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Sediment type and breeding strategy of the Bank Swallow *Riparia riparia* in western Sweden

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Abstract

This paper presents an investigation of the sediment used by the Bank Swallow (Sand Martin) *Riparia riparia* for the construction of breeding tunnels. Grain-size distribution, bulk density and hydraulic conductivity of breeding-tunnel sediment were investigated at four localities in western Sweden. The investigation shows that the Bank Swallow was consistent in using layers composed of a narrow range of fine and medium sand. Ninety percent of the investigated breeding burrows were located in fine to medium sand (0.125–0.5 mm) and 10% in coarse sand (0.5–1.0 mm). No breeding tunnels were found in sediment finer than fine sand or coarser than coarse sand. The fine to medium sand fraction has the properties to hold stable walls and keep dry tunnels even during rainy periods with heavy infiltration. The hydraulic conductivity of the sediment was in the range of 10^{-4} to 10^{-3} m/s and the bulk density 1510–1575 kg/m^3. In Sweden, artificially excavated slopes in gravel and sand pits have long been the dominating breeding locality for the Bank Swallow. However, during the last two decades, four major factors have led to the decrease of breeding localities: (1) a decreasing demand of aggregate resources, (2) landscaping of gravel and sand pits and stabilization of eroding slopes, including river banks and shorelines, (3) a change to quarries as a source for aggregate production, and (4) concentrating gravel and sand exploitation to fewer and larger pits. It is concluded that these factors are important for the decline of the Bank Swallow population in Sweden and possibly elsewhere in Europe and North America.

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Introduction

The Bank Swallow *Riparia riparia* is the smallest bird in the swallow family and it is distributed as a breeding bird in much of North America north of Mexico and reaches the Artic Sea in the northern Mackenzie Delta region. In Eurasia it breeds from the British Isles east to the Anadyr region and Kamchatka, and south to northern Indian subcontinent. The Bank Swallow is an obligate migratory species wintering in South America, Africa and southern Asia. There are also resident populations in northern Indian subcontinent and southwest China.

To avoid predation the Bank Swallow is known to dig breeding tunnels into vertical exposures of stiff, sandy sediment. In Sweden, artificially excavated slopes of gravel and sand pits have long been the dominating breeding locality. The species has benefited from the expansive building and construction period from the early 1950s up till the 1980s, a period during which many glaciofluvial deposits were exploited, and a large number of new gravel pits were opened. The swallow prefers fresh shaft walls with ongoing excavation every year. A shaft wall left to erode and slump will be abandoned within a few years.

The last twenty years, however, has brought about a decrease in gravel production and during the same period there has been an increase in conservation efforts to stabilize eroding slopes, including riverbanks and shorelines. At the same time a long-term decline (1970–1990) in the Bank Swallow population has been observed in western and north-western Europe (Tucker & Heath 1994, Gamell 1997). Similarly, there has been a long-term (1980–1994) as well as short-term (1994–1996) decrease in eastern Canada and eastern USA (DeGraaf & Rappole

1995).

Various explanations have been given as the cause of the decline of many migratory boreal species wintering in tropical areas, but apparently the reasons are multifunctional and few data exist on which part of the life cycle that is the most critical (John 1991). The loss of breeding habitat is the single factor where there seem to be a consensus among different authors but the decline in the Bank Swallow population in Europe has also been ascribed to the drought in the wintering area Sahel (Cowley 1979, Mead 1979, Szép 1995).

In Sweden it has been observed that the Bank Swallows dig their burrows as high up as possible in the banks (Svensson 1969). The typically breeding ground for the Bank Swallow in Sweden is within the uppermost 100 cm, sometimes only about 40 cm below the ground surface and 4 to10 meters up on the shaft wall in an active gravel pit where the vegetation layer has been removed. The hydraulic conductivity of such sediments is very high, 10^{-2} to 10^{-5} m/s, (600 to 0.6 mm/minute) (Brown 1972). This means that all precipitation, even during very rainy periods, can infiltrate and percolate through the soil profile. Because the vegetation cover is removed the evaporation is very small and during rainy periods, like in Sweden in July 1998 or 2000, more than 100 mm of rain may fall during 72 hours. This means that a 100 mm thick water body will move down through the soil profile. How can the Bank Swallow keep their breeding tunnels dry and warm? Why don't they drown when such a great amount of water passes through the sediment layer where they breed?

The purpose of this paper is to give the hydrogeological background to a clever and successful breeding strategy of the Bank Swallow and to highlight factors important for the decline in the Swedish Bank Swallow population.

Investigation method

An inventory was made of the breeding localities of Bank Swallow in an area of western Sweden covering about 14,000 km^2. It turned out that many of the former well known localities were destroyed and abandoned. Four major localities, Gråbo, Hyltenäs, Öxnevalla and Sjögärde in three different counties were found and chosen for investigation of sediment properties (Figure 1). All localities were built up of glaciofluvial deposits with alternating silty, sandy and gravely layers. Fifty sediment samples were taken both from the breeding horizons and from the surrounding horizons at all four localities. Samples were taken systematically to give a representative picture of the breeding horizons and a possibility to comparison with the surrounding. About 2 kg sediment were taken in each sample. In addition, three undisturbed cylinder samples (diameter 8.2 cm, height 5.0 cm) were taken from the uppermost breeding horizon at Gråbo. Grain size was measured using sieves with mesh size 2.0, 1.0, 0.5, 0.250, 0.125 and 0.074 mm. Grain-size statistics were computed using the equations of Folk and Ward (1957);

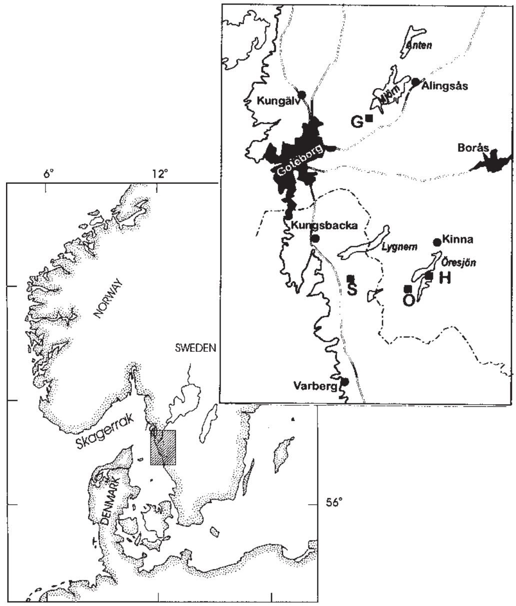

Figure 1. Investigation localities for sediment type and breeding strategy of the Bank Swallow in western Sweden: Gråbo (G), Hyltenäs (H), Öxnevalla (Ö) and Sjögärde (S).
Lokalar för undersökning av sedimenttyp och häckningssrategi för backsvala i västra Sverige: Gråbo (G), Hyltenäs (H), Öxnevalla (Ö) och Sjögärde (S).

Sorting, $S = (\phi84 - \phi16)/4 + (\phi95 - \phi5)/6.6$

Mean grain size, $Mz = (\phi16 + \phi50 + \phi84)/3$

The hydraulic conductivity (K) was measured in a constant head permeameter with a pressure head of 20 cm and the dry bulk density (ρd) was calculated.

Sediment properties of Bank Swallow breeding sites in Sweden

Bank Swallow breeding sites in Sweden typically consist of sandy sediments that are part of stratified

Figure 2. Photo from the locality Sjögärde showing breeding tunnels of Bank Swallow in selected sediment layers high up in vertical shaft walls.
Foto från Sjögärde visande häckningstunnlar i utvalda lager högt upp i den vertilaka schaktväggen.

glaciofluvial deposits with alternating silty, sandy and gravely layers. Practically all breeding localities for the Bank Swallow in western Sweden are situated in gravel and sand pits in glaciofluvial deposits that were deposited about 11,000 to 12,500 BP during the Weichselian deglaciation. The breeding horizons are situated in the uppermost sandy layers of stiff, vertical walls (Figure 2) usually within the upper 100 cm and four to ten meters from the cliff base.

Grain size distribution of sediment samples from breeding tunnel horizons at all four localities show that the Bank Swallow is consistent in using layers within a quite narrow range of fine and medium sand (Figure 3). The mean grain size for breeding-tunnel sediment ranges from 0.125 mm (fine sand) to 0.8 mm (coarse sand) with most samples occurring between 0.125 mm and 0.35 mm (medium sand). Ninety percent of the investigated breeding burrows were located in fine to medium sand (0.125–0.5 mm) and 10% in coarse sand (0.5–1.0 mm). The samples are moderately sorted with a sorting factor, according to Folk & Ward (1957) ranging from 0.6 to 1.3 (Figure 4). Most of the samples have a sorting factor between 0.5 and 1.0, which signifies moderately sorted sediment according to the relative scale suggested by Folk & Ward. The mean grain size of all samples is 0.143 mm (ϕ 2.8). There is no significant difference in grain size or sorting between the four localities. The actual breeding layers are surrounded by coarser sandy-gravely layers and finer, silty layers. There is no evidence for a systematic distribution of coarser or finer sediment over- or underlayering the breeding horizon. However, analysis of samples from surrounding horizons reveals that there are other sandy layers with similar conditions that are not used by the swallows (Figure 5).

The hydraulic conductivity (K) and the dry bulk density (ρd) of the sediments from the breeding horizon at Gråbo is presented in Table 1.

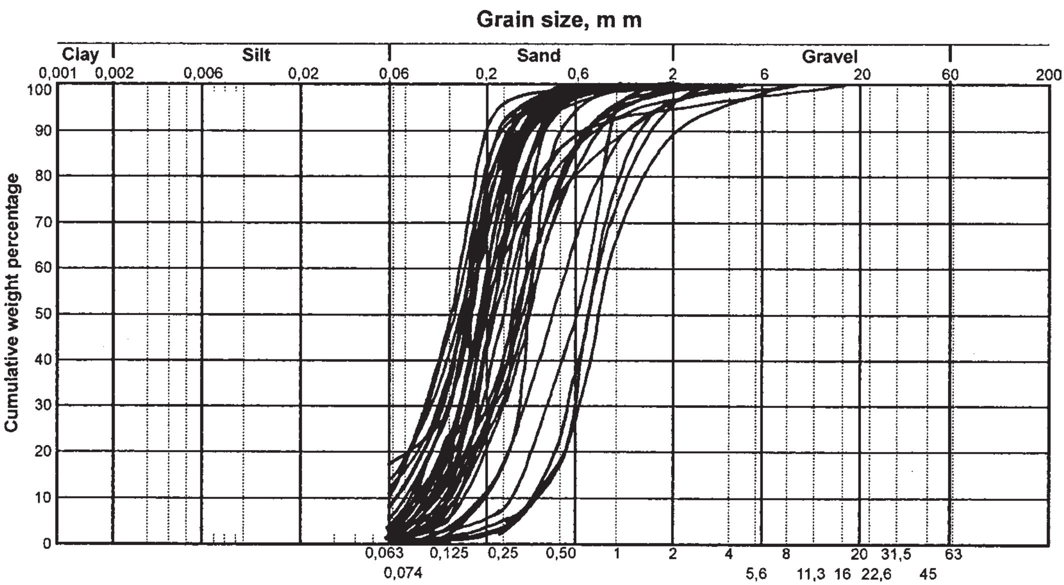

Figure 3. Grain size distribution curves for sediments with Bank Swallow breeding tunnels from all four investigation localities.
Kornstorlekskurvor på sediment från häckningshorisonter i alla fyra undersökningslokalerna.

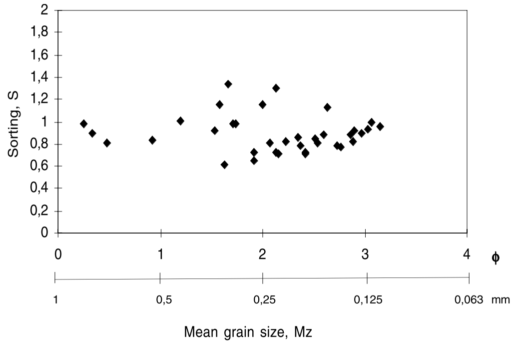

Figure 4. Mean grain size and sorting (Folk & Ward 1957) of sediments with breeding tunnels. 36 samples.
Medelkornstorlek och sortering (Folk & Ward 1957) hos sediment med häckningstunnlar, 36 prover.

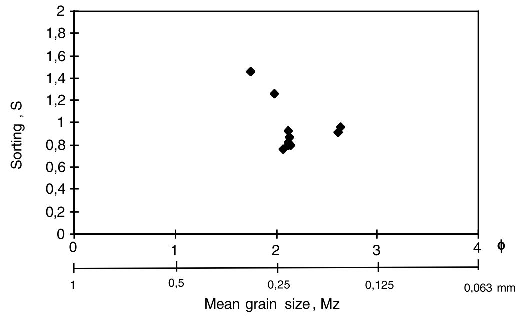

Figure 5. Mean grain size and sorting (Folk & Ward 1957) of sediments without breeding tunnels. 9 samples.
Medelkornstorlek och sortering (Folk & Ward 1957) hos sediment utan häckningstunnlar, 9 prover.

The K-values show that water at free drainage, with a gradient 1.0 can move through the soil profile at a velocity of about 0.4 to 3.0 mm/s. This means that once the sand is saturated, rainwater can infiltrate and percolate through the sand at about 1.4 to 10 m per hour. During heavy rains there will be a saturated water body moving down towards the breeding tunnels. Within the saturated zone all small pores in the soil will be filled with water. However, as shown below, the percolating water does not reach the birds' nests!

Sand is a consolidated sediment with a porous system consisting of a solid phase (the particles), a liquid phase (water) and a gaseous phase (air). In the absence of organic material water is held in the pore system by surface tension and the adsorption of water to the mineral particles. The pressure potential is considerably lower in the fine pores of the surrounding sand compared to the free air pressure in the breeding tunnel. When rainwater percolates through the sand and reaches the edge of a tunnel, it will stop with a concave surface towards the free air pressure in the tunnel.

If the rain does not stop, percolation continues, and there will be a saturated zone growing around the breeding tunnel. This will increase the pressure potential in the rising water body on top of the tunnel. If the tunnel is big, > 0.5 m in width, this can cause a breakthrough and water will drain rapidly into the bird nest. At smaller tunnels, like normal Bank Swallow nests, this will not happen because of the fact that the water is drained around the burrow. The unsaturated hydraulic conductivity increases exponentially with the water content (Irmany 1954). Consequently, as the water content is rising around the burrow, the hydraulic conductivity is increasing. Thus, all percolating water will drain around the burrows even through very rainy periods. This is characteristic for fine and medium sand. In coarser sand the capillary rise is much smaller causing a smaller difference in potential pressure between a pore and the free air in a breeding tunnel. Thus, the percolating water will drain into the tunnel and damage the nest.

The bulk density of the breeding site sediment was about 1500 kg/m^3 to 1575 kg/m^3, which is characteristic for relatively loose sediment (BABS 1967, Wahlström 1968, Avén et al. 1984). Finer sediment, like silt and clay, situated in a drained position in a pit wall has the disadvantage of being harder to dig. Riverbanks with clay saturated by the spring floods may be significantly softer, and provide good natural breeding conditions for the Bank Swallow. However, very few such localities are known in Sweden.

Table 1. Hydraulic conductivity and dry bulk density of breeding ground sediments of the bank swallow. Gråbo western Sweden.
Hydraulisk konduktivitet och skrymdensitet hos sediment från backsvalornas häckningshorisonter. Gråbo västra Sverige.

Sample	Hydraulic cond. K, m/s	Dry bulk density ρd, kg/m^3
1	$3x10^{-3}$	1575
2	$4x10^{-4}$	1509
3	$1x10^{-3}$	1518

Breeding behaviour, aggregate resources, and the decline of habitat for the Bank Swallow in Sweden

There is a strong trend of a declining number of breeding localities for the Bank Swallow in Sweden. During the last two decades there are four major factors affecting the breeding localities in Sweden: (1) a decreasing demand of aggregate resources, (2) landscaping of gravel and sand pits and stabilization of eroding slopes, including river banks and shorelines, (3) a change to quarries as a source for aggregate production, and (4) concentrating gravel and sand exploitation to fewer and larger pits.

The construction industry, including road and house construction, is the overall dominating consumer of aggregate resources, with gravel and sand as the major components. Since building activities are closely linked to the general economic conditions in the region, the use of aggregate is strongly influenced by economic expansion or recession (Irvine 1994, Vagt & Irvine 1998). In Sweden the production of gravel and sand reached a peak during the 1970s with100 Mt/year and has since then been declining. Only 30 Mt were produced in 1997 (Rydh & Berg 1998) and 29 Mt in 1999 (SGU 2000:3). During the same period the number of permissions for sand and gravel exploitation declined from about 8500 to about 3500, a reduction of 58% (SIND 1980:1, Rydh & Berg 1998). During the same period, the share of aggregate derived from stone quarries increased from 20% to 50%.

The Swedish legislature gives local authorities the authority to regulate the sand and gravel industry. In the interest of safety and environmental quality, these authorities have required that abandoned gravel pits be re-landscaped. With similar motives, there is an environmental policy in Sweden to decrease the number of sand and gravel pits, and to concentrate exploitation to fewer but bigger pits, often with mining down below the groundwater table (SNV 93). The national goal is that the consumption of natural sand and gravel shall decrease with 50% to 2010 and with 90% to 2020 compared with the consumption in 1997 (Boverket 1999).

These trends described above may seem rational from a resource perspective but they are definitely a growing threat for the Bank Swallow reproduction. In regions with relatively little glaciofluvial deposits, as in western Sweden, the situation may be critical. In the county of Bohuslän at the Swedish west coast there was in the year 2000 only about 45 active sand and gravel pits, and only a few of them was suitable as breeding sites for the Bank Swallow.

Discussion and conclusions

The sediment breeding hirundines, such as the Bank Swallow, are very light and weak birds, only 12–13 cm in length. The Bank Swallows are very dependent on loose sediments that are easy to dig. The nest sites are found in a great variety of sediments, from coarse gravely to clayey soils, but there is a strong concentration to fine-medium sand with a clay content less that 10% (Petersen 1955, Svensson 1969, Heneberg 2001). With the appropriate combination of fine to medium sand that is easy to dig and yet stable enough to give safe walls, they have found the ultimate strategy in their nesting. Besides the importance of the penetrability conditions (John 1991) the grain size also is crucial to the hydrogeological conditions. The sandy sediment has the right capillary conditions to be well drained and leave dry tunnels and yet keep enough moisture to uphold the electrostatic attraction between the sand grains. The breeding success is correlated with the synchronisation of broods but also with the length of the breeding tunnels (Siber 1980) – and that in turn is correlated to the sediment properties. The flow of water around the nest is guided by the pressure potential and the hydraulic conductivity (Figure 6). Where such sand layers are located high on vertical cliffs, the swallows are safe from predation. The use of fine and medium sand layers seem to be a collective choice. It looks like the first hand alternative is to dig the breeding tunnels at the same elevation – in the very same sediment layer. Only if that layer is fully used the birds will start to use other layers with similar conditions.

Among the hirundines, the Bank Swallow is only one of many species that use the strategy of breeding in tunnels. Of the nearly 80 different species of swallows, some 12 species regular dig out long tunnels in banks, including all species of *Riparia*, Banded Martin *Neophedina eurystomina*, Tawny-headed Swallow *Stelgidopteryx fucata*, White-backed Swallow *Cheramoeca leucosternus*, Grey-rumped Swallow *Hirundo griseopyga* and Brazzás Martin *Phedina brazza*. All but the last two are colonial. Among non-hirundines passerines and non-passerines, bee-eaters *Meropidae*, kingfishers *Alcedinidae*, motmots and some puffbirds excavate their own tunnels. The bee-eaters generally nest colonially as the Bank Swallow, while kingfishers, motmots and puffbirds nest solitarily. Furthermore a lot of species of Procellariiformes also nest in burrows. For the non-hirundine passerines and the non-passerines that are tunnel or burrow breeding,

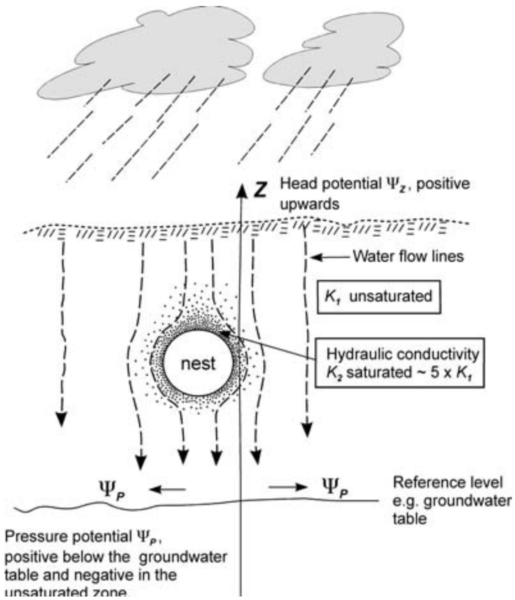

Figure 6. Hydrogeological conditions of water percolating around a Bank Swallow tunnel. The percolating water is drained around the *Riparia* nest because of the lower pressure potential in the fine pores of the surrounding sand compared to the free air pressure in the tunnel.
Hydrogeologiska förutsättningar för perkolerande vatten att passera runt backsvalornas häckningstunnlar. Sjunkvattnet dräneras runt tunneln på grund av den lägre tryckpotentialen i sandens finkorniga porsystem jämfört med det fria lufttrycket i tunneln.

the selection of soil material is not bound to fine to medium sand. Heavier species such as bee-eaters, kingsfishers and motmots, normally use finer grained material such as clay for their breeding sites. These tunnels are often wet and muddy but the birds are quite robust and can still survive with their young generations.

The Bank Swallow, however, is very dependent on the right kind of sediment and location. In Sweden much of these locations are to be found in sand and gravel pits. Thus the dramatically decrease in open pits to a great extent is affecting the Bank Swallow reproduction. We believe that this can be one important factor for the decline of the population in all western countries including Canada, USA and Europe. For the future it is important to save suitable breeding sites for the Bank Swallow and a strategy to keep natural and excavated steep slopes open must be developed. This calls for a creative co-operation between ecologists, environmentalists and engineers.

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Sammanfattning

Sedimenttyp och häckningsstrategi hos backsvalan Riparia riparia *i västra Sverige*

Denna uppsats redovisar en undersökning av de sediment som backsvala *Riparia riparia* utnyttjat för sina bohål i fyra häckningslokaler i västsverige. Kornstorleksfördelning, skrymdensitet och hydraulisk konduktivitet undersöktes på prover från både sedimentlager med häckningstunnlar och från omgivande lager utan tunnlar. Undersökningen visade på ett mycket konsekvent val av ett snävt intervall av finkornig sand för sina tunnlar. 90 procent av häckningstunnlarna var lokaliserade i finsand–mellansand med huvudsaklig kornstorlek 0,125–0,5 mm och övriga 10 procent i grov sand med huvudsaklig kornstorlek 0,5–1,0 mm. Inga tunnlar hittades i andra huvudfraktioner än sand. Finkornig sand har egenskapen att kunna hålla stabila tunnelväggar även under våta perioder med stor infiltration av regnvatten. Den hydrauliska konduktiviteten varierar mellan ca 10^{-4} och 10^{-3} m/s och skrymdensitetet mellan ca 1510–1575 kg/m^3.

Grävda slänter i sand- och grustag har länge varit den dominerande häckningslokalen för backsvala i Sverige. Under de senaste två decennierna kan man emellertid se en tydlig minskning av häckningslokaler för backsvala, huvudsakligen av fyra orsaker: (1) minskat behov av grusresurser, (2) efterbehandling av gamla grustag och stabilisering av naturliga erosionsslänter, (3) en övergång mot bergtäkter för att täcka grus- och makadambehovet och (4) koncentration av grusexploateringen till färre men större täkter. Ovanstående faktorer bedöms vara orsak till en minskande backsvalepopulation i Sverige och troligen också i övriga Europa och USA.