ambient radiation implying that the role of contamination differed among slices. Finally, there was an increase in the abundance of soil invertebrates under wood slices during 2013–2017 implying that the abundance of soil invertebrates increased over time. These findings imply that the abundance of soil animals colonizing wood slices was dependent on background radiation, radioactive contamination of wood and the interaction between contamination of wood and ambient radiation.

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1. Introduction

There are extensive studies of the effects of ionizing radiation on numerous organisms with birds being particularly well documented, even in naturally contaminated areas (Møller and Mousseau, 2013a). In contrast, there are few studies investigating the effects of radiation on soil microorganisms and invertebrates despite these playing important roles in decomposition and hence in ecosystem functioning (Mousseau et al., 2014; Bonzom et al., 2016). This situation is unfortunate because ecological processes in the soil play important roles at other trophic levels and hence for the processes involved in the functioning of ecosystems (e.g. Bardgett, 2005).

If decomposers are eliminated or reduced in abundance by ionizing radiation, this can have a significant impact on the rate of disappearance of organic matter and hence for the availability of nutrients for plants. Decomposition is an important ecological process that accounts for the recycling of organic matter, and it plays an important role in carbon and nutrient cycling (Attiwill and Adams, 1993; Bardgett, 2005). Mousseau et al. (2014) performed a decomposition experiment using uncontaminated leaf litter from four species of trees that were deposited in litter bags at sites at Chernobyl differing in levels of ambient radiation. The experiment showed that there was clear evidence of reduced decomposition in areas with higher levels of ionizing radiation, and that was the case both for decomposition due to microbial activity and decomposition due to soil invertebrates and vertebrates. Subsequently, Bonzom et al. (2016) conducted a decomposition experiment with litter bags containing uncontaminated leaf litter from two species of trees along a radiation gradient. They found higher loss rates of leaf litter in areas with higher levels of ambient radiation, suggesting that there was a positive effect of radioactive contamination on decomposition rates. This finding was counterintuitive and contrary to the findings of Mousseau et al. (2014).

Immediately following the Chernobyl disaster of 1986, the abundance, diversity and reproductive rates of soil invertebrates were markedly reduced in the Chernobyl Exclusion Zone and these effects were long-lasting and geographically extensive with the effects clearly visible for many years after the accident (Krivolutsky and Pokarzhevsky, 1992; Victorov, 1993; Zymenko et al., 1995; Krivolutsky et al., 1999; Maksimova, 2005). Indeed, recent investigations of the abundance of invertebrates on the soil surface using pitfall traps revealed that there were depressed abundances of beetles, Collembola, wasps and other insects in the most contaminated areas (Bezrukov et al., 2015). Thus ionizing radiation may have effects that affect interspecific interactions and even communities of organisms (Møller and Mousseau, 2011, 2013a,b; Møller et al., 2012, 2015a, b).

Reduced or even complete lack of decomposition has had strong effects on the accumulation of litter and wood, and the cessation of forestry in large areas of the Chernobyl Exclusion Zone has given rise to extensive accumulation of organic matter in forests. Indeed, there is a significant increase in the thickness of the forest floor from 4 cm in uncontaminated control sites to >16 cm in the most contaminated areas (Mousseau et al., 2014). Accumulation of organic material has been associated with extensive forest fires in Chernobyl and Fukushima (Evangeliou et al., 2014, 2015). In fact, fire has caused large amounts of radionuclides to be re-suspended into the atmosphere and transported away from Chernobyl with potentially negative impacts on health of humans and other organisms (see Evangeliou et al., 2016 for dose estimates). Whether there are effects of such fires on the abundance and the distribution of soil invertebrates is still an open question.

The objectives of this study were to (1) collect reliable information on the abundance of soil invertebrates and other organisms living on the surface of the soil in relation to ambient radioactivity, and (2) assess the impacts of a suite of invertebrates on wood decomposition after trees fall (e.g. following a fire or senescent death), while manipulating contamination levels of wood.

2. Materials and methods

We quantified the taxa and the number of soil invertebrates under standardized pieces of wood lying on the forest floor. For this, we cut down four large Scots pine trees (*Pinus sylvestris*) that were ca. 70 years old according to counts of growth rings. Two trees were from highly contaminated areas (ca. 50 μSv/h) in the Chernobyl Exclusion Zone while two others were from uncontaminated sites (ca. 0.1 μSv/h). These two categories are equivalent of ca. Cesium 137 activity of ca. 20 Bq/kg and ca. 30,000 Bq/kg, respectively (Mousseau et al., 2013, Fig. 2). We produced 80 ca. 10 cm thick slices (Fig. 1) that were placed in quadruplets on the soil surface in June 2014 with a numbered id tag and a thermo-luminescent radiometer (TLD) attached to measure total accumulated dose during a period of 1 year. These slices were subsequently turned over in August 2014 and then once a year in May–June 2015, 2016 and 2017, and the total number of soil invertebrates was recorded under each tree slice until there were no more animals moving (about 5 min). Arkhipov et al. (1994) have shown that pine stands at Chernobyl are affected by level of background radiation, and Mousseau et al. (2013) have shown that tree rings at Chernobyl depend on the dose level of wood.

2.1. Study sites

Animal diversity and abundance and wood decomposition were studied from May 2014 to June 2017 at 10 study sites (with two plots per site and hence a total of 8 slices) located within the Chernobyl Exclusion Zone or in areas adjacent on the southern and western borders of the zone. Sites were selected to ensure a wide range of ambient radiation levels and the locations are shown in Fig. 2. The study sites were within forests or successional forest stages of re-growth of farmland that are currently reverting to forests and are located in dry soil with little variation in elevation or climate.

2.2. Extraction of soil invertebrates with mustard flour

We used previously developed methods for efficiently extracting soil invertebrates (Högger, 1993; Valckx et al., 2011). We used a concentration of 100 g mustard powder (Frontier Natural Products, Co-Op, Norway, IA, USA) per liter of water because this substance has been shown to efficiently extract earthworms and other soil invertebrates (Högger, 1993; Valckx et al., 2011) and is significantly safer to transport and handle than formalin. We used 5 l of this mixture for extraction from 1 square meter of surface area that had been cleared of vegetation to facilitate detection and counts of all soil invertebrates. We had two such 1 m^2 square quadrats at each of the 16 study sites, or in total, 32 quadrats.

2.3. Making wood slices and using these for counting soil invertebrates

We cut the base of the trunks into 10 cm slices with a chain saw (Fig. 1). We placed four of these 10 cm slices from the two different, contaminated and the two different, uncontaminated pines in duplicate at each of the 10 randomly chosen sites that varied in ambient radiation level from 0.10 to 189.7 μSv/h. The distance between these slice quadruplets was a maximum of 50 cm between the centers of any two slices while the distance between replicate locations within a site varied between 100 and 200 m for a total of eight slices per site.