Spring mires fed by hot artesian water in Kruger National Park, South Africa

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SUMMARY

This article describes two spring mire complexes in the Kruger National Park (South Africa) that are fed by thermal water with a temperature of 37–42°C. The mires are small (1–20 m in diameter). The peat thickness is 1–2.5 m, of which 1–1.5 m is elevated above the surroundings. Some of the domes have dried out severely and show signs of erosion due to water flow and trampling by large animals. The mires lie in an almost straight line, supporting the hypothesis that the water originates from deep aquifers which discharge at geological faults. The long-term existence of these spring mire complexes may not be threatened because young stages of mire formation are present, but research to elucidate the timescales of peat development is needed to make a valid prognosis.

KEY WORDS: artesian water, erosion, hydrology, peat domes.

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INTRODUCTION

Seasonal and temporal wetlands are common in Kruger National Park (KNP). Although 5–8% of the KNP area is covered by wetlands, most are associated with preferential water flows in river valleys, depressions or hill-slope seeps, and much less than 1% of them have more than 30 cm of accumulated peat. Peat-forming systems can exist here only if they have ground or surface water sources. Unlike other rural areas, the wetlands in Kruger are not used by humans.

Although mires that are fed by warm water are globally rare, according to Scott & Vogel (1983) there are 50 thermal springs in South Africa, some with organic deposits. An example is the Wonderkrater spring mound which is 3.5 m high, 8 m deep, 35,000 years old (McCarthy *et al*. 2010) and appears to be of ambient temperature, but there is a thermal spring with a water temperature of 36 ± 4°C in the close vicinity (Mazor & Vehagen 1983).

Thermal springs originate from rainwater that percolates into permeable rocks or joints and becomes heated underground. The water reaches substantial depths and its temperature increases at a rate of 2–3°C per 100 m due to the geothermal gradient (Press & Siever 1986). Convection currents in the groundwater are created when the heated water expands and rises. A thermal spring is sometimes formed when the heated groundwater in an aquifer encounters a fracture zone or an aquitard such as a dyke which forces it to rise to the surface (Olivier *et al*. 2008).

Growth of *Sphagnum* on hot wet soils (40–60°C)

has been reported from the sub-Antarctic (Ile St Paul; J. Whigham, pers. comm.). Thermal springs also occur in Iceland (Guömundsson 2007), but the springs themselves are too hot to allow plant growth and thus peat accumulation, and bog vegetation types are found only where the water has cooled down sufficiently to allow vegetation to grow in surface water systems (A.J.M. Jansen, pers. comm.). A similar situation exists in Liard River Hot Springs Provincial Park in Canada, where the discharge of hot springs flows into a marsh (see also Weed 1889). We found no reports of discharging hot groundwater directly feeding a mire.

Local managers of KNP drew attention to the thermal mires because some of them had been badly damaged by wild animals and they wished to know if measures to protect the mires were needed. The objective of this paper is to present field data which were collected to support the formulation of hypotheses on the functioning of the mires, and to consider possible measures to protect them.

METHODS

Study area

Two hot spring mire areas in the north-eastern part of KNP were studied. The Malahlapanga spring mire (22° 53′ 20.0″ S, 31° 02′ 25.8″ E) is situated near the western boundary of KNP on a small tributary stream, close to its confluence with the Mphongolo River. The Mfayeni spring mire (23° 00′ 47.4″ S, 31° 14′ 15.9″ E) has a more easterly location (Figure 1).
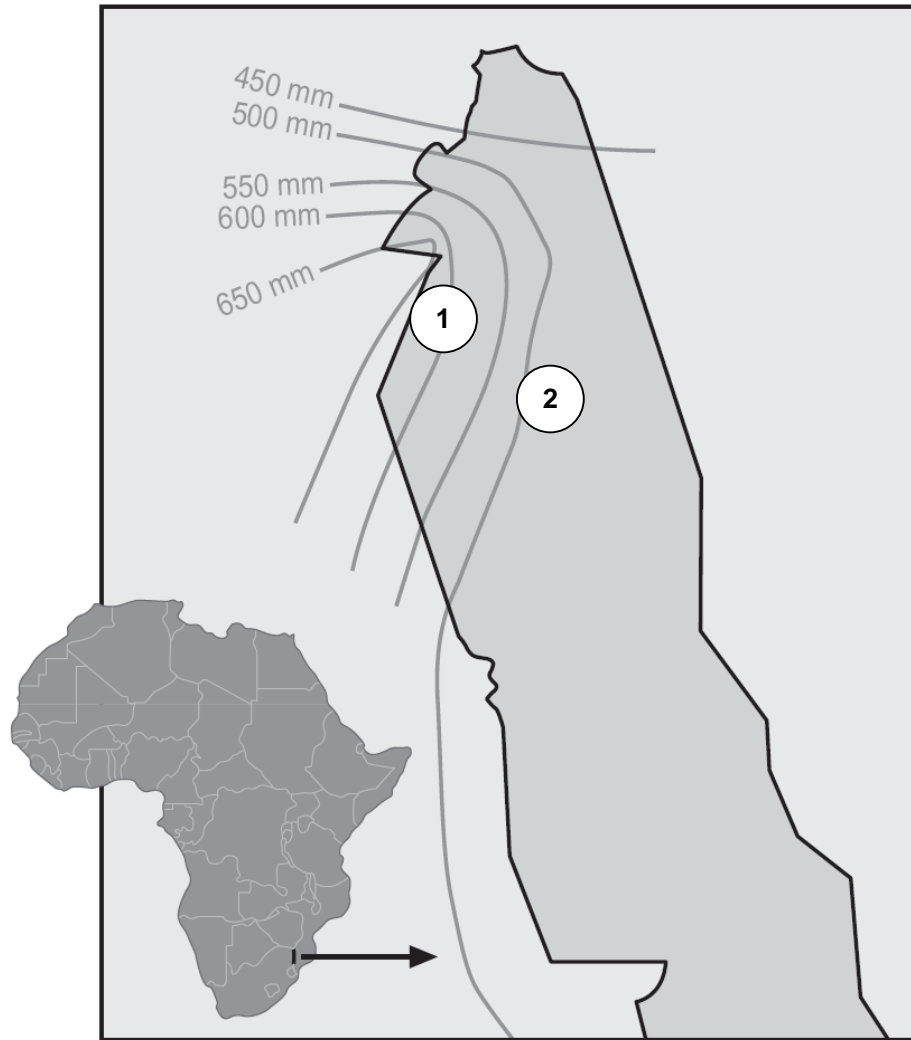
Figure 1. Map of the northern part of Kruger National Park showing the locations of the Malahlapanga (No. 1) and Mfayeni (No. 2) thermal spring mires in relation to mean annual rainfall distribution, adapted from Venter & Gertenbach (1986).

The KNP has a sub-tropical climate with hot and humid summers and rather mild, dry winters (Venter & Gertenbach 1986). Temperatures range from >40°C in summer to about 0°C in winter. The mean annual temperature in the northern part of Kruger is 23.2°C (/www.sanparks.org). Annual precipitation is 550–600 mm at Malahlapanga and 450–500 mm at Mfayeni (Gertenbach 1980), and the area has a strong soil water deficit (Venter & Gertenbach 1986, Mucina & Rutherford 2006).

Malahlapanga is underlain by the Goudplaats Gneiss. There is a major fault zone about 10 km to the north, with the Dzundwini and Nyunyani Faults striking from east to west (Figure 2). This fault zone dips northwards away from the site; but an offshoot from the southern Nyunyani Fault strikes roughly

north-south in line with, but stopping 2 km short of, Malahlapanga (Brandl 1981).

Gillson & Duffin (2010) carried out radiocarbon dating (AMS) on peat cores from both Malahlapanga and Mfayeni. From their research it can be concluded that the Mfayeni (110 cm depth) sequence began accumulating between 1640 and 1680 BP (before present). Malahlapanga is much older and in the Gillson & Duffin profile (72 cm) the peat began accumulating between 4940 and 4810 BP.

Data collection

The Malahlapanga mires were visited on 16 April 2009 (temperature measurements, peat coring) and in July 2010 (vegetation descriptions). Mfayeni was

visited on 27 April 2010 (temperature measurements, peat coring and water sampling) and in July 2010 (vegetation description).

The vegetation descriptions were restricted to dominant or important diagnostic species, including *Acacia grandicornuta, Bolboschoenus maritimus, Capparis tomentosa, Cyperus sexangularis Echinochloa colona, Eustachys paspaloides, Fuirena pubescens, Hemarthria altissima, Ischaemum afrum, Hibiscus surattensis, Leptochloa chinensis, L. fusca, Miscanthus junceus, Paspalum distachyum, Pavonia* spp., *Phoenix reclinata, Phragmites australis, Pycreus polystachyos, Sesbania bispinosa, S. sesban, Sphaeranthus peduncularis, Thelypteris confluens* and *Trichoneura grandiglumis* (Burrows 1990, Retief & Herman 1997, Pooley 1998, Van Oudtshoorn 1999, Schmidt *et al*. 2002, Leistner 2005).

Temperature and electrical conductivity were measured with a combined EC/Temperature device capable of measuring directly in peat (WTW, LF96) attached to a two-metre-long probe. Peat depth was determined with a 'Russian type' (closed chamber) corer. Water samples were analysed at the Institute for Soil, Climate and Water (ARC.LNR) in Pretoria.

HCO_3^- was measured by titration; Cl^- and SO_4^{2-} were analysed using a Dionex Ionchromatograph; and Na, Ca, Mg, were measured using an ICP (Inductively Coupled Plasma) mass sprectrometer (Wirsam).

RESULTS

Malahlapanga
At Malahlapanga, several thermal spring mires were present within an area of 4–6 hectares (Figures 2 and 5). The most spectacular view was of three small (*ca*. 200–500m^2) peat cupolas rising 1–2 m above their surroundings. Smaller wetland patches (1–10 m^2) were present between the larger mires. These were sparsely vegetated and damaged by animals such as elephant, rhinoceros and buffalo that had trampled the peat in order to get to the water. The tops of the two largest cupolas (A and C in Figure 5) were apparently dry and lacked wetland vegetation, which was present only at the bases of these domes. Two smaller and wetter cupolas lying between the two dried-out domes had many wetland species across their entire surfaces.
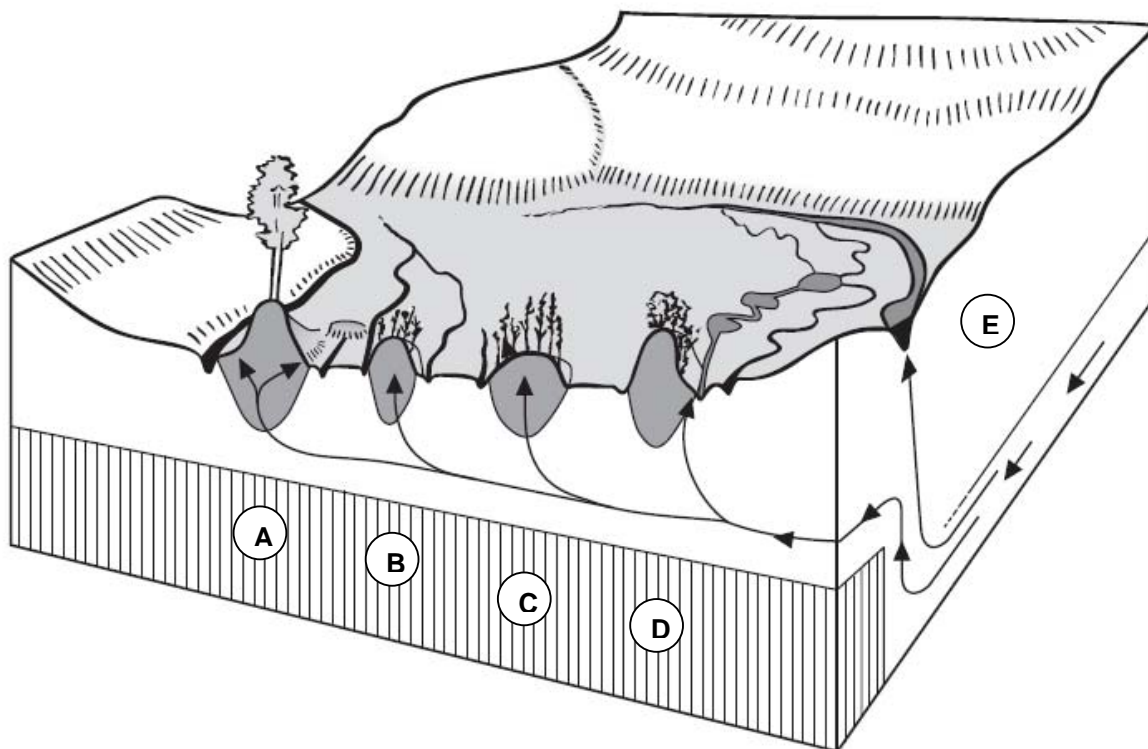

Figure 2. Schematic overview ('working model' *sensu* Grootjans *et al*. 2010) of the Malahlapanga wetland site showing four peat domes (A–D), as well as a mineral spring (E) that discharges warm groundwater (37°C) from a deep aquifer.

Peat coring in the largest cupola (A) showed that the total peat depth was approximately four metres, of which one metre lay below the level of the surrounding plateau. This cupola was covered by grasses and tall herbs with some large trees, and its edges were severely damaged by wild animal trampling. Although it had dried out considerably and a tree (*Acacia grandicornuta*) had established at the dry outer edge (Figures 3 and 5), some typical wetland species such as *Phragmites australis* and *Bolboschoenus maritimus* were still present but with low cover. Wetland vegetation occurred only at the base of the dome and along the eroding rivulets that transported spring water out of the wetland. The temperature of the water escaping from the base of the dome was *ca*. 33°C, but after a few hundred metres dropped to 23°C. Thus, it appeared that this dome was no longer fed by groundwater.

The cupola (D) on the right in Figure 2 was less damaged by animals but again there were no wetland species on its summit. It was covered by shrubs and grasses, with wetland species growing only around its base (Figure 5). A temperature profile to a depth of two metres showed that the warm water escaped at the base of the dome and did not reach the surface of the mire (Figure 6). On the other hand, a temperature profile in one of the two small and wet mires (C) showed that warm water rose to a height of 0.4 m below the top of the dome, although temperatures in the main rooting zone were close to air temperature. Species of healthy wetlands including *Thelypteris confluence, Leptochloa fusca* and *Bolboschoenus maritimus* were present in the cupola vegetation, indicating active wetland processes (Figure 4).

The mires were surrounded by numerous ponds, which had evidently been created by wild animals. These ponds collected surface water that was discharging from the mires and from a small unvegetated spring. The temperature of most pools was between 22°C and 23°C, which was about the same as the air temperature. The water discharging from a small spring pond was much warmer, with a temperature of 37°C. The electrical conductivity (EC), which is an indication of the total amount of dissolved minerals, showed that this water was rich in minerals (EC = 102 mS m^{-1}) but still in the range of fresh to slightly brackish water. The water emerging from the spring discharged into elongated muddy pools and watercourses, finally leaving the wetland *via* a small rivulet. The EC values of stagnant water in the muddy pools was very high (400–800 mS m^{-1}), most likely due to evaporation and consequent concentration of solutes.

It was evident in the field that the small mineral spring was the point of greatest groundwater discharge, since the surface water outflow was visibly greater than from the peat domes and other springs. We speculate that minor tectonic activity may have caused changes in flow patterns of the groundwater and that the groundwater discharge to the largest mires has decreased, causing compaction in the peat body. This may have forced groundwater to escape at the bases of the cupolas, instead of discharging at their summits. The concentrated groundwater outflow at the bases of the cupolas probably triggered further erosion around them.

The temperature profiles (Figure 6) indeed suggest that the upward flow of groundwater in the two largest peat domes has been blocked, forcing the water to escape sideways.

Elephant and other large animal activity is probably so severe in the larger domes because they have dried out. In order to reach the muddy water, animals dig and trample in the more central parts, probably just because they can. They appear to avoid the smaller wetter mire, probably because they do not want to risk sinking into the peat.

Phragmites australis				■	■	
Bolboschoenus maritimus			■	■		
Miscanthus junceus					■	
Capparis tomentosa				■		
Echinochloa colona			■	■		
Leptochloa chinensis		■	■			
Hibiscus surattensis	■	■	■			
Capparis tomentosa		■	■			
Acacia grandicornuta	■	■				
distance from edge of dome (m) 0			40			80

Figure 3. Occurrence of some species on a transect (80 m long) running from the outer edge to the centre of the dried-out cupola (A) at Malahlapanga.

Thelypteris confluens					■	■	
Leptochloa fusca						■	■
Hemarthria altissima						■	
Bolboschoenus maritimus					■	■	■
Pycreus polystachyos							■
Fuirena spp.			■	■			
Eustachys paspaloides		■	■				
Sesbania sesban					■	■	■
Miscanthus junceus							
Pavonia spp.		■	■				
distance from edge of dome (m) 0		15		30		45	

Figure 4. Occurrence of some species on a transect (45 m long) running from the outer edge to the centre of a wet cupola (C) at Malahlapanga.

Figure 5. Severely eroded peat cupolas in the Malahlapanga spring mire complex with trees (top left, A in Figure 2) or shrubs (top right, D in Figure 2) on their summits. A smaller peat dome (bottom left, C in Figure 2) is much wetter and covered with typical wetland species. The small pool (bottom right, E in Figure 2) is a spring that discharges groundwater at 37°C from a deep aquifer.
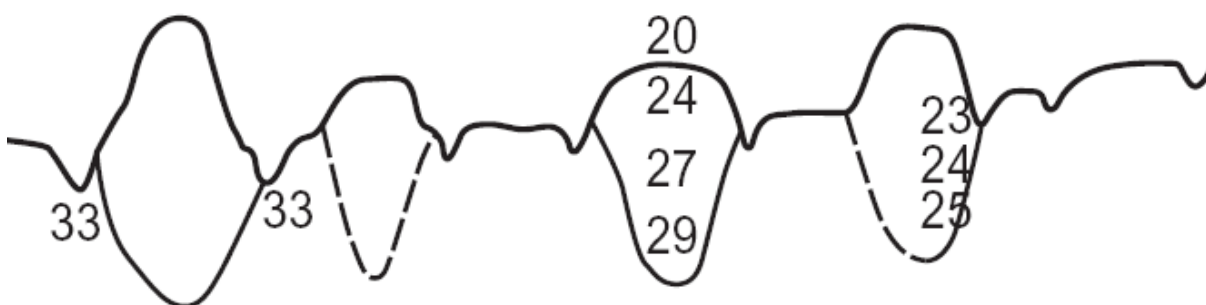

Figure 6. Temperature profiles in Malahlapanga for the two dried-out peat cupolas A (left) and D (right) and one cupola (C) whose summit is still wet (centre right). In Cupola C, warm water is rising higher in the profile than in the dry cupolas. Warm water is escaping at the base of the left-hand mire (A).

Mfayeni

The Mfayeni spring mire consisted of one large and little-disturbed cupola plus a few smaller highly mineralised and desiccated domes (Figures 7 and 9). Two of the smaller cupolas had some wetland species, but no wetland species remained on the driest one. We were unable to penetrate the dry cupolas with peat corers or the temperature probe.

The progression of dominant plant species from the outer edge to the permanently wet centre of the large dome is shown in Figure 8. This dome was treeless and the vegetation consisted of tall and short grasses, sedges and herbs. *Leptochloa chinensis, Cyperus sexangularis* and *Sesbania bispinosa* were rather common, while other species, such as *Fuirena pubescens* and *Sphaeranthus peduncularis* occupied specific zones within the cupola. The permanently wet centre of the dome was covered by tall, dense vegetation dominated by *Phragmites australis*, *Phoenix reclinata, Sesbania bispinosa* and the fern *Thelypteris confluens*.

At the location where most of the groundwater discharged, the reed had formed a quaking mire. We measured three temperature profiles, starting in the main groundwater outflow and working towards the edge of the cupola. In the main spring the temperature increased from 34.5°C at the surface to 42°C at a depth of 1.8 m (Figure 10). These measurements show clearly that warm groundwater was rising up to the surface at the centre of the mire and then cooling to 25–27°C, which was close to the air temperature, as it was discharged towards the edges of the mire.

	0			30			60
Phragmites australis						▓	▓
Thelypteris confluens						▓	▓
Phoenix reclinata						▓	▓
Sesbania bispinosa					▓	▓	▓
Pycreus polystachyos				▓			
Fuirena pubescens			▓	▓			
Ischaemum afrum		▓	▓				
Sphaeranthus peduncularis		▓					
Trichoneura grandiglumis	▓	▓					
Paspalum distachyum	▓	▓					
Leptochloa chinensis	▓						
Cyperus sexangularis	▓	▓	▓	▓	▓	▓	▓
distance from edge of dome (m)	0			30			60

Figure 8. Occurrence of dominant plant species on a transect (60 m long) running from the outer edge to the (wet) centre of the large mire dome at Mfayeni.
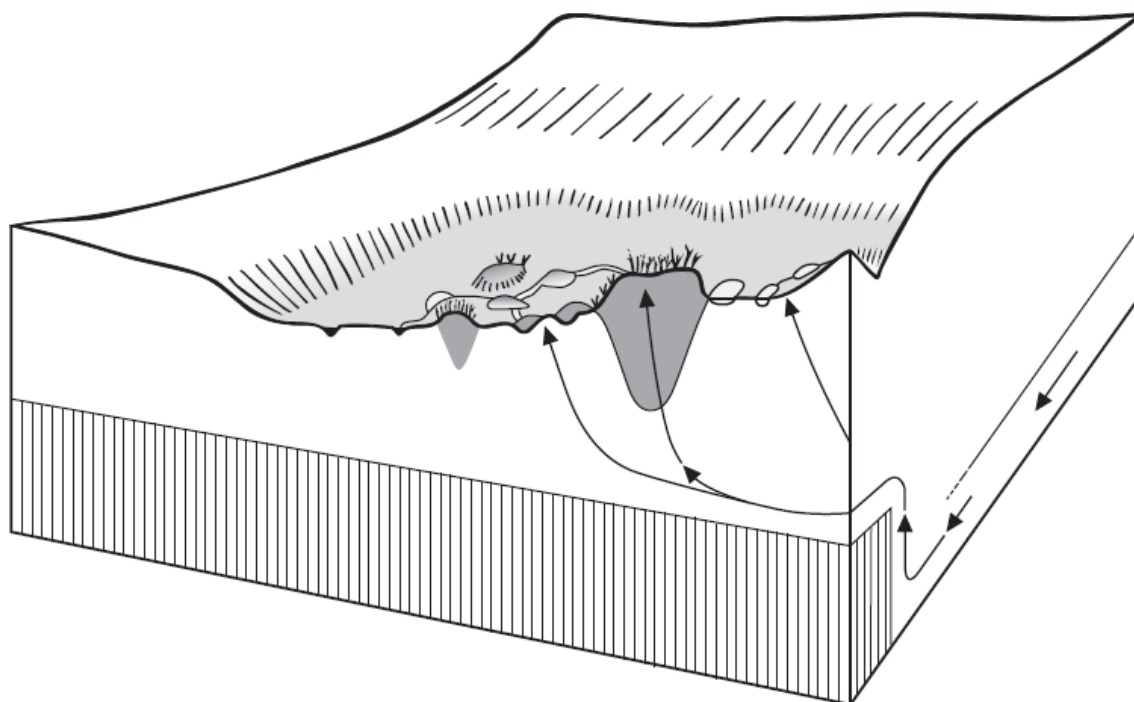

Figure 7. Schematic overview of the Mfayeni wetland site showing two small desiccated cupolas and one large and rather undisturbed cupola where warm groundwater (*ca.* 40°C) discharged into the rooting zone of the vegetation.

Figure 9. The large undisturbed cupola (top left) and the smaller highly mineralised cupolas (top right) at Mfayeni The large peat dome is very wet and covered with typical wetland species (bottom left). The pools (bottom right) between cupolas and at the southern edge of the wetland are used by animals for water.

The concentrations of dissolved minerals in the groundwater discharging from the spring at Mfayeni were much higher than at Malahlapanga. The Mfayeni groundwater was somewhat brackish and also rich in calcium and sulphate (Table 1), suggesting dissolution of gypsum in deeper layers. The high sodium and chloride contents suggest dissolution of sea salt from marine deposits. The composition of this water was very similar to that of groundwater discharging from a spring located at Matiyovila, more than 700 m to the north-west. Thus, it appeared that these widely separated spring systems were fed by the same groundwater source.

The area between the smaller cupolas and the large one, as well as areas south of the larger cupola, were heavily trampled by animals in search of water or in need of a mud bath. However, Mfayeni spring mire appeared generally to be in good condition although, judging from the occurrence of species such as *Sphaeranthus peduncularis* and *Trichoneura grandiglumis*, some parts had dried out. This is not unusual in a living spring mire system because groundwater discharge may shift position within the mire from time to time (Grootjans *et al.* 2005).

Table 1. Chemical composition of groundwater discharging from the spring in the large mire cupola at Mfayeni (0.5 m below the surface) and from another spring *ca.* 700 metres to the north-east (Matiyovila).

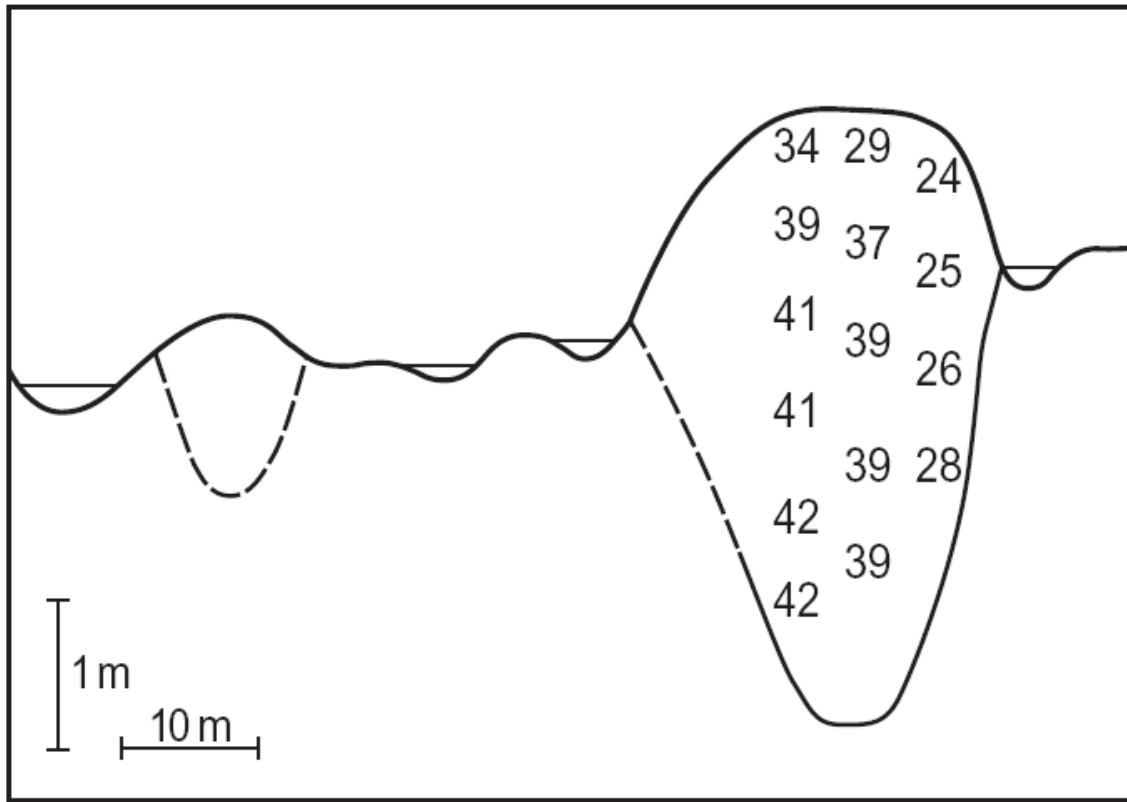|	Temp (°C)	EC (mS m^{-1})	Cl^{-} (Mmol L^{-1})	SO$_4^{2-}$ (Mmol L^{-1})	HCO$_3^{-}$ (Mmol L^{-1})	Na^{+} (Mmol L^{-1})	Ca^{2+} (Mmol L^{-1})	Mg^{2+} (Mmol L^{-1})
Mfayeni	42	407	20.2	6.8	0.3	21.2	16.6	0.01
Matiyovila	38.1	416	20.7	7.3	0.6	21.6	17.6	0.1

Figure 10. Temperature profiles (°C) in the large cupola in Mfayeni. Warm water was rising very high in the peat dome and cooled down only in the top 0.2 m. We were unable to investigate the dry cupola(s) shown on the left-hand side with the temperature probe, due to the high penetration resistance of the soil.

DISCUSSION

Timescales

Spring mires are well known for their very dynamic histories, observed over timescales of centuries or even decades. Water flow to a spring mire may change through time, and some spring mires may be partly cut off from groundwater discharge as a result of tectonic activity. Also, water may shift to other areas within the spring mire itself, triggering drying out and erosion of some parts and stimulating peat growth in others (Wolejko *et al.* 1994). Such processes promote decomposition of the peat and thus complicate precise dating of the mire. Gillson & Duffin (2010) estimated that peat formation started *ca*. 5000 BP at Malahlapanga and *ca*.1400 BP at Mfayeni. These are under-estimates for both mires, since the larger cupolas are much deeper than the maximum (110 cm) profile depth reported by these authors. Mfayeni, for instance, has a peat depth of 245 cm. The uppermost 50 cm consists almost entirely of water, but almost two metres of peat is present beneath. Some of the domes at Malahlapanga have similar thickness. Thus, a rather conservative estimate, based on peat thickness and accumulation rates from Gillson & Duffin (2010), suggests that some domes at Malahlapanga may be 7,000–14,000 years old and the large dome at Mfayeni could be 3,000–4,000 years old.

Restoration measures needed?

The observations and measurements described above indicate that the best-developed spring mire cupolas have warm water high in the profile, whereas in very degraded ones groundwater escapes from the base of the mire or no groundwater is discharged at all. Trampling and erosion of the peat was evident in practically all cupolas, but was most severe in those where groundwater no longer reached the tops of the domes. On one occasion we identified 'piping', which is preferential water flow through underground erosion channels in the mire. Such structures can intercept rising groundwater before it reaches the top of the dome, and in most cases cannot be repaired (Koska & Stegmann 2001).

The question that now arises is whether the KNP managers should take measures to protect the mires

against wild animals and/or to restore them. Our preliminary conclusion is that restoration of the damaged spring cupolas is not an urgent priority at present because younger stages of dome formation are still present and animals do not go into the very wet and growing parts of these mires. Damage is most severe in cupolas that have lost their groundwater supplies, most likely due to natural causes, but we cannot state this with certainty. We do not think that the future of thermal spring mires in the KNP will be threatened unless the discharge of groundwater within the whole system decreases or even stops. However, some monitoring of the situation is recommended.

Future research
Research on the geology of this area is important in order to identify future threats to the warm-water-fed spring mires within the National Park. Further knowledge about the timescales of peat formation within the spring area could also inform prognoses for recovery of the existing spring cupolas and/or the development of new ones.

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