# Using water chemistry to define ecological preferences within the moss genus *Scorpidium,* from Wales UK.

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**Abstract**

Three *Scorpidium* species; *S. scorpioides, S. cossonii* and *S. revolvens* are often associated with habitats of high conservation value. This is the first attempt to define the chemical niches of these *Scorpidium* species in Wales (UK) and allows us to compare to earlier European datasets. Water chemistry from sixteen locations was analysed from direct squeezing of mosses from a total of 77 spots and the principal water supply, e.g. springs and seepages. Spherical k-means clustering suggests there are two distinct groups in the dataset; one characterised by *S. cossonii* and another by *S. revolvens*, associated with differences in pH and Electric Conductivity (EC) of the habitat. The Wales habitats have higher pH and EC than Scandinavian habitats of the species, which could potentially be a result of different pollution histories or species compositions of the areas, the latter leading to different realised niches along the mineral poor to rich gradient. It is hoped that a better understanding of the chemical niches will support site managers and environmental regulators to make evidence-based decisions to protect these species and their habitats.

**Keywords:** cluster analysis, petrifying springs, Habitats Directive

# Introduction

Humans have long since influenced European nature both directly, through exploitation and management of different resources (e.g., Antrop, 2004; Kaplan *et al.*, 2009; Price, 2000) and indirectly, as shown by the ongoing climate warming (Met Office, UK's National Meteorological Service; https://www.metoffice.gov.uk/; accessed 2019.01.05). To protect our environment, including its biodiversity, we need methods and indicators that provide warnings when we come close to irreparable damage. A relatively rare European habitat that could potentially be negatively influenced by climate change-related effects, such as higher temperatures and increased evapotranspiration on the one hand, and increased precipitation on the other, is the European Habitats & Species Directive habitat ‘H7220 Petrifying springs with tufa formation (Cratoneurion)’. Member states, including the

UK at the time of writing, are required to report on the conservation status of these habitats to the European Commission.

Species of the genus *Scorpidium* (Calliergonaceae) are often, but not exclusively associated with European Habitats & Species Directive habitat H7220, and Scandinavian studies (Kooijman & Hedenäs, 1991; Hedenäs & Kooijman, 1996; Tahvanainen, 2004) suggest that they are useful as indicators of its status. *Scorpidium* includes three species, *S. scorpioides* (Hedw.) Limpr., *S. cossonii* (Schimp.) Hedenäs and *S. revolvens* (Sw.ex Anonymo) Rubers (Hedenäs, 1989). The genus occurs globally from temperate to arctic areas and in both the northern and southern hemispheres (Table 1). Water chemistry has been used as a useful tool to distinguish habitat preferences within the genus in Scandinavia (Kooijman & Hedenäs, 1991). This methodological approach has been applied in different ecological studies of aquatic bryophytes (Kooijman et al., 1994; Ceschin et al., 2012) and its possible applicability to sites in the UK with *Scorpidium* species is of interest to both environmental regulators and site managers for whom an improved understanding of the habitat requirements, and risks, will better inform decisions regarding management and conservation of these sites.

Field and laboratory observations (Kooijman & Hedenäs, 1991; Tahvanainen, 2004) show that *S. revolvens* occurs in a much narrower range of pH and conductivity than *S. scorpioides* and *S. cossonii* which are more often associated with calcium-rich spring-influenced habitats. Sites with *S. scorpioides* and *S. cossonii* are characterised by relatively high pore water Ca concentrations (Mettrop *et al.*, 2018) while *S. revolvens* is absent from calcium-rich sites (Hedenäs, 2003a). Acidification and eutrophication can have a negative effect and has resulted in the decrease of *S. scorpioides* populations in the Netherlands (Kooijman, A. 1992 and Kooijman & Westhoff, 1995). A recent study of Dutch sites (Paulissen, et. al., 2016) found that rich fens, i.e., mineral-rich fens that are often, but not always species-rich and include certain indicator species, such as *S. cossonii* (Joosten et al., 2017; Rydin et al., 1999), are at risk of rapid transition to poor fens by increased deposition of reduced nitrogen. Increased ammonium levels are shown to be directly toxic to *Scorpidium*, while *Sphagnum* was not affected. In addition, nitrogen (in particular nitrate) can indirectly influence moss growth through promoting vascular plants and Covuer et al. (2016) has highlighted the negative impact of eutrophication (nitrite and particularly phosphate) on the H7220 habitat in Belgium. *Scorpidium scorpioides* and *S. cossonii* sites in Sweden and the Netherlands are shown to be Ca-rich and Fe-poor with low associated P-availability (Mettrop et al., 2018); this further highlights the potential vulnerability of these sites to the process of eutrophication. Growth experiments comparing Canadian and Dutch *S. scorpioides* (Vitt et. al., 1993) found that Canadian plants respond best when grown in extreme-rich fen waters, while plants from the Netherlands respond best in waters from moderate-rich fens and in nutrient enhanced conditions. These authors suggested that this could be a result of ecotypic differentiation.

All these studies show that water chemistry is a critical factor affecting *Scorpidium* species and has important implications for the conservation of rich fens. Here we present the first Wales (taken to represent UK) dataset of water chemistry characterising the different chemical niches of the three *Scorpidium* species and compare this data set with data previously compiled in Sweden (Kooijman & Hedenäs, 1991). We ask whether all three species occur under similar water chemistry conditions at localities in Wales, and evaluate whether conditions differ between Wales and Sweden.

# Materials and methods

*Scorpidium* sites were identified from wetlands within designated sites (e.g. Special Areas of Conservation, National Nature Reserves), from the British Bryological Society (BBS) database and from expert local knowledge. The location, site extent, altitude and geology, as well as other characteristics and sampling years for the 16 sites included within this study are shown in Figure 1 with other key study areas in Sweden, the Republic of Ireland, the Netherlands, Denmark and Finland illustrated on the inset map. Bryophytes commonly associated with springs and flushes (such as *Scorpidium* species) can often occur towards the margins of areas of flushed vegetation or as part of hummocky vegetation that is partly raised above the flushing water (i.e., away from the main water supply to a site). To reflect this, water samples were collected both directly from the main water supply and by squeezing stands of the three *Scorpidium* species that represented the different habitats found by visual inspection at each locality. Seventy seven samples were collected from 16 sites with a range of between 1 and 9 samples per site reflecting both size and structural complexity of individual sites. Water chemical sampling was undertaken in January 2015 and 2016.

First a sample was obtained from as close to the water source as possible. If the flow was too diffuse to allow collection directly into a bottle, we used a 50 ml syringe to collect water. Field parameters with temperature (°C), pH and electrical conductivity, (µs/cm) (EC) were measured using a 'YSI$^{TM}$ Professional' field meter. Samples for spring water were filtered on site using a 0.45 µm filter and stored in two 30 mL Nalgene bottles. For sampling of individual stands of *Scorpidium* species, samples were collected as described and the moss was squeezed using a stainless steel potato ricer into a stainless steel jug, allowing sufficient depth of water from which to measure field parameters. Many of these samples, from now onwards called 'moss water', were too turbid to filter in the field. In these cases, water samples were collected in two 30 mL Nalgene bottles and returned to the lab to settle and be filtered through a 0.45 µm single use membrane filter (Sartorius-Minisart®) into 30 mL Nalgene bottles stored at 1-5 °C prior to conductivity and IC analysis. The sample for ICP-MS analysis was fixed in 1% $HNO_3$ and stored at 1-5 °C (see below). pH and alkalinity measurements were undertaken on unfiltered un-acidified samples. pH was measured in the field and also in the lab, potentiometrically by immersing a combined multi-probe electrode (XC-161) into the solution. Titration was performed using 0.005 M sulphuric acid prepared from VWR Prolabo Convol Normadose 0.1N solution made up to volume with freshly prepared MilliQ. Analysis of major anions, including $Ca^{2+}$, $Na^{+}$, $Mg^{2+}$, $K^{+}$, $SO_4^{2-}$, $Cl^{-}$, $HCO_3^{-}$ $F^{-}$, $NO_2^{-}$, $Br^{-}$, $NO_3^{-}$ and $HPO_4^{2-}$, were undertaken on a Dionex ICS5000 Ion Chromatograph system (S/N 10060887) controlled by the Chromeleon Software (version 7). Ionic balances were performed for each sample. Fifty seven major and trace elements in the core waters were analysed on an Agilent 7500cx series, quadrupole inductively coupled plasma mass spectrometer (ICP-MS) with an ORS, in combination with a CETAC autosampler. The ICP-MS instrument was calibrated at the beginning of every analytical run using at least three standards and a blank for each trace element and three standards and a blank for major elements.

Relatively pure stands of *Scorpidium* species occurring within each site were identified and selected in the field. Following squeezing to obtain a moss water sample the squeezed moss sample was collected and dried. Once dried, the sample was carefully examined and the small percentage of other bryophytes sometimes present estimated and recorded. For these occasional mixed stands, associated species have been annotated against the relevant chemical analysis. All samples were retained as a reference collection and all *S. cossonii* and *S. revolvens* specimens were checked microscopically following Hedenäs (1989). Other species occurring at sites were also recorded with an estimate of abundance using the DAFOR scale. Using ArcView, a Geographical Information System (GIS), elevation to the nearest 5 maOD (above ordnance datum) and geological information (British Geological Surveys‘ DigiMap’ 1:50,000 scale bedrock and superficial mapping) was assigned to each site.

### Statistical methodology

Four moss water chemistry parameters, EC, pH, Ca and $HCO_3^-$, were compared between Wales and Sweden for each of the three species. We used a preliminary ANOVA to check that the residuals were approximately normally distributed. This being the case, we compared our data sets for Wales and Sweden using ANOVA in the program STATISTICA 13 (Dell Inc., 2015).

From the full water chemistry dataset for Wales, only major ions and trace elements with average concentration > 0.2mg/L were considered relevant for statistical analysis. This included all the major ions and the trace element Mn. In addition to standard calculations of standard deviation (SD), standard error (SE), t-test (t), full statistical analysis of Welsh data was undertaken using a spherical k-means clustering computer programme (Hill et. al., 2013).

## Results

Following Kooijman & Hedenäs (1991), elevation and water chemistry data (moss water) of 124 samples from Sweden were compared against 77 samples from Wales. Water chemistry comprised seven major ions (Ca, Mg, $HCO_3^-$, $SO_4^{2-}$, $Cl^-$, Na, K). The same relationship between the three *Scorpidium* species and water chemistry (as described by Kooijman & Hedenäs, 1991) was seen with Welsh data, where *S. revolvens* occurs in a much narrower range of pH and conductivity than the other 2 species. Figure 2 shows this relationship between pH and EC for all Swedish and Welsh samples.

Swedish and Welsh data show ecological separation of *S. cossonii* and S. *revolvens* in terms of water chemistry. *Scorpidium cossonii* is associated with water that has significantly higher concentrations of $HCO_3^-$, pH, Ca, Mg and EC while conversely*, S. revolvens* is associated with significantly lower concentrations of these. Although both Swedish and Welsh data shows clear ecological separation of *S. cossonii* and S. *revolvens* in terms of water chemistry, Welsh *Scorpidium* sites occur at higher, pH (all species) and EC (*S. revolvens*), levels than found at Swedish sites (Table 2).

## Statistical Results for Welsh sites

Statistical analysis was undertaken on 77 water samples from 16 Welsh sites for pH, EC, major ions and trace elements occurring at a mean concentration > 0.2 mg/L. Samples comprised both flush water and moss water. Moss water samples comprise a pure bryophyte species stand or occasionally up to as many as five separate bryophyte species. A summary of moss water quality data is provided in Table 3. There are significant differences between the moss water chemistry of *Scorpidium cossonii* and *Scorpidium revolvens* sites (SE and t value) with respect to $HCO_3^{-,}$ pH, Ca, Mg and EC. These conclusions further support the findings of Kooijman & Hedenäs (1991). We could not demonstrate statistical difference between moss and flush water for *Scorpidium* species.

## Statistical species clustering

Using a **s**pherical k-means clustering analysis of combined site and water chemistry data, Welsh sites were separated into two and three species clusters. The most distinct separation was found with a two site/species cluster (Table 4), one group characterised by *Scorpidium cossonii* and a second group characterised by *Scorpidium revolvens.* A summary of the differences in water chemistry between these two groups is provided by Table 5.

Group 1 (*S. cossonii)* is associated with water with higher concentrations of Ca, Mg, frequent *Palustriella falcata, Campylium stellatum, Bryum pseudotriquetrum,* occasional *Scorpidium scorpioides* and are never associated with *Sphagna.* Group 2 (*S. revolvens)* is associated with water with lower concentrations of Ca, Mg, more closely associated with *Sphagna* (most typically *S. denticulatum*) and occasional *Sarmentypnum exannulatum*.

# Discussion

The *Scorpidium* habitats in Wales fit within the habitat parameter ranges reported for the species (Table 1) and, like in Scandinavia (Kooijman & Hedenäs, 1991), the habitats of *S. cossonii* and *S. revolvens* differ from each other in their water chemistry. The latter is further reflected in that many Welsh group I sites are associated with historic lime quarrying activities and can be large in extent (0.06-0.08 ha) while Welsh Group 2 sites tend to be natural and typically small in extent (0.0004-0.008 ha). Interestingly, all three *Scorpidium* species occur at higher pH and sometimes EC (*S. revolvens*) in Wales than in Sweden. Our information cannot fully explain this discrepancy, but several factors can potentially be involved. The Swedish localities have a somewhat lower buffering capacity than the Welsh ones (e.g., less Ca and $HCO_3^-$, Table 2). Less well-buffered *Scorpidium* sites are more sensitive to acidification (Kooijman, 2012) and potentially eutrophication (e.g., in relation to associated P-availability as highlighted by Mettrop *et al.*, 2018) and possibly less well-buffered Welsh sites have vanished due to higher atmospheric pollution levels in Wales than in Sweden. If the sites in Wales and Scandinavia have different species compositions, potentially resulting from different species pools or climates, this could also skew the realised niches of the *Scorpidium* species in different directions along the mineral poor to rich gradient (cf., Shaw, 1985; Stieperaere et al., 1997). Differences in geology or genetic set-up of the species (see Hedenäs, 2009; Kophimai, 2013) between the two areas could also affect the habitat preferences of the species. However, studies of ITS and *rpl*16 suggest that *S. cossonii* samples from the British Isles do not differ genetically from populations in Scandinavia (Hedenäs, 2009). Obviously, more detailed studies are required to find out which explanation or combination of explanations are most likely. The cluster analysis of associated bryophytes shows that *S. cossonii*, together with *S. scorpioides*, and *S. revolvens* belong to two rather different fen moss communities. The respective species associations lend statistical support to earlier observations on the ecology of the *Scorpidium* species in Britain (as summarised by Blockeel 2000). The corresponding water chemistry data suggests that this factor is likely decisive in explaining which species occur in the respective associations. However, the present analysis is limited to Welsh sites and to verify the general validity of the two moss associations identified, the results should be compared with the species growing with *Scorpidium* at sites across a wider geographical area.

This study could not demonstrate a statistical difference between moss and flush water for the *Scorpidium* species. In hindsight, we believe that both more frequent and detailed water sampling are required to fully test if temporal and microtopographic site variation explain this lack of difference. An investigation of the water chemistry of *Scorpidium*-rich fens in Finland (Tahvanainen, 2005) found variation in pH only at a microtopographic level (between capillary-held and surface water), and that this variation had a diurnal pattern probably relating to production and consumption of $CO_2$.

# Conclusions

- This study confirms the findings of Kooijman & Hedenäs (1991) that two species of *Scorpidium* (*S. cossonii* and S. *revolvens)* occupy different ecological niches in terms of water chemistry and that their methodology is repeatable.
- The ecology of Welsh *Scorpidium* sites is better understood following statistical cluster analysis of associated bryophytes species.
- This is the first detailed water chemistry dataset for Wales (and the UK) *Scorpidium* sites and will support environment managers in condition monitoring and conservation of *Scorpidium* sites.

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### Declaration of interest statement

No potential conflict of interest was reported by the authors.

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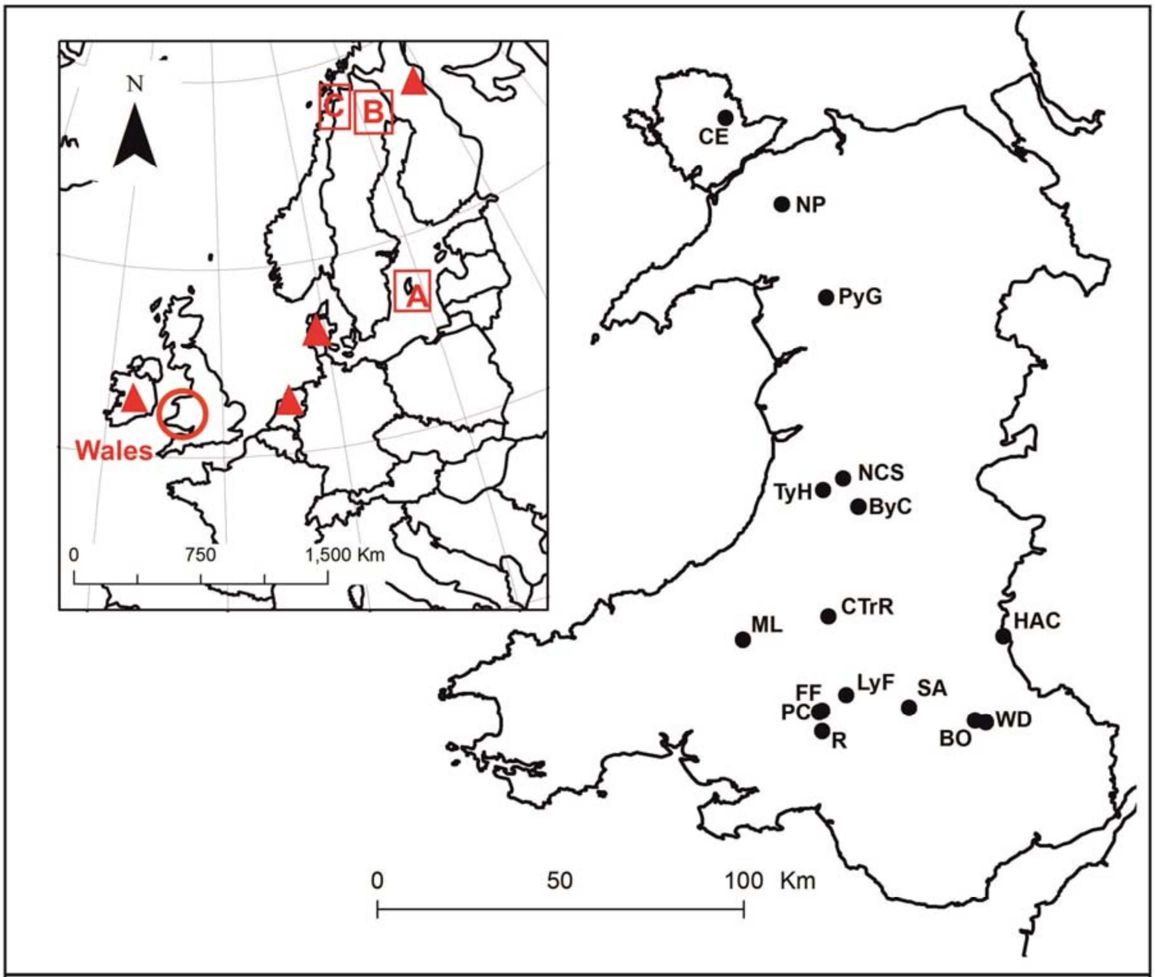

| Key | Site | Easting | Northing | Elevation (m) | Bedrock AGE | Bedrock Formation | Bedrock Type | Setting | Year |
|---|---|---|---|---|---|---|---|---|---|
| BO | Blaen Onnen | 315734 | 216888 | 420 | Carboniferous | Abercriban Oolite Subgroup | Limestone | Lime Spoil | 2015 |
| ByC | Blaen-yr-cwm | 283890 | 275397 | 305 | Silurian | Rhuddnant Grits Formation | Sandstone and mudstone | Natural | 2016 |
| CE | Cors Erdderiniog | 247593 | 382010 | 65 | Carboniferous | Clwyd Limestone Group | Limestone | Natural | 2014 |
| CTyR | Craig Troed-y-rhiw-fer | 275747 | 245362 | 190 | Silurian | Rhuddnant Grits Formation | Sandstone and mudstone | Natural | 2016 |
| FF | Foel Fawr Site | 273132 | 219121 | 455 | Carboniferous | Dowlias Limestone Formation | Limestone | Natural | 2015 |
| HAC | Hen Allt Common | 323517 | 239949 | 305 | Devonian | Senni Formation Calcrete | Sandstone | Natural | 2015 |
| LyF | Llyn y Fan site | 280571 | 223770 | 330 | Devonian | Senni Formation | Sandstone | Natural | 2015 |
| ML | Mynydd Llanllwni | 252363 | 239023 | 345 | Silurian | Rhuddnant Grits Formation | Sandstone and mudstone | Natural | 2016 |
| NCS | Nant Cwta slopes | 279755 | 283115 | 450 | Silurian | Devils Bridge Formation | Mudstones and sandstones | Natural | 2016 |
| NP | Nant Peris | 262995 | 358172 | 690 | Ordovician | Snowdon Volcanic Group | Acidic and basic volcanics | Natural | 2014 |
| PC | Pont Clydach | 273966 | 219557 | 325 | Devonian | Brownstones Formation | Sandstone and mudstone | Natural | 2015 |
| PyG | Pont-y-gain | 275130 | 332771 | 285 | Cambrian | Mawddach Group | Mudstone siltstone sandstone | Natural | 2016 |
| R | Rhosaman | 273975 | 213872 | 180 | Cambrian | Maentwrog Formation | Mudstones and sandstones | Natural | 2016 |
| SA | Storey Arms site | 297698 | 220381 | 430 | Devonian | Brownstones Formation | Sandstone and mudstone | Natural | 2016 |
| TyR | Troed-yr-henriw | 274215 | 279942 | 280 | Silurian | Devils Bridge Formation | Mudstones and sandstones | Natural | 2016 |
| WD | Waun Ddu | 318631 | 216377 | 290 | Carboniferous | Dowlais Limestone Formation | Limestone | Natural | 2015 |

**Figure 1.** Sample locations: Welsh sites, elevation, geology, setting and sampling year. Inset: previous studies in Sweden represented by squares labelled A, B and C (Koojiman & Hedenäs, 1991) and in Republic of Ireland, Netherlands and Finland by triangles (Koojiman & Westhoff, 1995). Contains Ordnance Survey Data © Crown Copyright and database rights 2018.

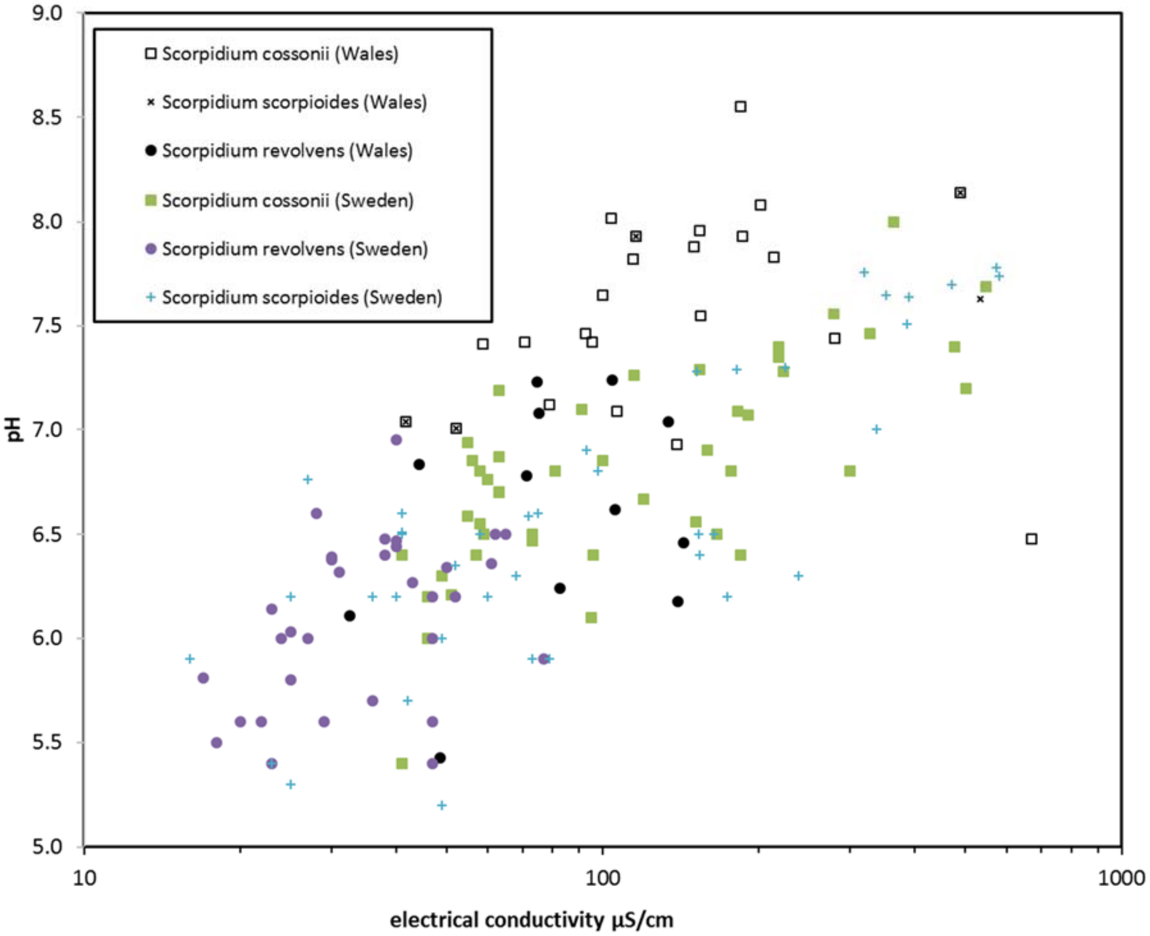

**Figure 2 – Relationship between pH and EC between Welsh and Swedish analysis. Swedish data collected between 1990-1997 (from Kooijman & Hedenäs 1991; plus unpublished data from different parts of Sweden by LH and A. Kooijman), Welsh data from 2014-2015.**

Table 1

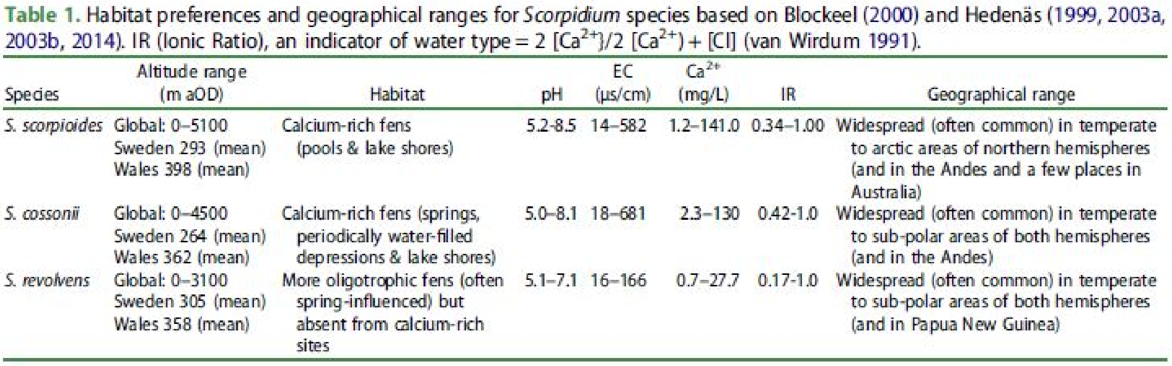

**Table 1.** Habitat preferences and geographical ranges for *Scorpidium* species based on Blockeel (2000) and Hedenäs (1999, 2003a, 2003b, 2014). IR (Ionic Ratio), an indicator of water type = 2 [$Ca^{2+}$]/2 [$Ca^{2+}$) + [Cl] (van Wirdum 1991).

| Species | Altitude range (m aOD) | Habitat | pH | EC (µs/cm) | $Ca^{2+}$ (mg/L) | IR | Geographical range |
|---|---|---|---|---|---|---|---|
| *S. scorpioides* | Global: 0–5100<br>Sweden 293 (mean)<br>Wales 398 (mean) | Calcium-rich fens (pools & lake shores) | 5.2-8.5 | 14–582 | 1.2–141.0 | 0.34–1.00 | Widespread (often common) in temperate to arctic areas of northern hemispheres (and in the Andes and a few places in Australia) |
| *S. cossonii* | Global: 0–4500<br>Sweden 264 (mean)<br>Wales 362 (mean) | Calcium-rich fens (springs, periodically water-filled depressions & lake shores) | 5.0–8.1 | 18–681 | 2.3–130 | 0.42-1.0 | Widespread (often common) in temperate to sub-polar areas of both hemispheres (and in the Andes) |
| *S. revolvens* | Global: 0–3100<br>Sweden 305 (mean)<br>Wales 358 (mean) | More oligotrophic fens (often spring-influenced) but absent from calcium-rich sites | 5.1–7.1 | 16–166 | 0.7–27.7 | 0.17-1.0 | Widespread (often common) in temperate to sub-polar areas of both hemispheres (and in Papua New Guinea) |

Table 2

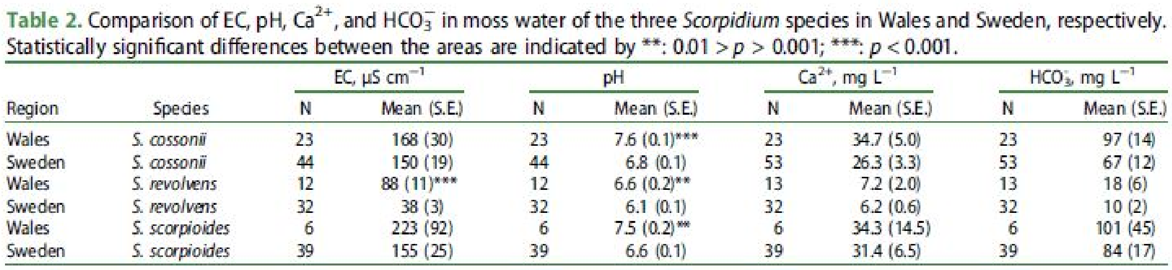

**Table 2.** Comparison of EC, pH, $Ca^{2+}$, and $HCO_3^-$ in moss water of the three *Scorpidium* species in Wales and Sweden, respectively. Statistically significant differences between the areas are indicated by **: 0.01 > $p$ > 0.001; ***: $p$ < 0.001.

| | | EC, µS $cm^{-1}$ | | pH | | $Ca^{2+}$, mg $L^{-1}$ | | $HCO_3^-$, mg $L^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|
| Region | Species | N | Mean (S.E.) | N | Mean (S.E.) | N | Mean (S.E.) | N | Mean (S.E.) |
| Wales | *S. cossonii* | 23 | 168 (30) | 23 | 7.6 (0.1)*** | 23 | 34.7 (5.0) | 23 | 97 (14) |
| Sweden | *S. cossonii* | 44 | 150 (19) | 44 | 6.8 (0.1) | 53 | 26.3 (3.3) | 53 | 67 (12) |
| Wales | *S. revolvens* | 12 | 88 (11)*** | 12 | 6.6 (0.2)** | 13 | 7.2 (2.0) | 13 | 18 (6) |
| Sweden | *S. revolvens* | 32 | 38 (3) | 32 | 6.1 (0.1) | 32 | 6.2 (0.6) | 32 | 10 (2) |
| Wales | *S. scorpioides* | 6 | 223 (92) | 6 | 7.5 (0.2)** | 6 | 34.3 (14.5) | 6 | 101 (45) |
| Sweden | *S. scorpioides* | 39 | 155 (25) | 39 | 6.6 (0.1) | 39 | 31.4 (6.5) | 39 | 84 (17) |

Table 3

| | **Scorpidium cossonii (n=23)** | | ***Scorpidium revolvens* (n=12)** | | ***Scorpidium cossonii - Scorpidium revolvens*** | ***Scorpidium cossonii - Scorpidium revolvens*** |
|---|---|---|---|---|---|---|
| | **Av** | **SE** | **Av** | **SE** | **SE** | **t** |
| **EC, µS/cm** | 167.50 | 30.17 | 88.02 | 10.87 | 14.54 | 5.78 |
| **$HCO_3^-$, mg/l** | 96.78 | 13.34 | 12.64 | 5.79 | 0.19 | 5.19 |
| **Ca, mg/l** | 34.69 | 5.02 | 7.05 | 2.19 | 5.48 | 5.04 |
| **$Cl^-$, mg/l** | 12.45 | 1.43 | 11.18 | 1.76 | 0.34 | 2.5 |
| **pH** | 7.57 | 0.10 | 6.60 | 0.16 | 32.06 | 2.48 |
| **Na, mg/l** | 6.82 | 0.74 | 6.75 | 1.09 | 1.15 | 1.55 |
| **$SO_4^{2-}$, mg/l** | 3.89 | 0.74 | 2.10 | 0.89 | 2.26 | 0.56 |
| **$SiO_2$, mg/l** | 3.53 | 0.41 | 3.55 | 0.33 | 0.39 | 0.54 |
| **Mg, mg/l** | 2.41 | 0.29 | 1.56 | 0.18 | 1.32 | 0.05 |
| **K, mg/l** | 2.20 | 0.27 | 2.49 | 0.86 | 0.25 | -0.04 |
| **Si, mg/l** | 1.65 | 0.19 | 1.66 | 0.15 | 0.52 | -0.04 |
| **$NO_3^-$, mg/l** | 0.55 | 0.38 | 0.34 | 0.09 | 0.29 | -0.17 |
| **Mn, mg/l** | 0.33 | 0.14 | 0.38 | 0.26 | 0.9 | -0.33 |

Table 4

| Site Name | Total number of samples | *Bryum psuedotriquetrum* | *Calliergonella cuspidata* | *Campylium stellatum* | *Crataneron filicinum* | *Ctenidium molluscum* | *Fissidens adianthoides* | *Palustriella commuata* | *Palustriella falcata* | *Philonotis calcarea* | *Philonotis fontana* | *Scororpidium cossonii* | *Scorpidium scorpioides* | *Sphagnum papillosum* | *Scorpidium revolvens* | *Aneura pinguis* | *Breutelia chrysoscoma* | *Hylocomium splendens* | *Sarmentypnum exannulatum* | *Sphagnum denticulatum* | *Sphagnum fallax* | *Sphagnum subnitens* | *Sphagnum teres* | *Straminergon stramineum* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cors Erdderiniog Site 7e** | **4** | | | **1** | | | | | | | | **1** | **1** | | | **2** | | | | | | | | |
| **Foel Fawr site 1** | **7** | | | | | **1** | **1** | | **1** | | | **1** | | | | | | | | | | | | |
| **Nant Cwta slopes (Eisteddfa Gurig)** | **5** | **1** | | | | | **1** | | | | | **1** | | **1** | | **2** | | | | | | | | |
| **Storey Arms site 1** | **3** | | | | | | **1** | | | | | **1** | **1** | | | | | | | | | | | |
| **Storey Arms site 2** | **3** | | | **1** | | | | | | | | **1** | **1** | | | | | | | | | | | |
| **Blaen Onnen** | **23** | **1** | **1** | **1** | **1** | | | **1** | **1** | **1** | **1** | **1** | | | | **2** | | | | | | | | |
| **Foel Fawr site 2** | **10** | **1** | | **1** | | | | | **1** | **1** | | **1** | **1** | | | | | | | | | | | |
| **Llyn y Fan site 1** | **12** | **1** | | **1** | | | | **1** | **1** | | | **1** | | | | **2** | | | | | | | | |
| **Llyn y Fan site 2** | **7** | | | | | | | **1** | **1** | | **1** | **1** | | | | **2** | | | | | | | | |
| **Pont Clydach site 1** | **8** | **1** | | **1** | | | | | **1** | | | | | | **2** | **2** | | | | | | | | |
| **Pont Clydach site 3** | **10** | **1** | | **1** | | | | | **1** | | | **1** | **1** | | | | | | | | | | | |
| **Waun Ddu** | **17** | **1** | **1** | **1** | **1** | | **1** | | **1** | | | **1** | | | | | | | **2** | **2** | | | | |
| **Blaen-yr-cwm** | **2** | | | | | | | | | | | | | | **2** | | | **2** | | | | | | |
| **Craig Troed-y-rhiw-fer** | **4** | | | | | | | | | | | | | | **2** | **2** | **2** | | | | | **2** | | |
| **Mynydd Llanllwni site 1** | **3** | | | | | | | | | | | | | | **2** | **2** | | | **2** | | | | | |
| **Mynydd Llanllwni site 2** | **4** | | | **1** | | | | | | | | | | | **2** | | | | | **2** | **2** | | | |
| **Mynydd Llanllwni site 4** | **6** | | | **1** | | | | | | | | | | | **2** | **2** | | | **2** | **2** | | | | |
| **Nant Peris site 1** | **4** | | | | | | | | | | | | **1** | | **2** | **2** | | | | | | | | **2** |
| **Nant Peris site 3** | **2** | | | | | | | | | | | | | | **2** | **2** | | | | | | | | |
| **Pont-y-gain** | **3** | | | | | | | | | | | | | | **2** | **2** | | | | | | | **2** | |
| **Troed-yr-henriw** | **4** | | | **1** | | | | | | | | | | | **2** | **2** | | | | | | | | |

Table 5

| | | **pH** | **EC** | **Ca** | **Mg** | **Na** | **K** | **HCO$_3^-$** | **Cl$^-$** | **SO$_4^{2-}$** | **NO$_3^-$** | **Si** | **SiO$_2$** | **Mn** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | µS/cm | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| **Group 1 characterised by *Scorpidium cossonii*** | Min | 5.3 | 26 | 0.7 | 0.3 | 2.5 | 0.2 | 5 | 3.8 | 1 | 0.2 | 0.2 | 0.4 | 0 |
| | Max | 11.8 | 787 | 98 | 9.7 | 113.7 | 7 | 261 | 201.4 | 17.6 | 9.2 | 5 | 10.6 | 11.7 |
| | **Mean** | **7.5** | **197** | **35.2** | **2.8** | **11.2** | **2.2** | **101** | **19.6** | **4.4** | **0.8** | **1.8** | **3.9** | **0.5** |
| **Group 2 characterised by *Scorpidium revolvens*** | Min | 5.1 | 33 | 0.3 | 0.4 | 3.8 | 0.2 | 5 | 5.4 | 1 | 0.2 | 0.4 | 0.8 | 0 |
| | Max | 7.2 | 143 | 26 | 2.7 | 16.1 | 10.7 | 68 | 23.2 | 10 | 1.3 | 4.4 | 9.5 | 0.4 |
| | **Mean** | **6.3** | **79** | **5** | **1.4** | **6.4** | **2.3** | **10** | **10.2** | **3.6** | **0.7** | **1.7** | **3.5** | **0.1** |