IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

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INFORMATION NOTE

Realistic dose reconstruction for non-human species to assess the ecological consequences of chronic exposure to ionizing radiation in the contaminated territories after the Fukushima accident

Several field studies dedicated to consequences of nuclear accidents on wildlife report significant deleterious effects for dose rates of ionising radiation estimated so low that their conclusions clearly challenge the basic knowledge in radiobiology.

On the basis of ecological data describing the bird community in the Fukushima area, a publication from IRSN in collaboration with two renowned ecologists highlights that a better dosimetric estimation reconciles in situ observed effects with scientific knowledge of dose-effect relationships.

IRSN has just published in collaboration with two world renowned ecologists Anders Møller (CNRS, laboratoire d'écologie, systématique et évolution, France) and Timothy Mousseau (University of South Carolina, USA) in *Scientific Reports* (NPG) a new analysis of the ecological dataset describing the abundance of birds in the Fukushima area. This dataset reports breeding bird censuses at 300 sampling sites visited once a year at the beginning of July during a 4-year period 2011-2014, after the Fukushima nuclear accident. The dataset is composed of specific abundances for 57 species of birds using the standardized point count census method, along with various environmental descriptors (*e.g.*, the time of day at the start of counts at each point, cloud cover, temperature, wind force, type of habitats). Absorbed dose rates were reconstructed for individual birds of each of the 57 species observed over 300 sites and during 4 years (2011-2014), by combining radionuclide measurements in soils (^{134}Cs, ^{137}Cs, ^{131}I) and models.

Radiological dose reconstruction for birds allows to take into account the spatial heterogeneity of radioactive deposits in the Fukushima area along with the influence of the species' mode of life on its exposure level.

Until this study, the deleterious effects on species diversity and abundance were linked to the ambient dose rate measured on observation sites, and as such were analyzed as a weakness by the scientific community of radioecologists. The reconstructed absorbed radiological dose or dose rate is likely the most appropriate variable reflecting the intensity of the radiological exposure and therefore using this metric ensures the scientific credibility of the outcoming relationships between absorbed doses and observed biological/ecological responses.

In the present study, a dose rate reconstruction work made it possible to take into account the external and internal radiation pathways, and the exposure characteristics of birds depending on their lifestyle. Thus, the reconstructed dose rates can be higher to a factor of 20 than the measured ambient radiation level using a hand-device. Moreover, for a given site, the reconstructed dose rates vary by a factor of 8 between the 57 species examined. Finally, for a given specie, reconstructed dose rates vary 44-fold among the 300 observation sites.

This clearly demonstrates the need to take into account these two factors (location and species) for dose reconstruction.

Comparing these reconstructed exposure levels for birds with knowledge on their relationships with potential induced effects as published by the International Commission of Radiation protection (ICRP, 2008), the study found that 90% of the 57 species constituting the observed bird community were likely chronically exposed at a dose rate that could potentially affect their reproductive success (**Figure 1**). This is consistent with conclusions published by Møller *et al*. (2015) regarding the link between the exposure level and the deleterious effects on bird abundance and species diversity.

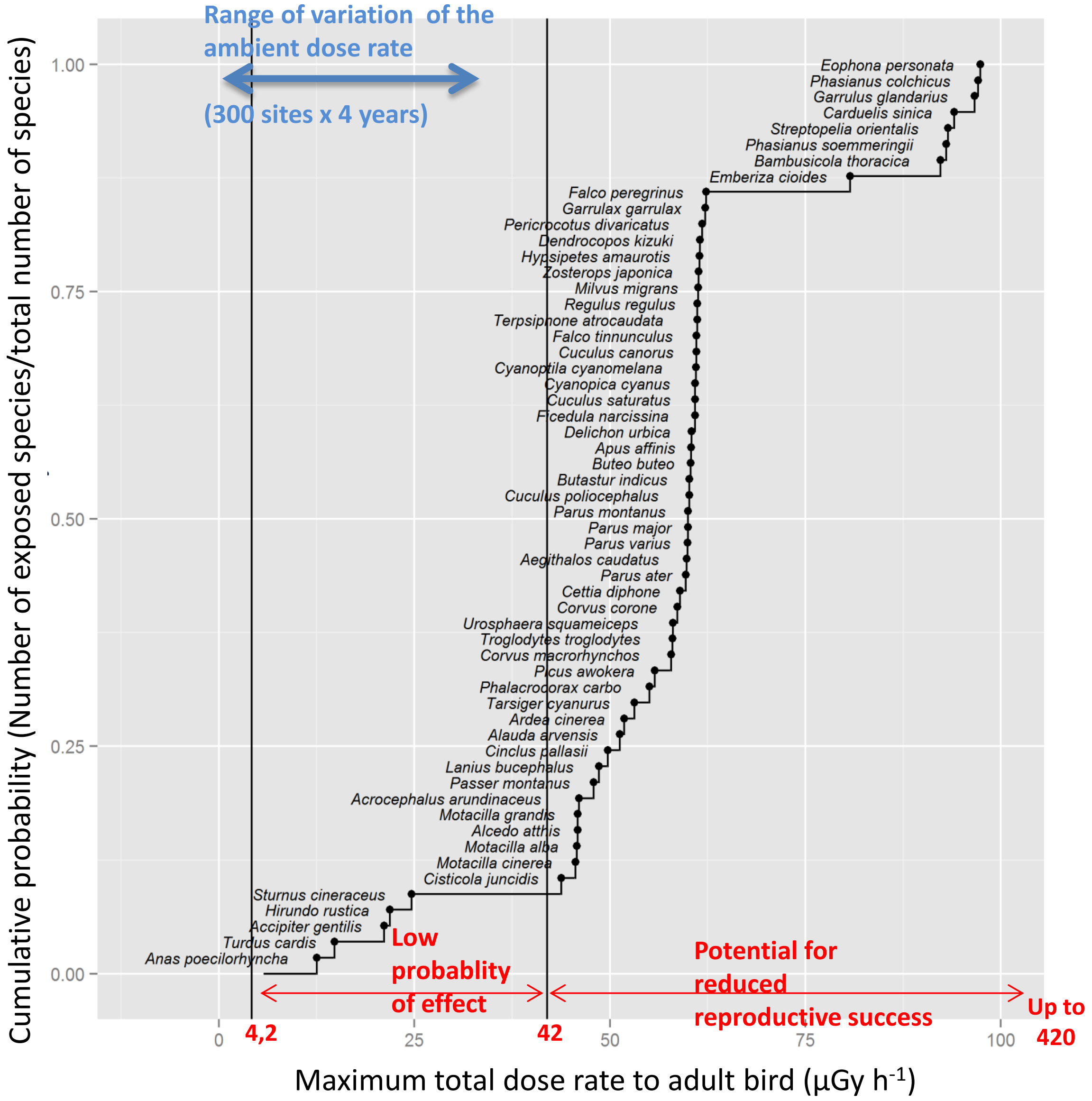

Figure 1- Simplified representation of the variation of the maximum exposure levels for adult birds (expressed in µGy/h) for the 57 species composing the bird community observed over 300 sites and 4 years (2011-2014). Comparison with the range of variation (in blue) of the ambient dose rate measured on sites and range of variation (in red) corresponding to various effects in birds published by ICRP (2008) (modified from Garnier-Laplace et al., Sci. Rep., on line).

Radiological dose reconstruction for birds reconciles outcomes of Fukushima regarding the deleterious effects observed on bird individual abundance with knowledge of dose-effect relationships.

The statistical analysis based on the reconstructed dose reveals the overall abundance of birds at Fukushima during 2011-2014 decreased significantly with increasing absorbed doses. More precisely, we were able to quantify a loss of 22% of the total number of individuals over the four-year post-accident period in the study area (see **Figure 2** where one can quantify a loss of 22% of individuals when the absorbed dose increases *e.g.*, from 10 to 100 mGy). On the basis of the present dataset and the statistical model we implemented to represent the full dataset while taking into account confounding variables describing environmental conditions, we estimated that a total dose of 550 mGy reduced by 50% the total number of birds in the study area over 2011-2014.

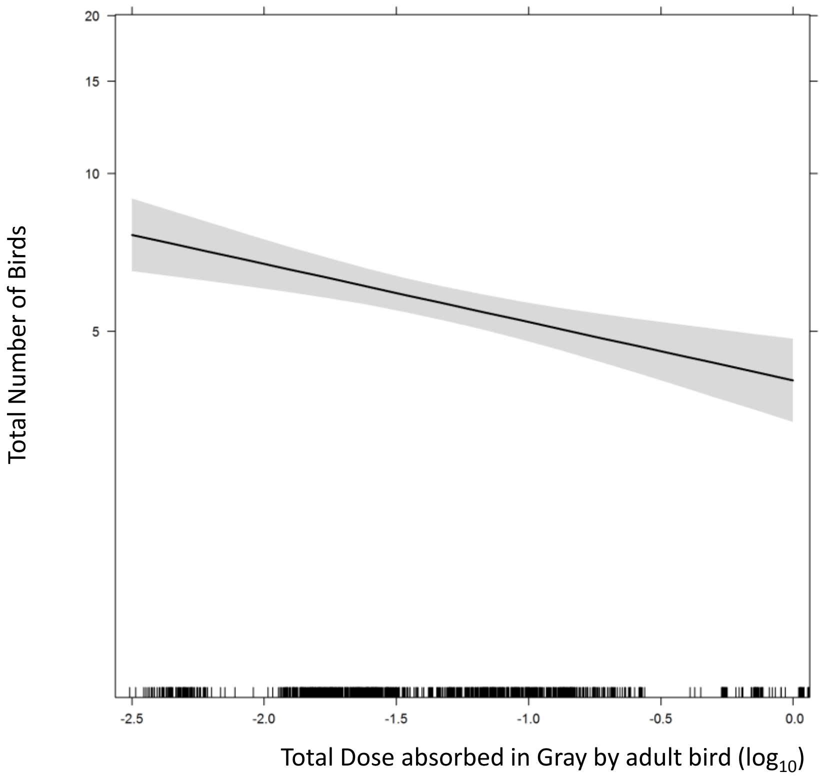

Figure 2- Total number of birds as a function of the total absorbed dose (log-10 transformed) predicted by the best statistical model obtained to represent the ecological dataset. The slope (partial regression coefficient of the model) is statistically highly significant. It allows to estimate the loss of the total number of birds according to the increase of the absorbed dose (*e.g.,* loss of 22% when the dose increases from 10 to 100 mGy) (modified from Garnier-Laplace et al., Sci. Rep., on line)

Combining dose reconstruction and advanced statistics to mathematically process ecological data set is promising to improve the understanding of ecological consequences associated to chronic low dose exposure situations.

To conclude, this paper highlights the need to combine dose reconstruction for non-human species of interest and statistical treatments to understand the key message from ecological datasets acquired in territories impacted by a nuclear accident. After the two major nuclear accidents which marked the history of civil electronuclear energy (Chernobyl, Ukraine, 1986 and Fukushima, Japan, 2011), *ca.* one hundred studies dealing with consequences on wildlife chronically exposed to ionising radiation and effects of "low doses" was published. These studies were carried out from year 2000 on wildlife in the Chernobyl Exclusion Zone and, from July 2011 within the 100-km area around the damaged Fukushima Daiichi nuclear power plant. Their goal was to assess the health consequences on populations of species composing the ecosystems impacted by the accidental releases of radioactive substances and, to identify/understand their cause, and to quantify the intensity of the resulting effects. Except a very few of them, these studies have a common feature: the estimation of the radiological dose absorbed by the organisms according to their exposure conditions is either missing or partial. IRSN is interested in analyzing these voluminous and precious datasets according to the methods presented in this publication. This will help to improve knowledge on ecological consequences of chronic exposure to ionising radiation, by analyzing dose-effect relationships acquired in radioactively contaminated area for ecologically relevant endpoints, i.e. those with potential consequences in terms of ecosystem structure and function and population demography. Any dose-effect relationship is complex to understand in the field since it can be modified due to the combination of radiotoxicity effects on growth rate/reproduction and of genetic diversity, competition, predation and changes driven by abiotic factors including other pollutants in addition to radionuclides

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