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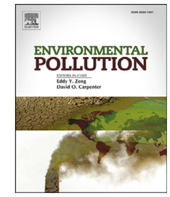

Radioactive contamination of nest materials of the Eurasian Tree Sparrow *Passer montanus* due to the Fukushima nuclear accident: The significance in the first year

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ABSTRACT

The 2011 Fukushima nuclear accident contaminated large areas of eastern and northeastern Japan, releasing vast amounts of radiation. Here we investigated radioactive contamination of the nest materials of the Eurasian Tree Sparrow *Passer montanus* from the breeding season of 2011 directly after the accident to the next breeding season of 2012 at two sites. In Tokyo (222 km southwest of the plant), ambient dose rates in the nestboxes were lower than those in Ibaraki (175 km southwest of the plant), where the levels of 2011 were higher than those of 2012. Further, the amount of radioactive Cs in each nest increased with the increase in nest weight, with a higher increment at Ibaraki than at Tokyo. These data suggested higher nest contamination levels in the breeding season directly after a nuclear accident than in later seasons, and an increment of nest contamination levels via nest materials of birds.

1. Introduction

On March 11, 2011, a 9.0 M earthquake struck off the east coast of Japan (38.10°N, 142.86°E, M 9.0 at 14:46:18 JST according to the Japan Meteorological Agency). It was one of the most powerful earthquakes ever recorded with modern monitoring equipment. It triggered massive tsunamis that severely damaged the Fukushima Daiichi nuclear power plant and caused it to discharge vast amounts of radioactive material into the atmosphere and ocean. Much of this radioactive material (e.g., radionuclides iodine-131, tellurium-129 m, and cesium (Cs) -134, Cs-136, and Cs-137) was deposited over large areas of eastern and northeastern Japan (Kinoshita et al., 2011; Yasunari et al., 2011).

There is growing evidence from studies on birds at Chernobyl that even low-level exposure to radiation can negatively affect partial albinism (Møller et al., 2007), blood titers of carotenoids and vitamins (Møller et al., 2005a) sperm abnormalities (Møller et al., 2005a), germline mutations (Ellegren et al., 1997), reproductive success (Møller et al., 2005b, 2008), and survival (Ellegren et al., 1997; Møller et al., 2007; Møller and, Mousseau, 2011; Møller et al., 2012). These effects have not only been recorded in birds but also in other taxa (see Møller and Mousseau, 2006, 2011; Mousseau and Møller, 2014 for reviews). Some studies performed in the Fukushima prefecture a few years after the catastrophe also reported effects of radiation on several taxa including insects, birds, and mammals (Hiyama et al., 2012; Ochiai et al., 2014; Murase et al., 2015).

Altricial birds, which require parental care for a period of time, build nests made of mud, grasses, twigs, moss, feathers, and spider webs, in which they incubate their eggs and raise their offspring (Hansell, 2000). In areas with high radioactive contamination, radionuclides may adhere to the surface of nest materials, elevating exposures of radiation to parents and their offspring (Bonisoli-Alquati et al., 2015).

In this study, we describe spatial and temporal changes in radioactive contamination of nest materials of the Eurasian Tree

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Sparrow *Passer montanus* from the breeding season of 2011 directly after the Fukushima nuclear accident to the following breeding season of 2012 in two regions in eastern Japan. In 2011 much of the radioactivity was likely to still be adherent to the external surfaces of vegetation such as annual plants at the time of nest building (i.e., at this short time after the accident the dominant contamination pathway unlikely to be root uptake). Thus we made three predictions. First, we predicted that levels of contamination in nestboxes would be higher in Ibaraki than in Tokyo because of a greater amount of fallout from the Fukushima nuclear accident on Ibaraki than on Tokyo (Yasunari et al., 2011). Second, radioactive contamination of nest materials would be higher in 2011 than in 2012, because the radioactive contaminants coating annual plants in 2011 would have been transferred to the soil by 2012. Finally, the amount of radioactive Cs in nests would be positively related to nest mass, because heavier nests are composed of more materials than light nests.

2. Methods

2.1. Study site and data collection

This study was conducted in Ibaraki Prefecture (175 km southwest of the Fukushima Daiichi nuclear power plant) from January to October 2011 and from January to May 2012, and in Tokyo (222 km from the power plant) from January to October 2011 and from January to August 2012.

We erected different numbers of wooden nestboxes at each site and in each year (Ibaraki: n = 70 in 2011, n = 61 in 2012; Tokyo: n = 36 in 2011, n = 36 in 2012). The nestboxes measured 19 × 20 × 30 cm (width × depth × height) with an entrance hole measuring 3.5 cm in diameter. The nestboxes at Ibaraki were placed on safety rails on the roofs of buildings or on tree trunks 2.5–3.5 m off the ground. In Tokyo, they were attached to tree trunks 2.5–3.5 m off the ground.

We measured γ radiation levels (μGy/h) 19 times at 10-s intervals over a 3-min period inside each nestbox and immediately repeated the process outside the nestbox at the same height using a GAMMA-SCOUT dosimeter (GAMMA-SCOUT GmbH & Co. KG, Schriesheim, Germany). We measured the radiation levels inside and outside 10 nestboxes on October 14, 2011, in Ibaraki; 15 nestboxes on 13–26 May, 2012 in Ibaraki; 7 nestboxes on October 1, 2011, in Tokyo; and 12 nestboxes on August 31, 2012, in Tokyo. All nestboxes contained active nests defined as nests containing eggs or nestlings. Subsequently, we weighed the nest materials of each nest (g-wet). Nest materials of 5 nestboxes were dried for 48 h at approximately 70 °C; the relationship between wet weight (g-wet) and dry weight (g-dry) of nest materials was strongly positively correlated (Spearman's $r = 1.0$, $P < 0.05$).

Nest materials at Ibaraki (n = 10) and Tokyo (n = 9) in 2012 were sampled homogenized, and analyzed by a germanium detector to obtain a γ-ray spectrum and to measure Cs activity concentrations (Bq/kg). Before analysis, nest materials were dried in the sun during the daytime, followed by drying with a warm current of air for 6 h using a drying machine, after which they were weighed (g-dry). The amount of Cs in the nestboxes was calculated using the formula:

$$\text{Amount of Cs in a nestbox (Bq/nest)} = \text{Cs activity concentration (Bq/g)} * \text{nest dry weight (g} - \text{dry)}$$

Table 1
Parameter estimates of the selected best GLM model according to ΔAIC (see Results). The model explaining the variation in ambient dose rate in nestboxes of Eurasian Tree Sparrows included three explanatory variables: year (2011, 2012), site (Ibaraki, Tokyo), and their interaction. Other variables (nest weight and other interactions) were not included in the best model.

Explanatory variables	Estimate	SE	*t*-value	*P*
Intercept	0.102	0.008	12.96	<0.001
Site_Ibaraki	0.071	0.011	6.75	<0.001
Year_2011	0.008	0.013	0.62	0.54
Site:Year	0.055	0.017	3.19	0.003

All data are expressed as Mean ± SD unless otherwise stated.

2.2. Statistics

We used paired *t*-test to compare ambient dose rate between the inside and the outside of the nestboxes in Tokyo and Ibaraki in 2011 and 2012. To compare the difference between 2011 and 2012 within a site, we used student *t*-test. Comparison in nest weight between the two sites in the two years was performed with the use of two-factor ANOVA based on Type II sums of squares (Bartlett's test: $df = 3$, $P = 0.75$). Nest weight or the difference of ambient dose rate between the inside and the outside of the nestboxes of the four groups (Tokyo in 2011, Tokyo in 2012, Ibaraki in 2011, and Ibaraki in 2012) were tested and confirmed for normality (One-sample Kolmogorov–Smirnov test).

We used generalized linear models (GLMs) with an identity link and a Gaussian error distribution to elucidate the factors affecting the dose rate (μGy/h) in nestboxes in the breeding seasons. We conducted model selection on the basis of Akaike's information criteria (AIC). Model comparisons were based on AIC differences (ΔAIC). We included six explanatory variables (year, site, nest weight, and these three interactions) in the initial model for the ambient dose rate in the nestboxes. We compared 17 models (generated from all combinations among the six explanatory variables and the null model) by ΔAIC. The dose rate in the nestboxes of the four groups (Tokyo in 2011, Tokyo in 2012, Ibaraki in 2011, and Ibaraki in 2012) were tested and confirmed for normality (One-sample Kolmogorov–Smirnov test).

We also used GLM with an identity link and Gaussian error distribution to examine the relationship between nest weight (g-dry) and the amounts of Cs in the nestboxes (Bq/nest) in 2012 in Tokyo and Ibaraki. We compared five models generated from combinations among the three explanatory variables (nest weight, site, and their interaction) in the initial model, and a null model based on ΔAIC (Burnham and Anderson, 2002). The amounts of Cs in nestboxes of the two groups at Tokyo and Ibaraki were tested and confirmed for normality (One-sample Kolmogorov–Smirnov test).

We used a computer application “R, version 3.1.2” (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Materials of Eurasian Tree Sparrows' nests, which were randomly selected in Tokyo (n = 3) and Ibarali (n = 3), consisted of dead herbaceous plants (89 ± 10%), twigs (5 ± 6%), dead leaves of trees (1 ± 1%), and other materials (5 ± 8%) – percentages by weight. Nest building in 2011 started earlier in Tokyo (March 18)