Ecohydrological analysis of a groundwater influenced blanket bog: occurrence of *Schoenus nigricans* in Roundstone Bog, Connemara, Ireland

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SUMMARY

Since the late 1960s, the occurrence of *Schoenus nigricans* in Irish blanket bogs has been attributed to inputs of salt spray to the blanket bogs, due to their proximity to the coast and the predominant westerly winds from the Atlantic Ocean. To test this hypothesis we carried out an ecohydrological field study at a large blanket bog in the western part of Connemara, Ireland. We described peat profiles in two transects and sampled pore water from peat at different depths. The water samples were analysed and their macro-ionic composition was used to locate possible inputs of calcareous groundwater to the system. We found clear evidence for inflow of calcareous groundwater at various sites and depths. Inflow of rather base-rich groundwater was indicated by high values of electrical conductivity (EC), high contents of calcium and bicarbonate, and high pH of the pore water. The peat profiles contained macro-remains of reed (*Phragmites australis*), in most cases only in deeper layers of peat, but at one location throughout the profile. This is another indication that the blanket bog was a groundwater-fed fen for quite some time. We conclude that the occurrence of *S. nigricans* in the blanket bog studied could be well explained by the hypothesis that *S. nigricans* is a relic from former more base-rich conditions. Relatively high base saturation could have persisted due to the prevailing groundwater flow in the upper layers preventing decalcification or other loss of cations from the whole soil profile including the topsoil.

KEY WORDS: base saturation, electrical conductivity, groundwater, hydrology, ionic composition

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INTRODUCTION

Blanket bogs occur in landscapes where precipitation is high (>1200 mm yr^{-1}) and evapotranspiration rather low (Conaghan 2000). Ireland has an extensive cover of blanket bogs (more than 101,000 ha; Conaghan 2000). Blanket bogs are particularly common along the west coast, and one of the best-preserved areas is the Connemara National Park. Here, and in many other locations, one can observe regular occurrence of the black bog-rush (*Schoenus nigricans*). This is quite remarkable because, in many parts of Europe, *S. nigricans* is considered to be an indicator species for calcareous or at least base-rich habitats (Clapham *et al*. 1968, Polunin 1969, Sival 1996, Lammerts & Grootjans 1998, Sýkora *et al*. 2004, Van der Meijden 2005).

Two hypotheses were originally proposed to explain this phenomenon. The first stated that sea spray could provide the peat with the mineral nutrients that *S. nigricans* needed (Tansley 1939 cited in Gorham 1953, Osvald 1949 cited in Gorham 1953, Mattson *et al*. 1944 cited in Gorham 1953). As bogs are considered to be ombrotrophic systems, it is easy to conclude that rainwater or (in the case of *Schoenus*) sea spray is responsible for an increase in electrolytes. On the other hand, Pearsall & Lind (1941) saw no reason to invoke an external source of bases, because the soils are base-deficient. These authors proposed that waterlogging and lack of oxidation in moist environments prevents acidification of the peat. Gorham (1953) rejected waterlogging as a defining factor, as he found that environments with comparable water contents differed widely in acidity. He stressed the importance of relief in relation to nutrient flow, even in bogs, and further proposed the idea that the mildness of the climate would contribute to the abundance of *S. nigricans*.

Pearsall & Gorham (1956) later discarded this idea, however, because a comparison between inland bogs and bogs near the coast in northern England and Scotland showed that there were no important floristic differences, even though the bogs near the sea were said to receive exceptional quantities of sea spray. Moreover, no studies were able to demonstrate significant differences in chemical composition between bogs with and without *S. nigricans*. At around the same time, Boatman (1957 cited in Boatman 1961) stated that, as no young plants could be found on the bog, the species was not successful and only managed to survive in blanket bogs due to vegetative

reproduction. Additionally, he suggested that the substrate (e.g. clay, rock) beneath the peat influences the plant community on the bog surface by affecting the early colonisation of the bog (Boatman 1961), and that potassium would be much more important to *S. nigricans* than sodium (Boatman 1962).

Sparling (1967a) returned to these ideas and suggested that sea spray was indeed the reason that *Schoenus* could grow on blanket bogs. He found that *S. nigricans* was extremely sensitive to high concentrations of aluminium ions (Sparling 1962, 1967a). Aluminium ions in ombrotrophic bogs are derived mainly from dust, and are absent or occur in very low concentrations in the blanket bogs of the west coast of Ireland because the prevailing winds are south-westerlies that blow in across the ocean. Sea-derived salts (sodium, chloride and magnesium ions) decrease with increasing distance from the coast, while aluminium ions increase.

Until now, ecological research on the occurrence of *S. nigricans* has focused almost exclusively on habitat characteristics of the sites rather than the hydrological functioning of these systems. More specifically, the possible influence of groundwater flow in the blanket bogs has not been studied recently, even though Gorham (1957) pointed out that the occurrence of *S. nigricans* on a valley bog (Cranesmore) in southern England could be related to input of mineral-rich groundwater. Burnett (1964) suggests the same for some Scottish sites.

In this article we hypothesise that *S. nigricans* is able to grow on bogs in western Ireland due to high base saturation. However, unlike other authors, we do not suggest that high base saturation is due to sea spray, but rather that the bog system is still influenced by mineral-rich groundwater. We discuss our results in the context of current theories concerning the abundance of this species in bogs.

STUDY AREA

Fieldwork was conducted in June 2012 and June 2014 in an area (approximate coordinates: 53° 25′ 40″ N, 9° 59′ 57″ W) around the village of Roundstone (Connemara, Ireland) on the lower slopes of Mount Errisbeg, a 250 m high (granite) hill. Figure 1 shows the location of the study area within the county of Connemara, while Figure 2a shows the (altitude) contour lines around the study area. The peat layers of the blanket bog follow these contour lines, suggesting that the dominant flow of groundwater is from south-east to north-west.

Roundstone has an average annual precipitation of 1208 mm and an average annual temperature of 9.8 °C. The driest month is March (mean precipitation total 63 mm) and the wettest month is December (mean precipitation total 135 mm) (http://en.climate-data.org/location/107673/).

The rocks beneath (and outcropping within) the peatland of Roundstone Bog are very old (470–400 Ma) and consist of igneous basalts which were later metamorphosed due to high pressures and temperatures (Leake 1986). At present, most of the outcropping rock is rather acidic. However, some 400 Ma ago the granites of Roundstone intruded into overlying rock layers. The area to the east of our study area has been subject to much geological research. Jenkin *et al.* (1992) mention the presence of permeable zones in their research area, possibly reflecting preferential water flow along jointing in the granite. Many geological faults, mainly trending north-northwest, can be seen in their study area. The area also contains isolated outcrops of ultrabasic, intermediate and acidic rock formations, so the presence of calcareous water near geological faults or dikes is plausible.

METHODS

Field measurements and sample collection

Field surveys, field measurements and data collections were conducted between the 12th and 15th of June 2014. Two (crossing) transects were selected to cover differences in flow direction (Figure 2). The main altitude differences were in the east–west direction (Transect I), although Transect II also encompassed a (smaller) range of altitudes. A 'Russian pattern' corer (Belokopytov & Beresnevich 1955) with chamber length 50 cm and sample volume 430 cm^3 (Eijkelkamp Soil & Water, Giesbeek, The Netherlands) was used to extract samples of peat at each of the sampling sites shown in Figure 2 (1–5 and A–E). The peat samples were described and their degree of decomposition was estimated according to the von Post humification or H-scale (Grosse-Brauckmann *et al.* 1977).

Temperatures in the soil profile were measured using an EC/Temperature probe (Van Wirdum 1984). This probe directly measures temperatures in the peat (bulk measurement for peat and soil water). Measurements were made at depth intervals of 20 cm, to a maximum depth of 2 m beneath the soil surface. Heights were measured by optical levelling.

A vegetation map of the entire study area was made on the 15 June 2014. On the basis of vegetation relevés recorded in 2012 (Table A1, Appendix), we distinguished four main vegetation types. These are described here as broad physiognomic types rather
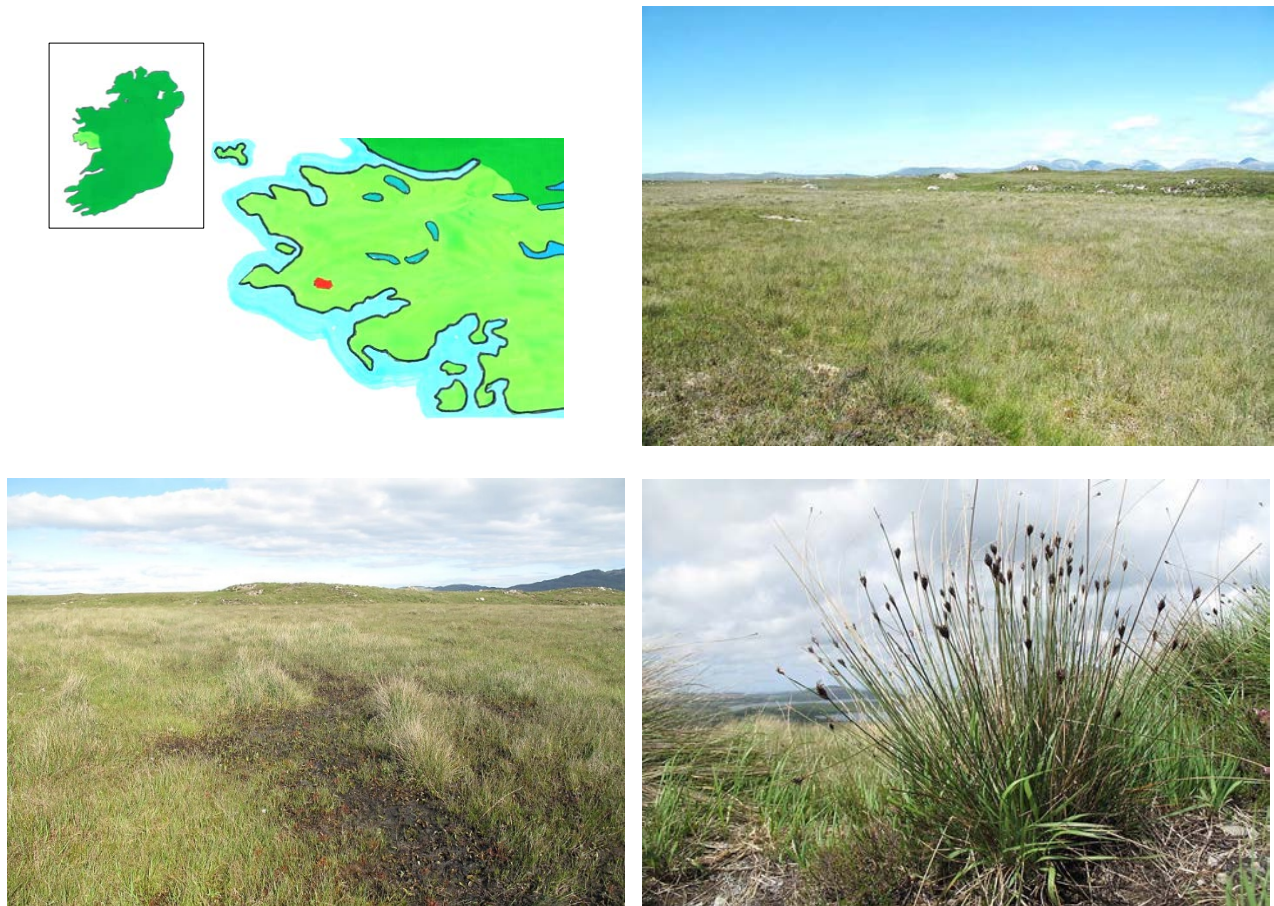
Figure 1. Connemara is situated on the west coast of Ireland (light green, upper left). The position of the research area (Roundstone Bog) is indicated in red. The blanket bogs near Roundstone slope towards the north-west (upper right). Soaks with pioneer vegetation (lower left) and *Schoenus nigricans* (lower right) are present.
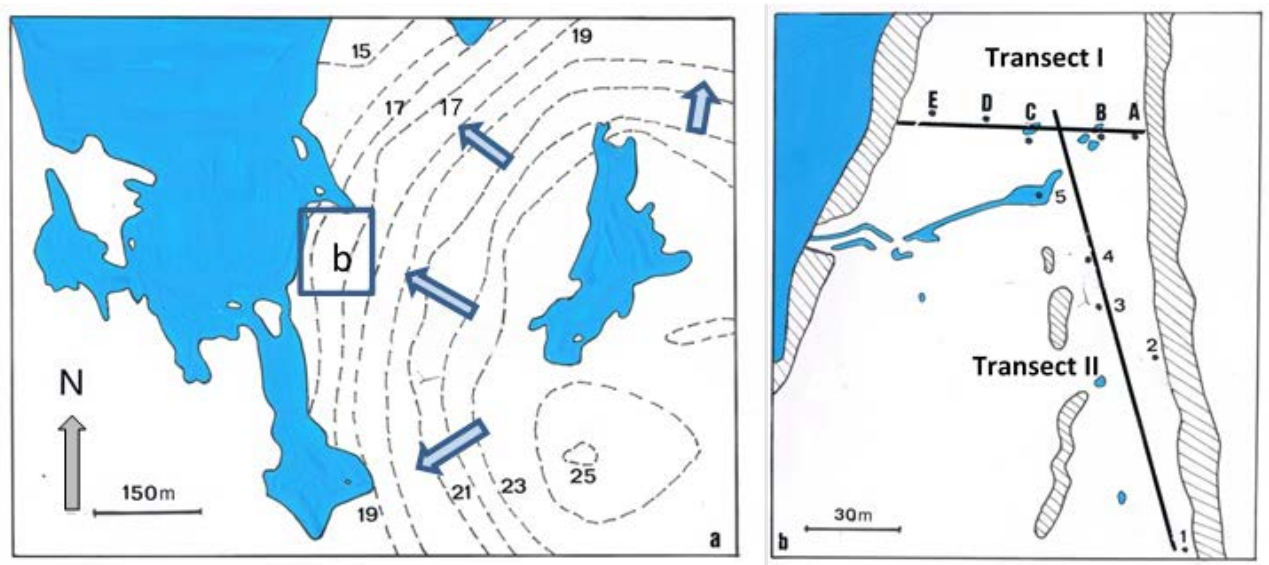

Figure 2. (a) Height map (derived from Google Earth) showing contour lines (m above sea level) and the inferred direction of (sub)surface water flows. (b) Position of the study area with sample points within two (crossing) transects. Open water (blue) and rock outcrops (shaded) are also indicated.

than phytosociological units. Relevés were made using the Braun-Blanquet approach (Van der Maarel 2005) in plots of 2 × 2 m.

Peat samples were placed in plastic bags with as much air removed as possible, and (pore) water samples were extracted from them using evacuated 60 ml syringes and 50 mm rhizons (SMS, pore size 0.1 µm; Eijkelkamp Soil & Water Giesbeek, The Netherlands). After collection, the pore water samples were kept under anaerobic conditions and stored at 4–10 °C until they were brought to the laboratory for analysis.

Concentrations of Al, Ca, Fe, Mg, Mn, Na, Si and S in the pore water samples were determined by ICP spectrometry (IRIS Intrepid II, Thermo Electron Corporation, Franklin, MA, USA). K was measured on a FLM3 Flame Photometer (Radiometer, Copenhagen, Denmark). Total inorganic carbon (TIC; bicarbonate and CO_2) was measured with an infrared gas analyser (IRGA; ABB Advance Optima). Chloride concentrations were measured calorimetrically (Bran+Luebbe AutoAnalyzer 3). All parent data were interpolated (Figures 5–9) using a simple linear interpolation technique and classified in 3–5 categories.

RESULTS

Vegetation
The vegetation of our study area was very varied (Figure 3). The most extensive vegetation type was wet heath with little *Sphagnum*, and there were only small areas with high cover of *Sphagnum* species. Most of the study area had a high frequency of *Schoenus nigricans*. We distinguished four main vegetation types (Figures 3, 4): (1) wet pioneer bog vegetation with much *Drosera rotundifolia* and frequent *Potamogeton polygonifolius*; (2) *Sphagnum* dominated bog vegetation; (3) wet heathland with *Erica tetralix*, *Molinia caerulea* and *S. nigricans*; and (4) dry heathland on rock outcrops, without peat (Figure 4). The wet pioneer vegetation was dominated by *D. rotundifolia* and had no *Sphagnum* species and little *Schoenus*. This vegetation type was usually surrounded by a slightly drier type with high cover of *Sphagnum* species and frequent *S. nigricans*. We also distinguished a subtype with low (< 10 %) cover of *Sphagnum* species but relatively high cover of *S. nigricans*. The most abundant vegetation type was a 'grassy' wet heathland type with low cover of *Sphagnum* species but frequent occurrence of *S. nigricans* and much *E. tetralix* and *Calluna vulgaris*. The vegetation of the dry rock outcrop with almost no peat was dominated by *C. vulgaris*.

Decomposition grade of the peat
Most of the peat sampled along the transects was moderately (H 6–7) to strongly (H 8–9) decomposed (von Post scale) throughout the profile. Highly decomposed peat was present in Transect I at depths of more than 50 cm. On Transect II, strongly decomposed peats were found only in the lower sections of the profiles, close to the underlying
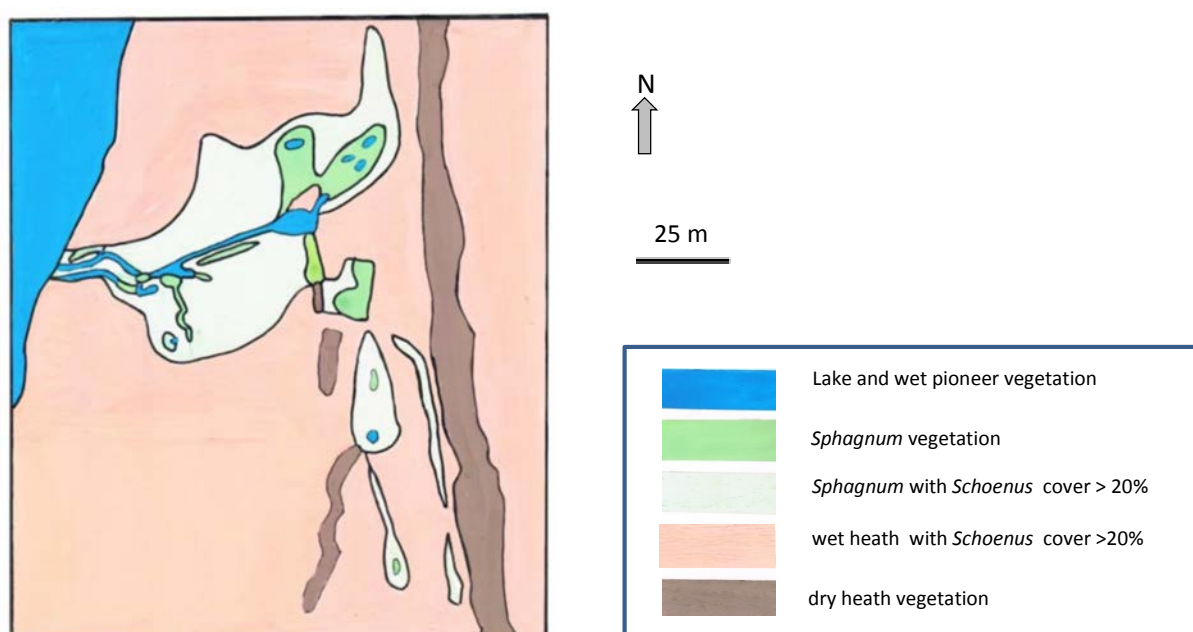

Figure 3. Vegetation map of the study area in Roundstone Bog. The colour codings for vegetation types apply also to Figures 5–10.
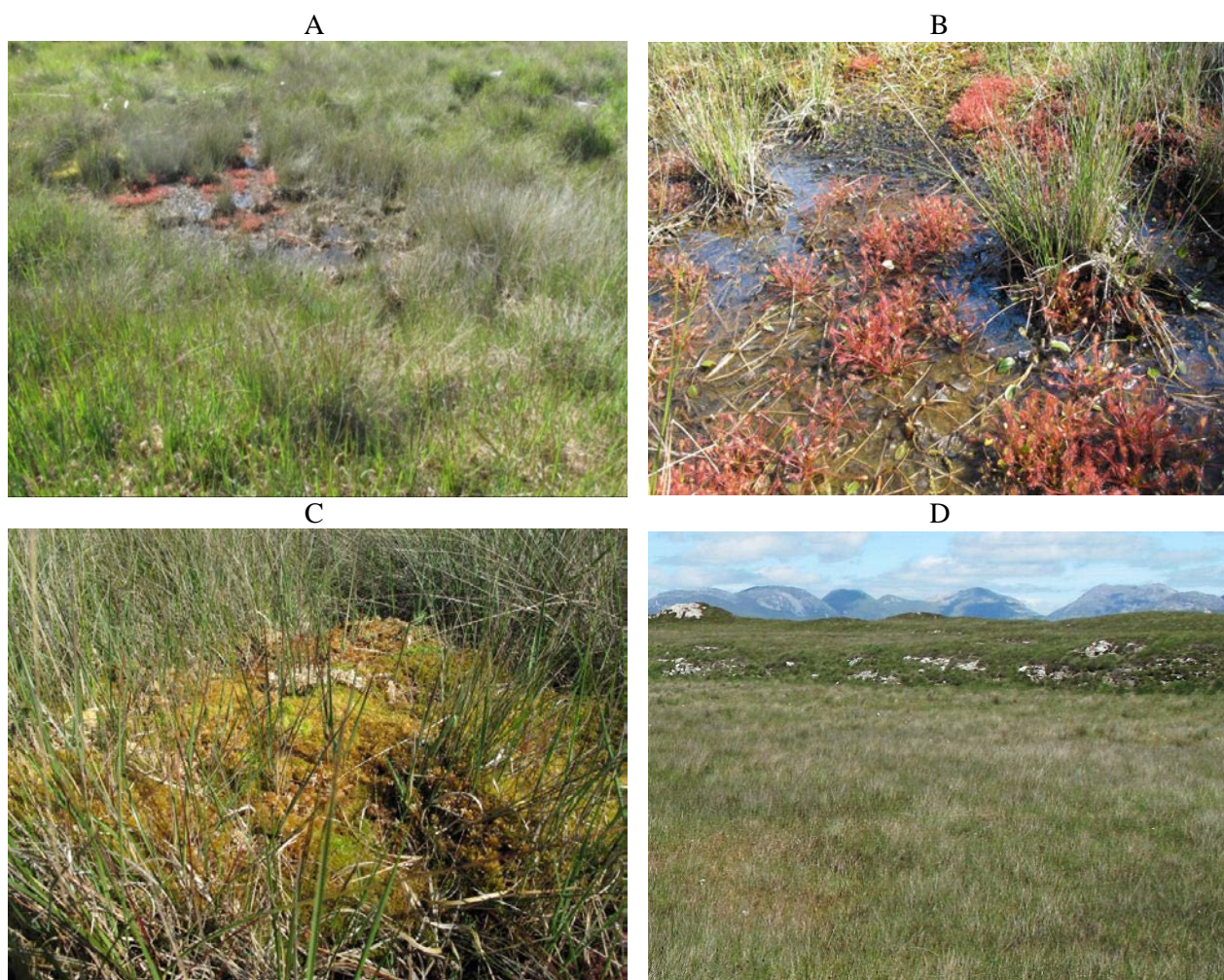
A

B

C

D

Figure 4. Photographs of the main vegetation types in the Roundstone Bog study area. A and B: open patches with *Drosera rotundifolia* and *Potamogeton polygonifolius*; C: *Sphagnum*-dominated bog vegetation with *Schoenus nigricans* and *Molinia caerulea*; D: wet heath with *S. nigricans* (foreground) and dry heath (on rock outcrops).

rocks (Figure 5). Well-preserved peats (H = 2–5) were found in the upper (10–20 cm) layers, especially beneath the wettest vegetation types which had very spongy upper peat layers where the peat was best preserved (H = 2–3). *Phragmites* remains also occurred high in the profile at site 5. Peat with *Phragmites australis* remains was found in deeper layers of Transect I. In Transect II, *Phragmites* remains were found throughout the profile at site 4.

Temperatures in the peat profile
The temperature profiles showed distinct stratification, i.e. temperature decreased with increasing depth (Figure 6). However, small differences could be detected between the different sites. At site 4 of Transect II the temperatures at 40–80 cm depth were slighter lower than at the other sites on Transect II.

Water chemistry in the peat profile
The ionic composition of pore water (Table A2, Appendix) showed relatively high values for calcium and magnesium in samples from the deepest layer (Figure 7). At site II-4 in particular, calcium values were relatively high, but the high calcium values did not reach the surface at the time of measuring. In most of the central part of Transect I, calcium values were very low at depths of less than ~ 1 m.

The pattern of silicon concentrations in the pore water resembled the pattern of the calcium concentrations (Figure 8), with high values in deeper layers and high values throughout the profile at site II-4. The highest values were found in the top layers.

The chloride concentrations showed little variation in Transects I and II (Figure 9). The values were slightly higher in deeper layers and at the (drier) west side of Transect I.

0.5 m

50 m

Transect II

Transect I

N

Von Post H scale

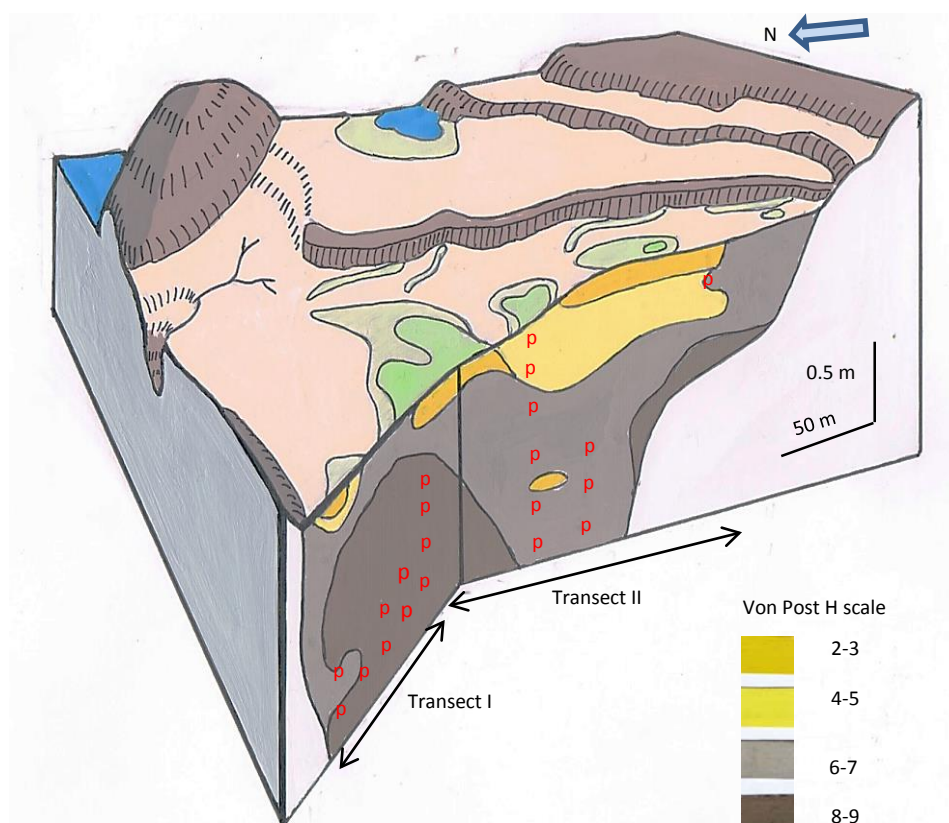|	
	2-3
	4-5
	6-7
	8-9

Figure 5. Degree of decomposition of peat profiles on Transects I and II according to the von Post humification (H) scale. Well-preserved peat is present only in the upper layers. P = remains of *Phragmites australis*.

°C

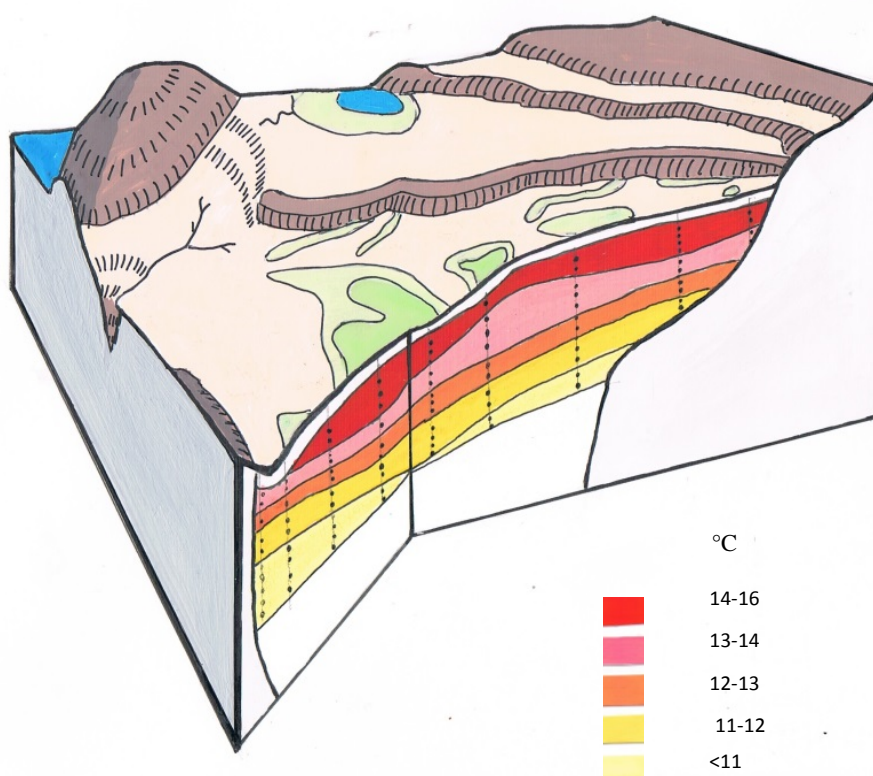|	
	14-16
	13-14
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	11-12
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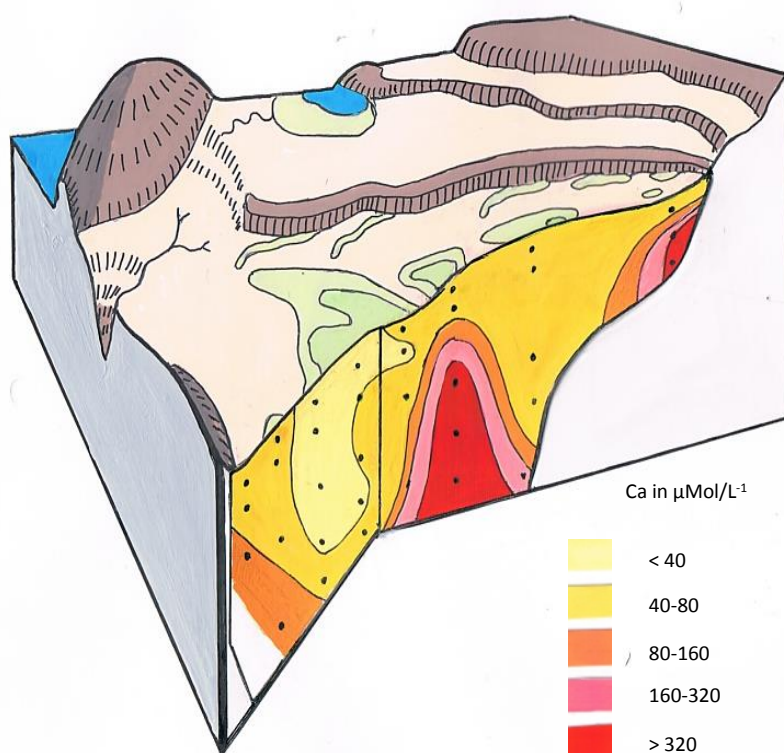Figure 6. Temperature profiles on Transects I and II. Vertical dots indicate measuring points.

Figure 7. Calcium contents (µmol L^{-1}) of pore water in peat profiles on Transects I and II. The vertical dots conform to sample locations.
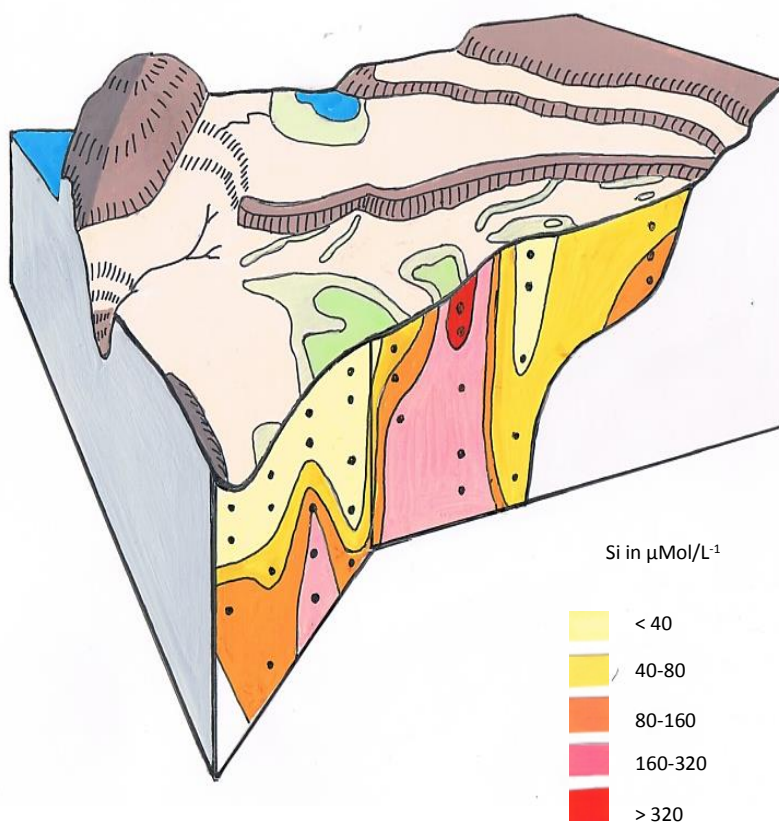

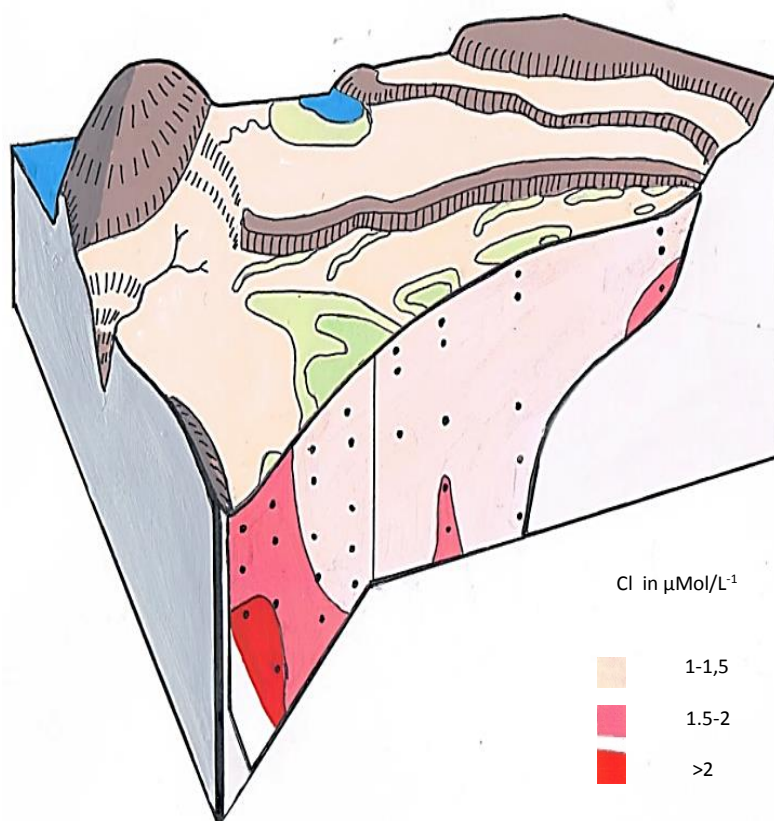Figure 8. Silicon contents (µmol L^{-1}) of pore water in peat profiles on Transects I and II.

Figure 9. Chloride contents (µmol L^{-1}) of pore water in peat profiles on Transects I and II.

DISCUSSION

Groundwater flow in Roundstone Bog

In our study area the temperature data show quite uniform layering which appears to be consistent with conduction-dominated heat transfer. In other words, the temperature data provide no clear evidence for upwelling of groundwater from below. However, the patterns of dissolved minerals in the pore water tell a different story. The calcium and silicon (and bicarbonate, not shown) values in particular indicate upwelling of mineral-rich groundwater at several sites. This is most pronounced in Transect II (site II-4), where relatively mineral-rich groundwater appears to reach the surface of the mire. As the mineral-rich groundwater signature is not reflected in the temperature stratification, this upwelling of (deeper) groundwater must be either temporary or very slow and dominated by shallow groundwater flow in the top layers (see Figure 10).

The von Post humfication data for Transect II support this interpretation. The peat in the upper layers of sites II.2–5 is well-preserved (H2–H3), which indicates that these layers have relatively high transmissivity (see Gilvear & Bradly 2009). Given the relatively large height differences over small distances, the hydraulic gradient is considerable. The result would be rather strong groundwater flow in the top 60 cm of peat, which in wet periods would mainly involve recently infiltrated precipitation water. This water flow would mix with the deeper groundwater in the shallow layers rather than in the deeper decomposed peat layers which offer comparatively high resistance to water flow.

Most of the peat of Transect I (in the foreground of Figures 5–9) is strongly decomposed and consequently has a high resistance to water flow. This prevents horizontal groundwater flow into the lower-lying section of the mire in the direction of the lake. As a result, very wet conditions occur in the more elevated parts of the mire (close to the rock outcrops). The higher chloride concentration on the west side of Transect I may be related to the presence of this strongly decomposed peat, which prevents mixing with subsurface water containing low concentrations of dissolved minerals during wet periods. The relatively high chloride concentrations in these stagnation zones could be the result of evaporation during dry periods (Stuyfzand 1993) combined with the absence of horizontal water flow.
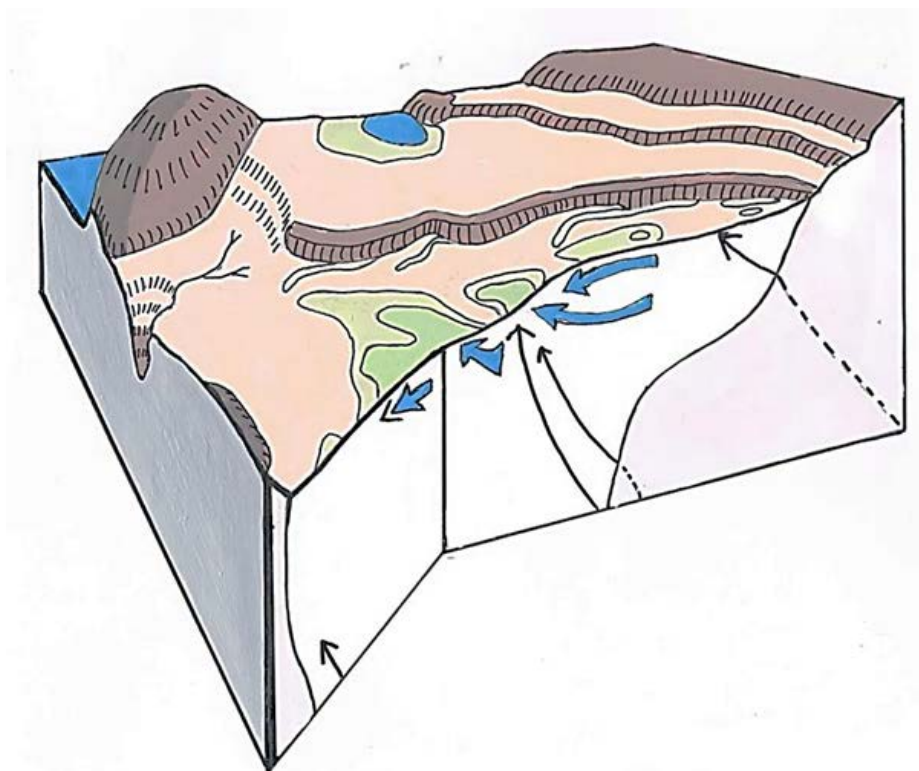
Figure 10. Conceptual model of groundwater flows in the study area. Groundwater flow occurs predominantly in the upper (less-decomposed) peat layers (large blue arrows). At several sites relatively base-rich groundwater emerges at the surface (thin black arrows), possibly from geological faults that enable preferential groundwater flow.

The high concentrations of minerals in the deeper layers appears to be associated with upwelling of groundwater that probably originates from cracks in the underlying rocks. This groundwater type has been enriched with calcium, bicarbonate and silicon due to dissolution of minerals from basic rocks that are present in the area (Jenkin *et al*. 1992). Differences in chloride concentrations can be explained by evaporation, but also by upwelling of groundwater. Salt spray could ultimately be the main source of chloride across the research area as a whole. But geohydrological conditions within the research area appear to determine differences in chloride concentrations locally.

Mire development in Roundstone Bog
We found remains of *Phragmites australis* in the soil starting from a depth of two metres, which points to influence of mineral-rich groundwater in earlier stages of mire formation. *Phragmites* was present throughout the profile at one sampling site with discharge of relatively calcareous groundwater and a high cover of *Schoenus nigricans*. Palynological research at Roundstone Bog (Teunissen &

Teunissen-Van Oorschot 1980) showed that lakes, reed swamps and fens were the dominant ecosystems before the Atlantic Period (7,000 BP). Bogs and heaths, as well as forests, developed during the Atlantic Period (7,000–5,000 BP). *P. australis* expanded during the Sub-Boreal (5,000–3,000 BP) then declined locally after the development of Sphagnacea and *Drosera* species. *P. australis* is not frequent in our research area now, but well-developed fens with *Phragmites* are present close by. *S. nigricans* appeared in the pollen record some 5,000 years BP and has increased in frequency since then, becoming quite abundant after 3,000 BP. Interestingly, Teunissen & Teunissen-Van Oorschot (1980) classified *S. nigricans* as a bog/heathland species. So, palynological research in the area indicates that bog and heath species have become abundant since 5,000 BP, but also that reed swamps with *Phragmites* have remained. The reed swamp/fen element declined only during the last 2,000 years and has never totally disappeared. Part of our research area still shows characteristics of a poor fen which is fed predominantly by precipitation water but also by mineral-rich groundwater and, therefore, is not a bog.

Our findings are in line with the concept of 'blanket mire complex' meaning that a blanket mire consists of various mire types, ranging from fens to bogs (Moore & Bellamy 1974, Lindsay 1995), and also with the idea of Moore *et al.* (1984) that 'in hydrological terms blanket mire is a complex of rheotrophic and ombrotrophic mire types' (for an overview of blanket bogs and the concept of blanket bog landscape, see Joosten *et al.* 2016).

Occurrence of *Schoenus nigricans* in blanket bogs
Our research showed that the occurrence of *Schoenus nigricans* in the bogs of western Ireland may not be primarily due to sea spray, although an influence of salt spray is likely to be present. But, contrary to what has been thought since the work of Sparling (1967a, 1967b, 1968), it may not be the salt spray that is important for high base saturation in the coastal blanket bogs, but a regular (although small) influx of calcareous groundwater to the blanket bog system. We suggest that periodic flows of calcareous groundwater through the bog deposit enough minerals to maintain high base saturation throughout the entire profile of the bog. This, in turn, provides suitable habitat conditions for *S. nigricans*.

ACKNOWLEDGEMENTS

REFERENCES

Belokopytov, I.E. & Beresnevich, V.V. (1955) Giktorf's peat borers. *Torfyanaya Promyshlennost*, 8, 9–10.

Boatman, D.J. (1961) Vegetation and peat characteristics of blanket bogs in County Kerry. *Journal of Ecology*, 49, 507–517.

Boatman, D.J. (1962) The growth of *Schoenus nigricans* on blanket bog peats. I. The response to pH and the level of potassium and magnesium. *Journal of Ecology*, 50, 23–32.

Burnett, J.H. (1964) *The Vegetation of Scotland*. Oliver & Boyd, Edinburgh and London, 464 pp.

Clapham, A.R., Tutin, T.G., Warburg, E.F. (1968) *Excursion Flora of the British Isles*. Second edition, Cambridge University Press, 501 pp.

Conaghan, J. (ed.) (2000) *Distribution, Ecology and Conservation of the Blanket Bogs in Ireland*; *a Synthesis of the Reports of the Blanket Bog Surveys Carried Out Between 1987 and 1991*. National Parks and Wildlife Service, Dublin, 137 pp.

Gilvear, D.J. & Bradly, C. (2009) Hydrological dynamics II: groundwater and hydrological connectivity. In: Maltby, E. & Barker, T. (eds.) *The Wetlands Handbook*, Wiley-Blackwell, Oxford, 169–193.

Gorham, E. (1953) A note on the acidity and base status of raised and blanket bogs. *Journal of Ecology*, 41, 153–156.

Gorham, E. (1957). The development of peatlands. *Quarterly Review of Biology*, 32, 145–166.

Grosse-Brauckmann, G., Hacker, E. & Tüxen, J. (1977) Moore in der bodenkundlichen Kartierung (Peatlands in pedological mapping). *Telma,* 7, 39–54 (in German).

Jenkin, G.R.T., Fallick, A.F. & Leake, B.E. (1992) A stable isotope study of retrograde alteration in SW Connemara, Ireland. *Contributions to Mineralogy and Petrology*, 110, 269–288.

Joosten, J., Szallies, I. & Tegetmeyer, C. (2016) *The Flow Country (Scotland) as a Blanket Bog Landscape; a Global Evaluation*. Greifswald Mire Centre and IMCG, Greifswald, 23 pp.

Lammerts, E.J. & Grootjans, A.P. (1998) Key environmental variables determining the occurrence and life span of basiphilous dune slack vegetation. *Acta Botanica Neerlandica,* 47, 369–392.

Leake, B.E. (1986) The geology of SW Connemara, Ireland: a fold and thrust Dalradian and metagabbroic-gneiss complex. *Journal of the Geological Society*, 143, 221–236.

Lindsay, R.A. (1995) *Bogs: the Ecology, Classification and Conservation of Ombrotrophic Mires*. Scottish Natural Heritage, Edinburgh, 120 pp.

Moore, P.D. & Bellamy, D.J. (1974) *Peatlands*. Elek Science, London, 221 pp.

Moore, P.D., Merryfield, D.L. & Price, M.D.R. (1984) The vegetation and development of blanket mires. In: Moore. P.D. (ed.) *European Mires*, Academic Press, London, 203–235.

Pearsall, W.H. & Gorham, E. (1956) Production ecology. I. Standing crops of natural vegetation. *Oikos*, 7, 193–201.

Pearsall, W.H. & Lind, E.M. (1941) A note on a Connemara bog type. *Journal of Ecology*, 29, 62–68.

Polunin, O. (1969) *Flowers of Europe*. Oxford

University Press, 565 pp.

Sival, F.P. (1996) Mesotrophic basiphilous communities affected by changes in soil properties in two dune slack chronosequences. *Acta Botanica Neerlandica*, 45, 95–106.

Sparling, J.H. (1962) Occurrence of *Schoenus nigricans* L. in the blanket bogs of western Ireland and northwest Scotland. *Nature*, 195, 723–724.

Sparling, J.H. (1967a) The occurrence of *Schoenus nigricans* L. in blanket bogs. I. Environmental conditions affecting the growth of *S. nigricans* in blanket bog. *Journal of Ecology*, 55, 1–13.

Sparling, J.H. (1967b) The occurrence of *Schoenus nigricans* L. in blanket bogs. II. Experiments on the growth of *S. nigricans* under controlled conditions. *Journal of Ecology*, 55, 15–31.

Sparling, J.H. (1968) *Schoenus nigricans* L. (*Chaetospora nigricans* Kunth). *Journal of Ecology*, 56, 883–899.

Stuyfzand, P.J. (1993) *Hydrochemistry and Hydrology of the Coastal Dune Area of the Western Netherlands.* PhD thesis, Faculty of Earth Sciences, Free University, Amsterdam,

366 pp.

Sýkora, K.V., Bogert, J.C. & Berendse, F. (2004) Changes in soil and vegetation during dune slack succession. *Journal of Vegetation Science*, 15, 209–218.

Teunissen, D. & Teunissen-van-Oorschot, H.G.C.M. (1980) The history of the vegetation in SW Connemara (Ireland). *Acta Botanica Neerlandica*, 29 (4), 285–306.

Van der Maarel, E. (2005) *Vegetation Ecology*. Wiley-Blackwell, Oxford, 395 pp.

Van der Meijden, R. (2005) *Heukels' Flora van Nederland* (*Heukels' Flora of The Netherlands*). 23rd edition, Wolters Noordhoff, The Netherlands, p.149 '*Schoenus nigricans*' (in Dutch).

Van Wirdum, G. (1984) *Development of Techniques for Ecohydrological Research*. Annual Report 1983, Research Institute for Nature Management, Leersum, The Netherlands, 21–25.

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Appendix

Table A1. Vegetation relevés on some sample points (June 2012).

Sample site (vegetation type)	A (2)	B (1)	C (2)	D(3)	E(3)	3(3)
Total cover (%)	95	60	97	98	98	98
Cover of dead material (%)	5	1	2	1	15	8
Cover of mosses (%)	90	10	95	95	73	70
Vascular plants						
Drosera rotundifolia	+	2	2	1	+	+
Schoenus nigricans	3	30	2	4	23	13
Phragmites australis	+	+				
Potamogeton polygonifolius	9	6	1			
Drosera intermedia	+	+	+	+		+
Narthecium ossifragum		1	2	2	1	+
Myrica gale	+	+	+	1		
Erica tetralix	+	+	+	+	2	9
Anagallis tenella	+					
Rhynchospora alba	3		4	4	2	3
Juncus bulbosus	+					
Molinia caerulea	13	1	3	7	17	13
Eriophorum angustifolium	+			r	+	+
Utricularia minor	+					
Menyanthes trifoliata		3	+	+		
Pedicularis sylvatica				+	+	
Carex limosa				+		
Potentilla erecta					+	1
Pinguicula lusitanica		+				
Mosses						
Sphagnum papillosum	2	1	3	< 1		
Sphagnum cuspidatum	72	9	81	31	1	
Sphagnum compatum		< 1		1	6	6
Sphagnum squarrosum	1					
Sphagnum magellanicum		1	1	1		
Sphagnum palustre						1
Sphagnum fuscum			1		< 1	10
Cladonia portentosa				+	< 1	< 1
Campylopus atrovirens				40		
Aulacomnium palustre					24	
Polytrichum commune					1	23
Odontoschisma sphagni						1
Cladonia uncialis						< 1

Table A2. Pore-water composition of the sampling stations at different depths in µmol L^{-1} (June 2014).

site	depth (cm)	pH	Ca	Fe	K	Mg	Al	Mn	Na	Cl	HCO$_3$	S	Si
1	10–20	6.2	95	5	99	88	1	2	1486	1358	421	28	61
	50–60	6.5	818	194	43	158	1	21	1260	1447	1828	9	129
	90–100	6.4	1044	108	38	197	1	22	1611	1559	3113	15	126
2	10–20	7.2	98	3	30	77	3	0	2336	1043	1126	115	43
	50–60	5.2	86	33	32	155	10	0	1270	1366	37	148	299
	90–100	5.3	129	33	36	168	8	1	1408	1406	196	99	263
	140–150	5.8	240	46	47	148	11	2	1461	1457	697	78	246
3	10–20	5.7	47	2	110	99	1	0	1054	1217	90	145	23
	60–70	5.2	48	4	21	148	1	0	1098	1385	144	20	26
	140–150	5.3	42	5	9	98	2	1	916	1064	68	18	40
	240–250	5.4	48	17	13	81	3	5	922	1114	115	45	45
	390–400	5.8	162	44	15	62	3	8	893	1216	439	30	66
4	10–20	6.1	137	70	106	126	2	6	1121	1403	404	67	317
	60–70	6.1	129	39	110	114	1	4	1006	1271	344	57	326
	140–150	6.1	491	73	44	87	1	5	1158	1401	1278	18	235
	240–250	6.5	563	65	28	94	0	4	1090	1505	1051	51	227
	310–320	6.5	631	62	37	116	0	4	1199	1507	1616	40	237
5	10–20	6.0	48	42	23	86	1	5	985	1220	70	56	57
	50–60	5.8	36	87	27	80	2	14	939	1266	150	64	154
	140–150	5.7	50	54	36	95	2	1	1208	1354	227	103	190
A	10–20		123	27	25	94	10	3	1244	1155	387	39	325
	50–60	6.1	109	53	24	117	19	1	1523	1417	205	108	328
	140–150	5.5	106	24	23	134	12	1	1155	1381	37	34	258
	190–200	6.0	166	23	28	130	6	5	1107	1413	157	73	192
B	10–20	6.0	38	5	35	105	1	1	1237	1200	112	65	23
	50–60	7.0	40	7	39	114	1	1	2050	1334	847	26	28
	140–150	6.2	40	8	38	106	2	1	976	1102	196	13	31
	240–250	5.8	29	15	17	79	2	2	940	1029	124	23	36
	490–500	5.4	44	21	25	78	4	4	949	1206	77	30	81
C	10–20	5.4	29	17	24	103	1	1	1105	1323	32	35	27
	50–60	5.9	26	25	31	89	1	2	1045	1286	15	23	33
	140–150	5.6	29	27	37	82	3	3	1094	1443	61	57	160
	240–250	5.5	33	16	49	64	5	1	1140	1477	47	57	177
	370–380	5.7	58	22	46	52	6	2	1323	1642	267	28	221
D	10–20	4.3	53	8	9	186	4	0	1478	1630	2	91	5
	50–60		41	12	-4	174	3	1	1966	1574	32	57	18
	140–150	5.1	68	33	50	158	2	0	1838	1984	4	55	74
	240–250	6.5	140	61	69	102	3	1	2799	1947	1586	35	132
E	10–20		77	10	33	230	0	0	2840	1841	296	121	8
	50–60	4.5	76	12	37	204	0	0	1779	1770	27	70	13
	110–120	5.5	89	76	28	194	2	2	1900	2093	194	27	100