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ORIGINAL ARTICLE

3D Topography and Structure Analysis of Three European Badger (*Meles meles*) Setts from Western Switzerland

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Abstract
European badgers (*Meles meles*) make an extensive use of underground burrows, called “setts” that they dig themselves. Their internal structure, however, has only rarely been investigated. In Geneva, western Switzerland, we had the opportunity to perform a systematic excavation of three burrow systems that had to be destroyed. We studied their three-dimensional (3D) organisation and a surveyor’s office developed 3D models to help visualize the internal structure of each sett. The burrow systems had between 18 and 24 entrances and possessed between 24 and 42 chambers. However, the number of entrances did not match the underground complexity of the setts, and for two of them all entrances were not linked to a unique tunnel network. The smallest sett was about 3 decades old (5 m^3 excavated, 94 m of tunnels) and the largest was about 5 decades old (13 m^3 excavated, 300 m of tunnels). The tunnel system of one of the setts was organized on two overlapping layers, with the deepest chambers located at 1.8 m underground. However, mean depths of the chambers ranged between 0.78 and 1.22 m. The 3D organization of the systems was strongly influenced by soil conditions. Tunnel sizes, shapes of chambers, and the presence of bedding material in some of them gave some clues on how the different setts were actually used. Several screen views are shown and a link is proposed to have access to 3D models.

Introduction

European badgers (*Meles meles*) are well known for their digging abilities. Burrows (or setts) have been reported to represent a limiting resource for badgers, as suitable setts are needed for reproduction, social contacts and as shelter [1]. Moreover badger setts can be used by several other species such as red foxes (*Vulpes vulpes*), feral cats (*Felis silvestris catus*), wild rabbits (*Oryctolagus cuniculus*), raccoon dogs (*Nyctereutes procyonides*) or rodents [2-4]. In addition, they are also reported to increase the herbaceous species richness [5]. Badgers are considered as ecosystem engineers and have an impact on plant and soil composition, through bioturbation and through the input of organic material (faeces, prey parts and carcasses) to the soil [1, 6]. The extent of the burrows may sometimes represent a management issue, as badgers can potentially cause damages to infrastructures (roads, river embankments, etc.), thus representing a source of conflict with human activities [7, 8].

Several categories of setts can be discerned depending on their size and frequency of use by badgers [9-11]. Main setts are characterized by many interconnected entrances and are in use all year through. There is only one main sett for a given badger clan (group) and this large shelter is used for reproduction. Annex or subsidiary setts are smaller and used less regularly. They are generally located close to the main sett and connected to it by well-worn paths. Finally, outliers are small setts with one or few entrances and are used for short periods only. They can be situated far from the main sett. When undisturbed, main setts can be used over several generations of badgers [1, 5]. New tunnels and chambers are added and parts of the complex can be cleared out to be reused. Although the mean number of entrances generally ranges from 5 to 15 [12, 13], records of setts with >40 entrances have been reported in various areas: >100 in the Netherlands [13], 80 in South Downs, England [14], >80 in Somerset, England [6], 40 in Geneva, Switzerland (authors' unpublished data). Such networks consisting of several dozen entrances are linked by hundreds of meters of tunnels, sometimes organized on several levels [1, 6]. However their real internal structure and tri-dimensional organization has been documented in only few instances, from badger diggers' reports giving only partial information, or from a few setts that were totally excavated [1-3]. As the underground interconnection between entrances is generally unknown, entrances located only a few meters from each other are usually considered as belonging to the same system.

Biologists, managers and naturalists interested in badgers often wonder how the internal structure of a sett is organized, especially when considering large burrow systems. Although indirect non-destructive methods have been proposed, such as soil resistivity measurements [15], or magneto-inductive tracking [16], excavation remains the best technique to accurately map burrow systems. In Geneva, Switzerland, we had the opportunity to investigate the internal structure on three badger setts that had to be destroyed in the framework of urban planning or flood management. The fine-scale excavation of the setts was authorized and financed by local authorities, and a surveyor's office developed a 3D model of each sett.

Study sites

The three study sites were located within canton Geneva, western Switzerland (Fig. 1).

Favra

This site was located in a rural area east of the city of Geneva. It consisted of a 2.2-ha-large, fenced wooded area that grew over spoil earth rich in clay originating from the construction of a neighbouring prison in 1972. The sett was discovered in 1998 but is probably older, though less than 3 decades old. Since 1998 badgers had been regularly observed at that sett.

Bossenailles Amont (= *Amont*)

This sett was located in a rural area south-west of the city of Geneva, within a small riverine forest bordering the river Aire. It was dug in alluvial deposits and was known since 1975. The river was canalised in 1932, stopping the river dynamic and thus also the deposition of new layers of soil. A riverine forest could then grow and it was fenced off in 1993 as it became a Nature Reserve. The soil profile is characterised by a thin organic layer rich in silt as top horizon, followed by a compacted, 1.5-m-thick, sandy horizon lying on a layer of gravel and pebbles. This sett was probably not older than 5 decades at the time the excavation took place.

Bossenailles Aval (= *Aval*)

This sett was located in the same riverine forest and was only 85 m away from Bossenailles Amont. Habitat and soil conditions were similar, except for the lower thickness of the sandy layer (ca. 1 m).

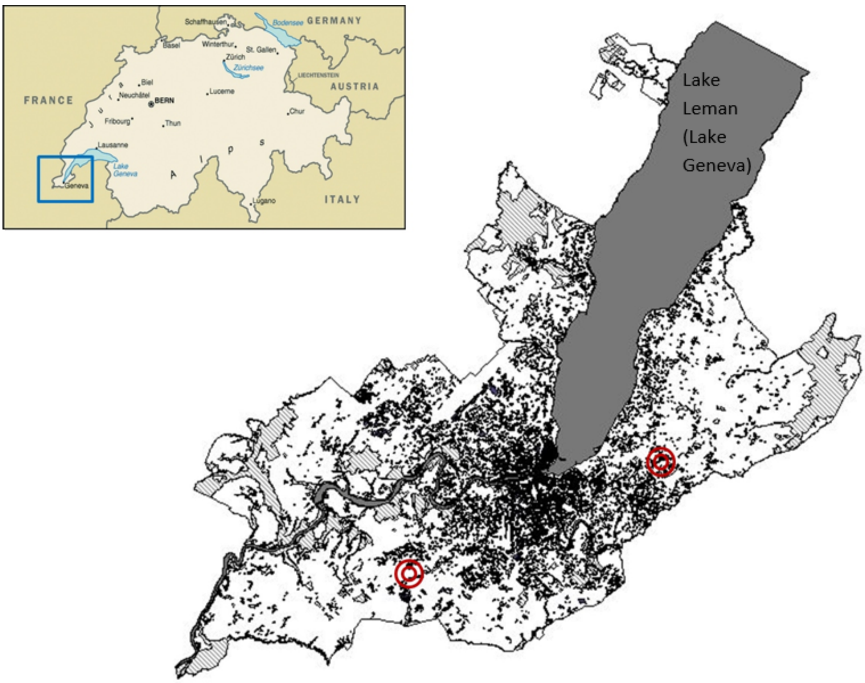


Figure 1: Study area in canton Geneva, western Switzerland, showing the locations (red circles) of the excavated European badger (*Meles meles*) setts. Dashed areas represent forests.

Methods

The excavation works were directed by one of us (F. Dunant) with the support of the respective surveyor's offices who regularly took measurements of the excavated setts. A small mechanical digger was used, and each uncovered tunnel was marked with either a numbered ball or a piece of paper that was pushed step by step along each tunnel (Fig. 2) until a chamber, another tunnel, or a dead-end was reached. Chambers were numbered too and assigned to one of two categories: true chambers (simply mentioned as "chambers" in the manuscript) with a bowl-shaped floor and bedding material [14], or "enlargements", consisting of places where tunnels widened out or several tunnels converged (Table 2). Compared to chambers, these enlargements had a flat bottom (Fig. 3), and no bedding material was found in them. Tunnels, chambers, and enlargements were regularly measured (height and width for the former; height, width and length for the other two) and geo-referenced using a total robotic station (Leika). In addition, bedding material and other items linked to the activity of the animals (faeces, bones, food remains) were recorded whenever met.

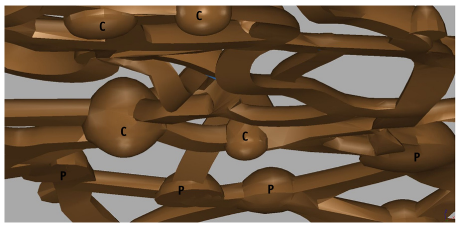


Figure 2 *(left)*: Numbered balls used to mark all tunnels.

Figure 3 *(right)*: Comparison of the shapes of true chambers (C), with a concave bottom, and enlargements (P), mainly at tunnel intersections, with a flat bottom.

Both burrow systems in Bossenailles were excavated 3 years after Favra (in July 2012 and November 2009, respectively). During the analysis of the Favra excavation, new ideas on complementary measurements arose (i.e. a 3D model of the surface area and linked depth of chambers and enlargements), and were thus recorded for Bossenailles. Consequently, the 3D shape of the surface area of the Favra system is not available. The 3D models were developed by BLENDER3D for Favra and using Autocad and 3DReshaper software for Bossenailles. Mann-Whitney U-test was used to assess differences between setts regarding chamber and tunnel sizes or chamber and enlargement sizes within the same system.

Results

The 3D models were based on 178 geo-references for Favra (Fig. 4A), 367 for Bossenailles Amont (Fig. 4B), and 312 for Bossenailles Aval (Fig. 4C). These complexes covered between 200 and 650 m^2, consisting of up to 300 m of tunnels and with volumes of earth extracted of up to 13 m^3. The number of entrances did not match the complexity of the underground system. For example, Favra had 22 entrances but only 94 m of tunnels and 24 chambers, whereas Aval had 18 entrances, 300 m of tunnels and 35 chambers (Table 1).

The number of entrances ranged between 18 (Aval) and 24 (Amont). Except for Bossenailles Aval, all the entrances of the burrow systems were not actually

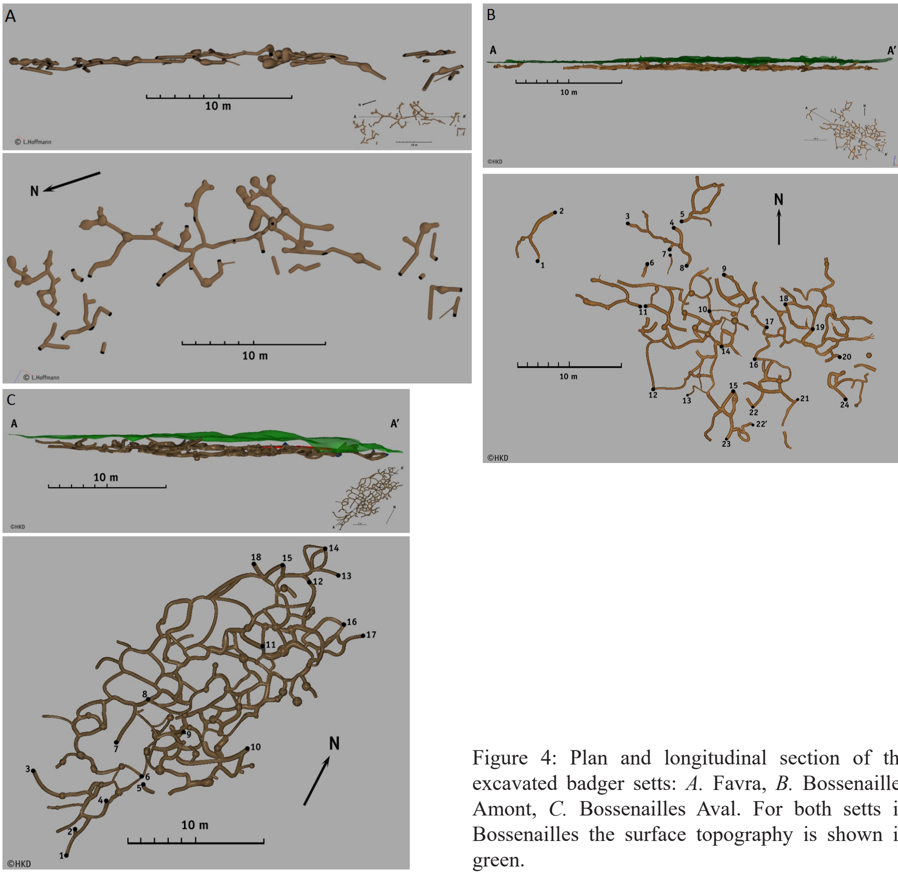


Figure 4: Plan and longitudinal section of the excavated badger setts: *A.* Favra, *B.* Bossenailles Amont, *C.* Bossenailles Aval. For both setts in Bossenailles the surface topography is shown in green.

Table 1: Sizes of the three excavated European badger (*Meles meles*) setts.

Sett name	No. of entrances	No. of chambers	Area covered (m^2)	Total tunnel length (m)	Estimated excavated volume (m^3)
Favra	22	24	200	94	5
Bossenailles Amont	24	42	650	297	13
Bossenailles Aval	18	35	420	300	13

interconnected by the tunnel network. In Favra there were 10 sub-groups of linked entrances (Fig. 5), in Bossenailles Amont six, plus two separate entrances with only one short tunnel that did not end into a chamber. The tunnels in Bossenailles Aval were organised in two different layers (Fig. 6), whereas in Bossenailles Amont the overall system ran between 60 and 90 cm in depth (Fig. 7). In Favra, the tunnels and chambers were located at various depths, but none overlapped. Mean tunnel size (height ± SD * width ± SD) was 19.5 ± 3.8 * 29.5 ± 6.1 cm in Aval, 16.5 ± 4.8 * 29.4 ± 6.7 cm in Amont, and 21.4 ± 3.9 * 31.4 ± 5.7 cm in Favra.

The deepest chambers were located 1.8 m below ground level (b.g.l.) in Bossenailles Aval (mean depth = 1.22 m), and 1.08 m b.g.l. in Amont (mean depth = 78 cm). The longest distance between a chamber and the nearest entrance was 7 m in Favra, 8.3 m in Amont and 7.7 m in Aval (Table 2), and the most distant point of a tunnel from the nearest entrance was 7.0 m, 8.7 m and 9.9 m, respectively. Mean chamber size (height

± SD * diameter ± SD) was 45.7 ± 11.4 * 55.7 ± 13.8 cm in Aval, 27.2 ± 6.5 * 50 ± 8.7 cm in Amont, and 44.7 ± 8.6 * 65.3 ± 8.1 cm in Favra. In Aval, chambers were, on average, significantly higher than enlargements (Mann-Whitney U-test: U = 330, $P < 0.01$; no data are available for Favra and Amont). Some chambers were connected with up to five tunnels (Fig. 8), but more generally with two or three of them. Some tunnels were parallel to each other, linking the same two chambers. Other tunnels did not reach any chambers.

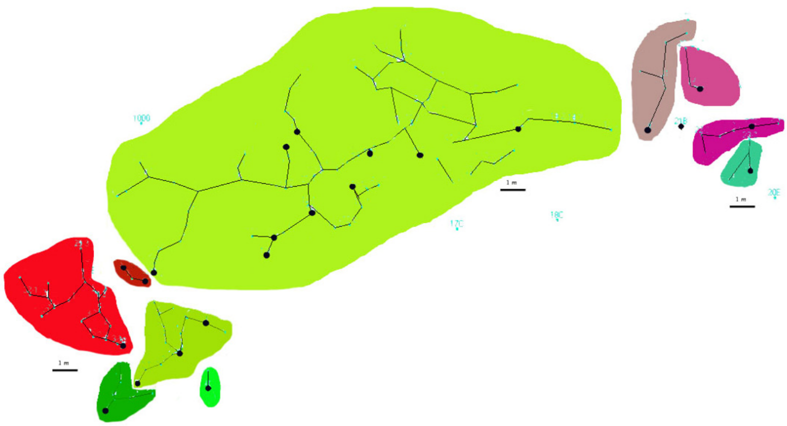


Figure 5: Sub-groups of inter-connected entrances in the burrow system of Favra.

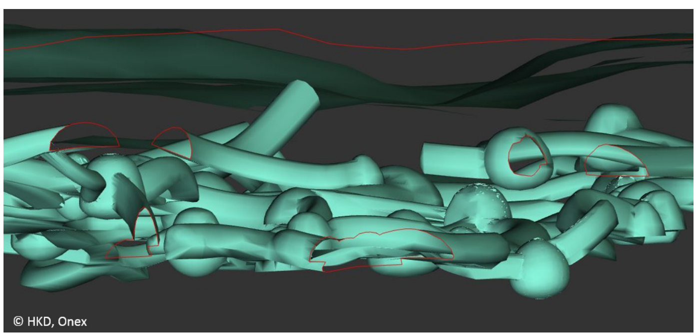


Figure 6: Cross-section of Bossenailles Aval showing overlapping tunnel layers.

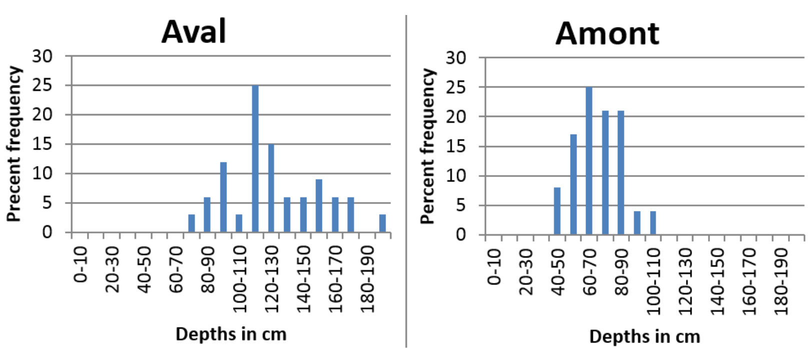


Figure 7: Percent frequency distribution of chamber depths in Bossenailles.

Table 2: Parameters of chambers and enlargements for each excavated sett.

Sett name	Total No. of chambers	No. of chambers at tunnel intersections	No. of chambers along tunnel	No. of chambers as dead end of tunnel	No. of chambers with bedding material	Enlargements	Longest distance to entrance (m)
Favra	23	1	9	13	10	5	7
Bossenailles Amont	26	0	18	7	1	17	8.3
Bossenailles Aval	35	12	18	5	16	13	7.7

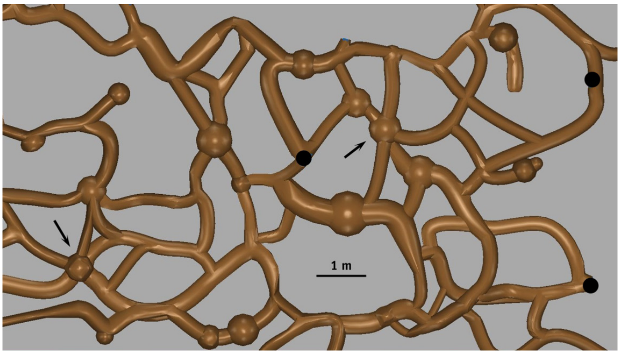
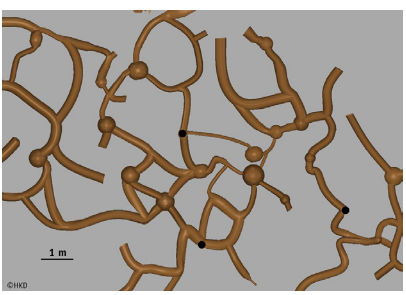


Figure 8: Up to 5 tunnels were recorded to branch off from some chambers (black arrows).

The internal structure of the two setts in Bossenailles was quite different. First, tunnel section was more variable in Amont, with a large proportion of very low tunnels and tunnel sizes changing within very short distances (Fig. 9) and mean chamber height was significantly higher (45 vs. 27 cm; Mann-Whitney U-test: $U = 690$, $P < 0.0001$) for Aval. Second, the chambers in Amont often showed small lateral extensions (“alcoves”) usually continuing as narrow tunnels (8-12 cm in diameter; Fig. 10). Finally, 46% of the chambers in Aval contained bedding material, while only one out of 26 did in Amont (3.8%). In the latter we regularly found small herb fragments and seed heaps, particularly in narrow tunnels, suggesting its use by rodents.



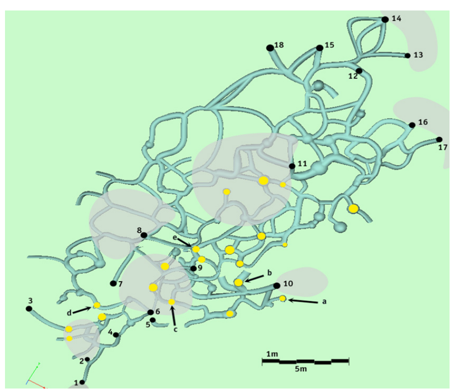
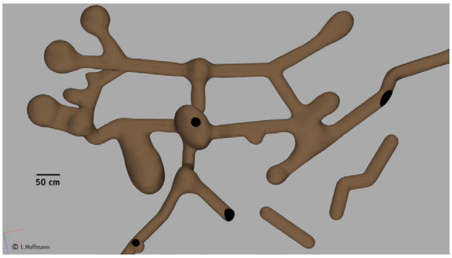


Figure 9 *(left)*: Zoom on Bossenailles Amont showing large variations in the width of the tunnels.

Figure 10 *(right)*: Burrow system of Bossenailles Aval showing the chambers with (yellow) and without bedding material (black spots). Enlargements are the same colour than tunnels. Observed spoil heaps are indicated as grey surfaces.

In Favra, most chambers were located in a layer of compacted sand (clay < 6%), and were often covered by impermeable clay lenses (deposits). Many of these chambers were shaped irregularly and large alcoves were scattered along the tunnels (Fig. 11). In addition, one large chamber was located higher than the surrounding entrances, with a heavily-sloping tunnel linking it to the closest entrance (Fig. 12).



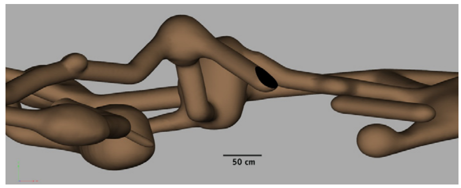


Figure 11 *(left)*: Details of Favra showing alcoves extending from tunnels and chambers in the sett of Favra.

Figure 12 *(right)*: Detail of Favra showing a chamber dug higher than surrounding entrances in Favra.

Regarding the internal environment, we measured volumes of bedding material of up to 37 L, with a mean of 17.8 L for Favra, 10.1 L for Aval, and 4.0 L for the single chamber with bedding material in Amont. In the chambers used by red foxes (as determined by signs of presence or direct observation in front of the entrances), no bedding material was recorded. No faeces were found in any sett, while some bones of a red fox cub were recovered in Amont.

Discussion

The setts that we had the opportunity to map were all well-developed burrow systems, despite being only 3-5 decades old (cf. study site section). Compared to other setts from canton Geneva, their number of entrances was much higher than the average (± SD) number of entrances for main setts (8.9 ± 6.3, n = 51) and for annexes and outliers (5.7 ± 5.8, n = 58; authors' unpublished data). We did not notice any obvious relationship between the number of entrances and the length of tunnels or the number of chambers. It is thus not possible to infer underground complexity of a burrow system from the number of entrances.

In Aval, both the higher proportion of chambers with bedding material and the larger size of the tunnels with respect to Amont, suggested that Aval was used as a main sett, while Amont was a subsidiary sett and was disused by badgers at the time of excavation. According to Mori *et al.* [17], the presence of rodent signs is typical of disused badger setts.

Regarding Favra, the regular observation of both badger adults and cubs indicated that it was a main sett. The particular shape of the chambers and tunnels in Favra, showing large alcoves, likely depends on soil characteristics, as this sett was dug in spoil earth including pieces of concrete or asphalt which badgers could not overcome, or compacted clay lenses that were too hard to dig through.

Mean tunnel and chamber sizes agreed with those reported in literature [1], except for the height of the chambers of Amont, which were lower than the average. Roper [1] also reported that setts are mostly two-dimensional and that systems with overlapping levels ("multi-storey" setts) are rare. In contrast, the sett in Aval was organised in multiple overlapping layers, which was allowed by the thickness of the sandy layer.

The setts that we had the opportunity to excavate showed a remarkable complexity. Hundreds of meters of tunnels linked dozens of entrances. Sett excavation showed that several entrances were not actually linked to the main tunnel network. However it is difficult to determine if they did in the past or the main network was in fact extending towards an outlier sett. Badgers exhibit an intense digging activity [18] and the structure of badger setts is dynamic [6]. New tunnels and chambers are created, while others are disused and may collapse and then be refreshed and used again. Some entrances might in fact correspond to collapsed tunnel roofs, when the latter are too close to the ground, particularly for "entrances" located on flat ground. Indeed, most of the spoil heaps that we observed were in front of tunnels dug crosswise into a slope, where it is easier to evacuate the excavated soil.

The 3D models that were developed in this study allow the precise visualizing of the complexity of badger setts that, until now, had only been described by bi-dimensional sketches. These models can be accessed through the following link:

http://hepia.hesge.ch/fr/rad-et-prestations/institut-intne/projets/udrn/sett-3D-topography

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