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Research article

Ionizing radiation and taxonomic, functional and evolutionary diversity of bird communities

Federico Morelli[a,*], Yanina Benedetti[a], Timothy A. Mousseau[b], Anders Pape Møller[c]

[a] Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Department of Applied Geoinformatics and Spatial Planning, Kamýcká 129, 165 00 Prague 6, Czech Republic
[b] Department of Biological Sciences, University of South Carolina, Columbia, SC 29208, USA
[c] Ecologie Systématique Evolution, Université Paris-Sud, CNRS, AgroParisTech, Université Paris-Saclay, F-91405 Orsay Cedex, France

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ABSTRACT

Ionizing radiation from nuclear accidents at Chernobyl, Fukushima and elsewhere has reduced the abundance, species richness and diversity of ecosystems. Here we analyzed the taxonomic, functional and evolutionary diversity of bird communities in forested areas around Chernobyl. Species richness decreased with increasing radiation, mainly in 2007. Functional richness, but not functional evenness and divergence, decreased with increasing level of ionizing radiation. Evolutionary distinctiveness of bird communities was higher in areas with higher levels of ionizing radiation. Regression tree models revealed that species richness was higher in bird communities in areas with radiation levels lower than 0.7 μSv/h. In contrast, when radiation levels were higher than 16.67 μSv/h, bird species richness reached a minimum. Functional richness was affected by two variables: Forest cover and radiation level. Higher functional richness was found in bird communities in areas with forest cover lower than 50%. In the areas with forest cover higher than 50%, the functional richness was lower when radiation level was higher than 0.91 μSv/h. Finally, the average evolutionary distinctiveness of bird communities was higher in areas with forest cover exceeding 50%. These findings imply that level of ionizing radiation interacted with forest cover to affect species richness and its component parts, i.e. taxonomic, functional, and evolutionary diversity.

1. Introduction

The loss of biodiversity is of critical concern, and an increasing number of studies indicate that biodiversity plays a central role in long-term ecosystem functioning (Groombridge and Jenkins, 2002; Pereira et al., 2012). For this reason, research focused on the spatial distribution of biodiversity is necessary. Species richness is often used as an operational variable reflecting the state of biological diversity (Jiguet et al., 2005), constituting one of the most useful biodiversity metrics, especially for the evaluation of bird communities (Gotelli and Colwell, 2001; Morelli, 2013; Ricklefs, 2012; Young et al., 2013), providing simple univariate measures of the community (Magurran, 2004). However, the species richness approach is limited by its inability to account for the ecological role and the diverse contributions species make to ecological communities (Safi et al., 2013). For this reason, multi-level or multidimensional approaches are needed and were recently proposed in many studies considering functional and phylogenetic aspects of diversity (Clough et al., 2009; Luck et al., 2013; Morelli et al., 2016, 2017; Sol et al., 2017).

Nuclear power plant accidents such as those at Chernobyl, Fukushima, Mayak and many others have contaminated several hundred thousand square kilometres in Europe and Asia (Lelieveld et al., 2012). Even if research activities were relatively modest during the first decades after these accidents, recently the interest of such research is increasing, considering that studies of animals may have significant implications for humans (Møller et al., 2013b). Some studies described the effects of radiation after nuclear accidents, highlighting many negative effects for biodiversity as well as for ecosystem services (Geras'kin, 2016; Sazykina and Kryshev, 2006; Wagner, 1965; Wehrden et al., 2012). These research activities can broadly be divided into studies of mutations (Abend et al., 2014; Bonisoli-Alquati et al., 2015, 2010; Dubrova et al., 2006; Ellegren et al., 1997; Møller et al., 2015b, 2010) and abnormalities (Hiyama et al., 2012; Kubota et al., 2015; Møller et al., 2007, 2005). Ionizing radiation has also resulted in medical conditions such as cataracts (Lehmann et al., 2016; Mousseau and Møller, 2013), tumors (Møller et al., 2013a) and other diseases (Abend et al., 2015; Leuraud et al., 2015; Moseeva et al., 2014), reduced brain size (Hayama et al., 2017; Møller et al., 2011), reduced

* Corresponding author.
E-mail address: fmorellius@gmail.com (F. Morelli).

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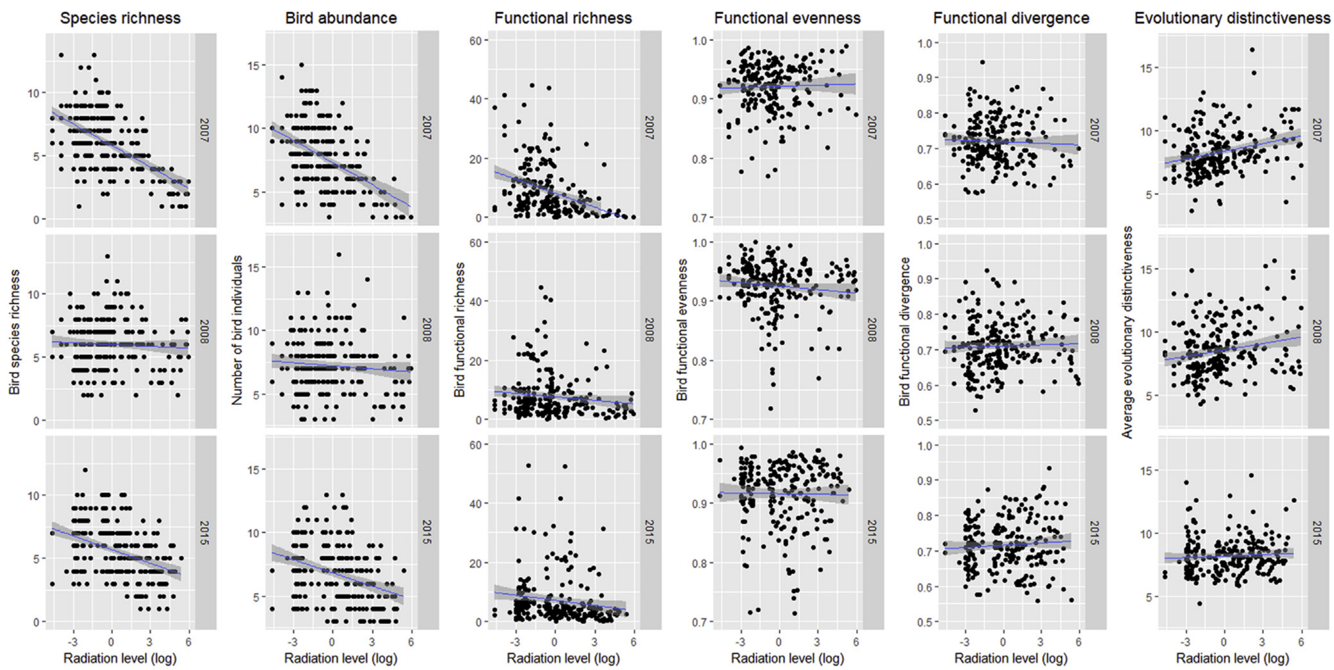

Fig. 1. Association between radiation level and each diversity and community metric estimated for bird communities in the Chernobyl region of Ukraine and Belarus. The plots show the linear regressions, split in the three different years of survey: 2007, 2008 and 2015. Envelopes around lines are 95% confidence intervals.

Table 1
Results of GLMM for best models relating species richness (a), bird abundance (b), functional richness (c) and community evolutionary distinctiveness (d) of bird communities in Chernobyl to background radiation level and environmental characteristics. The table shows estimates, 95% confidence intervals (CI), SE, *z* or *t* and p values.

Predictors	Estimate	CI	SE	*z/t*	*P*
a) Species richness					
Intercept	21.986	4.543/39.429	8.900	2.470	0.014
log Radiation	−0.003	−0.004/-0.002	0.000	−6.328	2.5e-10
Year	−0.010	−0.019/-0.002	0.004	−2.318	0.020
b) Bird abundance					
Intercept	24.526	8.172/40.880	8.344	2.939	0.003
log Radiation	−0.003	−0.004/-0.002	0.002	−6.848	7.5e-12
Year	−0.011	−0.019/-0.002	0.003	−2.756	0.006
c) Functional richness					
Intercept	60.359	18.064/102.654	21.579	2.797	0.005
log Radiation	−0.005	−0.007/-0.003	0.001	−4.897	9.7e-07
Year	−0.029	−0.050/-0.008	0.011	−2.742	0.006
d) Evolutionary distinctiveness					
Intercept	42.864	−30.898/116.627	37.635	1.139	0.255
log Radiation	0.004	0.002/0.007	0.001	3.368	0.001

sperm performance (Bonisoli-Alquati et al., 2010; Hermosell et al., 2013; Møller et al., 2014) and pollen viability (Møller et al., 2016). Impaired gamete function may reduce seed germination rates (Møller and Mousseau, 2017) and growth rates (Boratyński et al., 2016), but also biased sex ratios (Møller et al., 2012). An increased frequency of detrimental effects of ionizing radiation have resulted in an increased frequency of mortality (Møller et al., 2012, 2005) and a reduction in fecundity (Møller et al., 2005). In turn such effects have been shown to have population consequences for many species with dramatic decreases in the abundance and species richness of birds (Galván et al., 2011; Møller et al., 2013b; Møller and Mousseau, 2007), but also other organisms (Bezrukov et al., 2015; Møller et al., 2013b). These effects of nuclear accidents are not restricted to human activity. Indeed, naturally occurring ionizing radiation due to composition of the underlying rock has resulted in significant effects of radiation on wild organisms and their performance (Møller et al., 2013b). Thus, research on the effects of radiation on free living organisms may have implications beyond a few accidents at nuclear power plants (Møller et al., 2013b).

In this study, we assessed the association between the level of ambient ionizing radiation and land use composition on different components of bird diversity in Chernobyl, Ukraine, specifically, species richness, functional diversity and evolutionary uniqueness of bird communities. In addition, we investigated the environmental characteristics driving the change for each diversity metric and ecological score in these forested areas.

2. Methods

2.1. Study area and bird data collection

We studied birds in sites around Chernobyl on 25 May - 5 June, in three years between 2007 and 2015 (Møller et al., 2011, 2012). These sites are located within a distance of 60 km from Chernobyl and covered a wide range of radiation levels ranging from normal background radiation (0.02 μSv/h) to some of the most contaminated areas in the Chernobyl region. All sites were in early successional stages of primary forest with some parts having been covered by forest during the last 10 years.

Field data were collected using the point count survey method which provides reliable information on occurrence and abundance of bird species (Bibby et al., 2005; Blondel et al., 1970; Møller, 1983; Voříšek et al., 2010). The method is based on an observer recording all birds and other animals seen and heard for a period of 5 min at a given location. The breeding bird survey points were located at ca. 100-m intervals in forested areas within the Chernobyl Exclusion Zone or adjacent areas, or in areas in southern Belarus around Gomel during the breeding seasons 2007, 2008 and 2015 (898 census points) (Møller et al., 2015a). A.P.M. conducted all point counts. The fact that one person made all counts eliminates any variance in results due to inter-observer variability. There are no bird census data from before the Chernobyl accident, nor to the best of our knowledge have other scientists conducted bird censuses comparable to ours in the years following the accident (Møller et al., 2013b).