



Bryophytes in a latrine as indicators of climate change in the 17th century

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Abstract

Thirty-eight samples recovered from a latrine in the rural market town of Hadersdorf am Kamp (Lower Austria) and filled during the early 17th century were analysed and compared to the current bryophyte vegetation there and in its surroundings. Twenty-eight moss species from the latrine could be identified, and four taxa could be determined only to genus level because of missing sporophytes. The resulting data set is a valuable contribution to the state of knowledge of the bryophyte flora of that historic period, as none of the traditional methods such as herbaria date back to this early era. The most frequent species in the pit, *Leucodon sciuroides*, *Antitrichia curtipendula* and *Neckera complanata*, could hardly be found or not at all in the current bryophyte flora of the investigated area. A comparison of Ellenberg's indicator values of the historic and current moss taxa revealed significant differences for temperature, humidity and continentality. Temperature values were much lower for the taxa found in the latrine. Furthermore, the historic mosses reflect a more humid and less continental climate than the ones growing nowadays. Many of the mosses found in the latrine are epiphytic or epilithic and could not be found in the investigated area today. These results indicate a different climate during the time of the Little Ice Age in the investigated area. According to the low total biomass of mosses in the pit (1–2 g per 10 l) we suggest that those found in the latrine arrived there mainly by chance, as in sweepings.

Keywords Moss · Little Ice Age · Hadersdorf/Kamp · *Antitrichia curtipendula*

Introduction

Bryophytes (liverworts, hornworts and mosses) are an important part of the vegetation both in terms of biodiversity and cover (Glime 2017). According to their morphology and physiology, they reflect changes in environmental conditions quickly. Therefore, they are generally accepted as good indicators for environmental monitoring (for example, Zechmeister et al. 2003; Tuba et al. 2011; Ares et al. 2012; Nickel et al. 2017).

Bryophytes from peat cores have been investigated to assess climatic changes, mainly in the Holocene period (Dickson 1986; Blundell and Holden 2015). However, there have hardly been any investigations into changes in bryophyte vegetation within the last 300 years. It is assumed that major changes in bryophyte diversity have been caused by changes in agricultural land use during the last three centuries (Vanderpoorten and Goffinet 2009). Since the beginning of the industrial revolution a loss in species diversity can be assigned to atmospheric air pollution too (Zvereva and Kozlov 2011). A loss or increase in bryophyte species diversity as a result of climate change has hardly been assessed by any bryological investigation covering a period before the last 50 years. There is little to no knowledge of changes in bryophyte vegetation dating back to the Little Ice Age in the 17th century. This could be a consequence of the lack of scientific bryophyte records from this period. Most herbarium collections of bryophytes start with samples of the late 18th century, as in the natural history museums in London and in Vienna. Therefore, the data set of this present study gives valuable insights into historic bryophyte vegetation.

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There was a wide use of bryophytes (mainly mosses) in historical times for such purposes as medicine, toiletry, wound dressing material or fillings of mattresses (Richardson 1981). Only as a foodstuff, there was obviously no use for them (Glime 2017). Mosses were collected from the immediate vicinity and often ended up in the rubbish after use, which was deposited on muckheaps, in rivers and also in latrines. Therefore, bryophytes in these rubbish pits seem to be a valuable indicator for historic habits and/or historic environments. Nevertheless, with the exception of wet soils or specific circumstances of preservation such as in latrines, bryophytes are not preserved in most cases due to their decomposition in dry soils or disintegration in the predominantly charred archaeobotanical material (Jacomet and Kreuz 1999).

By investigating the filling of a latrine deposited in the 17th century in a historical building in Hadersdorf am Kamp, Austria, we tried to address the question whether there is any evidence for a change in bryophyte species diversity due to climatic changes. Furthermore, we attempted to solve the question of where the filling material came from and if any kinds of use for this material could be detected.

Methods

The rural village of Hadersdorf am Kamp is located in Niederösterreich (Lower Austria) (48°45' N, 15°72' E; 202 m a.s.l.; Fig. 1). It is situated at the western edge of the Pannonian climate thermophilic vegetation zone, and vineyards dominate the landscape today.

During restoration work in the town hall, a well or latrine was discovered and excavated in 1991/92 in a rescue excavation by Bundesdenkmalamt Österreich, the national heritage

agency. The feature was 4.5 m deep and 1.5 m in diameter on average, as the pit was slightly conical. The core was built as a well and had been reused as a latrine in the 17th century for unknown reasons. Latrines of this period were mostly used both as toilets as well as rubbish pits. Plenty of household rubbish and other artefacts were found (Sauer 1992). Beside archaeological artefacts (bricks, ceramics, glass and metallic objects) and archaeozoological remains (animal bones and fish remains), leather (fragments of shoes), wood and other plant remains (seeds/fruits, mainly uncharred) were also visible to the naked eye. Moreover, crystals of struvite (magnesium ammonium phosphate) were found in the Hadersdorf latrine, which usually derive from excrement and urine. The lowermost 70 cm of the complex was waterlogged. For sampling, the pit fill was divided into eight artificial strata. The deposited material had a volume of 3.5 m³. Whereas big artefacts and objects were sorted out during digging, the whole sediment and smaller remains were sampled and processed in 207 sediment samples each of 10 l and wet sieved into size fractions using a smallest mesh size of 0.8 mm. Subsequently all fractions were preserved in Tego 51B.

Investigations for the present study started in 2016 with an emphasis on 38 samples (15% of the overall material) taken from the various strata. Bryophyte samples were washed with water and transferred into a mixture of ethanol, glycerol and distilled water with added phenol and stored in small glass vials (Scharrer-Liška and Popovtšchak 2017). Specimens were identified to species level if possible. The amount of moss was approximately 1–2 g per 10 l sediment. The state of preservation was very good and bryophytes were not decomposed or only slightly. Nomenclature follows Köckinger et al. (2018).

For a comparison of the historic material with the current flora of the Hadersdorf area, we tried to record all bryophytes (mosses and liverworts) growing in the vicinity of the town hall. These investigations covered the market place of Hadersdorf itself (with parks, very old trees and alleys) and the surrounding areas including woods, vineyards, dry meadows and a valley, the Straßertal.

A comparison of ecological requirements of the historic and the current bryophytes was made using Ellenberg's indicator values (Ellenberg et al. 1992). We used two ways to calculate them, unweighted, in which each taxon is represented once, and weighted calculation. We weighted the values according to the frequency of their occurrence. For the historic samples, the frequency of occurrences in the 38 samples was taken, and for the recent samples the distribution as given, both in Table 1.

Statistical tests using these values were the F test for variance, a Kolmogorov–Smirnov test for comparing the distribution of these two data sets and a Mann–Whitney test for comparing the mean indicator values ($p < 0.05$).

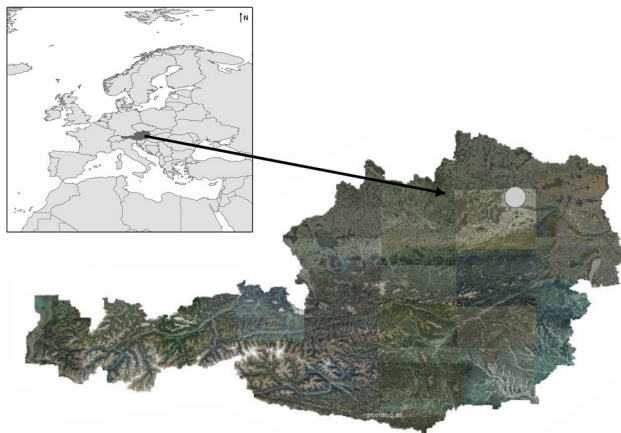


Fig. 1 Location of the investigated area around Hadersdorf am Kamp, Niederösterreich (Lower Austria); mapping from Geoland Basemap Orthofoto (2016)

Table 1 Bryophytes which were found in the latrine samples and those collected recently in the area around Hadersdorf am Kamp; nomenclature according to Köckinger et al. (2018); historic frequency refers to the number of subsamples from the latrine in which the taxa could be found; recent distribution and frequency of recent distribution in the area; *c* common, *s* scattered, *r* rare; habitats, most important substrates for the mosses

Taxa	Historic frequency	Recent distribution	Habitats
<i>Abietinella abietina</i>	6	<i>c</i>	Soil
<i>Aloina ambigua</i>		<i>r</i>	Soil
<i>Aloina rigida</i>		<i>r</i>	Soil
<i>Amblystegium confervoides</i>		<i>s</i>	Epilithic
<i>Amblystegium serpens</i>	4	<i>c</i>	Ubiquitous
<i>Anomodon attenuatus</i>	3	<i>s</i>	Epiphytic/epilithic
<i>Anomodon rugelii</i>		<i>r</i>	Epilithic
<i>Anomodon viticulosus</i>	2		Epiphytic/epilithic
<i>Antitrichia curtipendula</i>	14		Epiphytic/epilithic
<i>Atrichum undulatum</i>		<i>c</i>	Soil
<i>Barbula convoluta</i>		<i>c</i>	Soil
<i>Brachytheciastrum velutinum</i>		<i>c</i>	Ubiquitous
<i>Brachythecium</i> sp. incl. <i>Brachytheciastrum</i>	18		Ubiquitous
<i>Brachythecium albicans</i>		<i>s</i>	Soil
<i>Brachythecium rutabulum</i>		<i>c</i>	Ubiquitous
<i>Bryum argenteum</i>		<i>c</i>	Soil
<i>Bryum caespitium</i>		<i>s</i>	Soil
<i>Bryum capillare</i>		<i>s</i>	Soil
<i>Calliergonella cuspidata</i>	6		Soil
<i>Ceratodon purpureus</i>		<i>s</i>	Soil
<i>Climacium dendroides</i>	1		Soil
<i>Dicranum scoparium</i>		<i>s</i>	Soil
<i>Didymodon acutus</i>	1	<i>s</i>	Soil
<i>Didymodon fallax</i>	1	<i>s</i>	Soil
<i>Entodon concinnus</i>	3		Soil
<i>Funaria hygrometrica</i>		<i>s</i>	Soil
<i>Frullania dilatata</i>		<i>s</i>	Epiphytic
<i>Heterocladium heteropterum</i>		<i>r</i>	Epilithic
<i>Homalothecium lutescens</i>	8	<i>s</i>	Soil
<i>Homalothecium sericeum</i>	4		Epiphytic/epilithic
<i>Homomallium incurvatum</i>		<i>r</i>	Epilithic
<i>Hylocomium splendens</i>	1		Soil
<i>Hypnum cupressiforme</i>	9	<i>c</i>	Epiphytic/epilithic
<i>Hypnum</i> sp.	1		Epiphytic/epilithic
<i>Leucodon sciuroides</i>	34	<i>r</i>	Epiphytic/epilithic
<i>Marchantia polymorpha</i>		<i>r</i>	Soil
<i>Mnium</i> sp.	1		Soil
<i>Neckera complanata</i>	25	<i>r</i>	Epiphytic/epilithic
<i>Neckera crispa</i>	6		Epiphytic/epilithic
<i>Neckera pumila</i>	1		Epiphytic/epilithic
<i>Orthotrichum affine</i>		<i>r</i>	Epiphytic
<i>Orthotrichum anomalum</i>		<i>s</i>	Epilithic
<i>Orthotrichum diaphanum</i>		<i>s</i>	Epiphytic
<i>Orthotrichum obtusifolium</i>		<i>r</i>	Epiphytic
<i>Orthotrichum pumilum</i>		<i>r</i>	Epiphytic
<i>Orthotrichum speciosum</i> s. str.		<i>r</i>	Epiphytic
<i>Oxyrrhynchium hians</i>	4	<i>s</i>	Soil
<i>Oxyrrhynchium speciosum</i> cf.	3		Soil
<i>Plagiomnium cuspidatum</i>	1	<i>s</i>	Soil
<i>Plagiomnium undulatum</i>	1		Soil

Table 1 (continued)

Taxa	Historic frequency	Recent distribution	Habitats
<i>Pleurozium schreberi</i>	2		Soil
<i>Porella platyphylla</i>		r	Epilithic
<i>Pottia intermedia</i>		r	Soil
<i>Pottia lanceolata</i>		r	Soil
<i>Pottia truncata</i>		r	Soil
<i>Pseudoscleropodium purum</i>	3		Soil
<i>Pseudocrossidium hornschuchianum</i>		r	Soil
<i>Pylaisia polyantha</i>		r	Epiphytic
<i>Rhizomnium punctatum</i>	2		Soil
<i>Rhytidiadelphus triquetrus</i>	1		Soil
<i>Schistidium robustum</i>		s	Epilithic
<i>Scleropodium touretii</i>	1		Soil
<i>Syntrichia papillosa</i>		r	Epiphytic
<i>Syntrichia ruralis</i>		c	Soil
<i>Syntrichia virescens</i>		r	Epiphytic
<i>Thuidium delicatulum</i>	1	r	Soil
<i>Thuidium</i> sp.	4		Soil
<i>Tortula subulata</i>		r	Soil
<i>Weissia controversa</i>		r	Soil

Results

Bryophyte diversity in the latrine

The examined bryophytes were in a good state of preservation and could be identified to species level in most cases, resulting in 28 species and four taxa which could be identified only to genus level because of missing sporophytes. In Table 1 the bryophyte taxa, their number of occurrences in the various samples and their main habitats are listed.

All of these historic taxa can be ranked in the class of mosses (Bryopsida) and none of the bryophytes belong to liverworts (Marchantiopsida) or hornworts (Anthocerotopsida).

The distribution of mosses in the various samples is uneven. A small number of taxa could be found in many of the samples, of which the most frequent was *Leucodon sciuroides*, occurring in 34 out of 38 samples. In Austria, this species is a vigorously growing trunk epiphyte on free-standing trees, and in Pannonian areas it can also be found on rocks. Next most frequent was *Neckera complanata*, which grows in similar but slightly moister sites than *L. sciuroides*. Surprisingly high was the frequency of *Antitrichia curtipendula* (14 samples). In pre-industrial times, this species grew mainly as a trunk epiphyte in central Europe (Frahm 2011), but nowadays it is rare and found mainly on shaded rocks in Austria.

Generally, most of the less frequent mosses found in the latrine grow on dry, sunny soils in dry grasslands, vineyards

or pastures. Among these only *Homalothecium lutescens* (8 samples) and *Abietinella abietina* (6 samples) were more common. Many taxa occurred only once or in a very few samples. Among these *Scleropodium touretii* is most notable, now a Mediterranean species, which has no recent occurrence and has never been found in Niederösterreich (Lower Austria) before.

Distribution within strata

Comparing the eight investigated strata, no differences were found for bryophyte distribution. Frequent taxa ($n > 5$) could be found from the deepest to the uppermost strata. This reflects either a quick filling of the pit and/or an even distribution (and use) of these mosses within the area.

Comparison of historic and recent bryophyte distribution

During the search for current bryophytes, 50 species (47 mosses and three liverworts) could be found (Table 1) compared to 28 moss species and 24 specimens identified only to genus level in the historic samples. In both the historic and recent samples we found epiphytes (growing on plants), epilithic mosses (on stone) and ones growing on soils. In the historic samples vigorously growing taxa dominated, whereas smaller bryophytes dominated the recent samples.

The most frequent species in the historic records, *Leucodon sciuroides*, could be found only once in the recent

sampling. It did not grow in the market town itself, but close by, in the Straßertal. Other vigorously growing, weft forming species like *Antitrichia curtipendula*, *Neckera crispa* and *N. pumila* could either not be found in the recent sampling or only with a very low frequency, for example *Leucodon sciuroides*, *Neckera complanata* and *Anomodon attenuatus*, although substrates for their growth were still available, such as single trees, alleys, low growing oak woods or shaded siliceous rocks. The only species occurring in both collections more frequently was the ubiquitous *Hypnum cupressiforme*.

Although several mosses of open soils were detected both in the historic and current samples, such as *Abietinella abietina*, *Oxyrrhynchium hians*, *Homalothecium lutescens* and *H. sericeum*, a change in taxa and frequency could be observed. Some historic mosses which need moist conditions could not be found in the recent investigation (*Calliergonella cuspidata*, *Hylocomium splendens*, *Rhytidiadelphus triquetrus*), whereas recent bryophytes had an emphasis on dryer conditions (*Aloina* spp., *Pottia* spp., *Syntrichia ruralis*).

Ecology of bryophytes

The trends of both calculations (weighted and unweighted) were the same. By using unweighted calculations significant differences could be shown for temperature, whereas weighted calculations showed significant differences for all parameters except for the pH value. Weighting according to frequencies minimises the influence of rare or neglected taxa. Therefore, rare bryophytes in the recent sampling and very small ones, which might have been missed in the historic samples, did not strongly influence the results. In consequence we present only the results of the weighted calculation.

Figure 2 shows mean Ellenberg indicator values, both for mosses from the latrine as well as for those from the recent sampling. These values are given for light, temperature, continentality, humidity and soil pH value (Ellenberg et al. 1992).

Light value for the historic bryophytes was $6.3 (\pm 1.9)$ compared to $6.9 (\pm 1.7)$ for current ones, which reflects semi-shaded to partially shaded conditions, and is typical for *Neckera* species, for example. Most epiphytic taxa can be ranked within these values. The difference is weakly significant ($p = 0.015$).

The average temperature value for the latrine mosses was $3.8 (\pm 0.9)$ compared to $4.4 (\pm 1.2)$ for current bryophytes. The difference is strongly significant ($p = 0.0003$). Historic values reflect a cool temperate climate, which comes as a surprise, as Hadersdorf is situated in the Pannonian area now. Values for taxa from the recent collection were markedly higher.

Climatic continentality for the latrine mosses was $4.9 (\pm 0.6)$ compared to $5.2 (\pm 0.6)$ for taxa growing nowadays.

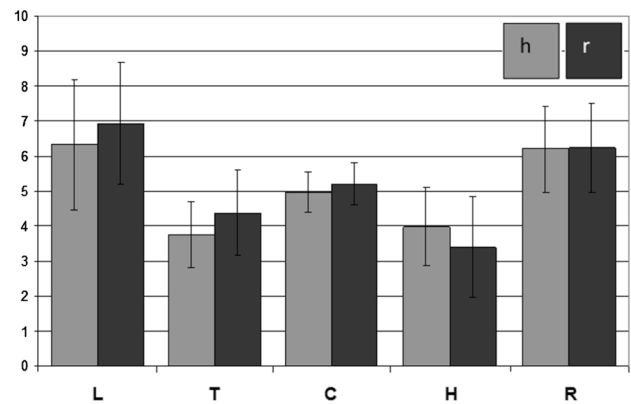


Fig. 2 Comparison of Ellenberg's indicator values for all moss taxa found in the latrine samples and collected in recent fieldwork. *L* light indicator value, *T* temperature indicator value, *C* continentality indicator value, *H* humidity indicator value, *R* substrate pH indicator value, *h* historic samples, *r* recent collection

The difference is significant ($p = 0.006$). The present-day value reflects conditions between a suboceanic and a subcontinental climate and is typical for the central European flora with a slight eastern emphasis—the historical one is slightly more oceanic.

The average humidity indicator value for the mosses in the latrine was $3.9 (\pm 1.1)$ compared to $3.4 (\pm 1.4)$ for current bryophytes. The difference is strongly significant ($p = 0.0007$). Current mosses reflect dryer site conditions whereas the historic ones indicate damper conditions.

Average reaction indicator (soil pH value) was $6.2 (\pm 1.2)$ for latrine mosses compared to $6.2 (\pm 1.3)$. There is no statistically significant difference between these two values. Since both investigated periods showed comparable values, site pH and therefore substrates are comparable in both periods. The value reflects weakly acid conditions, which can be found on tree trunks or on the gneissic rocks in the surroundings of the investigated market town.

Discussion

Most of the taxa which were abundant in the latrine samples are rare or absent in the area of Hadersdorf today (*Antitrichia curtipendula*, *Leucodon sciuroides*, *Neckera complanata*, *N. crispa*, *Hylocomium splendens* or *Rhytidiadelphus triquetrus*) although their required substrates are sufficiently available in the modern environment. All of them favour a more humid and cooler climate than today's. Temperature values of historic samples (3.8) were significantly lower than the mean temperature value of the recent collection (4.4), the same goes for light, humidity and in consequence also continentality.

Most remarkable is the frequent occurrence of *Antitrichia curtipendula* in the past, as nowadays it cannot be found in a wide area around Hadersdorf (Zechmeister et al. 2013). The nearest places where it grows now are situated either 50 km north of Hadersdorf at higher elevations with a cooler climate, or in areas with extremely high precipitation in the Alps. A comparable extinction of this species is also reported from other parts of central Europe (Frahm 2011). It is concluded that *A. curtipendula* disappeared mainly due to industrial pollution in many countries since the beginning of the industrial revolution (Frahm and Wiethold 2004). In fact, air pollution had detrimental effects on the distribution of many bryophytes (Franzen 2001; Zvereva and Kozlov 2011; Dittrich et al. 2016). A decrease or extinction of bryophytes could be mainly attributed to SO₂ emissions, one of the most important pollutants over the last 150 years, but which have decreased dramatically in recent decades in Europe (Umweltbundesamt 2018); a return of bryophytes into formerly heavily polluted areas has been observed (Sergio et al. 2016). At present, pollutants like NO_x or NH₄ still have strong effects on bryophyte diversity, facilitating nitrophiles, among these luxuriant growing species like *L. sciurioides* or *Hypnum cupressiforme* while discouraging others (Zechmeister et al. 2007). Recolonisation after disappearance is also a matter of diaspore dispersal and establishment. Ahrens (2007) shows for *Leucodon sciurioides* that the frequency of sexual reproduction decreased since historical times. It now occurs only in a temperate valley in the investigated area and not in the near vicinity of Hadersdorf, where the climate is slightly warmer and drier. The sensitivity of *L. sciurioides* to atmospheric pollution is discussed controversially (Frahm 1998; Sauer 2000). Assuming that it is sensitive to pollution, diaspore dispersal could have been an intrinsic factor, otherwise climate change (temperature, humidity) could have caused its absence. The fact that *L. sciurioides* as well as *A. curtipendula* can be found in areas nowadays which were heavily polluted before, as in north-western Niederösterreich, but which have a substantially cooler climate than the investigated area, suggests that the climate theory is correct. Therefore, we assume that at least *L. sciurioides* would occur more frequently in the Hadersdorf area if the climate was suitable for it there.

Landscape structure is another important cause of species diversity. One could assume that the structure of the historic landscape was different from today's, which would have led to a different bryophyte vegetation (Vanderpoorten and Engels 2003; Pharo and Zartman 2007). The area around Hadersdorf am Kamp is still a small scale structured landscape offering appropriate habitats for those species which have vanished since the 17th century. Beside vineyards, arable land and open broad-leaved woodlands are the most common elements of landscape structure today, even alleys and siliceous rocks can be found. All these would still

provide plenty of adequate substrates for the frequent taxa in the historic samples.

Taking into account all these factors we attribute the observed change in moss taxa mainly to climate differences since the 17th century and we assume that the historical climate was significantly wetter and cooler than the present one. Historic climatic data are not available for the investigated area, however our hypothesis is underpinned by overall climate change models, which report an average temperature during the 16th and 17th centuries in Europe which was 2.5 °C lower than today (von Storch et al. 2004; Glaser and Riemann 2009). This Little Ice Age period is documented not only by scientists but also in art and in social research (Fagan 2002; Roelofs 2010). Our data confirm a cooler and wetter climate in the early 17th century in the investigated area by using bryophytes and their ecological needs. The climatic conditions at that time were probably the main cause of a vigorous growth of large pleurocarp bryophytes on tree trunks in the village and on rocks in the surrounding hills, and in valleys such as Straßertal.

We postulate that the historic samples represent the local bryophyte flora from that time very well. Although the samples were dominated by larger mosses, small acrocarps (with upright growth, mostly unbranched) could be found regularly. It is unlikely that these tiny bryophytes were collected for a specific purpose due to their small size. They were obviously deposited by chance, as in sweepings. Furthermore, comparable indicator values for substrate (R values) suggest that the historic samples derive from the same area as the recent ones. That the historic mosses grew in the latrine itself is very unlikely. Considering their humidity (3.9 ± 1.1) and light requirements $6.3 (\pm 1.86)$, they probably grew on trees or stone surfaces.

The question about the use of the mosses however remains speculative. In the latrine, mainly larger sized mosses were found, which could be evidence that they were gathered selectively for special purposes. Large mosses have often been recovered from ancient latrines and some of the same taxa have been found in our investigation. Dickson (2000) and van den Bos et al. (2014) refer to the use of *Neckera crispa* und *N. complanata* as a filling for mattresses. Glime (2017) reports on the use of mosses for sanitary products as well as for preserving food, while Constantin and Kuijper (2002) suggest use as cleaning materials. In the Hadersdorf latrine, mosses were distributed regularly through all strata, which indicates either regular use or at least regular deposition of moss. The total biomass of mosses in the latrine was small (1–2 g per 10 l). Therefore intensive or regular, intended uses, such as toilet paper, are not obvious so far. Given the size and volume of the Hadersdorf latrine, mosses were probably used every now and then, probably for reasons reported in literature, as a sanitary product, for instance.

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