LESSONS LEARNT FOR HARVESTING SEED FROM SEMI-NATURAL GRASSLANDS IN BIODIVERSITY MITIGATION AND ENHANCEMENT SCHEMES IN THE SOUTH WALES COALFIELD, UK[1]

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Abstract: Planning applications for surface coal mine sites in South Wales are progressively being scrutinised more in respect of biodiversity mitigation and enhancement schemes for sustainable mining. In the mid- to late-1990s a commitment to establishing an often undefined type of semi-natural grassland was sufficient. This progressed to the specification of the target type of grassland in the next decade. Recent applications are seeing the planning authority and the statutory advisers demanding details of how this will be achieved and the evidence that this is possible. Given that ratcheting of the demands is a recent experience, it is difficult for the mining companies to provide the evidence on demand in the absence of a knowledge base.

The availability of local seed is one of those details now being demanded. It is a particularly insidious topic if the information is not available (as it is the basis of any grassland re-establishment proposal), and without a satisfactory answer the proposal will fail and might prejudice the coal project as a whole. The applicant needs to have a primary dedicated resource and a back-up resource available, and the knowledge and ability to exploit these resources.

The State coal company, British Coal, in the 1980-90's commissioned a number of research programs. One of these was an in depth investigation in the seed harvesting of grassland and fen meadow vegetation in South Wales. The results of this unpublished investigation of the early 1990's are now germane. The objective of this paper is to set out the lessons learnt from this previous work for both the practitioner and regulator.

One of the findings was more than one harvest in any growing season will be required for the full range of species, and this might span the period from June to October in some cases. This has implications for the harvesting strategy, whether it is a one year seeding or multi-year seeding program, how the seed resource is harvested spatially, and cognisance of the year to year variation in viable seed production due to weather and insect damage. The recommendations suggested in this Case Study may be beneficial elsewhere where harvesting local seed is necessary for successful reclamation.

Additional Key Words: MG5 grassland, M24 fen meadow, seed ripening

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Introduction

Major developments, and minerals in particular, are seen as an opportunity to enact the UK's no-net-loss biodiversity driven policies whether this is de novo creation of semi-natural habitats, or the enhancement and the restoration of existing ones (e.g., Office of the Deputy Prime Minister, 2005; Department for Communities and Local Government, 2006; Her Majesty's Government, 2006; Welsh Assembly Government, 2009, 2011).

For grasslands, in the middle to late 1990s this manifested itself as a simple commitment in the planning consents for mineral extraction to establish a semi-natural vegetation type of no particular definition than generic typing (e.g., acid, neutral or calcareous). Where schemes from these times were enacted, and many were amended or later omitted, they typically used commercially grown seed and achieved grasslands with lower value and lack of resemblance to those aspired to by the regulator and conservation bodies. As a result pressure was increased to ensure later consents were more specific as to the grassland types required. In these consents specific reference was often to the National Vegetation Classification reference types (Rodwell, 1991, 1992). However this, in itself, did not provide the certainty in practice that the undertaking would be delivered owing to issues of a sufficient supply of seed at a time when needed, and of a community type typical and fit for local conditions, and sometimes a reliance on acceptance by the planning authorities that it was too difficult and not enforceable.

Given these experiences, in the case of suitable seed supplies, the regulators and conservation bodies are, in current applications, insisting that the availability of local suitable seed sources are identified and harvesting is detailed as evidence that proposed schemes can be enacted prior to the decision to grant planning consent by the mineral authority. Such demands are of relatively recent occurrence and could prejudice or delay some schemes where the mining companies have not prepared sufficiently and have little knowledge as to what is required.

The then UK State coal company, British Coal, in the early 1990's commissioned the author to investigate seed collection for the establishment of semi-natural grassland and related vegetation types in the South Wales coalfield (Bell and Humphries, 1992). The findings of this 20 year old study are germane to the recent demand for evidence in planning applications and the objective of this paper is to set out lessons learnt for both the practitioner and the regulator.

Seed Collection Study

Sites and Plant Communities

The seed collection study involved five grassland sites typical of the exposed coalfield in South Wales (Table 1). These were selected as having communities of a type identified in the habitat and species UK and Local Biodiversity Action (recovery and enhancement) programmes (as being of particular conservation importance) and of a type aspired to by the conservation bodies and planning authorities on restored surface coal mine sites. The study was carried in full in 1992 with repeat less intensive studies in 1993 at two of the five sites (Action Fields and Glyn-yr-henllan).

Table 1: Study Sites and Vegetation Types.

Site Name & UK Grid Ref.	**National Vegetation Classification Reference Types (dominant in bold)**	**Site Conditions & Area Harvested and Dates**
Bryntirion - SN588.085	**MG5**	120m AOD, SW aspect, gentle slope, 4ha, 2nd & 30th July 1992
Aberaman – SO019.005	**MG5**	110-120m AOD, gently slopes, 1-2ha, 7th & 31st July 1992
Glyn-yr-henllan – SN597.153	MG5/**M23**	150-180m AOD, SW aspect, sloping & uneven, 6ha, 27th & 28th July 1992, 7th July 1993
Action Fields – SN576.146	**MG5**/MG8	180-190m AOD, SW aspect, sloping, 2ha, 28th July 1992, 6th July 1993
Blaenclairch – SN873.050	**MG24**/M25/U5	120m AOD, W aspect, uneven, 7ha, 7th July & 5th August 1992

The botanical composition and conservation value of grasslands in the UK coalfields had been described by Humphries, et. al., (1991) and included the communities and species of importance and particular conservation value in the South Wales Region. This was used to identify the grassland types (Rodwell 1991, 1992) for the seed collection study.

Mesotrophic grassland - MG5 *Cynosurus cristatus – Centaurea nigra* meadow

This community was the dominant type at two sites, Bryntirion and Aberaman and occurred as a significant component at two others, Glyn-yr-henllan and Action Fields.

Mesotrophic MG5 grassland in the South Wales Region is now of a rare occurrence in the lowlands and lower parts of the valleys. In a comprehensive survey, only 56ha of this type were recorded (Blackstock, et. al., 1991) of which much may be in a modified or degraded state.

The grasslands at Bryntirion have a typical community composition (grasses - *Agrostis capillaries, Cynosurus cristatus, Anthoxantum odoratum, Holcus lanatus*; forbs - *Leontodon hispidus, Plantage lanceolata, Stachys officinalis, Rhinanthus minor*), albeit with a low abundance of *Festuca rubra* and the occurrence of some *Molinia caerulea* and *Luzula multiflora*. Notably it has *Carum verticillatum*, and *Sanguisorba officinalis,* both species of particular conservation value in these grasslands. The MG5 grasslands at Aberaman are typical of the broad community type (*Cynosurus cristatus*, *Agrostis caplillaris*, *Rhinanthus minor*), but lacked species of particular value, whereas that in two of the four fields at Glyn-yr-henllan (*C. cristatus, A. odoratum, H. lanatus*, *Trifolium repens*, *T. pratense*, *Lotus corniculatus*) and Action fields (*C. cristatus, A. odoratum, A. capillaries, H. lanatus, R. minor, Centaurea nigra, Leontodon autumnalis, P. lanceolata*) had *C. verticillatum* as a species of particular value.

Mesotrophic grassland – MG8 *Cynosurus cristatus – Caltha palustris* wet pasture

This community occurred only at Action Fields and in combination with the MG5 type, and then to a lesser extent and in association with locally wet areas. Typically, it had the grasses *Alopecurus geniculatus, A. pratensis* and *Agrostis stolonifera* and the forbs *Caltha palustris, Fillipendula ulmaria, Euphrasia nemorosa, Eleocharis palutris Dactylorhiza praetermissa, Lychnis flos-cuculi, Mentha aquatica, Ranunculus flammula, Senecio aquaticus* and *Triglochin palustris*. *C. verticillatum* and *Cirsium dissectum* were species of conservation value.

Typical MG8 grassland on any scale in the coalfields of South Wales is likely to be of particular rare occurrence owing to agricultural improvement (e.g., drainage).

Mire – M23 *Juncus effusus – Juncus acutiflorus – Galium palustre* rush pasture

This community only occurred at the Glyn-yr-henllan site in two of the four fields. Here, there were extensive areas of *Juncus effusus* and *J. acutiflorus* with *H. lanatus, A. odoratum, A. capillaruis*, a number of *Carex* species and the forbs *Gallium palustre*, *Senecio aquaticus, Ranunculus flammula*, *Lychnis flos-cuculi* and *Potentilla erecta*.

It is typical of poor soil drainage and un-intensive agricultural management. Whilst it is of widespread occurrence in South Wales it tends to be particularly species impoverished. The pastures at this site were relatively species rich with a range of rush and grassland species (e.g., *Nardus stricta* and *Festuca ovina*) and forb species of conservation value (*C. verticillatum* and *C. dissectum*)

Mire – M24 *Molinia caerulea – Cirsium dissectum* fen meadow

This community was only represented by the grasslands at Blaenclairch. The grasslands at this site are a particular good example of the classical type dominated by the grasses *Molinai caerulea, Agrostis capillaries, Anthoxanthum odoratum, Nardus stricta* and *Danthonia decumbens* and locally the sedges *Carex panicea, C. nigra, C. ovalis* and *C. echinata*. The grasslands are of high conservation value, having extensive stands of scarce species such as *Carum verticillatum, Cirsium dissectum, Genista tinctoria, Sanguisorba officinalis* and *Serratula tinctoria*.

Here, there was variation in composition between the five constituent fields with locally affinities to other NVC types (M16b – *Erica tetralix – Sphagnum compactum* wet heath and M25 – *Molinia caerulea – Potentilla erecta* mire). The grasslands in two of the five fields are largely a mosaic of these types and the M24 fen meadow.

M24 occurs widely, although of limited extent, in South Wales and is typically degraded through overgrazing and agricultural improvement of hill farms. It is the target of a number of national recovery programmes including EU funded agri-environmental schemes.

Seed Development

Plant species differ intrinsically in their timing of flowering and seed maturation during the growing seasons. To a lesser extent they may differ according to site (aspect) and weather conditions between years. In some grassland communities, particularly those of less intensive grazing and hay meadows, there can be a range of flowering and seed-set times influencing the number and timing of collections required to achieve a representative harvest. To demonstrate this for the purpose of determining the number of harvests required, the recording of six development stages (vegetative / flower buds visible / flowering / developing seeds / ripe seeds / seeds shed) was undertaken in 1992 at all five grasslands between beginning of July and the end of August.

Table 2: Number of Species and their Seed Development.

Sites	**Shed early July**	**Ripe seed early July**	**Ripe seed late July / early August**	**Ripe seed late August**	**Seed not developed by late August**
Bryntirion	2	18	13	9	6
Aberaman	0	16	5	6	2
Glyn-yr-henllan	2	23	15	6	6
Action Fields	5	22	16	12	9
Bleanclairch	1	23	9	6	10

Seed for most of the species present at all five sites (including the mesotrophic and acid grassland, and mire types) ripened between July and early August, although all had some species that flowered later and did not set seed until after August (Table 2). Most species showed similar stages of development throughout the five study sites. *Athoxanthum odoratum* and *Holcus lanatus* ripened later at Blaenclairch than other sites, probably because the fields had been grazed over the previous winter, whereas the others had not.

The development stage reached by the majority of the individuals in each of the species populations at the time of the surveys was synchronised. Some species like *Hypochoeris radicata, Leontodon hispidus, Senecio aquaticus* and *Potentilla erecta* had flowers at different stages of development on the same plant. Others, such as *Plantago lanceolata* and *Cerastium fontanum* had later phases of flowering after the most of the population had flowered.

Important species and those making up a significant part of the grassland vegetation types had ripe seed during the harvest periods in early and late July in 1992 and 1993. For example: the grasses *A. odoratum, Festuca ovina, Danthonia decumbens, H. lanatus, Agrostis capilaris,* *Cynosurus cristatus* and the forbs *Rhinanthus minor* and *Plantago lanceolata*, including species of conservation importance like *Cirsium dissectum* and *Carum verticillium*.

Notably, other important species flowered later and would not have been expected have been harvested. These included the grass *Molinia caerulea* and several forbs such as *Lotus corniculatus* and *Succisa pratensis*, and species of conservation importance *Genista tinctoria*, *Serratula tinctoria* and *Sanguisorba officinalis*.

In 1993, seed development both later and substantially less at both the two sites studied. At Action Fields only three species, *Caltha palustris*, *C. panacea* and *P. lanceolata* had demonstrative seed development by the end of June and in late August late flowering species like *Pulicaria dysentarica* and *C. nigra* showed no seed development at all. The same contrast to seed development in 1992, with the exception of good seed development in *C. verticillatum*, also occurred at Glyn-yr-hellan. Both grasslands displayed lush vegetative growth at the expense of flowering and a tendency of the grasses to lodge and shade out the interstitial forb species. This was attributed to the much wetter and cooler spring-summer of 1993.

Seed Harvesting

The study sites were harvested using a Emorsgate Seed Harvester in 1992 (early July and late July/early August) and 1993 (early July) following the site assessments of seed development and maturation.

The harvester was a tractor drawn and powered vacuum (suction) device which traversed the grasslands at a speed of 2 miles/hour. Seed was sucked into the harvester by six nozzles brushing the plants and travelling close to the ground. Large and medium size seeds were deposited in the collection chamber and very small seeds were collected in a fine mesh sock behind the exhaust fan at the rear of the harvester. Seed from each harvest occasion, each field and each grassland-mire type within a field was kept separate for drying, analysis and storage.

Seed collection using mechanical harvesters can only be used when the sward is relatively dry. Initially, it had been intended that harvests would take place fortnightly throughout the seed maturation calendar for the grasslands from early July till the end of August. This proved not to be possible in 1992 and 1993, owing to days lost through wet weather, particularly during August when seed collection had to be abandoned.

Harvesting by mechanical harvester was restricted to accessible parts of the grasslands. Steep slopes and complex micro-topography, along with wet and soft ground were limitations. At two sites, Glyn-yr-hellan and Action Fields, the first harvest was deliberately delayed by three weeks to allow ground conditions to improve.

The collected seed was air dried and sieved to remove chaff and facilitate drying. Following drying the seeds were stored in paper or hessian bags for sowing in the following year.

Seed Harvested

The total harvested material in 1992 was 168.4kg (934.4 litres) and the estimated seed harvest was 134.2kg from 21ha of grasslands.

The physiognomic composition of the grassland and mire was approximately estimated for the grasses, herbaceous dicotyledons (forbs), and sedges and rushes. Overall, the percent cover of these plant groups in the field were 55%, 37% and 20%, respectively. In contrast the seed samples were 22%, 58% and 20% suggesting a bias against the grasses and in favour of the forb and sedge-rush species.

The composition of the harvested seed material was estimated at the species level from small (222cm3) samples and the frequency of occurrence categorised using the DAFOR (dominant, abundant, frequent, occasional, rare) scale of abundance.

Whilst in broad terms the majority of species recorded as having ripe seed were harvested and had similar abundance to that in the field, some species were more abundant than expected and possibly over represented in the harvest, these were the grass *A. capillaries*, the sedges *C. ovalis* and *L. multiflora* and the forbs *R. minor, Hypochoeris radicata, L. hispidis, P. lanceolata* and *Rumex acetosa*. Others, although common in the field were less well represented, these were the grasses *A. odoratum, H. lanatus, C. cristatus,* and the forbs *P. erecta, T. repens, T. pratense, R. flammula, S. aquaticus* and *L. flos-cuculi*.

A few species were common in the fields and had ripe seed, but were not harvested; these were the grass *Dactlis glomerata*, the sedges *C. nigra* and *C. echinata* and the forb *L. corniculatus*.

Three prime reasons for the harvest resulting in lower seed yields than expected for these species from the abundance in the field were identified during the study. For in species like:

- *C. cristatus, D. glomerata, Alopercurus* species, several sedge, rush, and clover species the seed or fruit was held tightly in the flower head despite being ripe. Others like *L. corniculatus* had seed held within pods and protected from the harvester mechanism
- *P. erecta, R. flammula* and *S. aquaticus* were abundant in the field and flowering, but displayed a wide range in development stages. Hence, lack of flowering and seed ripening synchronisation resulting in lower seed yields
- *A. odoratum, H, lanatus* and *L. flos-cuculi* appeared to readily and quickly shed a proportion of the seed between the assessment and the harvest

For others, *M. caerulea, Succisa pratensis, C. nigra* and *Leontodon autumnalis,* no ripe seed had yet formed at the August harvests.

The poor seed crop in 1993 meant that only one harvest was attempted at the two sites, and the only fields 1 and 3 and 1 and 5 warranted harvesting at Action Fields and Glyn-yr-hellan respectively. At Action Fields, despite the effect of the wet weather, the seed yield was similar with 6.9kg in 1993 compared to 7.8kg for the same two fields in 1992. In contrast the seed yield for the two fields was markedly lower (20%) at Glyn-yr-hellan with 10kg collected in 1993 compared to 49.4kg in 1992.

Potential for Establishing Grassland Types

The seed collected from the individual harvests, grassland and mire types and sites provides the prospect of re-establishing these plant communities. The use of some of this seed for this purpose at a restored site and its development as grassland communities has been previously reported (Humphries and Benyon, 1999).

The issue in this paper is whether the seed collected had the potential to recreate the target grassland and mire types. This is simply whether the composition of the banked seed was representative of the community types in terms of the *constant* species (core and characteristic for community type) and species of importance (high intrinsic conservation value). The significance of these two categories is that the former are required to have a defined and reference grassland or mire community such as MG5 and M24 and the latter are required to give the reference community the status of being of conservation importance.

When the composition and the proportion of the species in the collected seed are compared with the essential elements of the botanical composition of the communities it is evident that the 1992 harvest lacked some of the constant species and species of conservation interest. This was the case in all vegetation types harvested (Tables 3 and 4).

The grass and forb composition of the seed collected (including the over- and under-represented species) would facilitate the establishment of MG5 grassland similar to the reference type. The balance in relative abundance of species would 'adjust' over time under normal agricultural management as pasture or hay meadow to become more typical of local types as demonstrated by Humphries and Benyon (1999). The 'absent' species are not critical to this grassland type, but could be introduced by means of selective harvesting if necessary.

The seed collected from the M23 rush pasture would facilitate enhancement and re-establishment of this community type. Seed of species like *L. corniculatus* could be collected and introduced on an individual basis. Similarly, the seed collected from the M24 mire had the basis for this type of plant community, although one key constant species (*M. caerulea*) was notably absent (owing to the later ripening of this species). The missing sedge species are likely to require selective harvesting by other (probably hand) methods owing to the plant's flower/seed architecture. These species are only of importance for the sedge-lawn community variants.

For the species of high conservation importance, only *C. verticillatum* was well represented in the seed harvested. *C. verticillatum* is a characteristic species of mires and grassland in western England and Wales, where proximity to the Atlantic has climatic influences on plant communities. Enhancement and protection of such vegetation communities will be a key consideration by the conservation bodies. In such circumstances the re-establishment of this species and the regionally endemic 'whorled caraway' (*Carum verticillatum)* grasslands (MG5 & MG23) and mires (M24) is likely given its ease of harvest and the success of reintroduction (see Humphries and Benyon, 1999).

Table 3: Relative Seed Yield of Constant Species in Donor MG5 and MG23 Grassland and M24 Mire.

MG5	M23	M24
Agrostis capillaries		**Agrostis capillaris**
Anthoxanthum odoratum	*Anthoxanthum odoratum*	*Anthoxanthum odoratum*
Dactylis glomerata		
Plantago lanceolata		
Centaurea nigra		
Rhinanthus minor		
Rumex acetosa		
Holcus lanatus	*Holcus lanatus*	
Trifolium pratense		
Ranunculus acris		
Achillea millefolium		
Hypochoeris radicata		
	Carex ovalis	**Carex ovalis**
	Lotus corniculatus	
	Trifolium repens	
	Cynosarus cristatus	
	Festuca ovina	
	Juncus acutiflorus	
	Carex panacea	Carex panicea
	Nardus stricta	Nardus stricta
		Molinia caeruea
		Potentilla erecta
		Luzula multiflora
		Danthonia decumbens
		Carex nigra
		Carex echinata
Carum verticillatum	Carum verticillatum	Carum verticillatum

Key: Emboldened species = over represented. Normal type face = similar abundance. Italic = under represented Underlined = very rare or absent.

Table 4: Relative Seed Yield of Species of Importance in Donor MG5 & MG23 Grassland and M24 Mire.

MG5	M23	M24
Carum verticillatum	Carum verticillatum	Carum verticillatum
	Cirsium dissectum	Cirsium dissectum
Sanguisorba officinalis		Sanguisorba officinalis
		Genista tinctoria
		Serratula tinctoria
		Succisa pratensis

Key: Emboldened species = over represented. Normal type face = similar abundance. Italic = under represented. Underlined = very rare or absent

The other species of high importance were of too low frequency of occurrence (e.g., *G. tinctoria*), the seed was not conducive to being harvested by the machine (e.g., *C. dissectum*) or seed development was after the harvest period (e.g., *S. pratensis*). For these species different harvesting methods (probably relying on targeted and timely (hand) collections) would be needed for the successful introduction of these species.

Whilst the sowing of the 1992 seed harvest would have resulted in broadly similar plant communities as the reference types, it is self evident from the limited species collected that the poor seed harvest in 1993 would not have.

Harvest Method and Seed Collected

The above interpretation assumes that the harvester and harvesting technique used was passive in determining the seed collected. The mechanical influence of the harvester was investigated two ways at the contrasting sites of Bryntirion and Aberdare (both MG5 grasslands), and Bleanclairch (M24 mire). Firstly, by recording the change in seed developmental stages (see Table 2 above) between pre- and post-harvest in five 2 x 2m quadrats at each site, and secondly by comparing the number of seeds on a sample of between 25 and 50 plants per species between pre- and post-harvest.

Changes in Developmental Stage (developing, ripe, dehisced seed). Overall, there was a proportionate decrease in ripe seed and increase in dehisced seed indicating that the ripe seed was being effectively harvested by the machine. The overall efficiency of removing ripe seed was between 20-40% of the standing crop.

The grass *D. decumbens* and the forbs *L. hispidus*, *P. lanceolata, Ranunculus acris*, *R. minor* and *R. acetosa* (all being relatively over represented in the seed collections) showed a large change (>40%) indicating that the harvester was particularly effective in their respect. The grasses *A. capilaris, C. cristatus, N. stricta*, the rush *J. bufonius* and the sedges *C. nigra* and *Luzula multiflora*, and the forb *C. verticillatum* had poor rates of harvest (<20%). The lack of change in the rush *Juncus acutiflorus* indicated it was not being harvested.

These findings for *A. capilaris, C. cristatus* and *C. verticillatum* are curious given that they were assessed to be over-represented in the collected seed. This, on examination of the seed collected, was explained by the large quantity of unripe seed collected by the harvester. Unripe seed for the grasses *A. odoratum, N. stricta* and the forbs *C. verticillatum, P. erecta* and *R. minor* were also a component of the collected seed.

Changes in Number of Seed on Plants. Absolute counts were only practicable for the larger seeded species such as the sedges, some grasses and forbs like *N. stricta* and *P. erecta*. Where seed were small, as in *A. capillaries*, or in capsules, as in *L. corniculatus*, the seed to the nearest 'ten' in number was estimated or the number of capsules counted (as a surrogate for seed number). The seed counts were subjected to paired sample *t*-tests for each species recorded.

Eight of the 15 species recorded, the grasses *A. capilaris, A. odoratum, N. stricta*, the sedges *C. echinata, C. nigra, L. multiflora*, and the forbs *P. lanceolata*, and *R. minor*, showed significant difference (p = <0.1) between pre- and post- harvest seed numbers. For the other 7 species, the grasses *C. cristatus, D. glomerata, H. lanatus*, the sedges *C. ovalis* and *C. panacea*, the rush *J. conglomeratus* and the forb *P. erecta*, no significant difference was detected suggesting that little seed of these species was being collected by the harvester.

The two investigations independently demonstrated the harvester used was not passive for all species and that harvesting technique can, as would be expected, influence the spectrum and proportion of seed collected.

Lessons Learnt

The seed collection study carried out in the South Wales coalfields is useful and relevant in providing a series of practical lessons for practitioners and regulators can be drawn from the findings and experiences during the course of this study.

Two prime lessons for practitioners stand out. These are, 1) the importance of detail preparation in sourcing and ensuring sufficient quantity of the required seed, and 2) flexibility and responsiveness to weather conditions and seed ripening in field conditions. These form the framework for the following guidance:

Need for Seed-Burden Surveys. Whilst it is self-evident, it seems rarely that pre-harvest surveys and mapping of species composition and seed development are undertaken in practice with the time of harvesting being determined by other non-related factors (for example the availability of labour). Without the survey it is not possible to determine the seed yield potential of a site, an effective programme for collection of constituent species, likely community type arising from the collection, and the weed and alien species content that might preclude the site being used.

Pre-harvest surveys and harvesting programmes are essential. These should be detailed at the field scale, and include spatial variation and other limitations to collection (e.g., accessibility due to gradient, patterned ground and ground conditions) which may also determine the most suitable method of collection (see Robinson (2001) for range of methods).

The surveys should embrace both the year of harvesting and the preceding year, as the latter will indicate any prior management measures required (e.g., the cessation of grazing and control of weed species).

Need for Multiple Harvests. The data provided in this study demonstrated that a single harvest would not provide the full range of species required to establish either of the four target grassland-mire types. It is not infrequent that seed collection schemes rely on a single collection and this alone can explain previous failures in achieving the target communities on development sites. Multiple harvests spanning the full phenological spectrum of seed ripening are needed. For the communities studied this would involve harvests from mid July to late August or early September.

The study also suggests there may be year to year variation in seed set amongst species and access to sites owing to unfavourable weather conditions, as well as wet weather and poor ground conditions physically limiting the deployment of some harvesting methods. For this reason it is unlikely that a single year's collection, even if there were multiple harvests, would be a success.

Multiple harvests (i.e., successive years and across the seed development season) will be required for a reasonable degree of certainty of collecting the range of seed required in many proposed schemes. Hence, contingency planning should be part of the seed collection and seeding programme.

Need for Adequate Donor Sites. Again this is self-evident from the perspective of the necessary grassland type and species composition. Such sites need to be identified and accessed, and in many cases will need to be managed for seed collection purposes. This could be a tall order in many parts of the UK given their scarcity and degradation through either agricultural improvement or neglect. Where mining companies have in their control or opportunity for access, it will be important that they secure such sources of seed at least on the onset of the mine programme and preferably beforehand. There may be opportunities whereby seed collection actually facilitates the management of areas. For example, the collection of *Calluna vulgaris* seed from Cannock Chase enabled critical management of this near moribund over-mature heathland whilst providing the Author with seed for the restoration of the Bleak House surface coal mine site in Staffordshire.

Foresight of supply of seed is a factor for debate with the planning authorities, particularly where mining operations might be relying on the same source during the same period causing competition between sites. There is also the issue that seed collection is interfering with the regenerative dynamics of the donor site in that seed is being removed, and potentially in a disproportionate way thereby potentially inhibiting the maintenance of the community. Hence, some grasslands and mires will need to be rested. Where such demands are being made, monitoring should be undertaken to inform of any changes.

Whilst seed yield is likely to be subject to wide variations between and within sites and grassland-mire types, it is indicative that several harvests will be needed to supply sufficient viable seed to initiate the target communities. For example, overall about 130kg of seed was collected in 1992 from about 20ha of grassland-mire giving a yield of 6.5kg/ha. This equated to about 1.3kg grasses, 3.9kg forbs and 1.3kg sedges and rushes. In terms of donor area required for typical sowing rates (using the harvest data collected in 1992):

Grasses @ 10kg/ha = 8ha donor for each 1ha to be sown or 8 annual harvests for each 1ha to be sown

Forbs @ 5kg/ha = 1.3ha for each 1ha to be sown or 2 annual harvests for each 1ha to be sown

Sedges & Rushes @ 3 kg/ha = 2.3ha for each 1ha to be sown or 3 annual harvests for each 1ha to be sown

However, the above is likely to be too optimistic as seed viability is likely to be low and additional collected seed will be required. Viability is possibly 10% or less in many natural stands thereby increasing the seed requirement (i.e., the number harvests or area of donor land needed should be increased by a factor of 10). Because of this seed viability testing is important and should be undertaken where large areas are to be seeded by collected seed or where more than one site relies on the same site.

Need for Good Seed Storage and Control of Pests. The above emphasises the value of collected seed and the need for good seed preparation and storage after collection. Infestation by mildew and the white-shouldered house moth (*Endrosis sarcitrella*), both reduced the viability of the seed collected in 1992, required careful drying and the need for insecticide treatment.

Need for More Than One Method of Collection. There is a range of collection methods and tools available (Robinson, 2001). The above lessons are applicable to other methods of seed collection including the 'hay-spreading' technique (Jones, et. al., 1995), which is often deployed as a simpler alternative. This technique has the same limitations of donor composition, timing of collection and number of cuts taken, application rates and yields of viable seed (University of Reading, 2005).

As demonstrated by this study, the collection of seed by one method alone may not, for a range of reasons, provide for all the community constituent species and site conditions. The method and its application in the field and for the objective of the exercise need to be determined at the seed collection planning stage and the collection supplemented with additional seed from other sources or collection methods as appropriate.

For species of particular value or those of rare occurrence in the community targeted collection by hand or otherwise might be required. This might suit late flowering and seed setting species like *S. pratensis,* and others like *C. nigra* which are prone to weevil infestation and unaffected seed heads identified in the field.

Conclusions

The seed collection study carried out in the South Wales coalfields in the early 1990s is highly relevant to today's demands for evidence that promised schemes can be delivered. Importantly, it provides a series of practical lessons for practitioners and regulators alike, and highlights the need for informed and detailed planning, a high degree of flexibility and responsiveness, and the provision of sufficient contingencies for success to have a high degree of certainty.

The commitment to regenerating semi-natural grassland and mire communities from harvested seed harvesting could be considered by the unaware to be simple operation of collecting the standing crop. The study described here demonstrates that this is not the case and there is a need for careful and informed preplanning and a realistic and achievable programme of collection spanning the seed ripening seasons and probably over a number of years.

Seed resource availability and 'depletion' may also be important factors for consideration and need planning for where one resource is relied upon for several sites or large areas.

The study provides the practical basis for seed collection programmes and is tangible evidence for the planning authorities and regulators as to the technical basis and probability of success of proposed schemes. The recommendations suggested in this Case Study may be beneficial elsewhere where harvesting local seed is necessary for successful reclamation.

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