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Monitoring Guidelines for the Assessment of Petrifying Springs in Ireland

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Monitoring Guidelines for the Assessment of Petrifying Springs in Ireland

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Cover photo: *Saxifraga aizoides* and *Orthothecium rufescens* in a petrifying spring at Eagle's Rock, Co. Leitrim © Melinda Lyons

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Executive Summary

Petrifying springs are lime-rich water sources that deposit tufa, a porous calcareous rock. They constitute a highly specialised habitat with a distinctive flora, typically dominated by bryophytes and often containing rare species. Their small extent and their vulnerability are recognised by their designation as a priority habitat in Annex I of the European Union Habitats Directive (92/43/EEC); member states are obliged to monitor and report on the conservation status of such annexed habitats. This manual contains a description of the habitat as it occurs in Ireland, guidelines for monitoring and assessment, and a short summary of the results of the most recent conservation status assessment.

A field survey of petrifying springs was conducted island-wide (2011 – 2013): 186 relevés (sample plots, each $4m^2$) were recorded from 110 springs and the chemical composition of water from 91 springs was analysed for pH, macronutrients and other parameters. Relevés were allocated to eight groups (plant communities) using fuzzy cluster analysis and Indicator Species Analysis. Group 1 *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades consist of substantial tufa formations, dominated by bryophytes, formed on steep slopes. Group 2 *Palustriella commutata-Geranium robertianum* Springheads usually form on wooded hillsides, often giving rise downslope to flush vegetation constituting the Group 3 community, *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes. Group 4 *Palustriella commutata-Agrostis stolonifera* Springheads are intermediate in many respects between Groups 1 to 3 and Groups 5 to 8; they occur on unshaded, gentle slopes and are dominated by a combination of bryophytes and graminoids. Group 5 *Schoenus nigricans* Springs, Group 6 *Carex lepidocarpa* Small Sedge Springs and Group 7 *Palustriella falcata-Carex panicea* Springs are transitional between *Cratoneurion* petrifying spring communities and *Caricion davallianae* small-sedge fen communities. They occur on level or gently sloping ground and range from being weakly tufaceous to forming conspicuous deposits of consolidated paludal tufa; Group 7 is best exemplified on karst limestone in the Burren, Co. Clare. Group 8 *Saxifraga aizoides-Seligeria oelandica* Springs contain a suite of rare bryophytes and are of the highest conservation value. This community is of limited biogeographical extent and is best exemplified in the Benbulbin Range. It is weakly tufa-forming, typically producing a thin film of stream crust tufa over more or less vertical rock exposures.

Under the conservation status assessment, structures and functions were assessed on the basis of species composition, spring water composition and flow, and the impacts of grazing. *Saxifraga aizoides* and the rare bryophytes *Seligeria oelandica, S. patula, Orthothecium rufescens, Hymenostylium recurvirostrum* var. *insigne*, *Tomentypnum nitens* and *Leiocolea bantriensis* are high quality indicators of petrifying springs. More common positive indicator species are *Pinguicula vulgaris, Anagallis tenella, Festuca rubra, Carex lepidocarpa, C. panicea, Equisetum telmateia, Palustriella commutata, P. falcata,* *Campylium stellatum, Philonotis calcarea, Scorpidium cossonii, Eucladium verticillatum, Didymodon tophaceus, Bryum pseudotriquetrum, Pellia endiviifolia, Aneura pinguis* and *Jungermannia atrovirens*. Negative indicator species consist of the non-native woody plants *Prunus laurocerasus* and *Acer pseudoplatanus* (both of which can be invasive), the non-native herb *Epilobium brunnescens* and certain robust forbs and graminoids. The bryophytes *Cratoneuron filicinum, Brachythecium rivulare* and *Platyhypnidium riparioides* can, if abundant, be indicative of elevated macronutrient levels. Spring water nitrate levels should be below 10mg/l, phosphate levels below 15 µg/l and there should be no modification to the natural flow of water. Grazing is usually necessary at unwooded sites to prevent scrub encroachment and consequent loss of species diversity, but excessive poaching and overgrazing must be avoided. Conservation Scores were calculated for each site, taking account of species diversity and the extent of tufa formation, and sites were ranked according to their conservation value. Detailed assessments of seven sites – ranging from 'Favourable' to 'Unfavourable Bad' conservation status – are provided by way of example of the assessment process and the state of the habitat in Ireland. The overall conservation status of petrifying springs in Ireland was assessed as 'Unfavourable Inadequate'

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1. Introduction

1.1. Petrifying Springs

Petrifying springs are lime-rich water sources which deposit tufa (or travertine). The emerging spring water is rich in carbon dioxide and dissolved calcium carbonate. On contact with the atmosphere, carbon dioxide is outgassed and calcium carbonate is deposited as tufa. The resulting ecological conditions, with high pH and constant inundation by water and deposition of precipitated calcium carbonate, constitute a challenging environment for plants and animals to colonise, and the communities associated with petrifying springs are therefore highly specialised. The ecological significance of petrifying springs is seldom confined to a point source; rather, there is often a continuum of intergrading hydrological conditions from the spring head, through a flushed slope and into small streams. Spring heads may be distinct point locations giving rise to small streams immediately below the point of emergence, or water may seep to the surface in a more diffuse pattern over a larger area.

1.1.1 *Legal Context*

The Habitats Directive (92/43/EEC) recognises the ecological significance and vulnerability of petrifying springs by designating them as the priority habitat 'Petrifying Springs with Tufa Formation (*Cratoneurion*) 7220' (Commission of the European Communities 2013). An important stipulation within the habitats directive manual is that 'in order to preserve this habitat of very limited expanse in the field, it is essential to preserve its surroundings and the whole hydrological system concerned'. Petrifying springs fall under the remit of the Water Framework Directive (Directive 2000/60/EC) as groundwater-dependent terrestrial ecosystems (Curtis *et al*. 2009, Kimberley *et al*. 2013); their ecological significance is recognised under this legislation and there is a legal requirement to maintain or improve the status of the groundwaters with which they are fed.

1.1.2 *Background to this Manual*

This manual is based on a PhD project entitled 'The Flora and Conservation Status of Petrifying Springs in Ireland', carried out by Melinda Lyons under the supervision of Dr Daniel Kelly, Department of Botany, Trinity College Dublin (Lyons 2015) and funded by National Parks and Wildlife Service and Irish Research Council. The field survey methodology presented here is that used during the PhD project and the plant communities of Irish petrifying springs are those described within the PhD thesis.

Under Article 11 of the Habitats Directive, each member state is obliged to undertake surveillance of the conservation status of the natural habitats and species in the Annexes and under Article 17, to report to the European Commission every six years on their status. The conservation status of a habitat is defined in Article 1 of the Directive as the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species. The conservation status of a natural habitat will be taken as favourable when (i) its natural range and areas it covers within that range are stable or increasing, and (ii) the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and (iii) the conservation status of its typical species is favourable. Guidelines for assessing the conservation status of habitats and species are provided by Evans & Arvela (2011).

The first such conservation status assessment on petrifying springs was compiled from earlier reports and desk surveys, drawing largely on data on fens in Ireland, and on existing field records of the moss species characteristic of petrifying springs (Hammond 1979, Crushell 2000, Foss 2007a, 2007b, NPWS 2008). The second conservation status assessment was prepared as part of the present project (Lyons & Kelly 2013).

1.1.3 Habitat Definition

For the purposes of this investigation, a broad definition of the habitat was adopted and many of the sites surveyed did not conform strictly and in every sense to 'petrifying springs with tufa formation (*Cratoneurion*)'.

- Not all locations contained springs; for example, some of the tufa formations surveyed were situated on rivers, streams and waterfalls.
- All tufa-forming springs and seepages were deemed to fall within the habitat, whether or not their vegetation conformed to that of the *Cratoneurion* alliance; indeed, this vegetation type is not clearly delimited in the literature and can encompass a very broad range of floristic diversity (Lyons 2015).
- A small number of sites surveyed contained *Cratoneurion*-type vegetation but had little or no tufa.

The advantage of this approach was that it allowed for research to take account of interrelated habitat types and the multidimensional reality of ecological gradients; this permitted a more holistic view of the range of natural variation. It facilitated descriptions of the gradation from one habitat to another (for example between 'petrifying springs' and 'alkaline fen'). It helped to elucidate what constitutes *Cratoneurion* vegetation and it revealed that sites with very similar vegetation can be variable in the extent to which they are tufa forming (Lyons & Kelly, in prep.).

1.2 Tufa Formation and Types

1.2.1 Tufa Formation Process

The process of tufa formation is dependent upon groundwater which is rich in carbon dioxide and dissolves carbonate rocks as it travels below ground. Upon emergence at a spring point, carbon dioxide is lost to the atmosphere causing the deposition of the dissolved carbonate. This may be summarised by the chemical equation:

$$Ca^{2+} + 2(HCO_3)^- \leftrightarrow CaCO_3 + CO_2 + H_2O$$

A higher partial pressure of CO_2 below the ground surface (due principally to soil respiration) leads to elevated levels in groundwater and facilitates dissolution of $CaCO_3$. Conversely the lower partial pressure in the atmosphere contributes to subsequent precipitation and deposition of solutes.

The intimate association of biota with tufa has long given rise to speculation about the role of living organisms in deposition processes (*e.g.* Praeger *et al.* 1904). Experimental evidence suggests that photosynthesis makes only a small contribution to the precipitation of tufa and that abiotic factors which promote aeration of spring water are the predominant driving force in settings such as waterfalls (*e.g.* Pentecost 1978, 1996, Zhang *et al.* 2001, Chen *et al.* 2004 and Pentecost & Franke 2010). However, mesocosm flume experiments conducted by Pedley *et al.* (2009) demonstrated that tufa precipitation could be induced in the laboratory using untreated natural river water, while sterilised river water produced virtually no deposition. They concluded that deposition was closely associated with extracellular polymeric substances produced by a prokaryote-microphyte biofilm.

Studies on the travertine formations of Plitvice, Croatia (Emeis *et al.* 1987, Golubić *et al.* 2008) elucidated the role of biofilms in carbonate precipitation. Microorganisms (especially cyanobacteria and diatoms) overgrow older, non-photosynthetic moss stems and debris such as detached leaves and branches. Mucous excretions from these microorganisms form a sticky mat, trapping seed crystals of calcite which act as nucleation sites upon which further deposition can occur, while bryophytes provide an architectural framework for the deposit.

More recent investigations (*e.g.* Keppel *et al.* 2011, Manzo *et al.* 2012) also showed that no precipitation took place where the biofilm was absent and research by Shiraishi *et al.* (2008) indicated that photosynthesis was a crucial mechanism to overcome the kinetic barrier for calcite precipitation, even in highly supersaturated settings.

1.2.2 Tufa and Travertine

In contemporary studies, the term 'tufa' is frequently applied to cool water deposits of highly porous or 'spongy' freshwater carbonates rich in microphytic and macrophytic growths, leaves and woody tissue (Pedley 1990). The degree of lithification of deposits to which the term tufa is applied varies. Ford and Pedley (1996) apply it to all cool, freshwater, low-magnesium carbonates, regardless of the degree of lithificiation, whereas according to Pentecost (1993) 'calcareous tufa' describes poorly consolidated deposits while 'travertine' is used for the harder, less porous and more resilient deposits. However, Pentecost goes on to point out that it is impractical to separate the terms since wide variations in hardness and porosity occur even within a single formation and he therefore adopts the term 'travertine' to cover all deposits irrespective of their durability or porosity.

In this manual, the term 'tufa' is used throughout. Tufa is widely understood by ecologists and naturalists in the context of Irish wetland habitats to mean highly porous or poorly consolidated calcium carbonate deposits. The harder, more resilient deposits often implied in common usage by the term 'travertine' are not known to occur in Ireland.

1.2.3 Tufa Types

The tufa formation categories relevant to Irish habitats are summarised in Table 1. In their most typical forms these categories are clearly distinguishable from one another, but intergrading forms are common and many locations contain a complex mosaic of deposits with different morphological characteristics.

Table 1: Geomorphological classification of tufa formation types occurring in Ireland (adapted from Pentecost & Viles 1994, Pentecost 1995, 2005).

Category	Description
Cascade	Developing on steep slopes at varying distances from the water source; characterised by massive, frequently complex build-ups. (Generally corresponding to the 'perched springline' model of Ford & Pedley 1996, Pedley 1990 and Pedley *et al*. 2003) (Photos 1, 7, 8, 12 and 24).
Dam	Similar to cascades but forming along streams and rivers and causing the impoundment of water behind a tufa crest. (Photo 28).
Stream crust	Sheet-like deposits forming in streams of intermediate to low gradient; these may merge with cascades (Photos 2, 3, 19 and 34).
Paludal	Formed in low gradient mires where tufa accumulates around the bases of plants, often surrounded by carbonate muds (Photo 5, 15 and 16).
Cemented rudites	Gravels etc. cemented by tufa; often found on coasts where spring water seeps onto shingle banks (Photo 7).
Oncoids/ooids	Unattached, coated grains (<1mm up to 30 cm); the cortex may consist of biotic or abiotic particles, such as stones or plant fragments (Photo 4).

Photo 1: Tufa cascade on coastal cliffs at Ardmore Point, Co. Wicklow (Sept. 2013).

Photo 2: Stream crust tufa over limestone pavement on Moneen Mtn, Burren, Co. Clare (May 2012).

Photo 3: Stream crust tufa lining a small runnel, Knocksink Wood, Co. Wicklow (March 2013).

Photo 4: Oncoids/ooids at a hillside spring and flush, Glenade, Co. Leitrim (July 2013).

Photo 5: Paludal tufa beneath the vegetation at Corhawnagh, Co. Sligo (July 2012).

1.3 Structure of Manual

This manual sets out the methods used in the PhD project so that they can be reproduced, either at additional sites, or for the future monitoring of sites already surveyed. It gives a summary of the plant communities described by the PhD study, with a key to their identification. Methods for carrying out the Conservation Status Assessment under the Habitats Directive are then described, followed by some examples of how they have been applied to individual sites. Further publications of the results of the PhD study are in press/in preparation.

1.3.1 Nomenclature

Nomenclature follows Stace (2010) for vascular plants, Hill *et al*. (2008) for bryophytes and John *et al*. (2011) for algae. The term 'graminoids' is used to refer to grasses, sedges and rushes; 'pteridophytes' comprises ferns, horsetails and clubmosses; and 'forbs' includes all other herbaceous vascular plants. Algae are not comprehensively covered but some taxa of note are included.

2. Methods

2.1 Overview of methods

The principal means by which vegetation data were collected for the PhD survey was through the use of 4m^2 quadrats (Photo 6). In total, 186 relevés were recorded from 110 springs located in 18 counties, including three counties in Northern Ireland, between April 2011 and September 2013. At small springs, only one relevé was recorded; at larger springs, two or more relevés (up to a maximum of seven) were recorded to represent the range of variation present. Fuzzy cluster analysis and Indicator Species Analysis were used to allocate these relevés to groups. Thus, eight plant communities of Irish petrifying springs were described based on the relevé data (Lyons 2015); these are summarised in Chapter 3. The chemical composition of water was analysed for 91 individual springs for pH, alkalinity, calcium, magnesium, potassium, sodium, chloride, nitrate, phosphate and sulphate (Lyons 2015).

The method used for recording relevé data is presented below. For the purposes of site monitoring, and in particular for Conservation Status Assessments, data is also required at site level. Methods for collecting these data are discussed in Section 2.2.2 below; Chapter 4 is also relevant in this regard.

Photo 6: Recording vegetation data using a 2x2m quadrat at Knockree, Co. Wicklow (April 2012).

2.2 Field Survey Methods

2.2.1 *Recording Relevés*

A relevé size of $4m^2$ was used, to allow for adequate representation of the mosaic of microhabitats which were frequently present. At some locations, the extent of the habitat was less than $4m^2$ in total, and the relevé size was reduced accordingly. The default quadrat configuration was 2x2m, but this was adapted as necessary to 4x1m or an irregular $4m^2$ shape as appropriate, to fit within the bounds of the spring-influenced area. Appendix 1 contains the record sheet as used in the field.

2.2.1.1 GENERAL INFORMATION

The first section of the record sheet is concerned with recording general information relating to the sample:

- Coding / numbering of samples and sites
- Location of site / spring / sample (name, grid reference and sketch)
- Date and time of record
- Surveyor(s) names / initials
- Altitude
- Aspect
- Mean slope
- Relevé configuration (2x2m, 1x4m or irregular; note size if less than $4m^2$)
- Hydrological position: spring, flush, stream, springs in fen, etc.
- pH, electrical conductivity and temperature (as measured by portable meter in the field; optional)

2.2.1.2 TUFA

The types of tufa present in the relevé were classified according to Table 1 (above) and quantified as a percentage of the surface area within the quadrat. If paludal tufa was present, it was allocated to one of the following categories and the extent of that category estimated as a percentage of surface area:

- Paludal strength 1 = weakly formed, discontinuous, inconspicuous tufa; trace on soil or at base of plants
- Paludal strength 2 = intermediate
- Paludal strength 3 = strongly formed tufa, often crunchy underfoot, coating the ground with a conspicuous white layer, often with detached chunks of consolidated tufa.

If part of the surface area within the relevé lacked tufa, its extent was recorded as 'Non-tufa'. Therefore, the total area in this section (and in the two following sections) amounted to 100%.

2.2.1.3 WATER

The presence of surface water was recorded as flowing/trickling, pools/standing water or dripping water and the proportion of the surface area of the quadrat impacted by each type estimated. Where there was no evident water above the ground surface, it was classified as damp (to touch) or dry (not impacted by spring water).

2.2.1.4 SURFACE

The composition of the ground surface within the relevé was quantified (including surfaces below water) as living vegetation, bare (active) tufa, ancient/inactive tufa, leaf litter, bare soil, bare stone or other components.

2.2.1.5 FIELD/GROUND FLORA

All species of vascular plants and bryophytes rooted in the ground layer of vegetation were recorded and the area they occupied estimated as a percentage of the sample area. Some of the most frequently occurring species are listed on Page 1 of the record sheet; additional species may be recorded on Page 2. The total cover by each plant group (forbs, graminoids, bryophytes, woody plants <50cm tall, pteridophytes and algae) was recorded at the bottom of the relevant column. Cover by algae was somewhat problematic; it varied along a continuum from conspicuous filamentous masses to more or less invisible layers of microscopic algae. Therefore, all surfaces coated in algae (with the exception of *Chara* spp) were recorded as 'Bare' in the 'Surface' section above (*i.e.* devoid of vascular plants and bryophytes). If algae were conspicuous, this was noted separately in the relevant part of the 'Field/Ground Flora' section.

2.2.1.6 SHRUB AND CANOPY COVER

Total canopy cover of woody plants (>2m height) was recorded at the end of Page 1; details of canopy and shrub layers were entered on Page 2, noting whether tree and shrub species were rooted inside or outside the relevé.

Scrub in the height range 0.5 – 2.0m was absent from all but one sample. If present, and rooted in the quadrat, it can be included in the field layer data with a note. If rooted outside the quadrat, it can be included in the canopy layer with a note.

2.2.1.7 SAMPLES

Any additional samples (for example, water samples) collected from the relevé were coded and recorded on Page 2.

2.2.1.8 NOTES

Any features of interest not already recorded were noted in the last section of the record sheet on Page 2.

2.2.2 *Spring Level Assessments*

In addition to relevé data, or, depending on the context of the survey, instead of relevé data, certain attributes of the entire spring-irrigated habitat need to be recorded for each individual spring. The relevé record sheet in Appendix 1 can be amended for this purpose, replacing percentage cover with the DAFOR scale. In addition, a record should be made of the following as appropriate:

- Extent of tufa-forming spring habitat
- Modifications (if any) to the natural flow of water
- Other threats or pressures in evidence within the site or nearby which are deemed to impact on its conservation status (Table 13 contains a list of the impacts recorded in this survey)
- Grazing impact (or lack of grazing)

See also Chapter 4 for the procedure to assess the Conservation Status of sites and for a list of activities which were found to impact on springs during the PhD survey.

2.3 Recommendations on methods for future monitoring

For future conservation status monitoring, assessments at the level of the whole spring are, in general, preferable to the use of relevés; relevé data collected during the recent study were used primarily to define plant communities. Sites are, for the most part, small enough to be studied in their entirety and such surveys are likely to provide a more comprehensive assessment, for example, of threats and pressures. Relevés should be considered in the future for close-focus studies, for example, if there is concern over possible changes at sites, or to build up a more complete picture of some of the larger, more important sites. The optimum time for surveying is from late May to early September; although largely bryophyte-dominated, vascular plants make an important contribution to the habitat as well and must not be overlooked.

Selection of sites to survey should prioritise those of highest conservation value (see Table 17, Section 4.4). Sites of ‘Outstanding’ and ‘Very High’ conservation value should be monitored every reporting cycle. The remaining sites should be surveyed on a rotating basis, so that each is visited at least every second reporting cycle; a division could be made, for example, by geographical region. New sites should be added to the list as they become known.

3. Plant Communities

The eight plant communities of Irish petrifying springs described based on relevé data are:

No.	Name	n
Group 1	*Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades	18
Group 2	*Palustriella commutata-Geranium robertianum* Springheads	26
Group 3	*Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes	29
Group 4	*Palustriella commutata-Agrostis stolonifera* Springheads	28
Group 5	*Schoenus nigricans* Springs	22
Group 6	*Carex lepidocarpa* Small Sedge Springs	30
Group 7	*Palustriella falcata-Carex panicea* Springs	20
Group 8	*Saxifraga aizoides-Seligeria oelandica* Springs	13

These groups encompass a broad range of variation within petrifying springs as they occur in Ireland. The number of samples (n) in each group ranged from 13 (in Group 8) to 30 (in Group 6).

- Group 1 *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades consist of substantial tufa formations, dominated by bryophytes, formed on steep slopes; they have affinities with *Adiantion* communities of damp cliffs (*e.g.* Deil 1994).
- Group 2 *Palustriella commutata-Geranium robertianum* Springheads usually form on wooded hillsides, often giving rise downslope to flush vegetation constituting the Group 3 community, *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes. Both are related to the *Equiseto telmatejae-Fraxinetum* Oberd. ex Seib. 1987.
- Group 4 *Palustriella commutata-Agrostis stolonifera* Springheads are intermediate in many respects between Groups 1 to 3 and Groups 5 to 8; they occur on unshaded, gentle slopes and are dominated by a combination of bryophytes and graminoids.
- Group 5 *Schoenus nigricans* Springs, Group 6 *Carex lepidocarpa* Small Sedge Springs and Group 7 *Palustriella falcata-Carex panicea* Springs are transitional between *Cratoneurion* petrifying spring communities and *Caricion davallianae* small-sedge fen communities. They occur on level or gently sloping ground and range from being weakly tufaceous to forming conspicuous deposits of consolidated paludal tufa; Group 7 is best exemplified on karst limestone in the Burren, Co. Clare.

- Group 8 *Saxifraga aizoides-Seligeria oelandica* Springs constitute a highly specialised sub-community of the *Saxifragetum aizoidis* McVean & Ratcliffe 1962. This community is of limited biogeographical extent and is best exemplified on steep (mostly north-facing) cliffs of the Benbulbin Range. It contains a suite of rare bryophytes and is of the highest conservation value. It is weakly tufa-forming, typically producing a thin film of stream crust tufa over more or less vertical rock exposures.

3.1 Group 1: *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades

Group 1 *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades are steep, often massive, tufa cascades and they exemplify extreme tufa-forming habitats in which few species can survive. The mosses *Eucladium verticillatum* and *Didymodon tophaceus*, and the thallose liverwort, *Pellia endiviifolia*, are characteristic of this community. *Palustriella commutata* and *P. falcata* are often present, but not dominant. *Conocephalum conicum* agg. is occasional. Vascular plants are scarce – the most frequently occurring species are *Agrostis stolonifera* and *Festuca rubra* – and they typically grow along the margins of the tufa deposits.

This community occurs on coastal spray zone cliffs, but is also found on steep, inland (mostly wooded) sites. At coastal sites, *Plantago maritima*, *Cochlearia officinalis*, *Samolus valerandi* and *Armeria maritima* are frequent. Overall, species diversity is low.

Photo 7: The vertical surface of this coastal tufa cascade is dominated by *Eucladium verticillatum*. *Palustriella commutata* occurs on the more gently sloping upper portion. Beach pebbles are cemented into a solid mass at the base of the cascade (March 2012).

3.1.1 *Environmental Characteristics*

Tufa is usually in the form of cascades on steep hillsides or cliffs. Bare, unvegetated patches of tufa are often present, creating a striking appearance, sometimes with stalactites or intricate 'petrified' plant fragments. Dripping water is characteristic of these steep surfaces.

3.1.2 *Typical Examples*

3.1.2.1 SKERRIES, CO. DUBLIN

This heavily petrified springhead occurs on the coast north of Skerries, Co. Dublin (Photo 7, above). *Palustriella commutata* is plentiful on the gently sloping upper part of the cascade, but most of the sheer face is occupied by *Eucladium verticillatum* with small amounts of *Didymodon tophaceus*. Grasses – especially *Festuca rubra* and *Agrostis stolonifera* – grow around the edges. *Samolus valerandi* is occasional on the steep, bryophyte-dominated face of the cascade. The red alga *Chroothece* sp. also occupies part of this vertical surface. *Eucladium verticillatum* thrives best where slightly shaded, either by overhanging grasses or in crevices in the tufa. At the base of the cascade, pebbles from the beach have become incorporated into the rapidly forming tufa, constituting 'cemented rudites' (*e.g.* Pentecost 1995).

3.1.2.2 DYSART, CO. KILKENNY

On a steep, wooded hillside close to the River Nore at Dysart, Co. Kilkenny, a substantial tufa cascade has formed. Much of the steep surface is dominated by the moss *Eucladium verticillatum* (Photo 8). *Palustriella commutata* is also frequent, along with *Pellia endiviifolia* and *Conocephalum conicum*. Water seeps from the hillside, dripping over the cascade surface in places. Vascular plants are mostly confined to the tufa margins, but *Primula vulgaris, Geranium robertianum* and *Asplenium scolopendrium* occasionally grow on the more heavily petrified parts.

Photo 8: Tufa cascade at Dysart, Co. Kilkenny, dominated by *Eucladium verticillatum*, the dark green, acrocarpous moss in the centre of the photograph (May 2010).

3.2 Group 2: *Palustriella commutata-Geranium robertianum* Springheads

Group 2 *Palustriella commutata-Geranium robertianum* Springheads are characterised by large mounds of *Palustriella commutata* on woodland springhead tufa cascades on moderately steep slopes. *P. commutata*, a characteristic moss of wet, base-rich habitats, is frequent in all groups – in Group 2 it is the dominant species. *Geranium robertianum* is one of the few vascular plant species to root in consolidated tufa or within mounds of *P. commutata*. *Equisetum telmateia, Carex remota*, *Chrysosplenium oppositifolium* and *Rubus fruticosus* agg. are also indicators of this group. *Fraxinus excelsior* seedlings are often present on these springhead cascades, but they seldom survive beyond the seedling stage. Other woodland species occasionally present include *Hedera helix, Lonicera periclymenum, Glechoma hederacea, Brachypodium sylvaticum, Asplenium scolopendrium* and the moss *Thamnobryum alopecurum*. The thallose liverwort *Pellia endiviifolia* (an indicator of Group 1) is frequently present on steep, shaded tufa surfaces. Overall, bryophytes (especially *P. commutata*) dominate the vegetation, while graminoids, forbs and woody plants make a small contribution.

Photo 9: Woodland tufa cascade dominated by *Palustriella commutata* on the banks of the Camcor River, Glenregan, Slieve Bloom Mountains (June 2013).

3.2.1 *Environmental Characteristics*

These springheads are strongly tufa-forming; in some cases, tufa cascades are massive, measuring $100m^2$ or more. At other locations, cascades are more fragmented, and occur in conjunction with paludal tufa or oncoids/ooids. Most sites are shaded by tree canopies, although some occur in woodland clearings. Slope is variable, but most often in the range 20^o – 40^o. Water sometimes drips or trickles slowly over tufa, but mostly the surface is damp without obvious surface water.

3.2.2 *Typical Examples*

3.2.3.1 GLENREGAN FOREST, SLIEVE BLOOM MOUNTAINS

Springwater trickles over the banks of the Camcor River, Glenregan Forest, in the Slieve Bloom Mountains, giving rise to a tufa cascade dominated by bryophytes, of which *Palustriella commutata* is the most abundant species (Photo 9, above). It is accompanied by small amounts of *Pellia endiviifolia, Eucladium verticillatum* and *Fissidens adianthoides*. Graminoids are occasional – *Agrostis stolonifera, Deschampsia cespitosa, Carex remota, Poa trivialis* and *Brachypodium sylvaticum* are present – and forbs are scarce, with small amounts of *Geranium robertianum, Crepis paludosa* and *Ficaria verna*. Also present in small quantities are *Lonicera periclymenum, Hedera helix, Rubus fruticosus* agg. and *Asplenium scolopendrium*. The tree canopy is dense, consisting mostly of *Fraxinus excelsior* with some *Fagus sylvatica* and *Acer pseudoplatanus*. Water trickles over the tufa surface in small rivulets.

3.2.3.2 MONEYDUFF WOOD, CO. LEITRIM

This springhead (Photo 10) occurs on gently sloping ground with strongly-formed paludal tufa (bordering on consolidated cascade tufa). *Palustriella commutata* forms an almost continuous ground layer interspersed occasionally with *Asplenium scolopendrium, Carex remota, Geranium robertianum, Ranunculus repens, Cardamine pratensis, Ranunculus repens, Allium ursinum* and *Filipendula ulmaria*. Most of the ground surface is damp, without surface water, but a small stream trickles through, lined with oncoids. Canopy cover is dense, consisting of *Fraxinus excelsior* and *Fagus sylvatica* (rooted at the margins of the tufa deposits).

Photo 10: Springhead with heavily precipitated paludal tufa, dominated by *Palustriella commutata*; the fern *Asplenium scolopendrium* is conspicuous (July 2013).

3.3 Group 3: *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes

Group 3 *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes are characterised by the presence of trickling water in tufa-forming streams, waterfalls, flushes and seepage zones (Photo 11). This is a very variable group, both in its floristic composition and tufa forming capacity. Bare, unvegetated tufa is characteristic, especially beneath flowing water.

Three species are highly significant indicators: *Brachythecium rivulare*, *Ranunculus repens* and the semi-aquatic moss, *Platyhypnidium riparioides* (syn. *Rhynchostegium riparioides*). The first two species occur at the margins of small rivulets and on flushed ground. *P. riparioides* occurs in flowing water although it is rarely fully submerged (Photo 12); it tolerates fluctuations in flow, persisting in streams which dry out intermittently. *Cratoneuron filicinum* occurs frequently, usually colonising drier edges; both this species and *P. riparioides* dominate the vegetation in some instances. Forbs are plentiful; in addition to *R. repens*, *Nasturtium officinale* agg. and *Apium nodiflorum* are indicators of this group, typically occurring in shallow, slow-flowing water. Other frequently occurring species, usually with low cover values, are *Mentha aquatica, Geranium robertianum*, *Agrostis stolonifera, Palustriella commutata* and *Pellia endiviifolia.* Overall, species diversity is low.

Photo 11: Stream below springhead at Glenasmole, Co. Dublin, which is rapidly tufa forming. *Equisetum telmateia* lines the stream margins (June 2013).

3.3.1 Environmental Characteristics

Trickling water is characteristic of this group. Cascade tufa is the predominant form, but often occurs in conjunction with paludal and stream crust tufa. Tufa dams may be present, impounding pools along streams. The ground surface slopes somewhat more gently than in Groups 1 and 2, typically at 30^{o}. Most examples are at least lightly shaded by woodland canopies.

This community forms in both semi-natural and anthropogenically modified habitats. In some cases, spring waters contain high levels of macro-nutrients and/or other pollutants. Many modified examples are strongly tufa-forming (but often species-poor).

3.3.2 Typical Examples

3.3.2.1 GLENASMOLE, CO. DUBLIN

Glenasmole contains several examples of this community in its semi-natural state, on a wooded hillside, where heavily petrifying streams and flushes form below springheads and seepage zones (Photo 11). Tufa accumulates rapidly as a series of cascades and stream crusts, depending on the incline of the slope and the depth of water. Most of the tufa surface lies beneath flowing water and is unvegetated.

Equisetum telmateia is abundant along stream edges. The uneven tufa surface creates various microhabitats for bryophytes: *Palustriella commutata, Brachythecium rivulare, Cratoneuron filicinum, Didymodon tophaceus, Pohlia wahlenbergii, Plagiomnium undulatum* and *Pellia endiviifolia* are occasional to frequent. Frequently occurring vascular plants are *Mentha aquatica, Nasturtium officinale* agg., *Ranunculus repens, Agrostis stolonifera* and *Carex remota*.

3.3.2.2 WOODLANDS, CO. DUBLIN

An anthropogenically modified example of this community occurs at Woodlands, Co. Dublin, where a large tufa cascade has formed in the overflow from a golf course lake. The water contains high phosphate levels and is strongly tufa-forming; species diversity is very low and the tufa surface is dominated by *Platyhypnidium riparioides, Brachythecium rivulare* and filamentous algae (Photo 12). The cascade is partly shaded by nearby trees.

Photo 12: Tufa cascade with *Platyhypnidium riparioides* and *Brachythecium rivulare* at Woodlands, Co. Dublin (May 2013).

3.4 Group 4: *Palustriella commutata-Agrostis stolonifera* Springheads

Group 4 *Palustriella commutata-Agrostis stolonifera* Springheads consist of hillside springheads, seepages and flushes dominated by *Palustriella commutata*, accompanied by *Festuca rubra* and *Agrostis stolonifera* (Photo 13); in many respects, this community is the unshaded equivalent of the woodland Group 2 *Palustriella commutata-Geranium robertianum* Springheads. Group 4 is variable in both species composition and the extent to which it is tufa forming. In terms of tufa formation type and species diversity, it is intermediate between the strongly tufaceous, but often species-poor Groups 1-3 and the weakly tufaceous, but usually more species-rich Groups 5-8.

Accompanying species are varied but most often consist of wetland generalists such as *Filipendula ulmaria, Mentha aquatica, Carex flacca, Juncus articulatus, J. inflexus* and the moss *Calliergonella cuspidata*.

Photo 13: Springhead dominated jointly by *Palustriella commutata* and graminoid species in woodland clearing, Glenasmole (May 2012).

3.4.1 Environmental Characteristics

Tufa forms as cascades on steeply sloping sites and as paludal tufa where the ground is more gently sloping. The ground surface is usually damp with water seeping just below the soil surface; occasionally there are small rivulets or pools.

3.4.2 *Typical Examples*

3.4.2.1 GLENASMOLE, CO. DUBLIN

This example occurs on the hillside in Glenasmole in an area irrigated by a combination of diffuse seepage and flushing from a springhead above. The microhabitats are varied, with trickling rivulets of water, flat ground containing small pools and steeper, moss-dominated tufa surfaces (Photo 13). Tufa occurs mostly in the form of cascades and parts of the surface are unvegetated.

Palustriella commutata is the most abundant species, dominating parts of the tufa surface and forming an underlayer beneath a patchy sward of *Festuca rubra, Agrostis stolonifera, Carex flacca* and *Juncus articulatus*. *Eupatorium cannabinum, Filipendula ulmaria* and *Mentha aquatica* are occasional. *Calliergonella cuspidata* is locally abundant, and *Brachythecium rivulare, Bryum pseudotriquetrum* and *Plagiomnium elatum* are present in small quantities.

3.4.2.2 SKERRIES, CO. DUBLIN

This springhead in north Co. Dublin is situated in the coastal spray zone (Photo 14). It consists of a springhead tufa cascade, on a slope inclined at 45^{o}, dominated by *Palustriella commutata* and with smaller amounts of *Eucladium verticillatum, Calliergonella cuspidata* and *Cratoneuron filicinum*. Graminoids are conspicuous along the margins of the tufa deposits and include *Festuca rubra, Agrostis stolonifera, Carex flacca, Juncus articulatus* and *J. inflexus*. Forbs make a minor contribution, mostly consisting of *Eupatorium cannabinum* and *Tussilago farfara.* The surface is mostly damp, with small patches of dripping and trickling water.

Photo 14: Coastal springhead dominated by *Palustriella commutata* (golden colour in centre), near Skerries, Co. Dublin (March 2010).

3.5 Group 5: *Schoenus nigricans* Springs

This distinctive group of tufa-forming springs occurs within *Schoenus nigricans*-dominated fens. Spring vegetation is dominated by *S. nigricans* with an underlayer of 'brown mosses', of which *Campylium stellatum* is the most abundant species; *Scorpidium scorpioides, S. cossonii, Palustriella commutata, P. falcata* and the thallose liverwort *Aneura pinguis* are frequent. Other vascular plants which are frequent (but usually with low cover values) include *Anagallis tenella, Pinguicula vulgaris, Succisa pratensis, Festuca rubra, Molinia caerulea, Carex lepidocarpa, C. panicea* and *Selaginella selaginoides*. This is a species-rich community and occasionally contains uncommon species such as *Dactylorhiza majalis* ssp. *traunsteineroides, Eriophorum latifolium* and the 'Near Threatened' leafy liverwort *Leiocolea bantriensis*.

Photo 15: Paludal tufa and brown mosses beneath *Schoenus nigricans*-dominated vegetation at Corhawnagh, Co. Sligo (June 2010).

3.5.1 *Environmental Characteristics*

Strongly formed paludal tufa is characteristic and pools of water lined with marl are often present. These springs occur on level ground and are unshaded.

3.5.2 *Typical Examples*

3.5.2.1 CORHAWNAGH, CO. SLIGO

This small, species-rich fen lies in a hollow at the foot of the Ox Mountains. *Schoenus nigricans* tussocks form a hummock-hollow pattern in the vegetation. Paludal tufa is heavily precipitated in the hollows and chunks of consolidated tufa are frequent on the ground surface beneath the graminoid layer (Photo 15 above). *Molinia caerulea* is frequent and there are smaller amounts of *Festuca rubra, Carex lepidocarpa* and *Juncus subnodulosus*. *Campylium stellatum* is abundant in the bryophyte layer, accompanied by *Palustriella commutata, P. falcata, Scorpidium cossonii, Ctenidium molluscum, Philonotis calcarea* and *Aneura pinguis*. *Pinguicula vulgaris, Cirsium dissectum, Selaginella selaginoides* and *Equisetum variegatum* are occasional.

3.5.2.2 ESKERAGH, CO. MAYO

This species-rich site in Co. Mayo contains tufa-forming springs within an area of level ground surrounded by blanket bog. Paludal tufa forms as a thick, conspicuous white layer with occasional oncoids/ooids (Photo 16). *Schoenus nigricans* is the dominant species and *Campylium stellatum* and *Palustriella commutata* are abundant. Other species include *Anagallis tenella, Pinguicula vulgaris, P. lusitanica, Pedicularis palustris, Succisa pratensis, Festuca rubra, Molinia caerulea, Cladium mariscus, Carex lepidocarpa, C. panicea, Selaginella selaginoides, Palustriella falcata, Philonotis calcarea, Scorpidium scorpioides, S. cossonii, Fissidens adianthoides, Bryum pseudotriquetrum* and *Aneura pinguis*.

Photo 16: *Schoenus nigricans* Springs at Eskeragh, Co. Mayo, with *Pinguicula vulgaris* and small sedges on paludal tufa (June 2012).

3.6 Group 6: *Carex lepidocarpa* Small Sedge Springs

Group 6 *Carex lepidocarpa* Small Sedge Springs consist of small sedge vegetation in which *Carex lepidocarpa* is often conspicuous and *Palustriella commutata* and *Calliergonella cuspidata* are the dominant bryophyte species. Other frequently occurring species characteristic of this community are *Anagallis tenella, Triglochin palustris, Pedicularis palustris, Mentha aquatica, Succisa pratensis, Festuca rubra, Carex panicea, C. flacca, Eriophorum angustifolium, Juncus articulatus* and *Equisetum palustre*. The bryophytes *Campylium stellatum, Bryum pseudotriquetrum* and *Aneura pinguis* are frequent to occasional. The rare moss *Tomentypnum nitens* can occur in this community (for example, at Pollardstown Fen, Co. Kildare).

Photo 17: Spring vegetation at Louisa Bridge, Co. Kildare, dominated by small sedges, including *Carex lepidocarpa*, with a brown moss underlayer (June 2012).

3.6.1 *Environmental Characteristics*

This unshaded community of level ground has high species diversity but, on the whole, is only weakly tufaceous. Paludal tufa, although sometimes strongly formed, is often patchy and can be lacking from much of the ground surface.

3.6.2 *Typical Examples*

3.6.2.1 LOUISA BRIDGE, CO. KILDARE

This species-rich site contains a complex of springs, flushes and pools with paludal tufa, oncoids/ooids and marl (Photo 17 above). Tufa-forming springs and flushes are generally dominated by graminoid species, especially *Carex lepidocarpa C. panicea* and *Festuca rubra,* along with *Carex flacca, C. dioica, Eleocharis quinqueflora, Eriophorum angustifolium, Juncus articulatus* and *J. inflexus*. Bryophytes are abundant and locally dominant, with *Palustriella commutata, P. falcata, Scorpidium cossonii, Campylium stellatum, Fissidens adianthoides, Bryum pseudotriquetrum, Aneura pinguis* and *Riccardia chamedryfolia*. Forbs include *Anagallis tenella, Pinguicula vulgaris, Parnassia palustris, Samolus valerandi, Triglochin palustris, Crepis paludosa, Mentha aquatica* and *Succisa pratensis*.

3.6.2.2 BALLYMAN GLEN, CO. WICKLOW

Diffuse seepage zones in Ballyman Glen fen contain *Carex lepidocarpa* Small Sedge Springs, with *Festuca rubra, Juncus articulatus, Carex panicea, C. flacca* and *Eleocharis quinqueflora*. However, in the absence of grazing, the more robust *Molinia caerulea* is dominant in many areas (Photo 18). Beneath the graminoid layer, *Palustriella commutata, Calliergonella cuspidata* and *Campylium stellatum* are locally abundant, along with smaller amounts of *P. falcata, Philonotis calcarea, Fissidens adianthoides, Bryum pseudotriquetrum* and *Aneura pinguis*. *Succisa pratensis* is frequent and *Parnassia palustris* and *Pinguicula vulgaris* are occasional. Paludal tufa is patchy amongst the vegetation.

Photo 18: Brown mosses and the thallose liverwort, *Aneura pinguis* (centre left) with paludal tufa beneath the graminoid-dominated layer which contains Molinia caerulea at Ballyman Glen, Co. Wicklow (December 2012).

3.7 Group 7: *Palustriella falcata-Carex panicea* Springs

Group 7 *Palustriella falcata-Carex panicea* Springs are dominated by the moss *Palustriella falcata* accompanied by small sedges, most notably *Carex panicea*, but also *C. lepidocarpa* and *C. flacca*. *Palustriella commutata* frequently occurs in this group, but with lower cover values than *P. falcata*. Other frequently occurring species are *Succisa pratensis, Festuca rubra, Agrostis stolonifera, Juncus articulatus, Philonotis calcarea, Bryum pseudotriquetrum, Calliergonella cuspidata* and *Aneura pinguis*.

3.7.1 *Environmental Characteristics*

Palustriella falcata-Carex panicea Springs are especially characteristic of the Burren, where spring water issues over sparsely vegetated limestone pavement, forming thin stream crust tufa (Photo 19). *Pinguicula grandiflora* is sometimes present in these springs. Other examples are found on the lower slopes of the Benbulbin Range where the ground is gently sloping and unshaded. These springs typically form small cascades or paludal tufa of intermediate strength which is often unvegetated in patches (Photo 20). Shallow water trickles over parts of the ground surface or forms small pools.

Photo 19: Spring issuing over karst limestone on Moneen Mountain, Burren, with stream crust tufa (May 2012). *P. falcata* (centre) colonises irrigated edges of the bare limestone and the dark green leafy liverwort *Jungermannia atrovirens* (foreground, left) grows in shallow flowing water.

3.7.2 *Comparison with other groups*

Group 7 differs from Group 6 in that cover by *Palustriella falcata* exceeds that of *P. commutata*; bryophytes are more abundant relative to graminoids; and there is typically a high proportion of bare stone or bare tufa. In contrast, Group 6 is weakly tufaceous and more grassy in appearance. Group 7 has on the whole a more westerly distribution (best represented in the Burren and the lower slopes of the Benbulbin Range) than Group 6 (most typical of midland fens).

3.7.3 *Typical Examples*

3.7.3.1 MONEEN MOUNTAIN, BURREN, CO. CLARE

Small springs issue on the western slopes of Moneen Mountain, creating pockets of spring vegetation on shallow soils, interspersed by unvegetated limestone pavement coated in thin stream crust tufa. Water trickles in shallow sheets over much of the gently sloping surface beneath the springheads, often sinking underground a short distance below.

Palustriella falcata is plentiful at the springhead in Photo 19, where it thrives along the edges of bare, flushed rock. *P. commutata* is also present, but in smaller quantities, along with *Bryum pseudotriquetrum, Campylium stellatum, Philonotis calcarea, Breutelia chrysocoma* and the leafy liverwort *Jungermannia atrovirens*. Also present (with low cover) within the spring-irrigated area are *Samolus valerandi, Carex panicea, C. lepidocarpa, C. flacca, Schoenus nigricans, Chara vulgaris* and the cyanobacterium *Rivularia* sp.

3.7.3.2 GLENADE, CO. LEITRIM

Heavily petrified springs emerge on the lower slopes of Tievebaun Mt at the eastern end of the Benbulbin Range on gently sloping ground (Photo 20). Tufa forms as cascades, oncoids/ooids and strongly precipitated paludal tufa. Parts of the surface are bare, lacking vegetation. Water trickles over part the surface and forms small pools. *Palustriella falcata* is the most abundant bryophyte species. *P. commutata* is present with lower cover values, along with *Philonotis calcarea, Bryum pseudotriquetrum* and *Aneura pinguis*. The most frequently occurring vascular plants are *Pinguicula vulgaris, Anagallis tenella, Parnassia palustris, Festuca rubra, Carex panicea, C. lepidocarpa, C. flacca, C. dioica, Eleocharis quinqueflora, Eriophorum angustifolium* and *Selaginella selaginoides*.

Photo 20: Tufa cascade on the lower slopes of Tievebaun Mt, Co. Leitrim, dominated by *Palustriella falcata* (Sept. 2013).

3.8 Group 8 *Saxifraga aizoides-Seligeria oelandica* Springs

Group 8 *Saxifraga aizoides-Seligeria oelandica* Springs are exceptionally species-rich, characterised by the presence of *Saxifraga aizoides* and a suite of rare bryophytes: *Seligeria oelandica, S. patula, Orthothecium rufescens* and *Hymenostylium recurvirostrum* var. *insigne*. *S. oelandica* is 'Vulnerable' in Ireland; the other three bryophytes are 'Near Threatened' (Lockhart et al. 2012). These rare species are accompanied by a diverse range of more familiar plants: *Parnassia palustris, Pinguicula vulgaris, Succisa pratensis, Festuca rubra, Sesleria caerulea, Agrostis stolonifera, Carex flacca, Juncus articulatus, Palustriella commutata, P. falcata, Fissidens adianthoides, Breutelia chrysocoma, Ctenidium molluscum, Bryum pseudotriquetrum, Jungermannia atrovirens, Pellia endiviifolia* and *Aneura pinguis* are frequent.

Photo 21: *Saxifraga aizoides* (centre) colonises spring-irrigated cliffs at Annacoona, Co. Sligo (Sept. 2012). Tiny acrocarpous mosses of the genus *Seligeria* grow in thin layers of steam crust tufa on vertical rock surfaces.

3.8.1 Environmental Characteristics

This community is more upland than other groups, forming on steep cliffs in the Benbulbin Range, also west Fermanagh and north-east Antrim, where vegetation nestles in rock crevices and clings to sheer, flushed cliffs (Cover Photo, Photos 21 & 22). These springs are weakly tufaceous, forming thin stream crust tufa over exposed bedrock. They most often occur on north-facing slopes.

3.8.2 Typical Examples

3.8.2.1 ANNACOONA, CO. SLIGO

At Annacoona (Gleniff) on the north-facing side of the Benbulbin Range, spring water emerges from a series of cliffs along the steep hillside. These species-rich springs contain all the rare species of Group 8. *Saxifraga aizoides* is conspicuous in places, rooting in crevices; the surrounding rocks are often encrusted with a layer of thin, stream crust tufa colonised by the tiny blackish mosses *Seligeria oelandica* and *S. patula* (Photo 21). The much larger mosses, *Orthothecium rufescens* and *Hymenostylium recurvirostrum* var. *insigne,* are frequent, accompanied by *Campanula rotundifolia, Alchemilla glabra, Festuca rubra, Sesleria caerulea, Carex flacca, C. lepidocarpa, Juncus articulatus, Palustriella falcata, P. commutata, Breutelia chrysocoma, Philonotis calcarea, Bryum pseudotriquetrum, Pellia endiviifolia, Leiocolea bantriensis, Jungermannia atrovirens* and *Aneura pinguis.*

3.8.2.2 BENWISKIN, CO. SLIGO

At Benwiskin, a north-facing spring and flush contain large cushions of *Hymenostylium recurvirostrum* var. *insigne* (Photo 22), along with smaller amounts of *Seligeria oelandica, Orthothecium rufescens, Didymodon tophaceus, Eucladium verticillatum, Fissidens adianthoides, Palustriella commutata, Pellia endiviifolia, Breutelia chrysocoma* and *Gymnostomum aeruginosum.* Frequently occurring vascular plants are *Saxifraga aizoides, Alchemilla glabra, Pinguicula vulgaris, Parnassia palustris, Campanula rotundifolia, Sesleria caerulea, Festuca rubra, Carex panicea* and *C. lepidocarpa*.

Photo 22: The large acrocarpous moss, *Hymenostylium recurvirostrum* var. *insigne*, on cliffs dripping with spring water at Benwiskin, Co. Sligo (Sept. 2012).

3.9 Conspectus of Communities

The most characteristic forms of the communities described may be identified using the following conspectus. Many sites contain more than one community and intermediate or atypical communities are frequently found which do not conform strongly to any of the described groups.

1 Bryophyte-dominated springhead communities

a *Palustriella commutata* is the dominant species

(i) *Palustriella commutata-Geranium robertianum* Springheads (Group 2): shaded, woodland communities of moderately steep slopes often with *Pellia endiviifolia*.

(ii) *Palustriella commutata-Agrostis stolonifera* Springheads (Group 4): usually unshaded communities of springheads or flushes on moderate to gentle slopes, often containing *Festuca rubra* and wetland generalists such as *Filipendula ulmaria*, *Mentha aquatica* and *Juncus articulatus*.

b *P. commutata* is co-dominant with *Eucladium verticillatum*: see *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades (1c(i) below).

c *Eucladium verticillatum* is the dominant species

(i) *Eucladium verticillatum-Pellia endiviifolia* Tufa Cascades (Group 1): strongly tufa-forming springheads on very steep (often vertical) slopes, either shaded or unshaded, often containing *Didymodon tophaceus*. *Palustriella commutata* may be locally abundant.

d *Palustriella falcata* is the dominant species

(i) *Palustriella falcata-Carex panicea* Springs (Group 7): unshaded springs on gentle slopes, especially typical of the Burren and the lower slopes of the Benbulbin Range, but not restricted to these areas; often containing *Philonotis calcarea* and *Carex lepidocarpa*.

e *Saxifraga aizoides* is present

(i) *Saxifraga aizoides-Seligeria oelandica* Springs (Group 8): Montane springs in the north-west of Ireland or in Co. Antrim, on steep slopes, forming thin stream crust tufa, often sparsely vegetated and containing a range of bryophytes of which no one species is dominant. May contain the rare bryophyte species *Seligeria oelandica, S. patula, Hymenostylium recurvirostrum* var. *insigne* and/or *Orthothecium rufescens*.

2 Springs in graminoid-dominated vegetation on level or gently sloping ground

a *Schoenus nigricans* is the dominant species

(i) *Schoenus nigricans* Springs (Group 5): Springs and seepages forming paludal tufa amongst *Schoenus nigricans*-dominated vegetation on level (or gently sloping) unshaded sites, with a brown-moss underlayer containing *Campylium stellatum*, often accompanied by *Scorpidium cossonii, S. scorpioides, Palustriella commutata* and/or *P. falcata*.

b *Carex lepidocarpa* is prominent in a mixed sward of sedges, rushes and grasses

(i) *Carex lepidocarpa* Small Sedge Springs (Group 6): usually low-growing, sedge-dominated vegetation with an underlayer of *Palustriella commutata* and *Calliergonella cuspidata*, often weakly tufaceous with sparse paludal tufa, and usually containing *Festuca rubra, Carex panicea, C. flacca, Eriophorum angustifolium* and/or *Juncus articulatus.*

3 Tufa-forming flushes, streams and waterfalls

a *Saxifraga aizoides* is present: see *Saxifraga aizoides-Seligeria oelandica* Springs (1e(i) above).

b *Seligeria oelandica, S. patula, Hymenostylium recurvirostrum* var. *insigne* and/or *Orthothecium rufescens* is present: see *Saxifraga aizoides-Seligeria oelandica* Springs (1e(i) above).

c Woodland flushes, streams or waterfalls with low species diversity

(i) *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes (Group 3): sparsely vegetated, cascade or stream crust tufa, often with *Ranunculus repens, Nasturtium officinale* agg. and/or *Cratoneuron filicinum*.

4 If there is no good match in the descriptions above, consider

a *Palustriella commutata-Agrostis stolonifera* Springheads (Group 4): for damp, usually unshaded flushes or seepages, with little surface water.

b *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes (Group 3): where there is a conspicuous flow of water over sparsely vegetated tufa surfaces, or for tufa cascades dominated by atypical species.

4. Conservation Status Assessment

4.1 Area

Petrifying spring habitats are frequently of small extent, but determining their area can be problematic as the habitat forms mosaics and grades into other related habitat types.

For strongly tufa-forming habitats, such as *Eucladium verticillatum-Pellia endiviifolia* Springheads, *Palustriella commutata-Geranium robertianum* Springheads and *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Springs and Flushes, the area should be determined as the extent of the tufa-forming zone. This is often just a few square metres, but larger tufa cascades can measure in excess of 100m^2 and springs with tufa-forming flushes, such as those in Glenasmole, can occupy more than 2,000m^2.

Petrifying spring communities that occur within broader wetlands, such as those of *Schoenus nigricans* Springs and *Carex lepidocarpa* Small Sedge Springs, are more difficult to delimit. Where there is no obvious boundary to these communities, the wider wetland should be mapped and the area of petrifying springs estimated as a percentage of the total wetland area. Any especially strongly tufa-forming spring or seepage locations within the wetland can be recorded as point locations.

Palustriella falcata-Carex panicea Springheads often have distinct boundaries, with spring water forming a small stream immediately below the springhead. In the Burren, the water often disappears below ground a short distance below the springhead. *Saxifraga aizoides-Seligeria oelandica* Springs vary from discrete tufa-forming springheads with definable boundaries, to diffuse seepages grading into other adjacent wetlands or grasslands.

The area of petrifying springs in Ireland was estimated to be 13.87 Ha in the 2013 Conservation status assessment (Lyons & Kelly 2013, NPWS 2013).

4.2 Structures & Functions

4.2.1 Species Composition

Species occurring in petrifying spring habitats were assigned to the following categories:

- High quality indicator species
- Positive indicator species
- Accompanying species
- Potentially negative indicator species
- Negative indicator species
- Invasive species

4.2.2 *High Quality Indicator Species*

High Quality Indicator Species are highly ecologically significant species of petrifying springs. All are rare; they consist of one vascular plant species, *Saxifraga aizoides*, and several bryophyte species (Table 2).

Table 2: High Quality Indicator Species of petrifying springs.

Species	**Status in Ireland**	**Source**
Saxifraga aizoides	Rather rare; found in only six vice-counties	Parnell & Curtis 2012; Scannell & Synnott 1987
Seligeria oelandica	Vulnerable	Lockhart *et al*. 2012
Seligeria patula	Near Threatened	Lockhart *et al*. 2012
Orthothecium rufescens	Near Threatened	Lockhart *et al*. 2012
Hymenostylium recurvirostrum var. insigne	Near Threatened	Lockhart *et al*. 2012
Tomentypnum nitens	Vulnerable	Lockhart *et al*. 2012
Catoscopium nigritum	Near Threatened	Lockhart *et al*. 2012
Leiocolea bantriensis	Near Threatened	Lockhart *et al*. 2012

Saxifraga aizoides is a highly characteristic species of petrifying spring communities (*e.g*. Koch 1928, Braun-Blanquet & Braun-Blanquet 1931, McVean & Ratcliffe 1962, Rodwell 1998, Fossitt 2000 and Commission of the European Communities 2013). In Ireland, it has a limited geographical range centred on the Benbulbin Range of Counties Sligo and Leitrim, extending into west Fermanagh and south Donegal and occurring locally in north-east Antrim. It occurs on steep, damp, calcareous cliffs and hillsides (Cover Photo and Photo 21).

Seligeria oelandica, a tiny, blackish acrocarpous moss, colonises steep, flushed rock surfaces in the Benbulbin Range and in west Fermanagh where it grows in a thin film of poorly consolidated tufa. It is unknown elsewhere in Ireland and its status is Vulnerable. It has a single station in Britain (in the south of Wales, Bosanquet & Motley 2009), and a disjunct distribution worldwide; at most locations, it is declining or vulnerable (Lockhart *et al*. 2012). *S. patula* grows in similar situations to *S. oelandica* and, in Ireland, is confined to Sligo, Leitrim and Fermanagh, where it is somewhat more extensive than *S. oelandica* and its status is Near Threatened (Lockhart *et al*. 2012). *Orthothecium rufescens* is a pleurocarpous moss with long, metallic pinkish-red shoots. Its main centre of population in Ireland is in the north-west (Benbulbin Range, Fermanagh and west Donegal) but it also occurs in the Burren, at Black Head. It is Near Threatened in Ireland (Lockhart *et al*. 2012). *Hymenostylium recurvirostrum* var. *insigne* forms large, dark green cushions. It is Near Threatened in Ireland, confined to the Benbulbin Range (Lockhart *et al*. 2012). The last two species grow on steep cliff faces irrigated by calcareous spring water with sparse, poorly consolidated tufa deposits.

Tomentypnum nitens occurs in calcareous mires and flushes at several locations in Ireland and is Vulnerable. *Catoscopium nigritum* grows in dune slacks and damp machair along the west and north-west coasts of Ireland; it is Near Threatened. *Leiocolea bantriensis* is somewhat more widespread, occurring in fens and flushes, but is nevertheless Near Threatened (Lockhart et al. 2012). All three species can occur in association with paludal tufa.

For the purposes of assessment, High Quality Indicator Species were combined with Positive Indicator Species.

4.2.3 Positive Indicator Species

Ecologically significant species of petrifying springs which serve as positive indicators of habitat status consist largely of mosses and liverworts, with a smaller number of vascular plants (Table 3). The mosses *Palustriella commutata, P. falcata, Philonotis calcarea, Eucladium verticillatum, Didymodon tophaceus, Campylium stellatum, Scorpidium cossonii, S. scorpioides, Bryum pseudotriquetrum* and *Fissidens adianthoides* are highly characteristic, positive indicators, along with the liverworts *Pellia endiviifolia, Aneura pinguis* and *Jungermannia atrovirens*. Forbs which serve as positive indicators are *Pinguicula vulgaris, Parnassia palustris* and *Anagallis tenella*, and, especially in woodland springs, *Chrysosplenium oppositifolium* and *Crepis paludosa*. The graminoids *Festuca rubra, Carex lepidocarpa, C. panicea* and *Eriophorum latifolium* are positive indicators, as are the pteridophytes *Equisetum telmateia, E. variegatum* and *Selaginella selaginoides*. Stoneworts, especially *Chara vulgaris*, may also be present and serve as positive indicators.

Table 3: Positive indicator species of petrifying springs (V = vascular plant, M = moss, L = liverwort, A = alga).

Positive Indicator Species			
V	*Anagallis tenella*	M	*Eucladium verticillatum*
L	*Aneura pinguis*	V	*Festuca rubra*
M	*Bryum pseudotriquetrum*	M	*Fissidens adianthoides*
M	*Campylium stellatum*	L	*Jungermannia atrovirens*
V	*Carex lepidocarpa*	M	*Palustriella commutata*
V	*Carex panicea*	M	*Palustriella falcata*
A	*Chara vulgaris*	V	*Parnassia palustris*
V	*Chrysosplenium oppositifolium*	L	*Pellia endiviifolia*
V	*Crepis paludosa*	M	*Philonotis calcarea*
M	*Didymodon tophaceus*	V	*Pinguicula vulgaris*
V	*Equisetum telmateia*	M	*Scorpidium cossonii*
V	*Equisetum variegatum*	M	*Scorpidium scorpioides*
V	*Eriophorum latifolium*	V	*Selaginella selaginoides*

In carrying out the assessment, High Quality Indicator Species and Positive Indicator Species were combined as a single indicator. To pass, there must be at least three Positive / High Quality Indicator Species present **AND** there must be no loss from the baseline number of species in these combined categories (Table 9 below). It is anticipated that overlooked species will be added to these baseline numbers at many sites in subsequent assessments if there is no loss in conservation status.

4.2.4 Typical Accompanying Species

Characteristic species of petrifying springs are often accompanied by a wide range of wetland generalists which are neutral as indicators (Table 4). These includes a range of forbs such as *Cardamine pratensis, Mentha aquatica, Succisa pratensis, Nasturtium officinale* agg., *Cirsium palustre, Filipendula ulmaria, Ranunculus repens, R. flammula, Hypericum tetrapterum, Leontodon autumnalis, Bellis perennis, Prunella vulgaris, Epilobium parviflorum* and *Veronica beccabunga*. The graminoids *Agrostis stolonifera, Poa trivialis, Carex flacca, Eriophorum angustifolium, Juncus articulatus* and *J. inflexus* are widespread in petrifying springs. In woodlands, *Geranium robertianum* is ubiquitous on tufa and *Primula vulgaris* is sometimes present; *Sesleria caerulea* is frequently present in springs in the Burren and the Benbulbin Range and *Tussilago farfara* is common in sparsely vegetated springs on steep ground, especially after landslides. Accompanying bryophytes often include *Breutelia chrysocoma* (especially in western parts of Ireland), *Calliergonella cuspidata* (most abundant in the lower end of the pH range of petrifying springs), *Ctenidium molluscum* (in drier places, such as on hummocks), *Pohlia wahlenbergii* (where vegetation is sparse, especially after landslides), *Leiocolea turbinata, Plagiomnium elatum, Riccardia chamedryfolia* and *Trichostomum crispulum*.

Table 4: Accompanying species (neutral indicator species) of petrifying springs (V = vascular plant, M = moss, L = liverwort).

Accompanying Species			
V	*Agrostis stolonifera*	V	*Leontodon autumnalis*
V	*Bellis perennis*	V	*Mentha aquatica*
M	*Breutelia chrysocoma*	V	*Nasturtium officinale agg.*
M	*Calliergonella cuspidata*	M	*Plagiomnium elatum*
V	*Cardamine pratensis*	V	*Poa trivialis*
V	*Carex flacca*	M	*Pohlia wahlenbergii*
V	*Cirsium palustre*	V	*Primula vulgaris*
M	*Ctenidium molluscum*	V	*Prunella vulgaris*
V	*Epilobium parviflorum*	V	*Ranunculus flammula*
V	*Eriophorum angustifolium*	V	*Ranunculus repens*
V	*Filipendula ulmaria*	L	*Riccardia chamedryfolia*
V	*Geranium robertianum*	V	*Sesleria caerulea*
V	*Hypericum tetrapterum*	V	*Succisa pratensis*
V	*Juncus articulatus*	M	*Trichostomum crispulum*
V	*Juncus inflexus*	V	*Tussilago farfara*
L	*Leiocolea turbinata*	V	*Veronica beccabunga*

These species were not taken into account in the assessment of sites.

4.2.5 Invasive Species

The species found to have the greatest negative impacts on the conservation status of petrifying springs were the non-native *Prunus laurocerasus* and *Acer pseudoplatanus;* they were categorised as Invasive Species. Both have the capacity to grow within the spring-influenced area, but both can also be seriously damaging – and grow more vigorously – when rooted in peripheral areas, casting dense shade over the often small expanse of petrifying spring habitats. *Prunus laurocerasus* formerly dominated petrifying springs in Coneyburrow Wood, Slieve Bloom, although it has since been greatly reduced in extent by intervention to eradicate it. Nevertheless, some regeneration is taking place (Photo 23). *Acer pseudoplatanus* was most damaging at unwooded locations (and where it encroached from hedgerows); here its rapid growth caused shading of otherwise lightly shaded or unshaded springs. (Within woodlands, it was assessed as a Negative Indicator Species, depending on abundance.) The only other non-native species of relevance were *Epilobium brunnescens* (see Section 4.2.6) and *Fagus sylvatica*. The latter was present in the canopy at a small number of woodland springs (but rooted on dry ground outside the area of influence of spring water). In order to pass the assessment for this indicator, invasive species were required to be absent (Table 9 below).

Table 5: Invasive species of petrifying springs.

Invasive Species
Prunus laurocerasus
Acer pseudoplatanus (in unwooded habitats; Negative Indicator Species in woodland)

Photo 23: *Prunus laurocerasus* encroaching on tufa cascade at Coneyburrow Wood, Slieve Blooms, (May 2012).

4.2.6 Negative Indicator Species

Herbaceous, woody and bryophyte species were assessed separately as Negative Indicators, because they may be indicative of different impacts. Herbaceous species and bryophytes (and algae) can be indicative of nutrient enrichment, while woody species can indicate scrub encroachment. They are 'potentially' negative in that their presence can be interpreted differently at different sites (*e.g.* woody species can be negative indicators at unwooded sites, but accompanying species at wooded sites). Most of these species can occur with low cover values in springs of high conservation status, only becoming indicative of negative conditions when they are abundant or dominant within a site.

The robust, competitive forbs *Apium nodiflorum, Epilobium hirsutum, Eupatorium cannabinum, Heracleum sphondylium, Petasites hybridus, Rumex obtusifolius* and *Urtica dioica* and the graminoids *Dactylis glomerata, Phragmites australis* and *Juncus effusus* are not characteristic of petrifying springs, although they sometimes occur in small quantities or colonise the margins of spring-irrigated areas. However, if abundant or dominant in tufa-forming areas, they have a negative impact on the habitat, displacing characteristic petrifying spring species and in some cases indicating elevated macronutrient levels or other disturbances to the habitat. The non-native *Epilobium brunnescens* sometimes occurs in petrifying habitats; in the recent survey it was Rare at several sites and Occasional at two. For the purposes of assessment, negative herbaceous species should not be abundant or dominant, either individually or in combination.

Table 6: Herbaceous species which are Negative Indicators for petrifying springs.

Herbaceous Negative Indicator Species	
Apium nodiflorum	*Juncus effusus*
Dactylis glomerata	*Petasites hybridus*
Epilobium brunnescens	*Phragmites australis*
Epilobium hirsutum	*Rumex obtusifolius*
Eupatorium cannabinum	*Urtica dioica*
Heracleum sphondylium	

4.2.6.1 NEGATIVE BRYOPHYTE INDICATOR SPECIES

Three bryophyte species were categorised as Potentially Negative Indicator Species, depending the circumstances in which they occurred (Table 7). *Cratoneuron filicinum, Brachythecium rivulare* and *Platyhypnidium riparioides* can be indicative of nutrient enrichment, especially elevated phosphate levels. Where two or all of these three species were present, even at low abundance, phosphate levels were Poor in 70% and Bad in 26% of cases (n=27). However, these species (especially *C. filicinum*) can occur individually at low levels of abundance in springs with Good water quality, where they form part of a mixed bryophyte flora along with other characteristic petrifying spring species.

For the purposes of assessment, potentially negative bryophytes (and algae, see below) should not be abundant or dominant. If two or more of the species in this category are present, and if at least two are frequent, or at least one is abundant, then the habitat fails for this indicator.

Table 7: Bryophyte species which are potentially Negative Indicators for petrifying springs.

Potentially Negative Bryophyte Indicator Species
Brachythecium rivulare
Cratoneuron filicinum
Platyhypnidium riparioides

4.2.6.2 NEGATIVE WOODY INDICATOR SPECIES

Woody species occurring in unwooded springs may be indicative of undergrazing or abandonment of land (Table 8). Succession to scrub and woodland in petrifying spring habitats was found to be associated with a general decrease in diversity of both vascular plants and bryophytes. Late-successional sites had an increase in typical woodland species but not in specialist or rare species. Woody species such as *Fraxinus excelsior, Hedera helix, Lonicera periclymenum, Rubus fruticosus* agg. and *Salix cinerea* do not constitute Negative Indicators of springs located in woodland; they are, however, Negative Indicators of scrub encroachment onto unwooded springs where shading is likely to cause a reduction in species-richness. *Acer pseudoplatanus* was found to be less of a threat in woodlands than in open habitats, due to competition from other tree species. However, if abundant at woodland springs it is deemed to have a negative impact. *Ulex europaeus* is a Negative Indicator which typically encroaches at the margins rather than colonising tufa deposits but it can cause rapid and prolonged deterioration in conservation status of smaller springs by shading them and being resistant to subsequent grazing.

Table 8: Woody species which are negative indicators for petrifying springs.

Negative Indicator Species of open (unwooded) habitats
Acer pseudoplatanus (in woodland springs; Invasive in unwooded habitats)
Calluna vulgaris (potentially indicative of anthropogenic changes to spring water)
Fraxinus excelsior (in unwooded springs only)
Hedera helix (in unwooded springs only)
Lonicera periclymenum (in unwooded springs only)
Rubus fruticosus agg. (in unwooded springs only)
Salix cinerea (in unwooded springs only)
Ulex europaeus

Calluna vulgaris was sometimes present at petrifying spring locations, for example in the Burren, on the tops of hummocks around which spring water flowed. In such cases, it was not deemed to be indicative of negative conditions. In other situations, it may be indicative of natural processes of succession as the ground surface rises above the zone of mineral water influence. If loss of contact with spring water is deemed to be artificially induced, *C. vulgaris* could be categorised as a Negative Indicator.

In making the assessment, scrub was required to be absent from unwooded springs. At several unwooded sites, a few small seedlings of woody species were found and recorded as Very Rare; where these seedlings were deemed unlikely to survive, the site passed for this indicator. This indicator is generally Not Applicable to wooded springs (although it could be used if *Acer pseudoplatanus* or *Ulex europaeus* were abundant; this scenario did not arise in the recent assessment).

4.2.7 A note on algae and cyanobacteria

Algae were not surveyed systematically in the recent study, but some preliminary observations were made regarding their status in petrifying springs. The cyanobacterium *Rivularia biasolettiana* is characteristic of certain petrifying springs, for example in the Burren and at some coastal locations, where it forms distinctive spherical brown colonies. The uncommon red alga *Chroothece* sp. was recorded for the first time in Ireland during the recent study; it was present in petrifying springs at three separate coastal locations (Counties Clare, Dublin and Antrim). It has also been found recently at several petrifying springs in Britain (both coastal and inland; John *et al*. 2011, Pentecost *et al*. 2013). These two taxa are provisionally regarded as positive indicators of petrifying springs.

Vaucheria species, on the other hand, were found in abundance at several sites where spring water was enriched, especially by phosphates. There may be differences depending on the species of *Vaucheria* present but, on the whole, where this genus forms extensive dark green or blackish colonies in conjunction with an abundance of other potentially negative indicators (especially the mosses *Platyhypnidium riparioides, Cratoneuron filicinum* and *Brachythecium rivulare*), it seems likely to be indicative of elevated levels of macronutrients in the spring water.

4.2.8 Summary of Species Assessment Criteria

The assessment criteria described above are summarised in Table 9.

Table 9: Summary of assessment criteria for indicator species.

Indicator	Target	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline number of species	PASS
Invasive species	Absent	PASS
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant *	PASS
Potentially negative herbaceous species	Cover should not be Abundant/Dominant	PASS
Potentially negative woody species / scrub	Absent (except in woodland)	PASS

*If two or more of the species in this category are present, and if at least two are frequent, or at least one is abundant, then the habitat fails for this indicator.

4.2.9 *Spring water composition and flow*

Spring water quality was assessed on both nitrate and phosphate concentrations (Table 10). In order to pass, concentrations were required to be less than 10mg/l nitrate (McGarrigle *et al*. 2010) and less than 15 μg/l phosphate (Lyons 2015). Baseline levels were set according to concentrations measured in the recent study; in subsequent assessments, there should be no increase on these levels. These indicators were recorded as Not Determined (ND) where water samples were not collected.

Water flow should not be altered anthropogenically. However, in certain cases where there are historic modifications that had been in place over several decades and where it would be more disruptive to restore the original hydrological conditions of the site, the site may pass under that criterion. For example, at Louisa Bridge, the hydrology was modified during the 19th Century when the site was a popular destination for visitors to the warm spring; the site was passed for this indicator and the baseline was noted to have had 'Historic' modifications. At other locations, small-scale water extraction had been happening for some time, most often with a small proportion of spring water being diverted to a nearby trough for watering livestock. Such an arrangement often benefited the springhead by reducing trampling and dung as livestock were able to access water a short distance away rather than congregating at the springhead. Where the scale of extraction was deemed to be minor and to have an insignificant impact on the habitat, the site passed for this indicator and the baseline was noted to have 'Minor' modifications.

Table 10: Summary of assessment criteria for water composition and flow.

Indicator	Target	Assessment
Nitrate level	No increase from baseline and not above 10 mg/l	PASS
Phosphate level	No increase from baseline and not above 15 μg/l	PASS
Water flow	No alteration of natural flow *	PASS

* Exceptions can be made for Historic or Minor modifications (see text above for details)

4.2.10 *Impacts of grazing*

In addition to monitoring signs of scrub encroachment (above), grazing impacts were assessed in terms of the height of the field layer sward and the extent of trampling or dung in the habitat (Table 11). At most sites, a field layer height of 10cm to 50cm was considered indicative of appropriate grazing levels; at some bryophyte-dominated sites, lower ground vegetation heights were considered appropriate. Such sites were recorded as Bryophyte-dominated with ground vegetation <10cm in height and were assessed to Pass for this indicator. Some trampling and dung were inevitable at sites which were grazed; grazing in turn was necessary to prevent scrub encroachment and consequent reductions in species richness. However, if trampling and dung had caused significant damage to the vegetation, the site was deemed to fail for this indicator.

Table 11: Summary of assessment criteria for impacts of grazing.

Indicator	Target	Assessment
Field layer height	Height between 10 and 50cm *	PASS
Trampling/dung	Impact should not be Abundant/Dominant	PASS

* Exceptions can be made for bryophyte-dominated ground vegetation which is less than 10cm in height.

4.2.11 Overall Structure & Functions Assessment

Where all indicators passed, the overall assessment for Structures and Functions was 'Favourable' (Table 12). If only one indicator failed, and that fail was for a minor or borderline reason (e.g. nitrate or phosphate narrowly missing the target), the overall assessment was 'Favourable'. Where there were no 'fails' but some indicators were not determined, a minimum of five 'passes' was required for an overall 'Favourable' assessment and, in all cases, a pass for positive indicator species was necessary for a 'Favourable' outcome.

Table 12: Overall assessment of structures and functions.

Scoring	Assessment
All pass or one minor/borderline fail AND, if some indicators are Not Determined, the number of passes is at least five AND there is a pass for Positive Indicator Species	Green - Favourable
1 - 2 Fail	Amber - Unfavourable Inadequate
>2 Fail	Red - Unfavourable Bad

4.3 Future Prospects

Future prospects were assessed taking into account the present Structure and Functions as well as threats and pressures that were identified at the site. The activities found to impact on the sites surveyed are summarised in Table 13.

Table 13: Activities recorded at petrifying spring sites (in accordance with standardised list for Article 17 reporting).

Code	Activity
A04.01	Intensive grazing
A04.02	Non-intensive grazing
A04.03	Abandonment of pastoral systems, lack of grazing
B01.02	Artificial planting on open ground (non-native trees)
B02.02	Forestry clearance
D01.01	Paths, tracks, cycling tracks
D01.02	Roads, motorways
E01.01	Continuous urbanisation
E01.03	Dispersed habitation
E03.01	Disposal of household / recreational facility waste
G01	Outdoor sports and leisure activities, recreational activities
G01.04.03	Recreational cave visits
G01.08	Other outdoor sports and leisure activities
G05.01	Trampling, overuse
G05.05	Intensive maintenance of public parks /cleaning of beaches
G05.07	Missing or wrongly directed conservation measures
H02	Pollution to groundwater (point sources and diffuse sources)
I01	Invasive non-native species
J02.01	Landfill, land reclamation and drying out, general
J02.05	Modification of hydrographic functioning, general
J02.06.01	Surface water abstractions for agriculture
J02.07	Water abstractions from groundwater
L05	Collapse of terrain, landslide

Each activity at each site was recorded as having a High, Moderate or Low impact (H/M/L), as being positive, neutral or negative (+/0/-) for the conservation status of the site, and as originating inside or outside the habitat. Pollution was qualified as 'P' for phosphates, 'N' for nitrates and 'S' for sulphates. These were assessed for each site according to Table 14:

Table 14: Assessment of negative activities on conservation status of sites.

Scenarios	Assessment
All negative activities Low intensity and no increasing trend	Green - Favourable
Any other combination	Amber - Unfavourable Inadequate
≥2 High intensity negative activities or >4 with increasing trends	Red - Unfavourable Bad

4.4 Conservation Score

Conservation scores were calculated for each spring location, ranging from 1 (low conservation value for petrifying spring habitats) to 10 (highest conservation value). The Conservation Score was calculated as the total scores (up to a maximum of 10) for

- species diversity (Score 1 – 4, Table 15)
- the number of High Quality Indicator Species present
- the extent of tufa formation (Score 1 – 4, Table 16), and
- the presence of other positive characteristics (for example, hydrogeological / geological characteristics of merit relevant to the petrifying spring habitat, Score 0 - 1)

Table 15: Species diversity score.

Species Diversity	Criteria	Score
Very High	15+ positive indicator species*	4
High	10 – 14 positive indicator species*	3
Moderate	5 – 9 positive indicator species*	2
Low	1 – 4 positive indicator species*	1

* including High Quality Indicator Species (Section 4.2.2)

Table 16: Extent of tufa formation.

Tufa Formation	Criteria	Score
Very High	Massive, strongly consolidated deposits	4
High	Smaller consolidated deposits or strongly formed paludal tufa	3
Moderate	Patchy paludal tufa	2
Low	Sparse tufa formation	1

A summary of Conservation Scores from the recent field survey is shown below (Table 17). (Where species diversity was high, tufa formation extent was usually low, and vice versa, so no site exceeded a score of 10.) The overall conservation value of each spring was ranked on the basis of the Conservation Scores as low, moderate, high, very high or outstanding.

Table 17: Summary of Conservation Scores and ranking of springs.

Conservation Score	Rank	Number of Springs	% of Springs
1 – 2	Low	12	6.1%
3 – 4	Moderate	103	52.3%
5 - 6	High	65	33.0%
7 – 8	Very High	11	5.6%
9 - 10	Outstanding	6	3.0%
Total		**197**	**100%**

Sites with a score of 5 or higher were deemed to be of high conservation value. Sites with low scores are of least value in the context of petrifying spring habitats (many contain borderline habitat types), but they may be of high conservation value for other habitat types.

4.5 Overall Habitat Assessment

In total, 157 petrifying spring locations were assessed during the PhD project, with a combined area of 8.76 ha. The conservation status of Irish petrifying springs is assessed to be Favourable for 74% of the total area, Unfavourable Inadequate for 19% and Unfavourable Bad for 7% of total area. The geographical distribution of sites by conservation status is shown in Fig. 1 below. The overall conservation status for this habitat is assessed as Unfavourable Inadequate (Tables 18 and 19).

Table 18: Conservation status assessment by site area and number of spring locations (sites assessed in Lyons 2015, n=159).

	Favourable	**Unfavourable Inadequate**	**Unfavourable Bad**	**Overall Assessment**
Structures & Functions	6.50 ha (75%) 100 sites (69%)	1.67 ha (19%) 31 sites (22%)	0.54 ha (6%) 13 sites (9%)	Unfavourable Inadequate
Future Prospects	6.40 ha (74%) 93 sites (65%)	1.72 ha (20%) 36 sites (25%)	0.58 ha (7%) 15 sites (10%)	Unfavourable Inadequate
Overall Assessment	6.40 ha (74%) 93 sites (65%)	1.72 ha (20%) 36 sites (25%)	0.58 ha (7%) 15 sites (10%)	Unfavourable Inadequate

Table 19: Overall conservation status assessment for petrifying springs.

Range & Area [1]	Favourable
Structures & Functions	Unfavourable Inadequate
Future Prospects	Unfavourable Inadequate
Overall Assessment	**Unfavourable Inadequate**

[1] Range and Area were assessed for the 2013 Conservation Status Assessments (Lyons & Kelly 2013, NPWS 2013) and those data constitute a baseline measurement for the habitat. They include sites from other recent studies (in particular from the National Survey of Upland Habitats, Perrin *et al*. 2013a, b, c, d) which are not included in the data presented in Table 15.

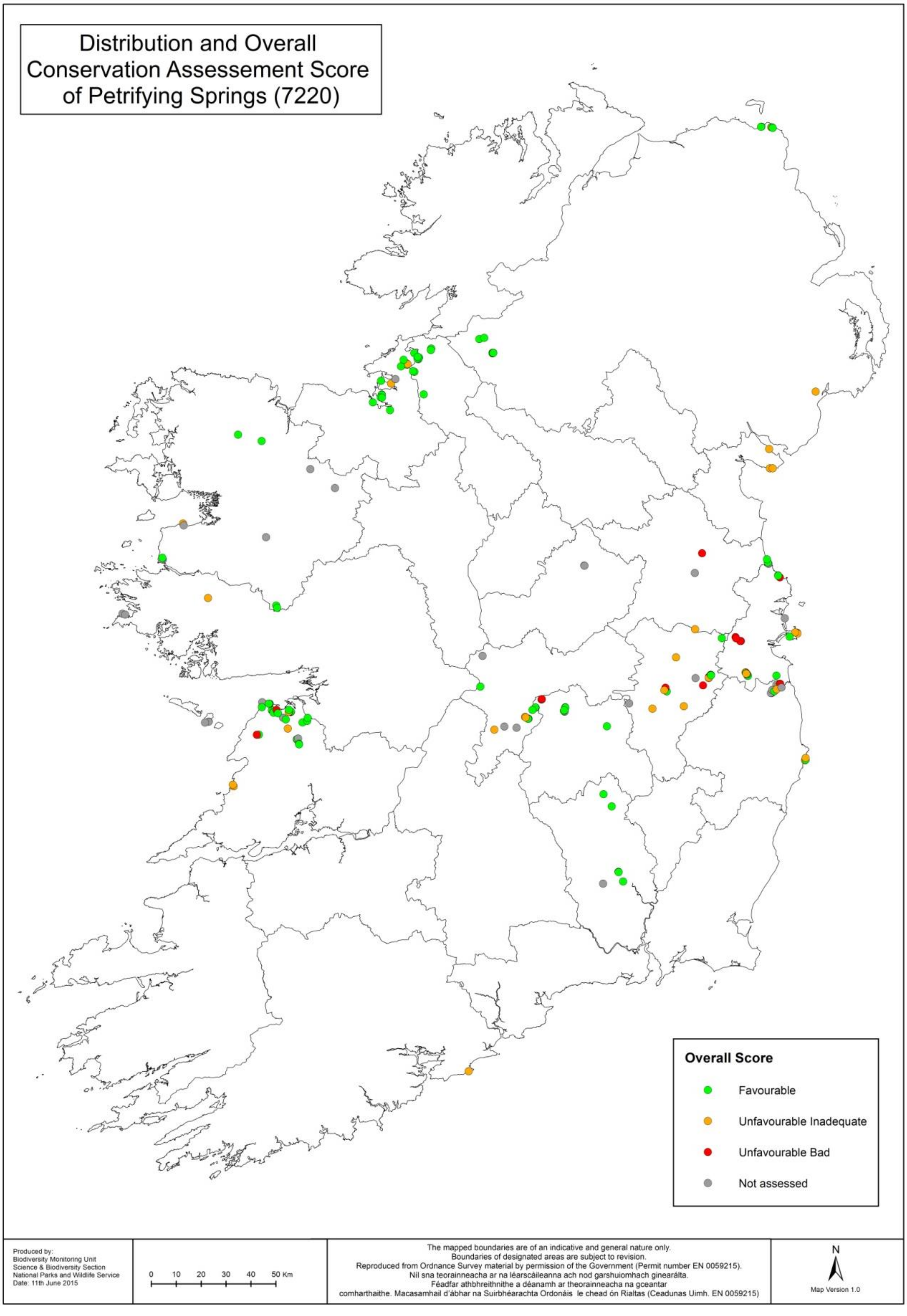

Fig. 1: Distribution of petrifying springs in Ireland by overall conservation status assessment.

5. Examples of Conservation Status Assessment

Seven examples are given to illustrate how the Conservation Status Assessment was applied to individual springs.

Example No.	Spring Location	Assessment Outcome
1	Spanish Point, Co. Clare	Unfavourable Inadequate
2	Glenasmole, Co. Dublin	Favourable
3	Fonthill, Co. Dublin	Unfavourable Bad
4	Pollardstown Fen, Co. Kildare	Unfavourable Bad
5	Ballycurrin Fen, Co. Mayo	Favourable
6	Glennamanagh, Co. Clare	Favourable
7	Benbulbin, Co. Sligo	Favourable

5.1 Example 1: Spanish Point

Photo 24: Tufa cascades on coastal cliffs (July 2013).

Photo 25: Much of the tufa surface is sparsely vegetated (April 2012).

Main petrifying spring community: *Eucladium verticillatum-Pellia endiviifolia* Springheads

Main tufa type(s): Tufa cascades

Location and Area

Site code	PS099a
Grid Ref.	IR 03566 77347
County	Clare
Setting	Coastal cliffs
Altitude	0m
Area	1,000 m^2

Conservation Score

Species Diversity	Moderate
HQ Indicator Species	0
Tufa-forming capacity	High
Other positive characteristics	
Conservation Score	**5**
Rank	**High**

Species

Positive Indicator Species

Chroothece sp.
Didymodon tophaceus
Eucladium verticillatum
Festuca rubra
Palustriella commutata
Palustriella falcata
Pellia endiviifolia
Rivularia sp.
Samolus valerandi

Accompanying Species

Agrostis stolonifera
Cochlearia officinalis
Leiocolea turbinata
Plantago maritima

DAFOR	Negative indicator species	Indicator type
O	*Cratoneuron filicinum*	Potentially Negative Bryophyte Species
R	*Vaucheria* cf *dillwynii*	Potentially Negative Alga

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	9	9	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Unwooded	0	Pass
Field layer height	Height between 10 and 50cm	Inaccessible to grazers	NA	NA
Trampling/dung	Cover should not be Abundant/Dominant	Inaccessible to grazers	NA	NA
Nitrate level	No increase from baseline and not above 10 mg/l	14.96	14.96	Fail
Phosphate level	No increase from baseline and not above 15 µg/l	6	6	Pass
Water flow	No alteration of natural flow	No alteration	0	Pass
Overall Structure & Functions				Unfavourable Inadequate

Threats & Pressures

Activity	Intensity	+ / 0 / -	Source	Pollution	Assessment
H02 Pollution to groundwater	M	-	Outside	N	M-
Overall Threats & Pressures					Unfavourable Inadequate

Overall Assessment

Area	Favourable
Structures & Functions	Unfavourable Inadequate
Future Prospects	Unfavourable Inadequate
Overall Assessment	**Unfavourable Inadequate**

5.2 Example 2: Glenasmole

Photo 26: Tufa cascade in seepage zone in woodland clearing (April 2013).

Photo 27: Tufa-forming stream below spring/seepage zone (April 2013).

Three separate petrifying spring communities occur within the area of influence of this spring:

- *Palustriella commutata-Geranium robertianum* Springhead (highest point of spring water emergence, with shaded tufa cascade)
- *Palustriella commutata-Agrostis stolonifera* Springhead (below the uppermost springhead, in woodland clearing where water seeps diffusely from the hillside, Photo 26).
- *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes (in the flush and stream that forms below the springhead and seepage zone, Photo 27).

Main tufa type(s): Tufa cascades, stream crust tufa, oncoids / ooids

Location and Area

Site code	PS015e
Grid Ref.	IO 09200 22853
County	Dublin
Setting	Wooded hillside
Altitude	180m
Area	2,800 m^2

Conservation Score

Species Diversity	High
HQ Indicator Species	0
Tufa-forming capacity	Very High
Other positive characteristics	
Conservation Score	**7**
Rank	**Very High**

Species

Positive Indicator Species	Accompanying Species		
Bryum pseudotriquetrum	*Agrostis stolonifera*	*Geranium robertianum*	*Pohlia melanodon*
Carex lepidocarpa	*Brachypodium sylvaticum*	*Glyceria notata*	*Pohlia wahlenbergii*
Carex remota	*Calliergonella cuspidata*	*Hedera helix*	*Primula vulgaris*
Chara vulgaris	*Cardamine flexuosa*	*Holcus lanatus*	*Ranunculus flammula*
Crepis paludosa	*Carex flacca*	*Hypericum tetrapterum*	*Ranunculus repens*
Didymodon tophaceus	*Deschampsia cespitosa*	*Juncus articulatus*	*Rubus fruticosus* agg.
Equisetum telmateia	*Dicranella varia*	*Juncus inflexus*	*Salix cinerea*
Festuca rubra	*Epilobium parviflorum*	*Mentha aquatica*	*Schedonorus arundinaceus*
Palustriella commutata	*Equisetum arvense*	*Nasturtium officinale* agg.	*Succisa pratensis*
Pellia endiviifolia	*Equisetum palustre*	*Plagiomnium elatum*	*Taraxacum officinale* agg.
Philonotis calcarea	*Filipendula ulmaria*	*Plagiomnium undulatum*	*Tussilago farfara*
	Fraxinus excelsior	*Poa trivialis*	*Veronica beccabunga*

DAFOR	Negative indicator species	Indicator type
F	*Brachythecium rivulare*	Potentially Negative Bryophyte Species
O	*Cratoneuron filicinum*	Potentially Negative Bryophyte Species
R	*Platyhypnidium riparioides*	Potentially Negative Bryophyte Species
F	*Eupatorium cannabinum*	Potentially Negative Herbaceous Species
O	*Juncus effusus*	Potentially Negative Herbaceous Species

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	11	11	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Woodland	NA	NA
Field layer height	Height between 10 and 50cm		TRUE	Pass

Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	2.95	2.95	Pass
Phosphate level	No increase from baseline and not above 15 µg/l	19	19	Fail
Water flow	No alteration of natural flow	No alteration	0	Pass
Overall Structure & Functions				Favourable

Threats & Pressures

Activity	**Intensity**	**+ / 0 / -**	**Source**	**Pollution**	**Assessment**
H02 Pollution to groundwater	L	-	Outside	P	L-
L05 Landslides	H	0	Inside		H0
Overall Threats & Pressures					Favourable

Overall Assessment

Area	Favourable
Structures & Functions	Favourable
Future Prospects	Favourable
Overall Assessment	Favourable

5.3 Example 3: Fonthill

Photo 28: Tufa dam on a small stream; the colour of the tufa is unusually dark due to presence of filamentous algae (April 2010).

Photo 29: Eroded dam a short distance downstream of Photo 28 (May 2013).

Main petrifying spring community: *Brachythecium rivulare-Platyhypnidium riparioides* Tufaceous Streams and Flushes

Main tufa type(s): Tufa dams and waterfalls

Location and Area

Site code	PS018b
Grid Ref.	IO 06875 35615
County	Dublin
Setting	Wooded hillside
Altitude	25m
Area	100 m^2

Conservation Score

Species Diversity	Low
HQ Indicator Species	0
Tufa-forming capacity	High
Other positive characteristics	
Conservation Score	**4**
Rank	**Moderate**

Species

Positive Indicator Species	Accompanying Species
Chrysosplenium oppositifolium	*Agrostis stolonifera*
Palustriella commutata	*Conocephalum conicum* s.s.
Pellia endiviifolia	*Geranium robertianum*
	Plagiomnium rostratum
	Ranunculus ficaria

DAFOR	Negative indicator species	Indicator type
O	*Brachythecium rivulare*	Potentially Negative Bryophyte Species
O	*Cratoneuron filicinum*	Potentially Negative Bryophyte Species
A	*Platyhypnidium riparioides*	Potentially Negative Bryophyte Species
A	*Vaucheria* sp.	Potentially Negative Alga

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	3	3	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		Abundant	Fail
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Woodland	NA	NA
Field layer height	Height between 10 and 50cm		TRUE	Pass
Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	5.48	5.48	Pass
Phosphate level	No increase from baseline and not above 15 μg/l	140	140	Fail
Water flow	No alteration of natural flow	Modified	Modified	Fail
Overall Structure & Functions				Unfavourable Bad

Threats & Pressures

Activity	Intensity	+ / 0 / -	Source	Pollution	Assessment
H02 Pollution to groundwater	H	-	Outside	P, S	H-
J02.05 Modified water flow	H	-	Outside		H-
Overall Threats & Pressures					Unfavourable Bad

Overall Assessment

Area	Favourable
Structures & Functions	Unfavourable Bad
Future Prospects	Unfavourable Bad
Overall Assessment	**Unfavourable Bad**

5.4 Example 4: Pollardstown Fen (Northern Margins)

Photo 30: Tall, ungrazed vegetation at the spring line along the fen margin (Sept. 2012).

Photo 31: Upwelling spring dominated by *Palustriella commutata* and *Bryum pseudotriquetrum* (Feb. 2012).

Main petrifying spring communities: *Carex lepidocarpa* Small Sedge Springs in diffuse seepage zone along the margins of the fen (Photo 30), with localised *Palustriella commutata-Agrostis stolonifera* springheads (Photo 31).

Main tufa type(s): Paludal tufa

Location and Area	
Site code	PS004d
Grid Ref.	IN 76899 16916
County	Kildare
Setting	Fen
Altitude	85m
Area	2,000 m^2

Conservation Score	
Species Diversity	High
HQ Indicator Species	0
Tufa-forming capacity	Low
Other positive characteristics	
Conservation Score	**4**
Rank	**Moderate**

Species

Positive Indicator Species	
Aneura pinguis	*Pedicularis palustris*
Bryum pseudotriquetrum	*Schoenus nigricans*
Carex lepidocarpa	*Scorpidium cossonii*
Carex panicea	
Festuca rubra	
Galium uliginosum	
Palustriella commutata	

Accompanying Species	
Agrostis stolonifera	*Juncus articulatus*
Calliergonella cuspidata	*Juncus subnodulosus*
Cardamine pratensis	*Mentha aquatica*
Carex flacca	*Molinia caerulea*
Deschampsia cespitosa	*Plagiomnium undulatum*
Equisetum arvense	*Potentilla erecta*
Eriophorum angustifolium	*Succisa pratensis*

DAFOR	Negative indicator species	Indicator type
O	*Cratoneuron filicinum*	Potentially Negative Bryophyte Species
O	*Eupatorium cannabinum*	Potentially Negative Herbaceous Species
O	*Phragmites australis*	Potentially Negative Herbaceous Species
R	*Fraxinus excelsior*	Potentially Negative Woody Species
O	*Salix cinerea*	Potentially Negative Woody Species

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	10	10	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Unwooded	Occasional	Fail
Field layer height	Height between 10 and 50cm		>50cm	Fail
Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	19.02	19.02	Fail
Phosphate level	No increase from baseline and not above 15 µg/l	20	20	Fail
Water flow	No alteration of natural flow	Historic	Historic	Pass
Overall Structure & Functions				Unfavourable Bad

Threats & Pressures

Activity	Intensity	+ / 0 / -	Source	Pollution	Assessment
A04.03 Lack of grazing	H	-	Inside		H-
H02 Pollution to groundwater	M	-	Outside	N, P	M-
J02.07 Groundwater abstraction	xx	xx	Both		xx
Overall Threats & Pressures					Unfavourable Inadequate

xx = Unknown

Overall Assessment

Area	Favourable
Structures & Functions	Unfavourable Bad
Future Prospects	Unfavourable Bad
Overall Assessment	**Unfavourable Bad**

5.5 Example 5: Ballycurrin Fen

Photo 32: Overview of site, with *Schoenus nigricans*-dominated vegetation (May 2011).

Photo 33: Detail of tufa formation (June 2012).

Main petrifying spring community: *Schoenus nigricans* Springs

Main tufa type(s): Paludal tufa, marl

Location and Area	
Site code	PS065
Grid Ref.	IM 20605 49864
County	Mayo
Setting	Fen
Altitude	14m
Area	500 m^2

Conservation Score	
Species Diversity	Very High
HQ Indicator Species	0
Tufa-forming capacity	Moderate
Other positive characteristics	
Conservation Score	**6**
Rank	**High**

Species

Positive Indicator Species	
Anagallis tenella	*Palustriella commutata*
Aneura pinguis	*Palustriella falcata*
Bryum pseudotriquetrum	*Parnassia palustris*
Campylium stellatum s.s.	*Pinguicula lusitanica*
Carex dioica	*Pinguicula vulgaris*
Carex hostiana	*Preissia quadrata*
Carex lepidocarpa	*Samolus valerandi*
Carex panicea	*Schoenus nigricans*
Eleocharis quinqueflora	*Scorpidium cossonii*
Eriophorum latifolium	*Scorpidium scorpioides*
Festuca rubra	*Selaginella selaginoides*
Fissidens adianthoides	*Triglochin palustris*
Neottia ovata	

Accompanying Species	
Breutelia chrysocoma	*Lotus corniculatus*
Calliergonella cuspidata	*Mentha aquatica*
Carex flacca	*Molinia caerulea*
Carex nigra	*Polygala vulgaris*
Centaurea nigra	*Potentilla erecta*
Ctenidium molluscum	*Prunella vulgaris*
Dactylorhiza fuchsii	*Succisa pratensis*
Dactylorhiza incarnata	
Eriophorum angustifolium	
Fissidens taxifolius	
Hydrocotyle vulgaris	
Hypericum tetrapterum	
Linum catharticum	

DAFOR	Negative indicator species	Indicator type
O	*Cratoneuron filicinum*	Potentially Negative Bryophyte Species
O	*Juncus effusus*	Potentially Negative Herbaceous Species
O	*Phragmites australis*	Potentially Negative Herbaceous Species
O	*Calluna vulgaris*	Potentially Negative Woody Species
R	*Crataegus monogyna*	Potentially Negative Woody Species
R	*Fraxinus excelsior*	Potentially Negative Woody Species

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	25	25	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Unwooded	V. Rare	Pass
Field layer height	Height between 10 and 50cm		TRUE	Pass
Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	<0.07	<0.07	Pass
Phosphate level	No increase from baseline and not above 15 μg/l	5	5	Pass
Water flow	No alteration of natural flow	Minor	Minor	Pass
Overall Structure & Functions				**Favourable**

Threats & Pressures

Activity	Intensity	+ / 0 / -	Source	Pollution	Assessment
J02.01 Presence of drain (old drain)	L	-	Inside		L-
Overall Threats & Pressures					**Favourable**

Overall Assessment

Area	Favourable
Structures & Functions	Favourable
Future Prospects	Favourable
Overall Assessment	**Favourable**

5.6 Example 6: Glennamanagh

Photo 34: Spring water issuing from karst limestone and flowing over bedrock, forming thin stream crust tufa (May 2012).

Photo 35: *Pinguicula grandiflora* in a mat of *Palustriella falcata* with small sedges including *Carex panicea* (May 2012).

Main petrifying spring community: *Palustriella falcata-Carex panicea* Springs

Main tufa type(s): Paludal & stream crust tufa

Location and Area	
Site code	PS092a
Grid Ref.	IM 26356 07081
County	Clare
Setting	Karst limestone
Altitude	122m
Area	1,550 m^2

Conservation Score	
Species Diversity	Very High
HQ Indicator Species	0
Tufa-forming capacity	Moderate
Other positive characteristics	
Conservation Score	**6**
Rank	**High**

Species

Positive Indicator Species	
Aneura pinguis	*Pellia endiviifolia*
Bryum pseudotriquetrum	*Philonotis calcarea*
Carex lepidocarpa	*Pinguicula grandiflora*
Carex panicea	*Pinguicula vulgaris*
Chara vulgaris	*Preissia quadrata*
Fissidens adianthoides	*Rivularia biasolettiana*

Accompanying Species	
Bellis perennis	*Mentha aquatica*
Briza media	*Molinia caerulea*
Cardamine pratensis	*Nasturtium officinale* agg.
Carex flacca	*Plantago maritima*
Carex nigra	*Polygala vulgaris*
Cirsium palustre	*Potentilla erecta*

Palustriella commutata	*Sagina nodosa*	*Conocephalum conicum* s.s.	*Sesleria caerulea*
Palustriella falcata	*Schoenus nigricans*	*Hypericum tetrapterum*	*Succisa pratensis*
		Juncus articulatus	*Tussilago farfara*

DAFOR	Negative indicator species	Indicator type
	None	

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	16	16	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Unwooded	0	Pass
Field layer height	Height between 10 and 50cm		TRUE	Pass
Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	1.50	1.50	Pass
Phosphate level	No increase from baseline and not above 15 µg/l	4	4	Pass
Water flow	No alteration of natural flow	Minor	Minor	Pass
Overall Structure & Functions				**Favourable**

Threats & Pressures

Activity	Intensity	+ / 0 / -	Source	Pollution	Assessment
J02.06.01 Water abstraction - agriculture	L	-	Inside		L-
Overall Threats & Pressures					**Favourable**

Overall Assessment

Area	Favourable
Structures & Functions	Favourable
Future Prospects	Favourable
Overall Assessment	**Favourable**

5.7 Example 7: Benbulbin

Photo 36: Springs issuing over steep, tufa-stained cliffs in centre of photograph (Sept. 2012).

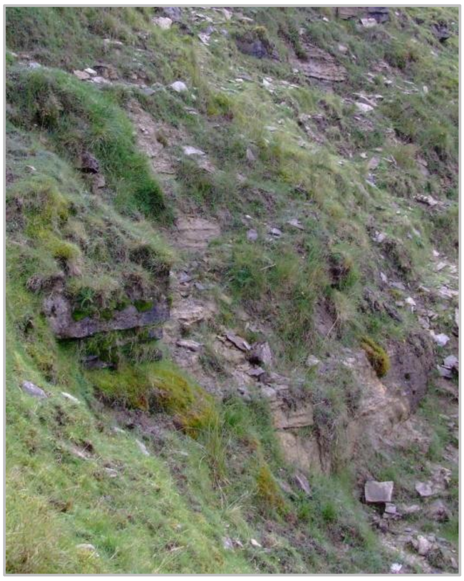

Photo 37: Sparsely deposited stream crust tufa amongst species-rich vegetation (Sept 2012).

Main petrifying spring community: *Saxifraga aizoides-Seligeria oelandica* Springs

Main tufa type(s): Paludal & stream crust tufa

Location and Area

Site code	PS107
Grid Ref.	IG 70720 45806
County	Sligo
Setting	Montane cliff
Altitude	324m
Area	350 m^2

Conservation Score

Species Diversity	Very high
HQ Indicator Species	5
Tufa-forming capacity	Low
Other positive characteristics	
Conservation Score	**10**
Rank	**Outstanding**

Species

High Quality Indicator Species	DAFOR

Accompanying Species

Hymenostylium recurvirostrum var. *insigne*	*R*
Orthothecium rufescens	*F*
Saxifraga aizoides	*F*
Seligeria oelandica	*F*
Seligeria patula	*R*

Positive Indicator Species	
Alchemilla glabra	*Palustriella commutata*
Aneura pinguis	*Pellia endiviifolia*
Bryum pseudotriquetrum	*Pinguicula vulgaris*
Carex lepidocarpa	*Triglochin palustris*
Carex panicea	
Eucladium verticillatum	
Festuca rubra	
Gymnostomum aeruginosum	
Hymenostylium recurvirostrum var. *recurvirostrum*	
Jungermannia atrovirens	
Lysimachia nemorum	

Agrostis stolonifera
Bellis perennis
Breutelia chrysocoma
Carex flacca
Cirsium palustre
Conocephalum salebrosum
Ctenidium molluscum
Deschampsia cespitosa
Dicranella varia
Equisetum palustre
Eriophorum angustifolium
Juncus articulatus
Leiocolea turbinata
Linum catharticum
Pohlia wahlenbergii
Scorzoneroides autumnalis
Sesleria caerulea
Taraxacum officinale agg.
Tussilago farfara

DAFOR	Negative indicator species	Indicator type
R	*Epilobium brunnescens*	Potentially Negative Herbaceous Species
R	*Juncus effusus*	Potentially Negative Herbaceous Species

Structures & Functions

Indicator	Target	Baseline	Result	Assessment
Positive species (including HQ indicator species)	At least 3 species; no loss from baseline no. of species	20	20	Pass
Invasive species	Absent		0	Pass
Potentially negative bryophytes and algae	Cover should not be Abundant/Dominant		0	Pass
Potentially negative herbaceous species	Cover should not be Abundant/Dominant		0	Pass
Scrub (potentially negative woody species)	Absent (except in woodland)	Unwooded	0	Pass
Field layer height	Height between 10 and 50cm		TRUE	Pass

Trampling/dung	Cover should not be Abundant/Dominant		0	Pass
Nitrate level	No increase from baseline and not above 10 mg/l	0.81	0.81	Pass
Phosphate level	No increase from baseline and not above 15 μg/l	5	5	Pass
Water flow	No alteration of natural flow	No alteration	0	Pass
Overall Structure & Functions				**Favourable**

Threats &Pressures

Activity	**Intensity**	**+ / 0 / -**	**Source**	**Pollution**	**Assessment**
No known threats					0
Overall Threats & Pressures					Favourable

Overall Assessment

Area	Favourable
Structures & Functions	Favourable
Future Prospects	Favourable
Overall Assessment	**Favourable**

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Appendix 1 Field Survey Record Sheet

PETRIFYING SPRING $4m^2$ RELEVÉ RECORD SHEET			**Quadrat No.**
Spring Ref:	**Date:**		**Relevé location:**
Site Name:			
Spring Name:			
Grid Ref: **± m**			
Start Time:	**Altitude:** **m**		
End Time:	**Aspect:**		
Surveyor(s):	**Slope:**		
❑ 2x2m ❑ 1x4m ❑ Irregular Size (if <$4m^2$):			
❑ Spring Head ❑ Flush ❑ Other:			
pH	EC µS/cm	Temp. °C	

Tufa (% of quadrat, inc. below veg/water)		**Water** (% of quadrat surface)		**Surface** (% quadrat, visible, excl. water)	
❑ Cascade	%	❑ Flowing / trickling	%	❑ Living field / ground flora	%
❑ Paludal 1 2 3	%	❑ Pool / standing water	%	❑ Bare tufa (active/recent)	%
❑ Stream crust	%	❑ Dripping	%	❑ Ancient / inactive tufa	%
❑ Oncoids / ooids	%	❑ Damp	%	❑ Leaf litter / standing dead	%
❑ Dam	%	❑ Dry, not impacted by spring	%	❑ Bare soil	%
❑ Cemented rudites	%	❑ Other	%	❑ Bare stone	%
❑ Non-tufa	%	❑ Other	%	❑ Other	%
TOTAL 100	**%**	**TOTAL 100**	**%**	**TOTAL 100**	**%**

Paludal tufa 1= weak/thin/discontinuous, 3 = strongly forming/continuous/conspicuous Cover values: record to nearest 5%. If <5%, then use: 3%, 1%, 0.5%, 0.1%

Field / Ground Flora

✓ **FORBS**	**%**	✓ **GRAMINOIDS**	**%**	✓ **BRYOPHYTES**	**%**	✓ **WOODY (<50cm)**	**%**
❑ Anagallis tenella		❑ Agrostis stolonifera		❑ Aneura pinguis		❑ Fraxinus excelsior	
❑ Cardamine pratensis		❑ Brachypodium sylvat.		❑ Brachythecium rivulare		❑ Hedera helix	
❑ Cirsium palustre		❑ Carex flacca		❑ Breutelia chrysocoma		❑ Rubus fruticosus	
❑ Crepis paludosa		❑ Carex lepidocarpa		❑ Bryum pseudotriquetrum		❑ Salix cinerea	
❑ Eupatorium cannabinum		❑ Carex panicea		❑ Calliergonella cuspidata		❑	
❑ Geranium robertianum		❑ Carex remota		❑ Campylium stellatum		❑	
❑ Hypericum tetrapterum		❑ Deschampsia cespitosa		❑ Cratoneuron filicinum		**TOTAL WOODY <50cm**	
❑ Mentha aquatica		❑ Eleocharis quinqueflora		❑ Ctenidium molluscum			
❑ Nasturtium officinale agg		❑ Eriophorum angust.		❑ Dicranella varia		✓ **PTERIDOPLYTES**	**%**
❑ Parnassia palustris		❑ Festuca rubra		❑ Didymodon tophaceus		❑ Equisetum arvense	
❑ Pinguicula vulgaris		❑ Holcus lanatus		❑ Eucladium verticillatum		❑ Equisetum palustre	
❑ Potentilla erecta		❑ Juncus articulatus		❑ Fissidens adianthoides		❑ Equisetum telmateia	
❑ Ranunculus repens		❑ Juncus inflexus		❑ Palustriella commutata		❑ Equisetum variegatum	
❑ Succisa pratensis		❑ Molinia caerulea		❑ Palustriella falcata		❑ Selaginella selaginoides	
❑ Triglochin palustris		❑ Poa trivialis		❑ Pellia endiviifolia		❑	
❑ Tussilago farfara		❑ Schoenus nigricans		❑ Philonotis calcarea		❑	
❑		❑		❑		**TOTAL PTERIDOPHYTES**	
❑		❑		❑			
❑		❑		❑		✓ **ALGAE**	
❑		❑		❑		❑ Chara	
❑		❑		❑		❑	
❑		❑		❑		**TOTAL ALGAE**	
TOTAL FORBS		**TOTAL GRAMINOIDS**		**TOTAL BRYOPHYTES**		**TOTAL CANOPY**	

Additional Ground Flora Species			
SPECIES	**%**	**SPECIES**	**%**

Shrub / Canopy Layer			
SPECIES	**Rooted outside % Canopy**	**Rooted inside % Canopy**	**Rooted inside Height (m)**
TOTAL CANOPY (ROOTED INSIDE + OUTSIDE) %	**Total %**	**Total %**	
MAX HEIGHT (m) ABOVE QUADRAT (ROOTED INSIDE + OUTSIDE):			

Record shrubs / saplings (≥50cm, <2m) and canopy cover ≥2m.

Samples										
Water Sample(s) Ref:										
Other Sample(s) Ref:										

NOTE