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RESEARCH

How animal dung can help to reconstruct past forest use: a late Neolithic case study from the Mooswinkel pile dwelling (Austria)

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Abstract

Animal dung analyses are a useful tool for vegetational studies. Preserved ruminant dung from archaeological layers offers a unique possibility for the reconstruction of past fodder management strategies, and further for studying the impact of fodder acquisition and pasturing on forests. In this case study we investigate the impact of Late Neolithic livestock keeping on the forest around the "Mooswinkel" pile dwelling at the Austrian lake Mondsee through the analysis of botanical macroremains, insect remains as well as microhistological analyses of botanical remains in animal dung. Seasonal plant parts in the dung point out that cattle, goats, and/or sheep were evidently kept inside the settlement during the winter for protection. During the daytime, they were allowed to forage around the settlement. Winter fodder consisted of dried leaf hay, hay from grasses and herbs, male flowers of early blooming bushes, and fresh twigs of evergreen species, such as fir (*Abies alba*), ivy (*Hedera helix*), and mistletoe (*Viscum album*).

Keywords Neolithic · Animal dung · Leaf hay · Forest management · Archaeobotany

Introduction

The analysis of herbivore animal dung is a very specific category of botanical research that has been studied in a variety of ways. In wildlife studies, such analyses aim to investigate the food habits of various animals such as rabbits, red deer, roe deer, or chamois (e.g., Dusi 1949; Hegg 1961). In some cases, the aim of this type of research is botanical, leading to investigations on the effect of animal foraging on vegetation (e.g., De Jong et al. 1995; Jaroszewicz et al. 2013). The goal of such approaches is to gather scientific knowledge on the effects of foraging, that in turn are used to inform forest management strategies. Vegetational studies have also employed the dung of domestic animals, like investigations of plant seed dispersal for example (e.g., Müller-Schneider 1954).

Archaeological layers often bear the dung of domesticated animals, and these are useful in botanical analyses. Like contemporary dung, their content can provide a wealth of information on the food habits of many animals and direct diet evidence that cannot be obtained through other archaeological and archaeobotanical finds. It is, therefore, useful for palaeoeconomical and palaeoecological analyses (Marinova et al. 2013). In the past, forest resources played a major role in fodder and stable litter acquisition, with livestock keeping and forest grazing having a strong impact on prehistoric and historic woodlands (Brockmann-Jerosch 1918; Hejcman et al. 2014). Traditional woodland management practices—such as obtaining fodder in forests through lopping and peeling (harvesting leaves, twigs, and bark as animal feed)—were commonly practiced and have shaped forests in Europe for millennia. This has been true in remote areas until the end of the last century (e.g., Austad et al. 1991; Halstead 1998). Studies by Fægri and Troels-Smith have shown that these practices were introduced into Europe during the Neolithic period (5.600–2.300 BCE in the area of

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Austria, after Felber and Ruttkay 1983) (Fægri 1940, 1944; Troels-Smith 1953, 1955, 1960). Knut Fægri and Jørgen Troels-Smith were the first scientists to propose leaf hay collection as early as the Neolithic. Their research was based on pollen analyses and connected leaf hay collection with the decline of elm trees. This is a phenomenon seen in a drastic decrease of elm pollen in pollen diagrams around 3.000 BCE in parts of Europe, presumably due to the regular lopping of elm trees for leaf hay that prevents them from flowering.

The first firm archaeobotanical evidence of leaf foddering in a Neolithic context was discovered in layers of animal dung found with heaps of leaf-bearing twigs in the Weier pile dwelling in Switzerland (Rasmussen 1989a, 1989b). Following this discovery, several studies were conducted, focusing on domestic animal dung from wetland sites from the Neolithic to the Bronze Age in the western Alps (Switzerland, southwestern Germany, and France), leading to the establishment of standardized archaeobotanical methods and approaches (e.g., Rasmussen 1993; Akeret and Jacomet 1997; Karg 1998; Akeret et al. 1999; Akeret and Rentzel 2001; Kühn and Hadorn 2004; Kühn et al. 2013 with further references). Although regional differences can be seen in animal feeding practices, most of the sites show evidence of leaf hay collected from deciduous trees (e.g., *Fagus sylvatica*, *Fraxinus excelsior*), animals fed with evergreen twigs (*Abies alba*, *Hedera helix*, and *Viscum album*) and unleafed twigs of catkin-bearing trees or shrubs like *Corylus avellana*, *Alnus*, and *Betula* species. *Rubus fruticosus* remains, which were also regularly found in dung, could indicate the foraging of animals nearby the villages. In some cases, the waste from processing cultivated plants (threshing remains of cereals and flax) is also found in the dung indicating its use as animal fodder (Akeret and Rentzel 2001; Kühn and Hadorn 2004; Kühn and Wick 2010; Ptáková et al. 2021).

Nonetheless, this research remains scarce in the eastern Alps. A study that was conducted on caprine dung from the Iceman "Ötzi" site looked for evidence for early transhumance, however, the droppings turned out to be game dung (*Capra ibex, Rupicapra rupicapra*) rather than deriving from goat or sheep (Oeggl et al. 2009). In Austria, evidence for fodder management practices at pile dwelling sites is still missing. Extensive pile dwelling research, which provides suitable waterlogged dung material, has only started recently after five Austrian pile dwellings joined UNESCO World Heritage Sites in 2011 (Kuratorium Pfahlbauten 2022a). In Austrian pile dwelling research, a sole study with a focus on dung analysis was conducted by Schmidt (1986) at the site of "See" at Mondsee. The study included pollen analysis of dung and manure samples from around 3.000 BCE; however, no macroremains or plant epidermal remains from the dung were examined. The pollen analysis indicated the feeding of domestic animals with cereal processing waste or perhaps the pasture of animals in fallow fields. Indeed, pastures rich in herbs seem to have been close to the settlement, and leafy hay seems to have been fed (Schmidt 1986).

The terms "grassland" or "pasture" must be considered with care in a Neolithic context since they would not have yet existed in a modern sense. The term "grassland" encompasses natural habitats with grassland species, such as natural alluvial or wetland grasslands, while "pastures" are understood as seminatural habitats influenced by grazing animals (Hejcman et al. 2013).

The aim of this research is to close the gap of knowledge in this part of Europe in the late Neolithic by providing insights into livestock feeding practices at the site and situate the use and management of forest resources within a wider perspective. The present study discusses the work conducted at the newly excavated "Mooswinkel" pile dwelling at Mondsee in Austria, with the goal of providing data for comparative analysis with dung studies conducted at other sites in the western Alps. Levels revealed at Mooswinkel contained fragments of cattle dung, as well as goat or sheep dung pellets that were dated to the 4th millennium BCE. The droppings of domestic animals were analyzed with a focus on their botanical content. Additionally, botanical macroremains from the archaeological layers themselves were investigated for additional information on stable manure and fodder.

The research questions forming the analysis at Mooswinkel are the following:

- What were the Mooswinkel pile dwellers feeding their domestic animals (cattle, goats/sheep)?
- Did the late Neolithic farmers at Mooswinkel practice forest management in form of lopping fodder trees?
- How do the results from this eastern Alps pile dwelling compare with studies from contemporaneous sites in the western Alps?

This research is unique, and a comparable, in-depth analysis like the one presented here has only been conducted in Austria at the Weyregg 2 pile dwelling in Attersee (Kühn et al. in preparation).

Materials and methods

The site of Mooswinkel

Mooswinkel is a pile dwelling site located in a calm bay on the northern shore of Mondsee, in the municipality of Innerschwand (Upper Austria) (Fig. 1). Unlike other pile dwelling sites such as "Scharfling" and "See," which were already discovered and excavated in the late nineteenth century, Mooswinkel was only discovered in the 1970s. Early research included small surveys by Johann Offenberger in

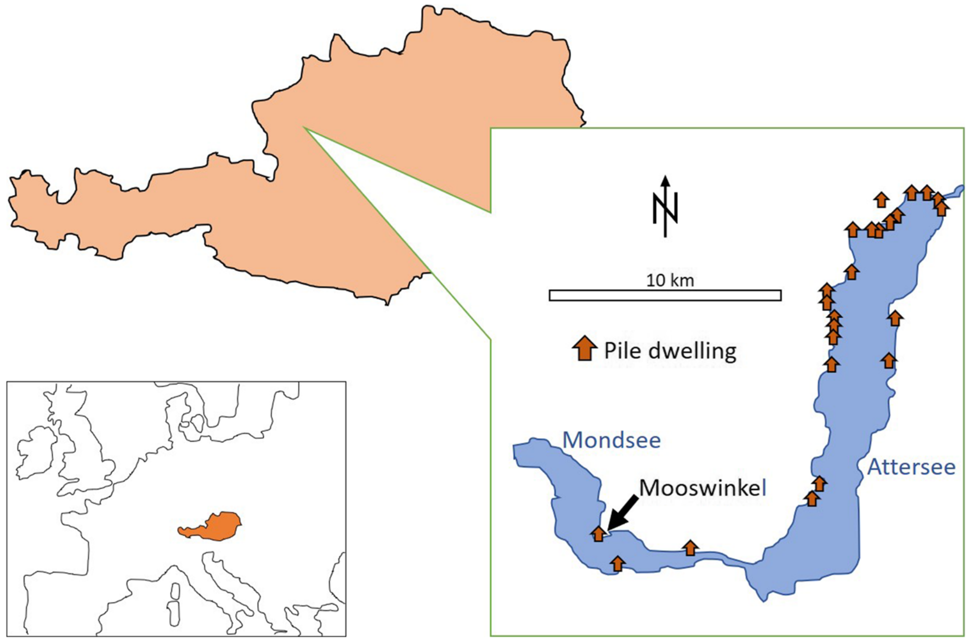

Fig. 1 Map showing the known pile dwellings at the Austrian lakes Mondsee and Attersee. The investigated site is indicated with an arrow

the 1970s, leading to the measurement of the site. A more detailed survey, without excavation, was conducted in 2003 by Reitmaier and Dworsky (Dworsky and Reitmaier 2004; Offenberger 2015; Pohl and Seidl da Fonseca 2018).

Excavations at the site started in 2018 within the project "Zeitensprung," which was initiated in 2015. This project started 4 years after the declaration of five Austrian pile dwellings as UNESCO World Heritage Sites. The project is financed by the *Direktion Kultur des Amtes der Oberösterreichischen Landesregierung*, under the leadership of Jutta Leskovar (Oberösterreichisches Landesmuseum) and Cyril Dvorsky (Kuratorium Pfahlbauten) (Kuratorium Pfahlbauten 2022b).

The small settlement, measuring 70 by 40 m, was situated on a headland, which is nowadays submerged under water. The shallow bank plate reaches from the shoreline to a depth of about 3.8 m under the water level, before steeply dropping to a depth of 8 m. The Mooswinkel bay is sheltered from strong winds and waves, enabling the preservation of the settlement. The first campaign of excavation lasted from May 2018 until June 2018. An excavation trench measuring 3 m by 1 m was set close to the edge of the bank plate, next to the steep slope, with a water depth of 2.8 to 3.5 m. Piles in this area can be found at a depth of two to three m, reaching down to about 7 m. Ten stratigraphic units (German abbreviation: SE, for *Stratigraphische Einheit*) were excavated and sampled for palynological, sedimentological, archaeobotanical, and dendroarchaeologial analyses, and C14 dating. Within the stratigraphic units, three layers were recognized as cultural layers and contained organic remains (SE 3, SE 6, and SE 8). The typology of pottery from the cultural layers is clearly attributed to the Mondsee group (3.800–3.500 BCE). Furthermore, the radiocarbon dating of organic remains puts the accumulation of these layers in a time frame of about 3.770 to 3.371 BCE (Pohl and Seidl da Fonseca 2018).

Sampling the site

The archaeological divers took direct samples from each cultural layer. During the excavation process, many samples were taken from every square meter in each layer. These samples were put in plastic containers of up to a volume of 300 ml, they were sealed under water and their coordinates were documented. Until their final analysis in the laboratory, the samples were stored in refrigerators at about 4 °C.

Macroremain analysis

Three waterlogged samples were randomly chosen for this research. They derive from two different cultural layers: two samples were taken from layer SE 8, and one sample was taken from layer SE 6 (Table 1). They were all wet-sieved using the wash-over method (Kenward et al. 1980; Hosch and Zibulski 2003; Steiner et al. 2015). Mesh sizes of 2 ml, 1 ml, and 0,25 ml were used for the wash-over sieving process. Fragile macroremains like twigs or dung pieces were removed in the sieving process and stored in separate containers. Ethanol (EtOH 98%) and distilled water (1:1) were added to the samples after sieving, and they were again stored at 4 °C until their examination to prevent fungal and bacterial growth. Two samples were subsampled due to their high content of organic material (Table 1). The subsamples were sorted until 384 macroremains were picked, which is the number necessary to get the desired accuracy when extrapolating the counts to the main volume (Van der Veen and Fjeller 1982).

Table 1 The three chosen samples taken from two different layers of the site Mooswinkel

	Sample		
	Pr. 128–Quadr. 12/100–DOF 10	Pr. 78–Quadr. 11/100D–DOF 10	Pr. 4–Quadr. 10/100A–DOF 7
Stratigraphical unit	SE 8	SE 8	SE 6
Volume	100 ml	160 ml	140 ml
Subsampling	None	20% of 0.25 mm fraction	20% of 1 mm fract., 20% of 0.25 mm fract
Cattle dung	Present (1.00 g analyzed)	Present (1.50 g analyzed)	Present (0.75 g analyzed)
Goat/sheep dung	Absent	Present (1.12 g analyzed = 10 pellets)	Present (1.24 g = 6 Pellets)

Plant material and dung pieces were sorted out under a stereoscopic microscope (Lacerta STM45) with magnifications of 6, 7–45×. Plant seeds and remains of cultivated plants were identified using common literature (e.g., Bertsch 1941; Berggren 1981; Anderberg 1994; Cappers et al. 2006) and the modern seed reference collection at the Austrian Archaeological Institute.

Wood remains (wood scraps from woodworking, small twigs, charcoal) were identified using Schweingruber (1978) as well as Zibulski and Schweingruber (2018). Due to their waterlogged state, wood scraps were too soft to prepare thin sections for microscopic determination. Therefore, they were embedded in PEG 1500 (polyethylene glycol) to stabilize them. Tree bud scales were identified using Tomlinson (1985). For the identifications of twigs and tree buds, reference material was collected and permanently mounted on microscopic slides. After identification, the plant material was quantitatively recorded, and data collection was conducted in Microsoft Excel. Phytosociological work by Oberdorfer (2001) was used for ecological classifications and interpretations.

Dung analysis

Dung material consisted of waterlogged fragments deriving from cattle dung and goat or sheep pellets (Fig. 2). The dung and the pellets were compared with recent dung collected by the first author from cattle, sheep, and goats in order to verify their provenance. Shape and consistency were the most important criteria for their identification. Ohnesorge et al. (1995) as well as Chame (2003) provide some guidance in identifying modern animal dung, which is equally useful for archaeological studies. A differentiation between goat and sheep pellets is not possible due to a large variation in breeds and sizes of animals and the dependence of pellet shape on the diet (Landsberg et al. 1994; Linseele et al. 2013). Cattle dung fragments were found in all three samples. Goat/sheep pellets were found in two samples (Table 1).

The dung and the pellets were carefully dissolved with a spatula in EtOH 70–96%. Plant remains were sorted out and mounted on microscope slides (standard slides 76×26 ml). Kaiser’s glycerol gelatin was used as a mounting medium.

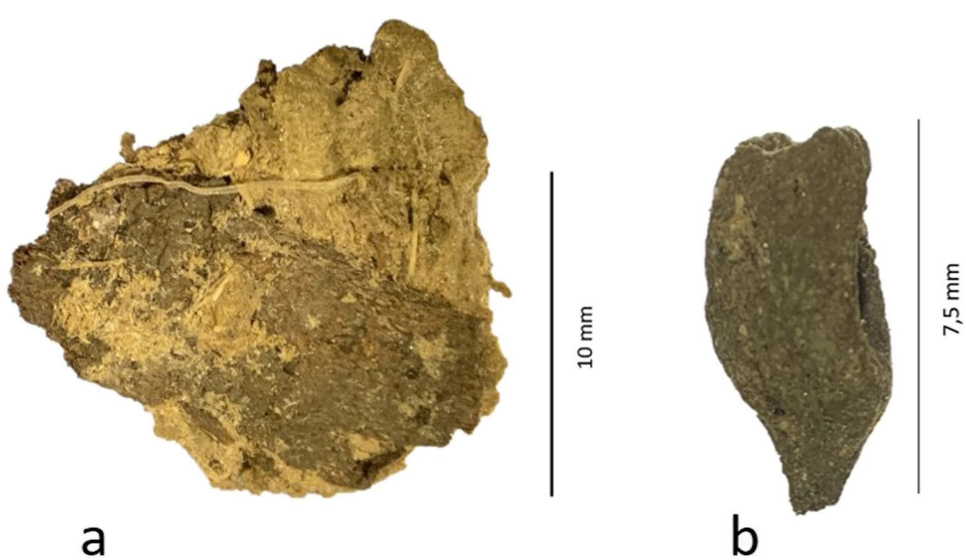

Fig. 2 Waterlogged dung material from archaeological layers: **a** cattle dung; **b** goat or sheep dung

The examination was done with a light microscope (BTC 135 T-LED) with magnifications of 50–500×.

The identification of plant epidermal material followed the methods described in Johnson et al. (1984), with identification literature (e.g., Metcalfe and Chalk 1979; Rech 2011) and a reference collection of plant epidermal tissues (leaf epidermises, established by the first author at the Austrian Archaeological Institute in Vienna). Seeds and other plant parts like tree bud scales were identified as described above in Sect. 2.3., and data collection and interpretations followed the same methods outlined above for macroremain analysis.

Results

Counting only identifications to a species level, a total amount of 72 different species from 28 different plant families have been found in the cultural layers and in the dung of the Mooswinkel pile dwelling.

Macroremain analysis

An overview of fruit, seed, and insect remains from the cultural layers is provided in Table 2, while the vegetative plant remains from the cultural layers are listed in Table 3. Remains of cultivated plants were found in a waterlogged and in a charred state. Most cultivated plant remains were found in layer SE 6. The majority of identified remains belong to the glume wheats einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*), the latter being the dominant one. Other cereals found are barley (*Hordeum vulgare*) and free-threshing wheat (*Triticum aestivum/durum/turgidum*). Oil- and fiber plants are represented by seeds of flax (*Linum usitatissimum*) and poppy (*Papaver somniferum*). Legumes, like peas and lentils, were not found.

Seeds and fruits of wild plant taxa have been found in a waterlogged state only. Sample Pr 78 from layer SE 8 contained the highest number of wild plant seeds and fruits. Some of the wild taxa can be attributed to gathered wild fruit used as food by the inhabitants of the settlement. They include hazelnut (*Corylus avellana*), European crab apple (*Malus sylvestris*), dewberry, bramble, and raspberry (*Rubus caesius, R. fruticosus, R. idaeus*), elder (*Sambucus nigra*), and wild strawberry (*Fragaria vesca*).

The analysis yielded 37 herbaceous species and 20 woody species (counting identifications to species level only). Herbaceous taxa were identified by seeds and fruits only (with one exception: bracken fern), while woody plant taxa were identified by their seeds, fruits, buds, anthers, and wood remains (wood scraps, twigs). Woody plants account for the majority of the macroremains, with vegetative remains, mostly in form of unidentifiable small wood scraps (<4 mm), and needles of spruce (*Picea abies*). Identifiable vegetative remains from herbaceous plants were only identified from bracken fern (*Pteridium aquilinum*) in form of leaves and stems. It cannot be ruled out, that a considerable number of vegetative remains derive from cereals and grasses (culms), and herbs (stems), but they were not investigated due to difficulties in their identification.

Dung analysis

Most dung pellets had the typical shape of goat and/or sheep pellets (Fig. 2), while some were out of shape from possible trampling (Fig. 3). The pellets occurred as single pellets only, not as clumps of dung.

Cow dung was preserved in the form of many small fragments ranged from about 2 by 2 ml up to about 15 by 15 ml in size. Cattle dung lacks compactness, and the fragmentation presumably resulted from trampling (cf. Kühn et al. 2013). Comparisons with recent cow dung revealed that cattle produced the dung, as did the fact that they exclusively contain botanical material.

Remains found in the dung samples are summarized in Table 4. What all dung remains have in common is a high content of unidentifiable wood remains (wood chips), smaller than 1 ml as a result of chewing and digestion. Also, trichomes from plant leaves and bud scales of *Fagus sylvatica* occur in every dung sample. Goat and/or sheep dung contained numerous tiny charcoal pieces, especially prominent in dung from the older layer SE 8. Charcoal was not found in any of the cattle dung samples. Most of the plant remains were derived from woody plants such as *Abies alba* needles, *Corylus avellana* anthers, *Fagus sylvatica* bud scales, *Hedera helix* leaf epidermis fragments, Rosaceae prickles, *Rubus* sp. seeds and stem epidermises of *Rubus fruticosus*, and bud scales as well as *Ulmus glabra* leaf epidermis fragments. Herbaceous plant remains were mostly encountered as seeds like those of *Ranunculus lanuginosus*, which occurred in high numbers in both cattle and goat and/or sheep dung. Only tough vegetative remains of non-woody plants were preserved in a recognizable state such as *Pteridium aquilinum* leaf epidermises, *Poaceae* epidermis fragments, and some bryophyte leaflets (unidentified and one from *Zygodon rupestris*). Most remains from cultivated plants were testa fragments of cereals, of which cattle dung contained the most.

Discussion

The investigated cultural layers at Mooswinkel are exceptionally well-preserved layers of stable litter. Such manure layers can easily be recognized because they contain dung mixed with bedding material and fodder. They occur in stalls

Table 2 Overview of fruit, seed, and insect remains from the cultural layers of the Mooswinkel pile dwelling. Numbers in brackets indicate fragmented remains. Classifications follow Oberdorfer (2001) and Fischer et al. (2008)

Taxa	Type of remain	SE 8 Pr 128 (100 ml)	SE 8 Pr 78 (160 ml)	SE 6 Pr 4 (140 ml)
Cultivated plants				
Cerealia	Testa fragment	74	>100	>100
Cerealia	Threshing remains	5	[1]	-
Cerealia	Threshing remains, charred	-	[16]	[11]
Hordeum vulgare	Rachis fragment	-	4	10
Hordeum vulgare	Rachis fragment, charred	1	-	16
Triticum aestivum/durum/turgidum	Rachis fragment	-	-	38
Triticum dicoccum	Glume base	5	14	130
Triticum dicoccum	Glume base, charred	2	-	7
Triticum monococcum	Glume base	3	1	66
Triticum monococcum	Glume base, charred	-	5	13
Triticum sp.	Glume base	-	93	342
Triticum sp.	Glume base, charred	-	1 [10]	5
Linum usitatissimum	Seed	-	5 [17]	27 [7]
Linum usitatissimum	Capsule fragment	6	6	40
Papaver somniferum	Seed	-	-	16
Cultivated fields and ruderal sites				
Brassica rapa	Seed	-	5	-
Crepis cf. tectorum	Seed	-	6 [1]	-
Silene cretica	Seed	-	1	9
Sonchus asper	Seed	-	6	5
Stellaria media	Seed	-	-	5
Grassland				
Achillea millefolium	Seed	-	5	-
Cerastium fontanum	Seed	-	10	-
Daucus carota	Seed	-	1	5
Pastinaca sativa	Seed	-	1	-
Plantago major	Seed	-	16	-
Poaceae gen. et sp. indet	Seed	-	10	-
Poaceae gen. et sp. indet	Glume	-	5	-
Prunella vulgaris	Seed	-	1	1
Stellaria graminea/palustris	Seed	-	-	1
Taraxacum officinale	Seed	-	1	-
Forest				
Brachypodium sylvaticum	Seed	-	1	-
Phyteuma spicatum	Seed	-	1	5
Ranunculus lanuginosus	Seed	-	11 [24]	1
Tilia cordata	Seed	-	-	1
Forest clearings/hedges				
Arctium nemorosum/lappa	Seed	-	6	-
Arctium nemorosum/lappa	Fruit	-	[60]	-
Carex pendula	Seed	1	6	-
Corylus avellana	Seed	-	-	[7]
Fragaria vesca	Seed	2	37	101 [25]
Geum urbanum	Seed	-	3	-
Hypericum hirsutum	Seed	1	-	-
Lapsana communis	Seed	1	2	-
Malus sylvestris	Seed	1 [3]	1 [3]	6 [53]
Malus sylvestris	Carpel	[11]	[27]	[104]

Table 2 (continued)

Taxa	Type of remain	SE 8 Pr 128 (100 ml)	SE 8 Pr 78 (160 ml)	SE 6 Pr 4 (140 ml)
Moehringia trinervia	Seed	-	5	-
Origanum vulgare	Seed	-	53	5
Rosa sp.	Seed	-	1	3
Rubus fruticosus	Seed	-	6	16
Rubus idaeus	Seed	1	14	126
Rubus sp.	Seed	[10]	[6]	[8]
Sambucus nigra	Seed	1	-	5
Sambucus sp.	Seed	-	-	1 [3]
Torilis japonica	Seed	-	2	-
Urtica dioica	Seed	-	40	-
Veronica teucrium	Seed	-	5	-
Lakeshore vegetation				
Alnus glutinosa	Seed	-	2	-
Alnus incana	Seed	-	-	1
Chaerophyllum hirsutum	Seed	-	2	-
Chrysosplenium alternifolium	Seed	-	10	-
Epilobium cf. palustre	Seed	-	15	-
Myosoton aquaticum	Seed	1	15	-
Poa cf. palustris	Seed	-	5	-
Polygonum hydropiper	Seed	-	-	1
Rubus caesius	Seed	-	2 [1]	1
Rumex conglomeratus	Fruit	-	1	2
Rumex conglomeratus	Seed	-	1	1
Schoenoplectus lacustris	Seed	-	-	1
Typha angustifolia/latifolia	Seed	-	-	5
Veronica anagallis-aquatica	Seed	1	20	-
Not assignable taxa				
Brassicaceae gen. et sp. indet	Seed	-	5	-
Carex sp.	Seed	-	6	-
Caryophyllaceae gen. et sp. indet	Seed	-	15	-
Juncus sp.	Seed	-	10	-
Panicoideae gen. et sp. indet	Seed	-	5	-
Polypodiopsida fam., gen. et sp. indet	Sorus	1	-	-
Scrophularia/Verbascum	Seed	-	1	-
Silene sp.	Seed	-	-	-
Fungi–sclerotia				
Cenococcum geophilum	Sclerotium	-	-	10
Claviceps purpurea	Sclerotium	-	-	1
Insects				
Chironomidae gen. et sp. indet	Larva	[10]	[2]	[150]
Coleoptera fam., gen. et sp. indet	Elytra	[2]	[1]	5 [20]
Diptera fam., gen. et sp. indet	Larva	1	-	1
Sepsis sp.	Puparium	-	7 [6]	-
Sphaeroceridae gen. et sp. indet	Larva	3	-	1
Trichoptera fam., gen. et sp. indet	Pupal case membrane	-	-	5
Indeterminata				
Indeterminata	Seed/fruit	2	51 [13]	1
Indeterminata	Seed/fruit, charred	-	-	1
indeterminata	Arthropod remains	[14]	[42]	[99]

and pens and can be interpreted as manure depots (Kühn et al. 2013), or as middens (Wallace and Charles 2013).

Kenward and Hall (1997, 2013) established a stable manure indicator group, which signals the presence of stable manure. Their suggestions for indicators largely agree with the macroremains found at Mooswinkel: cereals as feed, stable litter (e.g., bark, wood chips, and bracken fern), hay meadow plants (e.g., *Ranunculus*, *Prunella vulgaris*, *Carex*, *Juncus*, and Poaceae), and 'house fauna' insects like fly puparia. The finds of larvae of lesser dung flies (Sphaeroceridae), occurring in the layers and in the dung, clearly identify the layers as manure. These flies exclusively breed in animal dung, and they are the most abundant insects in (modern) dung samples. The puparia of *Sepsis* sp. flies from the layers indicate cattle dung, since Sepsids are ubiquitous in cow dung (Skidmore 1991).

The season of the accumulation of manure can be narrowed to the winter season by the shape of dung produced by Caprinae: goat and/or sheep pellets occurred as single pellets only, not as clumps. In temperate climates, many ungulates produce single dung pellets in the winter (ingestion of dry food), and dung clumps in the summer (ingestion of fresh plant material) (Ohnesorge et al.1995; Herbig 2009). Our own observations of goats and sheep resulted in the same conclusion (Fig. 4).

The seasonality is furthermore confirmed by macroremains inside the dung: almost all dung samples (goat and/or sheep and cattle dung) contained anthers of hazelnut (*Corylus avellana*), which blooms in late winter—usually in February—and during mild winters even in January (Edlin 1968; Fischer et al. 1994). In the layers, hazelnut anthers occurred together with anthers of alder (*Alnus* sp.), which bloom simultaneously or shortly after hazelnut (*A. incana*: February to March, *A. glutinosa*: starting from March, according to Fischer et al. 1994). *A. incana* and *A.* glutinosa seeds were also present at the site. The pollen in the hazelnut and alder anthers were fully developed, suggesting ingestion by the animals at the time of anthesis. In the past, it was a common practice to feed male flowers (catkins) of early blooming trees and/or shrubs (*Alnus*, *Betula*, *Corylus*) to domestic animals (Brockmann-Jerosch 1918). Evidence for feeding catkins has been found in contemporaneous settlements in Switzerland, where dung was excavated and examined for pollen and/or macroremains, such as in Egolzwil 3 (Rasmussen 1993), Arbon Bleiche 3 (Akeret and Rentzel 2001; Kühn and Hadorn 2004), and Pfäffikon-Burg (Kühn and Wick 2010).

Additional evidence for fodder harvested from woody plants can be seen in bud scales, which were found and identified from both the dung and manure layers. Various woody plant species have been traced by buds in the dung: *Abies alba*, *Alnus* sp., probably *Betula pendula*, *Fagus sylvatica*, *Picea abies*, *Salix* sp., and *Ulmus glabra* (Table 4). Elm buds (*Ulmus glabra*) make up most of the bud scales in dung, followed by beech (*Fagus sylvatica*). The results of bud scale counts from the manure layer are depicted in Fig. 5. Here, the majority belongs to spruce (*Picea abies*), closely followed by elm (*Ulmus glabra*).

Elm trees clearly played an important role in the feeding of animals, together with other deciduous trees, shrubs, and two conifers: spruce (*Picea abies*), and fir (*Abies alba*). Since bud scales already develop in early summer, the seasonality of harvesting twigs cannot be determined by bud scales alone. The investigation of tree rings on small twigs proved to be challenging due to the waterlogged state of the material. Nonetheless, four out of six thin twigs found in layer SE 8 were identified as *Fraxinus* or *Ulmus*. They had tree rings ending in early wood or in the transition of early wood to latewood, having been cut in spring or early summer. This is not firm evidence for the summer harvest of leaved elm twigs; however, it was possible to identify epidermal tissues of *Ulmus glabra* leaves in goat and/or sheep and cow dung, which is direct evidence for leaf hay.

It can be concluded, therefore, that the numerous bud scales of elm derive from leafed twigs that were harvested in the summer, dried, and given to animals as fodder in the winter. Furthermore, it can be assumed, that other deciduous species found as bud scales in dung were used in the same way. Beech especially seemed to have been fed as leaf hay in higher quantities too. According to historical and ethnobotanical literature, elm trees are a good source for leaf hay; however, any deciduous tree can give a fodder crop (Brockmann-Jerosch 1918; Austad et al. 1991). Beech leaves are known to store well because of their durability and were therefore also chosen as leaf hay in the past (Haas et al. 1998; Halstead et al. 1998). The lopping of fodder trees implies the regular cutting back of the trees, which would otherwise grow a crown that is too large for the stem and root system, resulting in the breaking of branches and windthrow of whole trees (Austad et al. 1991). A tree cannot be harvested every year, so a rotation period of about 4 years is necessary. Experiments and historical records have shown that, within a 4-year rotation system, the winter fodder for one cow would involve 72 trees (Rasmussen 1989b).

The ingested moss leaves found in cattle dung are another evidence for leaf fodder. *Zygodon rupestris* usually grows on tree bark, especially on ash (*Fraxinus excelsior*) and oak (*Quercus* sp.) at forest edges (Atherton et al. 2010). It is very likely that it was present on branches that were fed to cows as leaf hay.

Needle epidermises of conifers (*Abies alba, Picea abies*) were also found in the dung. Spruce needles (*Picea abies*) were found in the SE 8 manure layer in high quantities, while fir needles (*Abies alba*) were found in the younger SE 6 layer. Most of the twigs from manure layers derive

Table 3 Vegetative plant remains from the cultural layers of the Mooswinkel pile dwelling

Taxa	SE 8 Pr 128 (100 ml)							SE 8 Pr 78 (160 ml)							SE 6 Pr 4 (140 ml)						
	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle
Trees and shrubs																					
Abies alba	-	-	-	1	-	-	20	11	-	-	18	-	-	21	-	-	-	9	-	-	87
Alnus sp.	-	-	1	-	-	-	-	9	8	-	-	2	-	-	2	-	1	-	-	-	-
Corylus avellana	-	-	-	-	1	-	-	-	-	-	2	1	-	-	2	-	3	12	11	-	-
Euonymus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
Fagus sylvatica	1	-	-	3	-	-	-	5	-	-	15	-	-	-	3	4	5	20	-	-	-
Fraxinus excelsior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	2	-	-	-
Fraxinus/ Ulmus	3	5	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Larix/ Picea	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-
Larix decidua	-	-	-	-	-	-	1	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Picea abies	35	-	-	23	-	-	>100	63	-	-	125	-	-	>100	3	-	-	2	-	-	7
Populus sp.	-	3	-	-	-	-	-	-	3	-	-	-	-	-	-	1	2	-	-	-	-
Prunus avium/ padus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Prunus spinosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	2	-	-	-	-
Rosa sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosaceae gen. et sp. indet	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Rubus sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Salix sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sorbus aucuparia (cf.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-
Tilia sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-
Ulmus glabra	-	-	-	87	-	-	-	-	-	-	16	-	-	1	-	1	-	9	-	-	-
Viburnum lantana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-

Table 3 (continued)

Taxa	SE 8 Pr 128 (100 ml)							SE 8 Pr 78 (160 ml)							SE 6 Pr 4 (140 ml)						
	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/needle
Viburnum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Viscum album	-	-	-	-	-	-	-	-	-	-	-	-	-	>50	-	-	-	-	-	-	-
Herbacious plants																					
Pteridium aquilinum	-	-	-	-	-	-	74	-	-	-	-	-	-	>100	-	-	-	-	-	-	15
Indeterminata																					
Indeterminata	3	-	8	2	2	-	46	4	>500	61	12	29	-	>100	33	3	33	11	21	-	-
	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/nee-dle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/nee-dle	Twig	Wood scrap	Char-coal	Bud scale	Anther	Prickle	Leaf/nee-dle

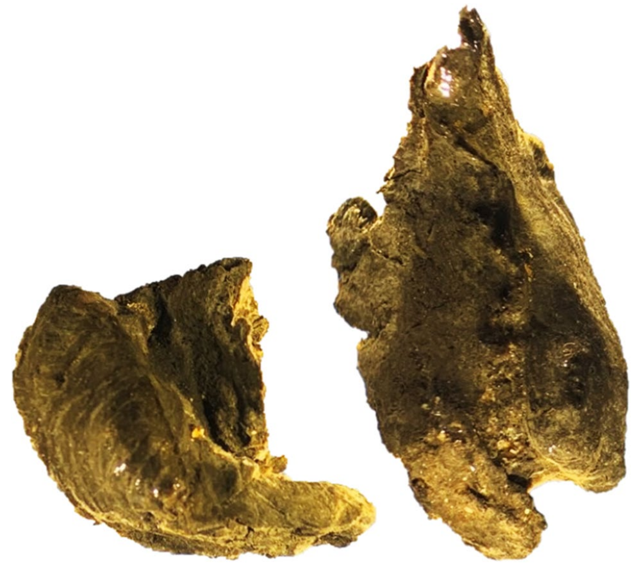

Fig. 3 Goat/sheep pellets deformed as a result of trampling. Scale = 1 cm

from spruce. Fir and spruce were pollarded in the past to gain animal bedding material, but they were also used as a source of fresh fodder in the winter (Brockmann-Jerosch 1918). The high quantity of spruce needles and twigs (and twigs with their needles still attached) in the manure layer, is interpreted as bedding material. Similarly, bracken fern (*Pteridium aquilinum*) would have been collected and used as bedding material, indicated by the high number of leaf and stem fragments found in manure layers. If harvested in autumn, when the fronds are brown, bracken makes a perfect bedding material for animals, even though it contains toxins (Rymer 1976; Madeja et al. 2009). Fir would have been used as additional fodder in the winter to provide fresh green plants for the animals since fir needles and bud scales occur in much higher numbers than spruce needles and bud scales in the dung. Fir was also reported as winterly gathered fodder from other archaeological sites from the Neolithic and later periods (e.g., Akeret and Rentzel 2001; Kühn and Hadorn 2004; Ptáková et al. 2021).

Together with fir branches, other evergreen plants were fed as fresh food in the winter. Leaf epidermises of ivy (*Hedera helix*) occur in high numbers in the dung of caprinae and cattle. Mistletoe (*Viscum album*) was found in cattle dung, and in high quantities in a layer of manure. Ivy and mistletoe are the best forages in a forest during winter due to their high nutritive value (Hejcman et al. 2014). They could have been grazed by the animals in the forest as ground cover (ivy) or as fallen specimens after strong winds (mistletoe). It is more likely that mistletoe was brought into the settlement with construction wood, and this could apply to fir branches as well. Winter is generally considered as

Table 4 Overview of botanical and insect remains found in the dung of goats or sheep and cattle

Taxa	Goat/sheep pellets			Cow dung		
	Type of remain	SE 8 Pr 78 (10 pellets, 1.12 g)	SE 6 Pr 4 (6 pellets, 1.24 g)	SE 8 Pr 128 (1 g dung)	SE 8 Pr 78 (1.5 g dung)	SE 6 Pr 4 (0.75 g dung)
Cultivated plants						
Cerealia	Testa	4	10	-	>30	5
Cerealia	Glume/glume base	1	-	-	-	2
Linum usitatissimum	Capsule fragment	-	-	1	-	-
Triticum sp.	Glume/glume base	-	-	-	2	-
Trees and shrubs						
Abies alba	Bud scale	3	-	-	1	-
Abies alba	Needle epidermis	20	5	-	8	10
Alnus sp.	Bud scale	-	-	-	-	1
Betula pendula (cf.)	Bud scale	-	2	-	-	-
Corylus avellana	Anther	2	12	-	1	2
Fagus sylvatica	Bud scale	3	5	1	1	1
Hedera helix	Leaf epidermis	-	11	2	35	10
Malus sylvestris	Carpel	1	3	-	2	3
Picea abies	Bud scale	-	-	1	-	-
Picea abies	Needle epidermis	-	-	5	3	1
Rosaceae gen. et sp. indet	Prickle	18	27	-	1	8
Rosaceae gen. et sp. indet	Stem epidermis	-	1	-	1	-
Rubus cf. *fruticosus*	Stem epidermis	2	1	-	-	-
Rubus sp.	Seed fragment	36	43	1	-	2
Salix sp.	Bud scale	2	-	-	-	-
Ulmus glabra	Bud scale	-	11	12	1	-
Ulmus glabra	Leaf epidermis	-	3	-	1	-
Viscum album	Leaf epidermis	-	-	-	1	-
Herbacious plants and bryophytes						
Alopecurus cf. *aequalis*	Seed	-	-	-	1	-
Bryophyta-Musci gen. et sp. indet	Leaflet	-	-	-	2	-
Cerastium fontanum	Seed	1	-	-	-	-
Daucus carota	Seed	-	-	-	-	1
Fragaria vesca	Seed	-	-	-	-	1
Juncus sp.	Seed	-	1	-	-	-
Phragmites australis	Seed	1	-	-	-	-
Poaceae gen. et sp. indet	Leaf epidermis	2	1	-	-	2
Pteridium aquilinum	Leaf epidermis	-	2	4	-	5
Ranunculus lanuginosus	Seed fragment	16	-	-	>30	-
Silene sp.	Seed	-	-	-	1	-
Veronica sp.	Seed	-	-	-	-	1
Zygodon rupestris	Leaflet	-	-	-	-	1
Insects						
Indeterminata	Insect fragm	3	2	-	-	-
Indeterminata	Parasite eggs	2	-	-	-	-
Sphaeroceridae gen. et sp. indet	Larva	-	-	1	-	-
Indeterminata						
Indeterminata	Anther	1	-	-	-	-
Indeterminata	Bark/bast/stem	91	78	4	>30	-
Indeterminata	Bud scale	15	3	-	-	4
Indeterminata	Charcoal	188	3	-	-	-

Table 4 (continued)

Taxa	Goat/sheep pellets			Cow dung		
	Type of remain	SE 8 Pr 78 (10 pellets, 1.12 g)	SE 6 Pr 4 (6 pellets, 1.24 g)	SE 8 Pr 128 (1 g dung)	SE 8 Pr 78 (1.5 g dung)	SE 6 Pr 4 (0.75 g dung)
Indeterminata	Leaf epidermis	97	35	-	8	10
Indeterminata	Seed fragment	-	8	-	>30	-
Indeterminata	Trichome	41	2	1	1	3
Indeterminata	Twig	-	-	6	-	15
Indeterminata	Wood chip	20	32	>30	>30	>30

Fig. 4 Seasonality of caprine dung. Left: sheep dung clump in the summer. Photo by T. Jakobitsch. Right: goat dung pellets in the winter. Photo by F. Bischof

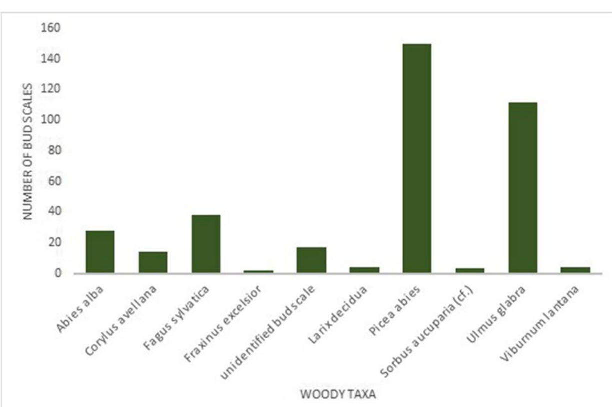

Fig. 5 Bud scale analysis performed with bud scales from manure layers of the Mooswinkel site, $N=372$

the season for cutting construction wood (Kühn and Wick 2010). Both plants (ivy and mistletoe) are well known as leaf fodder from Neolithic times (Rasmussen 1989a, 1993; Akeret et al. 1999; Kühn and Hadorn 2004; Kühn and Wick 2010, Ptáková et al. 2021).

A frequent find in the dung of all ruminants is the prickles of Rosaceae. They can be assigned to the genus *Rubus*, from which fragmented seeds were found in the dung of goats/sheep high numbers, but also in cattle dung. Stem epidermis fragments that were identified as possible bramble shoots (*Rubus* cf. *fruticosus*) lead to the assumption that the prickles and seeds also belong to this species. Bramble is another forage that is still providing fresh green leaves in winter and dried-up fruits can be still found in large quantities on plants even in late winter and spring (Fig. 6). It is possible, that bramble shrubs were gathered as fodder in winter like ivy, mistletoe, and fir branches. Most authors, however, interpret the find of bramble prickles and seeds in dung as the result of ruminants grazing in close vicinity to the settlement, when they were left free during the winter days to forage. Brambles do not grow very high, so animals could have easily reached them on their own (Akeret and Jacomet 1997; Akeret et al. 1999; Klee and Wick 2007).

Likewise, the small charcoal pieces found in the dung of goat and/or sheep could be indicative of outdoor grazing in areas of burnt vegetation. Patches of forests might have been cleared using fire to create small pastures, and the caprines grazed there during winter days (Kühn and Wick 2010; Kühn et al. 2013; Jacomet et al. 2016).

By grazing outside, the animals possibly transported the fruits and seeds of burdock (*Arctium nemorosum/lappa*) into the settlement, which was found in the manure layer. Burdock fruits are still attached to the plant in the winter, waiting for dispersal by passing animals (Fig. 7).

Grass hay was rarely discussed as a fodder type during the Neolithic, justified by the lack of metal tools to cut herbaceous and grassy hay in considerable amounts (Knörzer 1996, Hejcman et al. 2013). However, the collection of herbaceous and grassy hay cannot be completely excluded in pre-metal periods, since even in historical times grass was harvested in some regions by reaping with bare hands. The amount of hay harvested by hand was likely small and only used as an addition to leaf hay (Brockmann-Jerosch 1918). Neolithic flint sickles were used for grain harvesting, but they are of course also suitable for small-scale hay making (Gaillard et al. 1994). Evidence of grassy and herbaceous hay in Mooswinkel can be seen in numerous wild plant seeds of Poaceae and herbaceous species found not only in the manure layers but also in the dung itself. Herbig (2009) already discussed the possibility of feeding the hay of grassy and herbaceous plants at some Neolithic sites, indicated by the presence of grassland plant diaspores in cattle dung. Seeds of grasses and herbs found in livestock dung correspond well with vegetation types from where hay was collected (Müller-Schneider 1954; Schepers and Van Haaster 2015) and diaspores from archaeological layers can be equally useful in detecting hay deposits, with some species indicating grasslands and meadows (Greig 1984; Hejcman et al. 2013). During the summer harvest time, most hay plants would have developed seeds that can be detected in archaeological material (Greig 1984).

Plant taxa from manure layers indicative of grasslands, pastured lands, and/or hay (according to Greig 1984, Austad et al. 1991, Oberdorfer 2001, and Hejcman et al. 2013), include, for example, *Achillea millefolium*, *Brachypodium sylvaticum,* and other Poaceae, *Carex* sp., *Cerastium fontanum*, *Daucus carota*, *Geum urbanum*, *Juncus* sp., *Origanum vulgare*, *Pastinaca sativa*, *Plantago major*, *Prunella vulgaris*, *Ranunculus lanuginosus, Stellaria graminea/palustris*, *Stellaria media*, *Taraxacum officinale*, *Torilis japonica*, and *Urtica dioica*. Some of these species—*Cerastium fontanum*, *Daucus carota, Juncus* sp., and *Ranunculus lanuginosus*—appear in both manure layers and in dung. Although *Ranunculus* sp. are poisonous for ruminants when ingested fresh, they are harmless in the hay when dried (Oberdorfer 2001). This clearly indicates that the plant matter was dried before it was ingested. Additionally, the already mentioned

Fig. 6 Dried-up fruits of bramble (*Rubus fruticosus*) still on the shrub in early March. Photo taken by T. Jakobitsch in Vienna

Fig. 7 Fruits of burdock (*Arctium lappa*) still attached to the plant in the winter, waiting for dispersal by passing animals. Photo taken in February by T. Jakobitsch near Attersee (Oberösterreich)

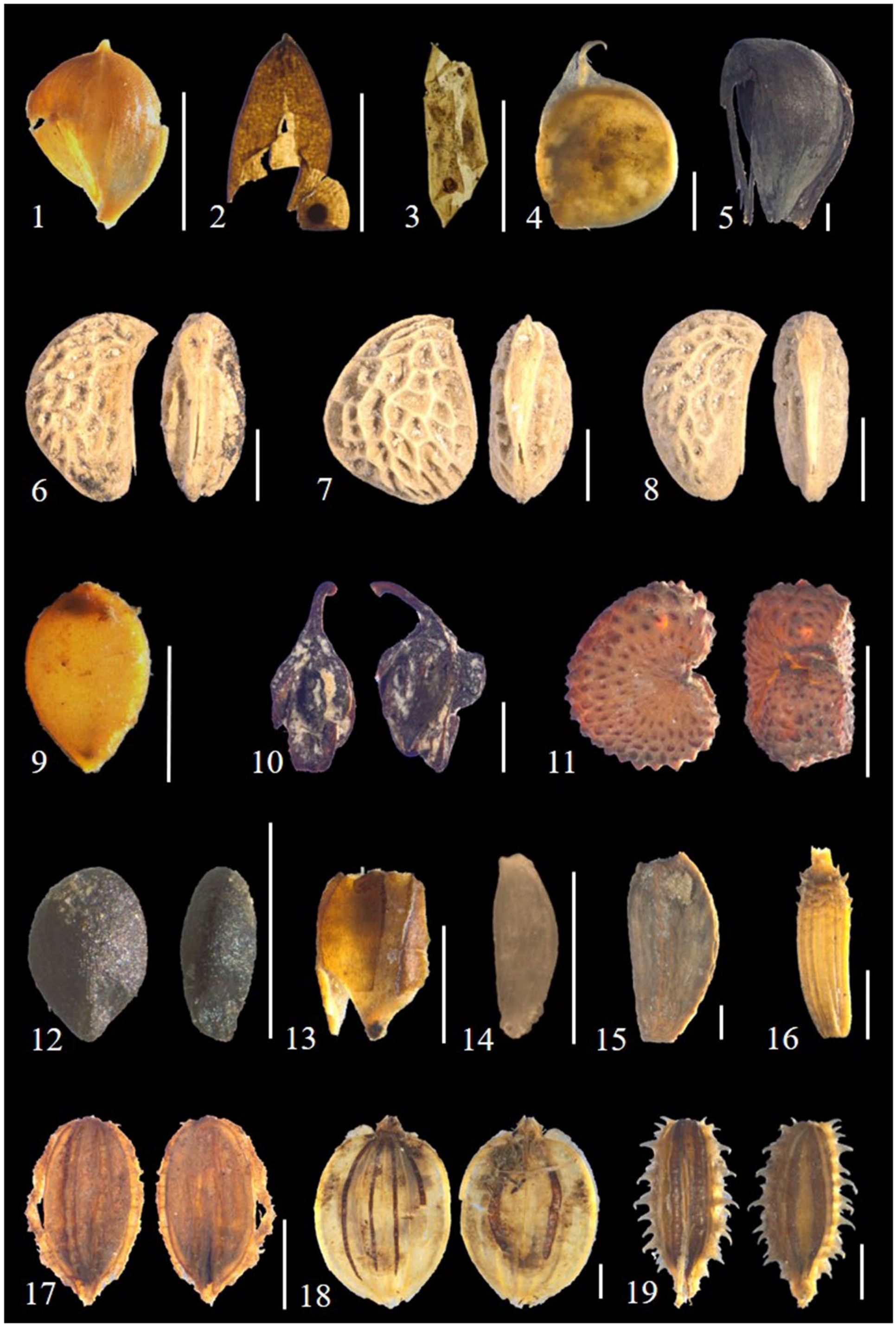

Plate 1 Selected subfossil seeds from manure layers and dung. **1** *Carex pendula*; **2** *Alopecurus cf. aequalis*, from cattle dung; **3** *Poa* cf. *palustris*; **4** *Ranunculus lanuginosus*; **5** *Malus sylvestris*; **6** *Rubus caesius*; **7** *Rubus fruticosus*; **8** *Rubus idaeus*; **9** *Urtica dioica*; **10** *Rumex conglomeratus*; **11** *Silene cretica*; **12** *Origanum vulgare*; **13** *Prunella vulgaris*; **14** *Achillea millefolium*; **15** *Arctium nemorosum lappa*; **16** *Taraxacum officinale*; **17** *Daucus carota*, from cattle dung; **18** *Pastinaca sativa*; **19** *Torilis japonica*; Scale = 1 mm

seasonality of the dung proves that herbaceous and grassy plants were eaten in the winter and must, therefore, have been stored (in dry form) until ingestion. Further evidence for this statement can be found in the Poaceae leaf epidermises found in the dung. We propose, therefore, that most diaspores of herbaceous and grassy plants in the manure layers originate from hay that was harvested in the summer and dried and stored as winter fodder in addition to the above-mentioned leaf hay, evergreens, and catkins (Plates 1 and 2).

Another fodder type was cereal grains and threshing remains of cereals and flax, as indicated by the macroremains in dung. This corresponds well with historical accounts (Brockmann-Jerosch 1918) and with contemporaneous settlements (e.g., Akeret and Rentzel 2001; Kühn and Hadorn 2004; Kühn and Wick 2010, Ptáková et al. 2021).

The remains of the European crab apple (*Malus sylvestris*) in the dung leads to the assumption that apples were not only intended for human consumption, but also for animals. They could also have been eaten during daytime grazing outside the settlement. In wood pastures, where *Malus sylvestris* has good light conditions for growing, the seeds of wild apples are regularly found in cattle dung (Vera 2000).

Contemporaneous sites around the lake zone in Austria are known at Mondsee and at the neighboring Attersee. The "See" pile dwelling was investigated by Schmidt (1986). He found evidence for herb-rich grasslands and pasturing of livestock around and in the settlement, and he discussed the possibility of feeding leaf hay.

At the Lenzing-Burgstall site, which is a Late Neolithic hill settlement near Attersee, charred seeds of juniper (*Juniperus communis*), field mugwort (*Artemisia* cf. *campestris*), and plantain (*Plantago media*) have been found (Jakobitsch et al. 2022). These plants are indicative of wooded pastures, hay meadows, and grasslands (Greig 1984; Austad et al. 1991; Oberdorfer 2001; Hejcman et al. 2013). Seeds of grassland species (e.g., *Daucus carota*, *Juncus acutiflorus*, *Origanum vulgare*) and goat and/or sheep droppings are also known from the contemporaneous pile dwelling Weyregg 2 at Attersee (Jakobitsch and Heiss in preparation).

Most striking is the similarity of the finds at Mooswinkel in comparison with dung analyses from Swiss pile dwellings in the Western Alps, especially Arbon Bleiche 3 (Akeret and Rentzel 2001; Kühn and Hadorn 2004). Other settlements, however, suggest different livestock husbandry regimes, like Pfäffikon-Burg, where indications for leaf hay are absent (Kühn and Wick 2010).

Conclusions

Bringing together the results of this study we can answer the research questions posed at the beginning of this paper. The layers investigated in the Mooswinkel pile dwelling are interpreted as manure layers consisting of animal bedding material, fodder, and dung. The macroremains from these layers suggest the following: in the winter, when the animals spent the night in the settlement or houses, the farmers fed them leaf hay and hay of grasses and herbs, which they were precautiously collecting in the summer season. Additionally, they were given fresh greens like fir branches and mistletoe, which were a by-product of the collection of wood for construction. In late winter, when hazel bushes and alder trees started to bloom, the dwellers collected the male flowers (catkins) and gave them as a nutritious addition. The prickles and seeds of brambles, ivy leaves, fruit remains of wild apples, burdock fruits, and charcoal in the dung might indicate outside grazing during the day, if the weather conditions allowed it. Since only dung from the winter period was found, it is likely that the ruminants were foraging during

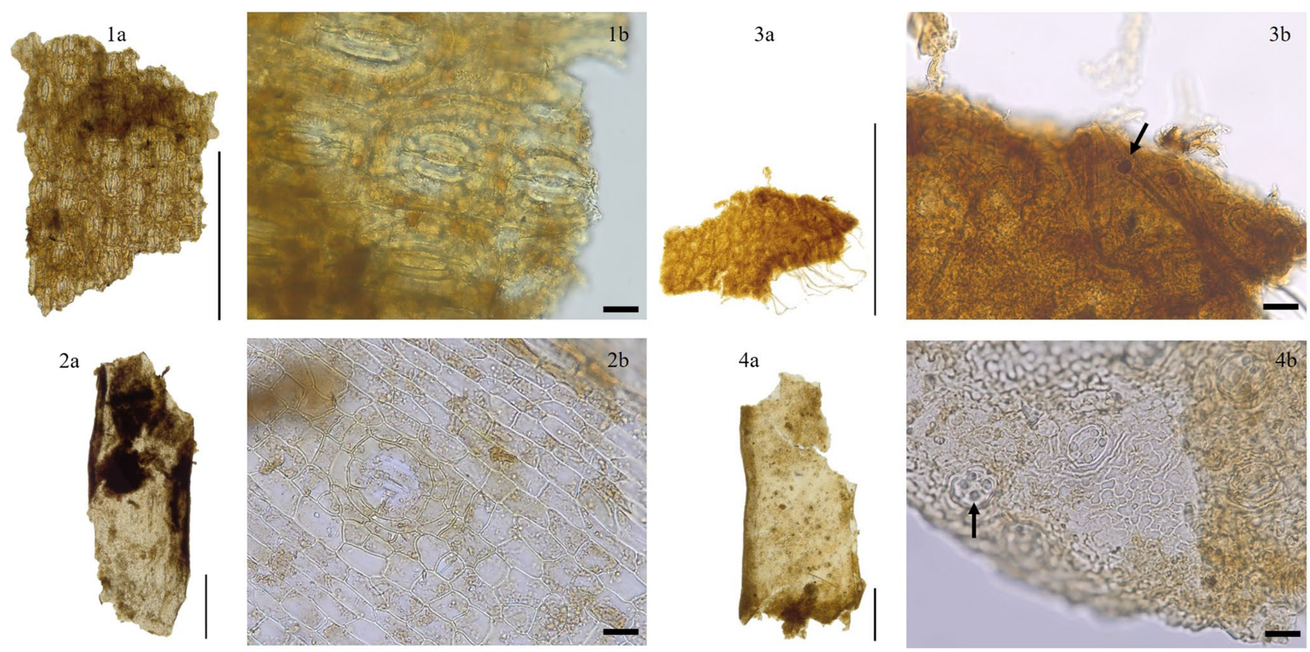

Plate 2 Selected leaf epidermis tissues found in the dung of goats/sheep and cattle. **1a** *Abies alba*, needle epidermis fragment; **1b** Detail showing aligned stomata arrangement in *Abies alba*; **2a** *Rubus* cf. *fruticosus* stem epidermis fragment; **3b** *Rubus* cf. *fruticosus* stomata with cyclocytic cell arrangement around stomata; **3a** *Ulmus glabra* leaf epidermis fragment; **3b** Detail showing trichome base cells (arrow); **4a** *Hedera helix* leaf epidermis fragment; **4b** Details showing stomata, epidermal cells and druse crystals (arrow). Scale in **1a**, **2a**, **3a**, and **4a** = 500 μm; Scale in **1b**, **2b**, **3b**, and **4b** = 20 μm

the spring and summer periods in the wood pastures and grasslands around the settlement. The plant habitats at the site, as indicated by the macroremains, draw a picture of a mosaic of forests and semi-open landscapes. Forest exploitation for animal fodder, grazing, hay collection, and crop cultivation shaped the landscape into modified forests, transitional zones from forests to open land, seminatural grasslands, cultivated fields, and lakeshore vegetation.

The question of forest management as early as in the Neolithic can clearly be answered with the evidence of lopping fodder trees: elm, beech, and other suitable deciduous trees were evidently harvested for fodder. The trees had to be cut back regularly in a rotation system to keep the trees healthy and provide enough fodder annually. Careful management and planning must have been necessary for a sustainable fodder production. The tree management would not have involved only a few trees, but a considerable area of a few hectares of managed forest (Austad et al. 1991; Rasmussen 1989b).

Animal dung studies can, therefore, be a useful tool to investigate fodder management practices and their impact on local and regional forests. This method can be used on modern studies as well in concert with archaeological material, for insights into modern and past forests and their resource use. The evidence for forest management as early as the Late Neolithic makes us aware of how long humans have been modifying their environment on a large scale.

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Data availability All relevant data are within the manuscript. All archaeological plant remains are stored at the Austrian Archaeological Institute and are available for scientific re-evaluation on request: Thorsten Jakobitsch, Austrian Archaeological Institute, Franz-Klein-Gasse 1, 1190 Vienna, Austria. E-mail: thorsten.jakobitsch@oeaw.ac.at, telephone: + 43 1 51,581–4114.

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