Chemical studies of some Irish bogs:
a newly discovered manuscript by Hugo Sjörs and Eville Gorham

Håkan Rydin

Department of Ecology and Genetics, Uppsala University, Uppsala, Sweden

_____

SUMMARY

This unpublished manuscript from 1966 by Hugo Sjörs and Eville Gorham was found in the archives at Uppsala University. It is published here to make their data available as historical reference material. Floristic data on higher plants, bryophytes, lichens and microalgae were obtained from ombrotrophic bogs in Ireland with and without *Schoenus nigricans*. Analyses were made for Na, K, Ca, Mg, Cl, SO_4, dissolved organic carbon, optical density and pH in the free superficial waters; for Na, K, Ca, Mg and pH in waters expressed from the bog peats; and for ash, P, pH, and the exchangeable cations Na, K, Ca, Mg and H in the peats themselves. The richness of the ombrotrophic flora in western Ireland is confirmed by this study, which demonstrates that bogs there contain many species of microalgae as well as higher plants which are restricted to minerotrophic fens in Sweden. Marine influence upon ion supply is very strong, with the Irish bog waters uncommonly high in Na, Mg and Cl. Exchangeable Na and Mg are also unusually abundant in the peats. Associated with marine influence are higher pH values than are normal in more continental sites, and a higher degree of adsorptive neutralisation of the peats. Total P is low by comparison with ombrotrophic peats in Sweden. Expressed waters are much higher than free superficial waters in K, and to a lesser extent in Ca, but they are much lower than free waters in H ions.

KEY WORDS: blanket bog, cations, historical data, marine influence, peat chemistry, *Schoenus nigricans*

_____

BACKGROUND BY H. RYDIN

I found this manuscript by chance as we were sorting out old material in the archives of what had earlier been the Department of Plant Ecology at Uppsala University. It contains unpublished chemical measurements from Irish peatlands collected by Eville Gorham and Hugo Sjörs in 1956. At the time, Gorham was at the Freshwater Biological Association, Ambleside, UK, where Sjörs was a visiting scientist. There was an incomplete manuscript with Gorham as first author from ca. 1961 (judging from the references included). The paper presented here is a submission-ready typescript from 1966 with Sjörs as first author, with only a few handwritten alterations. By then Sjörs was a professor at the Department of Plant Ecology at Uppsala University, Sweden, and Gorham was at the Department of Botany, University of Minnesota, USA. The manuscript was prepared while Sjörs was visiting Gorham during a sabbatical. Hugo Sjörs died in 2010 and Eville Gorham in 2020.

There is nothing to indicate that the manuscript was ever submitted to a journal, which is surprising as it contains potentially important environmental reference data. The quality of the research is not in question given that Gorham and Sjörs were undoubtedly the two leading peatland ecologists at the time, not least when it comes to peat and peat-water chemistry. The manuscript is not updated with reference to modern literature; rather the data are presented for their irreplaceable historical value. Among later publications dealing with the topics, Doyle (1982) and Proctor (2008) should be mentioned as particularly relevant.

The manuscript is presented here in a style resembling that of *Journal of Ecology* in the 1960s. Only the following changes are made: taxon nomenclature is updated according to Euro+Med Plantbase (Euro+Med 2006+). *Sphagnum imbricatum* is today split into *S. affine* and *S. austinii* and referred to as *S. affine/austinii*. *Sphagnum magellanicum* has been split into several species, with *S. divinum* and *S. medium* occurring in Ireland, and referred to as *S. divinum/medium*. Names of microalgae are retained from the original manuscript. The original hand-made graphs were redrawn, using data in Tables 3–6. These Tables are available in Excel format in a separate online file (Supplement), with columns to indicate if samples were ombrotrophic or minerotrophic, and whether *Schoenus nigricans* was present. This information was retrieved from the text and Tables, and I checked that the new graphs matched the originals. A reference was added for the cations/Cl proportions in sea water (Keddy 2024). A few clarifications suggested by the reviewers are added in square brackets.

CHEMICAL STUDIES OF SOME IRISH BOGS

BY HUGO SJÖRS AND EVILLE GORHAM

Department of Plant Ecology, Uppsala University, Uppsala, Sweden, and
Department of Botany, University of Minnesota, Minneapolis, U.S.A.

I. INTRODUCTION

The extremely oceanic bogs of western Ireland have long been known to display extreme traits in general appearance, hydrotopography and composition of vegetation (British Vegetation Committee 1908, Connolly 1930, Tansley 1939, Pearsall & Lind 1941, Osvald 1949, Lüdi 1952, Gorham 1953, Boatman 1957). The number of species able to grow in bogs that are strictly ombrotrophic (Du Rietz 1954), i.e. receive only precipitation and no water from the mineral soil, reaches a maximum on the bogs of the Irish west coast. On going east, the number of such species decreases steadily. The Baltic types of inland bogs, distributed in south-east and south-central Sweden, southern Finland and the region to the east and south-east of the Baltic, have a very restricted flora in comparison with the hyper-oceanic bogs.

The western Irish bogs have a species composition which is even comparable to that of the "poor fens" (Du Rietz 1949) of Scandinavia, although the floras are naturally somewhat different with respect to presence or absence of oceanic and boreal elements. The additional element in the Irish bogs, when compared with inland bogs in the areas around the Baltic, is only partly made up of species actually lacking in the Baltic area (*Erica mackaiana*, *Ulex gallii*, *Polygala serpyllifolia*, *Pleurozia purpurea*, etc.). The larger number of additional species occur also in the Baltic area, although entirely absent there from strictly ombrotrophic bogs. To the latter category belong several of the important co-dominants and sub-dominants in many Irish bogs, e.g. *Molinia caerulea*, *Eriophorum angustifolium*, *Carex panicea*, *Myrica gale*, *Menyanthes trifoliata*, *Potentilla erecta*, and *Sphagnum subnitens*. An intermediate position is occupied by *Erica tetralix*, *Narthecium ossifragum*, *Pedicularis sylvatica*, *Potamogeton polygonifolius*, *Sphagnum affine/austinii*, etc., with their restricted occurrence in the Baltic area. They are all minerotrophic (Du Rietz 1954) near their eastern limits, although in ombrotropic sites *E. tetralix* occurs further east than *N. ossifragum*.

Most of the species mentioned above occur as ombrotrophic bog-plants also outside western Ireland, e.g. in other parts of Ireland, in Great Britain and other countries surrounding the North Sea, so the changes in the ombrotrophic flora are gradual. However, the number and concentration of plants alien to the Baltic ombrotrophic bog types is particularly great in western Ireland, and even appreciably greater than in equally maritime areas further north such as Scotland and western Norway.

A particular problem is that of *Schoenus nigricans* which grows abundantly on ombrotrophic bogs in some parts of westernmost Ireland (and much more rarely in westernmost Scotland). It is otherwise a markedly minerotrophic and even calcicole plant in Central Europe, as well as on its few stations in the Baltic area where it is strictly confined to highly calcareous sites.

Apart from the *Schoenus* problem, the difference noted in the composition of the bog flora is on the whole a regular phenomenon that calls for a general theory rather than for explanations applicable to each separate species, such as difference in ecotype or autecological response to climate. At least three general hypotheses have been advanced. One of them is the idea (von Post & Granlund 1926) that the western blanket bogs are soligenous. It is unclear whether this opinion was founded only on the distinctly sloping condition of many of the blanket bogs, or whether these authors actually inferred that the blanket bogs were flushed by minerotrophic water. In a later paper, von Post (1937) only mentioned the occurrence of both ombrogenous and soligenous features in Irish peatland, leaving their relative importance to be revealed by further research. Later investigations, e.g. by Osvald (1949), showed that the bulk of the blanket peatland, both in Ireland and elsewhere, is ombrotrophic, minerotrophic flushing being confined to narrow "soaks" and in some cases to the lower parts of long slopes. The flora of the soaks and other flushed areas usually differs slightly from that of strictly ombrotrophic areas, although this contrast is less striking in western Ireland than in most peatland complexes elsewhere.

Another explanation was proposed by Pearsall (1938, Pearsall & Lind 1941), who thought that the western Irish bogs were so constantly water-saturated that a high acidity could never develop in them. According to Pearsall a high acidity will only develop in an oxidizing environment. The partial decomposition of the freshly formed peat would occur under more constantly reducing conditions in western Ireland than in bogs in less wet climates, where some of the decomposition occurs under oxidizing conditions, owing to aeration in dry

seasons. Pearsall & Lind (1941) were able to show that the acidity of blanket bog peat from Connemara increased very considerably upon drying of the samples. However, in other regions quite acid conditions may occur even in permanently water-logged sites (Gorham 1953). Moreover, the sloping blanket bogs of Ireland, with their remarkably firm peat, do not seem to be constantly water-saturated to the extreme degree that the theory requires, and they probably drain fairly well in the upper one or two inches between the rainy periods, even if these are more frequent in Ireland than elsewhere. The air content of our samples of wet superficial peat varied roughly between 50 and 250 ml L^{-1} (from data in Table 6), the higher values usually obtained from sampling in short spells (1−2 days) of dry weather.

A third explanation, suggested by Tansley (1939, p. 701) and Osvald (1949, p. 58) is "the falling of sea spray, driven by inshore gales, on the surface of the bog, thus changing the soil reaction". Since this theory was formulated, abundant data have been collected about the composition of rainwater, showing that the marine influence is not confined to the coast itself but affects large parts of the continents, although to a degree that decreases continuously in the inland direction (Eriksson 1952, 1955, 1959a,b,c,d, 1960, Emanuelsson *et al.* 1954, Rossby & Egnér 1955, Egnér & Eriksson 1955, Gorham 1955, 1957b, 1958a, Tamm 1958). Recently, Sparling (1962, 1967 a,b) has dealt with these theories, and specifically with the *Schoenus* problem.

II. MATERIAL AND METHODS

1. *Itinerary*

The aim of the present investigation was to collect data on the ionic composition of bog-water and peat in ombrotrophic sites in Ireland, particularly in the west. The field work was carried out on May 3–9, 1956. It was regarded as important that the sites selected should be strictly ombrotrophic, and the success in finding sites suitable in this and other respects was entirely due to the helpful cooperation of Mr. T.A. Barry of the Bord na Móna, Newbridge, Co. Kildare, who suggested our itinerary. Mr. Barry was able to locate a number of convex sites even within blanket bogs, where domed parts are comparatively scarce. It would have been impossible for us to find more than a few suitable sites in the limited time available without this information in advance. It was further required that the sites should be covered by at least about six feet (two metres) of peat, and be as little disturbed as possible by drainage, peat-cutting, burning, grazing and other influences which may greatly change chemical conditions in bogs. Mr. Barry entered the sites on the map with such precision that we did not miss a single locality despite our lack of acquaintance with the Irish landscape. He further accompanied us personally at four of the sampling sites.

2. *Sampling sites and their vegetation*

The early season had the disadvantage that some of the vascular plants of the bogs probably escaped attention. We did not try to estimate degree of cover or other quantitative properties except dominance because the vegetation was not well advanced. The limited time and the great distances we had to cover, partly on rough, narrow roads, excluded any detailed work on floristic composition of vegetation, which, however, is fairly well-known through the works cited above. Notes on the sites are given in Table 1. The somewhat incomplete notes on the vegetation are given in Table 2.

The majority of the sites are on convex parts of blanket bogs at variable distances from the Irish west coast (Figure 1), ranging from Donegal to Kerry and from near sea-level to about 600 feet (180 metres). Two sites (Mossy Bed and Slieve Bloom Bog) are from upland blanket bogs in south-central Ireland, at an elevation of about 1200–1600 feet (370–490 m). These upland bogs are strongly sloping and belong to a more extreme type of blanket bog than most of the western coastal bogs (although the Meenaharnish and Owenteskiny bogs in Donegal are also strongly sloping). A few sites are on raised bogs. Most of these are situated in plains not far from the west coast. The very extensive Easky and Drimina bogs and the *Schoenus* bogs sampled are transitional between the raised and the blanket type.

The Garryduff inland raised bog was included because Mr. Barry had found *S. nigricans* on part of it. We obtained samples both inside and outside the *Schoenus* area; both sampling sites showed higher dissolved and exchangeable calcium than normal. The explanation suggested by Barry is that some marl from the construction of the near-by Grand Canal had probably been spread very thinly over the bog for improvement of grazing. Introduced during or after the marling, *Schoenus* became established over part of the marled area and is now present as a relict species after nearly ombrotrophic conditions have been re-established. The ability

Table 1. List of the sampling sites. W: large water sample by E.G.; w: small water sample by H.S; p: peat sample by H.S.

Location, abbreviation, county	Samples	Notes
Western raised bogs without *Schoenus*		
Barnesmore, Ba, Donegal	2W	Upper Mournebeg, ca. 500 ft. Well-domed bog beside Lough Mourne.
Barnesmore, Ba, Donegal	325p	In a valley (blanket bogs on near-by hillsides). Standing surface water abundant.
Shronowen, Sh, Kerry	11W, 337p	ca. 100 ft. Raised bog cut at margins and recently being drained although vegetation of sampled part not yet affected. More *Sphagnum* than usual (note find of *S. balticum*, an eastern species).
Creevosheedy, Cr, Clare	10W	ca. 100 ft. Large raised bog much affected by drainage and burning except in sampled part (N. of road).
River Ferta, RF, Kerry	18W	North of River Ferta, ca. 150 ft., large raised bog. *Schoenus* absent on the bog except in soaks and low parts irrigated by the soaks.
River Ferta, RF, Kerry	15W	Soak in preceding bog: water from upper part with *Schoenus*; dominant *Narthecium*; *Myrica* dominates in places. (Iron ochre seen in lower part of the soak, but not at sampling site).
Drimina, Dr, Sligo	5W, 331p	ca. 200 ft. Raised bog (transitional to blanket bog), wet in centre. A relic *Phragmites* patch and a row of swallow holes occur in this bog.
Easky, Ea, Sligo	4W, 328p	ca. 450 ft. Very large bog (fairly flat, partly blanket, partly raised), covering about 3,000 hectares. Sampled area with many small pools and wet *Menyanthes* hollows.
Interior upland blanket bogs without *Schoenus*		
Slieve Bloom, SB, Offaly/Laois	17W, 342p	Slieve Bloom Mountains, 1550–1600 ft. Steep hillside blanket bog over 7 feet deep, incipient erosion. The peat has slipped downslope in places, but some of the cracks are being healed by new growth. Small pools also present despite the strong slope.
Mossy Bed, Mb, Cork	16W, 341p	ca. 1200 ft. Extensive blanket bog (5–6 feet deep) over rounded hills.
Western coastal blanket bogs without *Schoenus*		
Owenteskiny, Ow, Donegal	3W, 329p	ca. 300 ft. Blanket bog over domed hill. Sample from convex part. (*Schoenus* absent on the bog except in a few soaks; abundant in adjacent minerotrophic area).
Owenteskiny, Ow, Donegal	327w	Small soak in preceding, with some *Schoenus*.

Location, abbreviation, county	Samples	Notes
Meenaharnish, Me, Donegal	1W	ca. 600 ft. Blanket bog entirely covering a domed hill. In part strongly wind-eroded, particularly on the slope facing N.W. Incomplete notes of vegetation (not in Table 2): *Sphagnum papillosum*, *S. rubellum*, *Trichophorum caespitosum*, *Calluna*, *Eriophorum vaginatum* chief dominants, *Molinia* scarce, *Juncus squarrosus* common, *J. bulbosus* and *Eriophorum angustifolium* in wet trickles with *Sphagnum cuspidatum*. Water sample.
Reenacollee, Re, Kerry	12W, 338p	ca. 400 ft., in a deep valley with high hills to the north. Blanket bog limited to the sloping valley floor, sampled in a convex, purely ombrotrophic part not much affected by drains and not at all by firing; this part is somewhat differentiated into numerous wet hollows and drier hummocks (other parts are not).

Western coastal bogs with *Schoenus*

Location, abbreviation, county	Samples	Notes
Gowlan East, GE, Galway	8W, 333p	ca. 150 ft. Slightly convex part of large, flat blanket bog area in typical Connemara landscape. Undisturbed with few, widely spaced pools and occasional low hummocks (Gorham 1957c, p. 237).
Derreen, De, Kerry	14W, 340p	ca. 100 ft. Slightly convex part of small, not very sloping bog. Cattle trampling, otherwise not much disturbed. Shallow hollows with *Sphagnum cuspidatum*; low hummocks formed only by *Rhacomitrium* and *Leucobryum*.
Laghtanabba, La, Galway	6W, 332p	ca. 150 ft. Slightly convex part of flat bog expanse, on exposed low plateau S. of Cleggan Bay. Few pools, very scattered and shallow; hummocks rare.
Inny Ferry, IF, Kerry	13W, 339p	ca. 50 ft. Very close to the sea (to the south-west, i.e. in prevailing wind direction). One large and several small pools in domed area. Water sample taken from the small pools.
Inny Ferry, IF, Kerry	23W	The same, water from a large pool with *Nymphaea*.

Minerotrophic sites in the Connemara *Schoenus* bog district

Location, abbreviation, county	Samples	Notes
Craiggamore, Cm, Galway	7W	ca. 100 ft. (W. side of Lough Craiggamore). Slightly quaking, very wet part, probably weakly minerotrophic.
Screeb, Sc, Galway	9W, 334w, 335p	ca. 25 ft. Sloping, wet, strongly minerotrophic poor fen with abundant iron ochre.

Partly marled (?) raised bog in the interior lowland

Location, abbreviation, county	Samples	Notes
Garryduff, Gd, Galway	19W, 344w, 343p	ca. 150 ft. Large raised bog, a few acres with sparse *Schoenus*.
Garryduff, Gd, Galway	20W, 345p	Surroundings without *Schoenus*, with more *Sphagnum cuspidatum* hollows, and plentiful *Myrica gale*.

Interior lowland bog; with occurrence of birch

Location, abbreviation, county	Samples	Notes
Cloncreen, Cl, Offaly	22W	ca. 225 ft. with birch.
Cloncreen, Cl, Offaly	21W	Same without birch.

Table 2. Vegetation of sampled areas. Not quite complete notes by H.S and E.G. from areas of a few hundred m^2.

	Ombrotrophic														Minerotrophic		
	Ba	Sh	Cr	RF	Dr	Ea	SB	MB	Ow	Re	GE	De	La	IF	Cm	Sc	Gd
Andromeda polifolia			+				(+)										+
Calluna vulgaris	++	++	++	++	++	++	++	++		++	+	+	+	+			++
Carex limosa						++				+						+	
C. panicea			++	++		++		+		0		(+)					++
Drosera anglica			+		+							+		+	+	+	
D. intermedia	+									+				+	+		+
D. rotundifolia	+		+			+			+	+		+	+		+		+
Empetrum nigrum							+										
Erica tetralix	++	++	+	++	++	++	+	+	++	++	+	+	+	+	+	+	++
Eriophorum angustifolium	++	++	+	+	++	++	++	+	++	++	+	+	+	+	+		++
E. vaginatum	++	++	++	+	++	++	++	++	++	+	+	+	+	+	+	+	+
Lycopodium selago	+																+
Menyanthes trifoliata			+	++	++					+		+		+	+	+	(+)
Molinia caerulea	++	0	0	++	0	++	(+)	++	+	++	+	++	+	++	+	+	+
Myrica gale	(+)	0	(+)	+	0	0			+	++	0	+	0	+		+	++
Narthecium ossifragum	+	++	++	+	++	+	+	(+)	+	++	+	+	+	+	++		++
Pedicularis sylvatica		+	0	+			+		+	+		+	+	+	+	+	+
Phragmites australis	0	0	0	0	(+)	0	0	0	0	0	0	0	0	0	0	++	0
Pinguicula (not in flower)		0	0		+		+										
Polygala serpyllifolia		0	0	+		+	+		+	+	+	+	+	+		+	
Potamogeton polygonifolius															+	+	
Potentilla erecta			0	+		+		+	+		+	+	+	+	+		+
Rhynchospora alba	0	++	++	++	0					++	+	++	0	+	++	+	+
Schoenus nigricans	0	0	0	0	0	0	0	0	0	0	++	++	++	++	++	++	+
Trichophorum cespitosum	++	+	+	+	++	++	++	++	++	+	+	++	++		+		++
Ulex gallii							(+)						+				
Utricularia minor	+																
Sphagnum auriculatum	+	+				+				+	+	++	+		++	++	++
S. cuspidatum	++	++	++	++	+	++	+	+	+	++	0	++	+	++			++
S. fuscum		(+)	++	+	+					0		0	+	+			+
S. affine/austinii	+	++	++	+	+					++	(+)	0	+	+	(+)		+
S. divinum/medium										++	(+)	+	+	++	+	+	+
S. papillosum	++	++	++	++	+	++	+	++	+	++	+	+	+	++	++	+	++
S. subnitens							+					+					++
S. rubellum	+	++	+	+	+	++	++	++	+	+	+	+	+	++	+	+	++
S. tenellum	+	++	+	++	+	++	+	+	+	+	+	+	+	++	+		++
Aulacomnium palustre			+				+										
Campylopus spp.[1]	+	+	+		+	+	+	+		+	+	+	+	+			+
Hypnum cupressiforme[2]		+	+				+	+		+		+		+			+
Leucobryum glaucum		+	+	+	+					+	+	+	+	+	(+)		
Rhacomitrium lanuginosum	++	+	0	+	+	+			+	+	+	+	+	+	+		+
Diplophyllum albicans								+	+								
Odontoschisma sphagni		+	++	+	+		+		+	+		+	+	+	+		+
Pleurozia purpurea	+	+		+	+				+	+	+	+		+			+
Cladonia arbuscula agg.	+	+	+	+	++	+				+	+	+	+	+	+		+
C. uncialis	+	+	+		+	+	+				+	+	+	+	+		

[1] *Campylopus atrovirens* most frequent.

[2] v. *ericetorum*.

++; dominant, co-dominant, subdominant, or local dominant; + present in low quantity; (+) growing outside sampled area; 0 particularly noted as absent (this was not done consistently). Abbreviations of localities, see Table 1.

Additional species: *Hypericum elodes* (IF, aquatic), *Juncus acutiflorus* (Dr), *J.* cf *articulatus* (IF), *J. bulbosus* (IF), *J. squarrosus* (MB, outside sampled area), *Melampyrum pratense* (Gd), *Sphagnum balticum* (Sh), *S, pulchrum* (Sc), *S. subsecundum* (Ea), *Breutelia chrysocoma* (RF, outside sampled area), *Rhytidiadelphus loreus* (MB, outside sampled area), *Mylia anomala* (Cr, probably overlooked elsewhere). Small bryophytes and lichens not noted, several other species certainly overlooked because of insufficient time and the early season.
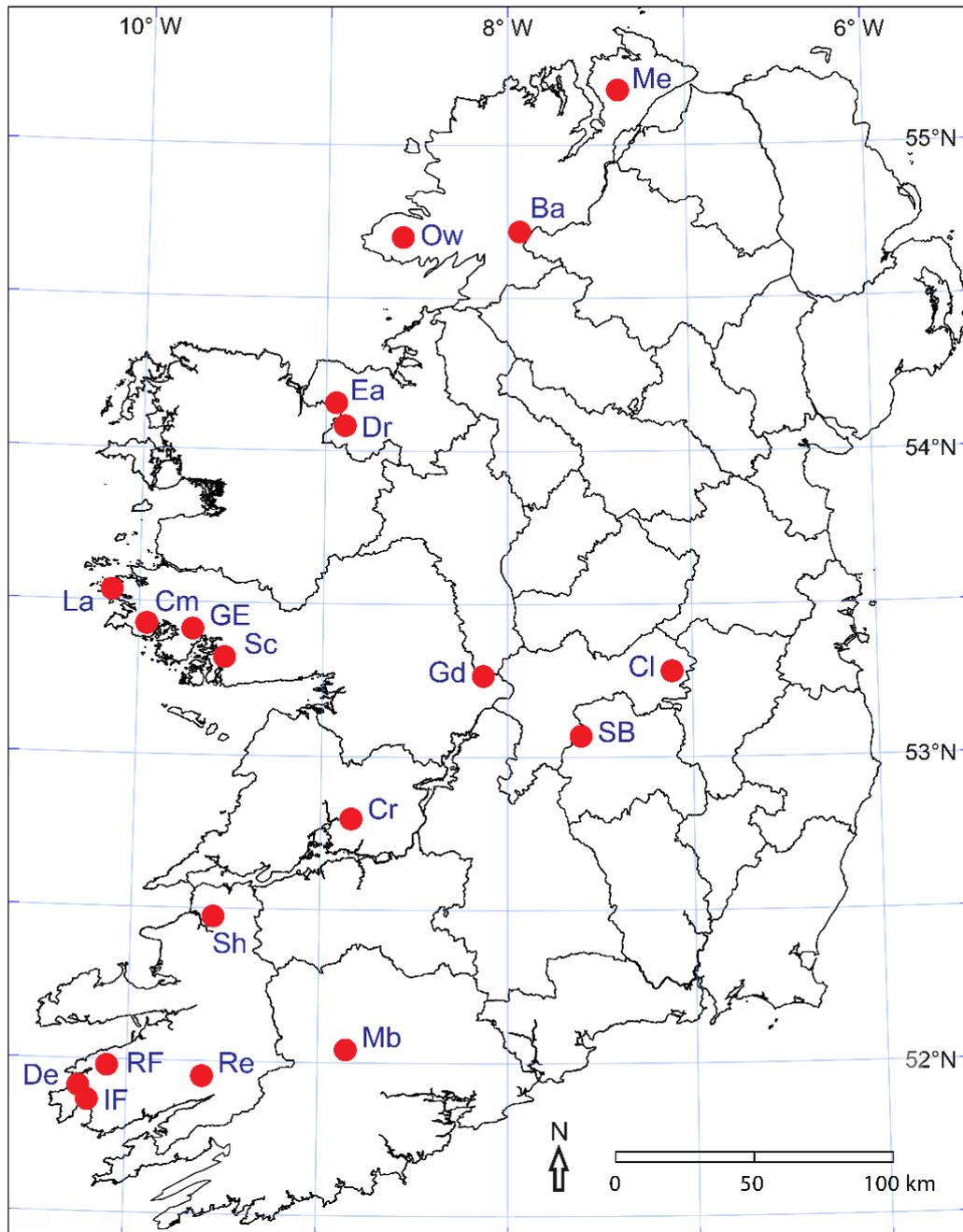
6

Figure 1. Sampling sites. See Table 1 for site abbreviations.

to grow there may be a sign that *Schoenus* is either unusually deep-rooted, or able to grow under conditions not very far from ombrotrophic even in central Ireland, although absent there in all true and uncontaminated ombrotrophic sites, as far as is known.

Two water samples were taken in soaks, one possibly and one certainly slightly minerotrophic, and both containing *Schoenus*, which in both cases was absent from the surrounding bog. Another doubtfully minerotrophic site (Craiggamore), and one certainly soligenous (i.e. minerotrophic) poor fen (Screeb), both in Connemara, were also sampled, to provide contrast with the strictly ombrotrophic bogs. Both fens and bogs contain *Schoenus* in this district. Further south (Co. Clare, etc.) *Schoenus* was also seen growing on wet limestone pavement (in a place resembling the "vät" sites on the "alvars" of the Baltic limestone island [this is obviously the Burren, a karstic region in north-west Co. Clare] but with *Plantago coronopus* and *P. maritima*, at a considerable distance from the seashore), and in calcareous fen sites, where it is much more

luxuriant than in the bogs. The latter sites were not sampled, but are doubtless alkaline and very rich in calcium, as are the Central European environments of this species, according to Lüdi (1952 p. 204).

The *Schoenus* bogs are so firm, and run-off is so rapid in them, that water samples could only be taken from occasional small and very shallow pools in the bog hollows, despite abundant rains previous to sampling. Between the rainy periods it was even possible to walk in ordinary shoes on these bogs without getting wet feet [these bogs seem to be at the dry end of a wetness spectrum]. Cattle do not sink more than a few inches in the dense *Schoenus* mat. The *Schoenus* bogs are chiefly used for sheep-grazing, but the sheep do not eat much of the *Schoenus*, which may be a reason for its nearly constant dominance when present.

Ombrotrophic *Schoenus* bogs have been reported by Bellamy (1959) from the S.W. Irish coast (Co. Kerry), where they were observed by us only at low altitude very near the coast. The easternmost such bog on the north side of Kenmare Bay (between Reenacollee and Inny Ferry on Figure 1) was seen west-south-west of Sneem. Around Inny Ferry and Derreen they were numerous but small, because of the topography, and much influenced by agriculture, burning and grazing except in the two areas sampled. A more northern example was noted near Dingle Bay, north of Lough Caragh (immediately north-west of Caragh Bridge), i.e. south-west of Killorglin. The River Ferta bog, however, lacks *Schoenus* except in some soaks and low-lying parts.

3. *Sampling*

Besides taking records of the vegetation, and collecting some samples of microalgae from hollows and pools, the field work included sampling of peat in moderately wet places and sampling of free water in shallow pools or bog-hollows, all within the convex parts of the bogs. After litter, moss and basal parts of living plants had been removed, peat samples were taken with a sampler constructed from a cylindrical tin 5 cm in length. Three peat samples (total volume 0.5 L) from each locality were packed in a polythene bag and subsequently mixed. The water samples were filtered in the evening through Whatman #541 papers, and stored in polythene bottles that were transported in the car used for the trip that lasted nine days or less, chiefly in cool weather. Later the samples were stored for a few days in a cool place (the former wine cellar of the Ferry House) before they were analyzed. The analytical work was done in the Freshwater Biological Association laboratory, Ferry House, Ambleside, England.

4. *Analytical methods*

The water samples were taken in polythene bottles of two different sizes. The larger samples (about 600 ml) were collected and worked up by Gorham and the smaller (about 200 ml) by Sjörs. The accuracy of most of the determinations is slightly lower in the smaller samples.

The large water samples were analyzed for pH (glass electrode); Na and K (EEL flame photometer with Calor-gas fuel); Ca and Mg (EDTA titration according to Heron & Mackereth 1955); SO_4 and Cl (by an ion-exchange procedure developed by Mackereth 1955; Cl is computed by difference, whereas other anions of strong acids are estimated as SO_4); dissolved organic carbon (gravimetric determination of CO_2 formed in wet oxidation with ammonium persulphate, according to Mackereth 1963); optical density (as $\log(I_0/I)$ at 350 nm 1 cm cells). The methods are briefly described in Gorham (1957a).

The small water samples were treated similarly for pH, Na and K. The procedures for organic carbon and optical density were omitted. To get a sample free of organic acids, an aliquot (usually 100 ml) was evaporated in a silica dish and the residue ignited at 550 °C. The residue on ignition was then leached over two days with 50 ml of water saturated with CO_2 and under a CO_2 atmosphere. It was not necessary to filter the solution except in fen-water samples containing iron. The low content of Ca and the high proportion of easily soluble salts in the residues made dissolution easy, but the method may not be suitable for calcareous waters. The filtrates, which were free of organic matter, were analyzed following the above-mentioned methods for Ca and Mg.

The peat samples were weighed wet, and portions were taken out for pH determination using the direct contact method using a glass electrode. In a few cases a water extract was made from 1 volume of peat diluted to 2 volumes with distilled water. The mixture was shaken for several hours and left to settle. A portion of the supernatant water was then filtered off and the pH of the clear filtrate was measured. The contact method gives much lower pH values than both extract and expressed water (see Tables).

It is highly important when pH is discussed that the method is stated: whether the determination was made by direct insertion of electrodes in the fresh peat or in a suspension of dried or fresh peat, or by using natural free water, pressed water or a water extract (and in the latter cases, whether the water was turbid or clear).

These methods usually yield highly different results in base-deficient peats, generally with pH rising in the order of methods stated. The turbid waters exert an ion-adsorption effect during measuring (Alvsaker 1943), which with acid colloid particles involves a release of H⁺ ions, i.e. a lowering of pH. Similar effects become especially strong with the direct contact method, which usually yields values more than a full pH unit lower than in clear water determinations (Gorham 1960). However, in some cases no significant difference has been found between contact pH of peat and pH of the corresponding water (Newbould & Gorham 1956). The peats investigated by these authors were not ombrotrophic, and about half neutralised (Newbould 1960).

The remainder of the peat sample was weighed again, and placed in a steel cylinder provided with a perforated bottom covered by several filter papers. Most of the interstitial water was then slowly squeezed out by a steel piston attached to a hydraulic press. The very high pressure exerted by the apparatus is mainly taken up by firm material in the peat, and therefore the interstitial water cannot be expelled completely even by prolonged application of high pressure. With highly humified material such as lake mud, the pressure works more effectively on the material and not only the interstitial water but also a large part of the colloidal water can be expelled, and a thin, half-dry disk is formed from the sample. (Some chironomid larvae in the mud survived this rough treatment, with pressures sometimes reaching several hundred kg cm^{-2}.)

The amount of water that could be expelled from the peat samples was variable, ranging from about 3/4 to less than 1/2 of the total water. The expressed water was usually somewhat turbid and therefore had to be filtered again (under suction). It was then analyzed in the same way as the small water samples.

From the pressed and re-weighed sample, a sub-sample (about 4−8 g, depending on wetness; dry weight about 1 g) was taken for extraction with 50 ml of normal ammonium acetate solution. From the pH of the filtered extract, the amount of exchangeable hydrogen ions in the peat was calculated (Brown's method, 1943; see also Sjörs 1961, Malmer and Sjörs 1955). An aliquot (25 ml) of the extract was then evaporated to dryness in a silica dish and the residue ignited at 550 °C until free of organic matter. The residue on ignition was then dissolved in 50 ml of CO_2-saturated water as described above. The residues from peat extracts are much richer in bivalent cations than the water samples, but poor in SO_4 and Cl, and therefore dissolve less rapidly in the CO_2-water. It seems that the procedure would hardly work with peats of higher Ca-saturation; fortunately, the Irish peats contain more of the easily soluble Mg than of Ca, and both metals were dissolved quantitatively according to a few tests. Na, K, Ca and Mg were determined with the same methods as in water, modified for the greater amounts occurring in the peat extracts.

The remaining part of the pressed peat sample was weighed, dried and weighed again as air-dry. From the successive weighings, the dry weight and water content of the pressed peat and of the original sample were calculated. The analytical values were then referable to original volume. A portion of the air-dried sample was dried at 105 °C and ignited at 550 °C, and the loss on ignition and ash content calculated. The analytical values could then be referred to dry weight of ash-free peat as in Sjörs 1961 (a few per cent higher than ordinary dry weight values). For some ions, notably Na, the exchangeable amount proper is less than the amount in the extract because the latter also contains an appreciable amount of ions that were originally in water solution. Therefore the dissolved ions, calculated from the concentrations in the expressed water, have been subtracted from the extracted amounts.

The ash was treated with 5 ml of 10% HC1 in a water bath; after complete evaporation 5 ml 1:200 HCl was added and the residue washed on filter paper with another portion of 5 ml 1:200 HCl and distilled water. The filter was ignited and the insoluble remains weighed. Thus the ash was divided into soluble and insoluble fractions; the latter consists of mineral grains and silica derived partly from plant ash, but to a great extent from diatoms. In the filtrate P was determined colorimetrically by the usual molybdate-stannous chloride method.

III. ANALYTICAL RESULTS

1. *Free waters*

The data on surface water samples are presented in Table 3. Total cations correlate very closely with total anions, but with a cation excess of about 5% which is presumably balanced by organic anions not analyzed in this study. The cation excess is slightly greater in the more concentrated samples, averaging 8% in the five samples highest in total cations.

Total ionic concentrations are greatest near the coast, owing to the abundance of Cl supplied in sea spray. In general Cl concentrations range between 10 and 15 ppm beyond about 15 miles (24 km) from the sea, and

Table 3. Determinations in free superficial water. W: large sample (E.G.); w: small sample (H.S.).

Location	Sample	pH	Tot cations (meq L^{-1})	Anions (meq L^{-1})	Na$^+$ (ppm)	K$^+$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Cl$^-$ (meq L^{-1})	SO$_4^{2-}$ (meq L^{-1})	DOC (ppm)	Opt dens log(I$_0$/I)
Western raised bogs without *Schoenus*												
Barnesmore	2W	4.40	0.49	0.47	7.9	0.2	0.3	1.0	12.6	5.6	9.8	0.087
Shronowen	11W	4.33	1.03	0.95	17.5	0.5	0.8	2.1	25.6	11.0	37.9	0.380
Creevosheedy	10W	4.50	0.63	0.60	10.1	0.5	0.9	1.3	14.1	9.8	25.7	0.238
River Ferta	18W	4.43	0.55	0.55	8.9	0.6	0.5	1.0	14.3	6.9	22.6	0.285
Drimina	5W	4.35	0.61	0.60	9.9	0.4	0.5	1.3	17.8	4.7	14.7	0.148
Easky	4W	4.50	0.62	0.60	10.0	0.4	0.5	1.4	17.8	4.5	8.8	0.084
Interior upland blanket bogs without *Schoenus*												
Slieve Bloom	17W	4.00	0.46	0.46	5.5	0.1	0.6	1.0	9.5	9.2	13.3	0.161
Mossy Bed	16W	4.28	0.39	0.40	5.1	0.3	0.6	1.0	9.9	5.9	14.9	0.161
Western coastal blanket bogs without *Schoenus*												
Owenteskiny	3W	4.41	0.72	0.67	11.8	0.4	0.7	1.4	19.6	5.9	16.1	0.219
Meenaharnish	1W	4.06	0.87	0.80	14.1	0.4	0.8	1.4	23.6	6.8	23.4	0.299
Reenacollee	12W	4.51	0.39	0.39	6.2	0.3	0.3	0.8	9.8	5.6	13.6	0.174
Western coastal bogs with *Schoenus*												
Gowlan East	8W	4.40	0.78	0.74	12.5	0.5	0.8	1.8	20.6	7.7	19.4	0.231
Derreen	14W	4.51	1.14	1.05	19.4	0.8	1.0	2.4	31.4	8.0	27.1	0.261
Laghtanabba	6W	4.42	1.29	1.18	21.9	0.8	1.1	2.8	34.0	10.7	20.8	0.240
Inny Ferry	13W	4.22	1.20	1.12	20.0	1.2	0.8	2.5	31.5	11.0	22.8	0.261
Inny Ferry (pool)	23W	4.93	0.83	0.80	14.9	0.2	0.5	1.6	24.3	5.6	-	-
Soaks and flushed minerotrophic sites												
Owenteskiny (soak)	327w	4.66	0.81	-	14.5	0.3	0.9	1.2	-	-	-	-
River Ferta (soak)	15W	4.81	0.56	0.55	9.5	0.5	0.7	1.0	14.6	6.3	16.9	0.246
Craiggamore	7W	4.70	1.02	0.94	17.6	0.5	1.4	1.8	28.6	6.4	24.1	0.323
Screeb (fen)	9W	4.97	0.73	0.67	11.8	0.5	1.1	1.5	20.1	4.9	12.9	0.202
Screeb (fen)	334w	5.20	0.78	-	12.8	0.8	1.5	1.5	-	-	-	-
Partly marled (?) raised bog in the interior lowland												
Garryduff with *Schoenus*	19W	4.48	0.64	0.59	8.9	0.4	2.2	1.3	13.2	10.5	28.4	0.292
Garryduff with *Schoenus*	344w	4.32	0.71	-	10.0	0.5	2.4	1.2	-	-	-	-
Garryduff no *Schoenus*	20W	4.40	0.55	0.52	7.8	0.4	1.5	1.0	13.4	6.9	24.9	0.215
Interior lowland bog with occurrence of birch												
Cloncreen, with birch	22W	4.16	0.61	0.62	8.9	1.6	0.6	1.0	14.5	10.4	51.5	0.717
Cloncreen, no birch	21W	4.34	0.54	0.52	7.8	0.7	1.2	0.9	13.7	6.2	23.8	0.171

rise to over 30 ppm within about 5 miles (8 km) of the coast. Sparling (1967a,b) has obtained essentially similar results. Slieve Bloom, the site at highest elevation (about 1600 ft, or 490 m) and inland, exhibited the lowest Cl concentration, 9.5 ppm. This may be compared with concentrations of 13.2 to 14.5 ppm for the low-level inland sites Garryduff and Cloncreen. Such an altitudinal decline is natural, since the larger droplets of sea spray will fall at low elevations (Slieve Bloom is not unusually low in non-marine ions, so other factors must be of over-riding significance in their case).

The marine influence upon the chemistry of Irish bog waters is shown in Figure 2, which relates the concentrations of various dissolved constituents to that of Cl, almost entirely supplied from the sea in this maritime region. Among the cations, Na and Mg show almost the same proportionality to Cl as that in sea water (the marine proportion from Keddy (2024) is indicated by the equivalence lines in the Figures). Na and Mg are therefore supplied mainly by sea spray. Ca and K[1] also tend to increase with a rise in Cl, but in these cases sea spray is not the only important source, since there is a marked excess in both instances over the marine supply indicated by the equivalence lines. pH and SO_4 show no relationship to chloride supply.

Dissolved organic carbon shows some tendency to increase with chloride, if a single highly coloured sample from the birch grove at Cloncreen is excluded from the comparison. No explanation of this correlation is offered. Optical density is highly correlated with dissolved organic carbon, as shown in Figure 3. The fen waters are slightly high in colour, perhaps owing to the presence of some filter-passing iron colloids.

The difference between ombrotrophic and minerotrophic sites is shown clearly by acidity, with the ombrotrophic samples below and the minerotrophic samples above pH 4.6. Differences in Ca concentration were not very great in these samples, since the minerotrophic sites were only very slightly influenced by water percolating mineral soil. Highly calcareous rich fens can, however, be found in many parts of Ireland.

2. *Expressed waters*

The expressed waters from the peat samples agree very closely with the free waters in their concentrations of the marine ions Na and Mg (Figure 4, Table 4). However, if expressed water is compared with free water from the same bogs, significant differences are found for K, Ca and H ions. Expressed waters generally contain less H, but more Ca and much more K, the average expressed/free ratios being 0.35, 1.8 and 6.1, respectively. To explain these differences, it would be important to know if a storage effect is involved, i.e. whether during storage the peat is exchanging metal ions for H ions from the interstitial water, or whether metal ions (notably K) are released from dying roots or from root surfaces still living but affected by lack of oxygen (normally supplied through aerenchyma in the root cortex). Living tissues take up K selectively against very strong gradients, K being about one hundred times more concentrated by living than by dead organic colloidal adsorbents (Malmer 1958, p. 282). If the living tissues are rendered inactive, a release of K ions can be expected. Such effects could easily be eliminated by using a simple squeezing apparatus in the field (but the necessary immediate filtration would require pressure or suction by means of a less easily transported apparatus). Some evidence for K release from peat particles into water samples during one week's storage has been presented by Tamm (see Gorham 1950, p. 224). No evidence of Ca release was observed during this very brief period. In the present study it is difficult to account for a release of Ca without a similar release of Mg, which is much more abundant in the exchangeable form.

Should some of the chemical differences found between free and interstitial water prove to exist *in situ*, they could be explained in various other ways. The less acid condition of the interstitial water might be owing to less oxidizing conditions within the peat. Oxidation of sulphide to sulphuric acid in aerated free waters has been shown to be accompanied by higher metal cation concentrations, but these are chiefly the divalent Ca and Mg (Gorham 1956, 1967). The low content of K (and the slightly lower content of Ca) in the free water might, on the other hand, be ascribed to the great demand for these nutrients by surface organisms (mosses, and in particular algae). Whereas the roots of higher plants which exploit considerable volumes of peat can make use of the large amounts of ions adsorbed on the peat particles, surface organisms must take up these nutrients solely from solution. The small supplies of ions in solution can easily be exhausted by an active growth of surface organisms, for instance the development of a sheet of algae a few hundredths of a mm thick will be able to deplete 1 dm^3 of water of nearly all K ions. In free surface water the ions used up can only be replaced slowly and partially through release and diffusion from the subjacent peat.

---

[1] Excluding a pair of Garryduff Ca analyses probably subject to residual influence of liming, and a Cloncreen K analysis from a birchwood.
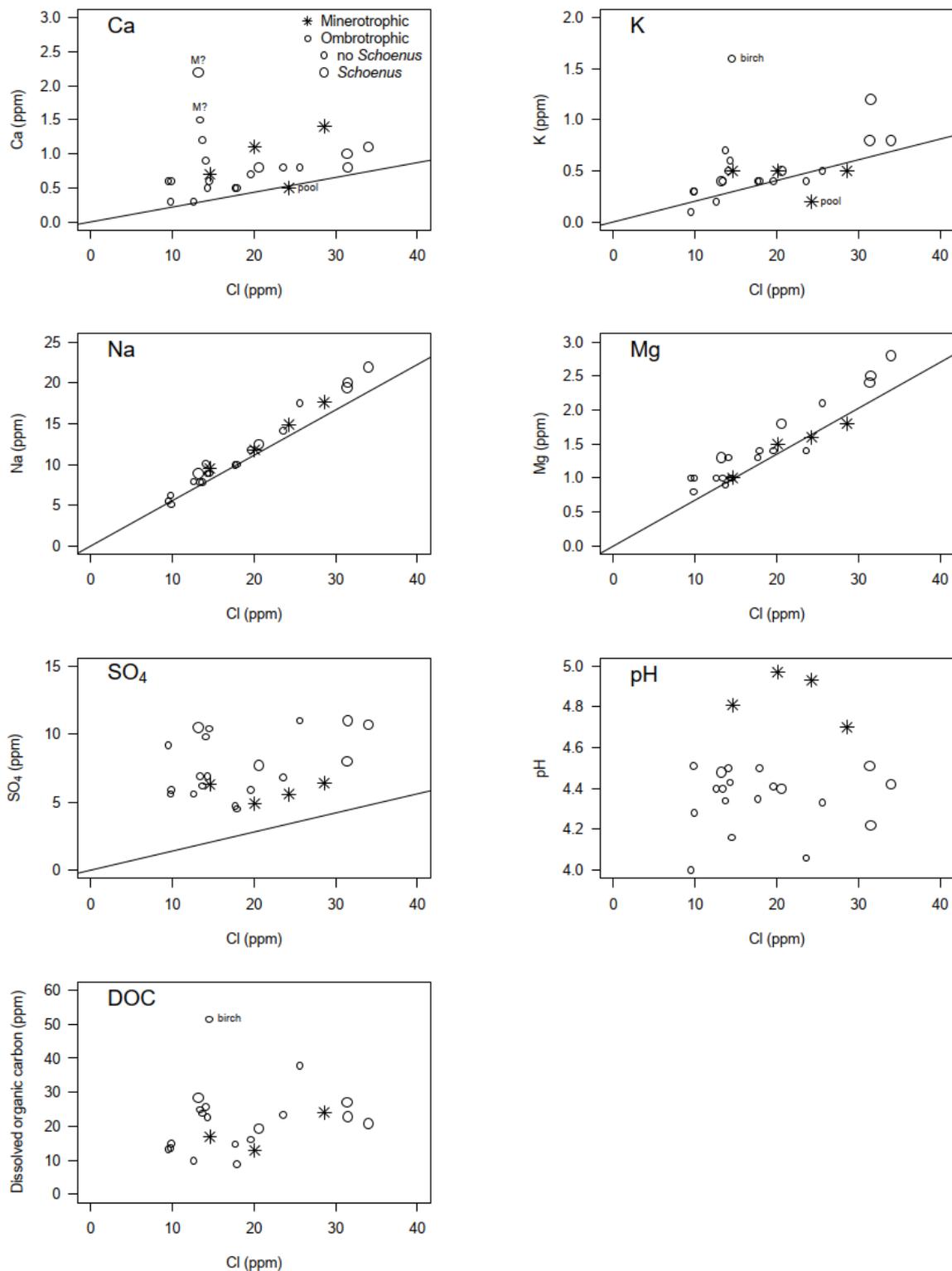
Figure 2. Marine influence upon water chemistry in Irish bogs, as shown by the relationships of various chemical properties to chloride concentration. Lines indicate ionic proportions in sea water. M?, possibly marled sites at Garryduff.
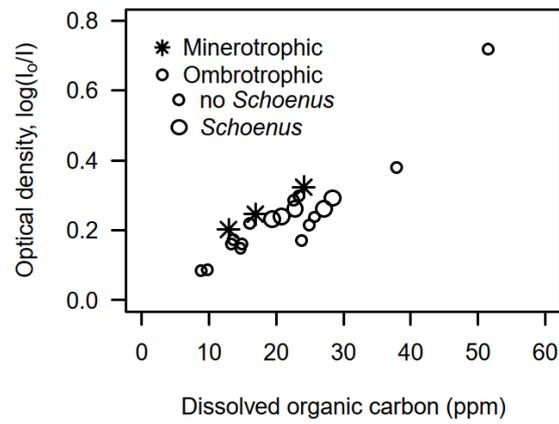
Figure 3. The relationship between optical density and dissolved organic carbon in waters from Irish bogs.
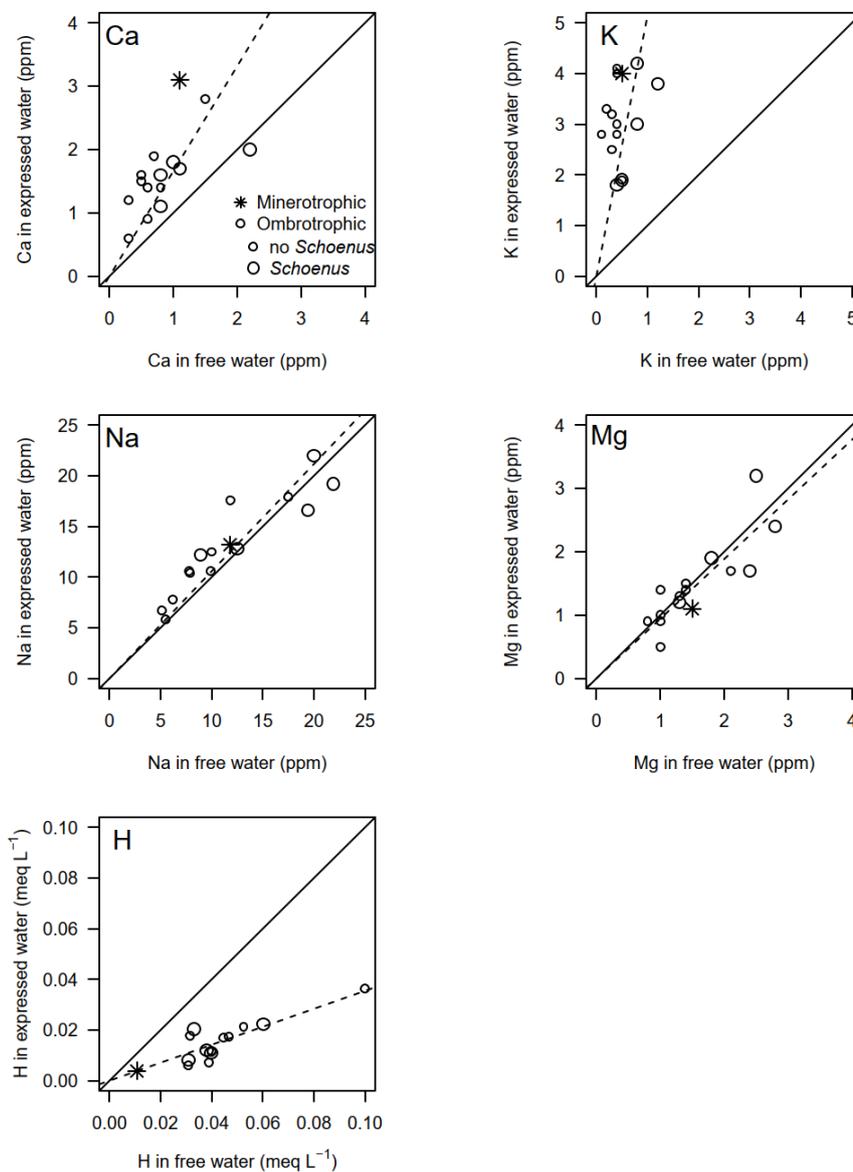

Figure 4. Relationship between ionic concentrations in free and expressed waters from Irish bogs. Solid lines indicate equal proportions, dashed lines have been fitted through mean values and the origin at zero.

Table 4. Determinations in water expressed from peat

Location	Sample	pH	Tot cations (meq L^{-1})	Na$^+$ (ppm)	K$^+$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)
Western raised bogs without Schoenus							
Barnesmore	325p	4.93	0.69	10.4	3.3	1.2	0.9
Shronowen	337p	4.76	1.06	17.9	1.9	1.4	1.7
Drimina	331p	4.77	0.76	10.6	4.0	1.5	1.3
Easky	328p	4.75	0.87	12.5	4.1	1.6	1.5
Interior upland blanket bogs without Schoenus							
Slieve Bloom	342p	4.44	0.45	5.8	2.8	0.9	0.5
Mossy Bed	341p	4.67	0.52	6.7	2.5	1.4	1.0
Western coastal blanket bogs without Schoenus							
Owenteskiny	329p	5.14	1.05	17.6	2.8	1.9	1.4
Reenacollee	338p	5.22	0.54	7.8	3.2	0.6	0.9
Western coastal bogs with Schoenus							
Gowlan East	333p	4.96	0.83	12.8	1.9	1.1	1.9
Derreen	340p	5.09	1.04	16.6	3.0	1.8	1.7
Laghtanabba	332p	4.92	1.23	19.2	4.2	1.7	2.4
Inny Ferry	339p	4.65	1.42	22.0	3.8	1.6	3.2
Flushed minerotrophic sites (fen) with Schoenus							
Screeb	335p	5.42	0.93	13.2	4.0	3.1	1.1
Partly marled (?) raised bog in the interior lowland							
Garryduff with _Schoenus_	343p	4.69	0.81	12.2	1.8	2.0	1.2
Garryduff no _Schoenus_	345p	4.94	0.81	10.6	3.0	2.8	1.4

3. *Extractable ions in peats*

The following ions (extractable with normal ammonium acetate solution) have been determined: H, Na, K, Ca and Mg. Iron is insignificant in the ombrotrophic sites but abundant in the minerotrophic fens, although only bivalent iron will be extracted. Appreciable amounts were seen in the extract from the Screeb fen sample, but no quantitative estimation was made.

The values for extractable cations are given in Table 5, and have been corrected for the ions in solution which were still present in the water remaining after the pressing, assuming that the residual water had the same content of dissolved ions as the expressed water. This correction is of little significance for ions other than Na. In the original samples with full water content, on average 46% of the Na is in aqueous solution (Table 6). When exchangeable ions are determined on ordinary fresh or dried samples (without expulsion of water) this part will be included.

Hydrogen ions predominate strongly on the exchange sites of the ombrotrophic peats, followed by Mg, Ca, Na and K in that order. In the one minerotrophic area (Screeb), adsorbed Mg, Ca and H ions are all about equal, between 20 and 25 meq per 100 g. The Garryduff area (marled in the past?) is unusual in exhibiting a predominance of Ca over Mg.

Adsorptive neutralization (sum of metallic cations as a percentage of the sum of total cations) ranges from 26 to 46% in the ombrotrophic sites, and reaches 71% in the minerotrophic site at Screeb. The four sites most strongly influenced by marine salts (Cl >25 ppm) range from 30 to 46%, in comparison to a range of 26 to 37% for the four sites least subject to marine influence (Cl <15 ppm).

Table 5. Ash, phosphorus, pH and exchangeable ions in peat. P is given as mg, and exchangeable ions (in N ammonium acetate) as meq. per 100 g of ash-free air-dry peat; dissolved ions have been subtracted from the latter (significant amounts only with respect to Na$^+$). Cap. signifies exchange capacity (sum of cations).

Location	Sample	Ash insol (%)	Ash sol (%)	P (mg per 100 g)	pH contact	pH extract	Neutralization (%)	Exchangeable ions (meq per 100 g)					
								Cap.	H$^+$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}
Western raised bogs without *Schoenus*													
Barnesmore	325p	2.0	1.2	30	3.9	-	26	42	31	0.7	0.7	3.5	5.7
Shronowen	337p	2.3	1.3	19	3.7	4.9	46	46	25	1.1	0.7	5.0	14.6
Drimina	331p	0.7	1.3	29	3.8	-	32	68	46	1.4	1.8	5.4	13.3
Easky	328p	0.8	1.4	21	3.6	-	-	-	-	1.2	1.3	5.9	10.0
Interior upland blanket bogs without *Schoenus*													
Slieve Bloom	342p	1.6	1.2	22	3.4	-	29	59	42	0.9	0.9	5.3	10.1
Mossy Bed	341p	1.4	1.5	40	3.7	-	37	49	31	0.9	0.8	4.8	11.2
Western coastal blanket bogs without *Schoenus*													
Owenteskiny	329p	1.5	1.3	20	3.8	5.0	38	68	42	1.5	0.8	6.9	16.7
Reenacollee	338p	1.2	1.5	11	3.9	5.1	34	44	29	0.7	1.0	4.0	9.4
Western coastal bogs with *Schoenus*													
Gowlan East	333p	2.2	1.0	14	3.7	-	35	57	37	2.1	0.8	5.3	11.9
Derreen	340p	1.0	1.3	19	3.9	-	30	64	45	1.9	0.9	5.2	11.4
Laghtanabba	332p	1.4	1.2	14	3.8	-	34	62	41	1.8	0.6	5.7	13.1
Inny Ferry	339p	1.7	1.1	14	3.9	4.9	39	54	33	1.4	0.7	5.2	14.0
Flushed minerotrophic sites (fen) with *Schoenus*													
Screeb	335p	3.3	6.0	36	4.8	-	71	69	20	1.4	0.9	21.7	24.5
Partly marled (?) raised bog in the interior lowland													
Garryduff with *Schoenus*	343p	1.3	1.5	16	3.8	-	39	89	54	2.2	0.9	18.9	12.6
Garryduff no *Schoenus*	345p	0.6	1.8	24	3.9	-	36	74	47	1.1	2.0	12.9	11.2

In Table 6 dissolved and exchangeable (adsorbed) ions are compared on the natural volume basis. The amount of dissolved ions in the water contained by one litre of peat is slightly lower than the corresponding value when calculated for one litre of water in the peat. The values for adsorbed ions per litre of peat are dependent on the content of solid matter (dry weight) of the peat and cannot be regarded as exact expressions of the intensity of adsorption (which is best expressed as ratio to the exchange capacity). The "adsorption ratios" of Table 6 therefore cannot be expected to be quite independent of the physical conditions in the peat, but nevertheless they give an idea of the ratio between the amounts of adsorbed and dissolved ions of each kind. The mean ratios are as follows: H, 2900; Na, 2.3; K, 12; Ca, 78; Mg, 111. The order of "adsorption ratios" for the major ions in ombrotrophic peat colloids in Ireland is therefore Na < K < Ca < Mg < H whereas in most other instances Ca > Mg. If the ratios were calculated from concentrations in free water instead of expressed, the values for K and Ca would be increased and the latter would probably surpass Mg. The most strongly adsorbed ion is H, despite its monovalence. The "dissolved fraction" of each ion of course varies inversely to the "adsorption ratio".

Similar values have been calculated by Malmer for peats from south-central Sweden (Malmer & Sjörs 1955 p. 70; the dissolved Na should be subtracted from the adsorbed Na, the values for adsorbed Mg in peat should be halved according to Malmer 1958). For an ombrotrophic peat site Malmer's ratios are: H 440, Na 4.5, K 150, Ca 250, and Mg 120. Malmer's values are computed from determinations in free water, and this will imply that the "adsorption ratio" will be lower for H and higher for Ca and particularly for K. The differences may also be due to the much greater acidity and lower ionic strength of the Swedish bog-water which will entail that the adsorbed fractions of metal ions should be higher, particularly for the least adsorbed metal ions (i.e., Na).

In a later work, Malmer (1960) has also calculated the ratio of ion uptake by plants to adsorption in peat. This ratio is particularly high for K. If calculated for equal volumes of plant tissue (of *Rhynchospora alba*) and ombrotrophic peat, it would be about 100 (about 15,000 for equal volumes of plant tissue and water). Thus K is taken up against an extremely strong gradient (which requires high selectivity and a great demand of energy). It surpasses by far the other metal ions studied in intensity of uptake relative to supply under these conditions of great deficiency. A ratio was also calculated by Malmer for K in the aerial standing crop of *Rhynchospora alba* and the top dm of the ombrotrophic peat substrate and found to be 0.64, i.e., nearly 40% of the total K was in the aerial standing crop. In some minerotrophic sites a still higher fraction of the K was in the aerial parts of the plants.

The present figures indicate only slightly easier K uptake for the plants than in Malmer's ombrotrophic site in Sweden. Mg uptake will be at least twice as easy, Ca uptake about equal, and Na uptake, if of any importance, about three times, if estimated from values for the peat. However, ion antagonism and other influences affect the uptake to a great extent. All of the ratios mentioned are tentative and highly variable.

4. *Ash contents*

The values for total ash (Table 5) are low, ranging from 2.0 to 3.6% in ombrotrophic sites. The minerotrophic Screeb fen peat showed 9.3% ash with a high content of iron. The colours of the ashes were also noted. Those from the Screeb fen were reddish-brown (brick-coloured). The ombrotrophic peat ashes ranged from grey-yellowish to grey-white, and were evidently very low in iron.

The acid-soluble ash (Table 5) ranged from 1.0 to 1.5% dry weight in ombrotrophic sites (a remarkably small variation) whereas the acid-insoluble fraction was much more variable 0.7–2.3% in the same sites). The Screeb fen had higher values in both respects: 6.0% soluble, 3.3% insoluble, iron occurring in both fractions (its solubility is evidently affected by the intensity of the ignition).

High values for the insoluble fraction of ombrotrophic peat ashes are likely to occur in dusty areas. Part of the insoluble ash consists of diatom shells which occur in considerable quantity in some of the ashes. Diatoms are known to be rare in more eastern ombrotrophic bogs (Du Rietz 1950a,b,c).

5. *Total phosphorus*

The total P values (Table 5) are very low. All ombrotrophic sites but one (Mossy Bed) have less than 30 mg P per 100 g of peat (0.03%), which is consistently lower than the total P in the Swedish ombrotrophic sites reported on by Sjörs (1961). Mossy Bed, Screeb fen (and a few minerotrophic peats from the English Lake District not reported here) have only slightly higher P values, and even these are lower than most values from Swedish bogs and poor fens.

Table 6. Dry weight, water content, and dissolved and exchangeable ions per litre of peat. The dissolved ions are calculated from the contents in the expressed water, and may be lower than in the natural state for H^+ and higher for Ca^{2+} and particularly for K^+. The "adsorption ratio" is given as the median (not mean!) ratio of exchangeable to dissolved ions, for each ion in all ombrotrophic samples (325–339, except 328). In the natural state, the "adsorption ratio" is probably lower for H^+ and higher for Ca^{2+}; it may even be several times higher for K^+. The "dissolved fraction" is the percentage of the amount of each ion which was in water solution during expression of water, calculated for the sample which is median with regard to "adsorption ratio".

Location	Sample	Dry weight (g)	Water content (g)	H^+ diss	H^+ exch	Na^+ diss	Na^+ exch	K^+ diss	K^+ exch	Ca^{2+} diss	Ca^{2+} exch	Mg^{2+} diss	Mg^{2+} exch
Western raised bogs without *Schoenus*													
Barnesmore	325p	98	813	0.010	29	0.38	0.7	0.07	0.6	0.05	3.3	0.06	5.4
Shronowen	337p	81	656	0.011	20	0.51	0.9	0.03	0.6	0.05	3.9	0.09	11.4
Drimina	331p	74	735	0.013	33	0.34	1.0	0.08	1.4	0.06	3.9	0.08	9.6
Easky	328p	68	-	-	-	-	-	0.8	-	0.9	-	4.0	-	6.7
Interior upland blanket bogs without *Schoenus*													
Slieve Bloom	342p	85	818	0.029	35	0.21	0.8	0.06	0.7	0.04	4.4	0.03	8.3
Mossy Bed	341p	58	790	0.017	17	0.23	0.5	0.05	0.4	0.05	2.7	0.06	6.3
Western coastal blanket bogs without *Schoenus*													
Owenteskiny	329p	92	861	0.006	37	0.66	1.4	0.06	0.7	0.08	6.2	0.10	14.9
Reenacollee	338p	70	733	0.004	19	0.25	0.5	0.06	0.7	0.02	2.8	0.06	10.4
Western coastal bogs with *Schoenus*													
Gowlan East	333p	75	858	0.009	27	0.48	1.5	0.04	0.6	0.05	3.8	0.13	8.6
Derreen	340p	82	853	0.007	36	0.61	1.5	0.07	0.8	0.08	4.2	0.12	9.1
Laghtanabba	332p	81	859	0.010	32	0.72	1.4	0.09	0.5	0.07	4.5	0.17	10.4
Inny Ferry	339p	56	728	0.017	18	0.70	0.8	0.07	0.4	0.06	2.8	0.19	7.6
"Adsorption ratio"				2900		2.1		12		66		105	
"Dissolved fraction" (%)				0.034		47		8.6		1.5		0.95	

Location	Sample	Dry weight	Water content	H^+ diss	H^+ exch	Na^+ diss	Na^+ exch	K^+ diss	K^+ exch	Ca^{2+} diss	Ca^{2+} exch	Mg^{2+} diss	Mg^{2+} exch
Flushed minerotrophic site (fen) with *Schoenus*													
Screeb	335p	34	850	0.003	6	0.49	0.5	0.09	0.3	0.13	5.0	0.08	7.5
Partly marled (?) raised bog in the interior lowland													
Garryduff with *Schoenus*	343p	81	835	0.017	42	0.45	1.7	0.04	0.7	0.09	14.8	0.08	9.9
Garryduff no *Schoenus*	345p	52	784	0.009	24	0.36	0.6	0.06	1.0	0.11	6.5	0.09	5.7

IV. DISCUSSION

1. *Marine influence upon water chemistry*

The major source for most of the ions in the surface waters of these bogs is the sea, as has been shown earlier (Gorham 1957c) for the Gowlan East site which is close to average for western Ireland. A comparison of marine ion supply to the dilute waters of inland sites (Mossy Bed, Slieve Bloom and Reenacollee) with supply to the more concentrated waters of extreme maritime sites (Derreen, Laghtanabba and Inny Ferry) is given in Table 7. In both types of site Na, K and Mg come mainly from the ocean. In the maritime sites about 70% of Ca and about 45% of SO_4 appear to come from the sea, while in the inland sites only about 40% Ca and 20% SO_4 appear marine in origin. Levels of non-marine Ca, Mg and SO_4 are rather similar in both maritime and inland waters, while non-marine Na and K appear distinctly higher in the maritime than in the inland samples, 0.5 as against 0.2 ppm Na and 0.3 as against 0.04 ppm K (cf. rain studies by Junge & Werby 1958, Eriksson 1960). It is possible that analytical errors may contribute to these differences, but other possibilities also exist, among them that of ionic separation, as for example in bursting sea-spray bubbles. Such ionic separations are known from laboratory studies (Bloch *et al*. 1966), as are separations owing to mixture of sodium chloride with sulphuric acid (Gorham 1958a), but their importance in nature is not at all clear, and they have not been taken into account in the calculation of Table 7.

The sea is also a very important source of ions to lake waters in western Ireland (Gorham 1957c), the following contributions being recorded for lakes on non-calcareous substrata (by the methods of Table 7): Na 95%, K 60%, Ca 8%, Mg 100%, HCO_3 1%, SO_4 40%. It is evident that the main soil contribution is derived from the weathering of $CaCO_3$, even in areas with very limited occurrences of limestone. Air-borne limestone dust may however have some influence (cf. Gorham 1957b).

The range of ionic concentrations in ombrotrophic waters of Ireland is compared in Table 8 with maximum and minimum values obtained elsewhere from ombrotrophic sites. The maximum values represent extremely oceanic sites in the Falkland Islands (Gorham & Cragg 1960), with one exception – the maximum pH value was recorded in Sutherland, northern Scotland. Minimum Na and Cl concentrations were observed in southern Poland (Tolpa & Gorham 1961), minimum K in north central England, minimum Mg in northern England and in Sweden (Witting 1948), minimum Ca in northern England, different parts of Scotland, and Sweden, and minimum SO_4 in central Scotland. Minimum pH was observed in northeastern England (Chapman 1964). If only European waters are considered, then the western Irish coastal bogs are richest in the marine ions Na, Mg and Cl, though the bogs of Sutherland, northern Scotland (Pearsall 1956), approach them closely in concentration.

Sparling (1967a,b) also has analyzed bog waters collected from Ireland between 1959 and 1961, and found essentially similar ranges for Cl (9–40 ppm) and Na (4–20 ppm). His K values reach a much higher maximum than ours (2.9 as against 1.2 ppm), as do his values for Ca (2.5 as compared to 1.1 ppm). His Mg data are also distinctly higher than ours (range 2–4 as against 0.8–2.8 ppm). Moreover, he shows a pH range for

Table 7. Marine* and non-marine ions in Irish bog waters subjected to different degrees of sea-spray influence.

	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cl (ppm)	SO_4 (ppm)
Inland sites						
Non-marine	0.2	0.04	0.3	0.3	-	5.6
Marine	5.4	0.2	0.2	0.7	9.7	1.4
% marine**	97	83	40	70	(100)	20
Extreme maritime sites						
Non-marine	0.5	0.3	0.3	0.4	-	5.4
Marine	17.9	0.7	0.7	2.2	32.3	4.5
% marine**	88	70	70	84	(100)	45

*Assuming all Cl from sea spray, and other marine ions in their sea-water proportions to Cl.
** Calculations based on one more decimal place than is presented.

ombrotrophic sites of about 4.25−4.95, as compared to 4.00−4.51 for the present study, in which values above 4.60 appeared to be associated with some degree of minerotrophic influence. Sparling also reported a distinct decline in pH away from the ocean, which is not evident in our data. The reasons for these discrepancies are not clear, but may involve a different judgment as to the boundary between ombrotrophic and minerotrophic conditions. Earlier, one of us (Gorham 1953) reported high contact peat values (mean pH 5.18) from blanket bog in Co. Mayo which was judged to be ombrotrophic. In view of the much lower contact pH values in the present study (3.4−3.9) it seems likely that the site was in fact subject to some minerotrophic influence.

2. *The acidity of the bog waters*

Irish bog waters tend on the whole to be less acid than those of more continental situations. One reason may be that air pollution by sulphuric acid, which affects many British bogs (Gorham 1958a,b), is not a problem over most of Ireland. Secondly, because of the high frequency of rainfall, oxidation of organic sulphur compounds to sulphuric acid during dry spells (Gorham 1956, 1958b, 1967) is not likely to be of as great importance as in more continental climates; moreover, any sulphuric acid produced will be liable to rapid dilution and washout by the frequent rains. In this connection, the data in Table 3 show no relation between H and SO_4 ions (even when the marine supply is subtracted), contrary to the case in Britain (Gorham 1958b, 1967), the Falkland Islands (Gorham & Cragg 1960) and Poland (Tolpa & Gorham 1961). Nor is there any clear correlation of SO_4 with the dissolved organic carbon of the Irish bog waters. In the highly coloured Polish bogwaters a clear correlation is evident between SO_4 and optical density[2] (in turn closely related to dissolved organic carbon as shown in Figure 3). This correlation suggests that in the Polish waters the high acidity is brought about largely by oxidative peat decomposition during dry weather, which releases both dissolved organic compounds and sulphuric acid at the same time.

Presumably much of the acidity in the Irish bogs is produced by a different mechanism – exchange of metallic cations brought down in rain for hydrogen ions adsorbed upon the surfaces of bog peats and plants (cf. Gorham & Cragg 1960, Clymo 1964, Gorham 1967). In this case acidity is essentially dependent upon the rate of plant growth and peat accumulation (Clymo 1963, 1964), which may vary greatly from site to site.

3. *Comparative chemistry of Irish and other bog peats*

Table 9 presents peat analyses from the Irish sites nearest to and farthest from the ocean (Inny Ferry and Slieve Bloom, respectively), from southwest Scotland (Silver Flowe, see Ratcliffe & Walker 1958), and from Sweden. Arrangement is in order of decreasing oceanicity, with Slieve Bloom and the Silver Flowe approximately similar and intermediate between the coastal Inny Ferry bog and the inland Swedish sites.

Table 8. The range of concentration in Irish bog waters as compared to minimum and maximum values observed for individual samples from ombrotrophic sites elsewhere.

	Minimum elsewhere	Minimum Ireland*	Maximum Ireland*	Maximum elsewhere
pH	3.12	4.00	4.51	4.64
Na (ppm)	0.12	5.1	21.9	63
K (ppm)	0.05	0.1	1.2	3.5
Ca (ppm)	0.3	0.3	1.1	3.2
Mg (ppm)	0.2	0.8	2.8	9.8
Cl (ppm)	0.2	9.5	34.0	120
SO_4 (ppm)	2.7	4.5	11.0	30

* Excluding Cloncreen and Garryduff as possibly altered sites.

---

[2] The optical density data were wrongly reported as determined in 10 cm cells, whereas in fact 1 cm cells were used. For comparison with the Irish data, therefore, Polish values should be multiplied by 10.

Marine influence is clearly seen in the high concentrations of adsorbed Na and Mg near the Irish coast (2.8 and l4 meq per 100g ash-free dry wt) as compared with the Swedish levels (0.6 and 4 meq per 100 g). Although Na exceeds Mg more than 8-fold in sea-water the importance of these two elements is reversed among the adsorbed metallic cations, because of the tendency for divalent ions to be much more strongly adsorbed than monovalent ions.

Adsorbed Ca and K show no definite trend, presumably because as marine supply declines inland there is a corresponding increase in the supply of these elements from soil-derived dust. Total ash content also shows no clear trend. As mentioned before, Swedish peats are distinctly higher in total P than are the British peats (see also Fraser 1933 for Scottish analyses and Walsh & Barry 1958 for additional Irish data).

Owing largely to the decline in Mg, the sum of adsorbed metallic cations declines inland. On the other hand the amount of adsorbed H ions increases greatly inland, as does the total adsorptive capacity of the peat. Presumably the inland peats are more highly decomposed and therefore more adsorptive than the maritime samples. Because of these opposing trends, adsorptive neutralization declines quite strikingly, from 41% in the oceanic Inny Ferry site to 13% in the Swedish bogs. The pH values of water extracts in these two areas are 4.9 and 4.0, respectively.

4. *Effect of pH and adsorptive neutralization upon bog vegetation*

The present study might be taken to corroborate the theory of Tansley (1939), Osvald (1949), Witting (1948), and others, that the main factor responsible for the floristic richness of western ombrotrophic bogs in Europe is a high content of metallic cations provided by the influx of atmospheric salts of marine origin, which in turn ameliorate the acidity of the western bog peats and improve their base status. However, it may be doubted whether the sea-spray factor is of major importance, since very high levels of Na, Mg and Cl have been recorded from more easterly coastal bogs (Sutherland in northern Scotland, Salta Moss in the English Lake District, see Pearsall 1956 and Gorham 1956) which do not attain the floristic richness of bogs on the Irish west coast. In the case of *S. nigricans*, a most interesting study by Sparling (1962, 1967a,b) has indicated that this species is extremely sensitive to aluminium toxicity, and its appearance in ombrotrophic habitats in western Ireland probably is due to the exceptionally low levels of aluminium ions there. (The odd occurrence on the Garryduff bog should be further examined in the light of this hypothesis.) Differences in the aluminium status of the bogs, largely a reflection of the atmospheric supply of soil dust particles, might also be responsible for the fact that *Schoenus* is absent from some western Irish bogs which show just as great a marine influence as those bogs in which it is present (see for example Shronowen and Meenaharnish in Table 3).

Whether aluminium toxicity can account for the other floristic differences between oceanic and continental ombrotrophic bogs remains to be established. Certainly Sparling's (1967a,b) experiments indicate that aluminium toxicity is unlikely to affect the distribution of *Molinia caerulea*, which increases greatly westward in its abundance on ombrotrophic bogs. Sparling (1967a,b) has provided numerous data elaborating an earlier

Table 9. Adsorbed cations, adsorptive neutralization, ash and phosphorus in air-dry and ash-free ombrotrophic peats from northern Europe.

	Na	K	Ca	Mg	Metal cations	H	Total cations	Neutralization	Ash	P
				(meq per 100 g)				(%)	(%)	(%)
Inny Ferry	1.4	0.7	5.2	14.0	21.3	33	54.3	39	2.8	0.014
Slieve Bloom	0.9	0.9	5.3	10.1	17.2	42	59.2	29	2.8	0.022
Silver Flowe, SW Scotland[1]	1.4	0.4	4	6	12	56	68	18	4	0.018
Sweden, median values[1]	0.6	1	6	4	12	80	92	13	3	0.05

[1]H. Sjörs (unpublished).

suggestion (Gorham 1953) that the exceptional mildness of oceanic climates may be an important factor in bog ecology, and although Sparling's experimental studies indicate that this is not the main factor controlling *Schoenus* distribution, it may yet be of significance for other members of the bog flora. Further to the climatic data presented by Sparling, it is interesting to note that the annual range of temperature in Britain declines markedly from east to west, with ombrotrophic and floristically rich *Schoenus-Molinia* bogs limited to the extreme western parts of Kerry and Connemara where the annual temperature range is less than 8.9 °C (16 °F) (Figure 5). They have not been reported (so far as we know) from Donegal and the Scottish mainland, where the annual temperature range exceeds this value; but are probably present in the Hebrides of Scotland, where one of us (E.G. unpublished) has recorded contact pH values down to 4.0 from *Schoenus* sites on South Uist (kindly sampled by Dr. Brian Hopkins). It is also interesting to observe that where the annual temperature range is greater than 13.3 °C (24 °F), in south-eastern England, *Schoenus* is most commonly found in the highly calcareous sites to which it is apparently restricted on the European continent.

5. *The algae of the Irish bogs*

Algal samples taken from bog hollows and pools during this excursion were examined by Dr. J.W.G. Lund, who has kindly allowed us to present the records in Table 10 and his comments upon them.

Figure 5. Isotherms for the ranges between the mean temperatures of the warmest and coldest months (redrawn from Tansley 1939).

The reason for taking the samples was to see whether the microflora of the western Irish bogs resembled the macroflora in having a number of species present which in Scandinavia would be considered as minerotrophic fen indicators (Du Rietz 1950a,b,c). The results indicate that this is the case, the first ten species in Table 8 being regarded by Du Rietz as restricted to fens in Sweden. The next eight species also appear from the accounts of Du Rietz to be so restricted, though his statements are less definite on this point. The nineteenth and twentieth species (*Chroococcus turgidus* and *Frustulia rhomboides* v. *saxonica*) are unusual in being fen indicators in east Sweden while extending into ombrotrophic habitats in south-west Sweden and in Britain. Certain species of the macroflora behave similarly (Gorham 1956). The last eleven species occur on ombrotrophic bogs in both Sweden and Ireland.

The Irish samples lack the diatoms[3] characteristic of Swedish fens (except *Pinnularia* at Meenaharnish) and all the *Closteria* typical of iron ochre areas.

As compared with samples collected earlier from English bogs (Tregaron, Moor House, Malham Tarn) by one of us (E.G.) and examined by Dr. Lund, the Irish samples are different in containing species of *Euastrum*, *Xanthidium*, *Micrasterias*, *Gymnozyga*, *Hyalotheca*, *Hapalosiphon* and *Stigonema*. *Chroococcus* and *Frustulia* were both abundant in the English bogs at Moor House and Tregaron. Among other species recorded on British bogs (Gorham 1956) are *Microthamnium kützingianum*, *Netrium digitus*, *Tetmemorus granulatus* and *T. laevis*, all minerotrophic fen indicators in Sweden.

Euastrum crassum v. *scrobiculatum* and *Xanthidium smithii* appear to be distinctly western in their distribution over the British Isles.
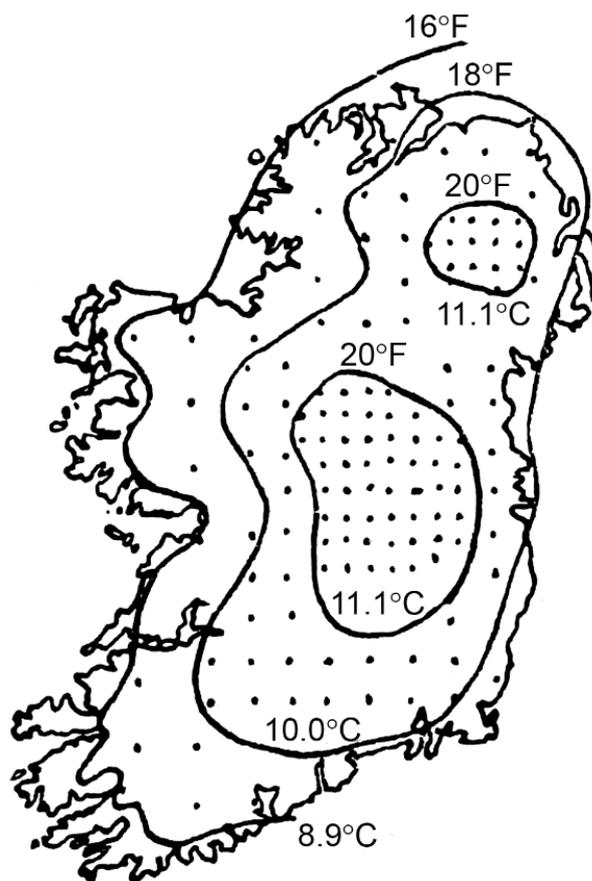
---

[3] Some of the peat ashes, however, contained numerous diatom shells in the insoluble fraction.

Table 10. Algae from hollows, and large pools (Barnesmore and Easky), in Irish bogs. Identified by J.W.G. Lund, va = very abundant, a = abundant, f = frequent, o = occasional, r = rare, vr = very rare.

Algae	*Schoenus* bogs			Bogs without *Schoenus*				
	Laghta-nabba	Gowlan East	Derreen	Meena-harnish	Creevo-sheedy	Shron-owen	Barnes-more	Easky
Euastrum ampullaceum	vr				r			r
Cosmarium contractum v. *ellipsoideum*	r							
Tetmemorus laevis	r		vr					
Tetmemorus granulatus			vr	r		f	r	o-f
Netrium digitus				o	vr			r
Xanthidium armatum					vr			vr
Euastrum crassum v. *subscrobiculatum*					vr		vr	vr
Micrasterias truncata					vr			vr
Hyalotheca dissiliens					vr		vr	
Pinnularia sudetica				f				
Xanthidium smithii					vr		vr	vr
Xanthidium variabile	vr							
Micrasterias jenneri v. *simplex*					vr		vr	vr
Euastrum elegans	r				o			
Eurastrum bidentatum	vr				vr			
Gymnozyga moniliformis							r	vr
Hapalosiphon hibernicus/ intricatus	a	a			o		o	vr
Stigonema ocellatum		o	o					
Chroococcus turgidus	vr			vr				
Frustulia rhomboides v. *saxonica*	r	o	r	o-f	r	o	r-o	r
Oocystis solitaria	o		vr	r-o	o		o	r
Coccmyxa sp.		f						
Oedogonium sp.	o				o-f	vr	r	f
Binuclearia tatrana	r	r			vr		r	
Chlorobotrys sp.	f		r	o	r	o	o	a
Dinobryon sertularia	r							
Merismopedia punctata	vr							
Zygogonium ericetorum	r		f		va	o	a	a
Cylindrocystis brebissonii	r	r-o		r			vr	
Netrium oblongum							vr	
Penium silvaenigrae								vr

ACKNOWLEDGEMENTS

Addition by H. Rydin: I thank R.S. Clymo who encouraged me to publish this old manuscript, Bengt Carlsson who redrew the maps, and the reviewers who suggested several clarifications in the original text.

REFERENCES

Alvsaker, E. (1943) Feilkilder ved elektrometriske pH-målinger i jord (Error sources in electromagnetic pH measurements). *Bergens Museums Årbok. Naturvitenskapelig rekke*, 9, 1–31 (in Norwegian).

Bellamy, D.J. (1959) Occurrence of *Schoenus nigricans* L. on ombrogenous peat. *Nature*, 184, 1590–1591.

Bloch, M.R., Kaplan, D., Kertes, V., Schnerb, J. (1966) Ion separation in bursting air bubbles: an explanation for the irregular ion ratios in atmospheric precipitations. *Nature*, 209, 802–803.

Boatman, D.J. (1957) An ecological study of two areas of blanket bog on the Galway-Mayo Peninsula, Ireland. *Proceedings of the Royal Irish Academy*, 59B, 3, 29–42.

British Vegetation Committee (1908) Report of the B.V.C.'s excursion to the west of Ireland. *New Phytologist*, 7, 253–260.

Brown, I.C. (1943) A rapid method of determining exchangeable hydrogen and total exchangeable bases of soils. *Soil Science*, 56, 353–357.

Chapman, S.B. (1964) The ecology of Coom Rigg Moss, Northumberland: II. The chemistry of peat profiles and the development of the bog system. *Journal of Ecology*, 52, 315–321.

Clymo, R.S. (1963) Ion exchange in *Sphagnum* and its relation to bog ecology. *Annals of Botany*, 27, 309–324.

Clymo, R.S. (1964) The origin of acidity in *Sphagnum* bogs. *Bryologist*, 67, 427–431.

Connolly, G. (1930) The vegetation of southern Connemara. *Proceedings of the Royal Irish Academy*, 39B, 203–231.

Doyle, G.J. (1982) The vegetation, ecology and productivity of Atlantic blanket bog in Mayo and Galway, western Ireland. In: White, J. (ed.) *Studies in Irish Vegetation*, Royal Dublin Society, Dublin, 147–164.

Du Rietz, G.E. (1949) Huvudenheter och huvudgränser i svensk myrvegetation (Main units and main limits in Swedish mire vegetation). *Svensk Botanisk Tidskrift*, 43, 274–309 (in Swedish with English summary).

Du Rietz, G.E. (1950a) Phytogeographical mire excursion to the Billingen-Falbygden district in Västergötland (southwestern Sweden). *Seventh International Botanical Congress Stockholm 1950 Excursion Guide*, A II b 1, 1–54.

Du Rietz, G.E. (1950b) Phytogeographical mire excursion to northeastern Småland and Östergötland. *Seventh International Botanical Congress Stockholm 1950 Excursion Guide*, A II b 2 (second part), 1–22.

Du Rietz, G.E. (1950c) Phytogeographical excursion to the Ryggmossen mire near Uppsala. *Seventh International Botanical Congress Stockholm 1950 Excursion Guide*, A II b 3, 1–24.

Du Rietz, G.E. (1954) Die Mineralbodenwasser-zeigergrenze als Grundlage einer natürlicher Zweigliederung der nord- und mitteleuropäischen Moore (The mineral soil water indicator boundary as the basis for a natural division of the northern and central European mires). *Vegetatio*, 5–6, 571–585 (in German).

Egnér, H., Eriksson, E. (1955) Current data on the chemical composition of air and precipitation. *Tellus*, 7, 134–139.

Emanuelsson, A., Eriksson, E., Egnér, H. (1954) Composition of atmospheric precipitation in Sweden. *Tellus*, 6, 261–267.

Eriksson, E. (1952) Composition of atmospheric precipitation. *Tellus*, 4, 215–232, 280–303.

Eriksson, E. (1955) Air borne salts and the chemical composition of river water. *Tellus*, 7, 243–250.

Eriksson, E. (1959a) Atmosfärens kemi (Chemistry of the atmosphere). *Svensk Kemisk Tidskrift*, 71, 15–32 (in Swedish).

Eriksson, E. (1959b) Tillförseln av näringsamnen i luft till mark och vegetation (Supply of nutrients in air to soil and vegetation). *Växtnäringsnytt Stockholm*, 15(5), 1–6 (in Swedish).

Eriksson, E. (1959c) On the geochemistry of chloride and sulfate. *American Geophysical Union Monographs*, 3, 124–127.

Eriksson, E. (1959d) The yearly circulation of chloride and sulphur in nature: meteorological, geochemical and pedological implications, part I. *Tellus*, 11, 376–403.

Eriksson, E. (1960) The yearly circulation of chloride and sulphur in nature: meteorological, geochemical and pedological implications, part II. *Tellus*, 12, 63–109.

Euro+Med Plantbase (2006+; continuously updated) Euro+Med PlantBase - the information resource for Euro-Mediterranean plant diversity. Online at: http://www.europlusmed.org, accessed 15 Nov 2024.

Fraser, G.K. (1933) *Studies of Certain Scottish*

Moorlands in Relation to Tree Growth. Bulletin No. 15, Forestry Commission, London, 112 pp.

Gorham, E. (1950) Variation in some chemical conditions along the borders of a *Carex lasiocarpa* fen community. *Oikos*, 2, 217–240.

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

Gorham, E. (1955) On the acidity and salinity of rain. *Geochimica et Cosmochimica Acta*, 7, 231–239.

Gorham, E. (1956) On the chemical composition of some waters from the Moor House Nature Reserve. *Journal of Ecology*, 44, 377–384.

Gorham, E. (1957a) The chemical composition of lake waters in Halifax County, Nova Scotia. *Limnology and Oceanography*, 2, 12–21.

Gorham, E. (1957b) The chemical composition of rain from Rosscahill in County Galway. *Irish Naturalists Journal*, 12, 1–4.

Gorham, E. (1957c) The chemical composition of some western Irish fresh waters. *Proceedings of the Royal Irish Academy*, 58, B 11, 237–243.

Gorham, E. (1958a) The influence and importance of daily weather conditions in the supply of chloride, sulphate and other ions to fresh waters from atmospheric precipitation. *Philosophical Transactions of the Royal Society B*, 241 (no. 679), 147–178.

Gorham, E. (1958b) Free acid in British soils. *Nature*, 181, 106.

Gorham, E. (1960) Note on the pH of fresh soils and soil solutions. *Ecology*, 41, 563.

Gorham, E. (1967) Some chemical aspects of wetland ecology. In: Butler, J., MacFarlane, I.C. (eds.) *Proceedings of the 12th Muskeg Research Conference* (Calgary, 19–20 May 1966), Technical Memorandum 90, Associate Committee on Geotechnical Research, National Research Council of Canada (NRC), 20–38.

Gorham, E., Cragg, J.B. (1960) The chemical composition of some bog waters from the Falkland Islands. *Journal of Ecology*, 48, 175–181.

Heron, J., Mackereth, F.J.H. (1955) The estimation of calcium and magnesium in natural waters, with particular reference to those of low alkalinity. *Internationale Vereinigung für Theoretische und Angewandte Limnologie: Mitteilungen*, 5, 1–7.

Junge, C.E., Werby, R.T. (1958) The concentration of chloride, sodium, potassium, calcium and sulfate in rain water over the United States. *Journal of Meteorology*, 15, 417–425.

Keddy, E. (2024) *Fundamentals of Oceanography*. LibreTexts Projects (Geosciences). Online at: https://LibreTexts.org, accessed 12 Oct 2024.

Lüdi, W. (1952) Die Standortsstetigkeit einiger irischer Gewächse aus mitteleuropäischem Blickpunkt gesehen (The location stability of some Irish plants seen from a Central European perspective. *Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rübel, Zürich*, 25, 201–213 (in German).

Mackereth, F.J.H. (1955) Rapid micro-estimation of the major anions of freshwater. *Proceeding of the Society for Water Treatment and Examination*, 4, 27–42.

Mackereth, F.J.H. (1963) *Some Methods of Water Analysis for Limnologists*. Scientific Publication No. 21, Freshwater Biological Association, Ambleside, Westmorland UK, 70 pp.

Malmer, N. (1958) Notes on the relation between the chemical composition of mire plants and peat. *Botaniska Notiser*, 111, 274–288.

Malmer, N. (1960) Some ecologic studies on lakes and brooks in the South Swedish uplands. *Botaniska Notiser*, 113, 87–116.

Malmer, N., Sjörs, H. (1955) Some determinations of elementary constituents in mire plants and peat. *Botaniska Notiser*, 108, 46–80.

Newbould, P.J. (1960) The ecology of Cranesmoor, a New Forest valley bog. I. The present vegetation. *Journal of Ecology*, 48, 361–383.

Newbould, P.J., Gorham, E. (1956) Acidity and specific conductivity measurements in some plant communities of the New Forest valley bogs. *Journal of Ecology*, 44, 118–128.

Osvald, H. (1949) *Notes on the Vegetation of British and Irish Mosses*. Acta Phytogeographica Suecica 26, Almqvist & Wiksells Boktryckeri AB, Uppsala, 62 pp.

Pearsall, W.H. (1938) The soil complex in relation to plant communities. III. Moorlands and bogs. *Journal of Ecology*, 26, 298–315.

Pearsall, W.H. (1956) Two blanket bogs in Sutherland. *Journal of Ecology*, 44, 493–516.

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

Proctor, M.C.F. (2008) Water analyses from some Irish bogs and fens, with thoughts on 'the *Schoenus* problem'. *Biology and Environment (Proceedings of the Royal Irish Academy)*, 108B, 81–95.

Ratcliffe, D.A., Walker, D. (1958) The Silver Flowe, Galloway, Scotland. *Journal of Ecology*, 46, 407–445.

Rossby, C.G., Egnér, H. (1955) On the chemical climate and its variation with the atmospheric circulation pattern. *Tellus*, 7, 118–133.

Sjörs, H. (1961) Some chemical properties of the

24

humus layer in Swedish natural soils. *Kungliga Skogshögskolans Skrifter*, 37, 1–51.

Sparling, J. (1962) Occurrence of *Schoenus nigricans* L. in the blanket bogs of western Ireland and north-west Scotland. *Nature*, 95, 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.

Tamm, C.O. (1958) Die Mineralstoffquellen der Pflanze (The mineral sources of the plant). *Handbuch der Pflanzenphysiologie*, 4, 233–242 (in German).

Tansley, A.G. (1939) *The British Islands and their Vegetation*. First edition, Cambridge University Press, Cambridge UK, 930 pp.

Tolpa, S., Gorham, E. (1961) The ionic composition of waters from three Polish bogs. *Journal of Ecology*, 49, 127–133.

von Post, L. (1937) The geographical survey of Irish bogs. *Irish Naturalists' Journal*, 6(9), 210–227.

von Post, L., Granlund, E. (1926) Södra Sveriges torvtillgångar I (Peat assets in southern Sweden I). *Sveriges Geologiska Undersökning. Serie C, Avhandlingar och Uppsatser*, 335, 1–127 (in Swedish).

Walsh, T., Barry, T.A. (1958) The chemical composition of some Irish peats. *Proceedings of the Royal Irish Academy*, 59B, 15, 305–328.

Witting, M. (1948) Preliminärt meddelande om fortsatta katjonsbestämningar i myrvatten sommaren 1947 (Preliminary report on continued cation determinations in mire-waters in the summer of 1947). *Svensk Botanisk Tidskrift*, 42, 116–134 (in Swedish).

_____

Author for correspondence: Professor Håkan Rydin, Department of Ecology and Genetics, Uppsala University, Norbyvägen 18D, SE-752 36 Uppsala, Sweden.   Tel: +46 70 331 6234;   E-mail: hakan.rydin@ebc.uu.se; orcid: https://orcid.org/0000-0002-7582-3998

SUPPLEMENTARY MATERIAL

An Excel file containing the data from Tables 3–6 is available for separate download.