A toolkit for field identification and ecohydrological interpretation of peatland deposits in Germany

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SUMMARY

Successful peatland restoration requires a knowledge of peatland stratigraphy in order to understand the hydrological and ecological conditions under which peat formation occurred and to identify realistic objectives and measures for the specific site. So far, the ability to accurately identify peat deposits and lake sediments has been largely restricted to experts. To facilitate identification by others, we provide an identification key for common peatland deposits in Germany and introduce standardised portraits of 17 peat and six gyttja types with extensive descriptions and supporting photographs. We also provide information on the indicative value of the peatland deposits in terms of site conditions at the time of deposition.

KEY WORDS: classification, guidance, gyttja, peat, restoration

INTRODUCTION

About 4.4 % (15,500 km²) of Germany's land surface is covered by organic soils (Roßkopf *et al*. 2015). Mainly owing to agricultural drainage, no more than 1 % of the country's former peatlands are still accumulating peat and providing the typical ecosystem services of undisturbed peatlands (Joosten & Couwenberg 2008). The fact that degraded peatlands are a source of greenhouse gases is receiving increasing attention in the context of global warming (Joosten *et al*. 2016), and large-scale peatland degradation may also affect mire biodiversity. As a result there has been an increase in peatland restoration activities in Germany (e.g. Rowinsky & Kobel 2011, Zak *et al*. 2011, Bonn *et al*. 2016) and elsewhere.

Restoration requires a knowledge of peatland stratigraphy to support site-specific goal setting, hydrological intervention and subsequent management. The botanical and material composition of peats and gyttjas provides indispensable information on former hydrological and ecological conditions and how they have changed over time (Joosten & Succow 2001a, Succow 2001a), while the condition of the topsoil indicates recent trophic and hydraulic properties.

So far, the accurate identification of peatland deposits has usually required the involvement of experts, who are not always available in restoration practice. The scarce descriptions in literature (e.g. Ad-hoc-AG Boden 2005) are unclear and insufficiently detailed for use by non-experts, amongst other reasons because they lack supporting illustrations. More detailed descriptions including some photographs of macrofossils are found only in older specialist literature (e.g. Grosse-Brauckmann 1972, Overbeck 1975), which is difficult to access and not comprehensive; or in literature that focuses, rather, on scientific palaeoecological analyses (e.g. Mauquoy & van Geel 2007). As a consequence, peatland deposits are seldom accurately identified and interpreted in peatland restoration and conservation practice. This may cause deficiencies in restoration projects and even result in their failure (Hasch *et al*. 2007).

This article presents a key with extensive portraits to facilitate the field identification of peatland deposits that are common in Germany, and provides information for interpreting these deposits in terms of site conditions (cf. Meier-Uhlherr *et al*. 2011).

METHODS

In Germany, peat ('Torf' in German) is defined as sedentarily accumulated material consisting of more than 30 % (dry mass) of incompletely decomposed plant remains and humic substances as products of their transformation (e.g. Succow & Stegmann 2001a, Ad-hoc-AG Boden 2005). Gyttja ('Mudde' in German) is defined as lake sediment with an organic

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matter content of at least 5 % (dry mass) (Merkt *et al*. 1971, Stegmann *et al*. 2001, Ad-hoc-AG Boden 2005). We include gyttjas in peatland deposits because they are often spatially connected with peat, e.g. occurring as the underlying stratum in terrestrialisation mires or as intercalations in cases where rising water level has resulted in the temporary establishment of water bodies (Joosten & Succow 2001a).

Various criteria are used to classify peat deposits including botanical composition, chemistry, degree of humification, structure, or certain physical variables (Schneekloth & Schneider 1972, Joosten *et al*. 2017). We chose botanical composition as the primary classification feature because macroscopically recognisable plant remains are a major and defining component of peat (Grosse-Brauckmann 1962a). For the classification of gyttjas we mainly followed Merkt *et al*. (1971) who distinguish gyttja types according to the fraction of organic matter, lime ($CaCO_3$) and silicates, the type of silicate (sand, silt, clay), particle size and the biological components of the organic matter.

To assess the variety, characteristics, abundance and distribution of peatland deposits in Germany, we analysed German-language literature on peatlands (Table A1.1 in Appendix 1), reviewed numerous stratigraphies (mainly from Succow 1988 and Succow & Joosten 2001), and cored more than 2000 metres of peat deposits at 500 sites on 62 peatlands in Germany (focusing on north-east Germany) using a 5 cm diameter, 50 cm long chamber corer and extension poles. Deposits were photographed using a Canon EOS 1000D reflex camera with a Sigma DC telephoto lens (17–70 mm focal length), a Cullmann Universal tripod, and a water-repellent unicolour underlay with integrated scale. We collected samples of peat and gyttja types for which zero or sparse information on C/N and pH_{KCl} values was available in literature. Organic carbon and nitrogen content of dry matter was determined by dry combustion with an elemental analyser including a correction for inorganic carbon by application of a calcimeter. pH was measured on fresh samples in potassium chloride suspension (concentration 1 mol L^{-1} in distilled water) with a calibrated pH meter.

Using this information we compiled extensive portraits for all types of peatland deposits that can be identified in the field without supplementary microscopic or laboratory analysis. We excluded deposit types that have been assessed in the reviewed literature as very rare or occurring rather as admixtures in peat formed by other plant taxa. To enable fast identification, we developed a dichotomous identification key.

RESULTS

We generated portraits of 17 peat types and six gyttja types, plus one for special deposits (bog iron ore, blue iron ore, spathic iron ore, lake marl, lake Laach tephra, burnt layers and spring deposits). The 24 portraits present characteristics for field identification with respect to both recognisable macrofossils and the matrix in which they are embedded. Furthermore, they give ecohydrological interpretations of the conditions under which the deposits were formed (Table 1). Frequently occurring mixed peats with co-dominance of different plant taxa (e.g. *Eriophorum-Sphagnum* peat) are described in the portrait of each taxon involved. Excerpts of the portraits for *Cladium* peat and detritus gyttja are presented in Figures 1–4, and the full set of portraits is provided as supplementary material in a format that lends itself to lamination for use in the field. A previous version in German may be accessed at http://www.mire-substrates.com (cf. Meier-Uhlherr *et al*. 2011).

We included two peat types that do not result directly from peat accumulation but are the outcome of oxygen-induced humification and degradation of another (botanical) peat type, namely: 'earthified peat' ('vererdet' in German) and 'murshified peat' ('vermulmt' in German). As is typical for Central and Eastern Europe, most German peatlands are drained and cultivated (Oleszczuk *et al.* 2008) leading to secondary soil formation in the peat by mineralisation and compaction, especially under continental climatic conditions. The natural peat structure changes gradually to a crumb or even fine granular structure with substantially changed soil properties, in a process referred to by Ilnicki & Zeitz (2003) as the 'moorsh-forming process' - a name derived from the Polish term 'Mursch' which was first introduced by Okruszko (1960 in Ilnicki & Zeitz (2003)). The first stage of soil degradation, characterised by a crumb structure resembling garden mould (organic garden soil), is known as 'earthification' in Germany (Roßkopf *et al*. 2015, Gabriel *et al.* 2018). Under intensive and continuous drainage, aeration and ongoing degradation, the crumb structure subsequently changes into a structure of fine granular soil particles, translated from German as 'moorsh' peat by Gabriel *et al.* (2018). We use the term 'murshified' peat, following the original notion of Okruszko (1960 in Ilnicki & Zeitz (2003)).

The identification key (Appendix 2) bases its primary distinction on the consistency of the deposit and the presence/absence of recognisable plant remains. Within 'peats without recognisable plant remains', the user is guided - on the basis of texture

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Table 1. Structure and content of the portraits of peatland deposits.

Structure and contents of the peat portraits	
Text: Characteristics for field identification • characteristics of the macrofossils (plant part, size, colour, structure) • appearance of the embedding matrix (components, colour, texture) • possible confusion with other peat types • typical admixtures • occurrence as pure peat / mixed peat • typical degrees of humification according to von Post (1924) Site conditions and ecohydrological indications • ecological and hydrological formation conditions • occurrence and position in the landscape • peat forming plant communities • occurrence in hydrogenetic mire types • occurrence in ecological mire types including trophic conditions (spectrum of measured C/N values) and base saturation conditions (spectrum of measured pH values) Classifications • according to KA5 (Ad-hoc-AG Boden 2005) and TGL 24300/04 (1985)	**Photos:** • typical appearance of peat in corer • close-up of exposed peat • varieties and peculiarities of peat • main peat forming living plants • main peat forming macrofossils • typical admixtures in peat
Structure and content of the gyttja portraits	
Text: Characteristics for field determination • characteristics of gyttja (components, texture, colour) • typical admixtures Site conditions and ecohydrological indications • ecological and hydrological formation conditions and occurrence • material composition: fraction of organic matter, lime ($CaCO_3$) and silicate Classification: • according to KA5 (Ad-hoc-AG Boden 2005) and TGL 24300/04 (1985)	**Photos:** • typical appearance

and colour - to 'highly decomposed peat', 'earthified peat' or 'murshified peat'. The 'peats with recognisable plant remains' are subdivided according to physiognomic plant groups (woody plants, mosses, herbs), their constituent plant organs, and the embedding matrix. The gyttjas are divided into 'organic gyttjas' and 'mineral gyttjas' on the basis of mineral content, consistency and colour. Texture, colour and organic constituents allow the user to distinguish between 'algal gyttja' and 'detritus gyttja'. 'Mineral gyttjas' are differentiated according to the fractions of lime, sand, silt or clay. Identification can be verified by comparison with the descriptions and photographs in the portraits.

DISCUSSION

We applied botanical composition as the main classification criterion because peat is defined by the presence of plant macrofossils (Grosse-Brauckmann 1962a) and botanical composition provides ample indication of a wide variety of site features that are relevant for conservation and restoration (Succow & Joosten 2001, Joosten *et al*. 2017). Various widely used peat typologies similarly define their types according to plant taxa (e.g. *Phragmites* peat) or organs (e.g. radicel peat) (Grosse-Brauckmann 1962a, 1972, 1974; Overbeck 1975, Working Group of Commission I of the International Peat Society

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Characteristics for field identification

The characteristic remains of saw-sedge are usually embedded in a thick, brown, slightly structured matrix, which quickly darkens in contact with air. The matrix often contains a considerable fraction of gyttja or, rarely, is formed by a thick brown felt of saw-sedge rootlets.
The upright stem bases of saw-sedge are the most obvious macrofossils. Even in more highly decomposed peat, they are usually well preserved. The stem bases are 1–2 cm thick and 3–5 cm long, ovate and elongated, often somewhat asymmetrically curved, truncated at the top and narrowed at the bottom. The dark brown bark of the stem base is mostly 2–3 mm thick and often quite woody (becoming softer at higher degrees of decomposition). The bark usually shows former leaf attachments, and rootlet holes up to 2 mm wide. Inside the bark there are very loose, carmine to brownish-orange, coarse-fibred remains of vascular bundles.
Occasionally, shiny dark brownish to bronze-brownish, not very compressed, 0.5–1 cm wide rhizomes of saw-sedge are found, also with reddish, coarse-fibred remains of vascular bundles inside them. The nodes of the rhizomes are close together (spacing 1–2 cm), inconspicuous, not distinctly confined, and occasionally with parallel-nerved, 1.5–2 cm long cataphylls.
Rarely, seeds of saw-sedge (black, oval, slightly three-part, 2 mm across) are found in the peat.
Saw-sedge peat might be confused with alder peat, due to the woody bark of the stem base and the reddish remains of the vascular bundles. The vascular bundles are always softer and more fibrous in saw-sedge than in alder wood.

Typical admixtures: gyttja, seeds of water plants (especially pond-lily), shells of molluscs, occasionally rootlets and rhizomes of common reed and sedges, brown mosses.

Occurrence as pure peat / mixed peat: mostly as pure peat with some gyttja, occasionally as common reed - saw-sedge peat, sedge - saw-sedge peat and brown moss - saw-sedge peat.

Typical degrees of humification: due to seasonal lake-level fluctuations during peat accumulation and subneutral to calcareous conditions, mostly moderately decomposed; sometimes also highly decomposed.

Figure 1. Excerpt from the portrait of *Cladium* peat, after Meier-Uhlherr *et al.* (2011) (page 2), translated from German.

Typical appearance of peat in corer

Moderately decomposed (H6) saw-sedge peat: reddish remains of saw-sedge vascular bundles in a brown matrix.

Close-up of exposed peat

Fibrous, carmine remains of vascular bundles and bark of stem base (circle) in a thick, brown, slightly structured matrix.

Figure 2. Excerpt from the portrait of *Cladium* peat, after Meier-Uhlherr *et al.* (2011) (page 3), translated from German.

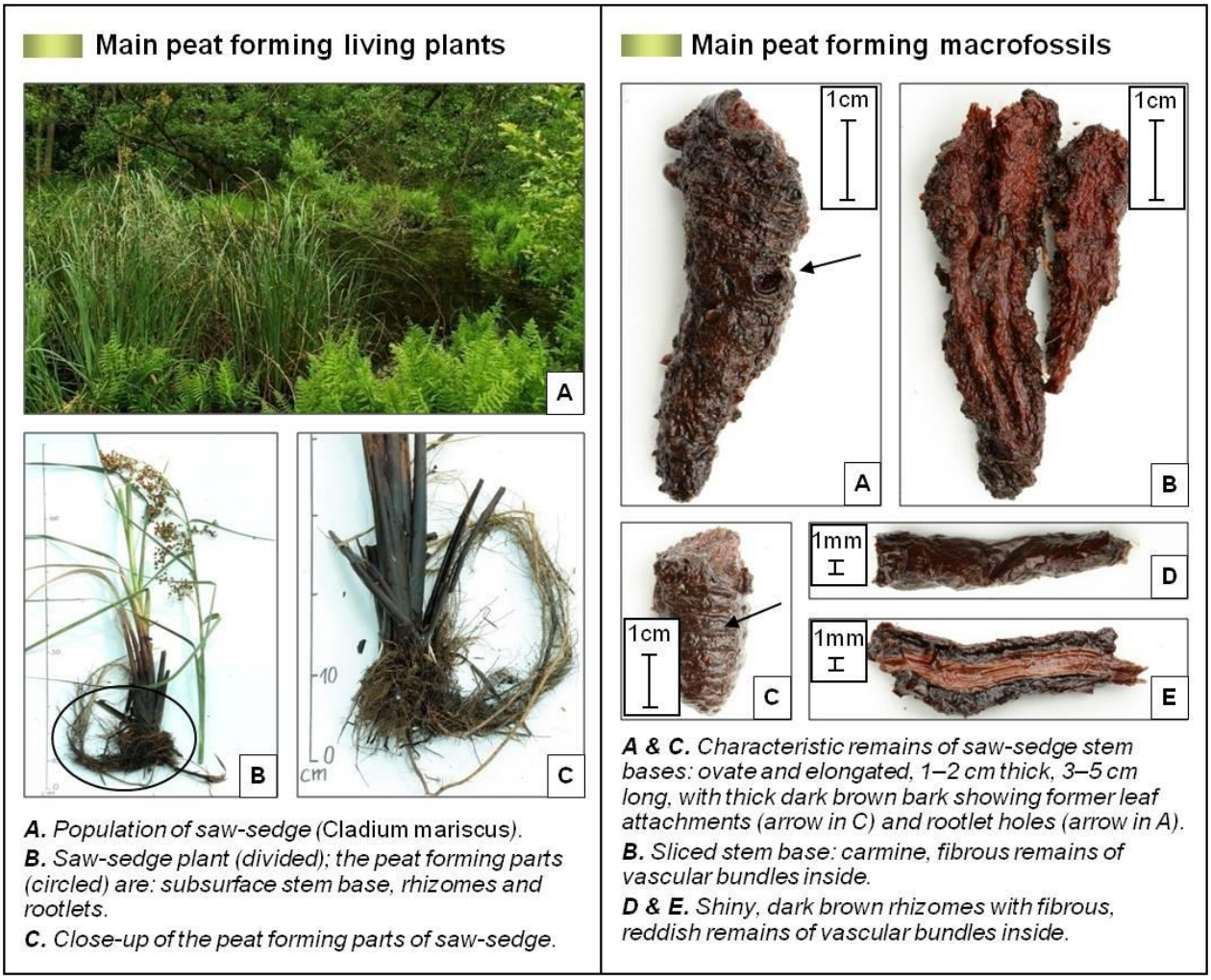

Figure 3. Excerpt from the portrait of *Cladium* peat, after Meier-Uhlherr *et al.* (2011) (page 4), translated from German.

1976, Succow 1988, Ad-hoc-AG Boden 2005). Our selection largely conforms with the latest Federal German soil mapping manual KA5 (Ad-hoc-AG Boden 2005) and the former German Democratic Republic soil mapping manual TGL 24300/04 (1985), which both distinguish 17 'botanical peat types' and 'peat types', respectively, albeit with somewhat different content (Tables A1.2 and A1.4). The KA5 classification does not differentiate within the 'amorphous peats' but includes the pedogenetic transformation processes earthification and murshification at a higher hierarchical level, in its 'soil classes' (Ad-hoc-AG Boden 2005). In contrast to KA5, we excluded '*Menyanthes* peat' because several key references do not mention this peat type (TGL 24300/04 1985, Succow 1988, Göttlich 1990) or describe *Menyanthes* remains only as a minor constituent of other peat types (Caspers 2010). Like KA5 we excluded the very rare or rarely described *Molinia* peat, *Salix* peat, fern peat and *Glyceria* peat. We grouped '*Cymbifolia* peat', '*Cuspidata* peat' and '*Acutifolia* peat' as '*Sphagnum* peat' because these types often occur together in one peatland or even in a single peat layer (Overbeck 1975, Caspers 2010) and the gain in ecohydrological indicator value does not outweigh the high cost in terms of expertise required to differentiate these *Sphagnum* sections in the field.

Our selection of gyttja types also largely corresponds with KA5 and TGL 24300/04 although TGL distinguishes more types, which are aggregated in KA5 (Tables A1.3 and A1.5). We did, however, exclude 'diatom gyttja' from our portraits, as it can be determined reliably only by using a microscope.

Peat-forming species frequently do not grow in pure stands but, rather, in plant communities forming peats with remains of mixed taxa (Göttlich 1990). This variety demands a clear delineation of the fractions of the various components in order to achieve consistent peat classification and

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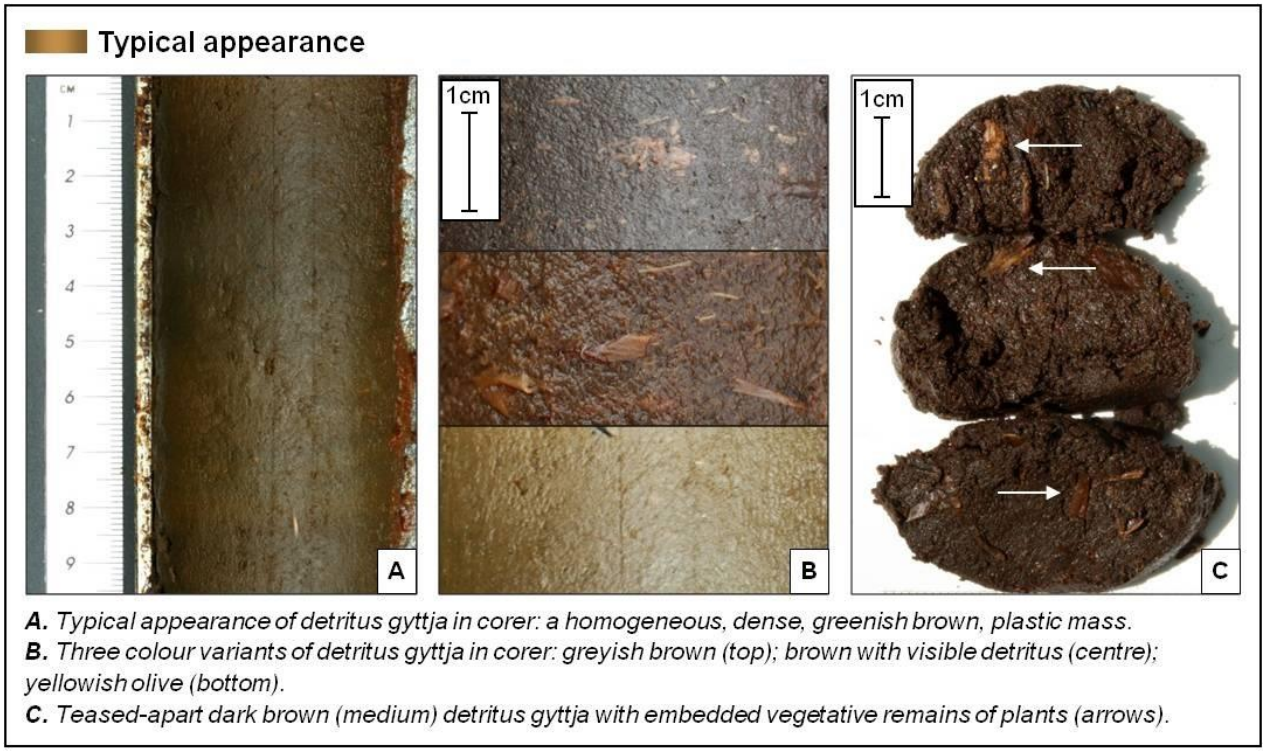

Figure 4. Excerpt from the portrait of detritus gyttja, after Meier-Uhlherr *et al.* (2011) (page 2), translated from German.

identification. TGL 24300/04 defines threshold values for the fractions of wood, mosses and other peat formers as a basis for differentiating between 'peat type groups' (Table A1.4), whereas TGL 24300/02 (1985) uses dominant or characteristic remains of plant species, species groups or structural features (cf. 'amorphous peats') to define a 'peat type'. We follow the latter approach in the portraits and identification key. TGL 24300/04 also provides threshold values for the fractions of organic, calcareous and silicate components as a basis for differentiation of gyttjas (Table A1.5).

The identification key and portraits together enable effective field identification of peat types, but do not replace systematic macrofossil analysis as a tool for fundamental research. The portraits place special emphasis on the palaeo-ecohydrological indicator value of the deposits, which may provide information relevant to restoration. The C/N and pH values presented allow the user to infer the quality of the water (in terms of nutrient and base supply) that formerly fed the mire (Succow 1988). As the vast majority of peatlands in Germany have lost their natural vegetation (Joosten & Couwenberg 2008), at most sites the undisturbed peat deposits now hold the only information about former vegetation that could provide a reference for site-specific restoration objectives. In the case of degraded topsoil, pedogenetically modified peats ('earthified peat', 'murshified peat') commonly feature high nutrient availability (Succow & Stegmann 2001b), leading to the initial establishment of highly eutrophic plant communities after rewetting - a problem that may be eliminated by topsoil removal (Rowinsky 2014, Pfeifenberger & Fock 2015, Kotowski *et al*. 2016). Therefore, it is essential to identify the peat type and its state of degradation before commencing restoration works. Furthermore, the deposits and their stratigraphy support identification of the 'hydrogenetic mire type' (Succow 1988, Joosten & Clarke 2002, Joosten *et al.* 2017) and may thus shed light on the former hydrological functioning of the peatland. Therefore, some knowledge of peatland stratigraphy is essential for planning hydrological restoration, especially with respect to the source, quality, volume and constancy of the water supply (Joosten *et al.* 2017). Moreover, the provision of specific ecosystem services is strongly linked to individual hydrogenetic mire types (Joosten 2016). Knowledge of the stratigraphy also allows calculation of the carbon stock and release potential of peatlands; for example, the free online tool 'CARBSTOR' (Institute of Agriculture and Horticulture, Humboldt Universität zu Berlin 2011) uses KA5 peat types as input data. Especially in the context of global warming, this application delivers

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effective arguments for peatland protection and restoration.

Although the guidance focuses on common deposits in Germany, it may be applicable over a wider geographical area because the peat forming plant taxa and resulting peat types that are included have wide distributions and largely similar ecology across Europe and beyond (Joosten *et al.* 2017). A limitation is, however, that excluded peat types such as those formed by *Molinia*, *Menyanthe*s, *Myrica* or fern species may be abundant outside of Germany, e.g. in Atlantic peatlands (Chambers *et al*. 1999, Mauquoy & van Geel 2007).

The identification guidance has already received substantial positive feedback from users including universities, planners and restoration practitioners, with the German-language homepage being accessed more than 600 times per month on average.

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AUTHOR CONTRIBUTIONS

VL supervised the project. CS and RMU conducted the fieldwork and took the photographs. CS, RMU and VL compiled the German version of the deposit portraits, and all authors participated in structural adaption of the English version. CS wrote the first draft of this article, VL and HJ wrote parts of later drafts, and all authors commented on all versions of the manuscript.

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Appendix 1

Table A1.1. Classification of topics relating to peatland types and their deposits covered by key German references.

References	peat-lands		peatland deposits								peat-land soils	
			peat				gyttja					
	definition	classification and characteristics	definition	classification	characteristics for identification	ecohydrological interpretation	definition	classification	characteristics for identification	ecohydrological interpretation	classification	processes of soil development
Succow 1988	■	■	■	■	■	■	■	■	■	■	■	■
Ad-hoc-AG Boden 2005, Göttlich 1990	■	■	■	■	■	■	■	■	■		■	■
von Bülow 1929	■	■	■	■	■	■	■	■	■	■		■
Overbeck 1975	■	■	■	■	■	■	■	■	■			
Sauerbrey & Zeitz 1999, Dierssen & Dierssen 2001	■	■	■	■	■	■	■				■	■
Roeschmann *et al.* 1993	■		■	■	■	■					■	■
TGL 24300/04 1985		■		■	■			■	■		■	■
Grosse-Brauckmann 1996	■	■		■		■					■	■
Arbeitskreis für Bodensystematik der Deutschen Bodenkundlichen Gesellschaft 1998	■	■	■	■							■	■
Weber 1903	■	■	■	■								
Succow & Stegmann 2001c			■			■	■			■		
TGL 24300/02 1985	■		■				■					
Joosten & Succow 2001b	■	■	■									
Schneekloth & Schneider 1972	■	■		■								
Hutter *et al.* 1997, Succow & Jeschke 1986	■	■										■
Colditz 1994, Schopp-Guth 1999	■	■										
Grosse-Brauckmann 1994			■	■	■	■						
DIN 11540 2005, Grosse-Brauckmann 1962a			■	■	■							
Michaelis 1998				■	■	■						
Koska 2001		■				■						
Grosse-Brauckmann 1962b, Joosten & Succow 2001a, Koska *et al.* 2001, Stegmann 2001, Succow 2001a, 2001b		■										
Succow & Stegmann 2001a			■				■					
Succow & Stegmann 2001d				■	■	■						
Tolpa *et al.* 1967				■	■							
Grosse-Brauckmann 1972, 1974					■							
Chmieleski 2006, Merkt *et al.* 1971, Stegmann *et al.* 2001							■	■	■	■		
Zeitz & Stegmann 2001											■	
Stegmann & Zeitz 2001												■

 DOI: 10.19189/MaP.2019.OMB.StA.1817

Table A1.2. Peat classification from the latest German soil mapping manual KA5 (Ad-hoc-AG Boden 2005), slightly modified and translated from German, compared to the peat types included in our key and portraits (grey).

Botanical peat type units	**Botanical peat type subunits**	**Botanical peat type** (with symbol)	**Assignment to pedological peat type groups**		
			Bog peat	Transition peat	Fen peat
moss peats	*Sphagnum* peats	*Cymbifolia* peat (Hhsy)	+	(+)	
		Cuspidata peat (Hhsu)	+	(+)	
		Acutifolia peat (Hhsa)	+		
		other *Sphagnum* peats (Hhs)		(+)	
	Bryales peats	various peat types (Hnb)		x	x
herbaceous peats	bog herbaceous peats	*Eriophorum* peat (Hhe)	+		
		Scheuchzeria peat (Hha)	+		
	reed peats	*Menyanthes* peat (Hnmy)		x	x
		Equisetum peat (Hnq)		x	x
		radicel peat (Hnr)		x	x
		Phragmites peat (Hnp)		(+)	+
		Cladium peat (Hnd)		(+)	+
dwarf shrub peats	bog dwarf shrub peats	*Calluna* peat (Hhi)	+		
wood peats	bog wood peats	*Pinus* bog peat (Hhk)	+		
	carr peats	*Pinus* carr peat (Hulk)		+	
		Betula carr peat (Hulb)		+	
		Alnus carr peat (Hnle)			+
amorphous peats (Ha)			x	x	x
+ = exclusive or predominant affiliation; x = about equal in more than one group; (+) = infrequent occurrence					

Table A1.3. Gyttja classification of the latest German soil mapping manual KA5 (Ad-hoc-AG Boden 2005), translated from German, compared to the gyttja types included in our key and portraits (grey).

Gyttja form (with symbol)	**Gyttja type** (with symbol)	**Material composition** (% dry mass)		
		organic fraction	lime ($CaCO_3$) fraction	silicate fraction
organo-mineral gyttjas (Fm)	sand gyttja (Fms)	5 to <30	no specification	predominant
	silt gyttja (Fmu)			
	clay gyttja (Fmt)			
	diatom gyttja (Fmi)			no specification
	calcareous gyttja (Fmk)			
organic gyttjas (Fh)	algal gyttja (Fhl)	≥30	no specification	no specification
	peat gyttja (Fhh)			
	detritus gyttja (Fhg)			

 DOI: 10.19189/MaP.2019.OMB.StA.1817

Table A1.4. Peat classification of the soil mapping manual of the former German Democratic Republic TGL 24300/04 (1985), slightly modified and translated from German, compared to the peat types included in our key and portraits (grey).

Peat type group (with symbol) and composition of plant remains [% by volume]	**Peat type** (with symbol)
wood peat (h-h) >15% wood, <85% mosses, <85% other peat formers	*Pinus* peat (h-hk)
	Betula peat (h-hi)
	Alnus peat (h-he)
	dwarf shrub peat (mostly *Ericaceae*) (h-hr)
moss peat (h-m) <15% wood, >50% mosses, <50% other peat formers	*Sphagnum* peat (h-mb)
	Bryales peat (h-ml)
reed peat (h-r) <15% wood, <50% mosses, >50% other peat formers	*Eriophorum* peat (h-rw)
	Scheuchzeria peat (h-rb)
	Magnocarex peat (h-rsg)
	Parvocarex peat (h-rsf)
	Juncus peat (h-rf)
	Cladium peat (h-rc)
	Phragmites peat (h-rp)
amorphous peat (h-a)	highly decomposed peat (h-az)
	earthified peat (h-av)
	murshified peat (h-am)
	aggregate peat (h-aa)

Table A1.5. Gyttja classification of the soil mapping manual of the former German Democratic Republic TGL 24300/04 (1985), translated from German, compared to the gyttja types included in our key and portraits (grey, partly aggregated).

Gyttja type group (with symbol)	**Gyttja type** (with symbol)	**Material composition** (% dry mass)		
		organic fraction	lime ($CaCO_3$) fraction	silicate fraction
organic gyttja (y-o)	algal gyttja (y-ol)	>30	<30	<70
	coarse detritus gyttja (y-odg)			
	medium detritus gyttja (y-odm)			
	fine detritus gyttja (y-odf)			
	peat gyttja (y-ot)			
calcareous gyttja (y-c)	fine calcareous gyttja (y-cf)	5 to <70	>30	<70
	coarse calcareous gyttja (y-cg)			
	lake marl (y-cc)			
silicate gyttja (y-s)	clay gyttja (y-st)	5 to <30	<30	>40
	silt gyttja (y-su)			
	sand gyttja (y-ss)			

Appendix 2

Identification key for peats and gyttjas

(after Meier-Uhlherr *et al.* (2011), translated from German and strongly modified).

Instructions for use

- The identification key describes the main characteristics of common peats and gyttjas in Germany, which are portrayed in detail in the 'portraits of peatland deposits' provided as supplementary material.
- The peats and gyttjas are described according to their ideal, typical and characteristic appearance. However, there are many natural variations, which means a flexible approach is required. For example, peats with high degree of humification are often darker than described and the plant remains are less recognisable.
- The key describes peats in their pure form only, excluding the also common mixed peat types. This may result in two requested options being correct. In such cases, both options must be followed.
- The user is advised to look at Portrait 3 ('other peatland deposits') first, in order to check whether the examined deposit might be a peatland deposit type other than peat or gyttja.
- After reaching the end of the key, the result should be compared with the description in the respective portrait.
- If no result is reached, the particular deposit may not be covered by this determination key (e.g. *Salix* peat, *Molinia* peat, *Menyanthes* peat, fern peat, peat gyttja).

Structure

Main groups	Peats without recognisable plant remains	Peats with recognisable plant remains	Gyttjas
Subgroups (with peats and gyttjas)	▪ no subgroups (highly decomposed peat, earthified peat, murshified peat)	▪ wood peats (dwarf-shrub peat, *Alnus* peat, *Betula* peat, *Pinus* peat) ▪ moss peats (*Sphagnum* peat, *Bryales* peat) ▪ herbaceous peats with radicels and rhizomes (*Equisetum* peat, *Juncus* peat, *Cladium* peat, *Phragmites* peat, *Scheuchzeria* peat, *Magnocarex* peat, *Parvocarex* peat) ▪ herbaceous peats with other plant remains (*Eriophorum* peat, *Cladium* peat)	▪ substantially organic gyttjas (algal gyttja, detritus gyytja) ▪ substantially mineral gyttjas (calcareous gyttja, sand gyttja, silt gyttja, clay gyttja)

Identification key

1a Dark brown to black mass; more similar to garden mould than 1b and 1c; consisting of dead plant material (= organic), but plant remains highly decomposed, barely or not recognisable and not assignable to a specific plant group; consistency: neither elastic nor plastic.

→ **2 (main group 'peats without recognisable plant remains')**

1b Consisting of dead plant material (= organic); plant remains well preserved, clearly recognisable and abundant; structure often felty; consistency neither elastic nor plastic.

→ **4 (main group 'peats with recognisable plant remains')**

1c Homogeneous, elastic to plastic or cohesive, dense mass; consisting of either very finely decomposed plant material (= organic) or mainly sand, silt, clay or lime with only a small fraction of organic material (= mineral); larger plant remains may be embedded.

→ **17 (main group 'gyttjas')**

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2 Dark brown to black mass with roots of living plants; crumb or fine grain structure; usually located at the surface (topsoil to 30 cm depth) in drained and utilised peatlands (e.g. for forestry or agriculture).
→ **3**

2* Compact, mainly homogeneous, dark brown to black mass; unstructured (amorphous) or aggregated into larger pieces; muddy to mushy consistency when wet, comparable to a squeezed-dry sponge when dry; no or a small amount of recognisable plant remains; plant remains usually limited to more highly decomposed wood or fibre fragments; in peatlands with natural water-level fluctuations or in drained peatlands often beneath *earthified* or *murshified* peat.
→ **Highly decomposed peat (Portrait 1.15)**

3 Dark brown to black-brown mass with crumb grain structure, consisting of bonded soil particles of various sizes (but mainly >1 mm); similar to garden mould; smeary consistency when wet, crumbly but never powdery-dusty when dry; no or only a small amount of recognisable plant remains.
→ **Earthified peat (Portrait 1.16)**

3* Black-brown to deep black, loose mass with fine granular structure, consisting of small (mainly <1 mm) bonded soil particles; thick, silty mass when very wet, smeary-granular when moist, distinctly granular and powdery-dusty when dry (resembling loose coal slack); no recognisable plant remains.
→ **Murshified peat (Portrait 1.17)**

4 Fraction of woody remains ≥15%, mostly embedded in a highly decomposed, unstructured (amorphous) matrix.
→ **7 (subgroup 'wood peats')**

4* Fraction of woody remains <15%.
→ **5**

5 Peat usually slightly to moderately decomposed; most or all plant remains from mosses; moss plants preserved entirely or peat consisting of small frail moss leaves and stem fragments.
→ **9 (subgroup 'moss peats')**

5* Most plant remains from plant species other than mosses.
→ **6**

6 Plant remains predominantly radicels (= rootlets) or rhizomes (= more or less flattened, ribbon-like structures with nodes, mostly lying horizontally in the matrix).
→ **10 (subgroup 'herbaceous peats with radicels and rhizomes')**

6* Plant remains predominantly other than radicels or rhizomes.
→ **16 (subgroup 'herbaceous peats with other plant remains')**

 DOI: 10.19189/MaP.2019.OMB.StA.1817

7 Numerous remains of dwarf shrubs mainly belonging to the heather family (*Ericaceae*): rather fine (<1–5, rarely 10 mm thick), brown to red-brown, woody stem fragments, often with small depressions from leaf attachments in a moderately to highly decomposed, dark brown matrix; occasionally also small, thick leaflets.

→ ***Ericaceae* peat (Dwarf-shrub peat) (portrait 1.14)**

7* Peat with different features.

→ **8**

8a Very soft, easily squeezable, pale brownish to pale greyish root wood; roots bark brown, dull or slightly shiny with fine lengthwise cracks; occasionally dark ruby coloured pieces of branch or trunk wood; usually embedded in a highly decomposed matrix.

→ ***Alnus* peat (Alder peat) (Portrait 1.11)**

8b Orange-reddish, rather firm root wood; root bark silvery, grey-brown, smooth and shiny with lateral cross-structures (lenticels); branch remains mostly 1–2 cm thick with white-grey bark with fine, blackish cross-structures; often in a strongly decomposed, orange-red to dark brown matrix, sometimes with greasy shine.

→ ***Betula* peat (Birch peat) (Portrait 1.12)**

8c Firm, tough and fibrous root wood with colour variations ranging from beige-brown (when sliced) to reddish-brown and dark brown; often quite thick and occasionally with scaly bark; rarely only a few mm thick, then often without bark; mostly embedded in a highly decomposed, unstructured, dark brown to red-brown matrix, which quickly darkens in contact with air.

→ ***Pinus* peat (Pine peat) (Portrait 1.13)**

9 Straw yellow to reddish-light brown, loosely bedded moss plants with relatively thick, soft, bright-transparent (rarely dark) small and apparently leafless stems; small ovate to lanceolate leaves, never shiny and always without a leaf vein; colour brightens when peat is compressed; when more highly decomposed, colour varies from moderately red-brown to dark red-brown and moss remains are more difficult to recognise.

→ ***Sphagnum* peat (Peat moss peat) (Portrait 1.1)**

9* Shiny (metallic), vibrant gold-brown, bronze or red-brown, small moss plants; stems: relatively robust, about 1 mm thick, opaque, unbranched or only slightly branched, occasionally with squarrose appearance and often fully foliated; leaves: shiny, opaque, polymorphic (e.g. acute-lanceolate, ovate, falcate), with leaf vein; when more highly decomposed, colour varies from dark brown to black and moss remains are more difficult to recognise.

→ ***Bryales* peat (Brown moss peat) (Portrait 1.2)**

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10 Very shiny and deep black (rarely dark brown) rhizomes, mostly ~1 cm (0.5–1.5 cm) wide, glowing dark ruby in back light; distinctive nodes several centimetres apart, often surrounded by denticulate leaf sheaths ('spiky collars'); nodes partially with very thin to 0.5 cm thick, dull, black and curved rootlets, also glowing dark ruby in back light.

→ ***Equisetum*** **peat (Horsetail peat) (Portrait 1.9)**

10* Roots and rhizomes with different features.

→ **11**

11 Plant remains in a highly compressed, brown to black matrix with substantial mineral components (silt, sand, clay) and varying quantities of unstructured organic substance; plant remains predominantly a felty mass of fine roots; roots mostly <1 mm thick, hollow, pale grey to bright brown; sometimes remains of flattened, 1–4 mm wide, dull, grey-yellow to dark brown rhizomes; not possible to identify the specific plant species in the field; almost exclusively formed in salt marshes that are closely bound to the regularly flooded coastal areas around Baltic Sea bays.

→ ***Juncus*** **peat (Salt marsh peat) (Portrait 1.10)**

11* Roots, rhizomes and matrix with different features.

→ **12**

12 Shiny dark brownish to bronze-brownish, not very compressed, 0.5–1 cm wide rhizomes; nodes inconspicuous, not distinctly confined and close together (spacing 1–2 cm); soft, remarkably carmine to brownish-orange, coarse-fibred remains of vascular bundles inside the rhizomes; occasionally brown and densely tangled rootlets; plant remains usually embedded in a thick, brown, slightly structured matrix which quickly darkens in contact with air.

→ ***Cladium*** **peat (Saw-sedge peat) (Portrait 1.6)**

12* Roots and rhizomes with different features.

→ **13**

13 Remarkably shiny, yellowish or bright grey to olive green, 1–3 cm wide rhizomes, flat or wavy, mostly splittable into two parchment-like layers; nodes without coronal bristles ('glabrous nodes') at intervals of 4–12 cm; ascending rhizomes more slender and irregularly compressed; rootlets yellowish and felty.

→ ***Phragmites*** **peat (Common reed peat) (Portrait 1.5)**

13* Roots and rhizomes with different features.

→ **14**

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14 Yellow-brown to red-brown, 4–6 mm wide, horizontally layered rhizomes with sharply circumscribed straight margins; every 1–5 cm sleek nodes with frail coronal bristles (‘pilose nodes’ - a distinctive characteristic); often one to two rootlet holes near the nodes; rhizomes usually embedded in a matrix of well preserved *Sphagnum* mosses.

→ ***Scheuchzeria*** **peat (Pod grass peat) (Portrait 1.8)**

14* Roots and rhizomes with different features.

→ **15**

15 Grey-yellow to dark brown, at most faintly shiny, 1–4 mm wide rhizomes; the majority of macrofossils are fine (<1 mm to a few mm thick), hollow, pale grey to yellow-grey rootlets or rootlet fragments (radicels); if more highly decomposed, rhizomes not embedded in root felt but in an unstructured, dense, medium to dark brown matrix.

→ ***Magnocarex*** **peat (Coarse sedge peat) (Portrait 1.3)**

15* Grey-yellow to brown, at most faintly shiny, <1 mm wide (at most, 10 % up to 4 mm wide) rhizomes; the majority of macrofossils are fine (<1 mm thick), hollow, pale grey to yellow-grey rootlets or rootlet fragments (radicels); if more highly decomposed, rhizomes not embedded in root felt but in an unstructured, dense, light to dark brown matrix.

→ ***Parvocarex*** **peat (Fine sedge peat) (Portrait 1.4)**

16 Remarkably tough, thick, slightly shiny, brown to dark brown tufts of fibres (subsurface leaf sheaths), which darken quickly in contact with air; often more than 10 cm long, hard to tear apart lengthwise, reminiscent of a thick tuft of hair or a flattened brush; usually embedded in a matrix of *Sphagnum* mosses.

→ ***Eriophorum*** **peat (Cotton grass peat) (Portrait 1.7)**

16* 1–2 cm thick and 3–5 cm long, ovate and elongated structures (stem bases), often somewhat asymmetrically curved, truncated at the top and narrowed at the bottom; bark of stem base mostly 2–3 mm thick and often quite woody; very loose, carmine to brownish-orange, coarse-fibred remains of vascular bundles inside the bark; plant remains often somewhat hidden in a mostly unstructured, thick, brown matrix which quickly darkens in contact with air.

→ ***Cladium*** **peat (Saw-sedge peat) (Portrait 1.6)**

17 Plastic (= permanently deformable) to slightly elastic or rubber-like gelatinous mass, due to a high fraction of very finely decomposed organic substance; occasionally with larger plant remains; usually only a small or no fraction of mineral material (sand, silt, clay or lime); colour often greenish brown.

→ **18 (subgroup ‘substantially organic gyttjas‘)**

17* Plastic to sticky-plastic, but not elastic, mass; high fraction of mineral material (sand, silt, clay or lime); variable amount of very finely decomposed, cohesive organic substance; rarely with large plant remains; colour mainly greyish or whitish.

→ **19 (subgroup ‘substantially mineral gyttjas‘)**

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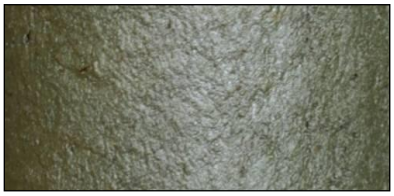
18 Thick, rubber-like, gelatinous consistency, reminiscent of raw liver; if strongly grasped, fracturing suddenly, splitting into shell-like pieces with sharp edges; colour mainly greenish-, reddish- or rarely yellowish-brown, slightly shiny; plant remains very fine (algae), barely visible or invisible to the naked eye.

→ **Algal gyttja (Liver gyttja) (Portrait 2.2)**

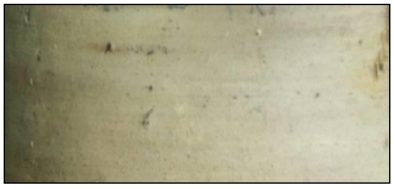


18* Thick, plastic to slightly elastic consistency; colour mainly greenish brown, but also greyish, yellowish, bluish, reddish or rarely black; mostly very finely decomposed organic substance, partly with large, clearly recognisable (aquatic) plant remains.

→ **Detritus gyttja (Portrait 2.1)**

19 High fraction of finely distributed limescale; therefore strong continuous foaming with bubbles on application of 10 % hydrochloric acid; thick, plastic consistency; occasionally with granular structure and remains of mollusc shells; colour often whitish-grey to whitish-yellow.

→ **Calcareous gyttja (Portrait 2.3)**



19* Gyttja with different features.

→ **20**

20a Noticeable fraction of sand particles when rubbed between fingertips; thick, inelastic consistency; rough mass with cohesive-granular structure; colour ranges from ochre through (mostly) different grey and brown shades to black.

→ **Sand gyttja (Portrait 2.4)**

20b Noticeable fraction of silt particles (fine granules) if placed on the tongue (not noticeable between fingertips); thick, slightly plastic consistency; conspicuously fast-drying, thereby becoming brighter and losing cohesion to form a powder with a ‘velvety flour’ texture that sticks in skin grooves when rubbed between the fingertips; colour mostly bright to dark grey.

→ **Silt gyttja (Portrait 2.5)**

20c Noticeable fraction of clay particles; therefore, exceedingly formable and very finely rollable; very thick, sticky-plastic consistency; tough, soapy-smeary mass; dry material hard and rough; colour mostly bright to dark grey-brown.

→ **Clay gyttja (Portrait 2.6)**

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