Holyoak, D. T., Lockhart, N. (2011) 'A survey of bryophytes and metallophyte vegetation of metalliferous spoil heaps in Ireland' *Journal of the Mining Heritage Trust of Ireland,* **11***,* pp. 3-16

ISSN 1649-0908

The Journal of the Mining Heritage Trust of Ireland

No. 11. November 2011

A view of the Silvermines Waelz complex buildings, as they were in May 2008 (view taken from scaffolding on the Ballygowan pumping engine house). See paper by John Morris inside.

Iris don Iontaobhas um Oidhreacht Mhianadóireachta

A SURVEY OF BRYOPHYTES AND METALLOPHYTE VEGETATION OF METALLIFEROUS MINE SPOIL IN IRELAND

by David T. Holyoak and Neil Lockhart

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Abstract: A wide-ranging survey of bryophytes (mosses and liverworts) at Irish metalliferous mine sites was undertaken by National Parks and Wildlife Service in 2008. It established that although most of the so called 'copper mosses' or metallophytes are rare plants in Ireland, they occur at additional localities, where they have been overlooked until recently. Vegetation of mine spoil with these rare bryophytes is ascribable to 'Calaminarian grasslands of the *Violetalia calaminariae*', a habitat listed on Annex I of the EU Habitats Directive. The extent of this protected vegetation type in Ireland is reassessed (total area of *ca* 15.6 ha) and suggestions are made for conservation of some of the best examples. The likely role of accidental transport by man in facilitating dispersal of metallophyte bryophytes is also briefly discussed. *Journal of the Mining Heritage Trust of Ireland*, **11**, 2011 3-16.

INTRODUCTION

Mine workings and their artificial spoil heaps can support specialised plants and vegetation communities that are tolerant of high levels of toxic metals, notably copper [Cu], lead [Pb] and zinc [Zn]. Such vegetation can be ascribed to the Calaminarian Grasslands of the *Violetalia calaminariae*, a habitat listed on Annex I of the EU Habitats Directive (hereafter referred to as Calaminarian Grassland). There are currently three candidate Special Areas of Conservation (SACs) in Ireland selected to protect stands of Calaminarian Grassland: Moneen Mountain, Co. Galway (cSAC code 000054); Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment, Co. Kerry (cSAC code 000365) and Kenmare River, Co. Cork (cSAC code 002158). Some stands of Calaminarian Grassland are notable for the presence of rare bryophytes (mosses and liverworts) such as *Cephaloziella integerrima*, *C. massalongi*, *C. nicholsonii*, *Ditrichum cornubicum*, *Scopelophila cataractae* and *Pohlia andalusica*, amongst others. Until recently, however, there were relatively few records from Ireland of these so called 'copper mosses' or metallophytes. None of the species involved were recorded in the classical compilations by McArdle (1904) and Lett (1915), the first records being of the liverwort *Cephaloziella massalongi* found at Allihies in Co. Cork by H. Milne-Redhead in 1955 (Castell 1957) and east of Bunmahon in Co. Waterford by R.D. Fitzgerald and D.M. Synnott in 1966 (Paton 1967). Subsequent visitors have added the moss *Pohlia andalusica* from both of the same two sites (Holyoak 2003).

During 1999-2005 a programme of research on Irish bryophytes was undertaken by National Parks and Wildlife Service (NPWS), resulting in many new records, although few involved 'copper mosses' (Holyoak 2006). Continuation of this work into Co. Cork in 2006 and Co. Waterford in 2007 resulted, however, in the first Irish records of the liverwort *Cephaloziella nicholsonii* and the mosses *Ditrichum cornubicum* and *Scopelophila cataractae*, among other finds, at old copper mine sites. This led to suspicion that other populations of metallophyte bryophytes may hitherto have been overlooked elsewhere in Ireland. A wide-ranging survey of bryophytes at Irish metalliferous mine sites was therefore undertaken by NPWS during 2008, which produced numerous new finds (Holyoak and Lockhart 2009), including the lead-tolerant moss *Ditrichum plumbicola* new to Ireland. The present paper gives a fuller account of this survey, its results and the implications for conservation of metallophyte vegetation in Ireland. The likely role of accidental transport by man in facilitating dispersal of metallophyte bryophytes is also briefly discussed. Taxonomy and nomenclature follow Hill *et al.* (2008) for bryophytes and Stace (2010) for phanerogams.

METHODS

A field survey was carried out by DTH on behalf of NPWS from April to June 2008 in order to provide fuller information on bryophyte species and communities on metalliferous mine spoil in Ireland. The detailed objectives of this survey were as follows:

1. To establish the distribution and extent of metallophyte bryophyte communities of mine spoil in Ireland;
2. To relate the distribution and extent of metallophyte bryophyte communities to that of the total Calaminarian Grassland resource in Ireland;
3. To classify and describe the range of variation of metalliferous mine-spoil vegetation;

4. To identify, list and rank metalliferous mine-spoil sites of conservation interest;
5. To determine the condition and future prospects of metalliferous mine-spoil sites of conservation interest;
6. To propose management recommendations to ensure favourable conservation status is achieved;
7. To propose a monitoring prescription for this habitat type.

Initial selection of the sites to be visited posed a challenge at the start of the survey. The Geological Survey of Ireland database of 'Mine Site Workings' lists *ca* 280 sites. It would have been impossible to visit all of these in the time available and probably pointless to do so, as many would by now have little or no botanical interest. It was therefore necessary to select a much smaller number of sites to visit (*ca* 40), that nevertheless included as many as possible of those with the greatest interest for metallophyte bryophytes. Based on experience in Cornwall and elsewhere, it appeared that the best sites were likely to be:

(a) those already known to have rare metallophyte bryophytes;

(b) among those that produced highest tonnages of Cu, Pb or Zn historically, especially in the relatively recent past;

(c) where extensive spoil tips have not been reclaimed or re-vegetated;

(d) sites of continuing interest to mineral collectors;

(e) sites with spoil in damp, low-lying settings but with largely unshaded fine-grained clayey spoil, rather than open sunny sites, or tree-shaded sites, or gravelly sites;

An initial list of sites was compiled from several sources. Phytosociological publications (Doyle 1982, Lötschert 1982) described only a few small disused lead mines. Cole (1922) provided an extensive review of mine sites worked up to the 1920s. More recent information was obtained from mining, mining company and mining history websites. Personal contacts with mineral collectors (particularly John Fisher) added some useful pointers to exposed spoil tips rich in copper and lead minerals. Mike Wyse Jackson suggested several significant sites in Co. Cork and Co. Kerry. A visit to the NPWS offices in Dublin at the start of the survey was used to assemble and copy relevant sections of 1:5000 and 1:10,560 maps, aerial photographs and other materials. Scrutiny of these, along with some notations of 'Shaft', 'Chimney' or 'Disused mine', were useful in locating sites.

A short list of sites most likely to be worth surveying was drawn up by applying criteria noted in points (a) to (e) above (Table 1). The sites visited were thus mainly those regarded as high ranking in Table 1, along with a selection of lower ranked sites intended to represent different regions of Ireland or different mine types (particularly small lead mines). Sites described by Doyle (1982) and Lötschert (1982) were also revisited; a disused copper mine at Brow Head (Co. Cork) was added on the advice of Mike Wyse Jackson; a 'new' find near Knockmahon village (Co. Waterford) was added when it became clear from a field visit that it was significant. Requests to visit the large modern mine at Lisheen initially met with bureaucratic delay, but this may have been fortuitous good luck since the proposed visit was abandoned after it became clear from fieldwork that tailings dams on the similar modern mine nearby at Galmoy had very little bryological interest.

In the end, several mine sites were visited that had no (remaining) metallophyte bryophyte interest (e.g. Ballycummisk, Ballydehob, Barrystown), even some high ranked sites had very little or no interest (notably Connary, Cronebane, Galmoy), but a few of the small sites selected proved to be significant new finds from a botanical viewpoint (notably Caim and Ballyhighland, Glenmalur and Shallee). There are doubtless other unsurveyed small sites that are of significant interest for bryophytes, but it seems that only chance finds or a really exhaustive survey are likely to reveal their whereabouts!

Standard information was recorded at each mine site where either significant metallophyte vegetation or rare metallophyte bryophytes were found. This information comprised a Site Survey Card (Table 2) and, where quadrat data were recorded, a Relevé Card (Table 3). Large numbers of digital photographs were taken using a Nikon Coolpix 4500 to show the general character of each site, with emphasis on metallophyte vegetation and locations with rare bryophytes. All relevés were also photographed. All of the photographs were given serial numbers prefaced with NPW08 and all are lodged with NPWS.

Following initial widespread searching and inspection of the vegetation at each mine site, relevés were routinely selected for representative samples of the different types of metallophyte vegetation encountered. Vegetation types that did not have strong evidence of metalliferous influence were mainly ignored during this sampling and recording process, although some 'weakly metalliferous' relevés were recorded. There was some deliberate bias towards siting relevés in small patches of habitat with rare metallophyte bryophytes, but this was to some extent countered by occasional recording of near-monospecific stands of *Agrostis* grassland on obviously toxic spoil.

Prior to the fieldwork, a decision was required regarding the size of quadrat to be used in recording relevé data. The 'standard' 2 × 2 m used for grassland surveys was clearly too large for recording small bryophytes, since accurate recording of each quadrat could take several hours. On the other hand, the 0.50 × 0.25 m adopted as a standard for bryophyte surveys by BRECOG (the British Bryological Society's 'Bryophyte Ecology Group') seemed rather small when vascular plants were also being recorded. Quadrats of 0.5 × 0.5 m were therefore chosen as a compromise and this size worked well in the field. A square frame (4 thin tent pegs joined by thin string stretched taut: Figure 1) was used when recording data.

Voucher specimens for microscopic identification were routinely collected from relevés. This sampling and subsequent curation of material was carried out as part of a programme of work recording threatened bryophytes for a *Red Data Book* of Irish bryophytes (Lockhart *et al.*, in press). Details of the methods involved and the standard Species-Site data forms are included in a separate unpublished report to NPWS (Holyoak 2008).

Visit	Rank	Name	County	Grid Ref.	Metal	Ore tonnage	Years	Reference
N	low	Beauparc	Cavan	N9471	Cu	1,001	1818-1914	Cole p. 28
N	very low	Ballyvergin	Clare	R4281	Pb	119	1859-1861	Cole pp. 117-8
N	low	Carrahin/Carrahan	Clare	R4380	Pb	444	1863-1880	Cole p. 118
N	very low	Milltown	Clare	R4680	Pb	54	1826-1864	Cole p. 118
N	low	Kilbreckan/Monanoe	Clare	R3776	Pb	>236	1834-1855	Cole pp. 119-20
Y	medium	Ballyhickey	Clare	R4276	Pb	3,182	1836-1846	Cole p. 119
N	low	Coosheen/Skull Bay	Cork	V939311	Cu	>1,957	1840-1878	Cole p. 54
Y	high	Allihies/Mountain	Cork	V589457	Cu	>206,574	1813-1918	Cole pp. 45-8
Y	low-med	Ballycummisk	Cork	V977322	Cu	>809	1814-1877	Cole pp. 50-51
Y	low	Ballydehob	Cork	V9935	Cu [Pb]	636	1817-1860	Cole pp. 51-2
Y	high	Cappaghglass	Cork	V990324	Cu	1,133	1819-1873	Cole p. 53
Y	low	Polleenateada	Cork	V780306	Cu	??	??	on 1:50 k sheet
Y	medium	Glentogher	Donegal	C4737	Pb	1,800	1780, 1905-6	Cole p. 91
Y	medium	Keeldrum	Donegal	B9027	Pb	1,229	1826-1862	Cole pp. 91-2
Y	medium	Ballycorus	Dublin	O2221	Pb	productive	1807-1865	Cole pp. 107-8
Y	medium	Tynagh (N. of)	Galway	M754133	Cu	??	-2004	visit by DTH
Y	high	Ross Island	Kerry	V944880	Cu	>4,749	1804-1810	Cole pp. 39-40
Y	medium	Annagh	Kerry	Q8303	Pb	>409	1788-1828	Cole p. 126
Y	high	Galmoy	Kilkenny	S2971	Zn, Pb	650,000 p.a.	1986-2008	Mining Life website
Y	high	Tara (Navan)	Meath	N8471	Zn, Pb	>2,000,000	1977-2008	Mining Life website
N	very low	Coolartrargh/Bond	Monaghan	H8421	Pb	124	1845-1864	Cole p. 97
N	low	Tassan	Monaghan	H8421	Pb	>165	1853-1865	Cole pp. 97-8
N	very low	Hope Mines etc.	Monaghan	H8421	Pb	142	1852-1869	Cole pp. 100-101
N	low	Annaglogh	Monaghan	H8421	Pb	>310	1852-1859	Cole p. 99
Y	high	Lisheen	Tipperary	R9730	Zn, Pb	160,000 p.a.	2001-2008	Mining Life website
N	very low	Killeen	Tipperary	R8062	Cu	182	1905-1909	Cole pp. 38-9
N	low	Hollyford	Tipperary	R9253	Cu	>565	1837-1862	Cole p. 39
Y	medium	Lackamore	Tipperary	R8060	Cu	2,848	1819-1859	Cole p. 38
Y	medium	Shallee W./E.	Tipperary	R7970	Pb	>678	1847-1874	Cole pp. 122-3
Y	medium	Gorteenadiha etc.	Tipperary	R8271	Pb, Zn, Cu	Pb >218, Zn 9,541	1819-1872	Cole pp. 123, 146
Y	high	Bunmahon etc.	Waterford	X4498	Cu	>80,000	1730-1907	Cole pp. 41-3
Y	medium	Caim etc.	Wexford	S8840	Pb [Cu]	>1,245	1815-1855	Cole p. 125
Y	medium	Barrystown	Wexford	S8612	Pb	573	1777-1847	Cole pp. 125-6
Y	high	Connary	Wicklow	T1984	Cu	15,206	1832-1885	Cole pp. 33, 144
Y	high	Cronebane	Wicklow	T2083	Cu	38,909	1720-1912	Cole pp. 33-4
Y	high	Tigrony	Wicklow	T2082	Cu	26,390	1822-1854	Cole p. 34
Y	medium	Ballygahan	Wicklow	T2081	Cu	>6,809	1828-1879	Cole p. 35
Y	high	Ballymurtagh	Wicklow	T1981	Cu	>52,111	1755-1879	Cole pp. 35-6
Y	high	Glendasan etc.	Wicklow	O1097	Pb	>12,900	1807-1900	Cole pp. 110-3
Y	medium	Glenmalur etc.	Wicklow	O0892	Pb	>1,395	1797-1864	Cole pp. 113-4

Table 1. Initial list of mine sites considered for survey in 2008.

Site name:	Time spent on site:	Date:

Townland name County	Site Area Extent of coverage Alt range (m)
Grid ref. Discovery Map no. 1:5000 sheet 6” sheet Air photo ID & year	Bedrock type Mineral type (Cu, Pb, Zn, etc.) Soil type Soil moisture regime Seasonal flooding (y/n)
NPWS Region NHA code SAC code SPA code	HC Habitats (% cover) EU 2 ED 2 ED 3 Other
Ownership	HD Habitats (% cover) Calaminarian Other

Site geography & landscape setting
Site history & management
Significance of site for bryophytes
Development of metallophyte plant communities
Assessment of conservation value
Threats/recommendations for conservation

Species list

Liverworts	**Mosses**	**Vascular plants**
Jungermannia gracillima	*Ceratodon purpureus*	Grasses indet.
Gymnocolea inflata	*Polytrichum juniperinum*	Dicot seedlings
Cephaloziella stellulifera	*Dicranella varia*	*Agrostis capillaris*
Cephaloziella sp.	*Pohlia annotina*	*Agrostis stolonifera*
Diplophyllum albicans	*Ditrichum cornubicum*	*Armeria maritima*
Scapania compacta	*Ditrichum lineare*	*Calluna vulgaris*
Nardia scalaris	*Pohlia andalusica*	*Erica cinerea*
Cephaloziella massalongi	*Scopelophila cataractae*	*Plantago coronopus*
Cephaloziella nicholsonii	*Weissia controversa* var. *densifolia*	*Plantago maritima*
Cephaloziella integerrima		*Silene vulgaris*
		Ulex gallii
		Ulex europaeus
		Ulex sp.

Impacting Activities (NATURA list codes)							

Table 2. Site survey card for the survey of vegetation on Irish metalliferous mines.

Site name: Date:

	Releve Number							
	Slope Aspect							
	Grid Ref Altitude Substrate type Description							
	Herb height (cm)							
	Photo ID							
	DOMIN scale							
General	Bare soil							
	Rock							
	Surface water							
	Litter							
	Vegetation							
	Vascular plant							
	Bryophyte							
	Lichen							
	Algae							
Liverworts	*Jungermannia gracillima*							
	Gymnocolea inflata							
	Cephaloziella stellulifera							
	Cephaloziella sp.							
	Diplophyllum albicans							
	Scapania compacta							
	Nardia scalaris							
	Cephaloziella massalongi							
	Cephaloziella nicholsonii							
	Cephaloziella integerrima							
Mosses	*Ceratodon purpureus*							
	Polytrichum juniperinum							
	Dicranella varia							
	Pohlia annotina							
	Ditrichum cornubicum							
	Ditrichum lineare							
	Pohlia andalusica							
	Scopelophila cataractae							
	Weissia controversa var. *densifolia*							
Vascular plants	Grasses indet.							
	Dicot seedlings							
	Agrostis capillaris							
	Agrostis stolonifera							
	Armeria maritima							
	Calluna vulgaris							
	Erica cinerea							
	Plantago coronopus							
	Plantago maritima							
	Silene vulgaris							
	Ulex gallii							
	Ulex europaeus							
	Ulex sp.							

Table 3. Relevé card for the survey of vegetation on Irish metalliferous mines.

***Figure 1. Relevé 1 at Ballycorus, Co. Dublin: lead mine spoil with sparse cover of* Ditrichum plumbicola *and* Solenostoma gracillimum.**

RESULTS

About 50 mine sites were visited by DTH during the fieldwork. A diary of the work, which took place from 12th April to 5th June 2008, was appended to the report by Holyoak (2008). Early spring was deliberately chosen as the best seasonal timing for the fieldwork, since many metallophyte bryophytes are tiny plants that make most of their growth during the winter and become very difficult to find in summer. Fortunately the weather during April and May 2008 was ideal, with frequent rain that kept bryophytes hydrated, but not so much rain that fieldwork was hampered.

Site Survey Cards were completed for 35 mine sites that had at least some slight metallophyte interest, although several of these were of little real importance for metallophyte vegetation or metallophyte bryophytes. The bulk of the unpublished Report held by NPWS consists of these Site Survey Cards, accompanied in most cases by Relevé Cards and marked maps, and often also by marked aerial photographs and other documentation.

A short paper has been published with new distributional records of metallophyte bryophytes from this survey, along with the more significant metallophyte records obtained from other surveys over the past few years (Holyoak and Lockhart 2009). In brief, the most notable results of the present survey were as follows: *Ditrichum plumbicola* new to Ireland at sites in Co. Dublin and Co. Galway; *Cephaloziella nicholsonii* at additional sites (new to Co. Galway, Co. Waterford, Co. Wicklow, Co. Wexford); *Cephaloziella massalongi* at additional sites (new to Co. Dublin, Co. Wicklow); *Cephaloziella integerrima* at additional sites (new to Co. Wicklow); *Scopelophila cataractae* at a third Irish site (new to Co. Wexford).

A draft of a second paper has been prepared and lodged with NPWS, to summarise phytosociological data and observations from this survey. The main conclusion from this is that existing literature deals very incompletely with metallophyte vegetation in Ireland (and indeed in the British Isles or Europe as a whole). Several vegetation types composed of single bryophyte species or very few species occur on copper mine spoil, all of them lacking formal names as syntaxa. Coining new names for such 'Associations' consisting of a single species seems illogical, so the temptation to do so was resisted. On less toxic substrata these monospecific or species-poor stands grade into several heathland and grassland vegetation types, resulting in complexity that existing phytosociological classification as '*Violetalia calaminariae*' does not adequately cover.

Much of the detailed material and discussion from the unpublished reports is not repeated here. Hence, the remainder of the present paper is mainly devoted to a consideration of the extent and distribution of the Calaminarian Grassland habitat in Ireland, discussion of priorities and practicalities for conservation of metallophyte vegetation and rare metallophyte species and a discussion of the likely role of man in the accidental dispersal of metallophyte bryophyte populations.

Extent and distribution of Calaminarian Grassland habitat in Ireland

The presence of indicator species was taken as the strongest evidence of Calaminarian Grassland vegetation. Thus:

(a) Obligate Cu bryophytes are *Cephaloziella massalongi*, *C. nicholsonii*, *Ditrichum cornubicum*, *Scopelophila cataractae*; the only obligate Pb bryophyte is *Ditrichum plumbicola*.

(b) All others are facultative metallophytes, those most indicative of high [Cu] being *Cephaloziella integerrima*, *C. stellulifera, Gymnocolea inflata*, *Solenostoma gracillimum*, *Pohlia andalusica*, *Scapania compacta*, *Weissia controversa* var. *densifolia*; some indicative of Pb or Zn are *Bryum pallescens* and *Weissia controversa* var. *densifolia*.

(c) All vascular plants are merely facultative indicators, *Minuartia verna* (Pb and Zn) being strongest, but inland populations of *Armeria* (in the lowlands) and *Plantago maritima* (Cu, Pb and Zn) are also significant. Generally, high Cu concentrations are characterised by poorly grown, near-monospecific stands of *Agrostis capillaris* and *Calluna vulgaris*, and are floristically very dull.

(d) These conclusions about indicator species are supported by a body of analytical data from Cornwall on available heavy metal contents of substrata on which the plants occur (Clements 1996, Rouen 2000, Walsh 2001). Such data are important to confirm that restriction of particular plant species to mine areas is due to the presence there of metal residues and not to other factors such as disturbance, minimal soil development or low nutrient levels.

Ground with high levels of heavy metals generally has species-poor vegetation, with only a few of the species from adjoining grassland or heathland growing well. However, other factors beside metal toxicity can produce species-poor communities, particularly recent disturbance, extreme acidity or alkalinity, extreme poverty in nutrients, other toxic substances (e.g. arsenic, certain organic compounds, selective herbicides), drought, or combinations of these. During this survey extremely species-poor and sparse vegetation at some mines in the Avoca Valley of Co. Wicklow (notably Cronebane and Connary) appeared to result from strongly acidic substrate reactions associated with high Sulphur levels in the bedrock, rather than from high metal levels. Hence little use was made of low species numbers as indicators of metallophyte vegetation in the absence of evidence from the indicator species listed above. It is quite likely therefore that the extent of Calaminarian Grassland habitat has been somewhat underestimated, but correspondingly unlikely that much of what has been recognised is misidentified.

The habitat is widely distributed geographically (Figures 2 and 3) and it occurs on a range of bedrock types from strongly basic (Carboniferous Limestone, calcareous shales) to distinctly acidic (granitic, schist, shale and quartzite) lithologies (Table 4). The diversity of plant association types found within Calaminarian Grassland vegetation in Ireland doubtless relates at least partly to this variability in bedrock geology, chemistry and hydrology. It is therefore desirable to protect a range of the better examples of Calaminarian Grassland vegetation from different bedrock and heavy metal types.

In order to estimate the total area of metallophyte vegetation in Ireland, many scattered occurrences of the moss community of *Weissia controversa* var. *densifolia*-*Bryum pallescens* were ignored. This community is evidently widespread in places far removed from mine sites, such as under the edges of galvanised iron roofs, crash barriers, fences and gates, and is not referable to Calaminarian Grassland, and of no conservation concern.

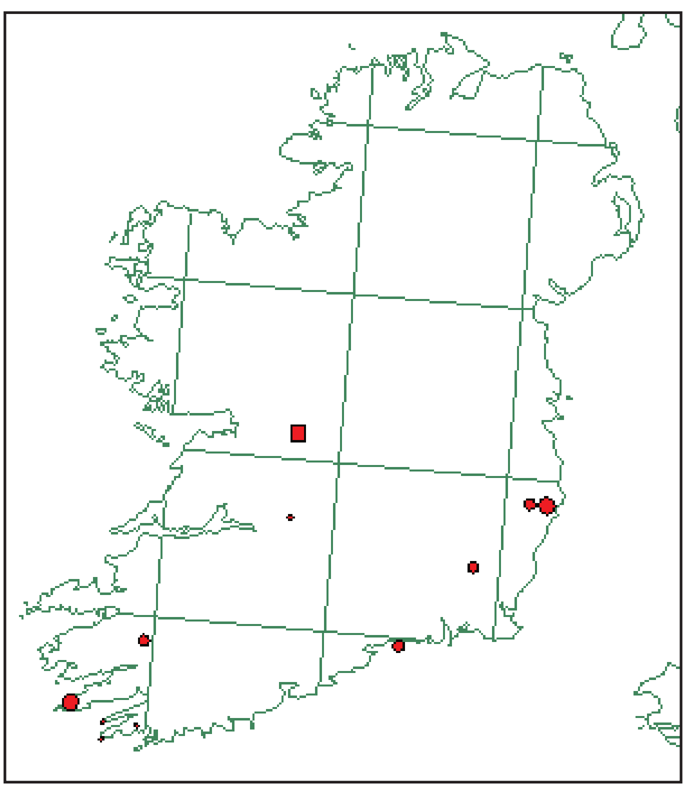

Figure 2. Distribution of Calaminarian Grassland at copper mine sites in Ireland. Large symbols > 1 ha, medium symbols 0.1-1.0 ha, small symbols < 0.1 ha; square symbols = vegetation on tailings dams.

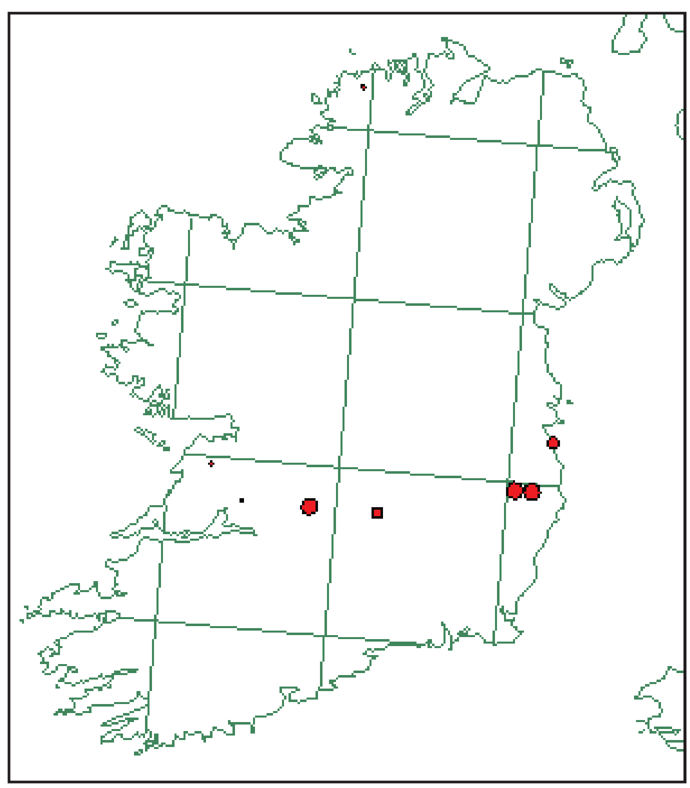

Figure 3. Distribution of Calaminarian Grassland at lead and zinc mine sites in Ireland. Symbols as in Figure 2.

Site	County	Grid ref.	Metal(s)	Bedrock	Calaminarian Grassland Area (ha)	Rare Bryophytes
Ballyhickey	Clare	R417768	Pb	limestone	0.009	-
Sheshodonnell East	Clare	R268969	Pb	limestone	0.014	-
Mogouhy	Clare	R274983	Pb	limestone	0	-
Allihies (Mountain)	Cork	V590458	Cu	sandstone	3.1	*C. int*, *C. mas*, *C. nic*, *D. cor*, *D. lin*, *P. and*, *S. cat*
N. of Caminches	Cork	V594455	Cu	sandstone	0.01	*P. and*
NE of Caminches	Cork	V597455	Cu	sandstone	0.006	-
Dooneen	Cork	V577459	Cu	sandstone	0.34	*C. mas*
Cappagh	Cork	V990324	Cu	sandstone	0.08	*C. nic*, *P. and*, *S. cat*
Brow Head	Cork	V771235	Cu	sandstone	0.07	-
Polleenateada	Cork	V780306	Cu	sandstone	0.015	-
Keeldrum	Donegal	B903262	Pb	quartzite, etc.	0.0009	-
Ballycorus	Dublin	O225208	Pb	mica-schist	0.12	*C. mas*, *D. plu*
Tynagh	Galway	M753133	Cu	limestone	2.5	-
Muckross Lake	Kerry	V948859	Cu	limestone	0.16	*C. mas*
Ross Island	Kerry	V945880	Cu, Pb	limestone	0.15	*C. mas*
Galmoy (trial cells)	Kilkenny	S274722	Zn, Pb	carbonates	0.01	-
Galmoy (dam)	Kilkenny	S271724	Zn, Pb	carbonates	0.7	-
Tara	Meath	N858716	Zn, Pb	shale/slate	0	-
Lackamore	Tipperary	R788602	Cu	shale	0.07	-
Shallee	Tipperary	R806712	Pb	shale	0.9	*C. nic*, *D. plu*
Garryard West	Tipperary	R826710	Pb, ?Zn	calc. shale	0.19	-
Bunmahon	Waterford	X444986	Cu	slate	0.02	*C. mas*, *P. and*
Tankardstown	Waterford	X451986	Cu	slate	0.006	-
Knockmahon 'village'	Waterford	X438990	Cu	metamorphic	0.28	*C. int*, *C. nic*, *P. and*
Caim & Ballyhighland	Wexford	S885409	Cu	metamorphic	0.16	*C. nic*, *S. cat*
Cronebane	Wicklow	T208831	Cu, S, etc.	shale, schist	0	-
nr Connary Hall	Wicklow	T211838	Cu	shale, etc.	2.2	-
Glendasan (old works)	Wicklow	T098981	Pb	granite, schist	3.6	*C. int*, *C. mas*, *C. nic*
Foxrock Mine	Wicklow	T104982	Pb	granite, schist	0.6	-
Ballymurtagh	Wicklow	T192815	Cu, S, Fe	schistose	0.11	-
Tigroney West	Wicklow	T199822	Cu, Fe, S	schistose	0.03	*C. nic*
Ballinafunshoge	Wicklow	T082925	Pb	schistose	0.10	-
Vale of Glendasan	Wicklow	T108977	Pb	schistose	0.97	-
Brockagh	Wicklow	T093992	Pb	schistose	0.20	-
E. of L. Nahanagan	Wicklow	T092988	Pb	schistose	0.10	-

C. int = Cephaloziella integerrima; *C. mas = Cephaloziella massalongi*; *C. nic = Cephaloziella nicholsonii*; *D. cor = Ditrichum cornubicum*; *D. lin = Ditrichum lineare*; *D. plu = Ditrichum plumbicola*; *P. and = Pohlia andalusica*; *S. cat = Scopelophila cataractae*

Table 4. Summary of data on mine sites surveyed

Table 5 ranks mine sites according to the extent of Calaminarian Grassland vegetation recorded. Only four sites have more than 1.0 ha of Calaminarian Grassland habitat (three Cu mines: Allihies (Mountain) 3.1 ha, Tynagh 2.5, near Connary Hall 2.2; one Pb mine: Glendasan (old works) 3.6, although two other Pb mines approach this amount, at Vale of Glendasan 0.97, Shallee 0.9 ha). These few relatively rich sites contribute a large proportion of the total resource of 16.8 ha of Calaminarian Grassland accumulated in Table 5.

However, in calculating the total extent of Calaminarian Grassland vegetation in Ireland several other points need to be considered. Two modern mines have Calaminarian Grassland vegetation restricted to damp, flat surfaces on fine silty-clay tailings (Galmoy 0.7 ha, Tynagh 2.5 ha); the vegetation involved is extraordinarily poor in species, it lacks rarities and it represents only a short-lived stage in vegetation succession on the sediment infilling lagoons within tailings dams. This vegetation has no conservation significance and it should therefore be discounted in arriving at figures for the total resource of the habitat. Adjustment of the totals is also necessary to take account of additional small lead mine sites that were not surveyed in detail in the Co. Wicklow hills (in Vale of Glendasan and around Van Diemen's Mines), where a total of perhaps 2 ha more of Calaminarian Grassland may exist scattered across about 15 small sites. Bearing in mind these corrections, the total resource of Calaminarian Grassland habitat in Ireland can be estimated as: 6.8 ha at Cu mine sites; 6.8 ha at Pb (and Zn) mine sites which were surveyed; 2.0 ha estimated at Pb mine sites in Co Wicklow hills not surveyed. Hence an overall total of 15.6 ha.

Priorities and practicalities in conservation of metallophyte vegetation and rare metallophyte species in Ireland

Conservation of Calaminarian Grassland vegetation for its own sake has little appeal, particularly when it consists of pure stands of metal tolerant ecotypes of the common grass *Agrostis capillaris* with or without such common herbs as *Cerastium fontanum* and *Rumex acetosa*. The artificial nature of these floristically dull habitats also discourages their conservation. It is the presence of rare species in the metallophyte vegetation

Copper mines	Calaminarian Grassland area (ha)	Lead or Zinc mines	Calaminarian Grassland area (ha)
Allihies (Mountain)	3.1	Glendasan (old works)	3.6
Tynagh	2.5*	Vale of Glendasan	0.97
near Connary Hall	2.2	Shallee	0.9
Dooneen	0.34	Galmoy (dam)	0.7*
Knockmahon 'village'	0.28	Foxrock Mine	0.6
Caim & Ballyhighland	0.16	Brockagh	0.2
Muckross Lake	0.16	Garryard West	0.19
Ross Island	0.15	Ballycorus	0.12
Ballymurtagh	0.11	Ballinafunshoge	0.1
Cappagh	0.08	E. of L. Nahanagan	0.1
Brow Head	0.07	Sheshodonnell East	0.014
Lackamore	0.07	Galmoy (trial cells)	0.01*
Tigroney West	0.03	Ballyhickey	0.009
Bunmahon	0.02	Keeldrum	0.0009
Polleenateada	0.015		
N. of Caminches	0.01		
NE of Caminches	0.006		
Tankardstown	0.006		
TOTAL	**9.307**	**TOTAL**	**7.5139**

* = only on silty-clay tailings at modern mines

Table 5. Analysis of data on mine sites surveyed. Ranking of sites by extent of Calaminarian Grassland vegetation.

that necessitates conservation concern. Eight bryophytes from the Irish Red List are closely associated with metalliferous sites (*Cephaloziella integerrima*, *C. massalongi*, *C. nicholsonii*, *Ditrichum cornubicum*, *D. lineare*, *D. plumbicola*, *Pohlia andalusica*, *Scopelophila cataractae*). Five of these are strict metallophytes (some populations of *C. integerrima* and *P. andalusica* and most of those of *D. lineare* also occur on uncontaminated substrata). Among them, *D. cornubicum* is on the European and British Red Lists (with three extant sites known globally) and *C. integerrima*, *C. massalongi*, *C. nicholsonii*, *D. plumbicola* and *S. cataractae* are on the British Red List (Hodgetts 2011). The present survey has reinforced the view that several other bryophytes found mainly at mine sites have too many records to remain on the Irish Red List (*Bryum*

Copper mines	Rare Bryophytes
Allihies (Mountain)	*C. int*, *C. mas*, *C. nic*, *D. cor*, *D. lin*, *P. and*, *S. cat*
Knockmahon 'village'	*C. int*, *C. nic*, *P. and*
Cappagh	*C. nic*, *P.and*, *S. cat*
Bunmahon	*C. mas*, *P. and*
Caim & Ballyhighland	*C. nic*, *S. cat*
Tigroney West	*C. nic*
Muckross Lake	*C. mas*
Ross Island	*C. mas*
N. of Caminches	*P. and*
Dooneen	*C. mas*
Lead mines	**Rare Bryophytes**
Glendasan (Old Works)	*C. int*, *C. mas*, *C. nic*
Shallee	*C. nic*, *D. plu*
Ballycorus	*C. mas*, *D. plu*

C. int = Cephaloziella integerrima; *C. mas = Cephaloziella massalongi*; *C. nic = Cephaloziella nicholsonii*; *D. cor = Ditrichum cornubicum*; *D. lin = Ditrichum lineare*; *D. plu = Ditrichum plumbicola*; *P. and = Pohlia andalusica*; *S. cat = Scopelophila cataractae*

Table 6. Analysis of data on mine sites surveyed. Ranking of sites by occurrence of rare bryophytes.

pallescens, *Cephaloziella stellulifera*, *Weissia controversa* var. *densifolia*). None of the vascular plants associated with metalliferous ground in Ireland depends on this habitat alone and none is really rare, although *Minuartia verna* is local and rather scarce.

The eight rare bryophytes closely associated with metalliferous sites in Ireland are more or less closely associated with peculiar, species-poor vegetation types. This vegetation, as well as the populations of rare species, merits conservation.

Two mining techniques have been used extensively at modern metalliferous mines in Ireland. These are extensive quarrying (open cast) operations, or underground mining of ore that is powdered in a mill and processed before residues (tailings) are pumped into a tailings dam. Study of modern open cast mine sites in Ireland (Cronebane and Connary, most of Ballymurtagh and Garryard West) and those with tailings dams (Galmoy, Tara, Tynagh) has failed to disclose any rare bryophytes or any habitat suitable for them. In contrast, a wider variety of mining techniques were used at mines worked during the eighteenth, nineteenth and early twentieth centuries, some of which resulted in spillage of ore or incomplete recovery of low grade ore. The rare metallophytes have persisted at some of those sites where metals were left behind.

It is therefore clear that the modern mines are of no interest for conservation of metallophyte bryophytes, the survival of which will depend on persistence and suitable management of relict patches of habitat that resulted from the older mining work, in many cases from the nineteenth century. These areas are often under pressure as potential development land, as untidy and potentially dangerous places that need 'landscaping' (and even attract EU grant aid for it) or they are merely lost under scrub and saplings after generations of neglect.

It is therefore important to ensure statutory protection and appropriate management of the most important of the metalliferous mine sites with rare bryophytes and the distinctive habitat types on which they depend. Table 6 ranks the mine sites according to the number of Red List bryophyte species they contain: ten disused copper mines and three disused lead mines are involved.

The richest site is at Allihies (Mountain Mine) with seven Red List species and this site has now been protected within the Kenmare River candidate SAC. Muckross Lake, Ross Island and Glendasan are also within protected areas and the sites at the tops of scenic coastal cliffs at Bunmahon and Dooneen also appear relatively safe.

Six sites thus lack protection. Two of these are relatively less significant than the others: Tigroney West has little of importance other than a strong patch of *Cephaloziella nicholsonii* on the river bank; Cappagh still has good populations of *C. nicholsonii* and *Pohlia andalusica* and a tiny patch of *Scopelophila cataractae*, but the site is small and already fragmented by housing and roads and hence difficult to protect effectively. This leaves four sites that may merit protection:

(1) Knockmahon 'village' is a copper mine spoil site, with the largest populations in Ireland of *Cephaloziella integerrima* and *Pohlia andalusica* (see Figure 4) and very strong populations of *Cephaloziella nicholsonii*. Calaminarian Grassland vegetation is well developed (0.28 ha). It is on flat and gently sloping ground and highly vulnerable to development, tipping or merely being covered over with soil. During a subsequent visit to this site in 2009, preliminary work on levelling the land for a housing development, with planning permission, was already underway. Its prospects for conservation appear to be bleak.

(2) Caim and Ballyhighland is a copper mine-spoil site with the largest population of *Scopelophila cataractae* extant in the British Isles (Figure 5), a strong population of *Cephaloziella nicholsonii* and well developed Calaminarian Grassland vegetation (0.16 ha). This site should be considered for Natural Heritage Area (NHA) status.

(3) Shallee is an extensive old and more modern lead mine site with much the largest of the two Irish populations of *Ditrichum plumbicola* (Figure 6) and a tiny amount of *Cephaloziella nicholsonii*. Calaminarian Grassland vegetation is extensive (0.9 ha) and well developed. Threats are obvious from ongoing restoration work on an engine house ruin, and existence of large areas of derelict land with rusting oil drums, cables and dangerous open adits and workings. The area of metallophyte bryophyte interest lies just outside the boundary of the Silvermines Mountains West candidate SAC, and this boundary should be extended to include it.

(4) Ballycorus is a historic lead mine site close to the southern edge of Dublin, with building ruins and structures of great interest to the mining historian. It has the second Irish population of *Ditrichum plumbicola*, a small amount of *Cephaloziella massalongi* (which is unusual at lead mines) and Calaminarian Grassland vegetation (0.12 ha). The mine spoil is currently disturbed by motorcycling. Although less important than sites (1)-(3) it is worthy of consideration for site protection.

Besides the desirability of obtaining statutory protection of these four additional sites, it is important to provide appropriate habitat management to ensure favourable conservation status is achieved or maintained at these and other localities with rare metallophyte bryophytes. Notes on threats to individual sites are given in the accounts of sites that form the body of the unpublished report to NPWS (Holyoak 2008). However, several recurrent themes are involved.

Metallophyte bryophytes are small plants that mainly have little tolerance of shading or competition from other plants. Their toxic substrata inhibit growth of competing plants, but the toxic patches are often small and prone to accumulation of litter from nearby vegetation. Planted trees, or scrub or saplings growing up in the vicinity may be particularly harmful, causing a rain of leaf litter in addition to direct shading.

Conservation workers and others (such as well intentioned builders) usually seek open patches of ground for fires to burn arisings from scrub clearance, etc. Unfortunately, the obvious open 'bare' patches are often the habitats of greatest interest for metallophyte bryophytes, because toxicity of the substrata keeps them 'bare'. Careful instruction and supervision of con-

Figure 4. Copper mine spoil at Knockmahon 'village', Co. Waterford: the unprepossessing vegetation in foreground has the largest Irish populations of both **Cephaloziella integerrima** *and* **Pohlia andalusica.**

Figure 5. Bank of highly toxic copper mine spoil at Caim and Ballyhighland Mine, Co. Wexford: steep spoil apparently lacks all vegetation at first sight, but close inspection reveals large patches of **Scopelophila cataractae** *(e.g. by knife), forming its largest population extant in British Isles.*

Figure 6. Relevé 68 at Shallee, Co. Tipperary: lead mine spoil with sparse cover of **Ditrichum plumbicola, Solenostoma gracillimum** *and* **Agrostis capillaris.**

servation management workers may therefore be needed.

Competing vegetation on open ground at mine sites is often kept trimmed by rabbits. Their needs should be considered if fencing or other obstacles are erected. Housing, public amenity or car park development near a mine site often results in more dogs, leading to fewer rabbits in the open places and inadequate grazing pressure.

Historic mine buildings (mainly ruined engine houses) are present at several mine sites. One of these was restored in 2002-2003 and another was being restored in May 2008. If more work of this kind is carried out it is important to ensure that it does not damage populations of rare bryophytes. Access for builders' vehicles may churn track surfaces; storage and mixing of building materials may also damage habitats. The rare metallophytes are all acidophiles and hence vulnerable to calcareous dust from cement or lime mortar, which may therefore need to be mixed off site. Similar considerations may apply to works to cap open mine shafts or to fence adits. At the most important bryophyte sites it may be necessary to carry out bryophyte surveys and prepare impact assessments prior to works, then arrange close supervision as work proceeds.

Particular care is needed if public access to mine areas is improved. At Tankardstown Mine all metallophyte interest in the vicinity of the restored engine house has been destroyed by landscaping work, involving covering mine spoil with soil, building steps, erecting seats, signboards and statues and planting saplings. Survey of bryophytes and impact assessment should precede consent for any such works at other mine sites.

Off road vehicles (motorcycles, quad bikes, sometimes even Land Rovers) regularly damage mine-spoil habitats at some sites. Fencing, new ditches or enforcement work by conservation rangers may be needed to exclude such activity. Dumping of rubbish is also a problem at many sites. Besides covering mine-spoil habitat, the material involved may be nutrient rich, resulting in damage to surrounding areas as a result of eutrophic run off.

Important sites for bryophytes that are protected as SAC or NHA need periodic monitoring. Annual visits (at least) from conservation rangers should suffice to reveal tipping, usage by off road vehicles, squatters, serious scrub encroachment and other obvious signs of damage. However, surveys by skilled bryologists are also necessary at longer intervals, to assess bryophyte populations and threats, and where possible to demonstrate the interest to conservation rangers. These surveys need to be carried out at appropriate times of year (usually winter or early spring) in suitably damp conditions, by workers competent to find and identify e.g. *Cephaloziella* and *Ditrichum* spp. Visits to the most important sites for this work should be at four year intervals, or more often if habitat management or other issues arise.

Research into the conservation biology of some of the metallophyte bryophytes (*Cephaloziella massalongi*, *C. nicholsonii* and *Ditrichum cornubicum*), including *in vitro* cultivation and cryopreservation techniques, is currently being undertaken at the National Botanic Gardens, Glasnevin, Dublin.

DISPERSAL OF METALLOPHYTE BRYOPHYTES BY MAN

Occurrence of tiny populations of metallophyte bryophytes at so few widely separated localities poses interesting questions about the methods by which they could have dispersed to reach the places in which they grow. Dispersal by wind blown spores can only be a likely explanation for one of the eight species involved (*Cephaloziella integerrima*), since capsules are unknown anywhere in three species (*Cephaloziella nicholsonii*, *Ditrichum cornubicum* and *D. plumbicola*), unknown in Europe for *Scopelophila cataractae*, unknown in Britain and Ireland for *Cephaloziella massalongi* and very rare in Europe for *Ditrichum lineare* and *Pohlia andalusica*; however, all of these have small bulbils, gemmae or tubers that might allow vegetative dispersal e.g. by animals, flowing water or on footwear (Hill *et al.* 2007, Lockhart *et al.* in press.). Human involvement in accidental dispersal of the rare metallophytes seems especially likely, since the history of metalliferous mining contains many examples of personnel and equipment moving long distances from one mining area to another.

Smith (2004) suggested that *Scopelophila cataractae* (Figure 7) may have reached a smelting works in south Wales as an accidental introduction with ore, but that introduction from smelting works to mines was less likely as ore was not transported back to mines. However, the nineteenth century sailing vessels that carried Cornish copper ore from Portreath to Swansea returned with coal to power the Cornish mine engines. As discussed by Holyoak and Lockhart (2009), the locations of the three Irish populations of *S. cataractae* are at disused mines in rather remote rural locations, like most of those in Cornwall and elsewhere in Britain. Hence the species has evidently been able to disperse efficiently to these relatively tiny and widely separated patches of habitat created by copper mining, a process in which accidental human involvement seems more likely than natural spread. However, this dispersal may have been more likely to have occurred during the nineteenth century when, in addition to the two way trade in copper ore and coal, personnel and equipment were frequently moved between active mines (cf. Cole 1922, Barton 1961). Furthermore, open spoil surfaces

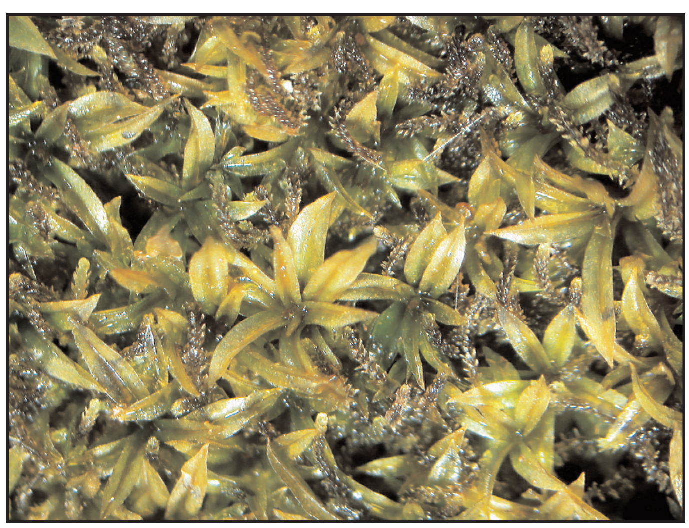

Figure 7.* Scopelophila cataractae *(green leaves) with* Cephaloziella nicholsonii *(thin blackish shoots), 2004, Higher Brea, West Cornwall.

Figure 8. **Ditrichum cornubicum***, 2004, Crow's Nest, East Cornwall.*

were most extensive in the nineteenth century, rather than during the twentieth century when there was little or no activity at the old mines and hence a declining extent of open mine spoil.

The Irish record of *Ditrichum cornubicum* (Figure 8) provides an even more extraordinary example of a disjunct distribution that is most likely to be explicable through accidental transport by man (Holyoak and Lockhart 2009). Prior to its discovery at Allihies in Co. Cork in 2006, the species had been found worldwide only at three localities in Cornwall, all on copper mine spoil, and only male plants are known. Holyoak and Lockhart (2009) noted that links between nineteenth century copper mining activity in Cornwall (the global centre of copper production by about 1850) and at Mountain Mine at Allihies have been well documented: a small number of Cornish mineworkers were present from 1813 to 1884 along with Cornish mine captains; they formed a small community living in their own village and in 1845 a Protestant Chapel was erected in Allihies for their use (Mahoney 1987, Williams 1991, Morris and Brown 2001, Allihies Copper Mine Museum 2006, The Cornish in West Cork 2006). The possibility therefore exists that *D. cornubicum* and possibly other metallophyte bryophytes were accidentally introduced from Cornwall to Allihies in the nineteenth century, maybe in soil on miners' boots or mining equipment.

However, there may be a greater likelihood that its introduction from Cornwall was much more recent. The population of *D. cornubicum* at Allihies is located on the track giving access to the man engine house, considered the best preserved example of a Cornish design man engine house anywhere in the world (Morris and Brown 2001). Consolidation works on this historic building were carried out in 2002-2003 by specialist builders and stonemasons from Cornwall: Darrock and Brown Ltd, Building Services, of Bodmin (Morris 2002, 2003). Bill Gladwell (Managing Director of Darrock and Brown Ltd) confirmed in 2008 that they repeatedly used the access track at Mountain Mine where *D. cornubicum* now occurs, sometimes unloading their van with equipment brought directly from Cornwall, including shovels and boots, very close to its location. He thought it quite possible that tubers of the moss might have been carried there from Cornwall amongst soil attached to their vehicle or equipment. Immediately before travelling to Ireland their van had been used for work at disused copper mines in West Cornwall (where *D. cornubicum* is unknown). More significantly, before 2002 it had been driven along a track to Prince of Wales Engine House at Phoenix United Mine in East Cornwall prior to the company providing a quotation for work there, around the time when *D. cornubicum* occurred in the middle of that short length of track.

As pointed out by Holyoak and Lockhart (2009), it will probably remain impossible to be certain of the means by which *D. cornubicum* reached Allihies or the timing, but the precise location of the population points strongly to it being associated with works at the Cornish design man engine house. Arrival of *D. cornubicum* at Allihies as recently as 2002 or 2003 would be consistent with its discovery at a single location there in 2006 and restriction to an area *ca* 20 m across in 2008.

More generally, it appears that the regional metallophyte bryophyte floras in different parts of western Europe share the same small group of characteristic species. Thus, of the eight rare metallophyte species from Ireland listed at the head of this section (*Cephaloziella integerrima*, *C. massalongi*, *C. nicholsonii*, *Ditrichum cornubicum*, *D. lineare*, *D. plumbicola*, *Pohlia andalusica*, *Scopelophila cataractae*), all eight occur in Cornwall, four occur in Devon, five occur in Wales and seven occur in Germany. Furthermore, lowland metalliferous sites in these regions do not have any metallophyte bryophyte species additional to the eight known in Ireland. This regional uniformity is remarkable in view of the wide geographical isolation of the relatively tiny land areas occupied by each of the species, the wide extent of unsuitable habitat between most of the sites and the apparently poor potential for dispersal of species which (with the exception of *C. integerrima*) rarely or never produce spores. A history of accidental dispersal involving centuries of human movements between mine sites may offer the simplest explanation for this.

ACKNOWLEDGEMENTS

This survey was funded by National Parks and Wildlife Service. Marie Dromey provided helpful liaison with ongoing grassland surveys. Naomi Kingston designed standard recording forms (Tables 2 and 3) and a database for the survey which saved much time in data recording. John Fisher and Mike Wyse Jackson provided details of worthwhile mine sites that might otherwise have been overlooked. Bill Gladwell (Managing Director of Darrock and Brown Ltd) kindly supplied information on his companies' work on historic mine buildings in Cornwall and in Co. Cork. Figures 2 and 3 were prepared using DMAPW © Dr Alan Morton.

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