CASE STUDY: APPRAISAL OF FOUR SOIL-BASED METRICS IN THE ESTABLISHMENT OF SUSTAINABLE UPLAND GRASSLAND AT A MINE SITE IN SOUTH WALES, UNITED KINGDOM[1]

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Abstract: In the United Kingdom, rehabilitated mineral workings are subject to a statutory minimum 5-year period of aftercare management to ensure that the rehabilitated land is of a 'standard' that enables the intended after-use to be "beneficial and sustainable." Aftercare begins on the completion of overburden backfilling, placement of soils, and the required sowing/planting. The current devolved Welsh Government guidance acknowledges that specific standards are difficult to define, so there is reliance on certain management activities having been undertaken, rather than specifying the outcome of evaluative methods. We appraise the application of four soil-based metrics (comprising the description of soil profile physical characteristics, grassland soil physical condition, soil fertiliser requirement, and a measurement of soil health) under operational circumstances at a rehabilitated mine site in South Wales. Here, the aim is to establish a sustainable upland acidic grassland ecosystem and to facilitate release of monies from the financial bond. It is concluded that evaluation of the upland grassland is more realistically and reliably based on determining the physical characteristics of the soil profile than the other three metrics deployed; although there is merit in the use of a more rapid visual assessment method for soil physical condition (VESS) for screening purposes and/or for increasing site coverage at a lower cost, as well as the determination of levels of organic matter and nitrogen mineralisation. The use of the soil profile characteristics metric enabled the planning authority to release the rehabilitated land from the financial bond.

Additional key words: soil profile physical characteristics, VESS, soil fertiliser indices, soil respiration indices, mining permit, release of financial bond

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Introduction

In Wales, United Kingdom, rehabilitated mineral workings are subject to a period of prescriptive management to ensure they have a good chance of achieving the proposed land use. Provisions are made in the devolved Welsh Government's guidance to the mineral planning authorities as to the appropriate and necessary works (referred to as 'aftercare', see Welsh Government, 2010, Annex 4) to be imposed as a planning condition in consented (permitted) mineral extraction schemes. Aftercare begins on the completion of overburden backfilling, replacement of soils, and the required sowing/planting. The statutory minimum aftercare period is for 5 years, this is to ensure that the rehabilitated land is of a 'standard' that enables the intended after-use to be "beneficial and sustainable" (Welsh Government, 2009, 2010 and 2016).

For agricultural use, the required 'standard' is loosely defined as "the keeping of livestock for food and production of materials" and either a) the reinstatement of the same (as practicable) soil physical conditions that existed before mineral extraction for "better quality land" (Welsh Government, 2010, para 41) or b) for poorer quality land and/or where no natural soils are present, land that is reasonably "fit for beneficial and sustainable agricultural use" (Welsh Government, 2010, paragraph 61). Mineral Technical Advice Note 2: Coal (MTAN2) is a little more specific where the aftercare programme is to promote soil recovery (structure and stability), drainage, and the establishment and management of the vegetation (Welsh Government, 2009, paragraph 273). Mineral Planning Guidance 7 (MPG7) (Welsh Government, 2010, paragraph 41) is the current core guidance for aftercare provisions and acknowledges that specific standards are difficult to define.

No methodology or sampling regime had been imposed in the aftercare conditions for the Selar Surface Mine site being referred to here, other than "chemical and soil analyses" should be undertaken to determine fertiliser and lime applications (Neath Port Talbot, 2014). In the absence of specific guidance and methods specified in the planning consent (permit), an opportunity arose in 2018 during the final year of aftercare at the Selar Mine to appraise, under normal operational circumstances, the application of four soil-based metrics. These are routinely used in the management and evaluation of productive agricultural land. This paper is about a simple comparative exercise with the aim of arriving at a practical and meaningful way of collecting and evaluating soil-based evidence that the rehabilitated land at the end of the aftercare period has reasonably achieved or is likely to achieve the intended purpose and expectations where the objective is to provide upland acidic grassland fit for low intensity livestock grazing.

Site

The Selar Surface Coal Mine in South Wales started working in 1997 and completed its final coaling operation in 2018. Rehabilitation has been undertaken progressively since 2006 as overburden was backfilled and soil material placed (Photo. 1).

Photo 1. Mosaic of land use and habitats (including upland acidic grassland) established on progressively rehabilitated land between 2006 and 2013 (aerial photograph taken in early 2017).

Thirty-seven hectares of land was rehabilitated to upland acidic grassland between 2011 and 2013, and in 2018 completed the statutory five-year aftercare programme. The grassland was officially released from the planning obligation by the planning authority in December 2018 on account that, supported by evidence presented in this paper, a beneficial and sustainable use had been achieved. This resulted in the release of monies relating to that part of the financial bond.

The Selar Mine is located at Latitude 51.730887 Longitude -3.6209393. It has an oceanic temperate climate with a typical annual rainfall of more than 2000mm. The Mine is on the north facing side of Myndd Pen-y-cae at an altitude of between about 170 – 300 m above sea level and within the transition zone between upland and lowland conditions. Typically, the natural undisturbed soils of the locality are shallow and have poor structural characteristics, and consequently are usually waterlogged for part of the year, often with organic/peaty top-soils (Rudeforth et al., 1984). The main limitations to agricultural use and plant productivity are climatic (high rainfall and cool temperatures), topographical complexity (slope), and poor soil drainage (due to a weak blocky soil structure). Most of the natural soils have been lost during previous working of the shallower seams of coal in the 1960s (a time when soils were often not recovered and reused).

On the completion of the coaling operation, the objective is to restore much of the Site to upland ‘moorland’ grassland for low intensity grazing as on the surrounding undisturbed land. In 2011 two compartments (nos. 6 and 7) were rehabilitated and two more (nos. 7 and 8) in 2013, totalling 37 ha. Each were backfilled with the previously excavated Carboniferous Coal Measure mudstones and covered with 0.5 - 0.7 m ‘soil forming material’ (SFM), a glacial drift, recovered during the mining operations. As part of the rehabilitation process, the surface of the backfill and the placed SFM were sequentially de-compacted, the SFM was cultivated and sown with an ‘upland acidic grassland’ seed mixture (comprising common bent (*Agrostis capillaris*), sheeps’ fescue (*Festuca ovina*), creeping red fescue (*F. rubra*), and perennial ryegrass (*Lolium perenne*)) (Photo 2). This was followed by a 5-year aftercare period imposed by the consent (permit) to extract coal from the Site (Neath Port Talbot, 2014). Further Conditions in the planning consent set out a list of measures that might be required “to bring the site to the required uses for agriculture” and provide for an annual review. The four compartments were fenced to enable the option of grazing and stocking levels were defined. Underdrainage was not installed, but annual NPK fertiliser applications were made based upon chemical analysis. Other than the confirmation that the actions during the aftercare period had been undertaken, no evidence-based performance criteria were required by the Planning Authority.

Photo 2. View of upland acidic grassland in compartment 8 in November 2018 after five years of aftercare.

The Soil-Based Metrics

In each case the following sampling exercises were undertaken in September 2018. The last fertiliser application within the aftercare programme had been in May 2018.

Soil Profile Physical Characteristics

The description of soil physical characteristics is an established means of evaluating their agricultural potential (MAFF, 1988). The method comprised visually and tactilely describing the soil profiles (horizon thickness, texture, structural development, packing density, etc.) within each rehabilitated area/compartment according to the standard Soil Survey methodology (Hodgson, 1974). With this method, three soil pits were dug in each of the compartments to represent the range of relative grassland performance (i.e., ‘good’ (pit a), ‘average’ (pit b), and ‘poor’ (pit c)).

The individual descriptions can be interpreted as to their functionality and used collectively to index (grade) land as to its physical land quality using the national land classification guidelines

(MAFF, 1988). The method is also applicable to rehabilitated land (Humphries and McQuire, 1994). The soil profile descriptions can also be put into local context by comparing with published descriptions of similar soils (see Rudeforth et al., 1984). Both the land quality grading and published accounts can be used as evidence to determine the suitability of the rehabilitated land for the intended land/agricultural use.

Grassland Soil Health

This methodology also describes soil physical condition, but only the upper soil layer is considered for grasslands. It has been widely advocated and used by agricultural practitioners because it is convenient and relevant to grassland management and utilisation (Ball et al., 2017). It is usually referred to as the Visual Evaluation of Soil Structure (VESS), it too is a visual and tactile physical description of the topsoil layer for grassland and the subsoil if arable land. The methodology describes the physical nature of the upper soil horizon (texture, soil strength, structure, porosity, packing density, roots, and lumbricid worm numbers) and is succinctly set out by the Scottish Rural College (Not Dated). In tandem with the above soil profile descriptions, three ‘turves’ were excavated next to the soil pits and examined to represent areas of relative grassland performance (‘good’ (turf a), ‘average’ (turf b), and ‘poor’ (turf c)).

From the above VESS descriptions, an index (1-5) of relative soil condition is derived as to soil physical condition, which are often evaluated as “Good” (Index 1) to “Poor” (Index 5) (Ball, 2017).

Fertiliser Requirement

This is a chemical-based set of determinations which uses the standard method in the UK for assessing the NPK fertiliser and lime requirements for productive agricultural grassland (AHDB, 2019a and 2019b). Here, extractable phosphorus (P), potassium (K), and magnesium (Mg) nutrient levels are indexed and fertiliser/lime application levels determined within the upper soils layer. The Indices have been traditionally used as a means of judging the need for fertiliser application to sustain rehabilitated agricultural grasslands, where soils with an Index 0-1 might be expected to be raised to Index 2 by the end of the aftercare period.

In this exercise, aggregated samples were collected using the standard ‘W’ sampling pattern covering the whole compartment (AHDB, 2019a), the samples were homogenised and then sent for analysis at an accredited laboratory for plant-available soil P, K, Mg, and pH (NRM Laboratories, 2016).

Soil Health

This methodology focuses on biological activity due to the growing concern about the health (condition) of agricultural soils (UK Parliament, 2018). It is an extension of the above fertiliser requirement approach with the additional determinations of soil organic matter (loss on ignition method (Hodgson, 1974)) and potential mineralisation of organic matter (microbial activity (Haney and Brinton, 2008)). The main purpose of this approach being measurement of the accumulation and turnover of soil carbon and potential mineralizable nitrogen (N).

Whilst all determinants, except for soil texture, are indexed so their status can be seen, only the mineralisation value is used independently for the indexing of soil health (biological activity) ranging from 'very low' to 'very high' (NRM Laboratories, 2016). The status of the other determinants can influence the rate of mineralisation and can be applied to make minor up/down adjustments.

The same aggregate and homogenised samples collected above, for determining the above fertiliser requirement approach, were used for this set of determination and sent to the same accredited laboratory (NRM Laboratories, 2016).

Results

Soil Profile Physical Characteristics

A summary of the key functional soil profile physical properties of the rehabilitated land is given in Table 1.

All the soil profiles had developed a shallow organic (root) mat of 2-3 cm thickness above the upper mineral soil layers. In two of the four rehabilitated compartments, the profile had apedal/massive structure and high packing density. In the other two compartments a medium sub-angular blocky structure had developed (Photo. 3). In these, the upper profile layer was generally a clay textured SFM. The exception was Compartment 7 which had no SFM cover and was a silty clay derived from weathering of the shale backfill.

Table 1. Summary of three physical characteristics of upper mineral soil layer (see Hodgson (1974) for descriptions).

		Physical Characteristic		
Compartment/Sample	**Upper Profile Layer Depth (cm)**	**Texture**	**Structure**	**Packing Density***
6a	2-25	Clay	Medium/coarse sub-angular blocky	High
6b	3-30	Clay	Apedal/Massive	High
6c	3-25	Clay	Apedal/Massive	High
7a	3-15	Silty Clay	Apedal/Massive	High
7b	3-15	Silty Clay	Apedal/Massive	High
7c	2-17	Silty Clay	Apedal/Massive	High
8a	2-30	Clay	Apedal/Massive	High
8b	2-13	Clay	Medium sub-angular blocky	High
8c	2-11	Clay	Medium sub-angular blocky	High
9a	2-22	Clay	Medium sub-angular blocky	High
9b	3-20	Clay	Medium sub-angular blocky	High
9c	2-12	Clay	Medium sub-angular blocky	High

*As exhibited in the field using the criteria set out in Hodgson (1974, Table 4)

Photo 3. Compartment 8 replaced 'subsoil' layer exhibiting the development of a medium sub-angular block structure by the end of the 5-year aftercare period.

The structural development in the upper profile in all cases was either weak blocky or not visually evident (i.e., apedal) and limited to cracks and root channels, as reflected by the high packing density.

Grassland Soil Health

The grassland soil health criteria used in the VESS method are set out in Table 2, along with the indexation of the samples from the rehabilitated compartments.

The methodology differentiated between three groups of samples, being either Index 3 (Adequate), 4 (Poor), or 5 (very Poor) owing to their soil (structural) aggregate size and shape in the upper soil layer (Photo. 4).

Table 2. Indexation of grassland soil health according to VESS methodology (see Scottish Rural College (Not Dated)).

	VESS Qualifying Physical Criteria				
VESS Index	**Topsoil Structural Condition as Productive Grassland**	**Soil Aggregate Size and Shape**	**Porosity**	**Root Frequency and Distribution**	**Assignment of Compartment Samples**
1	***Good***	Small and Rounded	Extremely	Many and Well	
2	***Good***	Rounded	Very	Good	
3	***Adequate***	*Large Rounded and Angular*	Moderately	Moderate	9(c)
4	***Poor***	*Large Angular*	Slightly	Poor and Restricted to Cracks and Large Pores	6 (a), 8(b and c), 9 (a and b)
5	***Very Poor***	*Very Large Angular*	Very Slightly	Mainly at Surface and Cracks/Large Pores	6(b and c), 7(a, b andc), 8(a)

Photo 4. Compartment 8 replaced soils exhibiting the *Very Poor* category of VESS Index for the 'topsoil' layer.

Fertiliser Requirement

The results of the laboratory analyses for determining agricultural fertiliser and lime requirements are given in Table 3. The soil in all compartments was acidic. Broadly, all soils had similar levels of extractable plant nutrients. P and K indices ranged from ‘low’ to ‘marginal’, and Mg ranged between the ‘target’ and ‘high’ indices.

Table3. Laboratory analyses for fertiliser and lime requirements (see AHDB, 2019a).

	Compartment			
	6	**7**	**8**	**9**
P Index (mg/l)	1 (13.8)	2 (23.8)	0 (9.2)	1 (10.4)
K Index (mg/l)	1 (86.2)	1 (83.8)	0 (54.4)	1 (62.8)
Mg Index (mg/l)	5 (592)	5 (305)	3 (152)	4 (203)
pH	6.7	5.6	5.8	5.4

Soil Health

The results for the soil biological activity are given in Table 4. Soil organic matter levels are similar for all compartments and all four have a ‘high’ potential for nitrogen mineralisation (i.e., microbial activity index).

Table 4. Laboratory analyses for soil organic matter and microbial activity (see NRM Laboratories, 2016).

	Compartment			
	6	**7**	**8**	**9**
Organic matter (LOI)* %	3.7	4.7	3.7	4.0
Microbial activity Index (mg CO_2/kg)	4.8 (132)	4.8 (137)	4.6 (115)	4.6 (111)

* LOI = loss on ignition

Discussion

In selecting a methodology and sampling regime, the key decision to make is whether their metrics will be useable and reliable. At the Selar site, having completed 5 years of aftercare, the aim was to be able to argue on an evidence-basis (Humphries, 2000 and 2013) whether the rehabilitated land was “reasonably fit for beneficial and sustainable agricultural use” as set out by the Welsh Government (2010, paragraph 61).

Soil Profile Physical Characteristics

The soil profile description approach identified that there will be physical limitations (particularly soil structure and packing density) which affect root growth, drainage, and nutrient cycling in both the upper and lower soil layers of the rehabilitated areas and consequently will limit agricultural potential and grassland productivity (MAFF, 1988).

Importantly, this methodology enables the metrics to be put into a land use context by reference to published literature, pre-working soil characteristics, and previous experience. The SFM drift material used to cover the mudstone backfill has the same physical characteristics of poorly developed structure and associated functional limitations (see Tables 1 and 5) as the subsoil layer of the locally occurring natural soils of the Wilcocks 1 Series at Selar and the subsoils of the Wilcocks 1 Soil Series of the reference profile described by Rudeforth et al. (1984).

Table 5. Summary of soil profile physical characteristics of local soils, reference site, and nearby rehabilitated Nant Helen Surface Mine Site.

	Profile Depth cm	**Texture**	**Structure**	**Packing Density***
Selar (undisturbed)	0-12 12-100	Clay loam Clay	Sub-angular Coarse angular/blocky	ND Medium
Wilcocks 1 Series	0-20 20-50 50-100	Humose clay loam Clay loam/sandy clay loam Clay loam	Granular Sub-angular/blocky Blocky/prismatic	ND ND ND
Nant Helen	0-59 59-70	Clay loam Silty clay loam	Apedal/massive Apedal/massive	Medium High

*As exhibited in the field using the criteria set out in Hodgson (1974, Table 4)

Hence, functionally, the rehabilitated profiles have the same land use potential as the local undisturbed soils of being "very poor-quality agricultural land with severe limitations and restricted use to permanent pasture or rough/low intensity grazing" (MAFF, 1988). The undisturbed land at Selar, an area of land rehabilitated in 1994 at the Nant Helen Surface Mine and the land at the Selar Site are all classified as Agricultural Land Classification Grade 5. The same type of upland acidic grassland at Nant Helen on similar SFM with similar physical characteristics and nutrient levels (Table 5 and 6) has continued to support, without intervention, the proposed low intensity grazing for the past 25 years. This is real evidence and in practice that sustainability is also likely to have been/likely to be achieved at the Selar Mine following the completion of the 5-year aftercare period. In these contexts, the descriptive soil profile methodology is predictive of whether rehabilitated land has met the criteria of being reasonably fit for beneficial and sustainable use, and hence the objective of the aftercare period has reasonably been met.

Table 6. Laboratory analysis for fertiliser and lime requirements (AHDB, 2019a) and Soil Health Index (see NRM Laboratories, 2016) for rehabilitated land at the Nant Helen Surface Mine Site.

	Sample Number		
	1	**2**	**3**
P Index (mg/l)	1 (11.8)	2 (16.4)	1 (12.2)
K Index (mg/l)	2 (140)	1 (85.8)	1 (78.2)
Mg Index (mg/l)	3 (118)	3 (104)	4 (227)
pH	5.0	4.7	5.5
Organic matter (LOI)*%	6.2	11.4	6.2
Microbial activity Index (mg CO_2/kg)	5.1 (177)	5.1 (172)	5.0 (159)

*LOI = loss on ignition

Grassland Soil Health

The description of the upper soil profile using the VESS method also identified the same physical limitations of soil structure and packing density (porosity) as the formal profile descriptions. The outcome is that the rehabilitated land scored Indices of 4 - 5 which descriptively labelled the upper layer to be in a ‘poor/very poor’ physical condition for productive grassland. If taken literally, this could be interpreted that the aftercare had failed and that the land was not fit for beneficial and sustainable agricultural use as upland grazing, however this is not considered to be the case. Hence, if the VESS method is used, it is necessary to set an appropriate index level as the target which is based on local land use and grasslands; in this case Index of 4 or 5.

The VESS grassland method has the advantage of being quicker and cheaper, as only the top soil layer is examined and may not need professional expertise, but it has the disadvantage of not examining the whole soil profile which may be more informative as demonstrated above with the whole profile description.

Fertiliser Requirement

Obviously, the deployment of this metric alone does not inform of the physical limitations and potential of the SFM on the suitability and sustainability of the rehabilitated land. Given the low extractable P and K indices along with low pH, what the analytical results only infer is that the rehabilitated land is in need of remedial fertiliser and lime applications for increased grassland production (AHDB, 2019b). However, for low productivity (acidic) grasslands, such is the objective of the rehabilitation at Selar, low pH, and low extractable P index would be expected and not require remedy (Critchley et al., 2002). Indeed, Humphries et al. (1999) found that low levels of nutrients and pH levels at the end of the aftercare period for SFM of a similar type to that at the Selar Site were adequate for sheep rearing without further fertiliser addition.

The fertiliser requirement metric, when taken in context, is helpful in confirming that nutrient availability (in the short-term) and soil reaction (pH) are likely to be fit for the intended beneficial use, but does not shed any further light on the fitness and potential land use of the land. The value of these analyses is they are supplementary in nature where there is a need to amend the nutrient levels and soil reaction to achieve the land use/grassland type.

Soil Health

Whilst soil health chemical analyses seemingly have the same benefits and disbenefits of the above fertiliser-based metric, the addition of organic matter and microbial activity determinations to the suite of soil analyses provides a useful indication of biological function (NRM Laboratories, 2016) in the evaluation of rehabilitation achievement. Humphries et al., (1999) demonstrated that soil N was important in the utilisation of this type of grassland. The soil health analyses demonstrated that soil organic matter accumulation is taking place and there is a potential for its microbial mineralisation and the supply of plant available N, thereby implying the establishment of a functional mineral cycle in the SFM. Similar levels are indicated in the upland acidic grassland on SFM at the rehabilitated Nant Helen Mine which is supporting upland grazing without additional fertiliser application since the completion of its 5-year aftercare programme (Table 6).

The analytical package used here has gained wide support in agriculture as an indicator of soil health and has merit in this respect, even if it is simply a matter of reassurance that attention is being given to this important aspect of soils. The package is relatively expensive, but as currently offered includes the fertiliser requirement analyses.

Choice of Metric

From the above, only the metrics describing the physical characteristics (condition) of the soil profile are able to provide the necessary evidence to determine whether the rehabilitated land is “reasonably fit for beneficial and sustainable agricultural use.” The most credible is the full description of the soil profile physical characteristics using the Soil Survey method (Hodgson, 1974). The two chemical-based metrics are unable to do this, but the soil health package could be a useful addition in the determining soil organic matter level and nitrogen mineralisation in respect of sustainable agricultural use under upland grazing conditions where the supplementary application of fertilisers and manures is unlikely.

Had the pre-mining land at Selar been of a “better quality” (i.e., ALC Grades 1 to 3 (MAFF, 1988)), the expectations and the evaluative methodology required would have been clearer as the guidance states “the reinstatement of the same (as practicable) soil physical conditions that existed before mineral extraction for “better quality land” (Welsh Government, 2010, paragraph 41). Here, the determination of the soil physical characteristics would have been expected, and most likely, the description and interpretation of the full profile using the Soil Survey method. However, there is no technical or logical reason why the same approach cannot be deployed for inherently poorer land such as that at Selar, as set out in Humphries and McQuire (1994).

All four of the metrics being considered are sample-based. The sampling regime to be adopted can differ according to the objectives. For example, areas of ‘better’ and ‘poorer’ performing land may be sampled for comparison or an average taken by selecting a ‘typical’ area or an aggregation of samples taken across the land. The targeted sampling approach could have been deployed for the chemical analyses to represent areas of ‘good,’ ‘average,’ and ‘poor’ grassland performance rather than the aggregated ‘W’ sampling pattern. Whilst this might give different values, it would not correct for the inherent limitations of the chemical-based methodologies.

In terms of expertise needed, the determination of soil profile physical characteristics will need professional soil practitioner expertise, whilst the VESS turf examination is capable of being undertaken by ‘trained’ persons (as was the purpose of devising the simple method for farmers). The chemical tests rely on laboratory services which provide the expert diagnosis and interpretation of processed samples and so no specialist expertise is needed in the field. Consequently, there are cost differences in obtaining the data (Table 7). For example, for 15 areas totalling about 140 ha in extent, the cost for profile physical descriptions by a professional practitioner could be in excess of US$1,900.00, the visual assessment about US$640.00 by trained operative, or US$1,280 by a professional practitioner; the laboratory analyses for fertiliser requirement between US$435.00 and US$580 (for 15 and 20 samples), and the soil health laboratory analyses between US$1,440.00 and US$1,920.00 (15 and 20 samples); if taken by trained operatives. If both the soil profile descriptions and soil health were to be undertaken together this would amount to almost US$4,000.00 (excluding personal expenses). Should there be a requirement for a greater number of samples, the costs would be proportionately greater.

Table 7. Illustrative unit labour and laboratory costs.

Methodology	**Labour Cost US$/hr***	**Laboratory Cost US$/sample**
Soil Profile Physical Description	80~	0
VESS	20#/80~	0
Fertiliser Requirement	20#	13
Soil Health	20#	80

~ Certified specialist, # Trained operative, *excludes personal expenses

<u>Other Metrics</u>

There are other metrics that might be used to determine the adequacy of the rehabilitation. The most obvious in the context of the grassland at the Selar Mine being the performance of the vegetation as cover, composition, and productivity. Here, the grassland composition was as intended (the original upland mixture had established across each of the compartments) and persistent ground cover was provided. Productivity targets were deliberately not adopted at Selar as it had been found at the nearby Nant Helen Mine that grass yield was a function of weather conditions (rainfall and temperature) and varied significantly between years (Humphries et al., 1999), making productivity comparisons with any standard difficult to interpret. Whilst the stock carrying capacity was determined by grass productivity, it was found that the forage value produced was independent of yield and adequate (without additional fertiliser application) to support low intensity upland grazing by sheep.

Other metrics, such as the index-based Landscape Function Analysis (LFA) developed by Tongway and co-workers, have been applied in Australia and elsewhere in mine rehabilitation appraisals (Humphries, 2016). This approach appears not to have been tested in the UK, but whilst it has merits, it may not be applicable.

Operational Significance

The 37ha of upland acidic grassland appraised is the first tranche completing the 5-year statutory aftercare period at the Selar Mine. In the absence of a specified methodology and metric to determine the achievement of a beneficial and sustainable use, this early phase of rehabilitation provided an opportunity for both the Company and the Planning Authority to review and agree the available options. This was particularly helpful as not only a further 145ha of rehabilitated upland acidic grassland had been established in 2018 and was to be evaluated in 2023, it provided both parties with some assurance that the rehabilitation and aftercare methods being deployed are capable of delivering the targeted and a sustainable land use. Had this not been the case, then there was time to reappraise and adopt any necessary alternative approaches. Furthermore, the Company has two other mine sites where, in total, some 250 ha of the upland acidic grassland land use is to be established in the near future. Hence, the experience of this appraisal at the Selar Mine will help both the Company and the Planning Authority in future appraisals of the rehabilitation achieved.

Wider Significance

The use of the rehabilitated soil profile characteristics, as a means of predicting and evaluating rehabilitated disturbed land, rather than the direct monitoring of biomass production, has been proposed as an alternative (Burley, 1991; Burley and Bauer, 1993; Barnhisel and Hower, 1994; Humphries and McQuire, 1994; Humphries, 1995; Bia et al., 2016). The option of using soil profile characteristics is of relevance not only in the UK and USA, but also internationally. Significantly, it negates the need for reference sites, is not subject to vagrancies such as the variation in weather between years, is 'immediately' apparent, and does incur delays of years collecting data, besides being more cost-effective. In addition, it enables the need for remedial actions to be determined at the earliest opportunity (Barnhisel and Hower, 1994) and to avoid unnecessary rehabilitation work to achieve the land use and sustainability objectives (Humphries and McQuire, 1994). Given this, it is curious that the approach appears not to have been more widely adopted.

Conclusions

The evaluation of poorer quality land being discharged from aftercare planning obligations can be reliably based on the physical characteristics of the soil profile. The full profile should be described and evaluated by a qualified practitioner. A VESS like approach examining the upper soil layer may be appropriate in some circumstances, but there is a need for it to be by trained personnel and verified by full profile descriptions undertaken by a professional practitioner. The VESS approach has merit for screening/ad hoc purposes and for increasing site coverage at a reasonable cost.

The adoption of chemical testing alone is not a means of determining if the rehabilitated land is fit for purpose. If undertaken, they should be in concert with the determination of soil physical characteristics/condition. There is merit in determining organic matter and nitrogen mineralisation levels as well as P, K, Mg, and pH as a package.

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