

# Recent Developments Concerning Impacts To Non-Human Biota in Fukushima

Timothy Mousseau  
University of South Carolina

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**OPEN** Morphological defects in native Japanese fir trees around the Fukushima Daiichi Nuclear Power Plant

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Naofumi Watanabe<sup>1</sup>, Satoru Ishikawa<sup>2</sup>, Masahide Kubota<sup>3</sup>, Akihito Hoshino<sup>4</sup>, Naofumi Kikuchi<sup>5</sup>, Kenichi Masuyama<sup>6</sup>, Masahiro Funai<sup>7</sup>, Ikuo Kameguchi<sup>8</sup>, Yuzo I. Yoshitake<sup>9</sup> & Satoshi Yoshida<sup>10</sup>

**A**



**B**



**C**



**Figure 3.** Representative morphological defects in Japanese fir trees. Arrowheads indicate the position of deleted leader shoot. (A) normal tree (S3), (B) defected tree (vertical forking, S1), (C) defected tree (horizontal forking, S2).

## Tree rings reveal extent of exposure to ionizing radiation in Scots pine *Pinus sylvestris*

Timothy A. Mousseau · Shane M. Welch · Igor Chizhevsky · Oleg Bondarenko · Gennadi Milinevsky · David J. Tedeschi · Andrea Bonisoli-Alquati · Anders Pape Møller

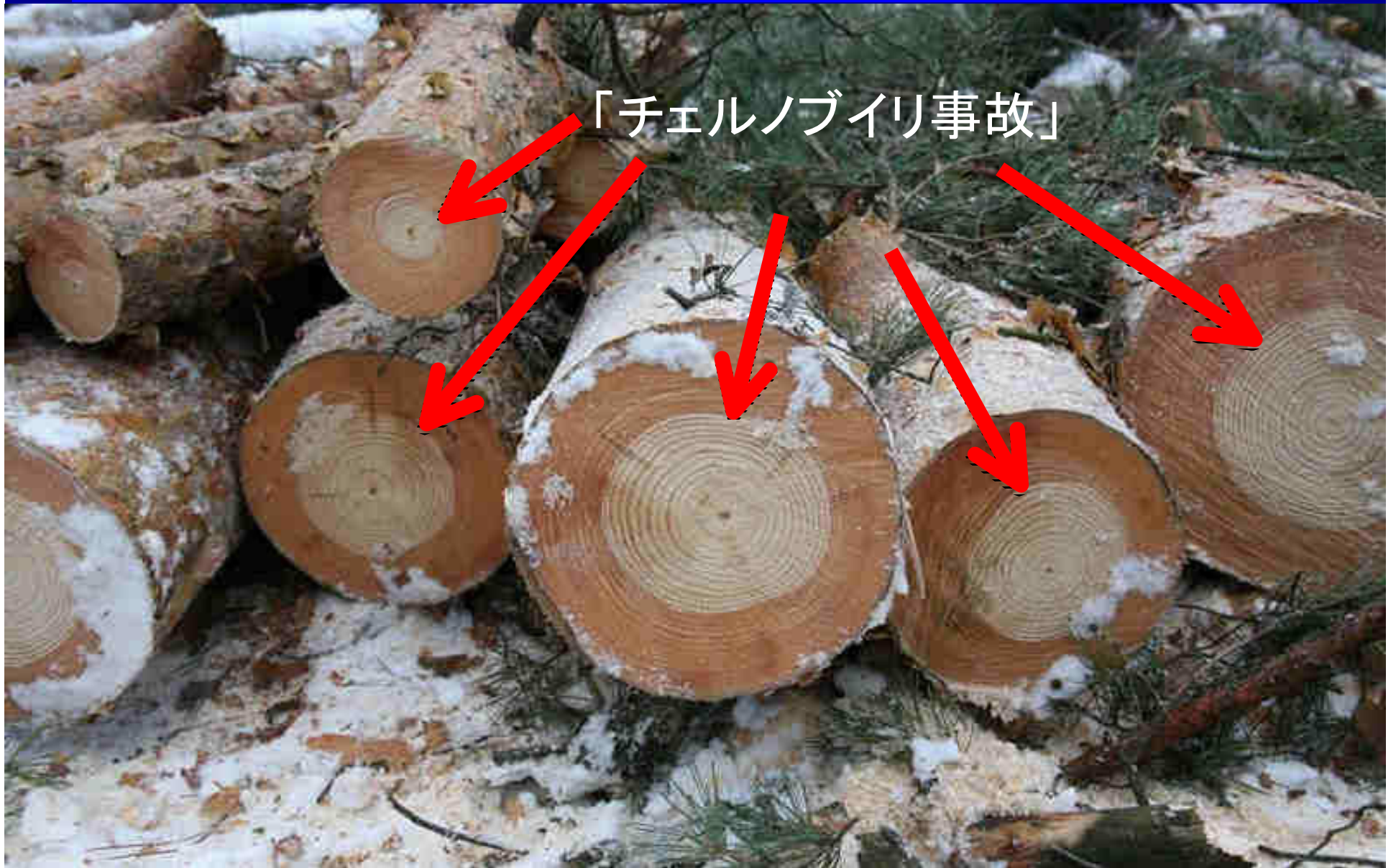
Received: 14 December 2012 / Revised: 12 April 2013 / Accepted: 30 May 2013  
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**Abstract** Tree growth has been hypothesized to provide a reliable indicator of the state of the external environment. Elevated levels of background ionizing radiation may impair growth trajectories of trees by reducing the annual

drought or their interactions with background radiation. Elevated temperatures suppressed individual growth rates in particular years. Finally, the negative effects of radioactive contaminants were particularly pronounced in

# 放射線と樹木の生長

「チェルノブイリ事故」



# Scots Pine Forest - “Normal”



## Abnormal Scots pine trees (*Pinus sylvestris*) from Chernobyl.



Mousseau, T.A., S.M. Welch, I. Chizhevsky, O. Bondarenko, G. Milinevsky, D. Tedeschi, A. Bonisoli-Alquati, and Møller, A.P., 2013. Tree rings reveal extent of exposure to radiation in Scots pine, *Pinus sylvestris*. *Trees – Structure and Function*, DOI 10.1007/s00468-013-0891-z

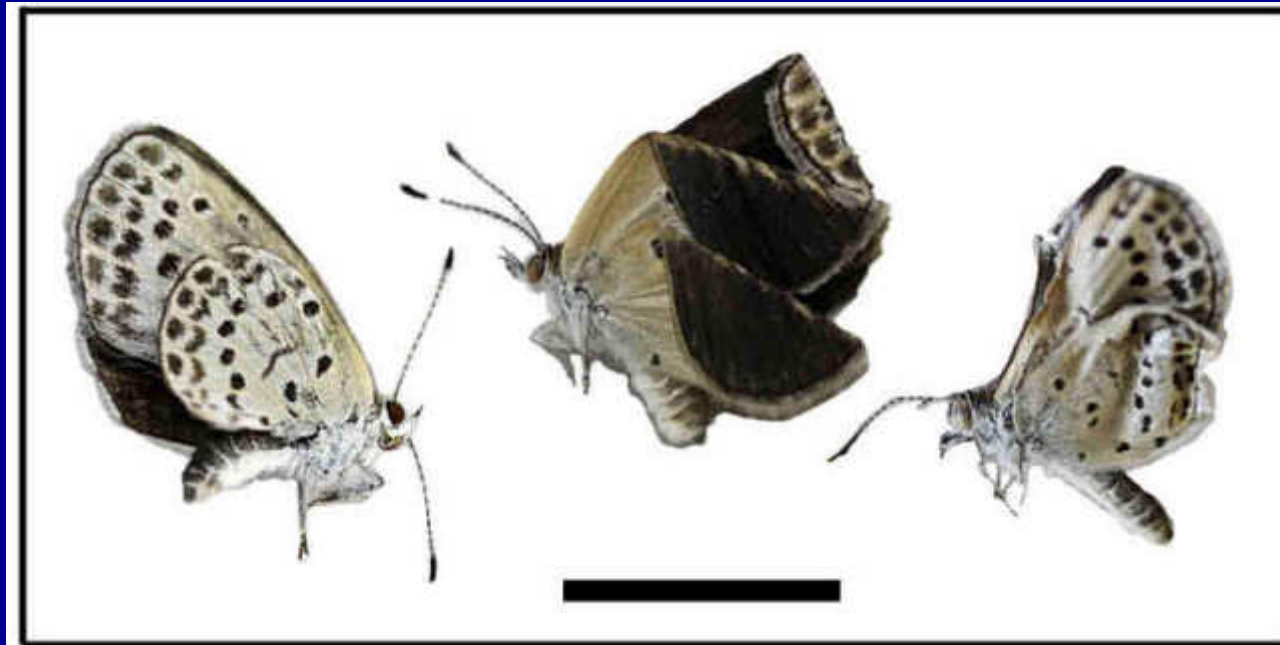
Chernobyl Pines - T.A. Mousseau (i) 2012



# The biological impacts of the Fukushima nuclear accident on the pale grass blue butterfly

SUBJECT AREAS:  
ENVIRONMENTAL  
SCIENCES  
ECOLOGY  
BIODIVERSITY

Atsuki Hiyama<sup>1\*</sup>, Chiyo Nohara<sup>1\*</sup>, Seira Kinjo<sup>1</sup>, Wataru Taira<sup>1</sup>, Shinichi Gima<sup>2</sup>, Akira Tanahara<sup>2</sup>  
& Joji M. Otaki<sup>1</sup>



# Firebug

*Pyrrhocoris apterus*

*"Facemask Bug"*





# Mutant Firebugs from Chernobyl



Mousseau & Møller, Chernobyl Firebugs (c) April 2011

J Ornithol  
DOI 10.1007/s10336-015-1173-x

REVIEW

## Ecological differences in response of bird species to radioactivity from Chernobyl and Fukushima

A. P. Møller · T. A. Mousseau · I. Nishiumi · K. Ueda

SCIENTIFIC  
REPORTS



OPEN

## Abundance and genetic damage of barn swallows from Fukushima

SUBJECT AREAS:  
ECOLOGICAL  
EPIDEMIOLOGY  
ECOPHYSIOLOGY

A. Bonisoli-Alquati<sup>1</sup>, K. Koyama<sup>2</sup>, D. J. Tedeschi<sup>3</sup>, W. Kitamura<sup>4</sup>, H. Sukuizi<sup>5</sup>, S. Ostermiller<sup>1</sup>, E. Arai<sup>6</sup>, A. P. Møller<sup>7</sup> & T. A. Mousseau<sup>1</sup>

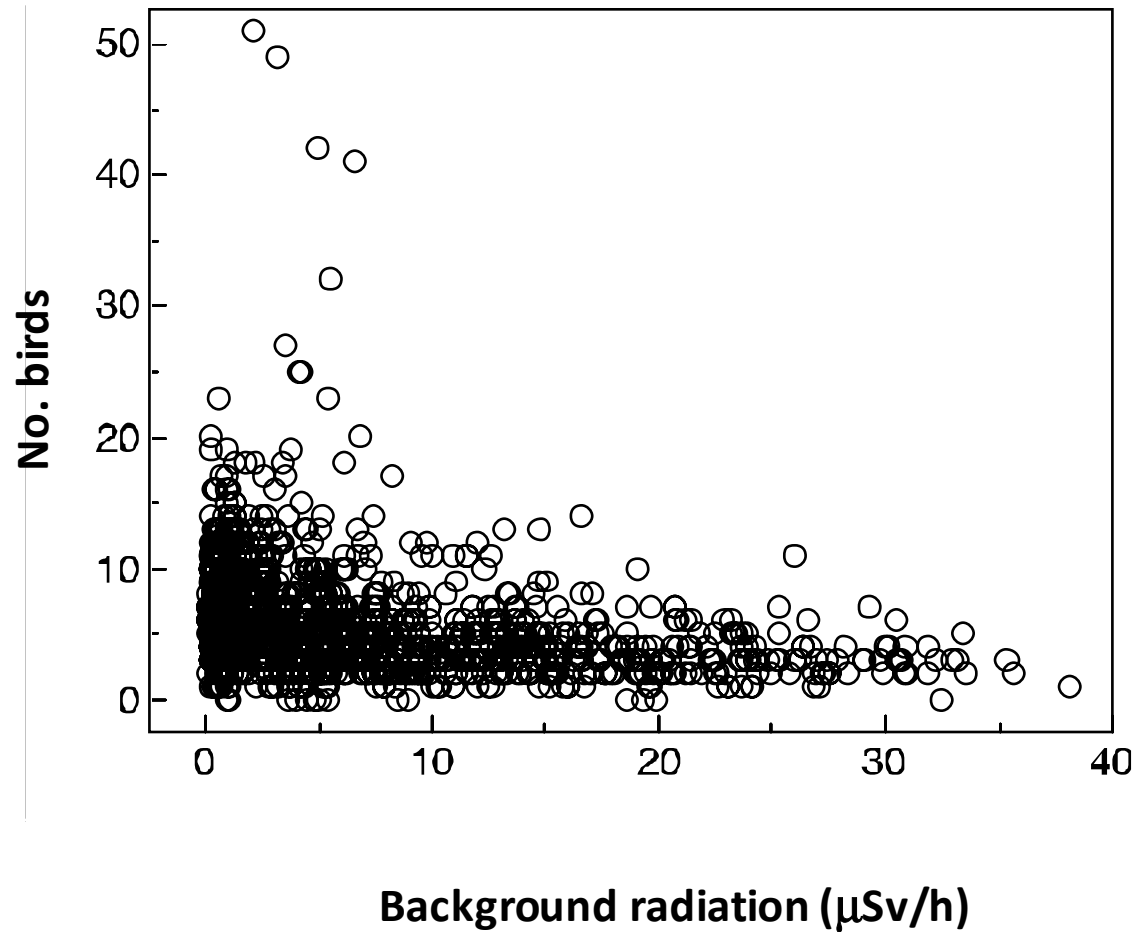
J Ornithol  
DOI 10.1007/s10336-015-1197-2

REVIEW

## Cumulative effects of radioactivity from Fukushima on the abundance and biodiversity of birds

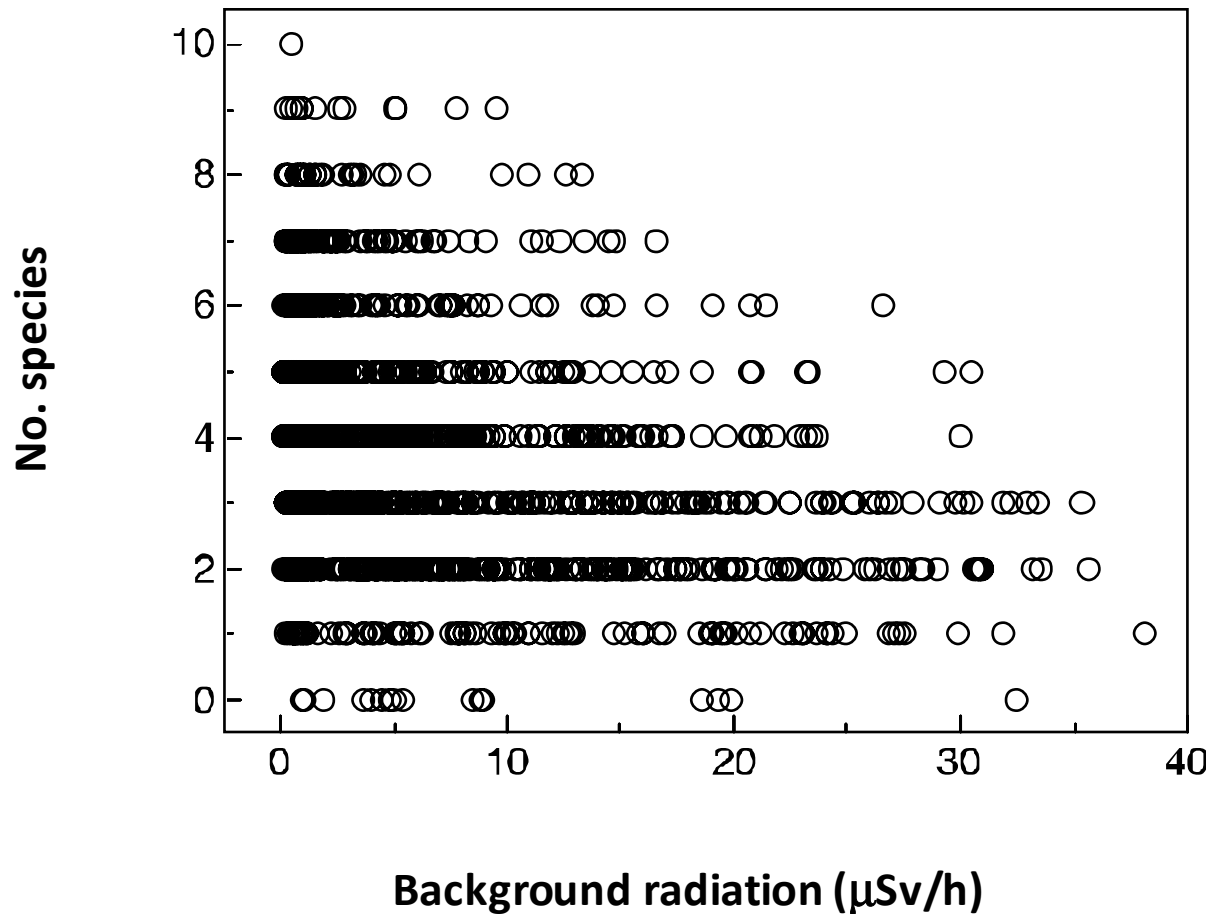
A. P. Møller<sup>1</sup> · I. Nishiumi<sup>2</sup> · T. A. Mousseau<sup>3,4</sup>

# Abundance and radiation – Fukushima Birds 2011-14



$$\chi^2 = 241.93, P < 0.0001$$

# Species richness and radiation - Fukushima Birds 2011-14



$\chi^2 = 100.30, P < 0.0001$



# SCIENTIFIC REPORTS



OPEN

## Radiological dose reconstruction for birds reconciles outcomes of Fukushima with knowledge of dose-effect relationships

Received: 07 July 2015

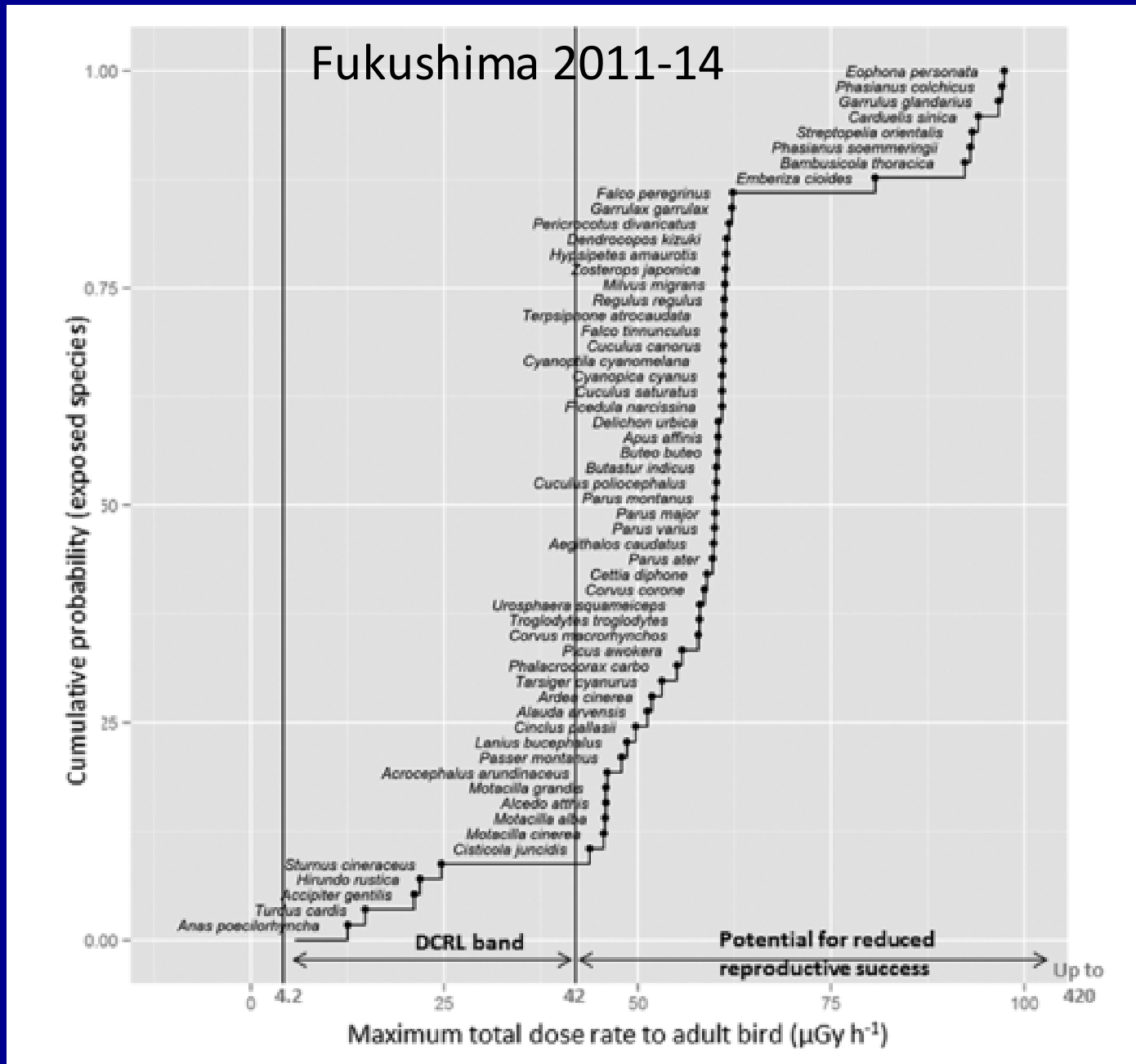
Accepted: 15 October 2015

Published: xx xx xxx

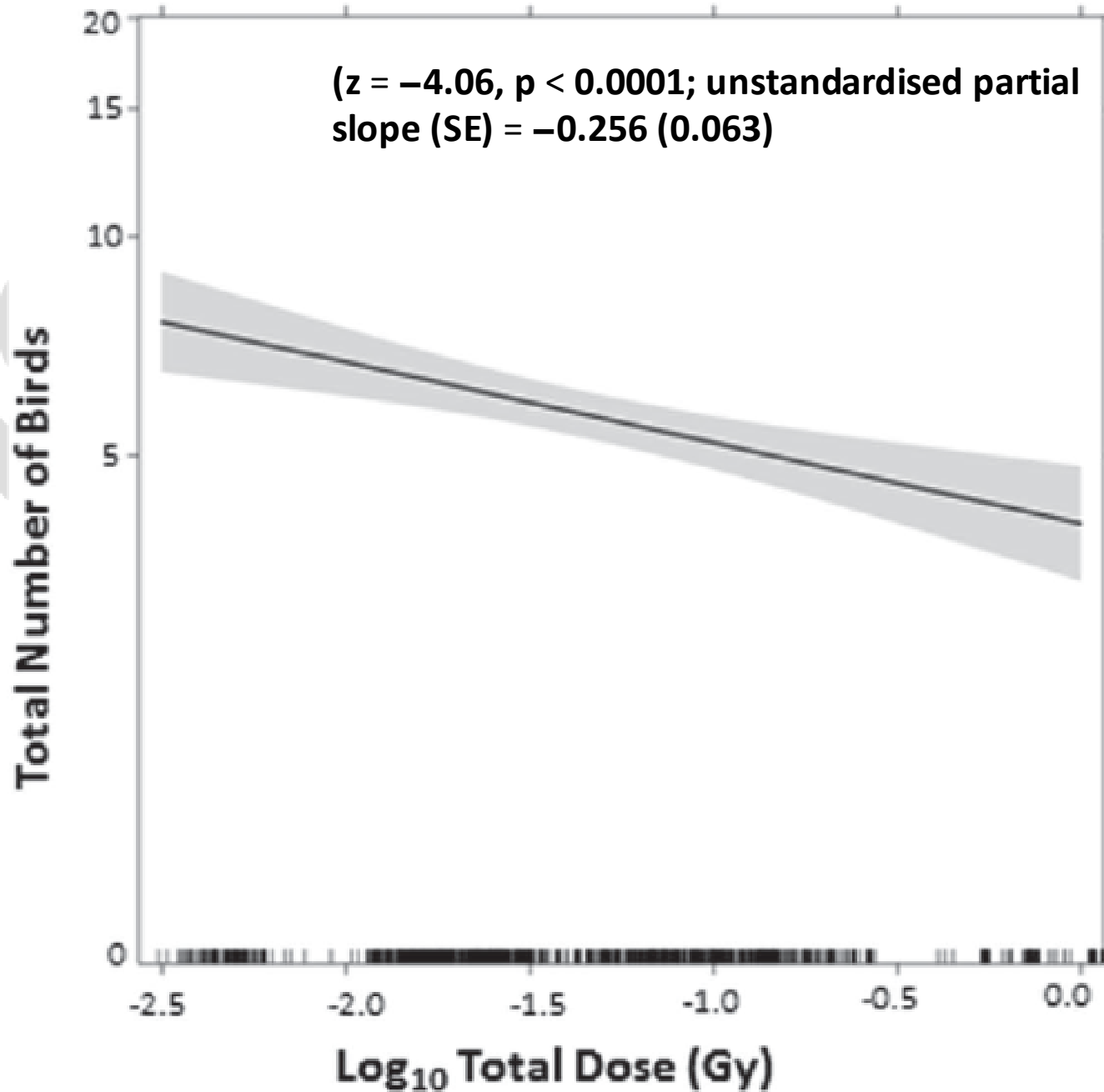
Jacqueline Garnier-Laplace<sup>1</sup>, Karine Beaugelin-Seiller<sup>1</sup>, Claire Della-Vedova<sup>1</sup>, Jean-Michel Métivier<sup>1</sup>, Christian Ritz<sup>2</sup>, Timothy A. Mousseau<sup>3</sup> & Anders Pape Møller<sup>4</sup>

We reconstructed the radiological dose for birds observed at 300 census sites in the 50-km northwest area affected by the accident at the Fukushima Daiichi nuclear power plant over 2011–2014. Substituting the ambient dose rate measured at the census points (from 0.16 to 31  $\mu\text{Gy h}^{-1}$ ) with the dose rate reconstructed for adult birds of each species (from 0.3 to 97  $\mu\text{Gy h}^{-1}$ ), we confirmed that the overall bird abundance at Fukushima decreased with increasing total doses. This relationship was directly consistent with exposure levels found in the literature to induce physiological disturbances in birds. Among the 57 species constituting the observed bird community, we found that 90% were likely chronically exposed at a dose rate that could potentially affect their reproductive success. We quantified a loss of 22.6% of the total number of individuals per increment of one unit  $\log_{10}$ -transformed total dose (in Gy), over the four-year post-accident period in the explored area. We estimated that a total dose of 0.55 Gy reduced by 50% the total number of birds in the study area over 2011–2014. The data also suggest a significant positive relationship between total dose and species diversity.

# Dose rate to most birds was high enough to cause significant reduction in reproduction



# Fukushima 2011-2014



“cold” site -  $< 0.6$  usv/h



[http://youtu.be/q6h-Mh8J\\_Ao](http://youtu.be/q6h-Mh8J_Ao)



## Hot Site – about 30 usv/h - “Silent Summer”



<http://youtu.be/QMsuCE97xr0>

# Ongoing Studies in Fukushima:

- Censuses of large mammals using camera traps.
- Censuses of rodents by trapping
- Censuses of birds, butterflies and moths
- Tests for effects of radiation on tree growth
- Tests for effects of radiation on microbial decomposition rates

# Using Camera Traps to Assess Large Mammals Abundances in Fukushima and Chornobyl:

- 40 camera traps placed across Fukushima Feb 2015 – Jan 2016, in areas from 1 to 30  $\mu\text{Sv/h}$
- Highly significant reductions in abundance and diversity in more radioactive locations
- 39 camera traps placed in Chornobyl Feb 2016





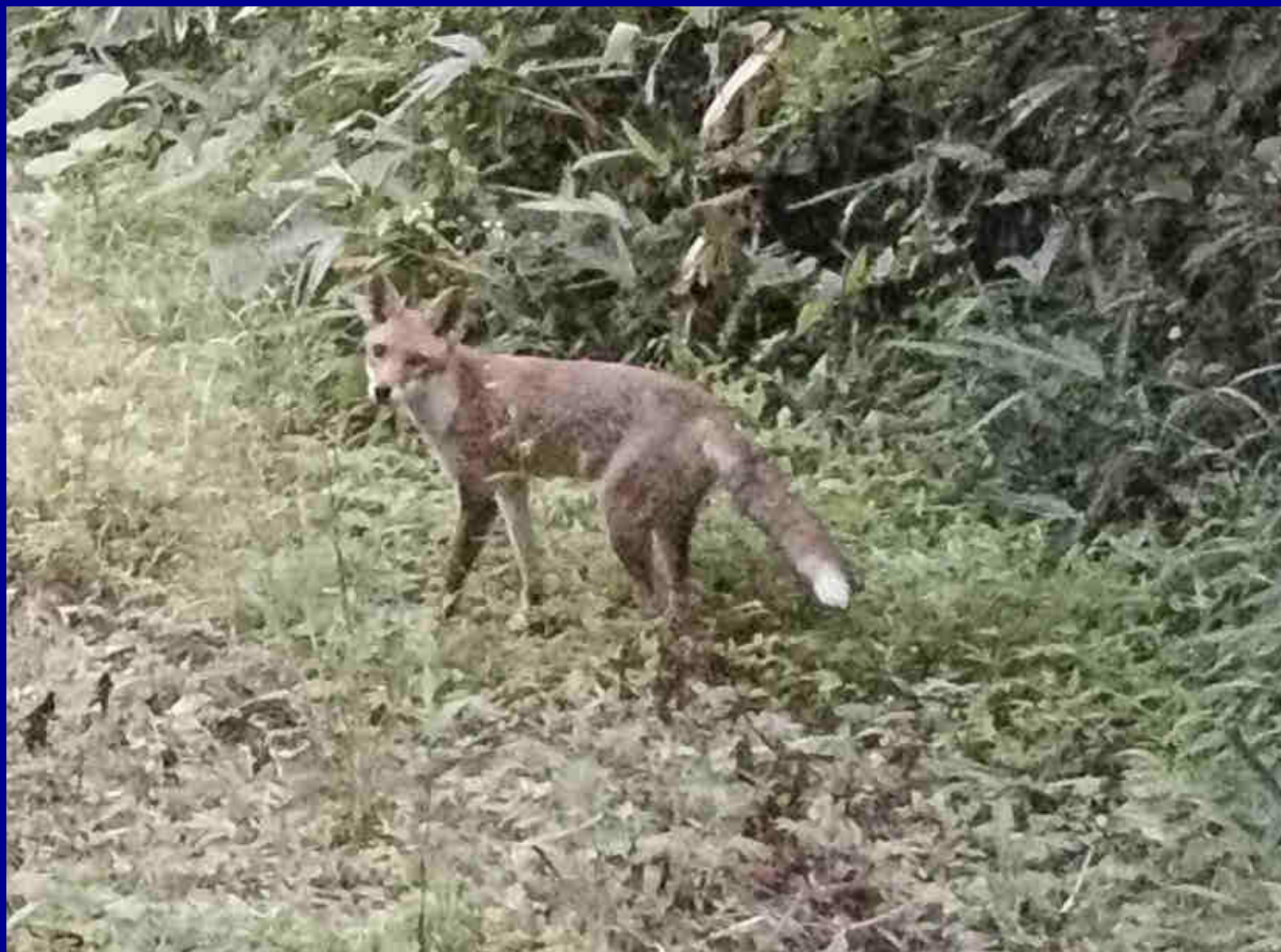
16C 05/24/2015 09:29AM CAMERA 11



54°F



09 / 06 / 2015



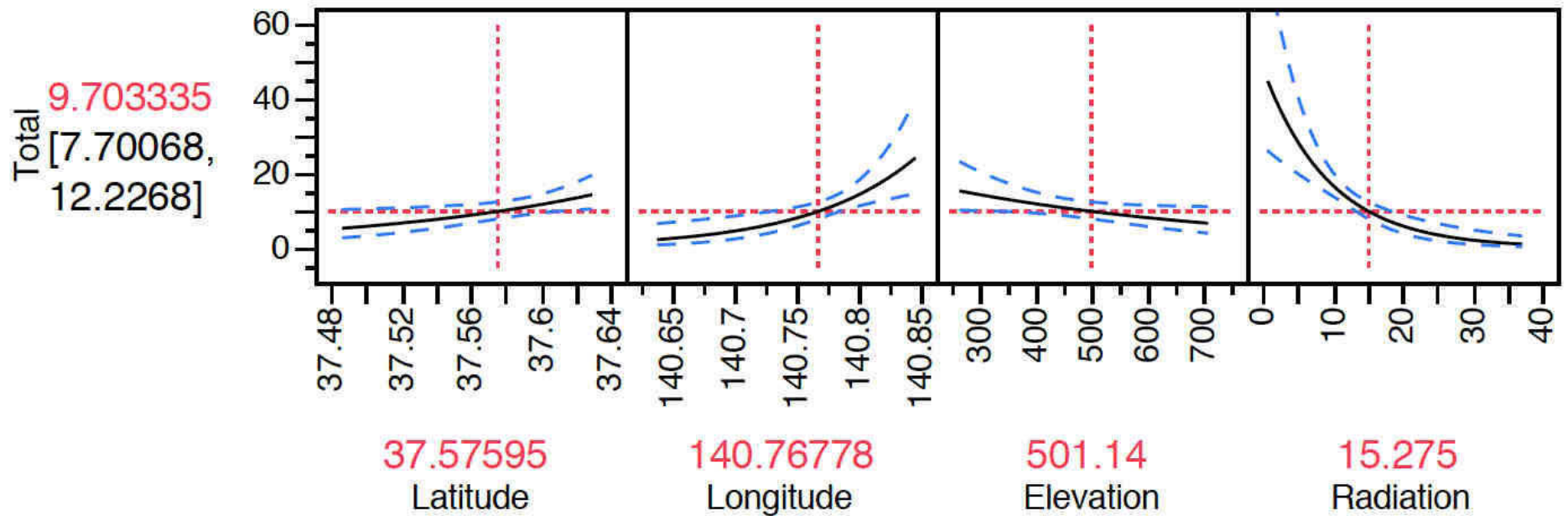
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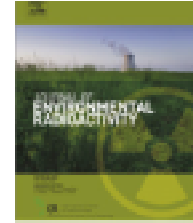
There are significantly fewer large mammals in areas of high radiation.

Radiation effects were much larger than other factors.

## Prediction Profiler







Are radiosensitivity data derived from natural field conditions consistent with data from controlled exposures? A case study of Chernobyl wildlife chronically exposed to low dose rates

**Animals living in the wild  
are about 8 times more  
sensitive to radiation  
than previously thought.**



OPEN

# Strong effects of ionizing radiation from Chernobyl on mutation rates

Anders Pape Møller<sup>1</sup> & Timothy A. Mousseau<sup>2</sup>

SUBJECT AREAS:  
ECOLOGICAL GENETICS  
EVOLUTIONARY GENETICS

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Correspondence and  
requests for materials  
should be addressed to  
A.P.M. (anders.  
moller@u-psud.fr)

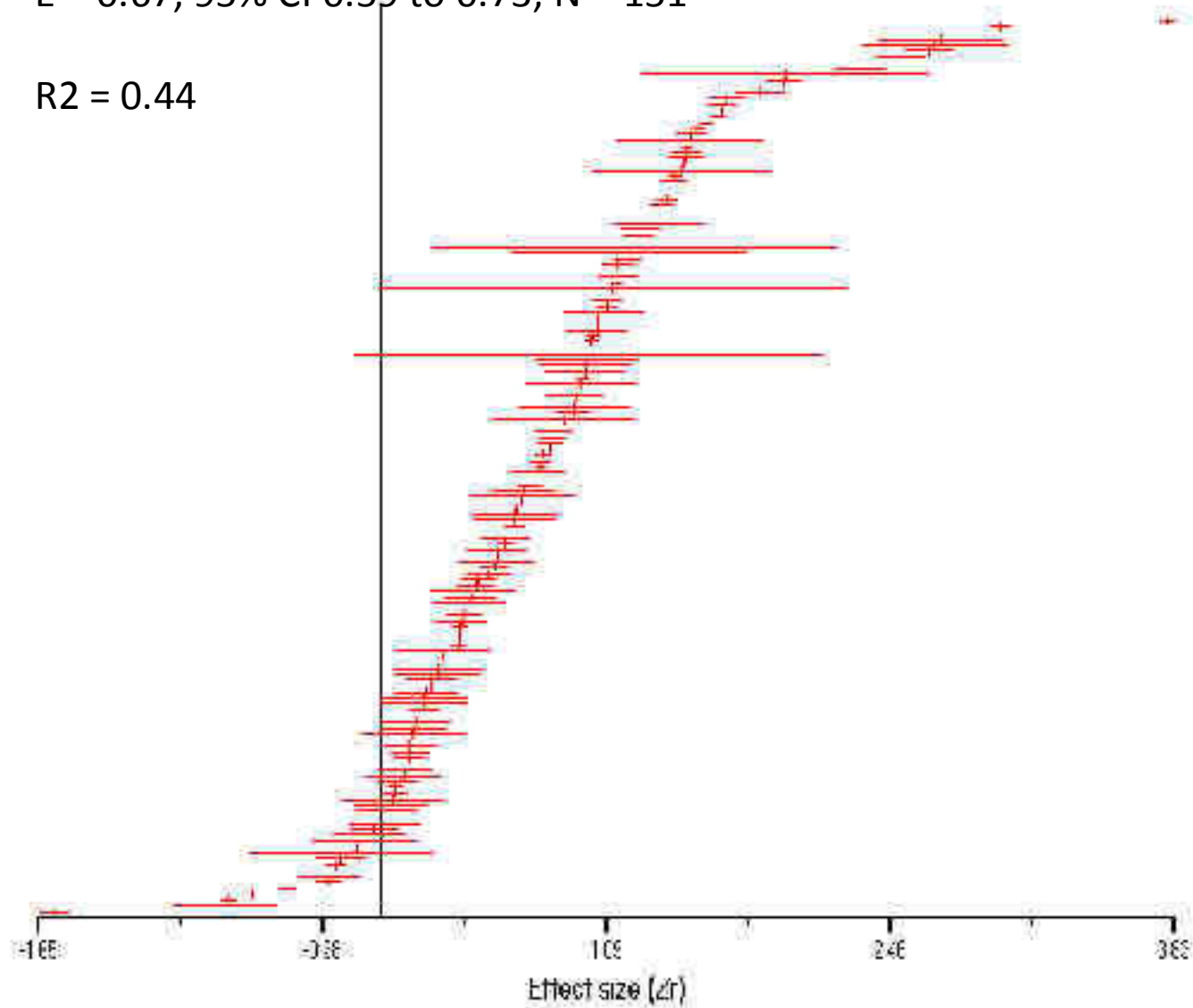
<sup>1</sup>Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Bâtiment 362, F-91405 Orsay Cedex, France, <sup>2</sup>Department of Biological Sciences, University of South Carolina, Columbia SC 29208, USA.

In this paper we use a meta-analysis to examine the relationship between radiation and mutation rates in Chernobyl across 45 published studies, covering 30 species. Overall effect size of radiation on mutation rates estimated as Pearson's product-moment correlation coefficient was very large ( $E = 0.67$ ; 95% confidence intervals (CI) 0.59 to 0.73), accounting for 44.3% of the total variance in an unstructured random-effects model. Fail-safe calculations reflecting the number of unpublished null results needed to eliminate this average effect size showed the extreme robustness of this finding (Rosenberg's method: 4135 at  $p = 0.05$ ). Indirect tests did not provide any evidence of publication bias. The effect of radiation on mutations varied among taxa, with plants showing a larger effect than animals. Humans were shown to have intermediate sensitivity of mutations to radiation compared to other species. Effect size did not decrease over time, providing no evidence for an improvement in environmental conditions. The surprisingly high mean effect size suggests a strong impact of radioactive contamination on individual fitness in current and future generations, with potentially significant population-level consequences, even beyond the area contaminated with radioactive material.

# Chernobyl: Radiation and Mutation, a Meta-Analysis

$E = 0.67$ ; 95% CI 0.59 to 0.73;  $N = 151$

$R^2 = 0.44$





Contents lists available at ScienceDirect

# Science of the Total Environment

journal homepage: [www.elsevier.com/locate/scitotenv](http://www.elsevier.com/locate/scitotenv)



## Ionizing radiation, antioxidant response and oxidative damage: A meta-analysis



D. Einor<sup>a</sup>, A. Bonisoli-Alquati<sup>a,b</sup>, D. Costantini<sup>c</sup>, T.A. Mousseau<sup>a,d</sup>, A.P. Møller<sup>e,\*</sup>

<sup>a</sup> Department of Biological Sciences, University of South Carolina, Columbia, SC 29208, USA

<sup>b</sup> School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803, USA

<sup>c</sup> Department of Biology, University of Antwerp, Wilrijk, B-2610, Antwerp, Belgium

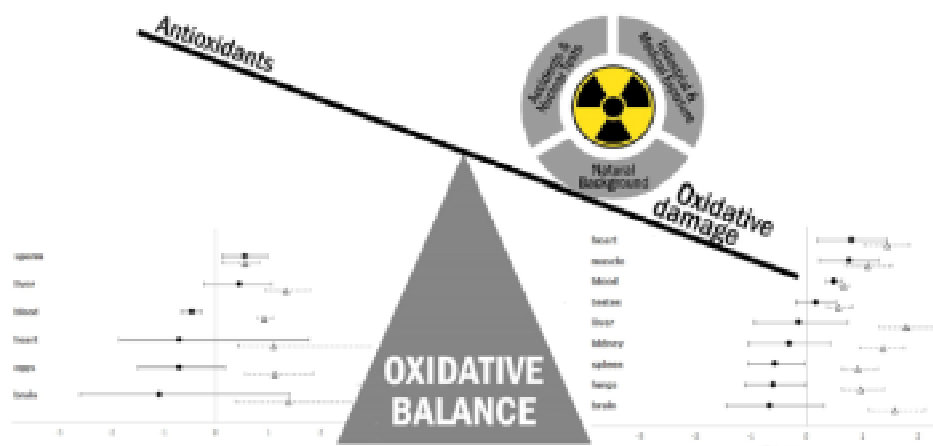
<sup>d</sup> Faculty of Bioscience and Biotechnology, Chubu University, Kasugai, Japan

<sup>e</sup> Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Bâtiment 362, F-91405 Orsay Cedex, France

### HIGHLIGHTS

- There is interest in variation in metabolic effects of chronic low-dose ionizing radiation
- A random effect meta-analysis of effect sizes of radioactive contamination was performed
- We found significant effects of radiation on oxidative damage and antioxidant response
- We found significant heterogeneity among biological matrices, species and age classes

### GRAPHICAL ABSTRACT



## Review

# Are Organisms Adapting to Ionizing Radiation at Chernobyl?

Anders Pape Møller<sup>1,2,\*</sup> and Timothy Alexander Mousseau<sup>3</sup>

Numerous organisms have shown an ability to survive and reproduce under low-dose ionizing radiation arising from natural background radiation or from nuclear accidents. In a literature review, we found a total of 17 supposed cases of adaptation, mostly based on common garden experiments with organisms only deriving from typically two or three sampling locations. We only found one experimental study showing evidence of improved resistance to radiation. Finally, we examined studies for the presence of hormesis (i.e., superior fitness at low levels of radiation compared with controls and high levels of radiation), but found no evidence to support its existence. We conclude that rigorous experiments based on extensive sampling from multiple sites are required.

### Trends

In total, 17 studies have suggested that they have demonstrated adaptation to ionizing radiation from Chernobyl, while in fact only two of these fulfill the criteria for evolutionary adaptation.

Lack of evidence of adaptation mainly derived from the lack of replication and of rigorous experimental design.

There was no evidence of hormesis, with organisms at low levels of radiation



## The number of syllables in Chernobyl cuckoo calls reliably indicate habitat, soil and radiation levels

Anders Pape Møller<sup>a,\*</sup>, Federico Morelli<sup>b</sup>, Timothy A. Mousseau<sup>c</sup>, Piotr Tryjanowski<sup>d</sup>

<sup>a</sup> *Ecologie Systématique Evolution, Université Paris-Sud, CNRS, AgroParisTech, Université Paris-Saclay, F-91405 Orsay Cedex, France*

<sup>b</sup> *Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Department of Applied Geoinformatics and Spatial Planning, Kamýcká 129, CZ-165 00 Prague 6, Czech Republic*

<sup>c</sup> *Department of Biological Sciences, University of South Carolina, SC 29208, USA*

<sup>d</sup> *Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, PL-60-625 Poznań, Poland*

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*Cuculus canorus*

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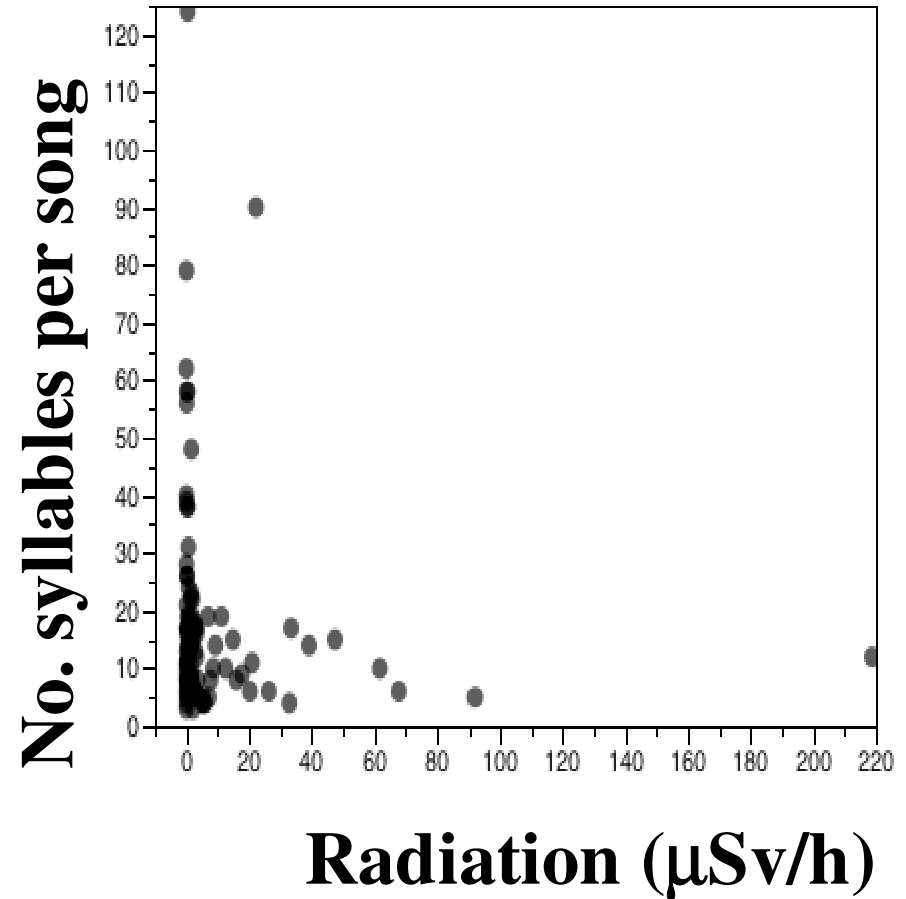
Radioactivity

Species richness

### ABSTRACT

Cuckoos *Cuculus canorus* produce calls that consist of a repeated but variable number of syllables that has given name to the species and the family. Here we tested the hypothesis that cuckoo calls are reliable indicators of environmental and individual quality by determining the number of repeated 'cuckoo' syllables in calls in relation to habitat and soil, ionizing radiation, presence of a female cuckoo and local density of male cuckoos at Chernobyl, Ukraine. Males were consistent in their production of syllables, producing more syllables per call when a female or another male arrived. This increase in the number of syllables was larger in males that already produced many syllables in the absence of conspecifics, implying that males of superior quality were still able to increase the number of syllables. Males produced more syllables per call in habitats with black soil and in forests. Furthermore, they produced fewer and more aberrant syllables in radioactively contaminated areas of Chernobyl providing evidence of an effect of environmental perturbation on the number of syllables. These findings are consistent with the hypothesis that the number of syllables is a condition-dependent signal used for attracting mates, repelling competitors, providing information about local environmental conditions for other cuckoos, but also for humans and thus can be used by humans to infer habitat quality.

# Cuckoos count the number of years you have left!



(Møller et al., Ecol. Indicators 2016)

## The Last Swallows of Futaba

**The overwhelming consequences of radiation exposure are obvious if you look and listen.**





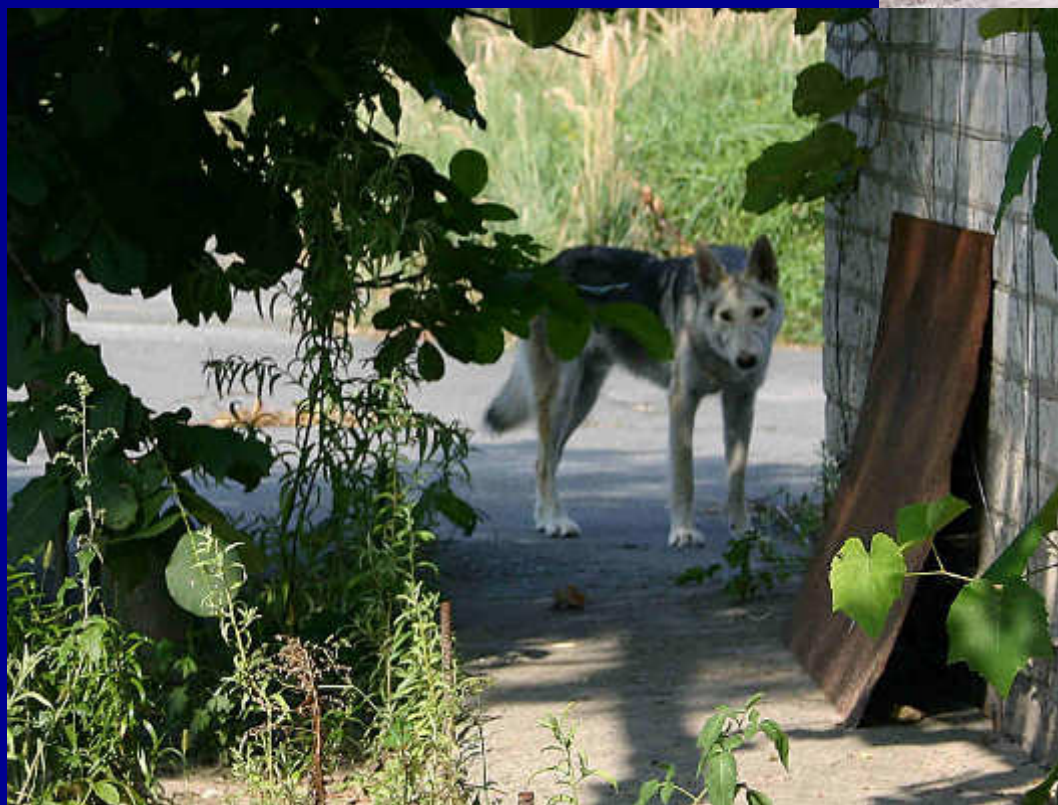
# The Effects of Radiation on Mammal Diversity and Abundance

- Past studies in Chernobyl have documented significantly reduced numbers of most mammals in areas of high radiation.
- Chernobyl studies were conducted by tracking animals from footprints in the snow and by large scale trapping for rodents.

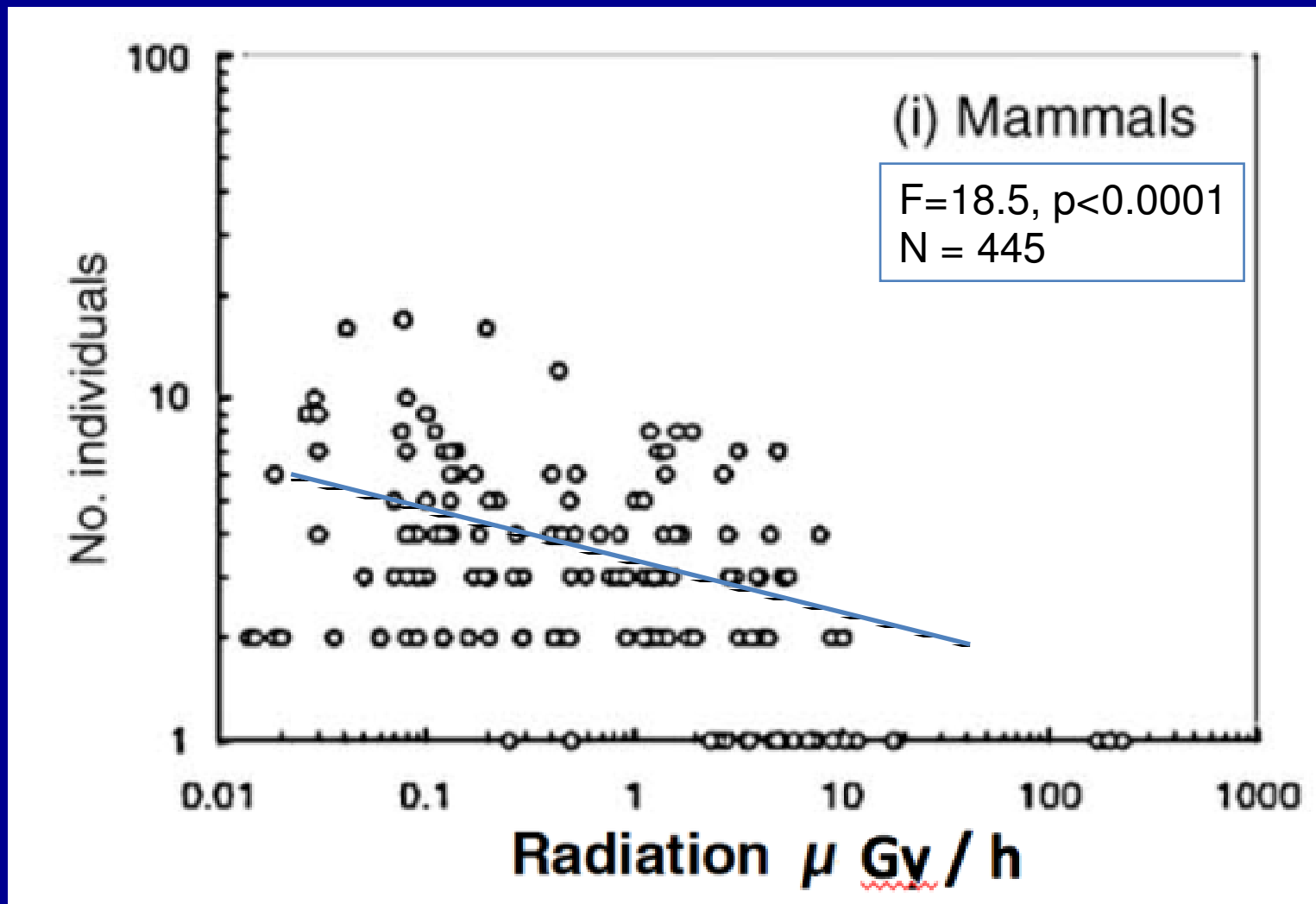
## Wolf footprint in snow in Chernobyl



# Wolves or Dogs? (or hybrids?)

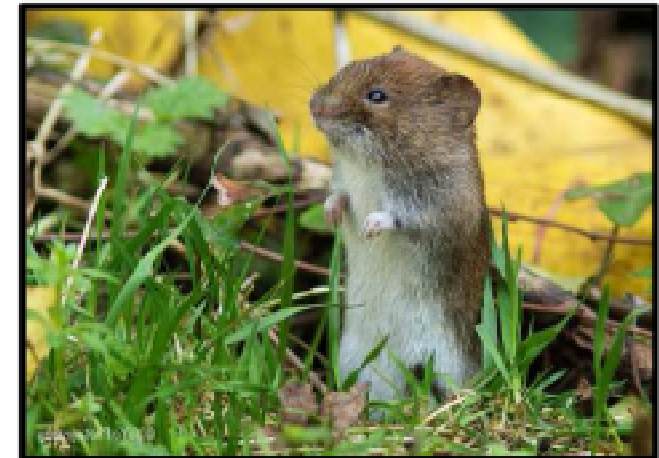
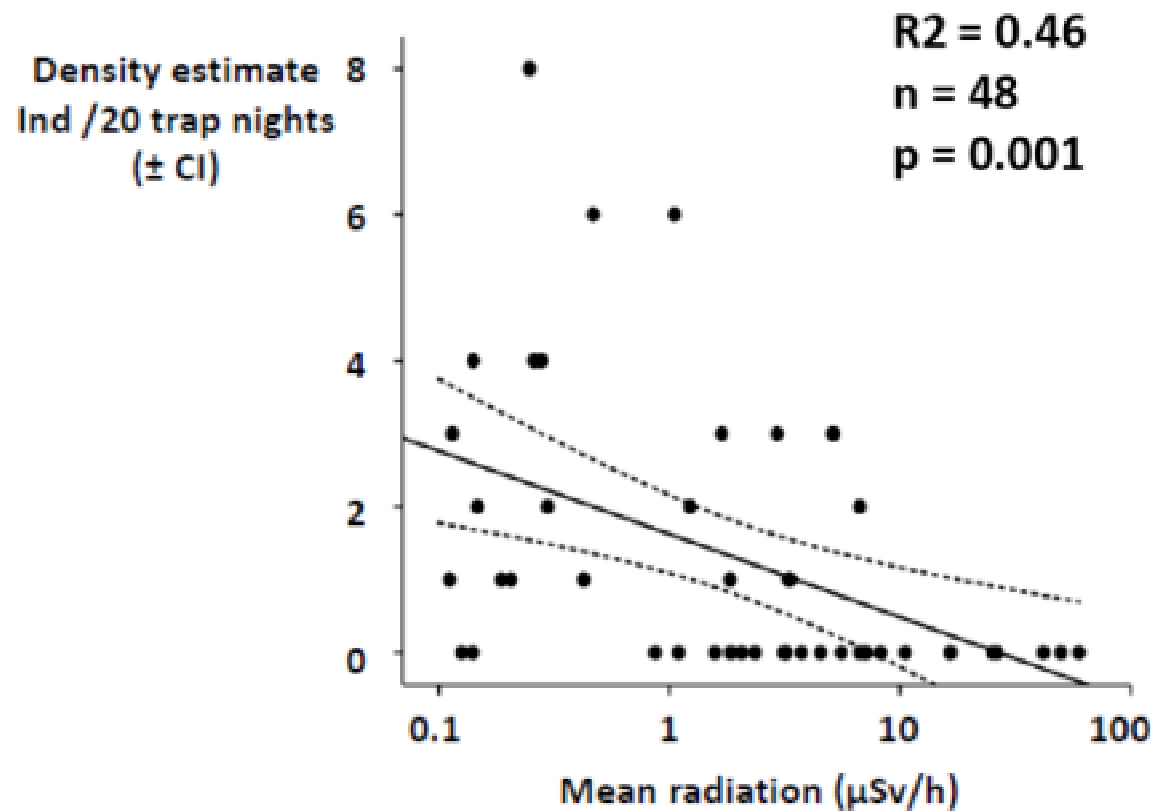


Most mammals show significant declines in areas of high contamination.



Moller and Mousseau. 2013. Ecological Indicators.  
Mousseau and Moller. 2011. Bulletin of the Atomic Scientists.

## Radiation effects on populations

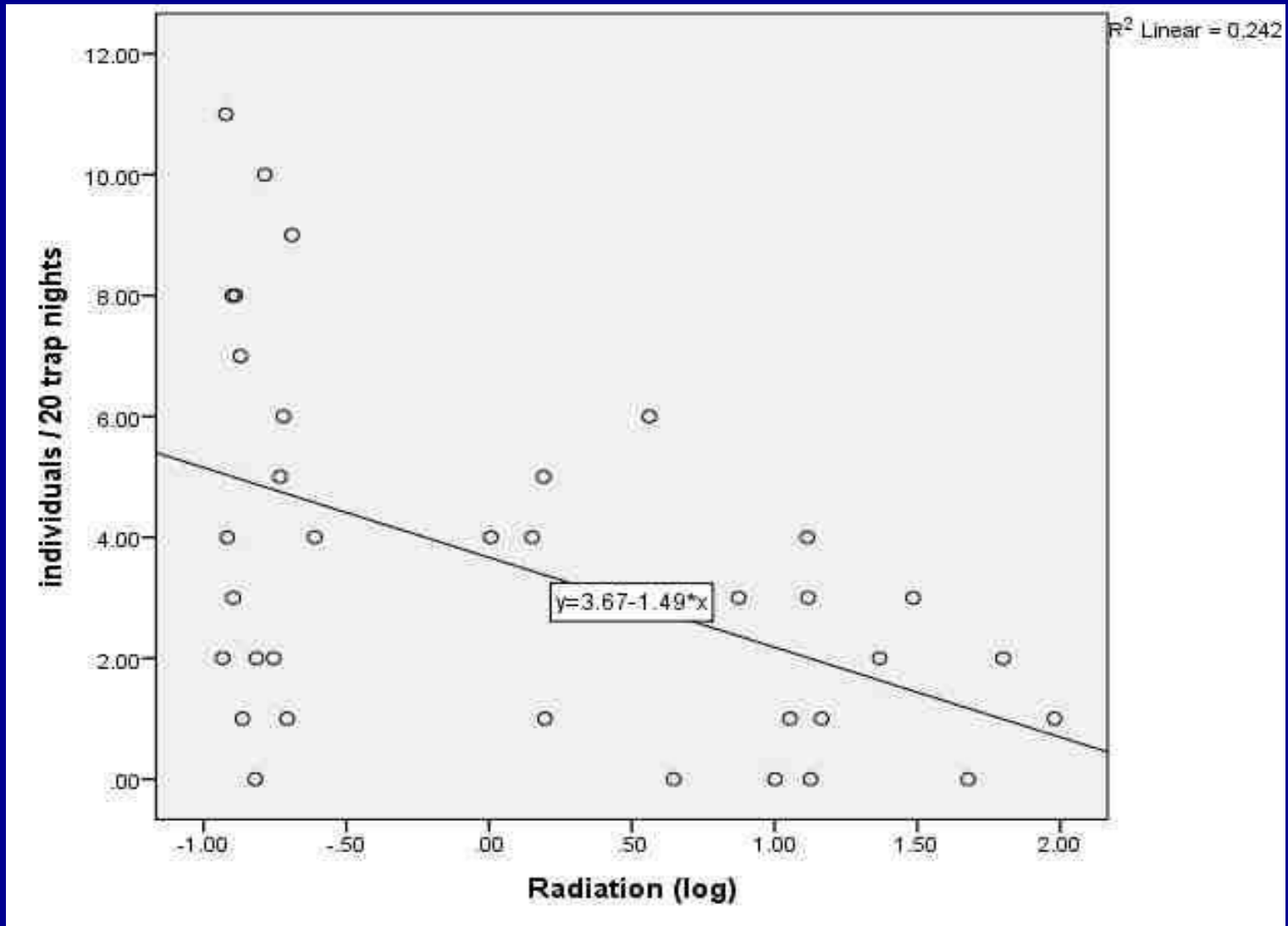


Radiation decrease the densities of voles

- no voles in higher than **10  $\mu\text{Sv} / \text{h}$**

- 48 trapping areas / 20 traps in each
- early breeding season
- density estimates only 2011

# Chornobyl Vole Winter 2016 Densities (Mappes et al. unpublished)





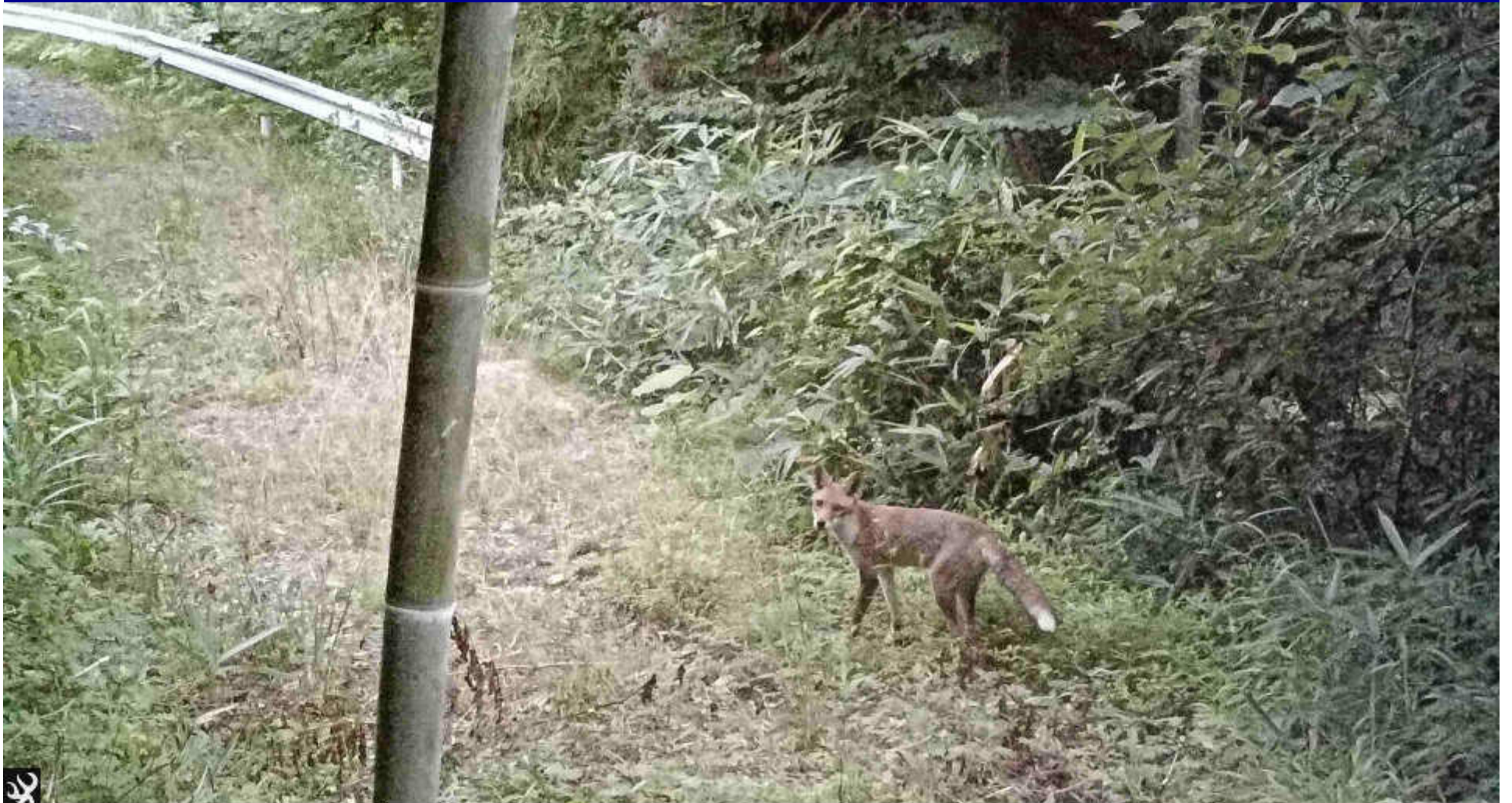
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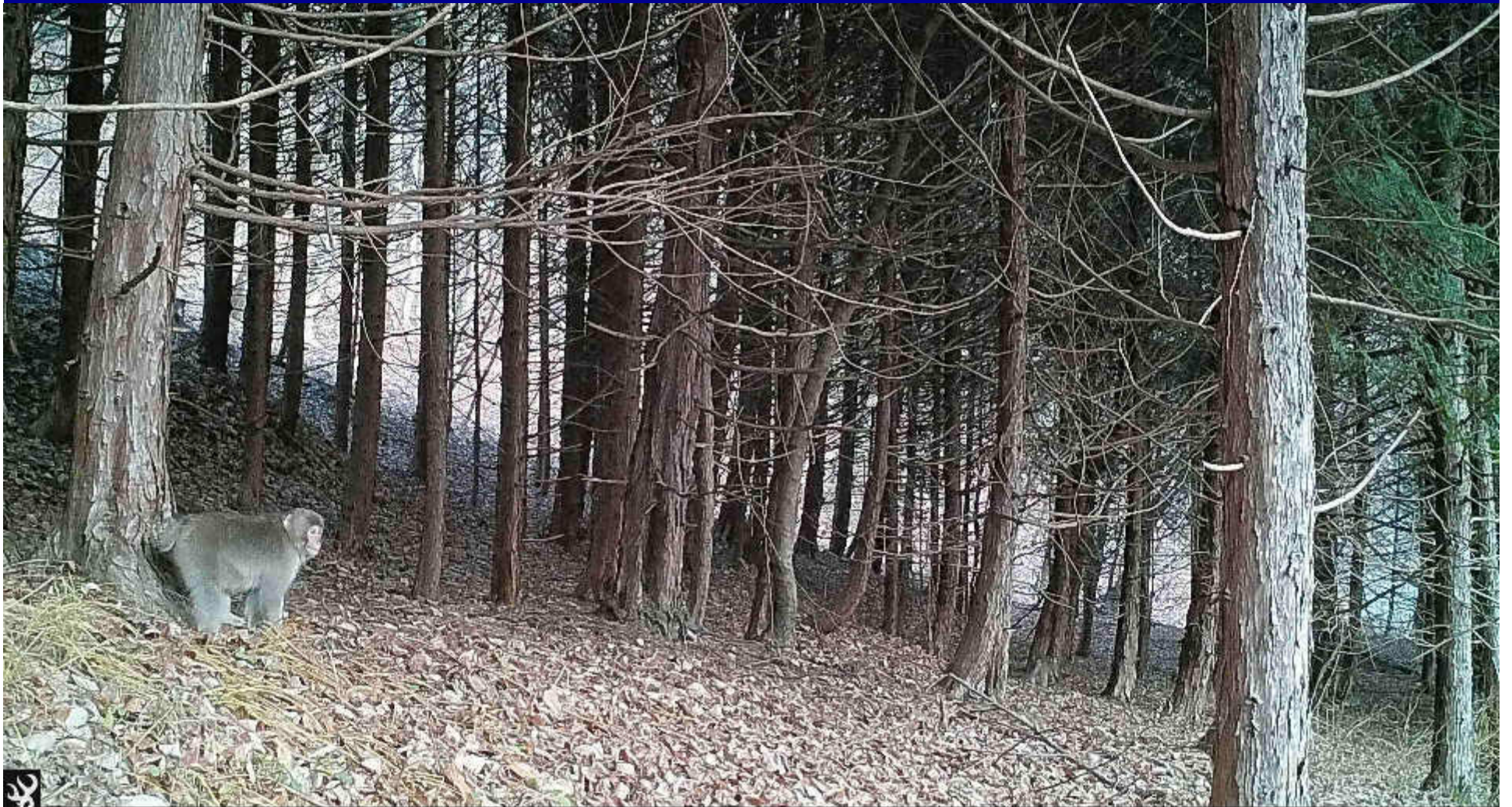
526

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68°F 07/28/2015 06:52PM CAMERA 18



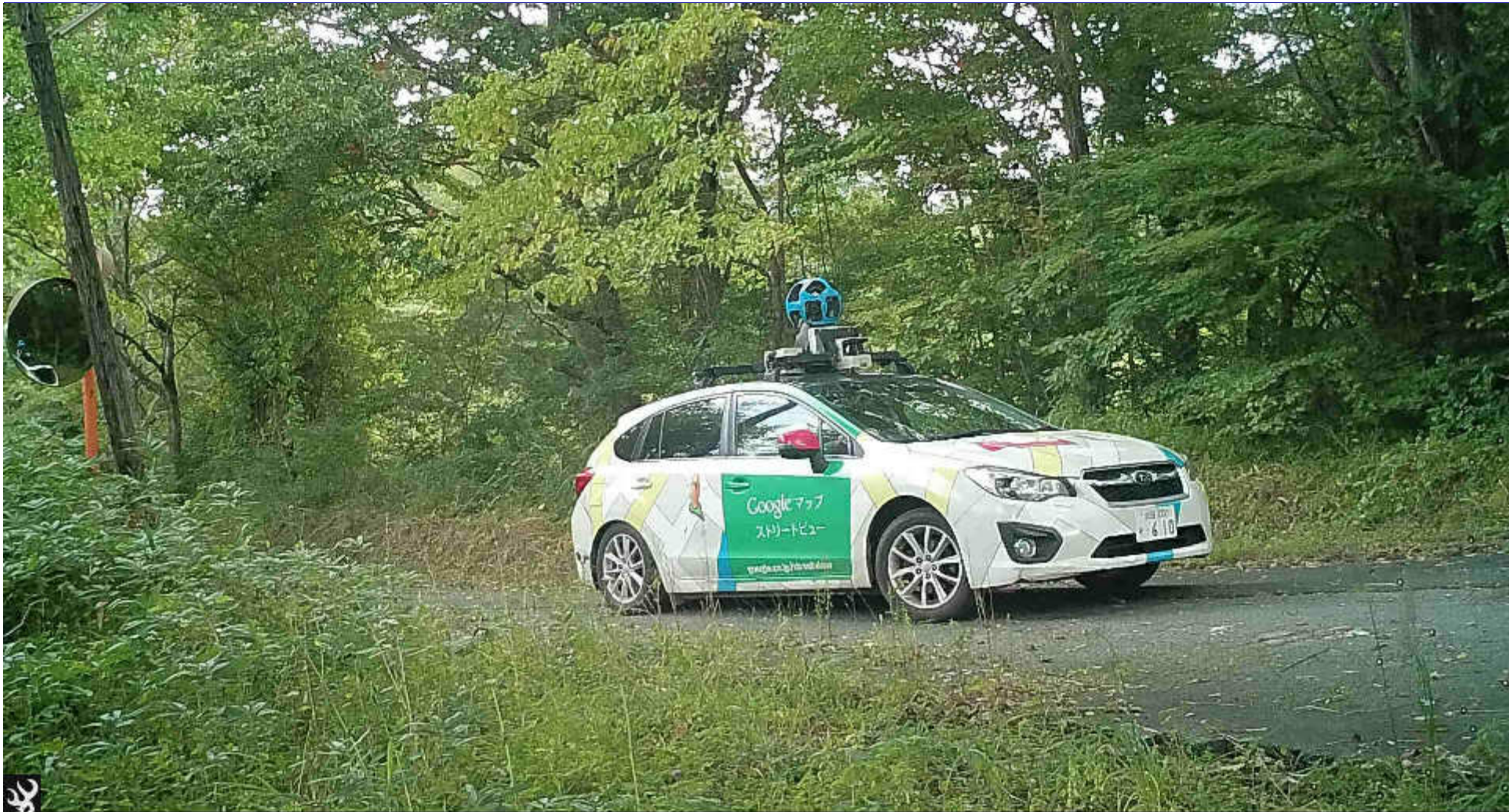
52°F ) 12/15/2015 02:44PM CAMERA 33





526

29.11 inHg - 4C 02/25/2015 04:21PM CAMERA 8



63°F ) 09/15/2015 10:58AM CAMERA 35



There are significantly fewer large mammals in areas of high radiation

### Parameter Estimates

Term	Estimate	Std Error	L-R		Lower CL	Upper CL
			ChiSquare	Prob>ChiSq		
Intercept	-1892.401	626.26264	10.046495	0.0015*	-3155.977	-701.1705
Latitude	7.0328784	3.1328213	5.2549808	0.0219*	1.0023404	13.290115
Longitude	11.600458	3.7878972	10.506569	0.0012*	4.429546	19.279483
Elevation	-0.001898	0.0009544	4.0610237	0.0439*	-0.003813	-5.163e-5
Radiation	-0.105577	0.0236285	32.70251	<.0001*	-0.155461	-0.062923



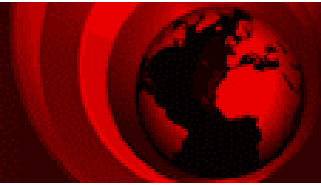




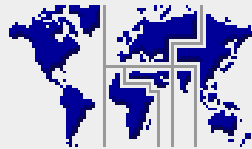
<https://youtu.be/4Oh7keJ7f3I>



<https://youtu.be/vRPHMO0NVGo>



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## Chernobyl 'not a wildlife haven'

By **Mark Kinver**  
Science and nature reporter, BBC News

**The idea that the exclusion zone around the Chernobyl nuclear power plant has created a wildlife haven is not scientifically justified, a study says.**

Recent studies said rare species had thrived despite raised radiation levels as a result of no human activity.

But scientists who assessed the 1986 disaster's impact on birds said the ecological effects were "considerably greater than previously assumed".



AFP