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SOIL PARTICLE COMPOSITION OF EURASIAN KINGFISHERS' (ALCEDO ATTHIS) NEST SITES

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The first granulometrical analysis of soil samples from nesting banks of the Eurasian Kingfisher (*Alcedo atthis*) is reported. In total 29 samples from 22 banks located in the Czech Republic were analysed using the dry sieve analysis and decantation. Twelve standardized particle size fractions were determined in all groups of samples. Mean particle size of soil samples from banks occupied by Kingfishers averaged 991±1747 µm, the variability of the content of particular soil particle fraction is higher than previously published on Sand Martins and Bee-Eaters. The results suggest that the presence/absence of some particle size fractions in extreme values is decisive for the presence/absence of Kingfishers in each appropriate nesting bank. Among banks unoccupied by Kingfishers were those with soil particles above 40,000 µm, or with the content of particle size fractions 2,346–774 µm below 5%. Kingfishers do not occupy banks with the content of the fraction 9.2–3.0 µm higher than 2.156%, or with the content of the particle size fraction 3.0–1.0 higher than 0.415%, too. Soils composed from grains exceeding any of these values are expected to be unoccupied by the Eurasian Kingfisher.

Key words: Eurasian Kingfisher, *Alcedo atthis*, habitat selection, soil requirements, granulometry

INTRODUCTION

Nesting in holes in sandy or loamy embankments is not uncommon among birds. It is considered as providing protection from changes in weather (HOOGLAND & SHERMAN 1976) and from predators (LACK 1968). Some information is available about the soil requirements of Sand Martins (*Riparia riparia*), especially about the particle composition of nesting banks and some other related factors like compactness, porosity, etc. (SPENCER 1962, SANDMANN-FUNKE 1972, SIEBER 1980, JOHN 1991, HENEBERG 2001). In recent years data afforded information that soil requirements are not exclusively restricted to Sand Martins; European Bee-Eaters (*Merops apiaster*) were identified as the second bird species with the distribution depending on granulometrical characteristics of soils constituting suitable banks for their breeding colonies (HENEBERG & ŠIMEČEK 2004). Thus, there is no evidence about the composition of breeding banks of other hole-digging species, just like Kingfishers (*Alcedo atthis*).

The Kingfisher occurs along slow current, streams, channels and dikes (CRAMP 1985, BUNZEL & DRUKE 1989, TYLER & ORMEROD 1991). This species avoids sites with sparse or very dense vegetation, prefers rivers with availability of fish about 54–60 mm, shallow waters and off course demands sandy or loamy banks for nesting (MORGAN & GLUE 1977, IRIBARREN & NEVADO 1982, RAVEN 1986, PERIS & RODRIGUEZ 1996, 1997, CAMPOS *et al.* 2000). Surprisingly, there are almost no studies involved into the description of basic characteristics of nesting banks. The only known parameters are average dimensions of these banks, and their distance to the water level (see e.g. LLOYD & STERTKAMP 1996). But there are not any exact data about soil requirements of this species except of some vague enunciations about preferences for more sandy or loamy soil types (LLOYD & STERTKAMP 1996).

Habitat is one of the most important factors determining the distribution and settlement of species (PARTRIDGE 1981). For a long time it was assumed that appropriate nesting sites are not limiting. However, an appropriate nesting site must offer food, shelter from predators and unfavourable weather conditions (LI & MARTIN 1991, MARTIN & ROPER 1988). In some cases, the limiting factor is basic and immediate like the location of an adequate substrate where to build the nest. Kingfishers do not need any special nest material but a very specific place where to dig the nest hole, mostly loamy banks along streams soft enough to be excavated but secure enough to avoid collapse caused by water the water stream below or by larger amount of precipitation which may occur during the breeding period. Thus I investigated the soil requirements of nesting Kingfishers as one of most important variables for Kingfishers. The aim was to answer the following questions. (1) What is the size of soil grains of the nesting banks of Kingfishers? (2) Are there any banks avoided by Kingfishers owing to its soil particle size composition? (3) Is there any difference between the composition of Kingfisher nesting banks and nesting banks of other hole-digging birds?

MATERIAL AND METHODS

During the years of 1999–2002 soil samples were collected from 29 holes in 22 nesting banks distributed randomly in the Czech Republic. Samples were collected in districts Benešov (49.47°N, 14.41°E), Liberec (50.46°N, 15.03°E), Plzeň-north (49.45°N, 13.15°E), Prague-west (49.55°N, 14.20°E), and Tachov (49.48°N, 12.38°E). The altitude range varied between 223 and 572 m a.s.l.; 19 nesting localities were in banks of streams, 2 in the riverbank, and one nestplace was in the quarry placed 35 m from the nearest brook. 14 sampling points were in the forest, 8 banks were selected on streams and rivers flowing through meadows and farmland. Because of the random selection the different areas have been combined in the analyses. Additionally, the second group of soil samples (n = 32) was collected from banks which were not occupied by Kingfishers, but fulfilled all parameters stated by PERIS and RODRIGUEZ (1996).

I found before that the Czech population of Kingfishers digs its holes in very homogenous banks that contain layers with very low granulometric variability (HENEBERG unpubl.). But there is the granulometric variability between places on different river terraces, and between places along the shoreline. And this is the reason why I compared samples taken from a large number of localities and not samples from one breeding bank.

A sample of the bank material was defined as an amount of soil collected at a given site on the surface of the bank weighing more than 150 g (sand was scooped at least one centimeter under the surface of the bank). First two groups of samples designated as "from holes" were collected from the soil strata where the breeding holes were present, mostly on places adjacent to breeding holes. Strata under and above holes may contain soil with different granulometrical characteristics (SIEBER 1980).

The HENEBERG (2003) protocol for particle size analysis was used. Briefly, a dry sieve analysis was used to determine the distribution of particle sizes over 0.9 mm in each soil sample (GEE & BANDER 1986, SCHMIDTS *et al.* 1999). Soil samples were treated with 10% H_2O_2 at room temperature. After gas development ceased to evolve, suspension was boiled and dried at 105°C. All retained material was fractionated into particle size ranges over 4.00, 4.00–3.00, 3.00–2.00, 2.00–1.25, 1.25–0.90 and less than 0.90 mm using shaking for 2 minutes. Diameter of particles over 4.00 mm was measured by the slide gauge and these particles were divided into particle sizes > 60.00, 60.00–40.00, 40.00–20.00, 20.00–10.00 and 10.00–4.00 mm. The soil of each size range retained was weighed and percentage by weight in each particle size calculated.

The decantation (BOUYOUCOS 1951) has been used to determine the psamitic, aleuritic and pelitic fraction. Samples were air-died, treated with 10% H_2O_2, aggregates were crushed and the soil was passed through a 2.00 mm sieve. A 100 g sample of particle size range less than 2.00 mm was placed in a glass cup, filled with water and boiled to remove the remains of air. After that 5 ml of 1N sodium hexametaphosphate was added and the contents of the cup stirred for 10 min to thoroughly mix the soil sample. The content was transferred to the sedimentation cylinder, topped to 1,000 ml, shaken for 2 minutes and then allowed to settle. After insertion of the hydrometer were performed readings after 30, 60 and 120 seconds after the end of shaking. Additional settling readings were performed after 5, 15, 30 and 45 minutes and after 1, 2, 5, 12 and 24 hours. Size of particles settled in these times was calculated separately for the particle density of each sample according to Stokes's law.

Particle size limits refer to equivalent spherical diameter, signifying the diameter of spherical particles with the same density and settling velocity as the analyzed particle (SCHMIDT *et al.* 1999). All measurements were taken at 24°C (gravity acceleration of distilled water 980.665 gal). The particle size distribution obtained by using of this method gives similar results like other commonly used methods (FONTAINE *et al.* 2000, NAIME *et al.* 2000).

Based on data obtained by these two methods shares of standardized particle size fractions were calculated. Twelve standardized particle size fractions were determined in all groups of samples – psephitic (over 2.346 mm, splitted into particle sizes > 60.00, 60.00–40.00, 40.00–20.00, 20.00–10.00 and 10.00–2.346 mm), macropsamitic (2.346–774 µm), mesopsamitic and micropsamitic (774–84 µm), macroaleuritic (84.0–28.0 µm), mesoaleuritic (28.0–9.2 µm), microaleuritic (9.2–3.0 µm), macropelitic (3.0–1.0 µm), mesopelitic and micropelitic soil fraction (less than 1.0 µm) (BLAŽEK *et al.* 1978, HENEBERG 2003). Mean particle size of samples was also calculated.

Soil analysis data were pooled into two groups from Kingfisher nestplaces and from banks where the Kingfisher holes were absent, but which fulfill hitherto known conditions for nesting of this species (see above). These groups were analysed separately to investigate the differences between the substrate from Bee-Eater colonies and other localities. Data shown are means ± SD unless stated otherwise.

Crude analysis of the mean particle size has been done using Student's unpaired *t*-test. All *p*-values reported are two-tailed; degree of feedom is shown as the *k*-value (n_1+n_2–2). Savage's index

(SAVAGE 1931) was used to analyse the degree of selection of Kingfishers for each soil category. This index ranges from 0 (maximum negative selection) to infinite, 1 being the central value of no selection. A negative selection occurs when use of a resource is significantly larger than expected at random. No selection, when use does not differ from expected at random. Manly's test (MANLY *et al.* 1993) have been used to find statistical differences of the degree of selectivity from random values. To obtain a significance level, we used comparison of Manly's test results with the critical value of a chi-square with one degree of freedom as stated in MANLY *et al.* (1993).

RESULTS AND DISCUSSION

Soil samples from 29 breeding holes of the Kingfisher were analysed. Physical characteristics of these holes are shown in Table 1. Mean particle size of soil samples from banks occupied by Kingfishers averaged 991±1,747 µm (max. 9,946 µm, min. 200 µm). Soil samples taken from Kinfisher breeding places shown greater variability than those taken previously from Sand Martin and Bee-Eater nestplaces. Differences of the mean particle size between Kingfisher nestplaces and places without any holes are insignificant (t-test $p > 0.05$; $k = 59$) because of the huge variability of these groups of samples. But there is the selection against the mean soil particle size below 200 µm (Manly's test comparing samples from Kingfisher holes and unoccupied places $p < 0.001$), which might be very important. As found previously, Bee-Eaters dig their holes in soils with the average particle size 42.76±13.58 µm, and the maximal average particle size of samples taken from soil strata occupied by Bee-Eaters was only 66.82 µm (HENEBERG & ŠIMEČEK 2004). The difference between samples from Kingfisher and Bee-Eater nestplaces is highly statistically significant (t-test $p < 0.001$; $k = 50$). I found also the significant difference between soil samples taken from Sand Martin holes (192.90±122.34 µm, max 498.96 µm, min 23.45 µm HENEBERG & ŠIMEČEK 2004) and samples from Kingfisher holes (t-test $p < 0.001$; $k = 161$). Selection of Kingfisher nesting

Table 1. Physical characteristics of Kingfisher holes from which the soil particle size was measured (n = 29). Distance to the bottom was measured as the distance to the water level or to the talus cone. Distances are shown in cm; slope in degrees

Physical characteristics	Mean±SD	Min.	Max.
Tunnel depth	57.4±11.6	40.0	82.0
Height of the entrance opening	6.5±1.2	5.0	9.5
Width of the entrance opening	5.9±1.0	4.5	9.0
Slope of the tunnel	5.9±2.5	3.0	11.0
Distance of the hole to the bank top	59.4±31.7	30.0	130.0
Distance of the hole to the bottom	138.8±85.8	52.0	460.0

banks seems to be less dependent on the mean particle size of soil samples than those published on other hole-digging species (HENEBERG 2001, HENEBERG & ŠIMEČEK 2004); nevertheless I found here the absence of Kingfisher holes in soils with the mean particle size below 200 µm.

From the distribution of twelve standardized particle size fractions of soil particles from Kingfisher breeding banks (Table 2) we may conclude that psephitic fractions (fractions above 2,346 µm) cannot be considered as the crucial factor for the nesting of Kingfishers becuse of its huge variability (average portion 13.551±15.686%). Kingfishers have avoided only banks with the majority of soil particles over 10,000 µm; I din't find any Kinghfisher hole in the material containing these particles. Selection against psephitic particles is known from Bee-Eaters (HENEBERG & ŠIMEČEK 2004). HENEBERG (2001) had observed absence of larger colonies of Sand Martins in embankments containing more than 10% of particles >10,000 µm.

Contrariwise, the content of particles sized between 2,346 and 28 µm shows only very low variability. Particle size fractions 2,346–774 µm, 774–84 µm and 84–28 µm represent this size of particles in the analysis presented here. Content of the particle size fraction 2,346–774 µm in samples from banks occupied by Kingfishers is 25.470±11.674%. This value is significantly higher (Manly's test $p < 0.01$) than values known from Bee-Eater and Sand Martin nestplaces (9.4%, and 18.0%, respectively; HENEBERG & ŠIMEČEK 2004). Variability of control samples from unoccupied banks ranged between 0.185% and 74.105%. Content of particles sized between 774 and 84 µm in the soil from Kingfisher nesting banks was 21.107±13.399%, range of control samples was between 0.000% and 62.827%.

Table 2. Distribution of standardized particle size fractions of soil particles from Kingfisher breeding banks (n = 29)

Fraction range [µm]	Relative portion (mean±SD)	Min.	Max.
40,000–20,000	0.417±3.918	0.000	21.100
20,000–10,000	0.644±3.575	0.000	19.252
10,000–2,346	12.101±12.554	0.000	49.169
> 2,346 (Σ psephitic particles)	13.551±15.686	0.000	62.401
2,346.0–774.0	25.470±11.674	6.847	59.736
744.0–84.0	21.107±13.399	4.112	48.087
84.0–28.0	33.106±17.440	7.732	76.288
28.0–9.2	6.430±6.417	0.245	23.367
9.2–3.0	0.624±0.608	0.011	2.156
3.0–1.0	0.009±0.117	0.000	0.415
< 1.0	0.092±0.099	0.000	0.270

HENEBERG & ŠIMEČEK (2004) found that the content of this particle size fraction (774–84 µm) amounted 37.5% in samples from Bee-Eater nestplaces and 53.6% in samples from Sand Martin holes. Difference between samples from Kingfisher and Sand Martin nestplaces is significant too (Manly's test $p < 0.001$). Soil particle size fraction between 84 and 28 µm amounted 33.106±17.440% in samples from Kingfisher nesting localities; whereas data obtained from Bee-Eater and Sand Martin localities reached 49.7±19.7% and 4.8±9.5% respectively (HENEBERG & ŠIMEČEK 2004). Differences of this particle size fraction between samples from Kingfisher and Sand Martin holes are statistically highly significant (Manly's test $p < 0.001$); its content in Kingfisher and Bee-Eater nestbanks is similar (Manly's test $p > 0.05$). Control groups of samples ranged between 89.587% and 1.890%.

Content of all four fractions under 28 µm was highly variable (Table 2), some samples did not contain any particles from the last two fractions. Control samples had only slightly higher varibility in these fractions; thus no significant difference was found in the content of these fractions (t-test $p > 0.05$ for all four fractions; $k = 59$). The only important fact is I have not found any occupied banks with the content of the fraction 9.2–3.0 µm higher than 2.156% (control samples have values up to 5.452%) and birds also avoided soils with the content of the particle size fraction 3.0–1.0 higher than 0.415% (control samples have content of this fraction up to 1.033%).

How to find banks avoided by Kingfishers because its soil particle size composition?

One of most frequent questions is: Which soil particle size might be used as an indicator, that the bank might be occupied by Kingfishers? To establish this indicator it may be very helpful to build man-made nestplaces for Kingfishers as well as routinely monitoring and conserving this species. Soil requirements of birds differ from species to species and the presence of each species mostly depends on the presence or absence of a few crucial soil particle size fractions together with other important biotical and abiotical factors like the vegetation present close to the bank, availability of fish of the appropriate size etc. (RAVEN 1986, PERIS & RODRIGUEZ 1997, CAMPOS *et al.* 2000, etc.). From data presented in Table 2, we know, which composition of nesting banks is preferred by Kingfishers, but we do not know whether there are any localities avoided by these birds. Before this study, I stated the hypothesis that the presence/absence of some particle size fractions in extreme values is decisive for the absence/presence of Kingfishers in each appropriate nesting bank. Therefore it is not possible to suggest any single particle size fraction which might serve as an indicator of the eligibility of each bank to be occupied by Kingfishers. Instead whole analysis should be done as performed for each sample here and after that we may see whether there are any extreme values which may cause the ineligibility of the bank to be occupied by Kingfishers. For this reason, we may use for example statistics of the Savage's index (SAVAGE 1931) and Manly's test (MANLY *et al.* 1993) as above, which would allow us to see differences between samples for each particle size tested.

Based on results acquired during this study, we may conclude that among banks unoccupied by Kingfishers are those with soil particles above 40,000 µm, or with the content of particle size fractions 2,346–774 µm below 5%, and those with the content of the fraction 9.2–3.0 µm higher than 2.156%, or with the content of the particle size fraction 3.0–1.0 higher than 0.415%. Soils composed from grains exceeding of any of these values are expected to be unoccupied by the Eurasian Kingfisher.

FUTURE VIEWS

It is highly interesting that all the three bird species with known soil requirements differ in preferences for each soil type. Nestplaces of Sand Martins localized to river banks may be used as a very good example for describing this fact. Despite the fact that most rivers and streams in the Czech Republic has regulated banks, there are still a few rivers having eroded sandy or loamy banks and allowing to see, whether there might be shared nestplaces of Kingfishers and Sand Martins. Sand Martins prefer sites without any vegetation before or even above the nesting banks, whereas nest sites of the Kingfisher do not display such a strong selection dependence on the vegetation cover close around the nestplace. Thus there should be the possibility to find these two species sharing mixed colonies. Banks of rivers Litavka, Svratka and Jihlava serve or served during the last five years as nestplaces for both these species. It was also possible to find their holes localized close to each other; it means in the order of meters. But I never found there any shared colony in meaning colony in the same type of substrate as characterized by the particle size. Kingfishers preferred everytime the more loamy layers whereas Sand Martin holes were in the more sandy parts of banks. The similar observation was reported previously for Bee-Eaters (HENEBERG & ŠIMEČEK 2004). Reasons for this habit are still unknown. We could speculate that it is because of different digging capabilities of these species. And if so, it might be explained as the classical differentiation of species to be able to use the whole spectrum of bank substrates available. As stated before in the case of woodpeckers, they are limited by the ability of suitable substrates (trees with appropriate hardness) (SCHEPPS *et al.* 1999). It would be very interesting to know whether the soil requirements of hole-digging birds differ similarly in tropical regions, where the higher number of such species compete for the available resources.

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