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Short communication

Radiocesium contamination of the web spider *Nephila clavata* (Nephilidae: Arachnida) 1.5 years after the Fukushima Dai-ichi Nuclear Power Plant accident☆

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ABSTRACT

We measured the concentrations of radiocesium (^{134}Cs and ^{137}Cs) in a large web spider, *Nephila clavata* L. Koch (Nephilidae: Arachnida), collected at three sites at different distances from the Fukushima Dai-ichi Nuclear Power Plant about 1.5 y after the accident in March 2011. The radiocesium concentrations in spiders were highest in a streamside secondary forest 33 km northwest of the power plant: mean ± a standard deviation of 2.401 ± 1.197 Bq g^{-1} dry for ^{134}Cs and 3.955 ± 1.756 Bq g^{-1} dry for ^{137}Cs. In a hillside secondary forest 37 km northwest of the power plant, the mean concentrations of ^{134}Cs and ^{137}Cs were 0.825 ± 0.247 Bq g^{-1} dry and 1.470 ± 0.454 Bq g^{-1} dry, respectively. In a pine forest 62 km west of the power plant, very low radiocesium concentrations were detected, but in only a few individuals. The concentrations of ^{134}Cs and ^{137}Cs in spiders collected at each site tended to be correlated with the air radiation dose rate at each site. Since spiders are key components of food webs in forests, the high concentrations in this species at contaminated sites suggested that the radiocesium from the accident has transferred through food chains and reached to higher trophic level of the food chains.

1. Introduction

The catastrophic accident at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) triggered by the Great East Japan Earthquake and the tsunami that followed on 11 March 2011 caused serious radioactive release (IAEA, 2011). Immediately after the accident, large amounts of radionuclides were emitted to the open air. Radioactive contamination of the terrestrial environment then expanded rapidly over a wide area, presumably by wet and dry fallout. Large contaminated areas and hotspots of high radiation doses due to the fallout were found on the forest floors of the deciduous broadleaved and evergreen coniferous forests that occupy over 70% of the entire land area of Fukushima Prefecture (Fukushima Prefecture, 2012).

The ecological processes involving organisms in forest ecosystems work through two different types of food chain. The grazing food chain starts with living plants, passing through herbivorous insects and animals, and then reaching their predators. In contrast, the detrital food chain starts with dead organic matter, such as plant litter, on the forest floor; the chain then moves to the soil layer, where energy flows via detritus feeders and microbes into their predators. In the terrestrial compartment of forest ecosystems, spiders function not only as the most effective predators of arthropods in both food chains (Moulder and Reichle, 1972; Wise, 1993) but also as major prey, along with insect caterpillars, for predators at higher trophic levels, such as insectivorous birds (e.g., Mizutani and Hijii, 2002; Naef-Daenzer et al., 2000). In the detrital food chain there are two pathways to reach spiders. One is that from aquatic insects, such as plecopterans, caddis-flies, and dragonflies, emerging from the rivers and streams, where they feed on sedimentary plant litter or other aquatic insect larvae, and the other is that from detritivorous and fungivorous insects, such as chironomids, mycetophilids, and many other dipterans, emerging from the litter in the tree canopy and on the forest floor (Shimazaki and Miyashita, 2005; Yoshida and Hijii, 2005).

In a coniferous forest near a nuclear fuel reprocessing plant in England, concentrations of radionuclides (^{137}Cs, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am) were significantly higher in detritus feeders than in

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other feeding groups, and they varied seasonally depending on the dietary menu (Copplestone et al., 1999). In the case of the Chernobyl accident, radioactive fallout had different effects on litter faunae, depending on the distance from the nuclear power plant and on the time since the accident (e.g., Krivolutzkii and Pokarzhevskii, 1992). Therefore, radioactive contamination of the litter and upper-soil layers of the forests in Fukushima by radioactive fallout from the FDNPP accident may have some impact on predators through bioconcentration in the food chain. Here, we report the results of a preliminary survey of radiocesium (^{134}Cs with a half-life of 2.1 y and ^{137}Cs with a half-life of 30.1 y) contamination of spiders about 1.5 y after the accident as examples of predators working at a middle trophic level in the grazing and detrital food chains.

2. Materials and methods

2.1. Sampling sites

Collection of spiders and measurement of air radiation dose rates were performed on 21 and 22 October 2012, about 1.5 y (19 months) after the FDNPP accident, at two sites in the Yamakiya district of Kawamata Town, and at another site in Koriyama City, in Fukushima Prefecture (Fig. 1). The sites were (1) site PS, a streamside secondary forest dominated by broadleaved trees about 33 km northwest of the FDNPP, and faced southeastern on an abandoned pasture opening toward the FDNPP; (2) site ES, a hillside secondary forest on the north side of the Yamakiya Elementary School about 37 km northwest of the FDNPP; and (3) site KR, an experimental pine forest in the Fukushima Prefectural Forestry Research Center in Koriyama City, about 62 km west of the FDNPP. As controls, spider individuals of the same species were collected on 30 October 2012 from site CT, in a secondary forest on the main campus of Nagoya University, Nagoya, about 450 km in a straight line southwest of the FDNPP.

2.2. Collection of spiders

We collected female adults of *Nephila clavata* L. Koch (Nephilidae: Arachnida). It is one of the largest web spider species in Japan and lives in an orb web set about 1–2 m above the ground. *Nephila clavata* is univoltine, overwinters as eggs, disperses as juveniles in April to May, and grows through seven or eight ecdyses to its largest size in September to October. The female spins an egg sack containing 500–1500 eggs after mating on the orb web in late August to October. It deposits the sack on trees or shrubs in October to November, and its life cycle ends by early winter. Body size is about 20 mm in female adults but no more than 10 mm in male adults. The size variability among mature female adults is large and depends on the amount of prey arthropods consumed (Miyashita, 1992).

Spiders collected at each site were placed individually into 20-mL collection vials and brought to the laboratory at Nagoya University. After the wet mass of each individual had been weighed on a microbalance, all spider samples were dried in a convection oven (85 °C, 48 h); the dry mass was individually weighed in the same manner.

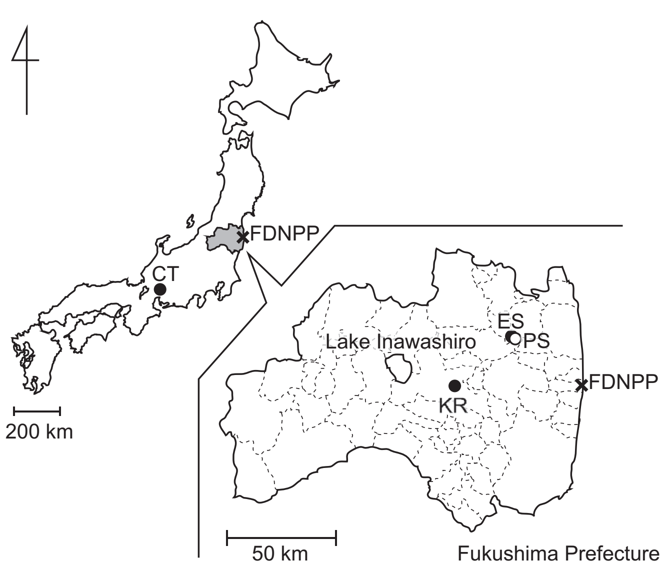

Fig. 1. A map of the sampling sites and the FDNPP. See Fukushima Prefecture (2012) for the results of measurement of air dose rate since March 2011 in Fukushima Prefecture.

2.3. Measurement of radiocesium concentrations of spiders and air radiation dose rates

After the measurement of spider dry mass, each body was put into a polyethylene tip with 5-mm-diameter zirconia beads and ground to powder with a bead-beater-type homogenizer. A composite sample was made by mixing two spiders, when each dry mass was under ca. 0.08 g. Concentration of radiocesium in the spider sample (Bq g^{-1} dry) was individually measured by a gamma spectrometer with a well-type germanium semiconductor detector (GWL-300-15-S, Seiko EG&G Ortec, Tokyo, Japan) for 1.6×10^4 to 3.5×10^5 s.

The counting efficiency of detector was calibrated using reference solution samples of ^{134}Cs (CZ010) and ^{137}Cs (CS010) obtained from Japan Radioisotope Association, Tokyo with the expanded uncertainty of 1.5% (the coverage factor $(k) = 2$). The radiocesium activities in samples were corrected for radioactive decay to the sampling date of the spiders. The detection limits of radiocesium

Table 1
Body-size traits and radiocesium contamination in spiders (mean ± standard deviation).

	Sites*			
	PS	ES	KR	CT
Body size (g)				
No. of spiders	8	11	22	12
Fresh mass	0.37 ± 0.19	0.34 ± 0.14	0.34 ± 0.26	0.59 ± 0.28
Dry mass	0.14 ± 0.08	0.12 ± 0.05	0.13 ± 0.10	0.19 ± 0.10
Dry/fresh ratio	0.36 ± 0.06	0.39 ± 0.09	0.36 ± 0.03	0.31 ± 0.04
Radioactivity[a] (Bq g^{-1} dry)				
No. of samples[b]	6	10	15	8
^{134}Cs	2.401 ± 1.197	0.875 ± 0.247	0.057 ($n = 1$)	N.D.
(Min–max)	1.217–4.415	0.437–1.258	–	–
CV[c]	0.50	0.28	–	–
^{137}Cs	3.955 ± 1.756	1.470 ± 0.454	0.040 ± 0.015 ($n = 3$)	N.D.
(Min–max)	2.072–6.819	0.828–2.307	0.027–0.057	–
CV[c]	0.44	0.31	–	–
Air radiation dose rate (μSv h^{-1})				
	4.41 ± 0.50	3.53 ± 0.41	1.09 ± 0.32	0.06 ± 0.01
CV[c]	0.11	0.12	0.29	0.17

*PS; 33 km northwest, ES; 37 km northwest, KR; 62 km west, CT; 450 km southwest of the FDNPP.
[a] Concentration of radiocesium was averaged with samples only for which radiocesium was detected.
[b] Several samples consisted of mixtures of small-size spiders (see Section 2.3 for details).
[c] CV is calculated with standard deviation/mean.