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Absorbed radiation dose from radon to the Sand Martin *Riparia riparia* during breeding at the sand mines in eastern Poland

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ABSTRACT: Animals that breed in ground holes can be exposed to higher doses of radiation from natural radioactive isotopes, including radon and its daughters, present in soil air. One of such species is the Sand Martin *Riparia riparia*. Examination of natural burrows in sand mines revealed radon levels of 2.82-1320 Bq/m^3 in the examined soil horizon where martins dug their burrows. It was shown that adult males whose colonial breeding took place in sand mines received the following average annual doses, respectively: 4.7 mGy (during the care for one brood) and 8.8 mGy (two broods). The doses for females were, respectively: 4.7 mGy (one brood) and 8.7 mGy (two broods). At the same time, the average dose to chicks from these colonies was 6.4 mGy. The results indicate that, apart from radon concentrations in the soil, also breeding behaviour – rearing either one or two broods – significantly affects the annual absorbed radiation dose to adult birds.

Key words: Radon, Absorbed dose, Sand Martin, Breeding, Burrows

INTRODUCTION

In recent years, there has been an increasing interest in the influence of radiation on the environment, from the perspective of radiological protection not only of humans but also of the total biota (ICRP, 2008). This new approach to radiological protection implies the need to conduct studies on selected species of living organisms in order to determine, among other things, the channels through which radioisotopes get into organisms and the related radiation dose limits.

The highest concentrations of radon are known to occur in the soil air (Appleton, 2007; Jüriado *et al.*, 2011). The air, occupying spaces between grains of soil, is in contact with the radioactive radium present in the soil (^{226}Ra), from which gaseous radon is liberated through emanation. In soil of intact structure a radioactive equilibrium between ^{226}Ra, ^{222}Rn and its daughter products is observed (Turekian & Graustein, 2011). Radon and its progenies are one of the main sources of ionizing radiation having an important influence on living organisms. This, of course, refers to uncontaminated areas, where anthropogenic isotopes are not present or where only those that result from the global fallout are found. Animals connected with the soil, especially those that breed in burrows dug in the soil, are the organisms most exposed to radiation from radon and its daughters (Macdonald & Laverock, 1998).

The literature on this issue is scant and concerns merely a few species of mammals. No published studies are known about birds that dig burrows in the ground and breed in them – despite the fact that many species of birds from the *Hirundinidae*, *Meropidae*, *Alcedinidae*, *Procellariidae*, *Spheniscidae*, and even *Strigidae*, *Anatidae* and *Psittacidae* families breed in ground burrows (Bub & Herroelen, 1981; Fry & Fry, 1992; Woodall, 2001; Warham, 1996; Stevenson & Woehler, 2007; Lutz & Plumpton, 1999; Cabot, 2009; Masello & Quillfeldt, 2002), where they are undoubtedly exposed to radon. In Central Europe, including Poland, the Sand Martin *Riparia riparia* are the species that nests in ground burrows in the largest number (Wolk, 1964; Cramp, 1988; Tomiałojć & Stawarczyk, 2003; Chmielewski, 2004). Sand Martins *Riparia riparia* are the smallest European hirundines *Hirundinidae* (swallows and

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martins). They are agile fliers, feeding on insects mainly over wet area. They perch on overhead wires or branches. They are gregarious in the breeding season and in winter. Over the past 50 years, the European population of this species has crashed on two occasions as a result of drought in the birds' African wintering grounds and possible troubles in migratory routes (Sparks & Tryjanowski, 2007).

Due to its mobility and usually a relatively large abundance of its parent nuclide in the environment, radon is ubiquitous. For this reason, it constitutes the largest component in the annual effective dose received by a person in Poland. Extensive studies are conducted on the accumulation of radon in certain areas, on the bonding of its daughter products with aerosols occurring in the air, on the mechanism of influence of radon and its daughters on the human organism, or on measurement methods themselves. The literature concerning this issue is exceptionally abundant and bases on appropriate dosimetric models developed for years (ICRP, 1987; Axelson & Forastiere, 1993). They enable exact assessment of the effects of inhalation of radon and its daughters in different conditions of exposition. Radiation from radon and its progeny accounts for half of the dose received by an inhabitant of Poland (Report PAA, 2011). Still, the literature provides very limited data in the case of other living creatures.

The study was aimed at specifying the radiation dose that adult individuals of Sand Martins during the breeding cycle as well as their chicks in ground burrows can actually be exposed to in their natural colonies in eastern Poland. This study presents the results of radon (^{222}Rn) activity measurements and dose estimations for free-living birds in natural nesting sites where breeding is certain to have taken place.

MATERIALS & METHODS

Measurements were performed in four places in south-eastern Poland (Lublin region): Bezek (51°10'18"N; 23°14'42"E), Syczyn (51°17'06"N; 23°15'24"E), Lechówka (51°09'56"N; 23°15'23"E) and Serebryszcze (51°08'40"N; 23°34'28"E), where colonies of Sand Martins occupying burrows were found, consisting of 16, 49, 453 and 92 pairs, respectively.

These birds used the steep walls of open-pit sand quarries, 4-15 metres high, in which they dug holes of 50-95cm in depth (at Bezek 30-60cm, Syczyn 45-90cm, Lechówka 40-85cm and Serebryszcze 50-95cm). Sandy soil shows relatively low penetration resistance, which is conducive to the settling of large numbers of birds (Heneberg, 2009).

Soil samples were collected from every site (from each horizon where burrows occurred) and subjected to radiometric analysis that identified gamma radiated isotopes by using a gamma spectrometer (Silena/Canberra) equipped with a HPGe detector (relative efficiency 17%, resolution FWHM 2keV, software Genie 2000, ver. 2010).

Measurements of radon concentration in burrows were carried out in late September, directly after the burrows had finally been left by birds after completed breeding. Inside a burrow, at its bottom, a Picorad passive detector (Niton, Packard) was placed for 24 hours. After exposition, radon concentration was determined by radioactivity measurement with a liquid scintillation method using a Quantulus spectrometer (Wallac, Perkin-Elmer) and Instafluor scintillation cocktail (Packard). On the basis of radioactivity measurements, radon concentration in the air present in the burrows was computed. Taking into account also parameters connected with bird behaviour, calculation was carried out of annual intake of radon in bequerels, annual intake of alpha energy of radon and its progeny expressed in millijoules, and annual absorbed dose to the lungs of an adult individual (male and female) and a chick (in miligreys). The calculations considered the changing mass of chicks from hatching until maturity (referring to daily mass changes) as well as the occurrence of either one or two breeding cycles (in the case of adults).

It is known that soil parameters (such as penetration resistance or proportion of small particles) influenced the nest site selection by birds (Heneberg, 2001, 2003, 2009). Analysing the data from Table 1 one can see that generally burrows occur in horizons of relatively high content of small particles, i.e. below 0.1 mm. This observation confirms Heneberg ascertainment (2003).

Bank Swallows are altricial and nidicolous at hatching. In favourable food and weather conditions, Sand Martins are capable of completing two breeding cycles during one season. Their young are naked, bright reddish pink, and weigh approximately 1.5-1.6 grams at hatching (Petersen, 1955; Turner & Bryant, 1979).

Based on data provided in the literature, the body mass of an adult bird was assumed to be 15.6 g for females and 15 g for males (Bub & Herroelen, 1981; Turner & Bryant, 1979; Turner, 1983; Peters, 1983). Sometimes ecological conditions (food resources, temperature, lack of precipitation, etc.) enable birds to go through one more breeding cycle. In that case, due to the reproductive costs connected with rearing the first brood, the average mass of adult birds during the care for the second brood is lower: 14.6 g for females and 14.1 g for males (Bub & Herroelen, 1981; Turner, 1983). Accurate determination of mass is important because it serves to compute other parameters relevant to dose assessment. These are: lung tidal volume, respiratory frequency and lung mass. Equations for computing these parameters were taken from publications (Macdonald & Laverock, 1998; Peters, 1983; Calder, 1968).

Doses were computed using the equation given by Macdonald & Laverock (1998), which they applied for computing doses to small mammals using burrows. This equation was modified by the omission of the component connected with winter hibernation (typical for some mammals), which does not occur in the case of the studied birds. Due to the different parental roles of adult Sand Martins and the related differences in parental investment during the breeding cycle, allowance was made for the different times that males and females spend in the burrow (in the case of one and two broods separately). For calculation purposes, day and night were assumed to last 14 and 10 hours, respectively. The adoption of this constant parameter stems from the fact that birds often cannot forage due to morning or evening mists, which often occur above depressions areas filled with water and reduce the activity of insects upon them.

In order to assess the time that adult individuals spent in burrows, the data provided in the literature were taken into account; according to these data, it takes a pair of adult Sand Martins 4 days to dig a burrow, and in the meantime they roost together in the burrow being dug. Both birds are equally involved in that activity (Cramp, 1988). As a result, the time spent in burrows by adult individuals amounts to 96 hours for males and females alike. Sand Martin incubation periods in Europe are 14-15 days, 14.5 days on average (Wolk, 1964; Cramp, 1988). During the day, birds of both sexes are involved to an equal extent in the incubation process. The individual that does not incubate forages away from the burrow at the time. At night, in a vast majority of nests controlled, females incubate alone, although some authors report a certain involvement of males in nocturnal incubation. At any rate, males are present in burrows at night (Cramp, 1988; Petersen, 1955). Thus, the total time spent in the burrow during the incubation period was estimated to be 246.5 hours for both males and females.

As they start from building a nest, both members of pairs roost in the nest inside a burrows. Also after the hatch they remain together until the twelfth day from hatching eggs (Cramp, 1988; Petersen, 1955). Periods spent in burrows on feeding chicks during the day are extremely short (lasting a maximum of between ten and twenty seconds). This results from the voracity of chicks caused by their high demand for food, connected with fast growth. With time, space becomes scant in burrows filled with offspring, which gather near the mouth of burrows. That time spent by parents in the burrow was not taken into account in our calculations. However, other authors report that the parents frequently stop-by for only couple seconds, but they also frequently enter the burrows for over a minute or even for over an hour, especially during the mid-day and they frequently spend the night in the burrow, as well. Thus, the time spent in the burrow in this stage of the breeding was estimated to be 120 hours for both males and females. Therefore, the total annual time spent in burrow by both male and female adults was calculated to be 462.5 hours each.

After hatching, on the first day, Sand Martin chicks weigh 1.6 g. This value increases quickly over the following days as a result of intensive feeding by adults (Bub & Herroelen, 1981). And thus, around the 12th or 14th day of life, the mass is already 10 times greater (Turner & Bryant, 1979). Dose calculations took into account those mass changes that had been computed for each day of the chick's life based on figures given by. The young spent their entire time in ground burrows, leaving the nest, on average, on the 22nd day after hatching (Turner & Bryant, 1979). After that time, the diurnal activity of chicks moves outside the burrow. In order to simplify calculations and owing to the lack of other data in the literature, this period of diurnal activity was estimated at 10 hours, just like in the case of adults. Cowley (1983) reports that the young roost in the colony for 10 more days after leaving the nest (until the 32nd day after hatching). Other researchers report a slightly shorter period in which martins still return to ground holes to roost (Sieber, 1980). For the purpose of dose computation, we assumed 22 days of constant presence of the young in ground burrows and another 10 days in which they spend 10 nocturnal hours there. The mass attained by females and males after leaving nests is 14.1 g and 14.6 g, respectively (Bub & Herroelen, 1981). The average value of 14.4 g was adopted for the calculations.

In computing doses, radon concentration outside the burrow, in atmospheric air, was assumed to be equal to 10 Bq/m^3, which is the maximum value for Poland (Radiation atlas of Poland, 2012). This value was used for calculating the doses received by birds outside burrows. However, this assumption is not fully reliable as Sand martins are migratory species and can be exposed to other radon concentrations during their life.

For analysing the obtained results, parametric or non parametric tests were used, depending on data distribution (Sokal & Rohlf, 1981). The results are given as arithmetic mean ± SD (standard deviation) and median value ± SE (standard error).

RESULTS & DISCUSSION

The measured values of gaseous radon concentration in each of the burrows are shown in the chart (Fig. 1), together with the location of colonies where measurements were performed. Soil samples were collected from each site of occurrence of the studied bird colonies in order to determine the concentrations of radioactive ^{226}Ra, the parent isotope for radon. The results obtained using the gamma spectrometric method are shown in Table 1.

For comparison, Table 1 also presents the values of activity concentration of another primordial radioisotope, ^{40}K. As it is shown, the activity concentration of ^{226}Ra is similar for the soil samples collected at the studied locations. Its values range from 8 to 24 Bq/kg and are lower than the average concentration of radium in soils in Poland. Similarly, concentration of ^{40}K in the soil ranges from 120 to 400 Bq/kg and is slightly below its average level in soils in Poland (Radiation atlas of Poland, 2012). A fairly good correlation was found between the amounts of ^{40}K and ^{226}Ra in the samples (Pearson coefficient $r=0.75$; $n=5$; $p=0.14$). However, this correlation was not statistically significant because of a small number of analysed samples. Also some correlation between the amounts of these isotopes and the value of the soil's exchange acidity was observed. This testifies to the bonding of radium with minerals containing potassium and to the influence of pH on this process. Both potassium and radium ions exchange of hydrogen and aluminium ions from the soil grain surface.

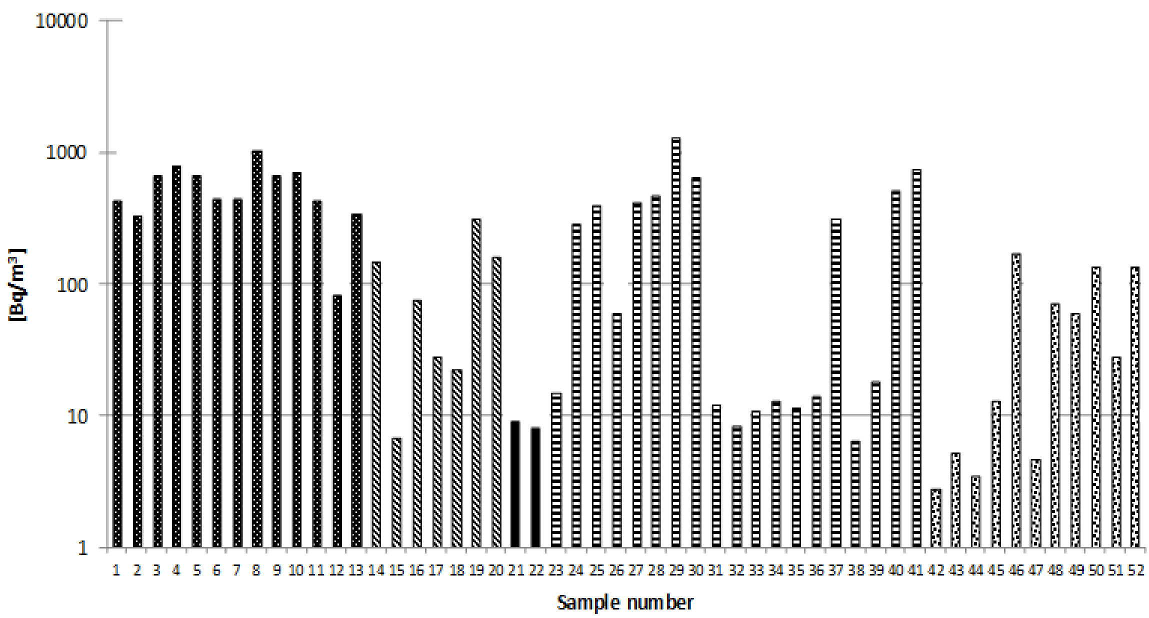

Fig. 1. Radon concentration in the air inside burrows (sample No. 1-13: Lechowka; 14-20: Bezek Kolonia; 21-22: Kamien; 23-41: Serebryszcze; 42-52: Syczyn) [Bq/m^3]

Table 1. Mean activity concentration of ^{40}K and ^{226}Ra by gamma spectrometry in soil samples (0.5 dm^3) taken near burrows, and range and median (in brackets) of ^{222}Rn concentration in the burrows, measured independently

Place	^{40}K [Bq·kg^{-1}]	^{226}Ra [Bq·kg^{-1}]	^{222}Rn [Bq·m^{-3}]
Lechówka	330±11	16±2.6	82 – 1025 (442)
Bezek Kolonia	120±5.2	8.4±2.6	7 – 318 (75)
Serebryszcze	400±5.3	24±0.88	7 – 1320 (61)
Syczyn	280±3.8	14±0.63	3 – 170 (28)
Polish soils (average value)	430	25.0	10

The determined values of radon concentration in ground holes (Fig. 1), constituted the basis for computing the doses received by chicks as well as by males and females during one and two breeding cycles. The results obtained are presented in Table 2. Due to diverse concentrations of radon, calculations were performed for each burrow. The Table 2 presents the values of annual alpha energy intake to the whole body [μJ/body] and the resulting annual dose to the lungs of a given individual [mGy], lungs being the critical organ for radon and its daughters. These calculations were performed for chicks as well as for females and males in two variants of breeding: with one brood or two broods. Also computed were the doses connected with the background level of radon. This concerns a hypothetical situation of birds being outside the burrows but still exposed to the inhalation of atmospheric radon (in this case, of the adopted value of 10 Bq/m^3). Independent parameters used for dose calculation was as follows: time which bird spent in burrow, measured radon concentration and bird body mass (in the case of chick - a daily changing mass). Other constant factors was assumed: radon equilibrium factor in soil = 1, and in atmospheric air = 0.5, conversion factor mJ/Bq = $5.56 \cdot 10^{-6}$ (ICRP, 1987). Basing on the body mass value, calculated as mentioned above, other vital parameters were calculated using allometric equation (Macdonald & Laverock, 1998): lung mass, lung tidal volume and respiratory frequency.

Data concerning radon concentration in burrows, presented in Fig. 1, show considerable diversity, even within the same colony of birds. The level below 10 Bq/m^3 was recognised to be the normal concentration of radon in the air (background radiation). Of all the measurements, in 9 cases (17% of all results) the values did not exceed the natural background radiation level. Average radon concentrations in the studied locations were the following: Lechówka – mean 542±244 Bq/m^3, median 442 Bq/m^3, range 81.9-1025 Bq/m^3; Bezek – mean 109±110 Bq/m^3, median 75 Bq/m^3, range 6.89-318 Bq/m^3; Serebryszcze – mean 280±354 Bq/m^3, median: 61 Bq/m^3, range 6.48-1320 Bq/m^3; Syczyn – mean 57±63 Bq/m^3, median 28 Bq/m^3, range 2.82-170 Bq/m^3.

For these four studied colonies, statistically significant differences were found in the amount of radon emitted by soils in particular sand mines (Kruskal-Wallis test: H = 19.496, df = 3, N = 50, p = 0.0002). The sand mine at Kamień was excluded from analyses because in that colony measurements were performed only for two burrows and radon concentrations were found to be, respectively, 9.0 and 8.0 Bq/m^3, which is below the value adopted as the background radiation. A comparison was made between median concentrations of radon in burrows dug in Miocene formations (Bezek colony: 75.1±48.5 Bq/m^3) and those in burrows dug in Pleistocene formations (the remaining colonies: median 169.8±49.2 Bq/m^3, range 2.82-1320 Bq/m^3). However, no statistically significant differences were found: Mann–Whitney U test: Z = 0.936, n_1 = 7, n_2 = 43, p = 0.348. No such differences were found, either, in the analysis of horizons in which burrows were located: C horizon of Serebryszcze colony (median value: 60.8±63.7 Bq/m^3, range: 6.48-1318 Bq/m^3), and both A and B horizons of Bezek, Lechówka and Syczyn colonies (median: 148.4±51.2 Bq/m^3, range 2.82-1025 Bq/m^3), Mann–Whitney U test: Z =0.459, n_1 = 19, n_2 = 31, p = 0.646.

Analysis of the results of calculations concerning the annual intake of alpha energy for 50 nesting burrows (Table 2) from 4 of the studied colonies of birds (two results concerning the colony in Kamień were rejected for reasons explained earlier) revealed no statistically significant differences (t = 0.179, df = 98, p = 0.857) between females (0.874±0.754 μJ per whole body) and males (0.848±0.732 μJ) in the case of one brood in a season. Since m artins are capable of rearing two broods during one season, calculations were performed for that case as well. It turned out that, when rearing two broods, differences in annual alpha energy intake between females (1.58±1.32 μJ) and males (1.53±1.28 μJ) were not statistically significant, either (t = 0.175, df = 98, p = 0.861). However, statistically significant differences (t = -3.31, df = 98, p = 0.0013) were found between females rearing one brood in a year (0.874±0.754 μJ) and those rearing two (1.58±1.32 μJ). Likewise, a statistically significant difference was found in annual alpha energy intake (t = -3.31, df = 98, p = 0.0013) between males rearing one brood in a year (0.848±0.732 μJ) and those rearing two (1.53±1.28 μJ).

As was to be expected, differences in annual alpha energy intake between chicks (0.923±0.832 μJ) and females rearing one brood (0.874±0.754 μJ) were not significant (t = -0.319, df = 98, p = 0.751). In contrast, females rearing two broods (1.58±1.32 μJ) were exposed to significantly higher intake of alpha energy (t = 2.99, df = 98, p = 0.0035) than their chicks (0.923±0.832 μJ). Similarly, statistically significant differences (t = 2.84, df = 102, p = 0.0054) were observed between chicks (0.923±0.832 μJ) and males rearing two broods (1.53±1.28 μJ), with higher alpha energy intake found for the latter.

Table 2. Radon concentration, annual alpha energy intake and radiation dose for chick and adult of Sand Martins caused by radon inhalation, calculated per lung mass (sampling places: Lechowka, Bezek Kolonia, Kamien, Serebryszcze, Syczyn)

Burrow No.	Radon	Chick		Female bird one hatching		Female bird two hatchings		Male bird, one hatching		Male bird, two hatchings	
	$Bq\cdot m^{-3}$	μJ	mGy	μJ	mGy	μJ	mGy	μJ	mGy	μJ	mGy
Lechowka											
1	438	1.39	9.78	1.30	6.96	2.33	12.82	1.26	7.02	2.26	12.92
2	331	1.10	7.68	1.04	5.55	1.86	10.27	1.01	5.60	1.81	10.35
3	673	2.03	14.40	1.88	10.06	3.34	18.41	1.82	10.14	3.24	18.55
4	788	2.35	16.67	2.17	11.59	3.84	21.16	2.10	11.68	3.73	21.32
5	668	2.02	14.31	1.87	10.00	3.32	18.30	1.81	10.09	3.23	18.44
6	442	1.40	9.86	1.31	7.01	2.34	12.91	1.27	7.07	2.28	13.01
7	442	1.40	9.86	1.31	7.01	2.34	12.91	1.27	7.07	2.28	13.01
8	1025	2.99	21.31	2.75	14.71	4.86	26.78	2.67	14.83	4.72	26.99
9	669	2.02	14.33	1.87	10.02	3.33	18.33	1.82	10.10	3.23	18.47
10	717	2.15	15.27	1.99	10.65	3.53	19.46	1.93	10.74	3.43	19.61
11	432	1.38	9.68	1.29	6.89	2.30	12.69	1.25	6.95	2.24	12.79
12	81.9	0.43	2.79	0.42	2.27	0.79	4.35	0.41	2.28	0.77	4.38
13	343	1.14	7.91	1.07	5.71	1.91	10.56	1.03	5.75	1.86	10.64
Bezek Kolonia											
14	148	0.61	4.09	0.59	3.14	1.08	5.93	0.57	3.17	1.04	5.98
15	6.89	0.22	1.31	0.24	1.28	0.46	2.56	0.23	1.29	0.45	2.58
16	75.1	0.41	2.65	0.41	2.18	0.76	4.19	0.39	2.19	0.74	4.22
17	28.7	0.28	1.74	0.29	1.56	0.56	3.08	0.28	1.58	0.54	3.11
18	22.3	0.26	1.62	0.28	1.48	0.53	2.93	0.27	1.49	0.52	2.95
19	318	1.07	7.43	1.01	5.38	1.81	9.97	0.98	5.43	1.76	10.04
20	162	0.64	4.36	0.62	3.32	1.13	6.25	0.60	3.35	1.10	6.30
Kamien											
21	9.01	0.23	1.35	0.24	1.30	0.47	2.61	0.24	1.31	0.46	2.63
22	7.97	0.22	1.33	0.24	1.29	0.47	2.59	0.23	1.30	0.46	2.61
Serebryszcze											
23	14.8	0.24	1.47	0.26	1.38	0.50	2.75	0.25	1.39	0.48	2.77
24	292	1.00	6.92	0.94	5.04	1.70	9.35	0.91	5.08	1.65	9.42
25	395	1.28	8.93	1.19	6.39	2.14	11.79	1.16	6.45	2.08	11.88
26	60.8	0.37	2.37	0.37	1.99	0.70	3.85	0.36	2.00	0.68	3.88
27	419	1.34	9.42	1.26	6.72	2.25	12.38	1.22	6.77	2.18	12.47
28	474	1.49	10.49	1.39	7.44	2.48	13.68	1.35	7.50	2.41	13.78
29	1318	3.79	27.09	3.47	18.58	6.13	33.77	3.37	18.73	5.95	34.03
30	656	1.99	14.07	1.84	9.84	3.27	18.01	1.78	9.92	3.18	18.15
31	12.4	0.24	1.42	0.25	1.35	0.49	2.70	0.24	1.36	0.47	2.72
32	8.35	0.23	1.34	0.24	1.30	0.47	2.60	0.23	1.31	0.46	2.62

Table 2. Radon concentration, annual alpha energy intake and radiation dose for chick and adult of Sand Martins caused by radon inhalation, calculated per lung mass (sampling places: Lechowka, Bezek Kolonia, Kamien, Serebryszcze, Syczyn)

Serebryszcze											
33	10.8	0.23	1.39	0.25	1.33	0.48	2.66	0.24	1.34	0.47	2.68
34	13.0	0.24	1.43	0.25	1.36	0.49	2.71	0.25	1.37	0.48	2.73
35	11.6	0.23	1.41	0.25	1.34	0.48	2.68	0.24	1.35	0.47	2.70
36	14.3	0.24	1.46	0.26	1.37	0.50	2.74	0.25	1.38	0.48	2.76
37	319	1.07	7.45	1.01	5.40	1.81	10.00	0.98	5.44	1.76	10.08
38	6.48	0.22	1.30	0.24	1.27	0.46	2.55	0.23	1.28	0.45	2.57
39	18.2	0.25	1.54	0.27	1.43	0.51	2.83	0.26	1.44	0.50	2.86
40	521	1.62	11.43	1.51	8.07	2.69	14.81	1.46	8.13	2.61	14.92
41	748	2.24	15.87	2.07	11.05	3.66	20.19	2.00	11.14	3.56	20.35
Syczyn											
42	2.82	0.21	1.23	0.23	1.22	0.45	2.47	0.22	1.23	0.43	2.49
43	5.28	0.22	1.28	0.23	1.25	0.46	2.53	0.23	1.27	0.44	2.55
44	3.53	0.21	1.25	0.23	1.23	0.45	2.48	0.22	1.24	0.44	2.50
45	13.0	0.24	1.43	0.25	1.36	0.49	2.71	0.25	1.37	0.48	2.73
46	170	0.67	4.52	0.64	3.43	1.17	6.44	0.62	3.45	1.13	6.49
47	4.70	0.22	1.27	0.23	1.25	0.45	2.51	0.23	1.26	0.44	2.53
48	71.7	0.40	2.59	0.40	2.13	0.74	4.11	0.39	2.15	0.72	4.14
49	60.0	0.37	2.36	0.37	1.98	0.69	3.83	0.36	1.99	0.67	3.86
50	135	0.57	3.84	0.56	2.97	1.02	5.62	0.54	2.99	0.99	5.66
51	28.1	0.28	1.73	0.29	1.56	0.56	3.07	0.28	1.57	0.54	3.09
52	135	0.57	3.83	0.55	2.97	1.02	5.62	0.54	2.99	0.99	5.66
Background=	10.0	0.23	1.37	0.25	1.32	0.23	1.32	0.24	1.33	0.23	1.33
Arith.mean=	265	0.92	6.38	0.87	4.68	1.58	8.70	0.85	4.72	1.53	8.77
Std. Dev.=	306	0.83	6.01	0.75	4.04	1.32	7.28	0.73	4.07	1.28	7.34
Min.=	2.82	0.21	1.23	0.23	1.22	0.45	2.47	0.22	1.23	0.43	2.49
Max.=	1318	3.79	27.09	3.47	18.58	6.13	33.77	3.37	18.73	5.95	34.03
Median=	135	0.57	3.83	0.55	2.97	1.02	5.62	0.54	2.99	0.99	5.66
Geom.mean=	83.5	0.61	4.02	0.61	3.26	1.13	6.23	0.59	3.29	1.10	6.28

Similar analyses of statistical significance were carried out for annual alpha radiation doses to the lungs of the studied martins. It was shown that in cases of pairs rearing only one brood doses to chicks (6.38±6.01 mGy, range 1.23-27.1 mGy) were higher than doses to females (4.68±4.04 mGy, range: 1.22-18.6 mGy) and to males (4.72±4.07 mGy, range 1.23-18.7 mGy). However, these differences turned out not to be statistically significant (ANOVA, $F_{2,147} = 2.149$, p = 0.120). Differences in annual dose between females (8.70±7.28 mGy, range 2.47-33.8 mGy) and males (8.77±7.34 mGy, range 2.49-34.0 mGy) from pairs rearing two broods were not statistically significant, either (t = -0.046, df = 98, p = 0.963). Statistically significant differences (t = -3.45, df = 98, p = 0.0008) were found for radiation doses between females rearing one brood in a year (4.68±4.04 mGy, range 1.22-18.6 mGy) and those rearing two (8.70±7.28 mGy, range 2.47-33.8 mGy), as well as between males (t = -3.45, df = 98, p = 0.0008) that participate in the care for one brood (4.72±4.07 mGy, range 1.23-18.7 mGy) and those that participate in the care for two (8.77±7.34 mGy, range 2.49-34.0 mGy).

Radon (^{222}Rn) is a radioactive natural gas. It is the decay product of ^{226}Ra, the nuclide of the ^{238}U decay series. A half-life of radon is 3.8 days (Browne *et al.*, 1986), and alpha radiation emission leads to the production of several genetically related radioactive daughters. It is these short-lived radon daughters (two of them – ^{214}Po and ^{218}Po– emit alpha radiation while the remaining ones – ^{214}Bi and ^{214}Pb – emit beta and gamma radiation) that constitute the greatest danger as regards radon inhalation.

Small animals (mammals, birds and reptiles) whose breeding is connected with ground holes may be exposed to relatively high doses of radiation due to small lung mass and high respiratory frequency (Peters, 1983). What poses danger for them is radon and its daughters, whose accumulation in burrows is supported by the so-called "stack effect," namely the pressure difference facilitating the exhalation of radon from the soil to the inside of the holes. Breeding, including the care for young individuals that find safe shelter in ground holes, extends the time spent by birds in places with limited air circulation and in contact with soil material containing radium (ground holes, caves, underground excavations, etc.); as a result, they may be exposed to higher doses of radiation from radon and its progeny. What is important in the case of radon is its gaseous state and the related ease of penetrating the lungs. Radon usually occurs in radioactive equilibrium with its short-lived daughters, which are easily retained in the lungs, causing the greatest radiation damage to tissues (Beresford *et al.*, 2012).

Estimated data concerning the harmfulness of radiation to small mammals were presented in UNSCEAR Report 2008 (UNSCEAR, 2008). It was stated that a radiation dose of less than 40 µGy/h (0.35 Gy/a) to the most highly exposed individual in a population would be unlikely to have an impact on the overall reproductive capacity of a mammalian population (UNSCEAR, 2008). Higher doses may be detrimental to these animals. Simultaneously, it was reported that chronic dose rates of less than 100 µGy/h (0.88 Gy/a) to the most highly exposed individuals would be unlikely to have significant effects on most terrestrial animal communities. Other authors suggested that value of 10 µGy/h (88 mGy/a) indicates that 85% of vertebrate species are protected in such conditions (Andersson *et al.*, 2009).

Concerning birds, the UNSCEAR Report (2008) concludes that the effects of radiation exposure on birds had been shown to be similar to those on small mammals. The ICRP Report (2008) suggests that at dose rates in the range of 0.1-1 mGy/d (0.036-0.36 Gy/a), there was only a very low probability of certain effects occurring that could result in reduced reproductive success or morbidity. At dose rates of the range of 1-10 mGy/d (0.36-3.6 Gy/a) there was some potential for reduced reproductive success. This statement concerns mammals in general (with deer and rat as reference mammals). In the case of birds (duck as a reference bird) it is suggested that, based on metabolism, longevity, and reproductive behaviour, it was reasonable to assume similar results to those for mammals (ICRP, 2008). Our study has shown that even those Sand Martin females that reared two broods received doses that were about 100 times lower than those indicated above. Still, we must realize that even low doses may influence the organisms of animals (Garnier-Laplace *et al.*, 2013), and this biological influence on small warm-blooded organisms is not fully known.

Considering the above, it is necessary to realize that ecological condition may, in certain circumstances, be a factor determining the dose received by birds nesting in burrows. Our study shows that Sand Martins use burrows dug in soils with diverse values of radon concentration. This behaviour, if it is deliberate, can be explained by the possibility of adaptation to specific environmental conditions and may partly account for the ephemeral character of the colonies of this species (Cramp, 1988).

It is obvious that high radiation dose cause more evident effect on birds organisms. Large studies by Møller at al. (2005, 2011, 2013), Møller & Mousseau, (2007, 2007a, 2009, 2011, 2013) and Bonisoli *et al*. (2010, 2010a) performed on the highly contaminated area around Chernobyl (up to 200 µSv/h) evidenced some interesting behaviour of animals, especially birds, made by radiation.They demonstrated that chronic exposure to radiation causes oxidative stress and subsequent morphological aberration (feather albinism, smaller brains), DNA damage and tumours. As a result, the abundance of bird population decreases and birds prefer to breed in areas with low contamination (Møller & Mousseau, 2007).

In all of the studied soil samples collected from nesting sites of the studied martins, we are dealing with similar types of soil with a similar characteristics. Differences in radium activity concentration may only be a result of local changes in physicochemical conditions and the related radioactive non-equilibrium. Activity concentrations of ^{40}K in the examined samples were in the range of 120 - 400 Bq/kg. The values of activity concentration of both radionuclides were below the average values found in the soils of Poland (Radiation atlas of Poland, 2012; Report PAA, 2011). Knowing the value of ^{226}Ra

activity concentration does not, however, make it legitimate to suggest a particular level of radon concentration. There are too many factors influencing the rate of radon exhalation and its accumulation in ground holes.

McDonald and Laverock (1989) examined five species of Canadian small mammals living in burrows, where the concentration of radon in the air reached $10kBq/m^3$. Based on the measured concentrations of radon and the respiratory activity of animals during various periods of their life in burrows, annual doses to the lungs were estimated, even reaching a value above 2.7 Gy (though usually falling between 0.1 and 1 Gy). A similar study was recently performed in England by Beresford et al. (2012), who determined radon concentrations in burrows and estimated the dose rate that mammals such as wood mouse *Apodemus sylaticus*, rabbit *Oryctolagus cuniculus* and fox *Vulpes vulpes* would be exposed to. In both these publications, studies concerned artificial burrows made by researchers and focused on precise determination of radon concentration in the air in the burrows. Based on these data, with an appropriate dosimetric model chosen, doses were estimated for particular species of small mammals. Thus, these authors did not conduct a study of real burrows, chosen, dug, and actually used for breeding by animals of particular species in the soil environment.

Interesting study was performed by Vives i Batlle at al. (2012) who developed a model for calculation of a whole body radiation dose arising from exposure to atmospheric radon. The calculations were performed for many organisms, including birds. However, their calculations led to largely higher doses (being a result of radon inhalation) than obtained in our study. As concerning birds the weighted total dose rate was calculated to be $3.69 \cdot 10^{-3}$ mGy/h per 1 Bq/m^3 of radon concentration in the air (Vives i Batlle, 2012). In our study it was assumed that all radon energy was adsorbed in lung and these values were given in Table 2.

CONCLUSIONS

Summing up, our study has shown that in the burrows dug by birds and used by them for breeding purposes, radon gas is found as a result of exhalation from soil. Based on the measured concentrations of radon in burrows, the time that adult birds and chicks annually spent in these conditions and their changing body mass, annual absorbed doses were computed for the studied birds. These doses were found to be much lower than the values given in the literature as endangering the population. They were also shown to be determined not only by radon concentration but also by ecological factors connected with bird behaviour.

REFERENCES

Andersson, P., Garnier-Laplace, J., Beresford, N.A., Copplestone, D., Howard, B.J., Howe, P., Oughton, D. and Whitehouse, P. (2009). Protection of the environment from ionizing radiation in a regulatory context (protect): proposed numerical benchmark values. J. Environ. Radioact. 100, 1100-1108.

Appleton, J.D. (2007). Radon: Sources, Health Risks, and Hazard Mapping. Ambio **36,** 85-89.

Axelson, O. and Forastiere, F. (1993). Radon as a risk factor for extra-pulmonary tumours. Med. Oncol. Tumor Pharmacother. **10,** 167-172.

Beresford, N.A., Barnett, C.L., Vives i Batlle, J., Potter, E.D., Ibrahimi, Z.-F., Barlow, T.S., Schieb, C., Jones, D.G. and Copplestone, D. (2012). Exposure of burrowing mammals to ^{222}Rn. Sci. Total Environ. **431,** 252-261.

Bonisoli-Alquati, A., Møller, A.P., Mousseau, T.A., Caproli, M. and Saino, N. (2010). Increased oxidative stress in barn swallows from the Chernobyl region. Comp. Biochem. Physiol., A155, 205-210.

Bonisoli-Alquati, A., Voris, A., Mousseau, T.A., Møller, A.P., Caproli, M., Saino, N. and Wyatt M.D. (2010a). DNA damage in in barn swallows (*Hirundo rustica*) from the Chernobyl region detected by use of the comet assay. Comp. Biochem. Physiol., C 151, 271-277.

Browne, E., Firestone, R.B. and Shirley, V.S. (1986). Table of Radioactive Isotopes (New York: John Wiley and Sons, Inc.).

Bub, H. and Herroelen, P. (1981). Lerchen und Schwalben: (*Alaudidae* und *Hirundinidae*). (Wittenberg: A. Ziemsen Verlag).

Cabot, D. (2009). Wildfowl. (London: Harper Collins).

Calder, W.C. (1968). Respiratory and heart rates of birds at rest. Condor **70,** 358-365.

Chmielewski, S. (2004). Sand Martin *Riparia riparia*. (In M. Gromadzki (ed.). Manual of species and site protection Natura 2000. Methodical Manual. Birds. Part 1 (7), (pp. 288-290). Warsaw: Ministry of Environment).

Cowley, E. (1983). Multi-brooding and mate infidelity in the Sand Martin. Bird Study **30,** 1–8.

Cramp, S. (1988). The Birds of the Western Palearctic, Vol. 5, Tyrant Flycatchers to Thrushes, (London: Oxford University Press).

Fry, C.H and Fry, K. (1992). Kingfishers, Bee-Eaters and Rollers. (Princeton: Princeton University Press).

Garnier-Laplace, J., Geras'kin S., Della-Vedova, C., Beaugelin-Seiller, K., Hinton, T.G., Real, A. and Oudalova, A. (2013). 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. J. Environ. Radioact. **121,** 12-21.

Heneberg, P. (2001). Size of sand grains as a significant factor affecting the nesting of bank swallows (*Riparia riparia*). Biologia, Bratislava **56,** 205-210.

Heneberg, P. (2003). Soil particle composition affects the physical characteristics of Sand Martin *Riparia riparia* holes. Ibis **145,** 392-399.

Heneberg, P.(2009). Soil penetrability as key factor affecting the nesting of burrowing birds. Ecol. Res. **24,** 453-459.

ICRP (1987). Lung Cancer Risk from Exposures to Radon Daughters. Publication 50. Annals of the ICRP 38 (Oxford: Elsevier).

ICRP (2008). Environmental Protection: the Concept an Use of Reference Animals and Plants. Publication 108. Annals of the ICRP 38 (Oxford: Elsevier).

IUSS (2007). World Reference Base for Soil Resources 2006, first update 2007, International Union of Soil Science. World Soil Working Group. Report 103. (pp. 1-116. Rome: FAO).

Jüriado, K, Petersell, V. and Raukas, A. (2011). Radon emissions in Harju County, North Estonia. Eston. J. Ecol. **60,** 305-320.

Lutz, R.S. and Plumpton, D.L. (1999). Philopatry and nest site reuse by burrowing owls: implications for productivity. J. Raptor Res. **3,** 149-153.

Macdonald, C.R. and Laverock, M.J. (1998). Radiation Exposure and Dose to Small Mammals in Radon-Rich Soils. Arch. Environ. Contam. Toxicol. **35,** 109-120.

Masello, J.F. and Quillfeldt, P. (2002). Chick growth and breeding success of the Burrowing Parrot. Condor **104,** 574–586.

Møller, A.P., Bonisoli-Alquati, A., Rudolfsen, G. and Mousseau, T.A. (2011). Chernobyl birds have smaller brains. Plos One **6,** 1-7.

Møller, A.P., Bonisoli-Alquati, A., Voris, A. and Mousseau, T.A. (2013). High frequency of albinism and tumors in free-living birds around Chernobyl. Mutation Res., Genetic Toxicol. Environ. Mutagenesis. **757,** 52-59.

Møller, A.P. and Mousseau, T.A. (2007). Birds prefer to breed in sites with low radioactivity in Chernobyl. Proc. Royal Soc. B: Biol. Sci. 274, 1616, 1443-1448.

Møller, A.P. and Mousseau, T.A. (2007a). Determinants of interspecific variation in population declines of birds after exposure to radiation at Chernobyl. J. Appl. Ecol. **44,** 909-919.

Møller, A.P. and Mousseau, T.A. (2009). Reduced abundance of raptors in radioactivity contaminated areas near Chernobyl. J. Ornithol. **150,** 239-246.

Møller, A.P. and Mousseau, T.A. (2011). Efficiency of bio-indicators for low-level radiation under field conditions. Ecol. Indicat. 11, 424-430.

Møller, A.P., Mousseau, T.A. (2013). Low-dose radiation, scientific scrutiny, and requirements for demonstrating effects. BMC Biol. **11,** 92, 1-3.

Møller, A.P., Mousseau, T.A., Malinevsky, G., Peklo, A., Pysanets, E. and Széps, T. (2005). Condition, reproduction and survival of barn swallows from Chernobyl. J. Anim. Ecol. **74,** 1102-1111.

Norris, K. and Evans, M.R. (2000). Ecological immunology: life history trade-offs and immune defense in birds. Behav. Ecol. 11, 19-26.

Peters, R.H. (1983). The ecological implications of body size. (Cambridge: Cambridge University Press).

Petersen, A.J. (1955). The breeding cycle in the bank swallow. Wilson Bull. 67, 235-286.

Radiation Atlas of Poland 2011. (2012). (Warsaw: Chief Inspectorate of Environmental Protection).

Report PAA (2011). Annual Report 2010 (Warsaw: Polish National Atomic Energy Agency).

Sieber, O. (1980). Kausale und funktionale Aspekte der Verteilung von Uferschwalbenbruten (*Riparia riparia* L.). Z. Tierpsychol. **252,** 19-56.

Sokal, R.R and Rohlf, F.J. (1981). Biometry. (San Francisco: W.H. Freeman).

Sparks, T. and Tryjanowski, P. (2007). Patterns of spring arrival dates differ in two hirundines. Clim. Res. **35,**159-164.

Stevenson, C. and Woehler, E.J. (2007). Population decreases in Little Penguins *Eudyptula minor* in southeastern Tasmania, Australia, over the past 45 years. Marine Ornithology, **35,** 71-76.

Tomiałojć, L. and Stawarczyk, T. (2003). The avifauna of Poland. Distribution, numbers and trends. Vol. 2. (Wroclaw: Pro Natura).

Turekian, K.K. and Graustein, W.C. (2011). Natural radionuclides in the atmosphere. (In H.D. Holland & K.K. Turekian (Eds.), Radioactive Geochronometry (pp. 251-278). London: Academic Press).

Turner, A.K. (1983). Time and energy constraints on the brood size of swallows, *Hirundo rustica*, and sand martins, *Riparia riparia*. Oecologia **59,** 331-338.

Turner, T. and Bryant, D.M. (1979). Growth of nestling Sand Martin. Bird Study **26,** 117-122.

UNSCEAR (2008). Effects of ionizing radiation on non-human biota, Report vol. II, Annex E (New York: United Nations).

Vives i Batlle, J., Copplestone, D. and Jones, S.R. (2012). Allometric methodology for the assessment of radon exposure to terrestrial wildlife. Sci. Total Envir. 427-428, 50-59.

Warham, J. (1996). The Behaviour, Population Biology and Physiology of the Petrels. (London: Academic Press).

Wolk, E. (1964). Contribution to the breeding biology of Sand Martin, *Riparia riparia*. Acta Orn. **8,** 125-138.

Woodall, P. (2001). Family *Alcedinidae* (Kingfishers). (In J. del Hoyo, A. Elliott & J. Sargatal, Handbook of the Birds of the World. Mousebirds to Hornbills. Vol. 6 (pp. 103-187). Barcelona: Lynx Edicions).