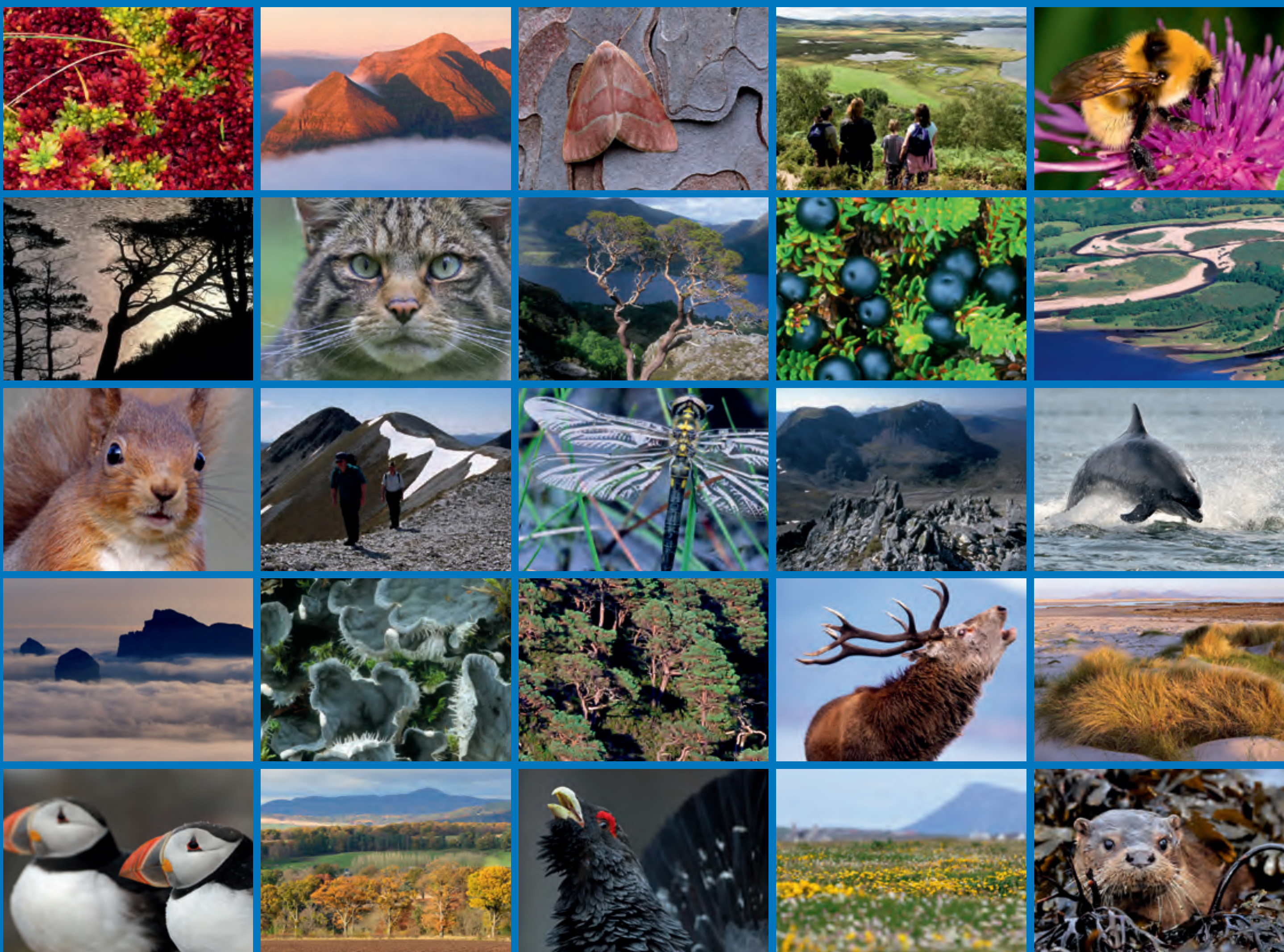
Scottish Natural Heritage
Commissioned Report No. 421

Assessing the impacts of small scale hydroelectric schemes on rare bryophytes and lichens



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Assessing the impacts of small scale hydroelectric schemes on rare bryophytes and lichens

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COMMISSIONED REPORT

Summary

Evaluating the impacts of small scale hydroelectric schemes on rare bryophytes and lichens

Commissioned Report No. 421 (Project no: 1288)
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Background

In the western Scottish uplands, where much of the potential for hydroelectric scheme development is situated, small streams frequently occur in sheltered ravine habitats. Such humid ravines and associated woodlands can be internationally important habitats for oceanic species, both bryophytes and lichens. There is currently no evidence regarding rare bryophytes and lichens on which to base responses to development proposals for small scale hydroelectric schemes. Many ecologists suggest that small changes in mid-flow rates will have little impact because species will adjust to small shifts in fluvial zones. There are, however, frequent reports of one or more nationally rare or scarce bryophyte or lichen species between the intake and outfall of such schemes. The ecology of such species, which are thought to have poor dispersal and establishment ability, may result in population losses as commoner species adjust more readily and dominate new habitat. In addition some species may be directly affected by changes in humidity or water level.

This report considers the potential impacts of small hydroelectric schemes on bryophytes and lichens. Monitoring methods to detect these impacts are reviewed and recommendations for future monitoring methods proposed.

Main findings

- Bryophytes and lichens have been largely under-recorded in the small streams where small hydroelectric schemes are likely to be developed (stream discharge ≈ 0.04 - 4 m^3 water s^{-1}). Therefore there is an urgent need to establish a baseline of their distribution in this habitat.
- Water abstraction for small hydroelectric schemes could considerably extend the duration of drought conditions from 5 to ~50% of the time in the river reaches affected. The impact of weirs constructed for hydroelectric operation on sediment transport will be dependent on stream slope.

- It is likely that the impact of hydroelectric schemes on rare species alone would not be detectable due to low frequencies of occurrence, therefore the survey designs and methodologies proposed in this report are for all species (rare and common).
- While the effects of small hydroelectric schemes may be detectable with high probabilities, the power of prediction at any single site may remain low due to natural variability. This issue is illustrated for lowland rivers impacted by water mills.
- Three complementary sampling designs are recommended: (1) before and after control impact assessment, (2) paired (control *vs* impacted) comparisons and (3) site reference condition modelling. For all of these designs, as wide a range of sites as possible should be sampled in order to maximise the chances of detecting impacts.
- A survey method specifically designed for the purpose of this study is presented. The survey may also provide an opportunity to gain additional information on bryophyte and lichen traits if samples are collected. Training for quality assurance purposes and a pilot study to determine optimum sampling effort is recommended.
- An additional approach is also described whereby core conservation areas for bryophytes and lichens could be identified using national species distribution data and a new algorithm developed to take into account spatial connectivity. This would provide national scale maps identifying those areas where hydroelectric scheme development should be discouraged, providing guidance at the national level.
- Quantification of the impact of small hydroelectric schemes on bryophytes and lichens will serve multiple purposes. In addition to informing impact assessment it will increase our general understanding of bryophyte and lichen distribution in small streams, enhance our ability to predict the consequences of climate change (through improved understanding of the impacts of flow regime changes), and assist with the definition of core conservation areas for bryophytes and lichens.

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Acronyms

BACI – Before and After Control Impact
BHA – British Hydropower Association
EC – Electric Conductivity
EIA – Environmental Impact Assessment
^{A}EQR – Adjusted Ecological Quality Ratio (observed÷expected)
PAR – Photosynthetic Active Radiation
Q – Stream discharge
Q_{50} – median flows (50% chance exceedance discharge)
Q_{95} – low flows (95% chance exceedance discharge)
RDB – Red Data Book
RMHI – River Macrophyte Hydraulic Index
SEPA – Scottish Environmental Protection Agency
UKTAG – UK Technical Advisory Group
WFD – Water Framework Directive

1 INTRODUCTION

1.1 Background to the project

There is currently no evidence base, regarding rare bryophytes and lichens, on which to formulate responses to development proposals for small scale hydroelectric schemes. Many developers suggest that small changes in mid-flow rates will have little impact because species will adjust to small shifts in fluvial zones. There are, however, frequent reports of one or more nationally rare or scarce bryophyte or lichen species between the intake and outfall of such schemes. The ecology of such species, which are thought to have poor dispersal and establishment ability (though see Cleavitt, 2002), may result in population losses as commoner species adjust more readily, or not at all, to the shift in ecotone (cf During & van Tooren, 1987; Vieira *et al.,* 2005). In addition, some species may be directly affected by changes in humidity (e.g. *Radula carringtonii*, Joint Nature Conservation Committee, 2005, p. 31) or water level (e.g. *Thamnobryum angustifolium*, *T. cataractarum*, JNCC 2005, p. 43-44).

1.2 Potential for hydroelectric scheme development in Scotland

The Scottish Government is committed to the expansion of renewable energy generation including hydroelectric power. A recent report by Forrest & Wallace (2009)[1] highlighted the potential scale of development, particularly of small hydroelectric schemes (Table 1) and the fact that much of this potential is located within western Scotland, co-incident with regions which are internationally important for oceanic bryophyte and lichen communities (Fig. 1). The large number of schemes involved and their location raises the risk of impact on bryophyte and lichen communities in these areas, but further information is needed to accurately assess the risks.

[1] Scottish government news about new report on hydroelectric schemes 21/01/2010
http://www.scotland.gov.uk/News/Releases/2010/01/21113034

the report in question:
http://www.scotland.gov.uk/Resource/Doc/299322/0093327.pdf

Table 1: Breakdown of hydroelectric power potential by Scottish region (Forrest & Wallace, 2009). Note that 75% of the potential for development lies in the regions (1, 9, 10, 11, 12) of most importance for rare oceanic bryophytes (Fig 1).

	1975-1996 Scottish administrative region	Number§	Total power† (MW)
1	Strathclyde	2,090	280
2	Dumfries & Galloway	282	47
3	Borders	158	33
4	Lothian	54	4
5	Central	176	33
6	Fife	29	2
7	Tayside	893	154
8	Grampian	199	43
9	Highland	3008	594
10	Western Isles	136	12
11	Shetland	10	1
12	Orkney	8	0.4

§ 97% of total power by <5 MW hydroelectric schemes
† 93% of total number by <0.5 MW hydroelectric schemes

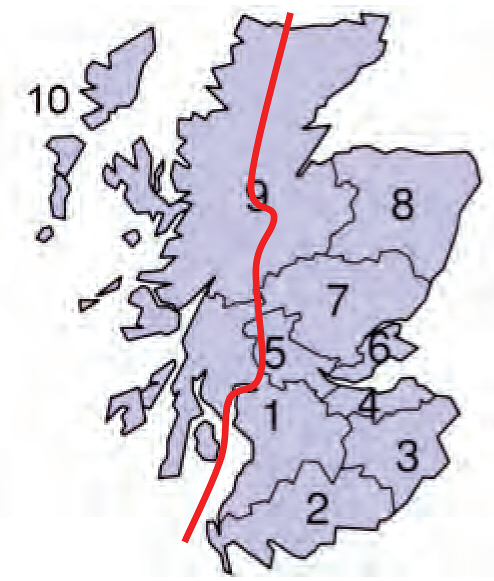

Figure 1: Eastern limit of the main area of distribution of rare oceanic bryophytes (red line; Ben Averis, pers.comm.) and Scottish administrative regions (1975-1996), numbers correspond to regions in Table 1. © GNU Free Documentation License 1.2 or any later version published by the Free Software Foundation.

1.3 Bryophyte and lichen communities associated with fluvial habitats

Freshwater habitats support a number of specialist species of bryophytes and lichens which require either permanent or frequent inundation and many more which prefer the high humidity conditions found close to water courses. Bryophyte and lichen communities associated with streams are generally best developed in the uplands where a combination of steep gradients and rocky outcrops give rise to well-aerated, cold water and a high diversity of microhabitats suitable for colonisation (Gilbert, 2000; Porley & Hodgetts, 2005). The characteristics that make streams likely to support a good bryophyte and lichen flora are, however, also those which make them well suited to development of small scale hydroelectric schemes.

Freshwater habitats are commonly divided into four zones with distinct species assemblages (Gilbert, 2000, Thüs & Schultz, 2009), namely (in order of decreasing duration of inundation); aquatic, amphibious (fluvial mesic), riparian (fluvial xeric) and terrestrial (fluvial terrestrial). The aquatic zone supports a relatively small number of highly specialised species able to tolerate more or less permanent submersion (*cf.* Glime & Vitt, 1987) and exposed only during periods of drought. The amphibious zone supports a much larger flora of species requiring permanently damp conditions, but tolerant of both submergence and periods of desiccation (Jonsson, 1997; Gilbert, 2000). In the riparian zone most species have no particular physiological adaptation to submergence but benefit from the generally humid conditions, this zone includes terrestrial species with wide ecological amplitude. Terrestrial zone species generally have low tolerance of submergence (Gilbert, 2000), but benefit from the absence of competition with higher plants in areas that are occasionally swept by winter floods. In addition, the disturbance associated with spate flows may be an important mechanism in creating bare habitat and regeneration niches for some 'rare' bryophytes or lichens.

In the western Scottish uplands, where much of the potential for hydroelectric power development is situated, small streams frequently occur in sheltered ravine habitats. Such humid ravines and associated woodlands (see JNCC, 2005) can be important habitats for oceanic species, both bryophytes and lichens, which are restricted to these damp habitats in western Britain (Fig. 1).

Relatively low numbers of species are specifically associated with aquatic habitats (e.g. 4% of the UK lichen flora); in the UK Gilbert (2000) recorded 15 lichen species in the aquatic zone of acid streams, 25 in the amphibious zone and 50 in the riparian zone with the amphibious zone supporting the highest diversity of specialist species. In total, around 160 lichen species have been recorded from freshwater habitats in the UK, with around 50% being restricted to these habitats and the other 50% also occurring on damp rock away from water courses. Seven Red Data Book species are associated with freshwater habitats (Gilbert, 2001), of which six occur in the Scottish uplands, namely *Aspicillia melanaspis*, *Collema parvum*, *Collema dichotomum*, *Lecanora achariana*, *Peltigera lepidophora* and *Phaeophyscia endococcinea*. While the *Collema* species are found in the aquatic zone the remainder tend to be associated with streamside rocks and bird-perch boulders. Similar patterns of diversity in aquatic habitats are described for bryophyte species; only 38 species are associated with surface running water habitats in the UK, while 295 occur in frequently inundated areas around water courses (Hill *et al.,* 2007). The majority of aquatic bryophytes are widespread in these habitats and the number of rarities is relatively limited (Porley & Hodgetts, 2005). In the latest field guide to riverine plants of Britain and Ireland, 63 species of bryophytes and 40 species of lichens of conservation concern were listed (Lansdown, 2009).

In western Scotland however, a large number of rare or scarce oceanic species (both bryophytes and lichens) are associated with the permanently humid conditions provided by streams running within ravines (especially wooded ravines) – see notes on the habitats of uncommon oceanic bryophytes species along western Scottish streams (Ben Averis, Annexe 1). These habitats can include some of the richest bryophyte and lichen communities in the UK (Coppins & Coppins, 2005; Rothero, 2005) and are of international significance.

Finally, it is important to note that both bryophytes and lichens have been largely under-recorded (due to lack of survey effort) in the small streams where further small scale hydroelectric schemes are likely to be developed (Lansdown, Pers. Comm.). Therefore there is an urgent need to establish a baseline of bryophyte and lichen distribution and ecology in these small streams (i.e. those with a mean flow, $Q_{mean} \approx 0.04$ to 4 $m^3 s^{-1}$ for hydroelectric schemes with installed capacity of 0.02-2 MW).

2 POTENTIAL IMPACTS OF HYDROELECTRIC SCHEMES ON STREAM HYDRO-MORPHOLOGY.

In this report we follow the definition of small hydroelectric schemes based on the Scottish Renewables hydro brief[2] as all hydroelectric schemes with an installed capacity under 10MW. Most small hydroelectric schemes are currently <2 MW (SEPA data, pers. comm.) and it is for schemes of this size where the majority of potential for further development lies (Table 1).

2.1 Typical design of a small hydroelectric scheme.

Small scale hydroelectric schemes vary in design and layout depending on the terrain where the scheme is to be installed, but all have several key features in common (Fig. 2). The first is the intake weir, which is the point at which water is abstracted from the main stream channel in order to power the turbine. Water abstracted at the weir is diverted into a forebay tank where screens filter out any water-borne debris before it flows down to the turbine located in the power house through a large diameter pipe or 'penstock'. The forebay tank may be located immediately next to the weir, with the penstock following the line of the stream to the power house, or there may be a canal diverting the abstracted water to a forebay tank located away from the stream (as in Fig. 2). The height differential between the forebay tank and the turbine, known as the 'head', is a key factor determining the amount of energy generated. After passing through the turbine the abstracted water is returned to the stream through a pipe or channel known as the 'tail race'.

Aside from the disturbance associated with construction, the key changes induced by the presence of a small scale hydroelectric scheme are the impoundment of water upstream of the intake weir, the abstraction of water between the intake weir and the tail race and disturbance associated with the return of water to the main channel at the tail race which are described in more detail below.

[2] http://www.scottishrenewables.com//MultimediaGallery/ae6ecea0-7084-49f3-b1fd-a63656bc3cfe.pdf

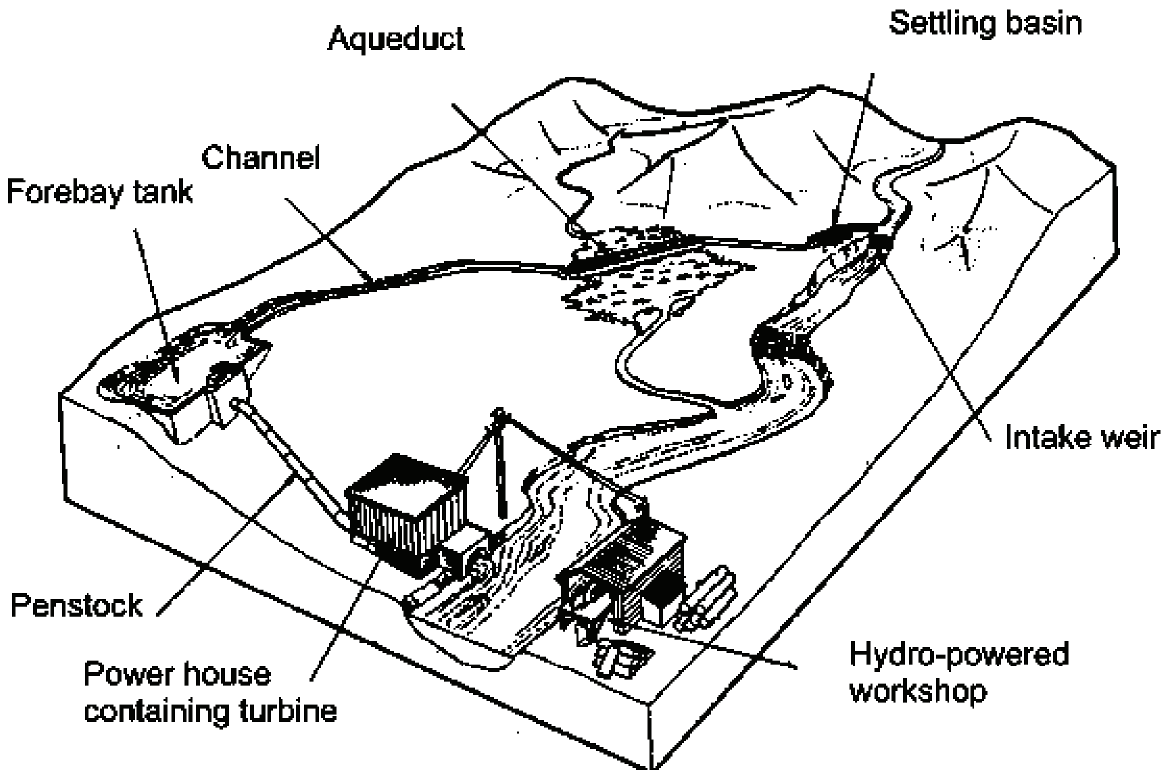

Figure 2: Layout of a typical micro hydroelectric scheme (Harvey et al., 1993). © GNU Free Documentation License 1.2 or any later version published by the Free Software Foundation.

2.2 Water abstraction between the intake weir and the tail race

Much information about hydroelectric schemes is provided by the British Hydropower Association (BHA), notably to assess the feasibility of planned schemes[3]. When planning a new development, the design flow (optimum water flow abstraction) should not exceed the average discharge of the stream (Q_{mean}) for cost and efficiency reasons. Generally the design flow is likely to be within 0.33 to 0.75 Q_{mean}. This provides a means to assess the likely impact of water abstraction on river flows.

The quantity of water abstracted by a hydroelectric scheme is related to its installed capacity, itself limited by the discharge and head of water available. The relationship between hydroelectric scheme capacity and water abstraction at 85 Scottish sites is illustrated in Fig. 3. The amount of compensation flow (i.e. the stream flow below which abstraction ceases) will depend on site-specific concerns, but a reasonable first estimate will lie between the 90 and 99% flow exceedance (Q_{90} and Q_{99}, respectively) values of river flow (e.g. Q90 is the flow rate that is exceeded for 90% of the time; see BHA, footnote 3, Annexe 2). As an example of the potential impacts, we illustrate the effect of a hydroelectric scheme on the River Spey at Kinrara, assuming a Q_{95} compensation flow and a design flow of 0.5 Q_{mean} (Fig. 4 & 5). Water abstraction would, in this case, considerably extend the duration of drought conditions in the river reach affected from 5 to 54% of the time.

[3] http://www.british-hydro.co.uk/

This case scenario only represents median impact conditions on stream flows however. Changes in flow could also result in substantial changes in wetted width of the stream channel, splash zone area, and ambient humidity, all of which could affect bryophytes and lichens (e.g. Proctor, 2004). Site specific data for a range of sites would be necessary, however, to accurately quantify these impacts.

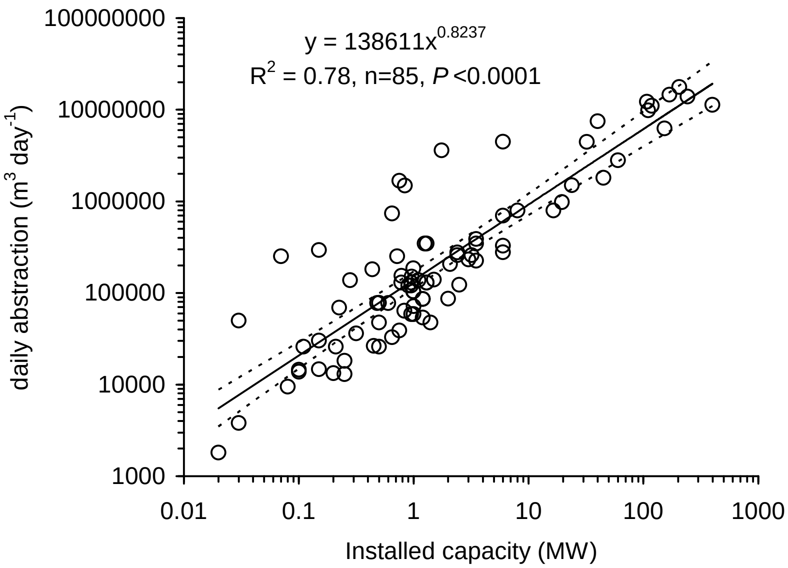

Figure 3: Stream daily flow required by Scottish hydroelectric schemes (SEPA data). Note that there is considerable variation for a few sites, likely to be due to local topography (water head height). Both axes are on log scales. 1 MW hydroelectric scheme would generate enough energy to power about 1000 households (assuming average household consumption of 3,300 kWh a year, average turbine efficiency of 70% and a load factor of 60%, see footnote 3). Sites above the regression line have a lower than average efficiency relative to water abstraction, probably indicating smaller than average water head height.

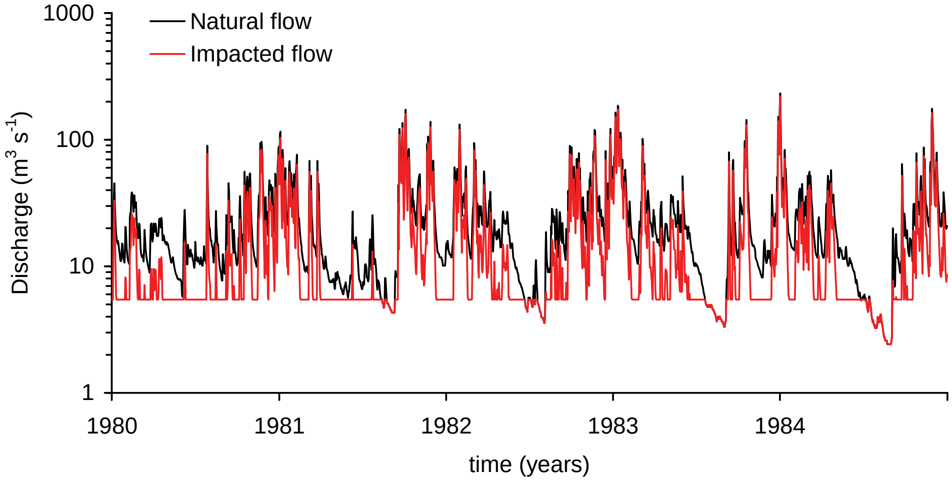

Figure 4: Potential impact of a hydroelectric scheme on river discharge illustrated by natural and impacted discharge data from SEPA gauging station, Kinrara, River Spey.

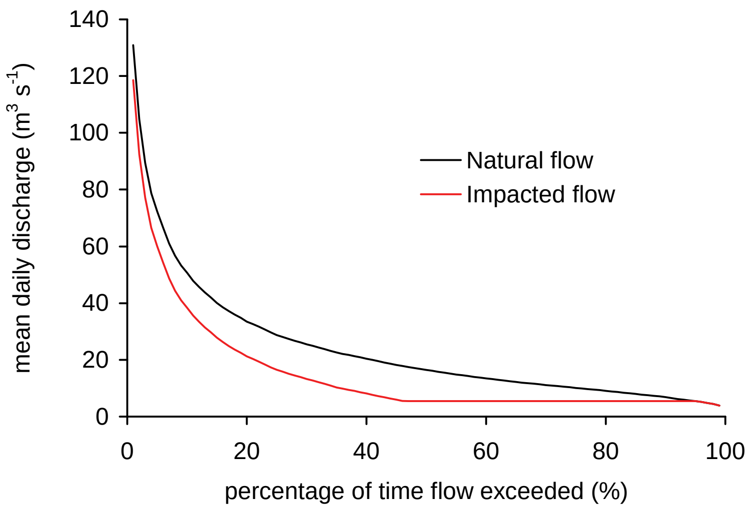

Figure 5: Potential impact of a hydroelectric scheme on the river flow duration curve. Illustrated by the River Spey at Kinrara gauging station (SEPA). Note that the shape of the natural flow duration curve of this river is typical of highland rivers where most small hydroelectric schemes are likely to be developed.

2.3 Impoundment by the weir

Installation of an intake weir will inevitably lead to changes in water level and velocity upstream. Although well maintained hydroelectric schemes should limit the amount of sediment accumulating upstream from the weir, changes in substrate composition (increase in the proportion of fine sediments) are inevitable. The length of stream channel potentially impacted by installation of small weirs is dependent on the slope of the stream and is illustrated in Fig. 6.

2.4 Scouring

Installation of a weir may substantially alter sediment transport along the stream channel, with increased fine sediment deposition upstream, as described above. On the downstream side of the weir this may result in net fine sediment depletion. In addition to these alterations in sediment transport there may be localised impacts of erosion and increased turbulence in the area around the tail race of a hydroelectric scheme, where the abstracted water rejoins the main channel.

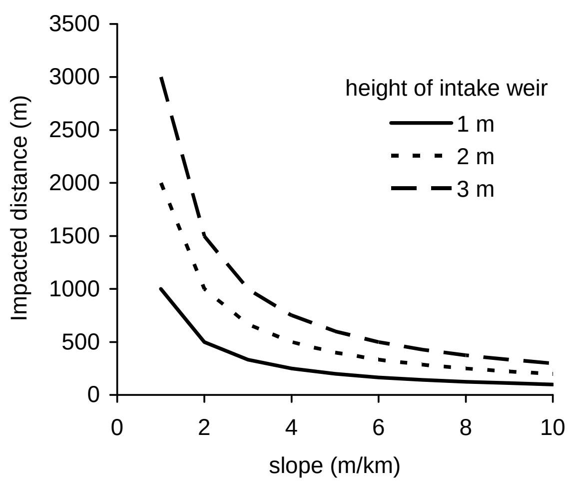

Figure 6: Impacted distance upstream from a weir as a function of slope and intake weir height.

3 POTENTIAL IMPACTS OF HYDROELECTRIC SCHEMES ON LICHENS AND BRYOPHYTES

Upland stream habitats are characterised by a high degree of variability and the majority of species occupying these habitats are adapted to periods of both inundation and desiccation. Since the major impact of hydroelectric scheme installation on the flow regime in the stream is to increase the duration of drought conditions, it might be expected that species occupying the boundary between aquatic and amphibious zones are most likely to show a response. Increased duration of desiccation may allow amphibious species to extend their range downwards and could depress the upper limit of those aquatic species that are intolerant of desiccation or of competition from amphibious species. The area of habitat that would be affected by such changes is dependent upon the channel profile and thus the change in wetted perimeter when water levels drop. *Collema dichotomum* is one example of a rare species which could be adversely affected by such a change; its preferred shallow rock-shelf habitat along river margins would be strongly adversely affected by a drop in water level. Upper limits of amphibious zones are unlikely to be impacted by hydroelectric schemes since they probably develop primarily in response to winter spate conditions which would be little changed. Similarly, turnover in species composition and creation of vacant niches within this zone, due to disturbance caused by spate flows, would be unchanged.

To date, few studies have investigated the impact of small hydroelectric schemes on riparian habitats, and especially bryophyte and lichen communities. Those studies which are reported in the literature generally relate to very large perturbations in the hydrological regime, such as large scale river regulation or reservoir construction. Such studies show that riparian plant communities along regulated rivers are significantly different to those along natural rivers, even 10-20 years after construction (Nilsson & Keddy, 1988; Nilsson *et al.,* 1991) and that flooding duration and frequency are the key drivers of community composition. Likewise, large changes in hydrological regime significantly alter the composition of spray influenced communities; Odland *et al.* (1991) showed that a 92% reduction in river flow led to loss of hygrophilous bryophytes and lichens in the spray zone of a waterfall in Norway.

Studies of natural systems give some indication of the speed of response of lichen communities to changes in water level regime. Tolerance of immersion is species dependent. Studies of saxicolous lichens found a loss of vigour after 30 days immersion (Marsh & Timoney, 2005) while in a floodplain forest corticolous species were killed by 1-2 weeks immersion (Hale, 1984). While bryophytes are dependent on external humidity for growth (Proctor, 2000), they are generally more resistant than lichens to changes in submersion or drought conditions, although resistance varies greatly between species (Arscott *et al.,* 2000; Proctor & Tuba, 2002). The time taken for freshwater lichens to colonise new substrates is estimated at between 3 and 50 years (Rosentreter, 1984; Timoney & Marsh, 2004; Keller, 2005; Nascimbene *et al.,* 2009). The distribution of these slow growing and long lived organisms represents the integration of conditions over a long time period. Such responses suggest that extremely long-term studies would be required to detect the effects of changes in the frequency and duration of inundation when extremes in water discharge remain unaffected.

Increased duration of drought conditions also has the potential to affect humidity in the streamside environment more generally, although it is unclear what the magnitude of impact might be (but see Fritz *et al.,* 2009). Reductions in humidity caused by reduced water flow could affect habitats away from the main stream channel, including surrounding woodland or ravine habitats which often support important lichen and bryophyte communities. Constant, high humidity is an important determinant of the distribution of oceanic bryophyte and lichen species in particular (Coppins & Coppins, 2005; Rothero, 2005); terrestrial bryophytes demanding a higher humidity and being more tolerant of shade than lichens (Frahm, 2003).

The construction of an intake weir and the associated increase in water level and siltation could affect a significant length of the stream channel depending on its morphology. Increased water levels would impact on all species in the amphibious zone, while siltation is a particularly serious problem for lichens, which are generally light demanding and intolerant of silty water (Gilbert, 2000).

4 DETECTING EFFECTS OF HYDROELECTRIC SCHEMES ON BRYOPHYTES AND LICHENS

The main aim of this project was to design a robust survey methodology which would allow the impacts of small scale hydroelectric schemes on bryophyte and lichen communities and particularly on rare species within those communities, to be tested. Designing such a scheme is not a straightforward task given the current rudimentary state of knowledge about the distribution and ecology of bryophyte and lichen species in Scottish freshwater stream habitats and the inherent difficulties with a focus on rare species. In the sections below we describe some of the main issues to be taken into account when designing such a scheme before suggesting a suite of potential survey designs and a recording methodology.

Clear hypotheses regarding the potential impacts of hydroelectric schemes on bryophyte and lichen communities, based on causal mechanisms, are ideally needed at the inception of the survey, rather than a simple control-impact hypothesis lacking any mechanism (Downes *et al.,* 2003). This would allow the survey methodology to be optimised to detect the predicted effects (e.g. by sampling different zones, habitats or substrates within the stream). Ideally, site specific information on hydroelectric schemes would be used to model average effects on stream flow or other hydro-morphological parameters and this would be used to help inform and target the survey design. In the absence of such data, the survey designs presented here are more general, focussing on comparison of control and impacted stream reaches in space and/or in time. Collection of additional information on key environmental parameters (e.g. temperature and humidity) or analysis in terms of species traits is strongly recommended as a means of exploring the mechanisms responsible for any observed changes (Nilsson *et al.,* 2002; Hill *et al.,* 2007; Demars & Trémolières, 2009).

Any survey design also needs to take into account the fact that changes in hydrological regime as a result of hydroelectric scheme installation may be relatively subtle, with changes in mid flows and frequency and duration of drought conditions, rather than changes in the extremes which define habitat zonation (see above). There may be no change in overall species diversity but rather changes in species or species trait composition, or changes associated with particular **macrohabitats** (open *vs* forested, north *vs* south slopes, stream order, altitude, geology, hydrology), **microclimate** (Photosynthetic Active Radiation, air temperature, vapour pressure deficit, relative humidity, soil moisture, rainfall), **substrates** (e.g. water Electrical Conductivity, Ellenberg plant indices, stream margin, waterfalls, boulders, woody debris), **life forms** (e.g. pleurocarpous *vs* acrocarpous mosses) or **phylogenetic groups** (e.g. liverworts *vs* mosses) (Suren, 1996; Pharo & Beattie, 1997; Stream Bryophyte Group, 1999; Berglund & Jonsson, 2001; Hylander *et al.,* 2005; Hylander & Dynesius, 2006; Stewart & Mallik, 2006; Åström *et al.,* 2007; Dynesius & Hylander, 2007; Dynesius *et al.,* 2009). The survey will need to cover as wide a range of sites and geographic areas as possible in order to maximise chances of detecting impacts.

See Annexe 3 for a summary existing survey methods for freshwater bryophytes and lichens.

4.1 Issues related to monitoring rare *versus* common species

The ecology of nationally rare species of bryophytes and lichens is generally poorly understood and the view that rare species have narrower fundamental niches than common species and that this is responsible for their restricted distribution has recently been challenged (Cleavitt, 2002). By their very nature many lichen and bryophyte species of conservation concern occur at very few locations within Scotland, e.g. many of the Red Data Book (RDB) lichens have <5 localities. Based on so few sites it is difficult to determine the ecological requirements of such species and their occurrence may in fact be stochastic.

In one study of riparian buffer strips, RDB species were found to be very sensitive to disturbance (Hylander *et al.,* 2005). In another study (Hylander & Dynesius, 2006), RDB species richness was weakly correlated with total species richness ($r=0.40$, $P=0.01$). Bergamini *et al.* (2007) looked at the use of environmental variables and macrolichen distribution to predict microlichen distribution (all species and rare species only) in woodlands. Macrolichen distribution could be predicted by environmental variables with reasonable accuracy but microlichen distribution could not. Adding macrolichen distribution to environmental variables improved the model for microlichens but performance for rare species was still very poor, suggesting that their distribution is not well coupled to the environment.

Given the lack of autecological information for rare bryophyte and lichen species and the possibility that their distribution is not well coupled to environmental factors, it may be very difficult to predict the effects of small scale hydroelectric schemes on these species beyond a case-by-case basis. Changes in the frequency of rare *vs* common species, i.e. in the shape of the frequency distribution curve, has been used in some studies to detect preferential impacts on rare *vs* common species, however, the species occupying the 'tail' of these curves represent locally rare species, not necessarily nationally rare species. Locally rare species are likely to represent chance events of colonisation or survey uncertainties such as inter-operator variability (Hurford & Lansdown, 2010). Generally rare species cannot be used with any confidence to indicate environmental pressures (Cleavitt, 2002), although the ecology (realised niche) of rare species may be defined by associated common species (Hill *et al.,* 1999). As a result we would recommend that any monitoring program to examine the general impacts of small scale hydroelectric schemes should consider the whole bryophyte and lichen community rather than focussing specifically on rare species. If there are specific rare species of conservation concern impacted by hydroelectric scheme development, monitoring should be implemented on a case-by case basis to suit local conditions and the species concerned.

4.2 Statistical power *versus* relevance

Changes in species distributions in response to changes in stream flow brought about by the installation of hydroelectric schemes are likely to be slow and may also be of limited extent. When designing a monitoring program, issues arise as to our ability to detect a significant change (statistical power; indicated by relationships with low P values) versus our ability to use such relationships to make predictions of impact at other sites (requires high explanatory power indicated by high r^2 values). Distributions of bryophytes and lichens are influenced by a large number of macro and micro habitat factors, climatic variables and substrate availability; even where we have sufficient statistical power to detect an impact of the hydroelectric scheme (high probability of detection, $P<0.001$), the impact is likely to be small (low r^2) (e.g. Bates *et al.,* 2005, Demars & Edwards, 2009, Lansdown & Bosanquet, 2010) and thus it is often difficult to extend predictions to other sites. This problem is exemplified by a use of a riverine macrophyte index in lowland rivers impacted by watermill impoundments (Fig. 7); while significant relationships between the index and key environmental variables can be detected, there is very large variability between sites and the predictive power of the relationships is poor.

A second example is the impact of flow regulation (from large hydroelectric schemes) on bryophytes in north Swedish rivers: Englund *et al*. (1997) found a decrease in species richness (-2.2 ±1.6 species) at sites with flow regulation (n=38) compared to unregulated sites (n=14; average species richness 9.2), after taking into account confounding environmental variables. The results were highly significant (based on 95% confidence interval) but the uncertainty was large (73% of the reported loss in species richness). This meant that observed impact on individual sites varied from slightly positive to severely negative (Englund *et al.,* 1997).

Clearly the more sites surveyed (whatever the survey design) the greater the likelihood of detecting impacts and the greater the confidence of the results. It is very difficult to predict the sampling intensity which would be required to predict impacts in the absence of data on the distribution of species within the areas to be sampled. We would strongly recommend that a pilot survey is carried out at a limited number of sites to trial the methodology, followed by a power analysis on the resulting data to ascertain whether effects can be detected with the required level of accuracy. The likelihood that no impact is detected should also be tested (e.g. Møller & Jennions, 2002). The survey methodology could then be refined and adjusted to be as efficient as possible before continuing with the full survey.

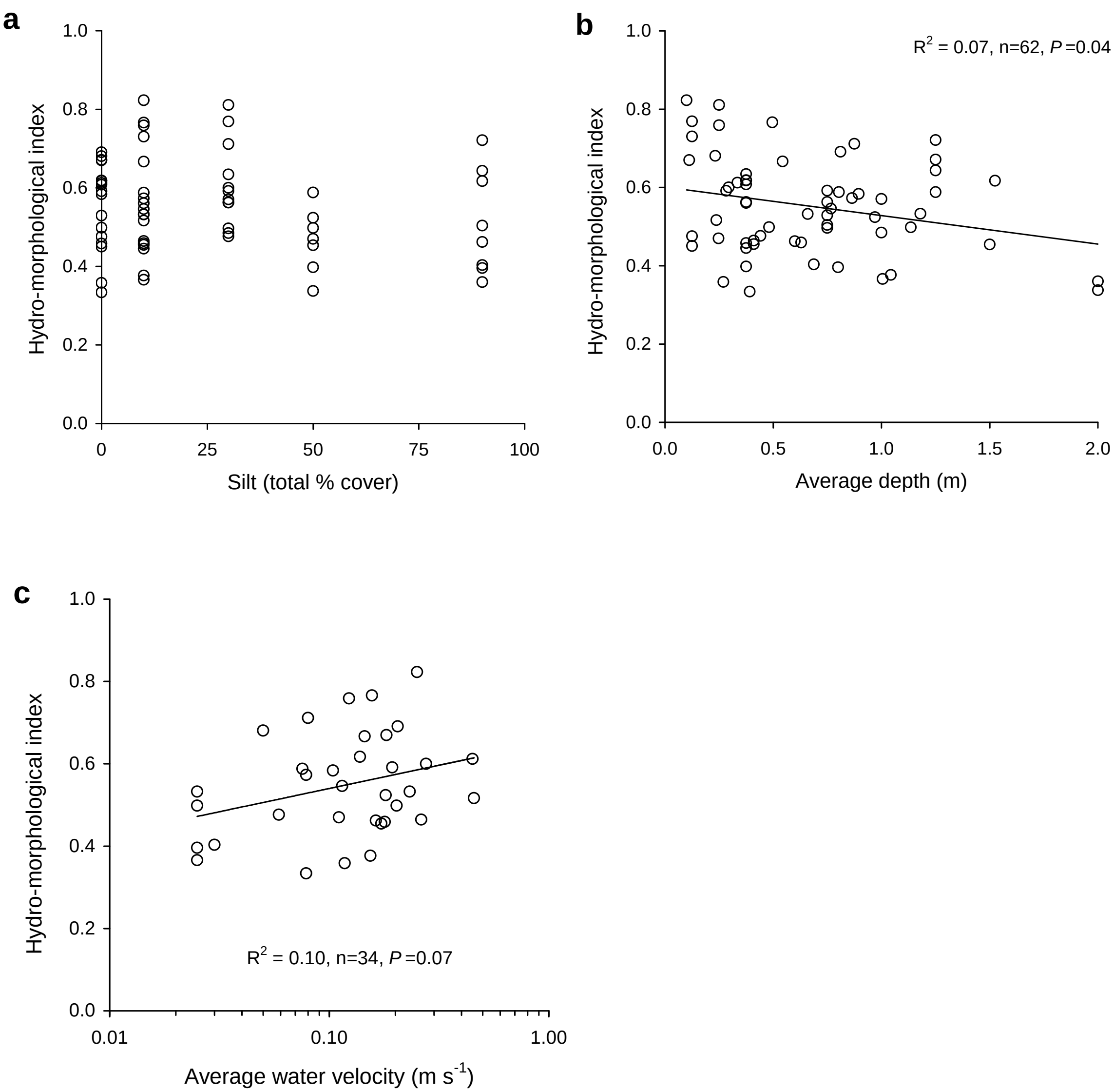

Figure 7: Aquatic macrophyte hydro-morphological index ($^{A}EQR_{RMHI}$)[4] tested in Norfolk calcareous rivers. The hydro-morphological index represents the deviation from expected reference conditions. While the index may be able to detect a statistically significant impact it is clear that site specific predictions necessary for WFD classification (or EIA) with this index will be extremely uncertain. Raw data from Demars & Harper (2002).

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[4] WFD-UKTAG River assessment methods. Macrophytes and phytobenthos. Macrophytes (River LEAFPACS), report available at http://www.wfduk.org/bio_assessment/bio_assessment/river%20macrophytes%20nw

4.3 Potential survey designs to detect impacts

Three alternative survey strategies are presented under the headings below. In all cases this includes the survey of both common and rare species is assumed.

4.3.1 Before and after control impact (BACI)

This survey design requires monitoring of impacted streams both before and after installation of the small hydroelectric scheme in control and impacted stream sections. This approach is the most powerful as it reduces problems with between site differences in environmental factors.

Survey of new small hydroelectric scheme sites would, ideally, monitor four river sections before and after installation of the hydroelectric scheme (Fig. 8) to give a complete picture of impacts. This is the most robust design (including control sections), but it will not provide a rapid answer (except perhaps to test for the effect of the construction phase) as bryophytes and lichens are notoriously slow to respond to chronic changes (see section 3; Brandrud, 2002). For example, it took 8 years of summer phosphate addition in tundra streams to see a change in bryophyte cover and shift in species dominance (Slavik *et al.,* 2004). Recovery from phosphate addition took just as long to approach control conditions in interaction with high peak flow events (Benstead *et al.,* 2007). Given the need to provide data to inform decisions about the location of new hydroelectric schemes this approach is unlikely to deliver results in a timely manner, though it could provide robust answers on the impacts of hydroelectric schemes.

4.3.2 Comparative surveys at paired section/sites

Survey of existing small scale hydroelectric schemes could be used where EIAs were performed before installation of the hydroelectric scheme. A re-survey could be conducted to determine change through time within individual sites. However, an informal survey of bryologists and lichenologists currently involved in EIA work within Scotland suggested that the number of existing small scale hydroelectric schemes for which detailed accounts of the bryophyte and lichen communities exist is extremely limited.

Existing small scale hydroelectric schemes, where suitable pre-installation data do not exist, still provide an opportunity to examine reference (a control section of stream with no water abstraction) and impacted sections on the same stream (or in a parallel stream) for ‘within’ site paired comparison (see Fig. 8). Species present under reference and impacted conditions could then be compared for different stream types (e.g. open vs. wooded), different substrate types (e.g. wood *vs*. rock) or species groups (e.g. bryophytes vs. lichens) as shown in Fig. 9. The power of this approach is that the influence of external environmental drivers may largely be discounted (without measuring them). It is also possible to infer the effect of time by comparing the difference between pairs of reference and impacted sections of hydroelectric schemes of different ages (space for time substitution).

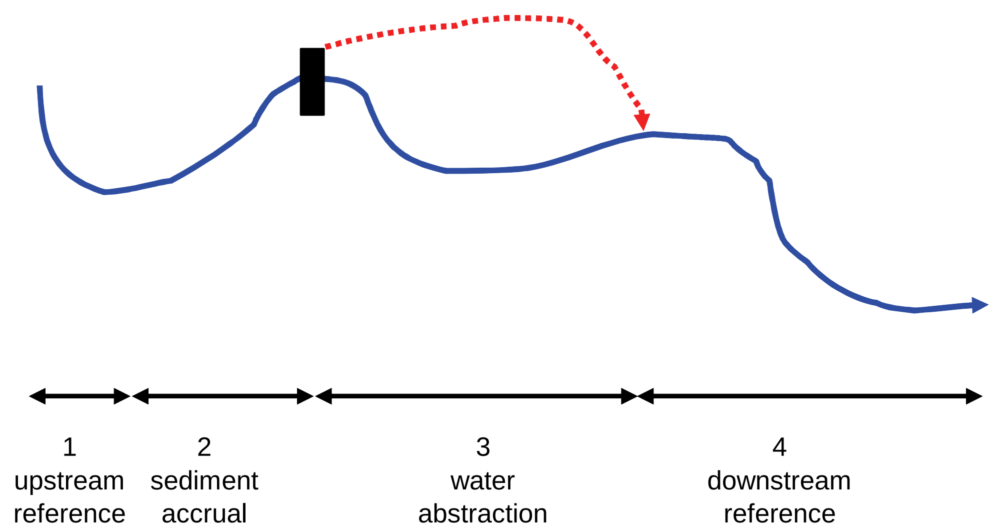

Figure 8: Ideally, reference and impacted zones should be on the same stream (blue line). Four longitudinal zones can be defined upstream/downstream of the weir (black rectangle). If reference zones are not similar to the impacted zones, then either another, more appropriate, site will have to be found as close by as possible, or reference conditions will have to be predicted from a site specific reference model based on site characteristics independent of the impacts.

The main difficulty with this approach is the determination of suitable reference sites (as closely comparable to the pre-impact state of the study area as possible) with which to compare the impacted streams or stream sections. Since small scale hydroelectric schemes tend to be located in small ravines or at discontinuities in the slope this may present a problem for finding reference sites on the same stream channel, detailed information on the location of individual hydroelectric schemes would be needed to determine how difficult it would be to obtain suitable reference sites (SEPA were unable to provide this information within the timeframe of this report).

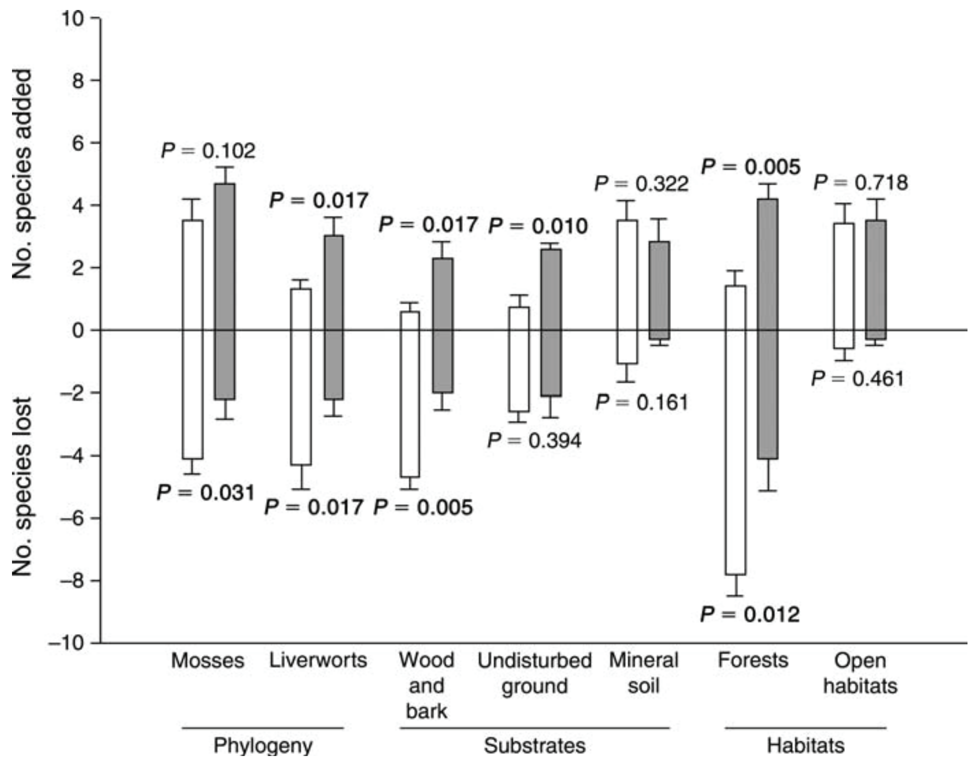

Figure 9: Example of output from Åström et al. (2007): comparison between south-facing (open bars) and north-facing (gray bars) slopes for the number of bryophyte species lost and added in response to clear-cutting. Differences in richness between opposite aspects were tested using Wilcoxon's signed rank tests. P values < 0.05 are shown in boldface type; N=10 plots of 200 m^2 each. Reproduced with permission from Ecological Society of America.

4.3.3 Site specific reference condition model

Where selection of suitable reference sites is problematic, an alternative approach is the site specific reference condition model. In this survey design, both species and environmental variables (predictor variables) are collected, so that bryophytes and lichens (response variables) may be related to environmental factors in different settings (e.g. open *vs.* forested streams). A wide variety of environmental variables are recorded alongside the species survey (including water and substrate samples for lab analyses; sediment particle size analyses etc). These data are subsequently used to develop models (based on regression analyses) which are then used to calculate reference conditions (e.g. what the species diversity should be) at impacted sites. The deviation between observed and predicted provides a measure of impact. This approach is likely to be more demanding (because of the need to survey more sites than the paired section/site approach) but the data collected would be applicable to a wide range of impacts in addition to hydroelectric schemes (e.g. acidification, nutrient enrichment). This approach has been used successfully to test the impact of flow regulation from large hydroelectric schemes on bryophyte species diversity (Englund *et al.,* 1997); and is currently the method of choice for the implementation of the Water Framework Directive (LEAFPACS method, see Fig. 7).

4.4 Survey methods

A methodology for species recording in stream habitats is presented below. This could be used with any of the three sampling designs already described above. The absolute sampling intensity required (i.e. number of quadrats) to detect effects in this habitat is difficult to determine in advance without data. We would strongly recommend that a pilot survey is first carried out to trial the methodology followed by a power analysis to determine the optimum number of quadrats to be surveyed, bearing in mind that the time required (and hence the cost) rises rapidly with the number of quadrats used. We would also strongly recommend that a one day training session regarding the sampling method should be carried out with surveyors to ensure high quality data collection and to minimise between-surveyor differences.

4.4.1 Zones within a stream section

The current definition of freshwater micro-habitats (section 1.3, Gilbert, 2000, Thüs & Schultz, 2009) is rather vague and may be difficult to apply in a field survey situation. Instead, we propose recording bryophytes and lichens within three broad zones defined by easily determined criteria (Fig. 10). These are: the **stream channel** (submerged zone, at or below the level of low flow conditions), the **stream bank** (at the interface of the stream edge and riparian zone, between the low flow water level and the 'bank full' mark of high flows generally indicated by a break in the slope with adjacent riparian corridor) and finally the **riparian corridor** (terrestrial habitat adjacent to the stream, above the bank full level and extending out 10m horizontally and vertically, where safely accessible). In this classification vertical zonation is combined with lateral zonation to better take into account distance from the stream and associated humidity. Hence, a large boulder in the middle of the stream might encompass all three zones (Fig. 10). Survey work should be undertaken during low flow conditions.

Where the stream is flowing within a narrow ravine the survey should cover both walls of the ravine as the equivalent of the 'riparian corridor' zone, above. The upper limit of the zone of water fluctuation (the 'stream bank' zone) should be determined subjectively based on vegetation zonation or evidence of disturbance during spate flows. When surveying in ravine situations, safety must be the foremost consideration and habitats should only be accessed where it is safe to do so.

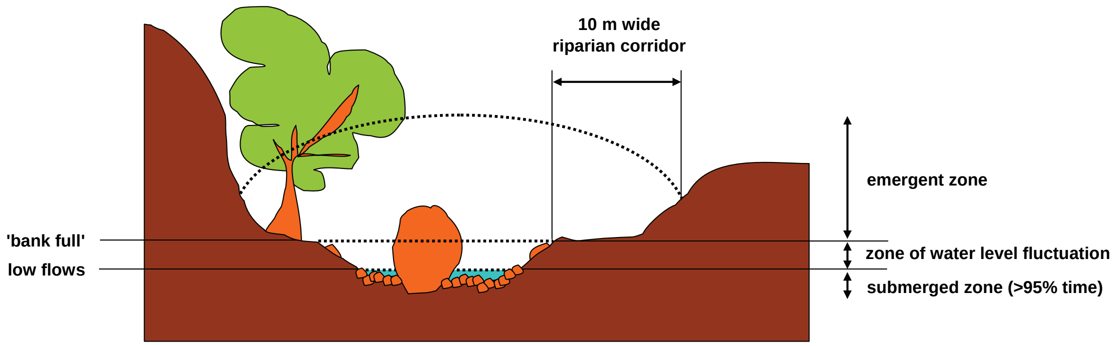

Figure 10: Proposed stream habitat zonation to be used for the survey.

4.4.2 Substrates within zones

Within the three zones, we propose that bryophytes and lichens should be recorded from two key substratum types: wood + bark (including live and dead wood and tree trunks within reach from the ground) and rock (including bedrock and stable rock such as boulders or armoured river bed). While other substratum types will undoubtedly be present and may be important for some species, increasing the number of substrates recorded rapidly increases the recording effort and hence time required to do the survey, so these two broad habitat types are suggested as a pragmatic approach.

4.4.3 Random stratified sampling

Once the three zones have been identified, all species of bryophytes and lichens should be recorded (presence only) within twenty (initially, but see comments above about trialling the method and power analysis), randomly distributed, 0.2 m x 0.2 m quadrats for each habitat within each zone. If all substrates are present in all zones, species will be recorded in a total of 120 quadrats (a total area of 4.8 m^2, which is not too onerous). If one type of substrate is absent from a zone, then the total number of quadrats will be decreased by 20. If one habitat is poorly represented, then less than 20 quadrats could be recorded. It is important to make a note of the total number of random quadrats for each type of substrate (see Table 2 for an example recording sheet). Quadrats with no species present must also be counted. This will allow calculation of species frequency within substrate type within zone (a surrogate for species abundance).

This sampling method applied to reference and impacted stream sections (see sampling design in section 4.3) will allow testing of whether changes in bryophyte and lichen species composition (weighted by their frequency) or diversity respond to the impacts of hydroelectric schemes (change in sediment composition or humidity), for all zones and types of substrates.

Table 2: Example recording spreadsheet for a stream section (reference or impacted) with the number of times species were recorded within twenty 0.2 x 0.2 m quadrats. Note: list of bryophyte and lichen species for illustration only.

zones	Stream channel		Stream bank		Riparian corridor	
substrates	wood + bark	rock	wood+ bark	rock	wood + bark	rock
Total number of quadrats[1]	2	20	10	20	20	20
List of species						
Fontinalis antipyretica	2	5				
Rhynchostegium riparoides		6				
Chiloscyphus polyantos		1				
Scapania undulata		12				
Pellia epiphylla				15		
Mnium hornum				10		
Brachythecium rutabulum			5		20	12
Orthotrichium affine					4	
Frullania dilatata					2	
Physcia tenella					5	
Xanthoria parietina					10	
Racodium rupestre						5

[1] maximum is 20 per substrate type

4.4.4 Causality

In order to reduce background noise in statistical analyses, the general characteristics of the stream section surveyed (e.g. slope, aspect, surrounding habitat types) should be recorded along with the species data (see Table 3 for example environmental data recording sheet). This additional information would assist in attributing changes in community composition and structure to specific impacts of the hydroelectric scheme. Two main impacts of hydroelectric scheme installation are predicted: change in substrate composition (essentially upstream from the weir) and change in humidity (due to change in stream flows). To determine humidity effects, micro-climatic data could be collected at a subset of sites to determine differences in humidity between reference and impacted pairs of stream sections with the use of data-loggers (e.g. Proctor, 2004). These changes would best be measured at sites in the planning stage, so that the BACI design could be used. Similarly, sediment composition within the stream channel could be quantitatively estimated by random sampling of stream bed sediments using a Wolman frame (~100 counts, Wolman, 1954) to study changes in the armoured layer, or sieving (~ 1 kg sediment below armoured layer) to study changes in fine sediment (<16mm). Direct demonstration of changes in sediment composition and/or humidity (which directly influence bryophytes and lichens) may also provide early indications as to the magnitude of potential impacts on the bryophyte and lichen community.

The causality of links between change in species composition and diversity and hydroelectric scheme installation could be further strengthened by investigation of changes in species traits. For example, we might predict that bryophytes with hair points, papillae, lamellae, dead hyaline leaves (to protect the photosynthetic leaves) or thick cell walls would better withstand a decrease in humidity or longer periods of desiccation (Gignac, 2001). These species traits should therefore increase. Similar predictions based on species traits are possible with the Ellenberg indicator values for moisture (Hill *et al.,* 2007). Reductions in water availability may also shift the dominant bryophyte growth form from streamers (e.g. *Fontinalis*), to cushions, to mat forming pleurocarps, to small acrocarpous (small erect tuft) (Gignac, 2001) and changes in the distribution of these growth forms could also be examined. Bryophytes and lichens which have evolved to better cope with desiccation may have a lower growth rate and higher carbon:nitrogen (C:N) and/or carbon:phosphorus (C:P) ratio than species accustomed to more humid conditions. Hence we predict an increase in C:N and C:P ratio with the hydroelectric scheme water abstraction impact. Bryophyte and lichen samples (5-10 g dry weight in an envelope with site name and grid reference) could be collected during the survey for C, N, P tissue analyses and reference collection.

4.5 Data analyses

A wide range of statistical analyses could be run on the data described above. The exact statistical strategy will depend on the choice of sampling designs. The details of individual methods are available within the references cited above in section 4.3.

Detection of hydroelectric scheme impacts on species composition could be done with either multivariate direct gradient analyses (e.g. Redundancy Analysis, Canonical Correspondence Analysis with Monte Carlo random permutation tests based on sampling design) or single species approach (e.g. based on Generalised Linear Modelling) combined with weighted average indices (e.g. Demars & Trémolières, 2009). We expect a large amount of unexplained variance due to the many natural environmental variables affecting bryophyte species distribution (such as pH, light) not taken into account by the sampling method.

Detection of hydroelectric scheme impacts on species diversity analyses could also be run with nested ANOVAs (Student's t-test or non-parametric Wilcoxon signed-rank test): e.g. time within substrate within zone within section.

Table 3: Example recording spreadsheet for a stream section.

<table>
<tr><td colspan="5">Surveyors:</td><td colspan="4">Date:</td></tr>
<tr><td colspan="9">Locality:</td></tr>
<tr><td colspan="9">Stream name:</td></tr>
<tr><td colspan="9">Stream section:</td></tr>
<tr><td colspan="2">NGR</td><td colspan="4">Top:</td><td colspan="3">Bottom:</td></tr>
<tr><td colspan="4">Stream order (1:50000 scale):</td><td colspan="2">Altitude:</td><td colspan="3">Geology:</td></tr>
<tr><td colspan="9">Canopy cover</td></tr>
<tr><td colspan="2">Forested</td><td colspan="2">Sparse trees</td><td colspan="2">Heath</td><td colspan="2">Grassland</td><td>Rock</td></tr>
<tr><td colspan="2">Stream facing</td><td colspan="2">North</td><td colspan="2">East</td><td colspan="2">South</td><td>West</td></tr>
<tr><td colspan="2">Water chemistry</td><td colspan="2">pH</td><td colspan="2">EC</td><td colspan="3">Water sample(s) collected:</td></tr>
<tr><td colspan="4">Stream slope
(m/km or degree):</td><td colspan="5">Riparian corridor steepness
(m/m or degree):</td></tr>
<tr><td colspan="2">Main substrate
% cover</td><td colspan="2">wood + bark</td><td colspan="2">rock</td><td colspan="3">unstable (e.g. soil, sand)</td></tr>
<tr><td colspan="2">Tree species
surveyed (list)</td><td colspan="7"></td></tr>
<tr><td colspan="8">Species collected (5-10 g dw) for trait analyses (list)</td><td></td></tr>
<tr><td colspan="9">Count 100 random pebbles using Wolman frame (mm)</td></tr>
<tr><td>> 256</td><td>256</td><td>180</td><td>128</td><td>90</td><td>64</td><td>45</td><td>32</td><td>22.5</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9">Sieve about 1 kg of sediment randomly collected and report mass (g)</td></tr>
<tr><td colspan="2">> 16 (mm)</td><td colspan="2">16</td><td colspan="2">8</td><td colspan="2">4</td><td>2</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Notes (access, …)</td><td colspan="7"></td></tr>
</table>

5 AN ADDITIONAL APPROACH

Another way forward, specifically focussing on rare species, may be to look at the species diversity of rare/scarce bryophytes or lichens of interest using national scale distribution data (e.g. Hill *et al.,* 1991, 1992, 1994) to prioritise core areas for conservation. This is a similar approach to that already used to characterise bird sensitivity to wind farm development[5]. A national approach to avoid hydroelectric schemes in highly sensitive areas would raise the profile of important sites across private and public sector stakeholders. This could help planning at the National scale rather than thinking site by site.

Recently Moilanen *et al.,* (2005) developed a zonation index determining core areas for conservation of target species after taking into account species diversity and spatial connectivity. This has also been adapted for stream networks (Moilanen *et al.,* 2008). We illustrate the value of such approach using the vascular plant records from the New Atlas (Fig. 11, Preston *et al.,* 2002). This may not necessarily be limited to bryophytes or lichens: other taxonomic groups associated with the riverine environment could also be included to give a comprehensive picture (Moilanen *et al.,* 2005, Paavola *et al.,* 2006).

[5] Birds in the GIS database: "Bird Sensitivity:Locational Guidance for Onshore Windfarms" Abstract: A bird sensitivity dataset to aid location of onshore wind farms in Scotland, based on distributional data for a suite of sensitive bird species. Species included are either listed on Annex I of the EU Birds Directive, and/or are species of conservation concern with known or suspected susceptibility to the effects of wind turbines on birds, notably collision mortality and disturbance displacement. The sensitivity data has been produced at a 1km square resolution, with each 1km square in Scotland being assigned one of three sensitivity ratings. These sensitivity ratings were assigned following reviews of literature and best available information for each species on foraging ranges, collision risk, disturbance distances and other relevant features of behavioural and population ecology, to develop 'sensitivity criteria' to determine appropriate buffering distances to apply to the distributional data for birds.

"Renewable Energy - Zones of Natural Heritage Sensitivity for Onshore Wind Farms" Abstract: This dataset provides an overview of the natural heritage sensitivity to wind farms. It identifies land with the greatest opportunity for wind farm development in natural heritage terms, and areas where natural heritage sensitivities indicate a medium or high level of constraint. The intermediate levels (Zone 3 high sensitivity - wild land search areas (hatched) and Zone 2 medium sensitivity (hatched)) indicate that the sensitivity does not apply to the entirety of that area, but only to a proportion. Zone 1 - lowest natural heritage sensitivity; Zone 2 - medium natural heritage sensitivity; Zone 3 - high natural heritage sensitivity. Further information can be found in the Strategic Locational Guidance for Onshore Wind Farms in respect of the Natural Heritage Policy Statement. Policy Statement No.02/02 updated March 2009.

Figure 11: Core areas (yellow to red colours) for conservation of aquatic vascular plants, calculated by Alessandro Gimona, based on the distribution of 164 species from the New Atlas (Preston et al., 2002). Raw data © Crown copyright material with the permission of the Controller of Her Majesty's Stationery Office, license V2006000771.

6 CONCLUSIONS, PERSPECTIVES AND RECOMMENDATIONS

Small hydroelectric schemes are seen as a solution to mitigating and adapting to climate change and so their number is predicted to increase (Forrest and Wallace, 2009). Their impact on river flows suggests that drought conditions could increase dramatically (from 5 to 50% of the time) in stream sections impacted by water abstraction. The impact on sediment transport (fine sediment deposition upstream from the weir and fine sediment depletion downstream from the weir) may also be substantial depending on stream slope.

There is virtually no information on the impact of small hydroelectric schemes on stream bryophytes and lichens. This is partly because the distribution of lower plants in small streams is largely unknown, but also because of a lack of information on the impact of water abstraction on local humidity and of the impact of altered humidity on individual species. There have also been too few EIAs reporting bryophyte or lichen status on which to base a judgement. Morever, most EIAs have not had post appraisal survey carried out.

Impacts of small scale hydroelectric schemes on rare bryophytes and lichens are NOT likely to be detected, because rare species distribution cannot be reliably linked to environmental conditions. Hence this report focuses on what may be done with all species (rare and common). Three survey designs have been considered: BACI, paired comparison, reference condition models and a site survey methodology has been suggested.

It is argued that clear causal mechanisms need to underline the survey design. Hypotheses regarding species responses may be formulated on species distribution, richness, species traits for a range of substrates (e.g. bedrock, woody debris) and zones (mid channel to riparia) across a wide range of habitats (e.g. 1st to 6th order stream, south *vs* north slopes, open *vs* forested, water pH and electric conductivity) and microclimate (e.g. humidity).

The quantification of the impact of small hydroelectric schemes on bryophytes and lichens can serve multiple purposes: understanding of bryophyte distribution in small streams, simulation of siltation consequences (increase in fine sediment above from the weir), simulation of climate change (increase in drought conditions without changes in peak flow magnitude and frequency), and defining core areas for conservation of rare bryophytes.

These aims will be best achieved by involving other UK conservation agencies and botanical societies, as well as government agencies (e.g. SEPA) and research institutes in the design of the survey and data analysis. Since bryophytes and lichens are difficult to determine and rare species are of special interest, experienced field botanists only should carry out the field surveys. It is recommended that the best way forward would be to organise a workshop to finalise a sampling design and survey method likely to satisfy several needs.

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ANNEXE 1: Notes on the habitats of uncommon oceanic bryophyte species along western Scottish streams.

By Ben Averis – Consultant bryologist

These notes refer mainly to the places where these species grow in and by streams in western Scotland. These are the main habitats of most of these species, but some species also grow in other habitats – these are mentioned briefly. This information is based mainly on my own observations but is supplemented by information from other sources, especially for those few species with which I am not very familiar (*Bryum riparium, Daltonia splachnoides, Fissidens polyphyllus, Grimmia lisae* and *Dumortiera hirsuta*). All of these species are uncommon nationally, and could be vulnerable to the effects of hydroelectric schemes through a need for high humidity provided by various means ranging from periodic submergence through splash and spray to a more generally humid atmosphere up to a few metres above water level (for which water volume and reasonably close proximity to the stream might still be significant).

MOSSES

Bryum riparium

This small moss grows in wet crevices of acid rocks in and by streams, and on banks and peaty ground which is occasionally flooded by stream water.

Campylopus setifolius

This large moss grows as patches or as scattered shoots among other large bryophytes, on steep banks with moist or wet, acidic soil, peat or humus. Less commonly it can also grow more directly on rock surfaces. Most of its ravine or streamside habitats are away from the immediate vicinity of the stream water (i.e. above the zones of splash or occasional submergence), but populations near waterfalls can be subject to occasional spray when the stream is in spate. Other populations are well away from streams: in damp heaths and on cliff ledges (in both cases especially on northerly aspects).

Campylopus subporodictyon (=*Dicranodontium subporodictyon*)

This large, very rare moss grows as patches on steep, moist or wet, acidic rock faces. These are mainly outcrops by streams but also include the sides of boulders: in either case the plants can be with 30 cm of water level and subject to periodic splash or even submergence, but they can be up to 3 m or so above water level on steep, dripping outcrops and wet rocky banks. Less commonly, the species also grows on steep, dripping rock faces and rocky banks further away from streams.

Daltonia splachnoides

This very rare moss forms small patches on acidic to quite basic rock and bark surfaces which are close to streams or streamlets and are subject to regular flushing by water.

Fissidens curnovii (=F. bryoides var. caespitans)

This small moss forms patches on steep, wet, acidic to neutral rock faces (outcrops more than boulders) and soily/rocky banks at the edges of fast-flowing streams. The wetness is commonly influenced by periodic splash from the stream (plants about 5-30 cm above water level), but can also be associated with dripping or seepage of water down more or less permanently wet streamside banks (in such cases it can be 1 m or more above stream water level).

Fissidens polyphyllos (=F. polyphyllus)

This rare, medium-sized moss grows on very wet, dripping, heavily shaded rocks and banks by sheltered streams and waterfalls. Found much less commonly in dripping sea caves.

Grimmia lisae

This small moss forms patches on wet rocks or wet, stony ground around or just above water level, along rocky streams. It is one of the more riparian oceanic bryophyte species.

Heterocladium wulfsbergii

This small moss forms patches on steep, wet, acidic rock faces (outcrops and boulders) at the edges of fast-flowing streams. The wetness is generally associated with frequent splash from the stream, as the plants are mostly less than 30 cm above water level.

Isothecium holtii

This moss forms medium-sized to large patches on acidic rocks along fast flowing streams and rivers. It grows on boulders and outcrops, and typically occupies steeply to gently sloping surfaces about 0-1 m above water level. It is one of the more riparian oceanic species: its habitats are evidently subject to at least fairly frequent splash and submergence – for example a very typical habitat is on the sides and upper surfaces of rather low outcrops and boulders in and at the edges of a watercourse. The necessary wetness is evidently periodic: at other times the habitat is quite well-drained. It is not a plant of more permanently wet, seeping or soggy habitats.

Paraleptodontium recurvifolium

The erect shoots of this rare moss form patches or grow scattered among other mosses on steep banks with moist to wet basic soils. It is one of the few calcicole oceanic bryophyte species. It grows in ravines and also on more open (but still rocky and relatively sheltered) N-facing mountainsides. Its ravine habitats are typically well above the water level of the stream, though on banks by waterfalls it can be more 'level' with the waterfall and therefore subject to periodic spray when the stream is in spate. It does not occur in splash or submergence zones.

Platyhypnidium alopecuroides (=P. lusitanicum)

This medium-sized moss forms patches on gently sloping to flattish acidic rock surfaces on the sides and tops of low rock outcrops and boulders in (and less commonly at the edges of) fast-flowing streams. It is one of the most aquatic/riparian oceanic bryophytes, growing from just below to about 10 cm above water level. Most shoots point in the same direction: the direction of water flow.

Rhabdoweisia crenulata

This moss forms small patches (of massed short, erect shoots) tucked into in damp crevices of steep acidic rock outcrops: ravine walls and (equally commonly) steep outcrops away from streams (and mainly on northerly aspects). These damp crevices evidently receive some flushing or seepage, at least periodically. Where *R. crenulata* grows near streams (i.e. mainly in ravines) it is generally at least 1 m or so above water level: above the zones of submergence and splash, though some populations near waterfalls might experience spray when the stream is in spate.

Sematophyllum micans

This scarce, glossy, golden-coloured moss forms thin but neat mats, with shoots all pointing downwards, on moist but well-drained acidic rock surfaces in sheltered (but not heavily shaded) woodland. The rocks may be boulders or outcrops, and this species most commonly occupies surfaces which are sloping at an angle of about 30-70^{o}, and which are evidently at least mildly flushed periodically. In many of its sites *S. micans* grows on rock by streams (generally at least 50 cm above water level, and not subject to frequent slash or spray). It also grows on rocks well away from streams. It is strongly associated with Ancient Woodland.

Trichostomum hibernicum

Like *Paraleptodontium recurvifolium* this moss has erect shoots which form patches or grow scattered among other mosses on steep banks with moist to wet basic soils. It is one of the few calcicole oceanic bryophyte species. It grows in ravines and also on more open (but still rocky and relatively sheltered) N-facing mountainsides. Its ravine habitats are typically well above the water level of the stream, though on banks by waterfalls it can be more 'level' with the waterfall and therefore subject to periodic spray when the stream is in spate. It does not occur in splash or submergence zones.

<u>LIVERWORTS</u>

Acrobolbus wilsonii

Scattered shoots of this small liverwort creep among other small bryophytes, or coalesce to form small patches, on steep to gently sloping, moist, acidic to neutral rock surfaces. The rocks can be outcrops or boulders, and are typically within or at the edges of rocky streams. *A. wilsonii* grows mainly about 50-200 cm above water level, on rock surfaces which are quite well drained but appear to be flushed with water periodically. It is mostly above the levels of frequent submergence, splash or spray. Most of its sites are near streams in wooded ravines, but some are outside woodland, in unwooded ravines or on rocky coastal slopes. All of these habitats are very sheltered and humid.

Aphanolejeunea microscopica

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of acidic to neutral boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage, but frequent submergence is evidently not a requirement. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. Also grows on trees in very sheltered woodland, but such occurrences are rare compared with those on rock.

Colura calyptrifolia

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of acidic to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage, but frequent submergence is evidently not a requirement. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. Also grows on trees and shrubs (especially in conifer plantations) and on heather and blaeberry stems in sheltered heaths.

Drepanolejeunea hamatifolia

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of acidic to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage, but frequent submergence is evidently not a requirement. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. Also grows on trees (mainly ash and hazel) in very sheltered woodland.

Dumortiera hirsuta

This very rare, medium-sized thalloid liverwort grows on steep, very wet, dripping, neutral to basic rocks and banks in shaded wooded ravines. The wetness here comes from water dripping from above (e.g. down steep ravine-side banks) rather than stream water, though some populations are in close proximity to waterfalls where stream water will be a more significant factor.   Found much less commonly in dripping caves.

Harpalejeunea molleri

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of acidic to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage, but frequent submergence is evidently not a requirement. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It can also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. Also grows on trees (mainly ash, hazel and in some places oak) in very sheltered woodland.

Jubula hutchinsiae

This small to medium-sized liverworts grows on steep, well-shaded, rock faces and banks which are more or less continuously wet as a result of dripping or seepage of water or, in the case of rocks and banks just above water level, splash and spray. Hence it grows mainly along rocky streams, and can be most abundant around the bottoms of waterfalls. In these habitats it will be subject to occasional submergence when water levels are high. It is more shade-demanding (and more tolerant of heavy shade) than most oceanic bryophytes. Some of its habitats are well shaded by vascular plant growth in the immediate vicinity, so it can be quite well hidden.

Leptoscyphus cuneifolius

This tiny oceanic liverwort forms small patches on moist but well-drained acidic bark on the trunks of birch, oak and alder in very humid woodland. It is commonest on slopes with a N or E aspect and evidently favours a cool, humid microclimate. It also grows on steep, moist but well-drained surfaces of acidic rocks - mainly outcrops rather than boulders – in humid, sheltered woodland and ravines.

Lophocolea fragrans

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of neutral to basic boulders and rock outcrops including the lower parts of ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage. Many populations are so close to water level that they must also be frequently submerged. It is comparatively rare away from the vicinity of rocky, wooded streams.

Metzgeria leptoneura

This rather large thalloid liverwort forms deep patches or scattered shoots among other large bryophytes on moist or wet, more or less neutral soils on steep woodland banks. It occurs mainly on the sides of ravines – anything from about 50 cm to many metres above the water level – but also grows on some steep, moist rock faces well away from streams. Some of its sites are within the spray zone of waterfalls, but unlike several smaller oceanic liverworts it tends not to grow closer to watercourses (i.e. not in the splash or submergence zones).

Plagiochila exigua

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of neutral to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or (less often) splash or very slight seepage, but are probably only rarely subject to direct submergence. It grows mainly from about 30 cm above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It can also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. Also grows much more rarely on trees (especially ash and hazel) in very sheltered woodland.

Radula aquilegia

This oceanic liverwort forms small patches on steep, moist surfaces (including some which are very slightly flushed or seeping) of neutral to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash, but frequent submergence is evidently not a requirement. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It can also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered. It can grow on trees (mainly ash) in very sheltered woodland, but is rare on bark compared with rock.

Radula carringtonii

This very rare oceanic liverwort forms small patches on steep, moist surfaces (including some which are very slightly flushed or seeping) of neutral to basic boulders and rock outcrops including ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray: less commonly splash and probably only rarely submergence. It grows from just above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It can also grow on rock faces away from watercourses: in fact a good proportion of its known sites are in coastal gullies.

Radula voluta

This rare oceanic liverwort forms small to medium-sized patches on steep, moist or wet surfaces of neutral to basic boulders and rock outcrops in humid, sheltered places, especially on rocks which are subject to frequent seepage, flushing, splash or submergence. Hence it grows mainly around and just above water level, on rocks in and at the edges of streams. It prefers streams which flow most often as modest trickles rather than raging torrents: for example I once heard a small stream with a particular kind of tinkling sound and thought *"Radula voluta"*, and upon investigation did indeed find this species it there. *R. voluta* grows mainly on southerly aspects (may need more warmth than many other oceanic species). It is extremely rare away from watercourses in Britain (but grows out on more open hillsides in SW Ireland). At many of its sites there are good populations along a certain length of stream, but with a sharply delineated upstream end and a more diffuse downstream end suggesting that bits get broken off some plants and carried downstream, possibly to colonize as new plants.

Sphenolobopsis pearsonii

(This species was previously thought to be oceanic but is now classed as suboceanic. It is retained in this set of descriptions because it is uncommon and markedly western in Britain, and grows mainly in humid ravines.)

This tiny oceanic liverwort forms small patches on steep, moist but well-drained surfaces of acidic rock outcrops, especially more or less vertical ravine walls. It evidently requires a very humid atmosphere. Its habitats can be subject to periodic spray or even splash or very slight seepage, but frequent submergence is evidently not a requirement. It grows from about 50 cm above water level up to a few metres in elevation, depending on humidity (can grow further above water level in deep, shaded and sheltered ravines, but is more confined to a low waterside zone in more topographically exposed situations). It can also grow on rock faces away from watercourses if the habitat is sufficiently humid and sheltered (most such occurrences are on cool N-facing slopes).

ANNEXE 2: An explanation of the use of Q-values to describe stream flow

Angus Tree (SNH Policy and Advice Officer – Freshwater)

In a river, the amount of water that flows past point *x* in a day is recorded as the daily mean flow (DMF).. It's the 'mean flow' as it's the average of the flow values collected at regular intervals throughout a day. This information is collected at a gauging station. 365 DMFs will be collected in a year. Q values, the amount of time as a percentage of a year that a particular quantity of water or greater flows past point *x*, are derived via the analysis of this DMF data:

DMFs are ranked highest to lowest;

the number of days (*n*) that a DMF of a particular magnitude occurred is calculated;

n is summed cumulatively; and

summed *n* is expressed as a percentage of the year over which data was collected for.

Example:

Discharge (DMF) at point x (m^3/s)	n	$\sum n$	$\frac{\sum n}{365} \times 100(\%)$
10	2	2	1
9	21	23	6
8	44	67	18
7	58	125	34
6	26	151	41
5	46	197	54
4	65	262	72
3	13	275	75
2	50	325	89
1	40	365	100

Where:
n = number of days that discharge occurred during the year
$\sum n$ = cumulative number of days, so the number of days that a discharge of a particular magnitude or greater occurred
$\frac{\sum n}{365} \times 100(\%)$ = the percentage of a year that a discharge of a particular magnitude or greater occurred

In the example above a discharge of 6 m^3/s occurred on 26 days in a year. A discharge of 6 m^3/s or greater occurred on 151 days in that year or 41% of the time. So, the Q_{41} flow was 6 m^3/s. In the same year, a discharge of 1 m^3/s or greater occurred for 100% of the year i.e. there was always some flow in the example watercourse. Interpolation allows values of e.g. Q_{95} to be established.

Flow duration curves are a plot of discharge (m^3/s on the y axis) against the percentage of time that discharge of a particular magnitude was equalled or exceeded (x axis), and they also can be used to establish values of Q.

ANNEXE 3: Summary of existing survey methods for freshwater bryophytes and lichens

- Habitats JNCC 2005[6].
- Short term transfer experiments monitoring growth rate or physiological conditions Carballeira *et al.,* 1998; Hylander *et al.,* 2002; Stewart & Mallik 2006.
- patch area using pins and photographic records Ben Averis, pers. comm..
- Random Quadrats Paavola *et al.,* 2006, submerged zone.
- Transects and quadrats contiguous or equally or random spaced Glime & Vitt 1987, Englund *et al.,* 1997; Jonsson 1997, Virtanen *et al.,* 2001.
- Point transect method Bowden *et al.,* 1994.
- Whole stream reach MTR method, Holmes *et al.,* 1999; LEAFPACS, footnote 4.
- Large plots 10 x 20 m Hylander *et al.,* 2005.
- Stream thalweg 30 m x 5 cm. Fritz et al; 2009.

[6] http://www.jncc.gov.uk/pdf/CSM_bryosLichens.pdf

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