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Short Communication

The role of litterfall in transferring Fukushima-derived radiocesium to a coniferous forest floor

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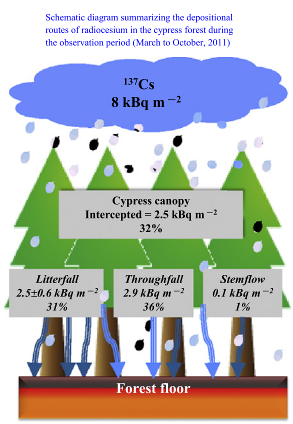
HIGHLIGHTS

- Fukushima-derived radiocesium deposition in a coniferous forest was explored.
- Approximately 68% of the radiocesium was deposited onto the forest floor.
- The ecological half-life of the radiocesium in the forest canopy was 180 days.
- The roles of hydrological pathways decreased over time.
- The litterfall route continued to deposit radiocesium onto the forest floor.

GRAPHICAL ABSTRACT



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ABSTRACT

The deposition of Fukushima-derived radiocesium via falling litter in a coniferous forest 180 km downwind immediately following the nuclear power plant accident was investigated. The litterfall contribution to the transfer of radiocesium from the forest canopy to the forest floor was determined, and this pathway was compared with hydrological pathways. The results demonstrated that during the observation period, a total of approximately 5.5 kBq m^{-2} of Fukushima-derived radiocesium was deposited on the forest floor through throughfall (53%), stemflow (2.3%) and litterfall (45%) routes. The data revealed that the contributions of hydrological pathways became less important as time passed. However, the litterfall route, which transferred approximately 31% (2.5 ± 0.6 kBq m^{-2}) of the local fallout within the observation period, continued depositing radiocesium onto the forest floor.

1. Introduction

Radiocesium (^{134}Cs: $t_{1/2} = 2.1$ years and ^{137}Cs: $t_{1/2} = 30.2$ years) derived from the Fukushima Dai-ichi Nuclear Power Plant (hereinafter FDNPP) accident has contaminated a wide range of environments,

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including forest areas in Fukushima and the neighboring prefectures (Koarashi et al., 2012). More than 70% of the Japanese archipelago is covered by forest, of which 60% is evergreen coniferous forest (Onda et al., 2010). This is also true in the highly contaminated area (≥1000 kBq m^{-2}), where 66% of the area is covered by forest (Hashimoto et al., 2012).

Previous studies have described the initial behavior of deposited radiocesium in the forests, including canopy interception and its subsequent processing, following the Chernobyl accident. For example, Bunzl et al. (1989) reported that weathering processes (rain wash and wind) transferred a large proportion of the radiocesium fallout to the forest floor, whereas the litterfall route transported only 7% in the first 600 days following the Chernobyl accident. However, most of these studies focused on the dry climate conditions of the regions affected by the Chernobyl accident, and studies are lacking for regions similar to those affected by the Fukushima reactor accident, which are in a more humid climate region and may experience different migration and distribution behaviors for radiocesium. Therefore, we hypothesized that radioanalysis in such an environment can provide new knowledge on the behavior of radiocesium in a terrestrial setting.

After the FDNPP accident, the initial behavior of radiocesium in the surrounding coniferous forest was investigated (Kato et al., 2012). Approximately 38% of the total local fallout was shown to have reached the cypress forest floor via hydrological pathways (throughfall and stemflow) during the five months following the accident. However, the role of litter in the transfer processes was overlooked, possibly because the contribution of litterfall was considered less important immediately after the fallout following the report of Bunzl et al. (1989). However, as indicated above, the environmental conditions surrounding Fukushima are quite different than those around Chernobyl, and hence to better understand and predict the behavior of radiocesium transfer, including the contribution of the litterfall deposition route is necessary.

Litterfall can contribute to the year-round deposition of contaminated canopy materials (leaves, branches, twigs, fruits, etc.) and to the prolonged radiocesium deposition onto the forest floor. It is therefore necessary to characterize the behavior of litterfall in order to understand radionuclide dynamics in terrestrial ecosystems and to assess radiation doses to human and non-human species. However, very little data are available on litterfall. Therefore, this study determined the total radiocesium transfer onto the forest floor via litterfall compared with that transferred via hydrological routes immediately following the FDNPP accident.

2. Materials and methods

2.1. Study site

The study was conducted in a 30-year old Japanese cypress (*Chamaecyparis obtusa* Endl.) plantation forest stand located on Karasawayama (139°44′ E; 36°23′ N), in the Tochigi prefecture of central Japan (Fig. 1). Japanese cypress is one of the dominant evergreen coniferous trees that covers most infertile upper slopes. Its leaf longevity ranges from 2.4 to 3.4 years on the basis of two-year observation data (Miyamoto et al., 2013). However, this phenomenon is highly variable due to its sensitivity to integrative factors, including daily aerodynamics, adverse conditions and altitude.

The study area is located 180 km downwind of the crippled FDNPP. The size of the catchment is 0.8 ha. Its climate is humid temperate, with a mean annual rainfall of 1259 mm and a mean annual temperature of 14.1 °C (based on 2010 and 2011 meteorological station data at the study site). The soil type can be classified as an Orthic cambisol. The estimated stand density is approximately 2500 trees per hectare. The forest floor under the closed canopy is composed of sparse understory plants (e.g., marlberry (*Ardisia japonica* (Thunb.) Blume) and herbs) and fallen leaf litter.

According to the MEXT (2011) aerial survey report, the plume that moved over the area including the study site deposited approximately 10 kBq m^{-2} of radiocesium. The low temperature at the time of the accident maintained the plume movement close to the ground surface, driven by the local wind. It is therefore assumed that the deposition primarily occurred through wet deposition (snow and rain droplets) on the forested mountains and hills of Japan's archipelago.

2.2. Litterfall sampling

To monitor the litterfall (*LF*) flux, four litter traps (nylon nets 1 m^2 in area) were suspended approximately 1 m above the ground in an almost uniformly spaced pattern to represent the study catchment (Fig. 1) ~7 months before the accident (installed on August 3, 2010). Following the FDNPP accident on 11 March 2011, the litter trap data were used to measure the radiocesium deposition due to litterfall. This provided an exceptional opportunity to measure litter-derived radiocesium deposition immediately following the accident. The litter traps were emptied approximately every month, and the radiocesium activities were determined (discussed below) as the litterfall mass weighted mean activity of the four litter traps (replications) to account for the spatial differences in *LF* mass during the observation period. The

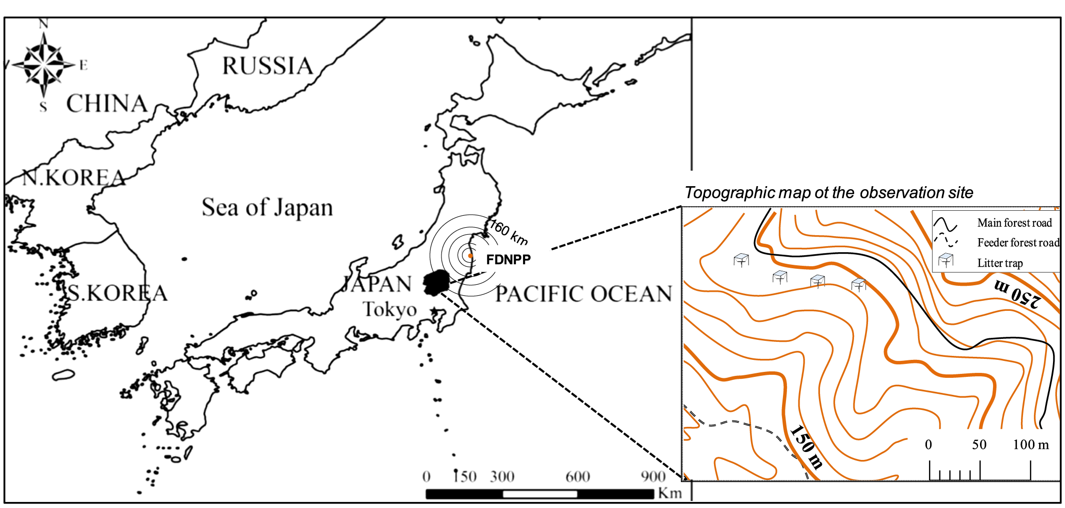

Fig. 1. Map of the study area and location of the litter traps.