The far from miserable flora of the muddy banks downstream the "Misère" forebay of the Upper-Sûre lake in Luxembourg

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Wolff, J.-P., F. Hans & Y. Krippel, 2024. The far from miserable flora of the muddy banks downstream the "Misère" forebay of the Upper-Sûre lake in Luxembourg. *Bulletin de la Société des naturalistes luxembourgeois* 126 : 33-51. https://doi.org/10.59513/snl.2024.126.033

Published online 7 July 2024 (ISSN 2716-750X), printed volume 9 December 2024 (ISSN 0404-9620).

Abstract. A recent survey of the muddy banks of the Upper-Sûre reservoir in Luxembourg led to the discovery of a considerable number of rare vascular plants and bryophytes as well as several insufficiently documented habitats for Luxembourg. *Bidens radiata* is newly listed for Luxembourg – locally occurring on gravel banks –, *Leersia oryzoides* has rarely been recorded in Luxembourg, while *Panicum barbipulvinatum* has only been observed once in 2005. *Riccia cavernosa*, *Riccia huebeneriana* and *Physcomitrium sphaericum* are among the bryological peculiarities. After the water receded, we observed an explosive spread of the uncommon alga *Botrydium granulatum*, covering large areas with its green globules. The muddy banks are a habitat for specific plant communities with many rare and protected species. Unfortunately, national legislation omits to protect this FFH Annex I habitat "3270 Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation".

Keywords. Lac de la Haute-Sûre, Luxembourg, muddy banks, *Bidens radiata*, Bidention, Chenopodion, Corrigiolion, Isoeto-Nanojuncetea, Riccio-Physcomitrelletum.

1. Introduction

The Upper-Sûre lake is located in the valley of the river Sûre in the north-west of Luxembourg. The groundbreaking ceremony for the construction of the dam near Esch-sur-Sûre was on the 30th of July 1955 (Anonymous 1955, A.S. 1955). The 47 m tall wall was built in only two years – the last concrete pour and the topping-out ceremony (lux. Straussfeier) took place on the 14th of October 1957. On the 1st of May 1959 the retention of the water began and 6 months later, the reservoir was full (Meyer 1965). At top water level, it covers an area of 3.8 km^2 and has a water capacity of almost 60 million m^3. The total length of the lake's banks is approximately 42 km. The catchment area covers a total of 428 km^2, of which 274 km^2 are located in Belgium (Heinerscheid 1962, Hansen 1981). There are two pre-dams, so-called "mud walls": one near Pont Misère (9.5 m tall with a fish pass) and one between Bavigne and Liefrange (23 m in height). These forebay dams were built to trap the fine alluvial sediments and driftwood from the upper reaches of the Sûre and the Béiwenerbaach (Heinerscheid 1962).

From a botanical point of view, the reservoir features a rather poor biodiversity, except for the areas situated upstream of the Misère

and Bavigne pre-dams, where huge wetland areas of high conservation value have developed. The usually flooded, mostly rocky margins of the main reservoir only provide a partially ephemeral habitat for a very specific flora during the periods when they fall dry due to water level regulation, exploitation of drinking water and/or lack of precipitation – or when the reservoir is drained like in 1991 (Colling & Helminger 1992).

During a short visit to the exposed banks and muddy areas located downstream of the Misère pre-dam with its fish-pass in September 2023 (Fig. 1), two of the authors (J.-P. W. & Y. K.) identified various rare to very rare vascular plants and bryophytes – including new taxa for Luxembourg. The area was rated as FFH Annex I habitat "3270 Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation" (a habitat that, at that time, was not listed for Luxembourg) and further investigations were scheduled. The present paper summarises the results of the surveys.

2. Material and methods

The study area is located in Luxembourg (LUREF 56,599/104,488) in the valley of the Upper-Sûre river in the country's northwest (the western "Éislek" region). The bedrock is Upper Siegenian (Devonian period), which is characterised by indistinctly layered coarse shale with rare beds of clayey sandstone (Bintz & Maquil 1992). The soil layer is formed by alluvial sediments. The study section covers an area of approx. 4 ha of which approx. 3.3 ha are situated on the left bank of the retained river.

The authors carried out several floristic and bryological surveys of the sludge banks during September and October 2023. In order to categorise the collected species in relation to the site's microhabitats, the dried-out sludge area has been divided into 4 zones (Fig 2).

The occurring species (vascular plants and mosses/bryophytes) were recorded with pinpoint accuracy using the BDM-L app. Frequency data according to a semi-quantitative scale.

The taxonomy and nomenclature follow Verloove & Van Rossum (2024) for the vascular plants and Hodgetts et al. (2020) for the bryophytes. The nomenclature of the plant communities is based on Pott (1995) and Rennwald (2000) and the nomenclature of bryophyte communities follows von Hübschmann (1986).

Soil samples (3-4 in each of the 4 zones) were taken to a max. depth of 15 cm using an Edelmann auger. The samples were analysed in the ASTA soil science laboratory for pH, nutrient content, organic matter, granulometry and stone content.



Fig. 1. View of the study area downstream of the Misère mud wall (photo J.-P. W., 2023-10-02).



Fig. 2. Map of the study area with the 4 flooding zones. Map based on Orthophoto 2022, © Administration du cadastre et de la topographie Luxembourg.

3. Results

3.1. Soil analyses

The soil samples from the higher located areas (Z1) show slightly acidic to neutral soil conditions with a pH of 5.8-6.6. The lower areas (Z2-Z4) are neatly acidic with pH values of 4.5-4.7. The C/N ratio is low; rapid mineralisation is taking place. The TOC content is quite low, the soils are all slightly to moderately rich in humus. On the right bank, Z2 and Z3, the sediments appear somewhat richer. The results of the soil analyses are summarised in Table 1.

3.2. Flora and vegetation

The surveys took place at the end of September/beginning of October 2023, so very few spring and summer annual species could

Table 1. Results of the soil analysis [Z1 - Z4 = flooding zones, RB = right bank, LB = left bank, pH = soil pH, C/N = carbon to nitrogen ratio, TOC = total organic carbon, SC = percentage of stone content, * = since 2016 flooding only in winter].

Zone	Flooding (months)	Granulometry	pH ($CaCl_2$)	C/N	TOC	SC (%)
Z1 LB	rarely	sandy loam	5.8	8.3	1.5	60
Z1 RB	rarely	sandy loam	6.6	7.3	1.1	72
Z2 LB	1-3*	silty loam	4.5	8.3	1.9	30
Z2 RB	1-3	sandy loam	5	8.3	2	54
Z3 LB	1-6(7)	silty loam	4.6	8.6	1.9	12
Z3 RB	1-6(7)	silty loam	4.5	8.8	2.3	13
Z4 RB	1-3	sandy clay	4.7	10.3	3.3	41

be confirmed. The final inventory (Table 2) resulted in a list of 72 species (2 algae, 16 bryophytes and 54 vascular plants).

The species are presented, grouped by growing zone, with a focus on a possible phyto-sociological assessment. Although classical vegetation surveys of homogenous stands have not been carried out, the species list allows for a visualisation of the sociological and ecological gradient of the area.

Table 2. List of the species recorded during the floristic inventories of the exposed mud at the Misère barrage [Z1 - Z4 = Frequency of observations in the 4 zones of the study area: a = abundant, s = scattered, i = isolated, r = rare, rd = rare-forms small-scale dominant stands, la = locally aspect building; cryptogams: bryo. = bryophyte, alg. = alga].

Taxa	Cryptogams	Z1	Z2	Z3	Z4
Species in Zones 1-3					
Characteristic species Isoeto-Nanojuncetea					
Gnaphalium uliginosum L.		a	a	a	
Limosella aquatica L.		s	a	a	
Corrigiola litoralis L.		s	s-la	s	
Species mainly in Bidentetea but also in Isoeteo-Nanojuncetea					
Oxybasis rubra (L.) S. Fuentes, Uotila et Borsch (incl. var. *humile* (Hook.) Mosyakin *)		r	r	a*	
Shrubs Phragmitetalia					
Juncus filiformis L.		s	a-la	s	
Species in Zones 1 & 2					
Characteristic species Isoeto-Nanojuncetea					
Lipandra polysperma (L.) S. Fuentes, Uotila et Borsch		s	s		
Plantago major subsp. *pleiosperma* Pilg.		s	s		
Species mainly in Bidentetea but also in Isoeteo-Nanojuncetea					
Bidens frondosa L.		a	a		
Bidens tripartita L.		a	a		
Persicaria lapathifolia (L.) Delarbre		a	a		
Rorippa palustris (L.) Besser		a	a		
Shrubs					
Mentha arvensis L.		a	a		
Lysimachia vulgaris L.		s	s		
Annuals					
Panicum barbipulvinatum Nash		s	s		
Poa annua L.		s	s		
Potentilla norvegica L. subsp. *hirsuta* Michaux Hyl.		s	s		
Drepanocladus aduncus (Hedw.) Warnst.	bryo.	a	a		
Species in Zones 2 & 3					
Characteristic species Isoeto-Nanojuncetea					
Lythrum portula (L.) D.A. Webb			a	a	
Riccia cavernosa Hoffm.	bryo.		a	a	

Table 2. (continued)

Taxa	Cryptogams	Z1	Z2	Z3	Z4
Riccia huebeneriana Lindenb.			s	s	
Species of Potentillion anserinae					
Persicaria amphibia (L.) S.F. Gray			a	a	
Equisetum fluviatile L.			r	r	
Potentilla anserina L.			s	s	
Spirodela polyrhiza (L.) Schleid.			r	r	
Physcomitrium sphaericum (C.F.Ludw. ex Schkuhr) Brid.	bryo.		a	a	
Funaria hygrometrica Hedw.	bryo.		s	s	
Leptodyctium riparium (Hedw.) Warnst.	bryo.		s	r	
Species in Zones 3 & 4					
Callitriche hamulata Kütz. ex Koch				s	s
Species only in Zone 1					
Shrubs Phragmitetalia					
Phalaris arundinacea L.		s			
Lythrum salicaria L.		s			
Myosoton aquaticum (L.) Moench		s			
Leersia oryzoides (L.) Swartz		s			
Shrubs Potentillion anserinae					
Carex hirta L.		s			
Ranunculus repens L.		s			
Galium palustre L.		a			
Stellaria alsine Grimm		s			
Aster lanceolatus Willd.		rd			
Annual species of dryer or ruderal locations					
Sagina procumbens L.		s			
Echinochloa crus-galli (L.) Beauv.		s			
Polygonum aviculare L.		s			
Vicia hirsuta (L.) S.F. Gray		r			
Atriplex patula L.		i			
Linum usitatissimum L.		i			
Ornithopus perpusillus L.		i			
Amaranthus retroflexus L.		r			
Solanum lycopersicum L.		i			
Brachythecium rivulare Schimp.	bryo.	a			
Calliergonella cuspidata (Hedw.) Loeske	bryo.	a			
Species only in Zone 2					
Shrubs Phragmitetalia					
Carex acuta L.			a-la		

Table 2. (continued)

Taxa	Cryptogams	Z1	Z2	Z3	Z4
Juncus effusus L.			a-la		
Lycopus europaeus L.			s		
Iris pseudacorus L.			r		
Rumex maritimus L.			r		
Annuals					
Juncus bufonius L.			a		
Spergularia rubra (L.) J. et C. Presl			a		
Matricaria maritima L. subsp. *inodora* (L.) Soó			s		
Cerastium glomeratum Thuill.			s		
Persicaria mitis (Schrank) Asenov, nom. conserv.			s		
Bidens radiata Thuill.			s		
Climacium dendroides (Hedw.) F.Weber & D.Mohr	bryo.		a		
Ptychostomum pseudotriquetrum var. *bimum* (Schreb.) Holyoak & N.Pedersen	bryo.		s		
Leptobryum pyriforme (Hedw.) Wilson	bryo.		s		
Physcomitrium pyriforme (Hedw.) Bruch & Schimp.	bryo.		s		
Pseudephemerum nitidum (Hedw.) Loeske	bryo.		s		
Riccia glauca L.	bryo.		s		
Riccia cf. *subbifurca* Warnst. ex Croz.	bryo.		s		
Tortula truncata (Hedw.) Mitt.	bryo.		s		
Trichodon cylindricus (Hedw.) Schimp.	bryo.		s		
Species only in Zone 3					
Botrydium granulatum L.	alg.			a-la	
Bumilleria sicula Borzì	alg.			a-la	
Oxybasis rubra var. *humilis* (Hook.) Mosyakin				a-la	
Ranunculus flammula L.				s	
Physcomitrium patens (Hedw.) Mitt.	bryo.			a	
Species only in Zone 4					
Callitriche stagnalis Scop.					r
Persicaria minor (Huds.) Opiz					s

3.2.1. Zones 1 and 2

In recent years, these zones have been partially flooded only in late winter/early spring (Fig. 3A). Although both zones are morphologically different and the soil conditions also slightly differ, there is no major difference in species composition. In both zones, species of the Chenopodio-Corrigioletum Hülb. et R. Tx. and the Cypero fusci-Limoselletum aquaticae (Oberd. 1957) Korneck 1960 such as *Oxybasis rubra*, *Lythrum portula*, *Limosella aquatica* and *Corrigiola litoralis* grow on the stonier soils. In the drier areas, we find a large population of the rare rice cut grass (*Leersia oryzoides*) showing a possible interlocking with the Leersietum oryzoidis Eggler 1933, an association that Pott (1995) ranges within the



Fig. 3. A – View from the mud wall on the flooded study area in early April 2024 (photo J.-P. W., 2024-04-02). B – Aspect of the Caricetum gracilis on the left bank (photo J.-P. W., 2023-09-15). C – *Juncus filiformis* stands in an open area of the large *Carex acuta* population (photo J.-P. W., 2023-09-24). D – Zone 3 with the shallow muddy areas that slope gently down to the former riverbed of the Sûre (photo J.-P. W., 2023-11-03). E – *Lythrum portula* forming large contiguous stands together with *Limosella aquatica* (photo J.-P. W., 2023-11-03). F – *Gnaphalium uliginosum*, *Limosella aquatica* and *Oxybasis rubra* var. *humilis* (photo J.-P. W., 2023-10-13). G – *Corrigiola litoralis* growing on grittier hummocks (photo J.-P. W., 2023-09-15).

reedbed associations. In this area, we also observe extended populations of *Panicum barbipulvinatum,* a rare but possibly overlooked species in Luxembourg.

Bidens tripartita and *Bidens frondosa* are omnipresent and sometimes form dense stands. On the right riverbank, these are accompanied by a *Bidens radiata* population covering about 50 square metres throughout which we find, in addition to *Bidens radiata* – newly documented for Luxembourg –, other constant companions of the *B. radiata* community such as *Lipandra polysperma*, *Polygonum lapathifolium*, *Plantago major* subsp. *pleiosperma*, *Potentilla norvegica*, *Rorippa palustris* and *Rumex maritimus*.

The species-poor Caricetum gracilis Almquist 1929 (Fig. 3B) is mainly found in zone 2, where *Carex acuta* (syn. *Carex gracilis*) forms extensive populations on both banks, with *Lycopus europaeus* and *Lysimachia vulgaris* growing in the gaps. Other *Carex* species are mixed in, but due to the late survey date further possibly occurring species like *Carex riparia* or *C. acutiformis* could not be identified based on the sole vegetative features.

On the extensive flat area of the left bank, a larger gap in the middle of the *Carex acuta* population is densely colonised by the rare thread rush (*Juncus filiformis*). Galunder (1988) describes extensive *Juncus filiformis* populations on the banks of the reservoirs of the German "Oberbergisches Land" district. In those locations, comparable to our study area, the species tend to become dominant in the forebay basins. Budde & Brockhaus (1954) describe the *Juncus filiformis* stands at the dams of the "Süderbergland" as "Juncus filiformis subassociation of Plantago intermedia prov.". According to Galunder (1988), *J. filiformis* stands form a "relatively stable pioneer community". More recently Gehlken et al. (2019) have described a "Juncus filiformis" variant of the Corrigiolion Gehlken & Hülb. 2011 adjoining the *Carex acuta* zone on gently sloping banks. Old stalks of *Lythrum salicaria*, which occasionally remained in the stands, indicate that they had already dried out in previous years". This description renders the exact situation of zone 2 of our study area (Fig. 3C).

3.2.2. Zone 3

Zone 3 represents the shallow muddy areas that, in places, slope gently down to the former riverbed of the Sûre (Fig. 3D). These areas are regularly flooded until late spring and only fall dry in the following months. The allochthonous sediments are characterised by silty loam with a low stone content. Low-growing vegetation arises from the existing or alluvial seed bank (Colling & Helminger 1992) and only reaches its optimum in September-October.

In this zone, species from the Cypero-Limoselletum are prevailing. *Lythrum portula* forms large contiguous stands together with *Limosella aquatica* (Fig. 3E). Constant companions are juvenile plants of *Gnaphalium uliginosum* (Fig. 3F), the land form of *Callitriche hamulata* and *Oxybasis rubra* var. *humilis*, a very small-growing variety (Verloove & Van Rossum 2024) that also plays a role in the Chenopodio-Corrigioletum, which is closely intertwined with the Limoselletum in this zone. *Corrigiola littoralis* (Fig. 3G), growing on somewhat grittier hummocks at the edge of the extensive mud flats as well as *Oxybasis rubra* var. *humilis* and *Limosella aquatica* occurring in large numbers in the muddy hollows on the reservoir banks, characterise the aspect of this zone.

At the end of September, the recently dried up, very moist muddy areas, which were not yet overgrown with vegetation, were covered by a carpet of one to two millimetres small, vivid green spheres (Fig. 4A) – the uncommon alga *Botrydium granulatum* heralds, according to Diekjobst & Ant (1967), the subsequent development of higher vegetation in these muddy areas.

After the algae had died off a few weeks later, an explosive spread of *Ricciaceae* took place and unusually large populations of some rare, ephemeral acrocarpous mosses developed on the muddy ground. von Hübschmann (1957) describes the development of a Riccio cavernosae-Physcomitrelletum (Allorge 1921) v. Hübschmann 1957 after the dying off of *Botrydium granulatum* (Fig. 4B). This community is mostly composed of acrocarpous ephemeral mosses and *Riccia* species: *Tortula truncata*, *Physcomitrium pyriforme*, *P. sphaericum*, *P. patens*, *Riccia cavernosa* (= *crystal-*



Fig. 4. A – The vivid green spheres of *Botrydium granulatum* (photo J.-P. W., 2023-09-20). B – Aspect of the Riccio cavernosae-Physcomitrelletum community (photo J.-P. W., 2023-09-15). C – *Bidens radiata* (photo J.-P. W., 2023-09-20). D – *Leersia oryzoides* (herb. LUX MNHNL153379). E – *Oxybasis rubra* var. *rubra* (photo J.-P. W., 2023-09-24). F – *Oxybasis rubra* var. *humilis* and juvenile *Gnaphalium uliginosum* (photo J.-P. W., 2023-10-05). G – *Panicum barbipulvinatum* (photo Y. K., 2023-09-15). H – *Potentilla norvegica* subsp. *hirsuta* (photo Y. K., 2023-09-15). I – *Physcomitrium sphaericum* (photo J.-P. W., 2023-09-15).

lina p.p.), *R. huebeneriana* and, in view of our observations, represents the pioneer stage of the muddy banks introducing the development of vascular plants.

3.2.3. Zone 4

On the right bank of the lake, close to the hillslope, there is a small, wet depression of approx. 40 square metres. Spring water seems to seep in from the nearby steep, spruce-covered slope. Zone 4 is species-poor. Apart from *Callitriche hamulata* and *Callitriche stagnalis*, there is a rather large pure population of the rare small knotweed (*Persicaria minor*).

3.3. New and rare vascular plants

The inventory of the margins of the reservoir downstream of the Misère pre-dam led to the discovery of one new vascular plant species for Luxembourg as well as to the confirmation of a list of 14 rare to very rare taxa (Verloove & Van Rossum 2024) of which 11 are Red List species (Colling et al. in prep.). Nine of the species are protected by law (Memorial 2010).

With reference to Table 3, we provide an exhaustive description of the new or very rare taxa observed in the study area.

Bidens radiata Thuill.

Bidens radiata (Fig. 4C) was collected on the 15th of September 2023 (herb. LUX n° MNHNL153364). To our knowledge, it had never been documented in Luxembourg.

The latest editions of the *Nouvelle Flore* (Lambinon & Verloove 2015, Verloove & Van Rossum 2024) describe *Bidens radiata* as very rare (RR). It has occasionally been observed in the French region of the *Nou-*

Table 3. List of rare species recorded during the floristic inventories of the exposed mud at the Misère dam [1 = Red List of vascular plants for Luxembourg (Colling et al. in prep.): CR = critically endangered, EN = endangered, VU = vulnerable, NT = near threatened. 2 = frequency in the *Nouvelle Flore* for the Ardennes district (Verloove & Van Rossum 2024): AC = quite common, AR = quite rare, R = rare, RR = very rare, adv. = adventive. Species marked with * are protected by law (Mémorial 2010)].

Taxa	(1) Red List (in prep.)	(2) Frequency, Ard. distr. (Verloove & Van Rossum 2024)
Bidens radiata Thuill.	-	-
Callitriche hamulata L.	-	AR
Corrigiola litoralis L.*	EN	R-RR
Iris pseudacorus L.*	NT	AC-AR
Juncus filiformis L.*	VU	RR
Leersia oryzoides (L.) Swartz*	CR	R-RR
Limosella aquatica L.*	CR	RR
Lythrum portula (L.) D.A. Webb	NT	R
Oxybasis rubra (L.) S. Fuentes, Uotila et Borsch*	CR	RR
Oxybasis rubra var. *humilis* (Hook.) Mosyakin*	-	-
Panicum barbipulvinatum Nash	-	RR (adv.)
Persicaria minor (Huds.) Opiz*	EN	AR-R
Persicaria mitis (Schrank)*	CR	AR-R
Plantago major subsp. *pleiosperma* Pilg.	-	R-RR
Potentilla norvegica L. subsp. *hirsuta* Michaux Hyl.	EA	RR (adv.)
Rumex maritimus L.*	CR	adv.
Spirodela polyrhiza (L.) Schleid.*	-	AR-R

velle Flore; since 2005 it is documented in Belgium, mainly in anthropogenic habitats, where it was probably introduced through migrating birds.

In the adjacent Trier region, it also occurs very rarely (Hand et al. 2016). The few occurrences are all in submontane-montane locations on moderately nutrient-rich, more or less acidic mud on the banks of standing waters and dammed lakes. According to Haffner et al. (1979), the species occurred in the valleys of the Moselle and the Saar, but has not been confirmed in these places in a long time (Sauer 1993).

Corrigiola litoralis L.

Corrigiola litoralis (Fig. 3G) is already mentioned on the gravelly riverbanks of the Sûre by Tinant (1836). Other ancient Floras – i.e. Koltz (1873), Krombach (1875) and Klein (1897) – also consider it generally widespread in the Ardennes region.

Nowadays, the strapwort is a rather rare to very rare species of gravelly and sandy riverbanks (Verloove & Van Rossum 2024) and in the new Red List of vascular plants of Luxembourg (Colling et al. in prep.), it is rated as endangered (EN). In the adjacent Rhineland-Palatinate, it is considered as critically endangered (Hanselmann et al. 2023) and even on the verge of extinction in the Trier region (Hand et al. 2016). On the gravel of the Upper-Sûre lake riverbanks, *C. litoralis* is however the most common species alongside *Gnaphalium uliginosum* and *Lipandra polysperma*.

Juncus filiformis L.

Colling (2005) describes *J. filiformis* as critically endangered (CR) in Luxembourg. The 7th edition of the *Nouvelle Flore* (Verloove & Van Rossum 2024) notes that the thread rush occurs very rarely in the Ardennes, mostly growing on acid soil of wet meadows (usually mown), low fens and edges of ponds.

According to Koltz (1873) and Krombach (1875) that rare rush occurs in wet areas, watersides and peat marshes. In Luxembourg, only 28 observations have been recorded up until 2023 (MNHNL 2000-), mostly in wet meadows and low fens in the northern region of the country – most observations were made after 2000 as part of the "Biotopkataster" surveys. In the revised edition of the Red List (Colling et al. in prep.), *J. filiformis* will thus pass from CR to VU (vulnerable). In the German border region, the thread rush is considered a critically endangered species with only a few stands covering a few square meters in the Ruwer floodplain (Hand et al. 2016).

The impressively large and pure stands of *Juncus filiformis* (Fig. 3C) observed in the study area are quite exceptional for Luxembourg, whereas several authors describe a similar phenomenon from reservoir banks in Western Germany (Budde & Brockhaus 1954, Galunder 1988).

Leersia oryzoides (L.) Swartz

For *Leersia oryzoides* (Fig. 4D), there are only 27 records for Luxembourg up until 2023, the latest one being from 2012 by Sonja Naumann (MNHNL 2000-). Colling (2005) classifies it as critically endangered (CR), a status that will be confirmed through the revised Red List (Colling et al. in prep.). Verloove & Van Rossum (2024) consider *L. oryzoides* as rare to very rare in the Oesling, growing mainly on riverbanks. At the end of the 19th century, Koltz (1873), Krombach (1875) and Klein (1897) mention *Leersia* or *Oryza clandestina* as a rare species, occurring along ditches, rivers, ponds as well as along the Moselle river. In nearby Rhineland-Palatinate and Saarland, the species is known from the valleys of the Moselle and the Saar with populations strongly declining however (Haffner et al. 1979, Sauer 1993). As the existing populations are poor in individuals, Hand et al. (2016) expect a further considerable decline in the future.

Limosella aquatica L.

The first observation for Luxembourg of *Limosella aquatica* (Fig. 3F) dates from 1887, when it was found by Jean Feltgen near Wintrange (herb. LUX n° 12603). According to Klein (1897), it is a rare species.

The first observation of this extremely rare species in the Éislek region was made by one of the authors (Y. K.) in 2002 on wet muddy banks of the Upper-Sûre lake (Krippel & Colling 2004), where *Limosella* is able to develop expansive populations with millions of individuals. Each of the few other locations in Luxembourg (Gutland) known to that date only hosted a few plants (Reichling 1955, 1981, 1990, Colling & Krippel 2001).

According to Verloove & Van Rossum (2024), the mudwort is regressing in the territory of the *Nouvelle Flore* and although it can, in good years, develop huge populations downriver of the Misère mud wall, *L. aquatica* is still considered as critically endangered (CR) in the updated Red List (Colling et al. in prep.).

Oxybasis rubra (L.) S. Fuentes, Uotila et Borsch and ***O. rubra*** var. ***humilis*** (Hook.) Mosyakin

Verloove & Van Rossum (2024) differentiate between *O. rubra* var. *rubra* (Fig. 4E), the more widespread variety occurring mostly on wasteland, ruderalised dunes, dry parts of salt meadows, dried-up mudflats, crops or manure, and *O. r.* var. *humilis* (Fig. 4F), which seems to be linked to dried-up mudflats. For the Ardennes district, *Oxybasis rubra* is considered very rare (Verloove & Van Rossum 2024).

In the Red List of the vascular plants of Luxembourg (Colling 2005), *Oxybasis rubra* (Syn.: *Chenopodium rubrum*) is considered extremely rare (R); the status in the revised Red List (Colling et al. in prep.) will probably be critically endangered (CR). For the adjoining Trier region, Hand et al. (2016) describe the species as endangered without providing any abundance figures though; they do not mention var. *humilis*. In the Saarland, it is considered as unsteady (Haffner et al. 1979, Sauer 1993).

In the ancient floras concerning Luxembourg, Tinant (1836), Koltz (1873) and Krombach (1875) mention *Chenopodium*/*Blitum rubrum* occurring in villages, growing along pathways, at the foot of walls, on rubble, riverbanks and near ponds. Koltz (1873) notes it as rare at Vianden castle and rather common in the surroundings of Luxembourg.

For Galunder (1988), *Oxybasis rubra* var. *humilis* is a characteristic taxon of the water knotweed community, which can, however, only rarely be observed on the reservoir margins of the "Oberbergisches Land".

Panicum barbipulvinatum Nash

Panicum barbipulvinatum (Fig. 4G) is a recent newcomer to the Upper-Sûre reservoir region as well as to the Luxembourgish flora. This adventitious taxon was discovered for the first time in Luxembourg by Jacques Lambinon at the edge of a field near Liefrange (Lambinon 2006).

During inventories carried out for the Naturpark Öewersauer in 2022 and 2023 the first author (J.-P. W.) found a larger stand of *Panicum barbipulvinatum* on the banks of the reservoir near Insenborn; it was thus not surprising that the witchgrass was also recorded near the mud wall.

Verloove & Van Rossum (2024) describe *P. barbipulvinatum* (Syn.: *P. capillare* subsp. *barbipulvinatum*) as a very rare adventive weed, naturalised in places. *Panicum capillare*, a species native to western North America (Verloove 2001, Amarell et al. 2014), seems to have been introduced to Europe along with corn seeds during the 18th century (Amarell et al. op. cit.); the species is widespread in Central Europe but may have been overlooked for a long time. For instance, a check in the herbarium of the Botanical Museum of Lausanne revealed several specimens dated 1869 to 1889, all labelled *Panicum capillare* that turned out to be *P. barbipulvinatum*.

Potentilla norvegica L. subsp. ***hirsuta*** Michaux Hyl.

Verloove & Van Rossum (2024) describe *Potentilla norvegica* (Fig. 4H) as occurring on waste ground, roadsides and railway ballast. They consider it as a rare to very rare adventive weed, sometimes naturalised. The *Nouvelle Flore* distinguishes between two subspecies: the very rare *P. n.* subsp. *norvegica* and the rare but sometimes natural-

ised *P. n.* subsp. *hirsuta* Michaux Hyl. – both observed on the riverbanks of the Upper-Sûre lake (Krippel & Colling 2004, 2012, Krippel et al. 2018).

The first record in Luxembourg of *P. norvegica* from Echternach dates back to 1947 (Beck et al. 1950). In the 1950s, it was observed near Mersch [the LUX herbarium holds two specimens collected by L. Reichling and L. Faber (herb. LUX n° 21647 & n° 21648) in the surroundings of the ruins of Pettange castle], and in 2003, it was rediscovered on the banks of the Upper-Sûre reservoir near Burfelt (Krippel & Colling 2004). Since then, this established alien is regularly observed. All recent observations are however restricted to the riverbanks of the lake (MNHNL 2000-).

Hand et al. (2016) report a tendency for it to establish in the Moselle valley of the Trier Region. Only sparse records exist and it is currently still considered a rare species.

Galunder (1988) considers *P. norvegica* as a constant accompanying species of the *Bidens radiata* association. The neophyte has slowly been spreading from Eastern Europe to Central and Western Europe since 1880 (Oberdorfer 2001). It grows within Sisymbrion- and Rumicion communities, but also with Nanocyperion or Bidention species (Oberdorfer op. cit.).

Rumex maritimus L.

Rumex maritimus is already mentioned by Tinant (1836) in damp places in Hollerich and Kockelscheuer. The ancient Floras – Koltz (1873), Krombach (1875) and Klein (1897) – consider the golden dock as quite a rare species. Today, *R. maritimus* remains relatively rare in the territory of the *Nouvelle Flore* (Verloove & Van Rossum 2024) and even very rare in some districts, like the Ardennes. Its preferred habitats are the edges of ponds and ditches (with fresh or slightly brackish water, eutrophic), river gravel, damp humus-bearing sands, exposed mud, sometimes sub-ruderal. Lambinon (2006) mentions having found an impressive specimen of *Rumex maritimus* in the witchgrass stand near Liefrange, which, according to him, constitutes the only find in the Ardennes to that date. Colling & Helminger (1992) however had already reported repeated *Rumex maritimus* observations on dried out muddy areas of the reservoir, even in large populations. Near the Misère barrage, numerous individuals of the golden dock were observed in 2011 (Krippel & Colling 2012). In the revised Red List (Colling et al. in prep.), it will pass from "EN" (Colling 2005) to critically endangered (CR).

In the Trier region, the endangered *R. maritimus* colonises dry, nutrient- and base-rich muddy areas on the banks of large rivers and ponds. Apart from one site in the Eifel, it is restricted to the warmer areas along the Moselle (Hand et al. 2016). For the Saarland, one location in the valley of the Moselle river is known (Haffner et al. 1979), where it appears to have spread after the river development (Sauer 1993).

3.4. Rare bryophytes

The moss flora in the Pont Misère area of the Upper-Sûre reservoir was first investigated by Jean Werner in 1990. Werner reports a "long, dry summer that led to a lowering of the water level. This resulted in the development of a riverbank mudflat over a length of several tens of metres, which is dominated by the moss *Physcomitrium sphaericum*" (Werner & Hans 1991). It was the first documented evidence of *P. sphaericum* for Luxembourg. An older record without evidence comes from the surroundings of Echternach (Koltz 1880). The two records in Werner's publication (1996) "Die Moosflora des Luxemburger Oeslings" refer to the same locality (grid boundary).

Werner (1996) mentions a total of 15 species from several bryosociological records, including *Riccia huebeneriana* which is very rare in Luxembourg. During our recent survey on the 25th of September 2023, a total of 17 species were identified, including six species already recorded by Werner (Table 4).

Fortunately, *Physcomitrium sphaericum* (Fig. 4I) and *Riccia huebeneriana* were found again in 2023. Both species are extremely

Table 4. Comparison of bryophytes recorded during the studies of 1990 (by Werner) and 2023 (by Wolff & Hans) [1 = rarity status according to Werner (2003): R = rare, RR = extremely rare. 2 = Red List status according to Werner (2003): EN = endangered, VU = vulnerable, NT = near threatened]. Species marked with * are protected by law (Mémorial 2010).

Species	(1) Rarity	(2) Red list	Werner 1990	Wolff & Hans 2023
Species of the Cypero-Limoselletum ass.				
Physcomitrium patens (Hedw.) Mitt.	R		●	●
Riccia cavernosa Hoffm.	RR	NT		●
Riccia glauca L.				●
Riccia huebeneriana Lindenb.*	RR	EN	●	●
Species of the Riccio cavernetae-Phiscomitrelletum ass.				
Funaria hygrometrica Hedw.			●	●
Leptobryum pyriforme (Hedw.) Wilson	AR			●
Physcomitrium patens (Hedw.) Mitt.	R		●	●
Physcomitrium pyriforme (Hedw.) Bruch & Schimp.	R			●
Physcomitrium sphaericum (C.F.Ludw. ex Schkuhr) Brid.	RR	VU	●	●
Pseudephemerum nitidum (Hedw.) Loeske			●	●
Riccia cavernosa Hoffm.	RR	NT		●
Riccia glauca L.				●
Riccia huebeneriana Lindenb.*	RR	EN	●	●
Tortula truncata (Hedw.) Mitt.				●
Other species				
Brachythecium rivulare Schimp.				●
Bryum argenteum Hedw.			●	
Bryum gemmilucens R.Wilczek & Demaret	R	NT	●	
Calliergonella cuspidata (Hedw.) Loeske				●
Climacium dendroides (Hedw.) F.Weber & D.Mohr				●
Dicranella staphylina H.Whitehouse			●	
Drepanocladus aduncus (Hedw.) Warnst.	R			●
Imbribryum subapiculatum (Hampe) D.Bell. & Holyoak			●	
Marchantia polymorpha L.	R		●	
Phaeoceros carolianus (Michx.) Prosk.	R		●	
Pohlia camptotrachela (Renauld & Cardot) Broth.	R	NT	●	
Pohlia lutescens (Limpr.) H.Lindb.			●	
Ptychostomum pallens (Sw.) J.R.Spence	R		●	
Ptychostomum pseudotriquetrum var. *bimum* (Schreb.) Holyoak & N.Pedersen				●
Riccia cf. *subbifurca* Warnst. ex Croz.	RR	EN		●
Trichodon cylindricus (Hedw.) Schimp.			●	●
Total			**15**	**17**

scarce in Luxembourg (Werner 2011). The quantities recorded in 2023 for both species surpass Werner's data by many times as they cover several hundred metres in length and up to 100 metres in width along the shoreline.

During the 2023 survey, only *Ptychostomum pseudotriquetrum* var. *bimum* was detected as we were unable to identify several collected sterile *Bryum* specimens lacking rhizoid brood bodies. In contrast to Werner, we however collected four species from the genus *Riccia*, including *Riccia* cf. *subbifurca*, which has only been recorded once in Luxembourg, as well as huge populations of *Riccia cavernosa*.

4. Discussion

During the exploration of the study area in late September/beginning of October 2023, the lower muddy banks, that only fall dry in summer, had gained their floristic optimum. The vegetation of the slightly higher, gravelly parts was well developed and already partially decaying.

According to Diekjobst & Ant (1967), the floristic composition of the Cypero-Limoselletum can be subject to large variations. The appearance of the community changes in response to the evolution of the basic substrate from silty, near the river, to gravelly on the edge of the reservoir. In these locations, the Limoselletum is gradually transitioning to Corrigioletum communities (Gehlken & Hülbusch 2011).

Richter (1974) speaks of "eco phases" (hydro phase, littoral phase, limose (silty) phase, terrestrial phase), during which the plants undergo one or possibly several development cycles, depending on the variation of the water level. An increased number of eco phases within a short time frame can disrupt or completely prevent the development of plant communities. Stable water levels may support the development of perennial communities in a specific direction, whereas persistence in one phase, e.g. the littoral phase, may lead to the favouring of one species or group. These phases also explain the floristic proximity of many stands of Corrigioletum to Chenopodion rubri (Bidentetea) communities. The *Corrigiola* communities grow somewhat higher, therefore dry out earlier and have more time to develop (Gehlken in litt.).

Community populations that occur in different zones but have grown at different times can differ from each other in terms of the mass reproduction of individual species. This could also be observed in the study area, where in zones 1 and 2, the large stands of *Gnaphalium uliginosum* were already decaying, whereas on the lower silty banks, a real explosion of juvenile *Gnaphalium* plants took place. Chouard (1971) observed that the progressive lowering of the water level as the days become shorter not only reveals a zonation of different species, but above all a zonation of different responses of the same plants to photoperiodic conditions, corresponding to increasingly longer nights. Until the end of October, the germinating plants of the muddy banks are exposed to short days of about 11 hours only. Most of them immediately produce flowers or flower heads on very short stems in a terminal position and in all the leaf axils, often even in the cotyledonary axils, thus displaying a more or less neotenic habit. This can easily be observed in the study area, where huge populations of only two to three centimetres tall plants of *Gnaphalium uliginosum* and *Oxybasis rubra* var. *humilis* are covering the silt (Fig. 4F).

Gehlken (2017) underlines that, while Wiegleb (1979) assigned these stands as a variant of *Corrigiola* to a rankless *Plantago intermedia* community, Tüxen (1979) described a new Chenopodio-Corrigioletum litoralis (Malcuit 1929) Hülbusch et Tüxen 1978, which he assigned to the class Bidentetea. As a result of many consistent observations, Gehlken & Hülbusch (2011) point out that Corrigioletum and Limoselletum associations regularly occur in close proximity or even interpenetrate each other. The Corrigioletum always colonises stony (or sandy on the Elbe and Oder) areas, while the Limoselletum grows in muddy depressions. Incidentally, this has led these authors to separate the Corrigioletum from the class

Bidentetea and categorise it in the class Isoeto-Nanojuncetea.

In their report related to an inspection of the muddy areas of the lake, Krippel et al. (2019) point out the presence of rare species of the Bidentetalia tripartitae Br.-Bl. et Tx. 1943 ex Klika et Hadac 1944 and the Isoeto-Nanojuncetea bufonii Br.-Bl. et Tx. 1943 ex Westhoff, Dijk et Paschier 1946. The occurrence of these species has been confirmed during the present survey. The species list from 2023 shows 8 character species of the Bidentetea and 14 character species of the Isoeto-Nanojuncetea as well as 17 Red List (Colling et al. in prep.) or rare (Verloove & Van Rossum 2024) species.

These findings, i.e. a relevant number of rare species combined with a significant number of typical species of the Bidentetea as well as the Isoeto-Nanojuncetea, lead to the conclusion that these rare and sensitive habitats need further surveying. The FFH directive (JOCE 1992) includes in its Annex I the habitat "3270 Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation". Yet, this habitat does not appear in the list of protected habitats mentioned in the Luxembourgish nature conservation law from 2018 (Memorial 2018). One possible explanation for this deficiency might be the fact that the phenomenon of the dry falling banks of the Upper-Sûre has only been occurring on a regular basis since 2016 and that there were no comparable perennial habitats of this type before this time. The Isoeto-Nanojuncetea habitat 3130 is however legally protected in Luxembourg.

Compared to Werner & Hans (1991), the 2023 study enabled us to observe not only ephemeral bryophyte species but also several perennial species almost all over zones 1 and 2, especially juvenile plants of *Climacium dendroides*, very small *Drepanocladus aduncus* and, more rarely, *Leptodictyum riparium* and *Brachythecium rivulare*. This can be seen as an indication that these areas have run dry for over a year. It will thus be interesting to observe the further development of the moss vegetation of the study area, which will mainly depend on whether the reservoir in the study area will be completely filled with water again.

Physcomitrium eurystomum, which occurs in similar places, has not been found despite thorough searches, as was the case for Werner & Hans (1991). Unlike *Physcomitrium sphaericum*, which occurs in nutrient-poor sites, *P. eurystomum* appears to avoid nutrient-poor sites (Meinunger & Schroeder 2007), preferring basic soil in dried out reservoirs (Smith 1978).

Of the 26 recorded bryophyte species only six were found in both studies (1990 and 2023). The number of ephemeral species from the *Bryaceae* family is strikingly high in Werner & Hans (1991) with seven taxa, whereas we recently recorded only one species, i.e. *Ptychostomum pseudotriquetrum* var. *bimum*.

The *Riccia* species – some of which are very difficult to distinguish in the field and also difficult to identify microscopically – occur in very large numbers in the area. It is possible that other species have been overlooked.

Watterlot et al. (2021) describe the phenomenon of the massive appearances of the alga *Botrydium granulatum* in the Oise valley. In 13 of the 21 explored sites, the presence of *B. granulatum* was closely linked to the vicinity of the Riccio cavernosae-Physcomitrelletum patentis bryophyte association and induced succession by low-lying Nanocyperion vegetation on the least eutrophic substrates and by Bidention communities on richer soils. They also point out that, following the frequent observation of the Riccio-Physcomitrelletum in the Oise region, although very rare elsewhere in France, the association can now be included in the ecological and heritage issues in the management plans of the organisations in charge of these alluvial environments.

This is consistent with our earlier recommendation to strengthen the measures needed to preserve the FFH 3270 habitat as well as to include both habitats (3130 and 3270), with 25 rare species typically related to these habitats, in the existing monitoring scheme.

Some other rare species are probably missing from our survey, were overlooked or had possibly already vanished due to the late season. On the other hand, considering the

fact that the drying out of these areas has only been occurring on a regular basis since 2016, the existing flora must be considered as remarkably "complete" (Gehlken in litt.).

Several very rare species such as *Littorella uniflora, Elatine* sp. or *Illecebrum verticillatum* have not recently been recorded in Luxembourg but might nevertheless occur in these specific habitats and are worthwhile looking for at the occasion of further surveys.

Acknowledgements

We are grateful to Filip Verloove (NBGB, B-Meise) for confirming the identification of *Bidens radiata*, to Thierry Helminger (MNHNL, Luxembourg) for the information concerning the specimens in the LUX herbarium, Simone Marx and Lionel Leydet (ASTA Laboratory, L-Ettelbruck) for the analysis and interpretation hints for soil sampling, Steffen Caspari (RLZ, D-Bonn) for a first critical review of a preliminary version of the manuscript and Lara Schroeder (The Natural Translator, L-Erpeldange/Sûre) for a linguistic check. A special thanks goes to Bernd Gehlken (Fakultät für Forstwissenschaften und Waldökologie ,Georg-August-Universität D-Göttingen) for inspiring discussions and his suggestions concerning the syntaxonomic classification of the flora. Many thanks to Dominique Remy (Universität Osnabrück, D-Osnabrück) for the final review of the manuscript, to Claude Meisch for the editorial work, and Thierry Helminger for the final page layout.

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