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TRACES OF PAST BOG BURNING CULTURE IN REWETTED BOG SOILS (EMSLAND REGION, GERMANY)

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With 5 figures and 3 tables
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Summary: Until the beginning of the 20th century, bog burning culture was a common cultivation system for food production on otherwise non-arable bog peat soils. Burning and preliminary drainage of the peat impacted the soils nutrient supply, bog morphology and soils properties. To gain insights into the long-term effects of bog burning culture on the landscape and soils, a burned and unburned area within a rewetted bog complex were comparatively analysed. It was hypothesised that bog burning had a lasting effect on the soil chemistry, that the trenches created for drainage prior to burning are still detectable in the bog morphology, and that the altered soil chemistry exhibiting enhanced nutrient supply resulted in a change of vegetation patterns. To verify this, the soil chemistry was analysed regarding pH, carbon/nitrogen (C/N) ratio, and contents of plant available phosphate (PO_4^{3-}) and potassium (K). The morphology was examined by means of aerial imagery and vegetation patterns were assessed in the field. It was shown that while PO_4^{3-}- contents were similar, pH values and K contents of the burned area were elevated compared with the unburned area. Accordingly, they can be used as an indicator for bog burning culture, even a century after the end of the practice. As expected, C/N ratios were narrowed in the burned area, which however cannot exclusively be attributed to bog burning, since peat mineralisation in the previously drained bog soils caused narrowing C/N ratios as well. The trench structure for drainage was still visible in aerial images and vegetation patterns were similar in the burned and unburned areas. Overall, the aftermath of bog burning was still apparent in morphology and soil chemistry, however the effect was less severe than expected, as vegetation patterns and the overall restoration success were not impacted. This provides a reasonable expectation that bogs are resilient towards bog burning and the latter is no obstacle for successful restoration.

Zusammenfassung: Bis zum Beginn des 20. Jahrhunderts war die Moorbrandkultur eine gängige Kultivierungspraxis zur landwirtschaftlichen Nutzbarmachung von Hochmoorböden. Die Nährstoffzufuhr durch das Moorbrennen sowie die vorherige Trockenlegung veränderten die Morphologie und Bodeneigenschaften. Um die Langzeitfolgen der Moorbrandkultur auf die Bodeneigenschaften und Vegetationsentwicklung zu untersuchen, wurden eine gebrannte und eine ungebrannte Fläche eines wiedervernässten Hochmoores vergleichend analysiert. Die Haupthypothese lautete, dass das Moorbrennen den Bodenchemismus nachhaltig beeinflusst hat. Eine zweite Hypothese war, dass die vor dem Moorbrennen zur Drainage angelegte Grüppenstruktur in der Hochmoor Morphologie noch zu erkennen ist. Außerdem wurde angenommen, dass die Nährstoffzufuhr durch das Moorbrennen zur Ausbildung eines veränderten Vegetationsmusters geführt hat. Um dies zu untersuchen wurde der Bodenchemismus hinsichtlich pH-Werten, Kohlenstoff/Stickstoff (C/N) Verhältnis sowie Gehalt an pflanzenverfügbarem Phosphat (PO_4^{3-}) und Kalium (K) untersucht, die Oberflächenmorphologie wurden anhand von Luftbildmaterial untersucht und die Vegetationstypen wurden im Gelände bestimmt. Es konnte gezeigt werden, dass während sich die PO_4^{3-} Gehalte ähnelten, die pH-Werte und Gehalte an pflanzenverfügbarem K in der gebrannten Fläche im Vergleich mit der ungebrannten Fläche erhöht waren und somit noch ein Jahrhundert nach Ende der Methode als ein Indikator für die frühere Moorbrandkultur dienen. Wie erwartet waren die C/N Verhältnisse in der gebrannten Fläche verengt, was jedoch nicht ausschließlich auf das Torfbrennen zurückgeführt werden kann, da die C/N Verhältnisse durch die vorangegangene Trockenlegung zusätzlich stark durch Mineralisierung beeinflusst wurden. Die charakteristische Grüppenstruktur für die Drainage war in den Luftbildern deutlich zu erkennen. Die Vegetationsstrukturen der gebrannten und ungebrannten Flächen ähnelten sich weitgehend. Die Nachwirkungen der Moorbrandkultur können also noch heute in der Oberflächenmorphologie und im Bodenchemismus nachgewiesen werden. Letztere fielen weniger stark aus als erwartet, da sie sich offenbar nicht maßgeblich auf die Vegetationsentwicklung auswirkten. Daher besteht Grund zur Annahme, dass Hochmoore resilient auf Moorbrandkultur reagieren und dass Moorbrandkultur kein Hindernis für den Erfolg einer Renaturierung darstellt.

Keywords: Bog burning, bog morphology, bog fertilisation, bog soil chemistry, agricultural history, moorland cultivation, peat

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1 Introduction

Bogs, which are exclusively rainfed ombrotrophic mires or peatlands (Sjörs 1980), once characterised the landscape of the lowlands of northwest Lower Saxony in Germany. Since the 17th century, settlers started to cultivate bogs by cutting peat or converting them into agricultural land. Thereby, they fundamentally changed the moorlands and the area of pristine bogs decreased continuously (Blankenburg 2015).

A widespread agricultural technique was the bog burning culture with buckwheat cultivation and sheep grazing. It was first documented during the mid-17th century in the German and Dutch border region and was presumably practiced for centuries in the whole area (Eggelsmann & Blankenburg 1990). To prepare and aerate the peat, the area was shallowly drained by trenching. The drained peat was then hoed and left to freeze over the winter. In the following spring, the upper peat layer was burned, thereby mobilising nutrients and increasing soil fertility. Buckwheat was then sown into the warm ashes. This procedure was repeated for about five to ten years, after which soil fertility was exhausted and the area left as fallow for 20 to 30 years, during which it was generally used for beekeeping and sheep grazing (Goldammer et al. 1997). From the middle of the 18th century public criticism of the method had been expressed, especially because it caused strong smoke development. This resulted in the legal ban of the bog burning culture in 1923 (Zeitz 2014: 5). During the following decades, nature conservationists recognised the worth of bogs for various ecosystem services, e.g., as carbon sinks or biological habitats (Sjörs 1980, Joosten & Couwenberg 2008). In 1981 the state of Lower Saxony introduced the first peatland protection programme, whereupon restoration of peat extraction sites and otherwise formerly cultivated peat areas was initiated (Blankenburg 2004, Caspers & Schmatzler 2009).

It is generally known that bog burning culture changed the landscape morphology, as trenching for drainage left behind a characteristic structure of parallel trenches over the entire area (Günther 2012). It is however unclear whether these structures, created centuries ago, persist today or were levelled out in the meantime.

Beyond that, burn cultivation is known to have altered the peat chemistry. The pH values of pristine bog soils are mainly determined by the release of H^+-Ions by peat mosses (*Sphagnum* species), making them naturally acid ecosystems with pH ($CaCl_2$) < 3–4 (Blume et al. 2010: 344). Bog burning is known to elevate the pH value of the peat (Sulaeman et al. 2021), due to Calcium (Ca) supply from the ashes. In addition, peat burning facilitates the transformation of organically bound Phosphorous (P) into inorganic forms and can thus raise contents of plant available phosphates by more than double the contents observed in pristine bog soils (Wang et al. 2015). This process causes an initial short-lived fertilisation effect and is accompanied by enhanced P adsorption capacity in the burned upper soil layer due to raised pH values (Scheffer & Kuntze 1979). Similarly, burning liberates organically bound K, making it plant available again (Dikici & Yilmaz 2006). There is, however, little research on the longevity of these chemical traces.

It is further assumed that bog burning influenced the C/N ratios due to drainage-induced aeration and mineralisation. Deeper peat layers that are anaerobic due to water saturation generally show a wider C/N ratio than higher and temporarily aerobic layers (Verhoeven et al. 1990, Brake et al. 1999). Correspondingly, pristine bogs that are permanently waterlogged typically display C/N ratios > 30 (Dierssen & Dierssen 2008: 113), while drained bogs exhibit narrower C/N ratios of 22 in aerobic horizons and 39 in anaerobic horizons (Brake et al. 1999). Another effect on the C/N ratios is the burning itself, as regular burning is known to result in reduced C storage of the peat (Garnett et al. 2000).

Pristine bogs usually host a unique assemblance of plant species that are adapted to the prevailing low pH values and low amounts of plant available nutrients. Bog plant communities usually exhibit a mosaic of mainly *Sphagnum* species, cotton grass (*Eriophorum* species) and heather (Ericaceous species like *Erica tetralix* and *Calluna vulgaris*) (Dierssen & Dierssen 2008: 50). The above delineated change of soil properties due to bog burning give rise to the assumption that vegetation patterns also changed, favouring species that are adapted to the altered conditions. Successional stages after bog burning culture were often dominated by heather species that benefited from the aftermath of bog burning. This favoured the development of heather moorlands, which supplanted the typical bog vegetation (Eggelsmann & Blankenburg 1990, Goldammer et al. 1997).

Until now there has been little research on the long-term effects of bog burning culture on bog development. This paper aims to contribute to filling this gap by providing insight into soil chemistry, morphology, and vegetation patterns in burned and unburned bog soils. The objective was to assess traces of former bog burning and buckwheat cultivation practices in todays' soils. Our research was guided by the question of how bog burning affected the soil chemistry, topographical morphology, and vegetation patterns. We hypothesise that in the burned areas; (1) contents of the plant available nutrients; PO_4^{3-}-P and K, as well as pH values, are elevated and C/N ratios are narrowed, in contrast with unburned areas due to the fertilisation effect caused by peat burning and enhanced mineralisation; (2) the topographical morphology of the area is characterised by the trenches created for drainage; (3) due to higher pH values and higher levels of plant available nutrients the vegetation patterns differ from those of the unburned areas.

2 Study area

The study area (52° 59' 26" N, 7° 33' 29" E) is located in the southern part of the 450-ha nature-conservation area Leegmoor (Fig. 1). Originally the local term 'Leegmoor' stems from the Low German language meaning either a low-lying or a cutover peat bog (Nick et al. 1993: 8). The Leegmoor is a bog complex situated in the East Frisian Geest in the state of Lower Saxony (see Nachtigall & Giani 2022 for a detailed geographical description). The ombrotrophic bog developed on fluvioglacial and ground-moraine substrates from the Saalian ice-age (Eggelsmann & Blankenburg 1990).

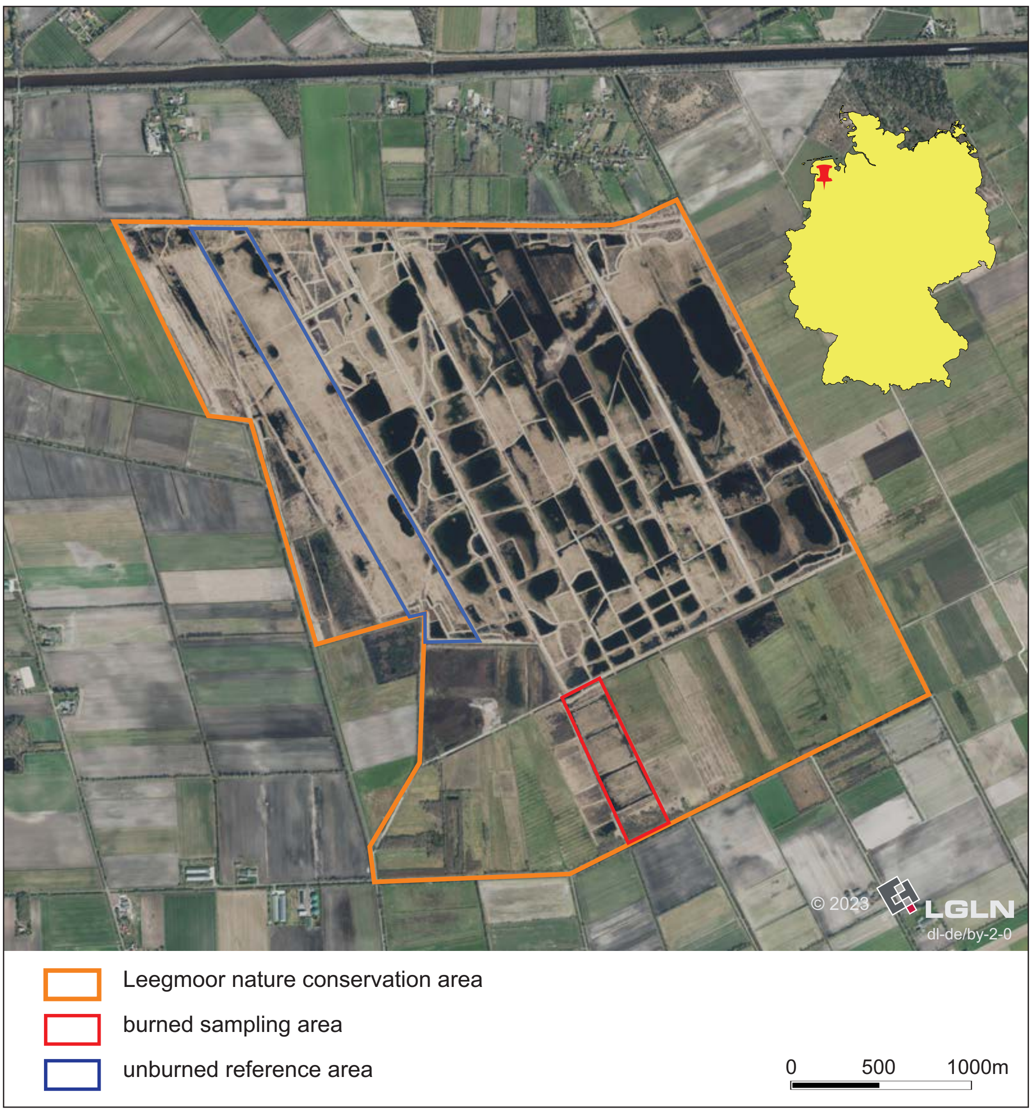

Fig. 1: Map of the Leegmoor bog complex with marked sampling area in the south and reference 1 area in the north

The study area was formerly used for bog burning culture and buckwheat acreage. Eggelsmann & Blankenburg (1990) calculated the loss of peat substance caused by bog burning culture in the Leegmoor area. They assumed that on average bog burning was practiced for six years in a row, resulting in a mean peat substance loss of at least 20 cm. This was followed by a fallow period of about 30 years. Assuming that bog burning culture was practiced for about 210 years, between 1710 until its prohibition in 1923, a total of five to six burning cycles occurred, resulting in a total peat loss of at least 1 m. After bog burning was prohibited the study area was left fallow until restoration efforts began. Starting in the 1950s, a major part of the peat bog was industrially extracted. About 2.0 to 2.5 m of the peat layer and by that any bog burning traces were removed. In 1983 it was placed under protection and rewetted (Nick et al. 1993: 5), resulting in mostly near-natural conditions nowadays (Nachtigall & Giani 2022). A small part in the south was excluded from excavation and as well set under protection and rewetted. Here the soil profile morphology that remained after buckwheat cultivation is supposedly unchanged.

In this study we compare soil properties of a small area in the southern part of the Leegmoor conservation area which was left fallow after the end of bog burning culture and was excluded from later peat extraction (Nick et al. 1993: 9; hereinafter referred to as burned area) with an area located in the northern part of the Leegmoor where the burned soil layer was removed during peat extractions (hereinafter referred to as unburned area) (Fig. 1).

3 Methods

Before the selection of sampling sites in the burned area, the occurring biotopes were mapped according to von Drachenfels (2016). Two of the eight occurring biotope types were excluded from subsequent sampling, because they were located at the margins of the sampling area and influence from the surrounding areas could not be ruled out (Fig. 2)

Sampling in the burned area took place between the end of August and beginning of November of 2020. The biotope type MGT (= dry heather stage) was chosen for a preliminary study. To examine whether a nutrient gradient exists within the soil column, a core of 90 cm depth was split into four parts (0-10 cm, 10-30 cm, 30-60 cm and 60-90 cm) and analysed (see results in Tab. 1). As the analysis yielded no notable differences in all three of the lower soil layers, and nutrient contents were miniscule, further sampling was limited to the upper soil layer.

Four plots were randomly chosen in each of the six biotope types for soil sampling. In each plot, three samples were collected with a boring rod (type 'Edelman' by Eijkelkamp). The whole core was visually examined for coal residues remaining from burned peat. For each plot, the upper soil layer of 15 cm was bagged (PE bags), thereby combining the individual samples to one composite sample. Sampling in the unburned area took place between April of 2019 and February of 2020 (see Nachtigall & Giani 2022 for a detailed description).

Bulk density samples were collected using 100 cm^3 steel cylinders according to DIN 19672-1:1968-04.

The pH values were determined electrometrically according to Blume et al. (2011: 110) on fine soil samples (≤ 2 mm, oven dried at 40 °C) in bi-distilled H_2O and 0.01 M $CaCl_2$ solution respectively, applying a soil-solution ratio of 1:5 (Knick Portamess 911 pH).

Plant available P and K contents were determined in calcium-acetate-lactate extracts (0.6 wt-%, pH 3.6) of fine soil samples according to VDLUFA (1991), applying a soil-solution ratio of 1:25. P was measured colorimetrically as PO_4^{3-}-P (spectrophotometer Shimadzu UVmin-1240). K was measured by atomic absorption spectroscopy (Agilent 240 AAS).

For the analysis of total carbon (C_t) and total nitrogen (N_t), fine soil samples were ground to powdered soil in a ball mill and transferred into tin caps. C_t and N_t were determined by CN elemental analysis (Thermo Fisher Scientific, Flash 2000).

Tab. 1: Soil parameters by sampling depth in the burned area, MGT (= dry heather stage) biotope type

sampling depth	BD (g cm^{-3})	PO_4^{3-}-P content (mg g^{-1})	K content (mg g^{-1})	pH ($CaCl_2$)	pH (H_2O)	C/N ratio
0-10 cm	0.17	0.02	0.10	2.8	3.2	40
10-30cm	0.10	0.00	0.03	2.7	3.1	50
30-60cm	0.10	0.00	0.01	2.7	3.1	51
60-90cm	0.10	0.00	0.00	2.8	3.3	51

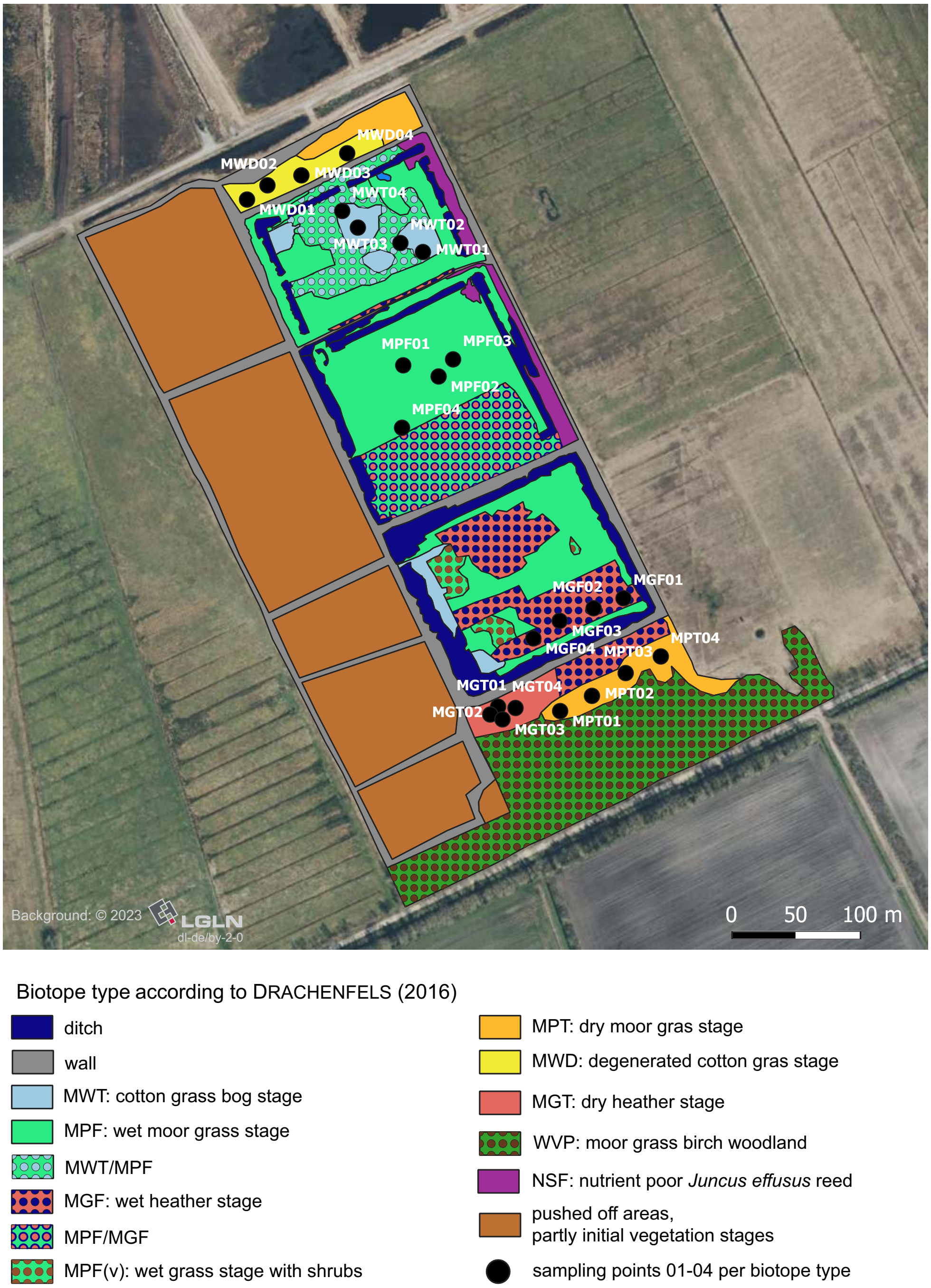

Fig. 2: Biotope types of the burned area and location of sampling points

Bulk densities were calculated as relation of cylinder volume, fresh and dry weight. Soil nutrient concentrations were calculated from bulk densities (Tab. 2) and soil nutrient contents. C/N ratios were calculated from C_t and N_t.

For the burned area, the data of the individual biotope types was arranged to form three groups according to the dominant vegetation aspect of (1) moor grass, (2) heather and (3) cotton grass. The data for the unburned area was analysed in composite samples (K) or determined as means (pH, PO_4^{3-}-P, C/N) from an existing dataset (Nachtigall & Giani 2022), arranging the sampling plots to form the same groups of dominant vegetation (S3–5 for moor grass, S2 for heather, S7 for cotton grass).

Tab. 2: Bulk densities of the upper soil layer (0 – 15 cm) by vegetation classes in the burned area

vegetation class	bulk density (g cm^{-3})
moor grass	0.14
heather	0.16
cotton grass	0.09

Maps were created in QGis (Version 3.16.5) and ArcMap (Version 10.6). Means were calculated in MS Excel (MS Office Version 365 2022). Statistical evaluation was performed in IBM SPSS (Version 28). The Kolmogorov-Smirnoff test yielded normal distribution of all parameters ($p \leq 0.05$). Thus, differences between the burned and unburned area were determined using the unpaired t-Test. The preceding Levene's test revealed variance homogeneity for all parameters, except C/N ratio, and the t-Test was read out accordingly.

4 Results

4.1 Topographical morphology

The geomorphological characteristics indicating past burning culture can be assessed in a high resolution aerial image (Fig. 2). The parallel lines running at a distance of about 5 m from each other are remnants of the trenches that were created for drainage.

Fig. 3: High resolution (10 cm) aerial image of the sampling area (bordered red); trench structures from past cultivation practice are still visible (modified after Blankenburg et al. 2023)

The upper soil layers of the parcel left of the sampling area was ablated during the restoration process, which is why the trenches are no longer visible in this part. No coal residues were found in the examined soil cores.

4.2 Vegetation patterns

Eight biotope types were mapped, of which two were excluded from further examination (nutrient poor *Juncus effusus* reed = NSF, moor grass birch woodland = WVP) (cf. Fig. 2). The drier biotope types (degenerated cotton grass stage = MWD, dry moor grass stage = MPT, dry heather stage = MGT) dominated in the peripheral areas. The wetter ones (wet moor grass stage = MPF, wet heather stage = MGF) dominated in the central parcel, and the northern parcel (cotton grass bog stage = MWT).

It was striking that the moor grass *Molinia caerulea* occurred with higher abundance along the parallel structures of the former trenches. Apart from that, no distinct differences were found between vegetation patterns in the burned and unburned areas (see also Nachtigall & Giani 2022).

4.3 Soil chemistry

4.3.1 pH

The pH (H_2O) in the burned area was between 3.4 and 3.7 and between 3.3 and 3.4 in the unburned area (Fig. 4). The pH ($CaCl_2$) in the burned area was consistently 2.9 and between 2.5 and 2.7 in the unburned area. H^+ concentrations in the burned area were higher than in the unburned area, which was statistically significant ($p \leq 0.05$, Tab. 3).

4.3.2 Phosphate

The lowest average contents of PO_4^{3-}-P occurred under cotton grass (Fig. 5a) and were similar in both areas (burned area 14.2 mg kg^{-1}, unburned area 13.7 mg kg^{-1}). Contents under moor grass were also similar and about 30 mg kg^{-1} in both areas. Only the contents under heather vegetation showed a notable difference and were higher in der unburned area (42.9 mg kg^{-1}) in contrast with the burned area (29.5 mg kg^{-1}). Differences between the PO_4^{3-}-P contents of the unburned and burned area were not statistically significant (Tab. 3).

4.3.3 Potassium

Like PO_4^{3-}-P, the lowest levels of K occurred under cotton grass (Fig. 5b; burned area 66 mg kg^{-1}, unburned area 40.8 mg kg^{-1}), while K contents under heather and moor grass were similarly high. K contents in the burned area were clearly higher than in the unburned area under all vegetation classes, however, those differences were not statistically significant (Tab. 3).

4.3.4 C/N ratio

In the burned area, the narrowest C/N ratio of 34 occurred under moor grass and the widest C/N ratio of 44 under cotton grass (Fig. 5c). In the un-

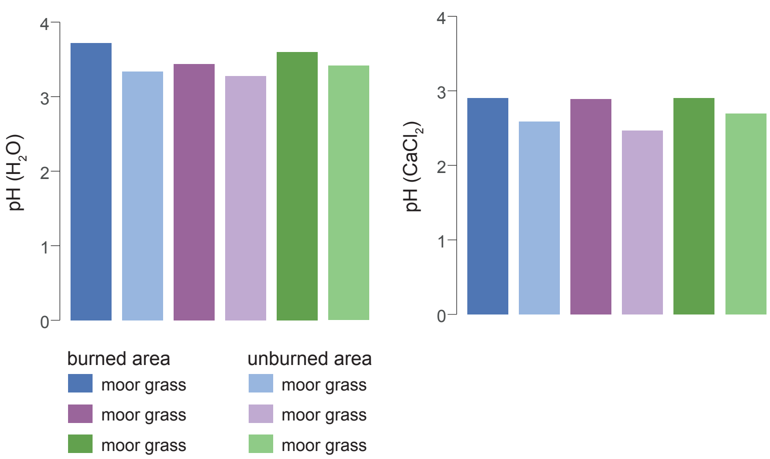

Fig. 4: pH values of the upper soil layer (0–15 cm) in the burned area vs. unburned area (data: Nachtigal & Giani 2022)

Tab. 3: Statistics and central tendencies of soil chemical properties

	unit	burned area μ ± s	unburned area μ ± s	t-test sig. (2-sided)
H^+ (H_2O)	Mol L^{-1}	0.00027 ± 0.00009 (pH 3.6 ± 0.1)	0.00046 ± 0.00007 (pH 3.3 ± 0.1)	0.05*
H^+ ($CaCl_2$)	Mol L^{-1}	0.00126 ± 0.00003 (pH 2.9 ± 0.01)	0.00268 ± 0.00068 (pH 2.6 ± 0.1)	0.02*
PO_4^{3-}-P	mg kg^{-1}	25.1 ± 9.5	29.7 ± 14.8	0.67
	mg L^{-1}	3.4 ± 1.9	4.9 ± 2.1	0.40
K	mg kg^{-1}	112.2 ± 40.1	58.5 ± 18.1	0.10
	mg L^{-1}	15.3 ± 8.2	9.7 ± 2.1	0.32
C/N ratio	-	38 ± 5	51 ± 0.4	0.05*

* $p \leq 0.05$, sig. = significance, μ = mean, s = standard deviation

burned area, the C/N ratios were uniform (50 under moor grass and 51 under heather and cotton grass). Overall C/N ratios were significantly wider ($p \leq 0.05$) in the unburned area compared to the burned area (Tab. 3).

5 Discussion

5.1 Characteristics of morphology

We were able to confirm our hypothesis that the topographical morphology of the burned area is characterised by traces of the former bog burning culture. We demonstrated that the typical trench system that was created for draining the area (Goldammer et al. 1997) is still clearly visible. This specific topographic morphology seems to be a reliable indicator, as it was also reported in other areas with former bog burning culture (Günther 2012, Blankenburg, personal comment).

5.2 Impact on soil chemistry

Our data partly confirmed the hypothesis that contents of some plant available nutrients as well as pH values are elevated, and C/N ratios are narrowed due to bog burning. Burning liberates organically bound nutrients from the peat, making them plant available again. Zeitz (2014: 3) mentioned that burning 5 cm of young (white) bog peat (with a bulk density of 50 g L^{1-} and ≤ 1 wt-% ash content) may liberate up to 88 kg of $CaCO_3$, 35 kg of H_3PO_4 and 20 kg of K. Similar findings were presented by Eggelsmann and Blankenburg (1990).

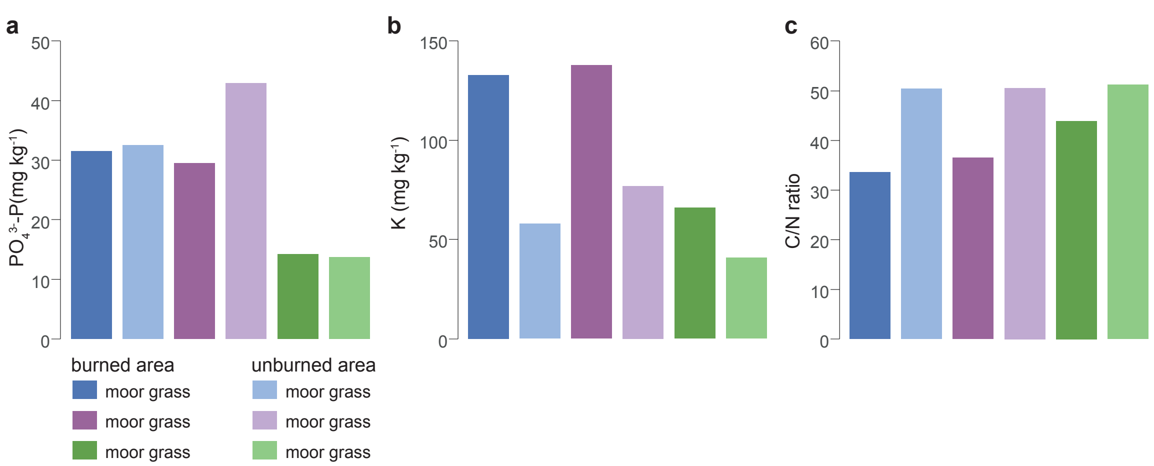

Fig. 5: Contents of plant available PO_4^{3-}-P (a)*, K (b) and C/N (c) ratios in the upper soil layer (0 – 15 cm) of the burned area vs. the unburned area (* data Nachtigal & Giani 2022)

Soil pH (as H^+ concentration) in the burned area was significantly higher than in the unburned area, which can be explained by the release of $CaCO_3$ from the ashes (Sulaeman et al. 2021). The underlying chemical process is the formation of hydro carbonates through the reaction of $CaCO_3$ with protons in the soil solution lowering the proton concentration, thus increasing the pH value. However, differences are small and both the burned area and unburned area, are within the pH ($CaCl_2$) range < 3–4 (Blume et al. 2010: 344), which is typical for pristine bogs.

Opposed to our hypothesis, plant available PO_4^{3-}-P contents in the burned area were similarly high as in the unburned area. This is most likely because the fire induced release of P, through the artificial acceleration of the P-cycle and thereby increased contents of plant available phosphates in the upper soil layer (by more than double the contents found in pristine bog soils (Wang et al. 2015)), provided only a short-lived fertilisation effect (Haverkamp 2011). Initially enhanced P levels were then quickly alleviated by either harvesting or leaching, since phosphate mobility is generally known to be high in bogs (Kuntze & Scheffer 1979), especially under flooded conditions (Stepniewska et al. 2006) that were established in the Leegmoor bog complex after the restoration. It is not clear which one is the decisive process, but it is important to note that after a century, traces of enhanced PO_4^{3-}-P levels from bog burning are no longer existent. Unlike PO_4^{3-}-P, soil K contents in the burned area were higher than in the unburned area.

The lack of statistically significant differences in K contents between the burned and unburned area, is likely due to the diverging K contents under different vegetation types. Nevertheless, our results are consistent with findings by Dikici & Yilmaz (2006), who demonstrated that, in contrast to unburned and largely undisturbed areas, plant available K concentrations were increased by about four times in areas that experienced a peat fire event about 40 years earlier. Thus, the slightly increased K contents in the burned area serve as an indicator for former bog burning culture, resulting most obviously from increased K sorption capacity of the soil. It further indicates that the unexpectedly low PO_4^{3-}-P contents were induced by P leaching rather than by withdrawal via the harvested buckwheat.

The significantly narrower C/N ratios of the burned area (mean 38) compared to the unburned area (mean 51) through C releases are presumably the result of two effects: mineralisation and burning. The latter is supported by findings from blanket bogs in the United Kingdom (UK), where rotational burning of bogs is still practiced, demonstrating that regular burning resulted in reduced C storage in the peat compared to unburned areas (Garnett et al. 2000). Moreover, narrower C/N ratios are a clear indicator of mineralisation, occurring under aerobic conditions. Mineralisation causes the release of C as CO_2 while the majority of N remains in the soil pool, ingested in microbial biomass (Blume et al. 2010: 59). Consistent to that, data by Frank et al. (2014) show C/N ratios of 53 in near-natural bog soils, in contrast to drained soils with C/N ratios of 20. Similarly, Brake et al. (1999) documented C/N ratios as low as 22 in aerobic horizons of drained bogs. Both the burned and unburned area display C/N ratios > 30, which can be assumed as typical for near-natural bogs (Dierssen & Dierssen 2008: 113). Yet, the lower C/N ratios in the burned area show more advanced mineralisation compared to the unburned area. In the latter, the formerly mineralised upper soil layer was removed during peat extractions, exposing deeper and hitherto anaerobic peat layers with high C/N ratio. The promptly induced rewetting prevented intense mineralisation and narrowing of the C/N ratio. In contrast to that, intense mineralisation in the burned area started with the beginning of bog burning culture and continued for centuries until restoration. Hence, besides the effects of bog burning, mineralisation due to drainage is also reflected in the significantly lower C/N ratios. This implies that the C/N ratio is not a reliable indicator for former bog burning culture.

5.3 Effect on vegetation patterns

The initial hypothesis that the vegetation patterns in the burned area are different from those of the unburned area was not confirmed. The vegetation patterns of the burned and unburned areas are strikingly similar. This indicates that the physiochemical soil properties at both sites were also reasonably similar (discussed above) and either remained mostly unaffected by bog burning or, more likely, were alleviated in the meantime. It has often been observed that former bogs evolved into heather moorlands after the end of bog burning culture, because heather species, such as *Calluna vulgaris*, benefit from the effects of previous burning (Eggelsmann & Blankenburg 1990, Goldammer et al. 1997). However, as *Calluna vulgaris* and *Erica tetralix* occurred only in rather small sections in both the burned and unburned areas, the appearance of heather does not seem to be a consistent indication for former bog burning culture. On the contrary, there have been findings from a long-term experiment in a blanket bog in the UK, demonstrating that regular burning every 10 years favoured the abundance of the peat forming species *Eriophorum vaginatum* and *Sphagnum* spp. (Lee et al. 2013). This was not reflected in our findings, since bog typical wool grass biotopes that are considered as pristine habitats (Dierssen & Dierssen 2008: 50) and development goals in bog restoration, were found in the wetter sections of both the burned and unburned area. However, large parts of both areas were dominated by the moor grass species *Molinia caerulea*, typically found in formerly drained and rewetted bogs (Pott 1997). In contrast to typical bog plant species, it is robust against fluctuating water tables (Gatis et al. 2019), and are therefore regarded as an indicator for degradation in bogs. Thus, although the burned area shows some characteristics of formerly drained bogs, bog burning seemed to have no significant impact on the restoration success.

6 Conclusion

Our study showed that past bog burning culture had long-lasting effects on the examined bog soils. This was confirmed in the landscape morphology, which still displayed the characteristic ditch structure, and elevated pH and K contents in the previously burned areas. Hence, both exhibited long-term traces of former bog burning practise. However, the soil chemical differences had no considerable effect on the development of the vegetation, giving reason to presume that the restoration success was not influenced by previous bog burning culture, at least not after a century. This provides a reasonable expectation that bogs in general are resilient towards bog burning and that previous bog burning culture is no obstacle for successful restoration. It remains to be seen whether the soil chemical characteristics in areas of past bog burning culture will completely diminish in future.

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