Cyfoeth Naturiol Cymru
Natural Resources Wales

Population trends in hyperoceanic liverworts in Bontddu Gorge after hydroelectric power development

Des Callaghan (Bryophyte Surveys Ltd)

Evidence Report No 743

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We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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- Having a well-resourced proactive programme of evidence work;
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Frontispiece: *Drepanolejeunea hamatifolia* with *Frullania tamarisci*.

Contents

1. Crynodeb Gweithredol

Mae bryoffytau yn cynnwys grŵp amrywiol o organebau sy'n ddangosyddion sensitif o gyflwr yr amgylchedd. Mae goddefiad i ddysychu'n amrywio'n fawr rhwng rhywogaethau, ac mae rhai o'r rhywogaethau mwyaf sensitif wedi'u cyfyngu i hinsoddau cefnforol iawn. Mae'r rhywogaethau cefnforol mwyaf eithafol, neu 'tra-chefnforol' fel y'u gelwir, wedi'u cyfyngu i raddau helaeth i ochr orllewinol Ynysoedd Prydain ac maent yn brin ar dir mawr Ewrop. Ceir y cymunedau cefnforol mwyaf amrywiol mewn ceunentydd iseldir cysgodol ar hyd nentydd ac afonydd yng ngorllewin yr Alban, gogledd-orllewin Cymru (Eryri), gogledd-orllewin Lloegr (Ardal y Llynnoedd) a gorllewin Iwerddon.

Gosodwyd cynllun pŵer trydan dŵr bach (90 kW) yn 2013 ar hyd rhan o afon Cwm Llechen sy'n cynnwys Ceunant Bontddu. Dechreuwyd gwaith monitro bryoffytau sylfaenol cyn i'r cynllun ddod yn weithredol yn 2013, ac fe'i gwnaed eto yn 2017 ac yn ystod y gwaith presennol, yn 2023. Mae monitro'n canolbwyntio ar y digonedd o bum math o lysiau'r afu tra-chefnforol o fewn naw llain ffotograffig fawr, gyda chyfanswm arwynebedd o 170 metr sgwâr, wedi'u lleoli ar hyd afon Cwm Llechen yng Ngheunant Bontddu. Ni chrëwyd lleiniau rheolydd gan nad oes cynefinoedd ceunant tebyg yn bodoli uwchlaw neu islaw'r dyfroedd hynny yn yr afon sydd wedi'u dihysbyddu, ac nid oedd modd dod o hyd i safle rheolydd posibl yn rhywle arall yn yr ardal leol pan gychwynnwyd yr astudiaeth.

Ychydig iawn o newid a fu yn niferoedd llysiau'r afu tra-chefnforol rhwng y flwyddyn sylfaen a 2017. Fodd bynnag, mae newid sylweddol rhwng y flwyddyn sylfaen a 2023, gyda phoblogaeth pedwar o'r pum rhywogaeth wedi lleihau hyd at -43%, a mynegai cyfun o bob rhywogaeth yn dangos gostyngiad o -17%. Dylid nodi bod y tueddiadau hyn yn seiliedig ar ddata o dri chyfnod monitro yn unig dros gyfnod o ddeng mlynedd, ac nid oes data tebyg o safleoedd rheolydd ar gael i gymharu â hwy. Naill ai mae'r newidiadau a ganfuwyd o fewn ffiniau dynameg y boblogaeth naturiol neu maent yn cynrychioli dirywiad gwirioneddol yn y boblogaeth. Os ydynt yn ostyngiadau gwirioneddol, gallai hyn gael ei achosi gan y cynllun pŵer trydan dŵr neu ffactor anhysbys arall, sy'n ymwneud â'r hinsawdd efallai, neu gyfuniad o ffactorau.

Er na ellir dod i gasgliadau pendant am effeithiau'r cynllun pŵer trydan dŵr ar hyd afon Cwm Llechen ar lysiau'r afu tra-chefnforol yng Ngheunant Bontddu o'r wybodaeth sydd ar gael, mae'r dirywiad mawr ym mhoblogaeth y rhywogaeth hon rhwng y flwyddyn sylfaen a 2023 yn codi pryder am effeithiau posibl cynlluniau pŵer trydan dŵr ar bryoffytau sydd ag anoddefiad i dysychu ac sy'n peri pryder cadwraethol. Mae hefyd yn tynnu sylw at yr angen i fonitro'r rhywogaethau hyn yn well ar safleoedd pwysig lle mae cynlluniau pŵer trydan

dŵr wedi'u gosod, gan gynnwys yn hollbwysig monitro cyfochrog mewn safleoedd rheolydd.

2. Executive Summary

Bryophytes comprise a diverse group of organisms that are sensitive indicators of the state of the environment. Desiccation tolerance varies greatly between species, and some of the most sensitive species are limited to highly oceanic climates. The most extreme oceanic species, termed 'hyperoceanic', are largely confined to the west side of the British Isles and are rare on the European mainland. The most diverse oceanic communities are found in sheltered lowland ravines along streams and rivers in west Scotland, north-west Wales (Eryri), north-west England (the English Lake District) and west Ireland.

A small (90 kW) hydroelectric power (HEP) scheme was installed in 2013 along a length of the Afon Cwm Llechen that includes Bontddu Gorge. Baseline bryophyte monitoring was established before the scheme became operational in 2013, and was repeated in 2017 and during the present work, in 2023. Monitoring focuses on the abundance of five hyperoceanic liverworts within nine large photographic plots, with a total area of 170 m^2, located along the Afon Cwm Llechen within Bontddu Gorge. Control plots were not established because comparative ravine habitat does not occur above or below the depleted reach of the river, and finding a potential control site elsewhere within the local region was not possible when the study was established.

There was very little change in the abundance of the hyperoceanic liverworts between the baseline year and 2017. However, there is significant change between the baseline year and 2023, with four of the five species having undergone a decline of up to -43%, and a combined all species index showing a decline of -17%. It should be noted that these trends are based on data from only three monitoring episodes over a period of 10 years, and comparable data from control sites are not available. Either the changes detected are within the bounds of natural population dynamics or they represent real population declines. If they are real declines, their cause could be the HEP scheme or it could be some other unknown factor, such as climate related, or a combination of factors.

Whilst firm conclusions about the effects of the HEP scheme along the Afon Cwm Llechen on hyperoceanic liverworts in Bontddu Gorge cannot be reached from the information available, the significant decline in this species assemblage between the baseline year and 2023 raises concern about the potential impacts of HEP schemes on desiccation intolerant bryophytes of conservation concern. It also highlights the need for better monitoring of these species at important

sites where HEP schemes are installed, crucially including parallel monitoring at control sites.

3. Background

Bryophytes comprise a diverse group of organisms that are sensitive indicators of the state of the environment. They are typified by their poikilohydric physiology, whereby much physiologically important free water is located outside the plant body, held in capillary spaces. Many of the details of bryophyte leaf and shoot structure appear to be adaptations maximizing the capacity to store water externally while minimizing interference with gas exchange (Proctor 2011). Desiccation tolerance varies greatly between species, and some of the most sensitive species are limited to highly oceanic climates. Oceanic bryophytes are more strongly represented in the British Isles than in any other part of Europe and, due to their general rarity and phytogeographic interest, have received much attention from bryologists and conservationists. Many are rare and included in national Red Lists. The most extreme oceanic species, termed 'hyperoceanic', are largely confined to the west side of the British Isles and are rare on the European mainland (Hill and Preston 1998). The most diverse oceanic communities are found in sheltered lowland ravines along streams and rivers in west Scotland, north-west Wales (Eryri), north-west England (the English Lake District) and west Ireland. The best assemblages trigger the selection of Sites of Special Scientific Interest in Britain (Bosanquet et al. 2018) and are of principal importance for conservation under Section 7 of The Environment (Wales) Act 2016. Oceanic bryophytes are also specifically mentioned as a key feature of 'Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles', a habitat included on Annex 1 of the European Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

The effects of small-scale HEP schemes on bryophytes remain very poorly understood. Within the range of possible impacts, most concern regards reduced flow along the depleted reach and the possible effects this may have on species of conservation concern. The author was instructed by Natural Resources Wales to undertake monitoring of bryophytes in Bontddu Gorge following the installation of a HEP scheme in 2013. Two monitoring visits have been undertaken previously, including a baseline survey prior to the installation of the scheme and a subsequent visit in 2017, after which the results were published as a preliminary study of the effects of HEP development on hyperoceanic bryophytes (Callaghan et al. 2019). This report provides the results of the third visit. Taxonomy follows Blockeel et al. (2021).

4. Methods

4.1. Study site

Bontddu Gorge (52°45′10.2″N, 3°58′30.3″W; 70 m a.s.l.) is located along the Afon Cwm Llechen within Eryri National Park, on the southern flank of the Harlech Dome, in north-west Wales. The climate is oceanic, with 169 raindays yr^{-1} and average temperatures of 15.8°C during the hottest month (July) and 4.7°C during the coldest month (February) for the period 1961–2002 (Met Office data supplied through the UK Climate Impact Programme). Despite its relatively small size, with a main ravine just 200 m long, the site ranks as 11th best in Wales for oceanic ravine bryophytes, using the scoring system of Bosanquet (2011), and is the most important where a recent HEP development has been installed. The geology comprises Cambrian mudstone from the Clogau Formation, characterized by acidophilous bryophytes, and an unnamed Ordovician igneous intrusion of quartz-microdiorite, characterised by basophiles. The Afon Cwm Llechen is typically about 6–8 m wide, of steep gradient with rocky banks, and with frequent small waterfalls and bouldery cascades. Semi-natural deciduous woodland, comprising W17 *Quercus petraea-Betula pubescens-Dicranum majus* woodland (Rodwell 1991), shelters the river and main ravine.

4.2. HEP development

In February 2013, planning permission was granted for a small (90 kW) HEP scheme along the length of the Afon Cwm Llechen that includes Bontddu Gorge, which was installed and began operation in December 2013 (Figure 1). The intake weir along was located at 105 m a.s.l. and the turbine house at 45 m a.s.l., providing a 60 m head of water pressure. The abstraction license allows water extraction all year, with a maximum of 20,218 m^3 day^{-1} and 4,447,872 m^3 yr^{-1}, at an instantaneous rate not exceeding 234 l sec^{-1}. To ensure a flow in the watercourse for the maintenance of riverine habitat for the conservation of flora and fauna, the license does not allow abstraction unless the rate of flow in the river immediately below the intake weir is Q95, which is the flow that would be equaled or exceeded 95% of the time under natural conditions (i.e. the 5-per-centile flow). Further, during 1 April to 31 December the water abstracted cannot exceed 40% of the natural river flow > Q95, and from 1 January to 31 March abstraction cannot exceed 60% of the natural river flow > Q95 (Callaghan et al. 2019).

There are no site-specific data on river level or flow for the Afon Cwm Llechen, but flows were modelled by Callaghan et al. (2019), which demonstrated that from the start of operation in December 2013 to 30 June 2017, the HEP scheme abstracted 13,161,000 m^3 of water from the river, which equated to

approximately 20% of the total river flow at the intake. However, the scale of abstraction, proportionate to total river flow, varies significantly across the flow range. For example, flows at Q80 (i.e. those equalled or exceeded under natural conditions for 80% of the time), are only equalled or exceeded 60% of the time after abstraction. In other words, river flow in the depleted reach falls below Q80 for double the amount of time, 40% vs. 20%, than would occur naturally. During particularly dry months, little water is abstracted, for example during July 2014 abstraction occurred 8% of the time, taking 4% of total river flow during that month. During particularly wet months, abstraction can occur 100% of the time, for example during December 2015 when abstraction accounted for 11% of total river flow. Further details are provided in Callaghan et al. (2019).

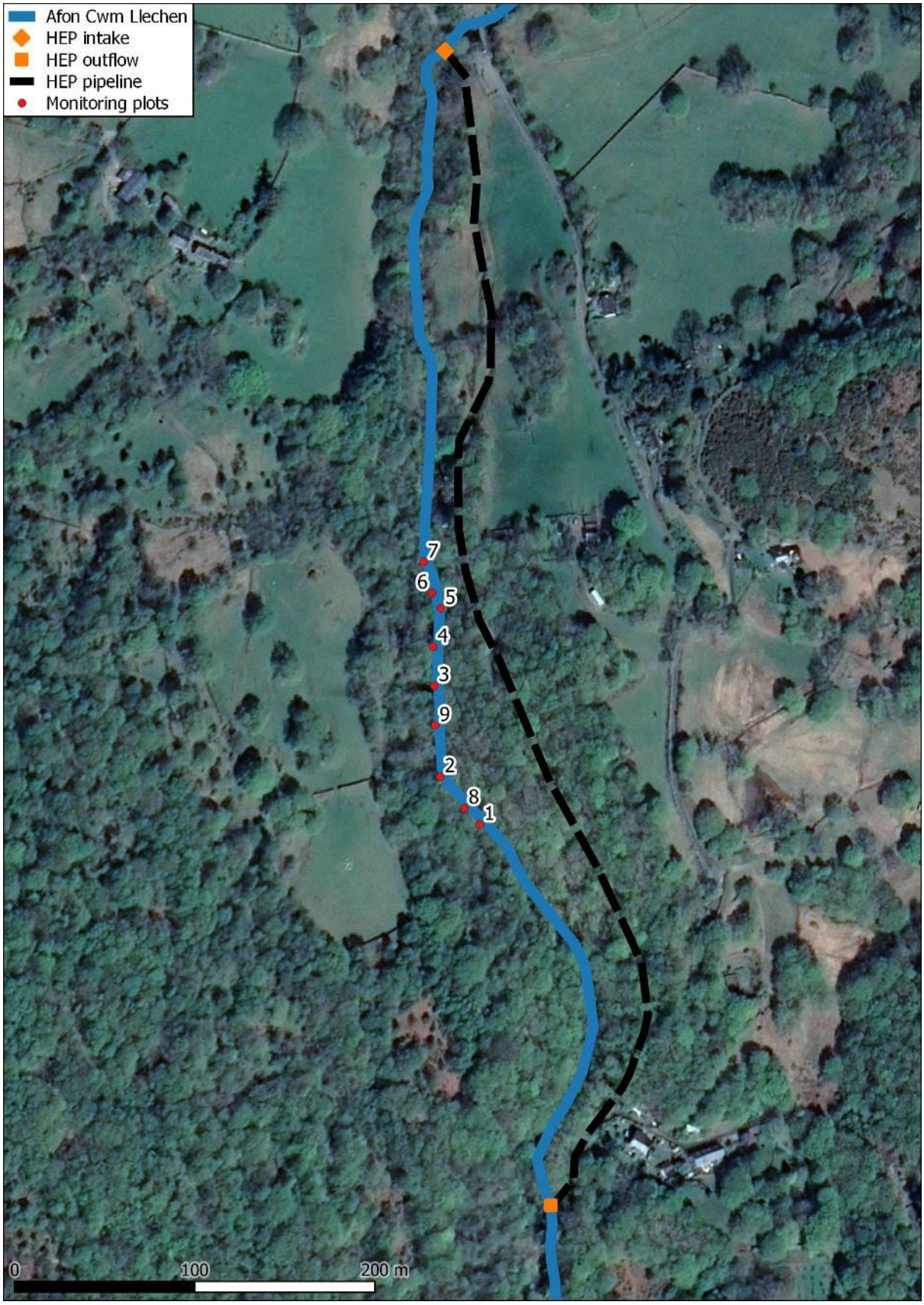

Figure 1. Location of study site and HEP scheme. Monitoring plots are distributed throughout the main length of Bontddu Gorge.

4.3. Bryophyte monitoring

Three initial focal species were chosen for monitoring, comprising *Cololejeunea microscopica, Drepanolejeunea hamatifolia* and *Harpalejeunea molleri*. These are all rare within Europe, competitively inferior, desiccation-sensitive, highly characteristic of the best oceanic ravine bryophyte assemblages in Britain and commonly considered at risk from HEP development. There was a good population of each within the main ravine of the study site, allowing an adequate sample size, and their habitat patches were accessible for monitoring, allowing good population coverage. The monitoring plots established for these three species (see below) also contained a large sample of *Jubula hutchinsiae* and the only colonies of *Radula voluta*, both hyperoceanic liverworts of conservation interest and so were added to the set of focal species.

Monitoring focuses on the abundance of the five hyperoceanic liverworts within nine large photographic plots, with a total area of 170 m^2, located along the depleted reach of the Afon Cwm Llechen within Bontddu Gorge (Figure 1). Control plots were not established because comparative ravine habitat does not occur above or below the depleted reach, and finding a potential control site elsewhere within the local region was not possible when the study was established. Baseline monitoring of the plots was undertaken five months before the HEP installation in 2013. Post-installation monitoring was undertaken in 2017 and during the present work, in 2023. During monitoring of a plot, a rule of 25 cm length is placed within the plot and a camera is mounted on a tripod on the opposite river bank, facing the plot from a fixed point. The plot is then searched for colonies of focal species, with the aid of an illuminated 20× lens. Once a target colony is found, its location is marked within a temporary flag. Flags are placed at a minimum distance of 10 cm from each other. Once all locations for a species are flagged, the plot is photographed, flags are removed, and the process is repeated for any further focal species present within the plot.

Photographs of plots are opened in Adobe Photoshop, where the approximate real-world dimensions of individual pixels are calculated from the 25 cm rule that was placed in each plot. A grid is then drawn over the photograph comprising cells of 25 x 25 cm. Counts are then made of the number of 25 cm grid cells occupied by each focal species in each plot, which provides a standardised proxy measure of their abundance.

4.4. Trend analysis

Counts of occupied 25 cm grid cells were summed across plots to provide a site total for each species. This was done for the new data collected in 2023, and for the data collected in 2013 and 2017. Count data were then standardised

across species by assigning an index of 100 to the baseline year (2013) and calculating indices for 2017 and 2023 so that each corresponds to a percentage measure of the baseline index. For example, counts of 25 cm grid cells occupied by *Cololejeunea microscopica* totalled 37 in 2013, 39 in 2017 and 22 in 2023. The corresponding population indices are 100 in 2013, 105 in 2017 (i.e. 105% of what it was in 2013) and 59 in 2023 (i.e. 59% of what it was in 2013). A composite 'all species' population index was also created, from summed counts across species.

5. Results

5.1. Changes in physical structure of plots

A comparison of the current condition of the plots compared to images of them obtained during the previous monitoring periods in 2013 and 2017, showed their overall condition has changed little, with no major changes in their physical structure, for example due to rock-falls.

5.2. Species abundance and population trends

Photographic images, marked locations of colonies and occupied 25 cm grid cells of each of the five focal species within each of the monitoring plots is shown in Appendix 1. The abundance data from all three monitoring episodes is provided in Table 1. Table 2 shows percentage change in the abundance of species in 2017 and 2023 from the baseline year, and Figure 2 shows population trends of species. Except for *Radula voluta*, which is only represented by a small sample, there was no substantial change in the abundance of species between the baseline and 2017, with the all species index showing a change of just -1%. By 2023, significant change has occurred, with four of the five species having declined, and the all species index showing a change of -17% from the baseline.

Table 1 Counts of occupied 25 cm grid cells of hyperoceanic liverworts within monitoring plots at Bontddu Gorge in 2013, 2017 and 2023.

Species by year	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Total
Cololejeunea microscopica 2013	21	3	0	0	0	11	1	1	0	37
Cololejeunea microscopica 2017	26	8	0	0	0	3	1	1	0	39
Cololejeunea microscopica 2023	17	1	0	0	0	2	1	1	0	22
Drepanolejeunea hamatifolia 2013	0	0	14	5	33	6	1	1	8	68
Drepanolejeunea hamatifolia 2017	0	0	20	4	21	8	1	2	8	64
Drepanolejeunea hamatifolia 2023	0	0	10	2	16	4	0	2	5	39
Harpalejeunea molleri 2013	0	0	6	4	5	7	1	0	16	39
Harpalejeunea molleri 2017	0	0	6	7	2	6	1	0	16	38
Harpalejeunea molleri 2023	0	0	6	7	1	3	1	0	14	32
Jubula hutchinsiae 2013	30	3	8	7	0	12	0	50	1	111
Jubula hutchinsiae 2017	33	1	6	7	0	9	0	58	1	115
Jubula hutchinsiae 2023	30	2	8	7	0	9	0	60	2	118
Radula voluta 2013	0	0	0	0	0	0	0	0	10	10
Radula voluta 2017	0	0	0	0	0	0	0	0	6	6
Radula voluta 2023	0	0	0	0	0	1	0	0	5	6
All species 2013	51	6	28	16	38	36	3	52	35	265
All species 2017	59	9	32	18	23	26	3	61	31	262
All species 2023	47	3	24	16	17	19	2	63	26	217

Table 2 Percentage change in the abundance of hyperoceanic liverworts in Bontddu Gorge in 2017 and 2023 compared to 2013 baseline year.

Species	Percentage change from 2013 baseline: 2017	Percentage change from 2013 baseline: 2023
Cololejeunea microscopica	5%	-41%
Drepanolejeunea hamatifolia	-6%	-43%
Harpalejeunea molleri	-3%	-18%
Jubula hutchinsiae	4%	6%
Radula voluta	-40%	-40%
All species	1%	-17%

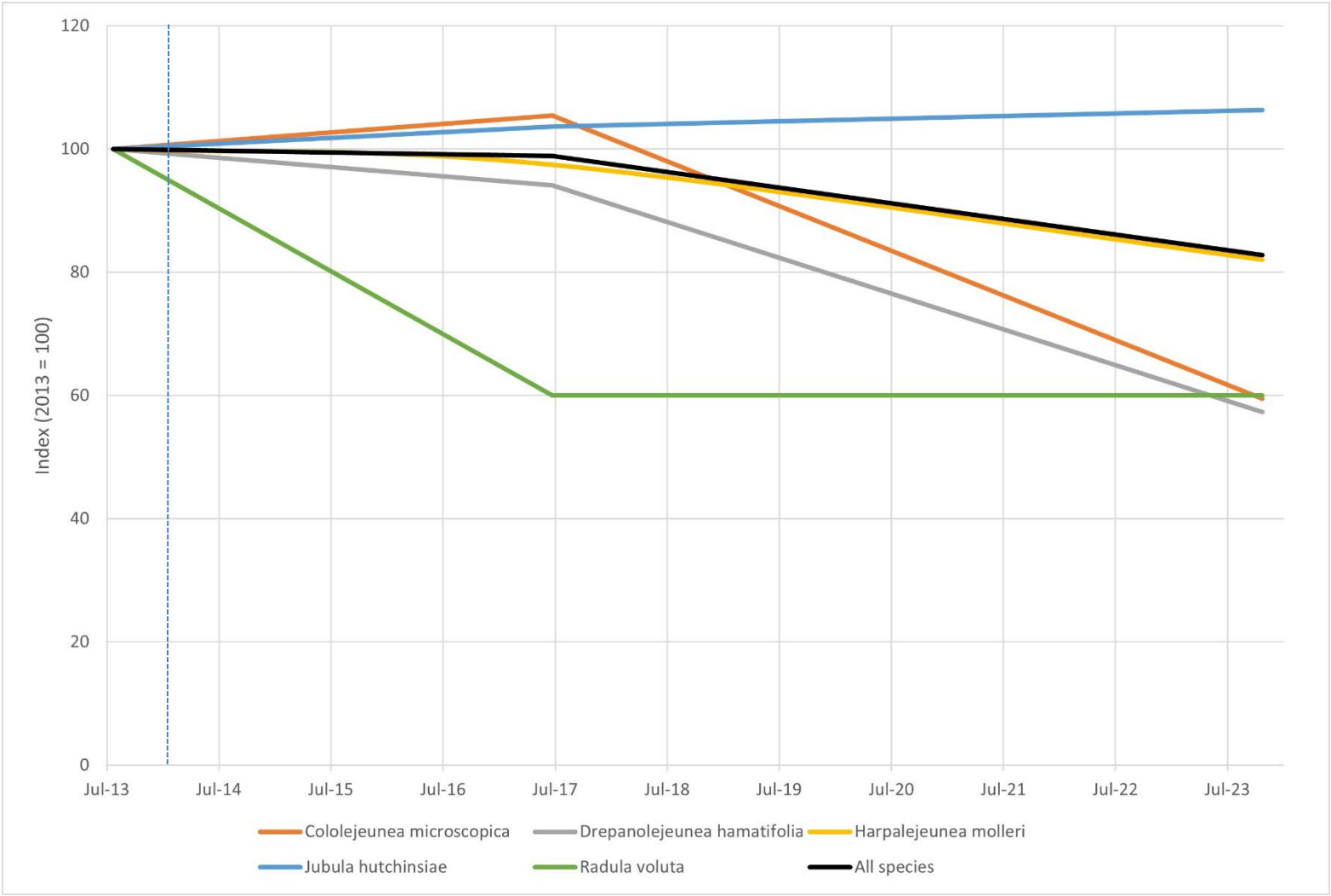

Figure 2. Population trends in hyperoceanic liverworts in Bontddu Gorge. The dotted line indicates when the HEP scheme became operational.

6. Discussion

The data from this study shows very little change in the abundance of five hyperoceanic liverworts between the baseline year (2013), when the HEP scheme was installed, and the first re-monitoring visit that was undertaken four years later, in 2017. However, data from 2023 show significant change from the baseline, with four of the five species having undergone a decline by up to -43%, and the combined all species index showing a decline of -17%. Two possible effects from the HEP scheme on hyperoceanic liverworts are increased desiccation stress and competitive exclusion by more robust species, either of which could cause population declines and local extinction. In the present context, there is no information on the former but observations within monitoring plots in 2023 did not suggest competitive exclusion was a substantial factor, at least by larger bryophytes, since many precise locations that were occupied by *Cololejeunea microscopica, Drepanolejeunea hamatifolia* and *Harpalejeunea molleri* in 2017 comprised bare rock in 2023.

Whilst the results of this study clearly give cause for concern, it should be noted that the population trends are based on data from only three monitoring episodes over a period of 10 years. It is possible that the changes detected are within the bounds of natural population dynamics and that 2023 was just a poor year. It is also possible that the declines are not just part of natural fluctuations but are real population declines. If they are real declines, their cause could be the HEP scheme or it could be some other unknown factor, perhaps climate related, or a combination of factors. This study does not include a control site, and nothing is known about population trends in these species at similar sites across a similar time period. The only available information concerns national trends, which at the scale of Britain during 1980–2015 indicates increases in *Cololejeunea microscopica, Drepanolejeunea hamatifolia* and *Harpalejeunea molleri*, and stability in *Jubula hutchinsiae* (too few data were available to infer the likely trend in *Radula voluta*) (unpublished data).

The fact that *Jubula hutchinsiae* has undergone a small increase compared to the baseline, while the other four species have undergone a large decline is curious and not easily explained. Amongst these species, *J. hutchinsiae* may be expected to be most at risk from HEP development because its niche is tied most closely with the river hydrology, as can be seen from its distribution within the monitoring plots (Appendix 1), generally occurring just above the water level during average flows but mostly beneath the level of spate flows. This liverwort can often occupy bankside seepages, disconnected from the river hydrology, but this does not occur substantially within the monitoring plots at Bontddu Gorge. Of the five species, *J. hutchinsiae* is the least oceanic and occupies the broadest geographic range in Britain and Ireland. It is also able to survive within

stands of the most robust mosses, such as *Thamnobryum alopecurum*, by growing within and over them, something not exhibited by *Cololejeunea microscopica, Drepanolejeunea hamatifolia* or *Harpalejeunea molleri* within monitoring plots, where they are confined to bare rock. These differences may suggest *J. hutchinsiae* is better able to withstand the environmental change that has occurred in Bontddu Gorge over the past 10 years.

7. Conclusions

Whilst firm conclusions about the effects of the HEP scheme along the Afon Cwm Llechen on hyperoceanic liverworts in Bontddu Gorge cannot be reached from the information available, the significant decline in this species assemblage by 2023 raises concern about the potential impacts of HEP schemes on desiccation intolerant bryophytes of conservation concern. It also highlights the need for better monitoring of these species at important sites where HEP schemes are installed, crucially including parallel monitoring at suitable control sites.

8. Acknowledgements

Thanks to Sam Bosanquet (NRW) for organising the contract.

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10. Appendices

10.1. Appendix 1: Monitoring plots showing results from 2023

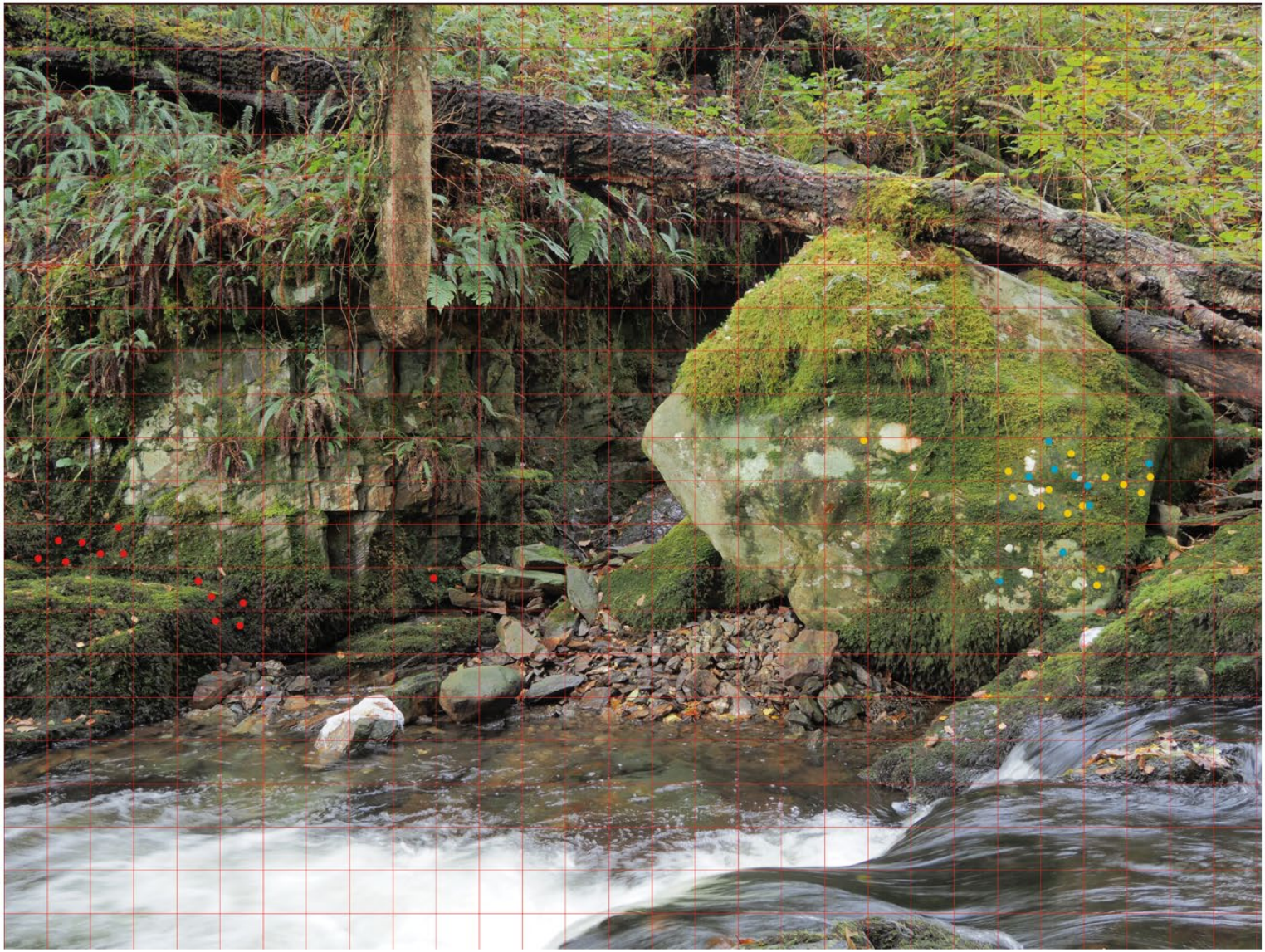
Plot 1


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 2


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 3


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 4


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 5


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 6


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 7

- *Cololejeunea microscopica*
- *Drepanolejeunea hamatifolia*
- *Harpalejeunea molleri*
- *Jubula hutchinsiae*
- *Radula voluta*

Plot 8


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

Plot 9


Cololejeunea microscopica
Drepanolejeunea hamatifolia
Harpalejeunea molleri
Jubula hutchinsiae
Radula voluta

11. Data Archive Appendix

Data outputs associated with this project are archived on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

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