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ORIGINAL ARTICLE

Reduced abundance of raptors in radioactively contaminated areas near Chernobyl

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Abstract The negative ecological effects of radioactive contamination around Chernobyl have recently been suggested to be moderate and declining because of an increasing number of anecdotal observations of several species of rare animals including predators. However, these claims were not based on empirical evidence. Radionuclides show bio-accumulation with trophic level, and the abundance of birds is depressed in radioactively contaminated areas around Chernobyl. Therefore, we predicted that birds of prey should be less abundant with increasing levels of radiation. Here, we use our long-term field data from 1991 to 2007 in three different analyses based on observations of raptors using standardized point counts, censuses during capture of barn swallows *Hirundo rustica* that habitually give alarm calls when a raptor is present, and line transects while driving on roads. Analyses suggest that the abundance of birds of prey is reduced in contaminated areas, and that there is evidence of a recent increase in abundance of raptors in less contaminated areas, but not in the most contaminated ones. Our findings suggest that birds of prey that are top level consumers in ecosystems suffer from reduced abundance in radioactively contaminated areas.

Keywords Birds of prey · Predators · Radiation at Chernobyl · Trophic level

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Introduction

The ecological consequences of radiation from the Chernobyl catastrophe remain poorly known, despite 21 years having passed since the catastrophe (reviews in Zakharov and Krysanov 1996; Møller and Mousseau 2006). Without scientific justification, a number of institutions and private persons have promoted the Chernobyl Exclusion Zone as a thriving ecosystem because a number of uncommon species such as eagles, wolves *Canis lupus* and perhaps even a bear *Ursus arctos* have appeared in recent years (Chernobyl Forum 2005a, b; UN Chernobyl Forum Expert Group "Environment" 2005; Mycio 2005; Rosenthal 2005; Stephan 2005). These claims about increasing abundance of predators and other rare species within the Chernobyl Exclusion Zone have been promoted by the official United Nations and International Atomic Energy Agency reports as evidence of a recovery of the ecosystem (Chernobyl Forum 2005a, b; UN Chernobyl Forum Expert Group "Environment" 2005). Surprisingly, these agencies did not provide any empirical basis for their claims by reporting information from control areas, or by reporting temporal trends in population levels, and there are to the best of our knowledge no empirical data supporting the claim. Such casual comments are surprising given the rigor that these agencies claimed to be using when investigating the biological, medical, and social consequences of the Chernobyl catastrophe (Chernobyl Forum 2005a, b; UN Chernobyl Forum Expert Group "Environment" 2005).

There are three reasons in addition to the complete lack of quantitative information why we consider the conclusions by the official reports of the United Nations and the International Atomic Energy Agency to be unlikely. First, bio-accumulation of radionuclides are common (Voitovich and Afonin 2002; Yakushev et al. 1999), and animals at higher trophic levels generally have higher levels of radionuclide concentrations than animals at lower levels (e.g., Kryshev and Ryabov 1990; Kryshev et al. 1992; Smith et al. 2002). Therefore, we should expect predators to have higher concentrations of radionuclides than detritivores, herbivores, or primary level predators such as many song birds. Second, Møller and Mousseau (2007b, c) reported that the most contaminated forest sites in Chernobyl have severely depressed species richness, abundance, and population density of birds, reduced by more than 50% compared to nearby sites with normal background levels of radiation. Given that avian predators mainly eat passerine birds and small mammals, we should expect species richness and density of birds of prey to be depressed in Chernobyl compared to uncontaminated control areas because the abundance of prey is reduced. Third, birds of prey are generally more abundant in man-made habitats such as farmland and managed forests than in undisturbed habitats, simply because the abundance of potential prey reaches much higher levels in manmade habitats (e.g., Newton 1986). The Chernobyl Exclusion Zone has not been managed by humans for 21 years, suggesting that the abundance of prey should be reduced compared to nearby agricultural and forest habitats managed by humans.

Here, we provide the first quantitative assessment of the claim that the abundance of raptors is high and increasing around Chernobyl compared to nearby uncontaminated sites, relying on our own extensive data collected in 10 years during 1991–2007, using three different census methods. First, we used standardized point counts lasting 5 min each to census breeding birds at 489 points in forests mainly within the Chernobyl Exclusion Zone during 2006–2007 (see Møller and Mousseau 2007a, b). Second, we censused birds of prey during our capture sessions of barn swallows *Hirundo rustica* around Chernobyl and in uncontaminated control areas in 1991–2007. Barn swallows act as sentinels for the presence of raptors that are readily detected. The presence of a raptor is revealed by frequent alarm calls that barn swallows emit at a frequency of more than 50 per min. Other passerine birds respond quickly to these alarm calls by giving their own alarm calls. Møller (1987) showed that a little owl *Athene noctua* model was detected by barn swallows after a maximum of a few minutes, but much more rapidly in colonies, where this raptor was detected after less than a minute. Third, we used line transects on roads by recording all birds of prey during our regular trips between Kiev and our study sites for barn swallows in Central and Northern Ukraine and Belarus during 1991–2007. Relying on data collected during more than 100 such trips we were able to assess the abundance of birds of prey for a total distance exceeding 12,000 km.

Materials and methods

Bird census

A.P.M. (wearing a radiation protection suit during censuses in the Red Forest) conducted standard point counts during 29 May–9 June 2006 and 1–11 June 2007, with each count lasting 5 min during which all bird species and individuals seen or heard were recorded (Møller 1983; Bibby et al. 2005). The census was conducted within the Chernobyl Exclusion Zone with a permit from the Ukrainian authorities or in areas adjacent on the southern, western, and northern borders in Ukraine and Belarus (Fig. 1). A total of 489 points were located at a distance of ca. 100-m intervals within forested areas, excluding successional stages of secondary forest due to abandoned farming; these areas are still almost exclusively open grassland. The following point counts of birds provide highly reliable estimates of species richness and abundance (Møller 1983; Bibby et al. 2005). We directly tested the reliability of our counts for a sample of 10 points where two persons performed the counts. The second person performing the counts was unaware of the purpose of his counts. The Pearson product–moment correlation between species richness in these two series of counts was high (Møller and Mousseau 2007b).

The second type of census was conducted during capture sessions of barn swallows during 1991, 1996, and 2000–2007 in the same areas, as described above for point counts (Fig. 1). The annual duration of these censuses lasted on average 23.45 h (2.61), range 15.24–41.30 h. When barn swallows encounter a bird of prey, they emit alarm calls that can be readily heard while mobbing the predator. Therefore, every time barn swallows emitted alarm calls, we determined the cause of the alarm and it was in all cases the presence of a raptor. Capture sessions lasted 0.5–9.5 h, on average 3.8 h ($SD = 0.3$), $n = 56$, and duration of capture sessions was used as a predictor variable to control for differences in sampling effort. A.P.M. conducted similar censuses during 142 capture sessions of barn swallows in open farmland in Northern Denmark during May–June 2008.

The third type of census was conducted while driving between Kiev and various sites where barn swallows were captured (most of these transects are shown in Fig. 1) during 1991, 1996 and 2000–2007. While a driver was driving a normal speed (ca. 80–90 km/h), A.P.M. recorded

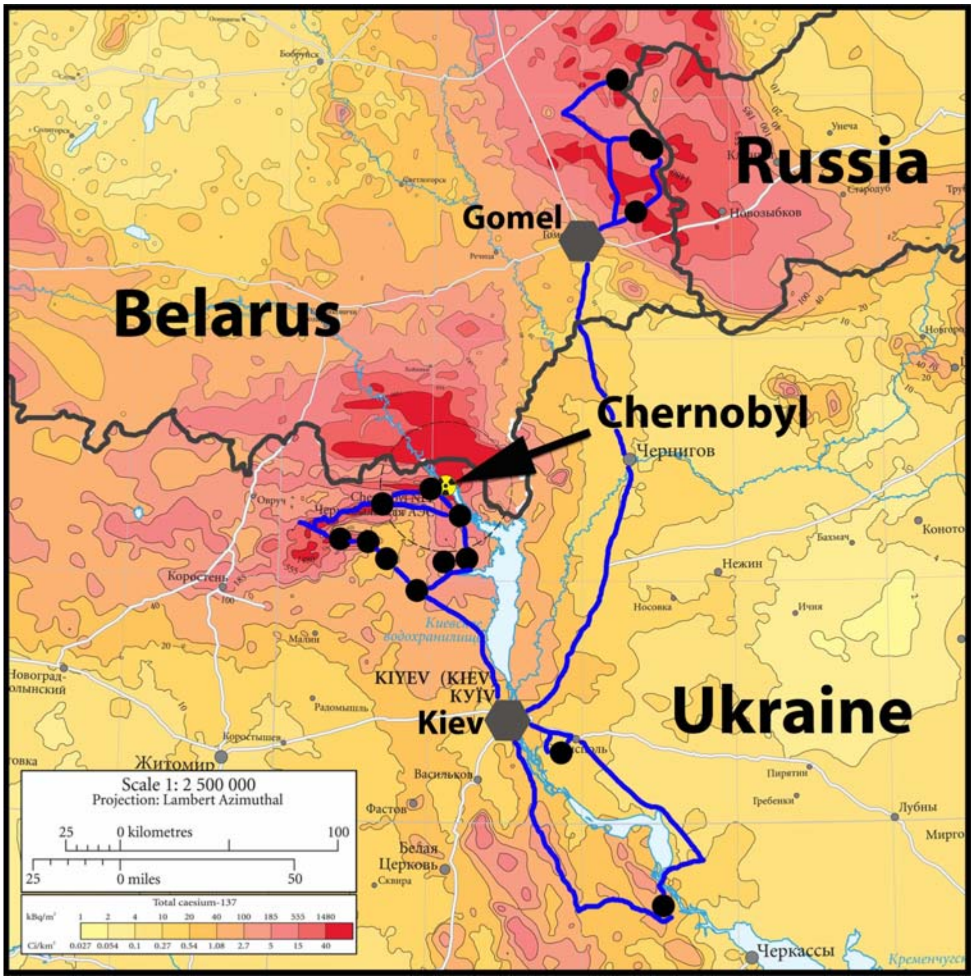

Fig. 1 Location of line transects and clusters of farms (*dots*) where barn swallows *Hirundo rustica* were captured, with information on levels of radiation from Chernobyl in parts of Ukraine, Belarus and Russia

all birds of prey. The distances traveled ranged from 5 to 250 km, mean (SE) = 118 km (5), $n = 105$, taking on average 0.06–3.13 h of driving. The annual distance of these censuses was on average 1,373 km (137.5), range 840–2,025 km. A.P.M. conducted 92 similar censuses of raptors in open farmland in Northern Denmark during May–June 2008.

Confounding variables

Bird abundance estimates can be affected by numerous potentially confounding variables (Møller 1983; Bibby et al. 2005). Thus, it is crucial to control for such variables statistically. We quantified habitat as follows: agricultural habitats with grassland or shrub, either currently or previously cultivated, deciduous forest, or coniferous forest estimated to the nearest 10% of ground coverage within a distance of 50 m from the observation point. Agricultural habitat thus also controlled statistically for any effects of edge habitat. Maximum height of trees was estimated to the nearest 5 m, and soil type was recorded as loam/clay or sand. The presence of open water within a distance of 50 m was also recorded. Weather conditions can affect animal activity and hence census results (Møller 1983; Bibby et al. 2005), and we recorded cloud cover at the start of each point count (to the nearest eighth, range 0–1 during the censuses), temperature (°C, range 12–30°C), and wind force (Beaufort, range 0–4 during the censuses). For each point count, we recorded time of day when the count was started (to the nearest min). Because bird activity may show a curvilinear relationship with time of day, with high levels of activity in the morning and to a lesser extent in the evening (Møller 1983; Bibby et al. 2005), we also included time squared as an additional variable.

Confounding variables during capture sessions were date, duration of the session, time of day, and time of day squared as defined above. We did not include habitat as a confounding variable because all capture sessions took place at farms.

Confounding variables during car censuses were date, distance travelled, time of day, and time of day squared as defined above. Car censuses by definition covered a range of different habitats, and we had no possibility for quantifying habitats during the censuses. Hence, the conclusions from these censuses should be considered with this caveat in mind.

Measuring background radiation levels

We obtained radiation estimates from our measurements and cross-validated these with measurements by the Ministry of Emergencies. We measured α, β, and γ radiation at ground level directly at each point where we censused birds using a hand-held dosimeter (Inspector; SE International, Summertown, TN, USA). All measurements were deliberately made *after* the census to avoid any unintentional bias, ensuring that censuses were made blindly with respect to radiation level. We measured levels 2–3 times at each site and averaged the measurements. Our data were validated with correlation against data from the governmental measurements published by Shestopalov (1996), estimated as the mid-point of the ranges published. This analysis revealed a strong positive relationship (Møller and Mousseau 2007b), suggesting that our estimates of radiation provided the same ranking of levels of radiation as did published estimates. The measurements by the Ministry of Emergencies were obtained by repeated standardized measurement of radiation at the ground level in a large number of different localities in Ukraine. Radiation levels vary considerably at very short geographical distances due to heterogeneity in the deposition of radiation after the Chernobyl accident (Shestopalov 1996). Our measurements at the census points ranged from 0.04 to 135.89 mR/h, while levels of radiation at the barn swallow breeding sites ranged from 0.02 to 2.90 mR/h, and the levels along the road transects ranged from 0.02 to 1.00 mR/h.

Statistical methods

Radiation level was $\log_{10}$-transformed, while coverage with farmland, deciduous forest, and coniferous forest was square-root arcsine-transformed. We also included radiation level squared to account for non-linear relationships between species richness and abundance, respectively, and radiation. We developed best-fit general linear models to assess the relationship between abundance (dependent variable) and radiation, assuming a Poisson distribution, after inclusion of potentially confounding variables, as implemented in the statistical software JMP (SAS Institute 2000). We started with the full models including radiation, radiation squared, and all potentially confounding variables as predictors. We then eliminated terms using F test or likelihood ratio test (LRT) for model selection. The statistical significance of each variable was tested using a backward stepwise procedure. The final model was reached when all variables had a significant effect at $P < 0.10$. The final models from this approach are listed in Tables 2, 3, 4. None of the conclusions from these models differed from those derived from the full models.

The frequency distribution of counts of birds was skewed, with a disproportionate number of zeros. Therefore, we repeated the analyses using Kendall rank-order correlation and partial rank-order correlation (controlling for the confounding variables listed above), and the statistical conclusions remained unchanged.

Results

We censused birds using standardized point counts at a total of 489 points during 2006–2007 (Møller and Mousseau 2007b, c) and recorded a total of 12 raptors belonging to five species (Table 1). Species composition differed among methods, but this reflected habitat differences (point counts were mainly made in forests; censuses during catches of barn swallows at farms; and car censuses in open farmland). The mean (SE) abundance of raptors observed per 5-min census was 0.031 (0.011), $n = 489$ point censuses. In comparison, the abundance of raptors per point census in Northern Denmark was ca. 0.200 (Grell 1998), which was significantly more than recorded in Ukraine and Belarus (Mann–Whitney U test: $U = 55{,}000$, $P < 0.0001$). The abundance of raptors decreased significantly with increasing level of background radiation [$F = 5.06$, $df = 1, 487$, $P = 0.025$, slope, (SE) $= -0.010$ (0.005)]. There was a higher level of coverage with coniferous trees at points with radiation levels above compared to below the median level of radiation (0.45 mR/h) [above median:

Table 1 Number of birds of prey recorded during three different types of censuses in Ukraine and Belarus, 1991–2007

Species	No. birds of prey recorded during standardized point counts	No. birds of prey recorded during censuses during barn swallow captures	No. birds of prey recorded during car line transects
Accipiter gentilis	1	1	1
Accipiter nisus	0	16	1
Aquila pomarina	1	0	0
Buteo buteo	10	14	103
Circaetus gallicus	1	1	1
Circus aeruginosus	0	2	54
Circus pygargus	0	2	30
Falco subbuteo	0	0	1
Falco tinnunculus	1	2	12
Falco vespertinus	0	0	1
Haliaeetus albicilla	0	0	16
Pernis apivorus	0	1	1
Total	14	39	221

Table 2 Best-fit model of the relationship between abundance of birds of prey recorded during standardized point counts and environmental variables, including background radiation (mR/h)

Variable	Sum of squares	*df*	*F*	*P*	Slope (SE)
Year	0.068	1	5.73	0.017	−0.015 (0.006)
Date	0.065	1	5.48	0.020	−0.007 (0.003)
Time	0.042	1	3.54	0.061	−0.004 (0.002)
Cloud cover	0.200	1	16.88	<0.0001	−0.008 (0.002)
Farmland	0.039	1	3.32	0.069	0.0007 (0.0004)
Radiation	0.084	1	7.08	0.008	−0.014 (0.005)
Error	5.697	482			

The overall model had the statistics $F = 5.12$, $df = 6, 482$, $r^2 = 0.06$, $P < 0.0001$

40.7% (SE = 2.3), below median: 21.8% (SE = 2.1)], and there was less habitat with deciduous trees [above median: 51.8% (SE = 2.4), below median: 77.0% (SE = 2.1)] and farmland [above median: 9.3% (SE = 1.2), below median: 1.4% (SE = 0.4)] in areas with high levels of radiation. However, the effect of radiation remained after adjustment for effects of year, date, time, cloud cover, and habitat including farmland habitat (Table 2). We found a significant difference in abundance of birds of prey among years, a decrease in abundance with time during the season, and a reduction in abundance with increasing cloud cover as expected (Table 2). In addition, we found weak effects of time of day (lower abundance recorded later in the day) and farmland habitat (increasing abundance with increasing level of farmland habitat, as expected because farmland has higher abundance of potential prey) on abundance of birds of prey (Table 2).

While catching barn swallows we spent a total of 211 h in the field during 56 field trips. This amount of time produced 39 observations of raptors belonging to 8 species (Table 1) that were associated with alarm calls by barn swallows. The mean abundance (SE) of raptors observed per h was 0.16 (0.03), $n = 56$. This was significantly less than the mean number of raptors recorded during ringing of barn swallows in Denmark in 2008 [Mann–Whitney U test: $U = -795$, $P < 0.001$; mean (SE) = 0.96 (0.03), $n = 142$]. There was highly significant variation in abundance of raptors among sites ($F = 5.78$, $df = 24, 55$, $P < 0.0001$), showing that the same sites tended to have similar abundances of raptors, with an additional effect of duration of observations [$F = 17.58$, $df = 1, 55$, $P = 0.0002$, slope (SE) = 0.146 (0.035)]. The among-site variation was accounted for by level of radiation [Fig. 2; Table 3; $F = 6.86$, $df = 1, 55$, $P = 0.012$, slope (SE) = −0.37 (0.14)]. There was no significant temporal trend in raptor abundance (effect of year: $F = 0.57$, $df = 1, 52$, $P = 0.45$).

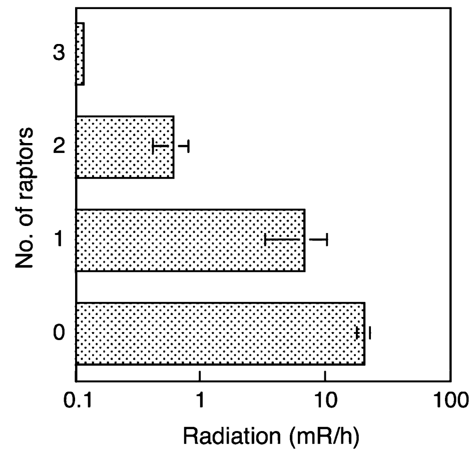

Fig. 2 Abundance of birds of prey during point counts in relation to level of radiation [mR/h, mean (SE)]. Among the 489 point counts, 446 had no raptors

Table 3 Best-fit model of the relationship between abundance of raptors recorded during barn swallow captures and background radiation (mR/h), year and observation effort (number of hours of observation)

Variable	Sum of squares	*df*	*F*	*P*	Slope (SE)
Radiation	3.13	1	6.91	0.011	−0.37 (0.14)
Observation effort	5.07	1	11.17	0.0015	0.15 (0.05)
Error	24.05	53			

Year was not retained in the model. The model had the statistics $F = 10.48$, $df = 2, 53$, $r^2 = 0.28$, $P < 0.0001$

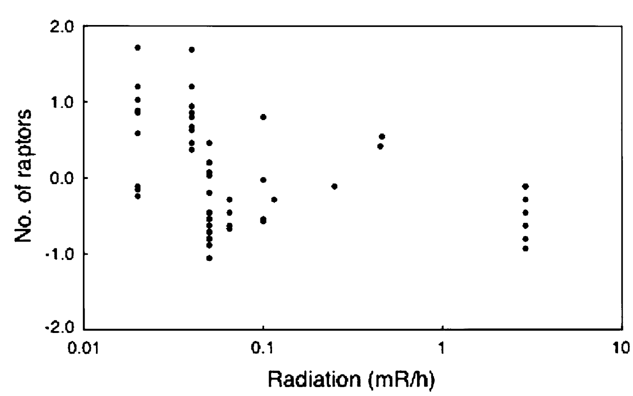

Fig. 3 Abundance of birds of prey during captures of barn swallows in relation to level of radiation (mR/h), after adjustment of abundance of raptors for sampling effort (number of h of observation). Mean abundance at the lowest level of radiation (0.02 mR/h) was standardized to 1 to facilitate comparison with Fig. 4

The third data set consisted of observations of birds of prey from a car while driving between sites where we captured barn swallows. This data set consisted of 106 trips of a total of 12,540 km, revealing a total of 221 birds of prey belonging to 11 species (Table 1). Mean (SE) number of raptors per 100 km driven was 1.74 (0.26), $n = 105$ transects, which was significantly less than was recorded by A.P.M. in Northern Denmark in 2008 [Mann–Whitney U test: $U = 2{,}570.5$, $P < 0.001$, mean (SE) = 6.22 (0.12), $n = 92$ transects]. There was highly significant variation in abundance of raptors among sites ($F = 6.03$, $df = 38, 66$, $P < 0.0001$), showing that the same sites tended to have similar abundances of raptors, with an additional effect of distance travelled [$F = 64.16$, $df = 1, 103$, $P < 0.0001$, slope (SE) = 0.031 (0.004)]. Mean abundance was 1.52 raptors per 100 km in Chernobyl (SE = 0.16), $n = 13$, while it was 3.23 raptors per 100 km in other areas (SE = 1.77), $n = 92$. The among-site variation was accounted for by level of radiation (Fig. 3, Table 4). There was a weakly increasing temporal trend in raptor abundance during 1991–2007 (Table 4). Finally, there was a significant interaction between year and radiation, with an increasing trend in population size in uncontaminated areas, but no significant trend in contaminated areas [Table 4; slope for uncontaminated areas: 0.011 (0.005); slope for contaminated areas: 0.038 (0.038)].

Discussion

The main findings of this study were that (1) the abundance of birds of prey decreased with increasing level of radiation, according to three different census methods; (2) these effects were independent of a number of potentially confounding variables; and (3) the abundance of birds of prey increased weakly in recent years, but mainly in areas with little or no radioactive contamination.

We assessed the abundance of birds of prey during standardized point counts, censuses during field work while catching breeding barn swallows, and line transects by car, and analyses of all three data sets revealed a negative relationship between abundance of raptors and level of radiation independently of whether we controlled for

Table 4 Best-fit model of the relationship between abundance of raptors recorded during car transects and background radiation (mR/h), distance (km) and year

Variable	Sum of squares	*df*	*F*	*P*	Slope (SE)
Radiation (R)	0.74	1	17.45	<0.0001	−0.43 (0.10)
Year (Y)	1.17	8	3.46	0.0017	0.10 (0.05)
R × Y	2.17	8	6.39	<0.0001	0.40 (0.14)
Distance	2.44	1	57.69	<0.0001	0.031 (0.004)
Error	3.64	86			

The model had the statistics $F = 9.61$, $df = 18, 86$, $r^2 = 0.67$, $P < 0.0001$

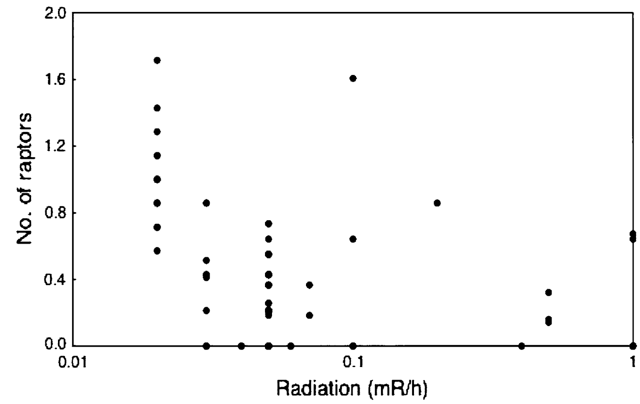

Fig. 4 Abundance of birds of prey during car line transect censuses in relation to level of radiation (mR/h). Mean abundance at the lowest level of radiation (0.02 mR/h) was standardized to 1 to facilitate comparison with Fig. 3

potentially confounding variables. Radiation accounted for 25% of the variance explained by point counts, 12% of the variance for the censuses during capture of swallows, and 23% for car transects. The three census methods are not directly comparable because they targeted birds of prey in different habitats. The point counts were only used to census birds in forests, while the censuses during capture of barn swallows accounted for birds of prey near farms, and the line transects mainly birds of prey in open habitats near main roads. The values of R^2 of the three models differed considerably from 6% for point counts over 28% for censuses during barn swallow captures to 67% during car censuses. These differences among methods are related to the large number of zeros in point counts (91%) compared to swallow censuses (57%) and car censuses (34%), causing the many different factors associated with an absence of raptors to play a disproportionately large role for this type of census. The slope of the relationship between abundance of raptors and radiation was less steep for point counts (−0.014) than for swallow censuses (−0.37) and car censuses (−0.43). Again, point counts in areas covered with forest provided less opportunities for locating raptors than the two other kinds of censuses, and the frequency of points with low levels of radiation was very low. Indeed, if mean abundance of raptors at the lowest level of radiation (0.02 mR/h) was standardized to one, the slope of abundance in relation to level of radiation was −0.12 for point counts, −0.32 for swallow censuses and −0.36 for car censuses.

The official reports by the United Nations and the International Atomic Energy Agency have indicated that there is a temporally increasing trend in abundance of birds of prey in the Chernobyl Exclusion Zone (Chernobyl Forum 2005a, b; UN Chernobyl Forum Expert Group "Environment" 2005), although no empirical evidence for this claim has ever been provided. Using extensive census data based on three different methods, we found a weakly increasing abundance of birds of prey in our long-term data based on car transects. This effect was not the same across sites, only applying to study sites uncontaminated by radioactivity (radiation by year interaction in Table 4). Therefore, there was no evidence that the abundance of birds of prey increased in the most contaminated areas in recent years as claimed by the United Nations and the International Atomic Energy Agency. We could also show that the overall abundance of raptors was very small compared to similar data collected by the same observer in Denmark (A.P.M.).

The abundance of birds of prey is high in farmland because farmland habitats often have high population densities of potential prey (e.g., Newton 1986). Accordingly, we found a weakly increasing abundance of birds of prey in areas with a larger fraction of farmland, although this effect did not reach statistical significance (Table 2).

Previous studies of a number of organisms in Chernobyl and other contaminated areas suggested that bio-accumulation of radionuclides is common (Voitovich and Afonin 2002; Yakushev et al. 1999), and that levels of contamination increases with trophic level (e.g., Kryshev and Ryabov 1990; Kryshev et al. 1992; Smith et al. 2002). Thus, we suggest that effects of bio-accumulation with increasing trophic level may account for the findings reported here.

Radioactive contamination from Chernobyl apparently has strong negative effects on many species of birds as reflected by their reduced species richness and abundance (Møller and Mousseau 2007b, c). These effects may at least partly be caused by a preference for nest sites in uncontaminated areas (Møller and Mousseau 2007a). Furthermore, passerine birds breeding in contaminated areas have reduced levels of antioxidants, reduced hatching success and fecundity, and reduced survival prospects (Møller et al. 2005a, b). Therefore, populations breeding in radioactive sites can only be maintained by immigration from elsewhere, rendering Chernobyl an ecological trap for such immigrants (Møller et al. 2006). The findings that we have reported here suggest that a similar situation may apply to birds of prey.

In conclusion, populations of birds of prey are reduced in radioactively contaminated areas, as revealed by three different census methods. Although population sizes of birds of prey increased weakly in recent years according to one type of census, this effect was significantly more pronounced in areas with low levels of radiation than in the most contaminated areas. Therefore, we suggest that breeding populations of birds of prey around Chernobyl may be reduced due to the effects of radiation on predators themselves, or due to indirect effects of radiation on the abundance of prey.

Zusammenfassung

Verringerte Abundanz von Greifvögeln in radioaktiv verseuchten Gebieten in der Nähe von Tschernobyl

Kürzlich wurde vorgeschlagen, dass die negativen ökologischen Effekte der radioaktiven Kontamination um Tschernobyl moderat seien und zudem abnehmen, da zunehmend anekdotenhafte Sichtungen seltener Tierarten, einschließlich Prädatoren, berichtet wurden. Diese Behauptungen basierten jedoch nicht auf empirischen Befunden. Radionuklide zeigen eine biologische Akkumulation mit höherer Stufe in der Nahrungskette, und die Abundanz von Vögeln ist in radioaktiv verseuchten Gebieten um Tschernobyl abgesunken. Daher sagten wir vorher, dass Greifvögel mit ansteigendem Strahlungslevel seltener werden sollten. Hier nutzen wir unsere Langzeit-Felddaten von 1991–2007 in drei unterschiedlichen, auf Beobachtungen von Greifvögeln basierenden Analysen, die von Standard-Punktzählungen, Erhebungen während des Fangens von Rauchschwalben *Hirundo rustica*, die regelmäßig Alarmrufe ausstoßen, wenn ein Greifvogel anwesend ist, und Linientaxierung während Autofahrten Gebrauch machen. Die Analysen lassen darauf schließen, dass die Abundanz von Greifvögeln in verseuchten Gebieten reduziert ist und dass es Belege für einen kürzlichen Anstieg in der Abundanz von Greifvögeln in weniger kontaminierten Regionen gibt, jedoch nicht in den am stärksten kontaminierten. Unsere Befunde deuten darauf hin, dass Greifvögel, die als Spitzenkonsumenten in Ökosystemen fungieren, unter verringerter Abundanz in radioaktiv verseuchten Gebieten leiden.

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