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Radioactive and stable cesium isotope distributions and dynamics in Japanese cedar forests

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ABSTRACT

Dynamics of the Fukushima-derived radiocesium and distribution of the natural stable isotope ^{133}Cs in Japanese cedar (*Cryptomeria japonica* D. Don) forest ecosystems were studied during 2014–2016. For the experimental site in Yamakiya, Fukushima Prefecture, we present the redistribution of radiocesium among ecosystem compartments during the entire observation period, while the results obtained at another two experimental site were used to demonstrate similarity of the main trends in the Japanese forest ecosystems. Our observations at the Yamakiya site revealed significant redistribution of radiocesium between the ecosystem compartments during 2014–2016. During this same period radionuclide inventories in the aboveground tree biomass were relatively stable, however, radiocesium in forest litter decreased from 20 ± 11% of the total deposition in 2014 to 4.6 ± 2.7% in 2016. Radiocesium in the soil profile accumulated in the 5-cm topsoil layers. In 2016, more than 80% of the total radionuclide deposition in the ecosystem resided in the 5-cm topsoil layer.

The radiocesium distribution between the aboveground biomass compartments at Yamakiya during 2014–2016 was gradually approaching a quasi-equilibrium distribution with stable cesium. Strong correlations of radioactive and stable cesium isotope concentrations in all compartments of the ecosystem have not been reached yet. However, in some compartments the correlation is already strong. An increase of radiocesium concentrations in young foliage in 2016, compared to 2015, and an increase in 2015–2016 of the ^{137}Cs/^{133}Cs concentration ratio in the biomass compartments with strong correlations indicate an increase in root uptake of radiocesium from the soil profile. Mass balance of the radionuclide inventories, and accounting for radiocesium fluxes in litterfall, throughfall and stemflow, enabled a rough estimate of the annual radiocesium root uptake flux as 2 ± 1% of the total inventory in the ecosystem.

1. Introduction

On March 11th, 2011, 14:46 JST, the Great East Japan earthquake of magnitude 9.0, the worldwide fourth largest earthquake recorded in history, occurred off the Tohoku region of Japan. The tsunami that followed severely damaged Units 1–4 of Fukushima Daiichi Nuclear Power Plant (FDNPP). As a result, large amounts of radionuclides were released into the environment (Atomic Energy Society of Japan, 2015). The accident at the FDNPP was the second largest nuclear accident in human history, after the Chernobyl accident (IAEA, 2011). In contrast to the Chernobyl accident, the Fukushima release consisted mainly of volatile radionuclides, and the only long-lived radionuclide released in significant amounts was ^{137}Cs ($T_{1/2}$ 30.1 y). Estimated total releases to the environment are 19–24 PBq (Aoyama et al., 2016). This value is two orders of magnitude higher than the estimated release of the long-lived ^{90}Sr and 5-7 orders of magnitude higher than the release estimates of the long-lived ^{129}I and isotopes of Pu (Steinhauser et al., 2014). Accordingly, these radionuclides contribute little to the total radioactive deposition onto the Fukushima Prefecture. For example, ^{129}I deposition levels do not exceed some Bq m^{-2} along the north-western trace of the Fukushima release (Miyake et al., 2012). In general, the area contaminated by the Chernobyl accident is much larger (Steinhauser et al., 2014; Ohta, 2011); however, ^{137}Cs deposition values in the near zones of the two accidents are similar. Impacts to forest systems at Chernobyl and Fukushima were compared in a review paper (Yoschenko et al., 2017b).

The Fukushima Prefecture is dominated by forests cover (about 71%; Fukushima Prefecture, 2014). About 343,000 ha of the forests (~35%) are artificial plantations (MAFF, 2012). The main forestry species is *Cryptomeria japonica* D. Don (also called Japanese cedar, or

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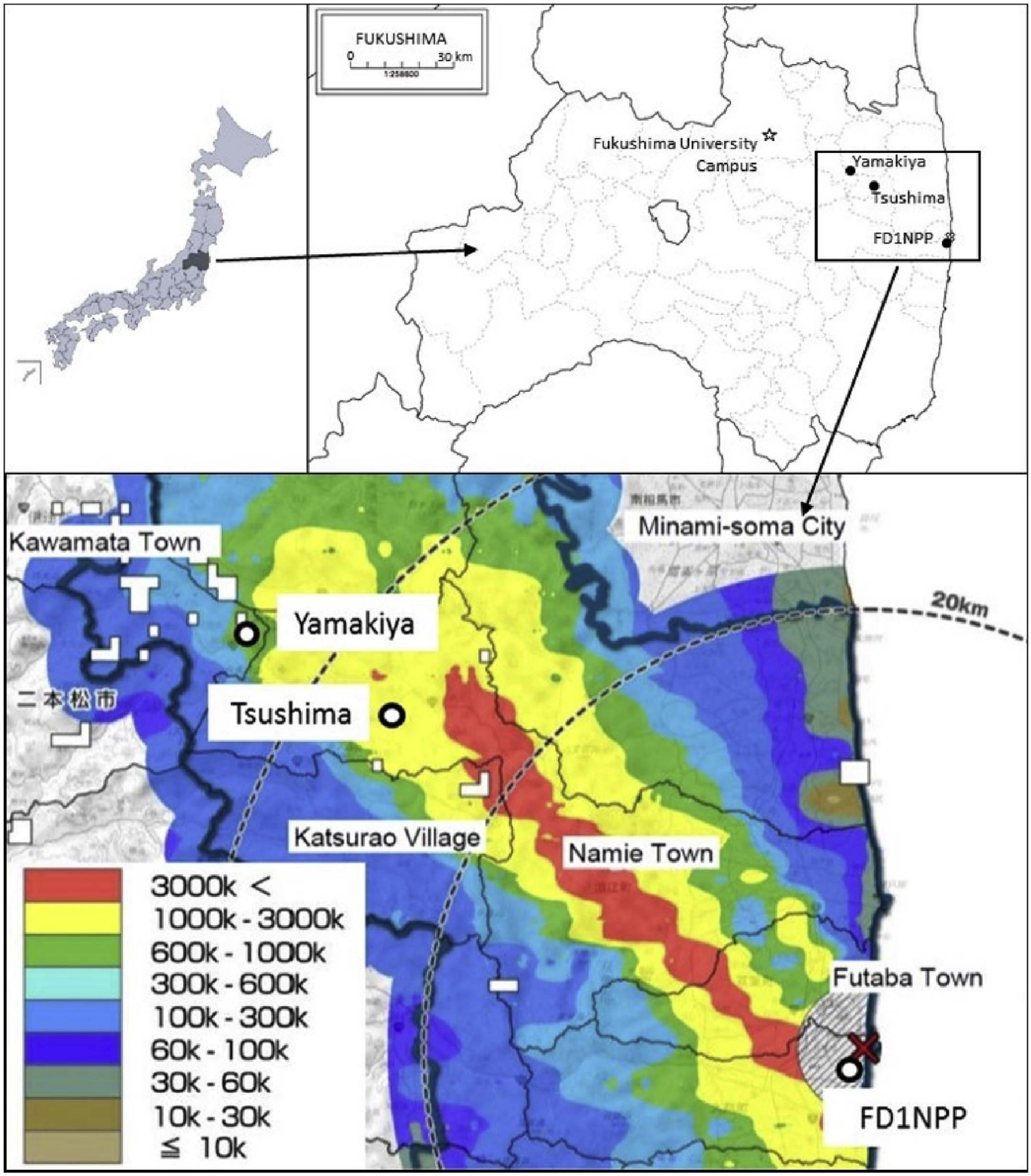

Fig. 1. Location of the experimental sites. Background maps: Nuclear Regulation Authority (2013) and http://www.freemap.jp/. Legend: ^{137}Cs deposition, Bq m^{-2} (as of March 11, 2013).

Sugi). Japanese cedar contributed 450,000 m^3 to the annual round-wood production of 655,000 m^3 in 2014 (MAFF, 2014).

Extensive decontamination measures are being conducted in agricultural and residential areas of Fukushima's evacuation zones. For some towns and villages the evacuation orders have already been lifted. However, large-scale decontamination of the forests is not planned; instead, decontamination activities in forests are aimed only to reduce air dose rates and thus are performed in limited areas adjacent to human settlements (Fukushima Prefecture, 2015; JAEA, 2015a,b; IAEA, 2015).

In absence of large-scale decontamination, a strategy should be developed for managing the radioactive contaminated Fukushima