

Going to waste? The potential impacts on nature conservation and cultural heritage from resource recovery on former mineral extraction sites in England and Wales

Danielle Sinnett

Centre for Sustainable Planning and Environments, University of the West of England,
Bristol, UK, BS16 1QY.

danielle.sinnett@uwe.ac.uk

Abstract

Scarcity of mineral supplies globally means that there is an international effort to examine the potential to extract resources from mine wastes. Such sites are often perceived as degraded and of little value. However, many sites are protected for their ecological, geological or historical significance. This paper examines the scale of the association between these designations and former mineral extraction sites in England and Wales. Around 69,000 mines (44%) are co-located with some form of designation; ranging from 27% of sand and gravel quarries in Wales to 84% of metal mines in England. Some designations are coincidental to mining and may benefit from resource recovery combined with remediation activities, others exist due to previous mining activities and may be adversely affected. This creates a tension in the long-term management of former mineral extraction, which should be considered when assessing the potential for, and desirability of, resource recovery.

Keywords

Contaminated land, brownfield land, land reclamation, environmental planning, ecosystem services

Introduction

The exploitation of minerals globally has been a key driver in technological advancement providing the materials for economic, social and cultural development. However, most extractive processes result in areas of land that are visually unattractive and devoid of vegetation. Such sites often have physiochemical properties that are unable to support plant growth or are toxic to ecosystem and human health (Bradshaw, 2000). Many countries bear the scars of mineral extraction through a legacy of both abandoned and restored mines and quarries. In terms of abandoned mines, for example, the USA has in excess of 600,000 sites, Canada 10,100, the UK, 11,700, South Africa 8000 and Australia 32,600 (Worrall et al., 2009). Member states of the European Union are now required to develop inventories of their wastes from previous mining activities that pose a risk to people and the environment (Directive 2006/21/EC), and include measures to manage the risks (Bellenfant et al., 2013). There is also a diminishing supply of resources such as metals in many countries, for example, the European Union have identified 26 minerals that have high economic importance, of which fourteen are seen as ‘critical’ due to their high supply risk (Hennebel et al., 2015). This has resulted in a growing interest in the opportunities for recovering resources from these wastes (e.g. Bellenfant et al., 2013; Crane et al., 2017; Sapsford, Cleall and Harbottle, 2017), which may increase the security of supply of metals and reduce the need for new mines (Dunbar, 2017). In addition, the land resource occupied by former mineral extraction sites could be made available for other uses; in England, many such sites are allocated for housing and commercial development (Sinnott et al., 2014).

Resource recovery is also seen as an opportunity to mitigate some of the adverse impacts of mineral extraction (Bellenfant et al., 2013; Crane et al., 2017), including the loss of visual amenity and water pollution (Mayes et al., 2009; Svobodova et al., 2012). In Europe this has become increasingly relevant in the context of the Mine Waste Directive (2006/21/EC) which seeks to protect the environment and human health from pollution originating in mine wastes, and promotes the recovery of resources from mine waste (Bellenfant et al., 2013). Abandoned or unrestored sites, in particular, are assumed to have no inherent value without some form of intervention. The result is that sites with economically viable resources in their wastes are considered for further exploitation (e.g. for coal or metals), those causing pollution problems are remediated, and those in areas with high demand for new development are prioritised for new building, with little consideration of the benefits the sites may provide now or in the future. But former mineral extraction sites may possess rare habitats or geological features

(Batty, 2005; Davies, 2006; Tropek et al., 2012; Wilker et al., 2016) and can represent an important part in an area's cultural heritage (Howard, Kinsey and Carey, 2015).

Internationally, there is currently an emphasis on developing new technologies for resource recovery from mine wastes (e.g. Bellenfant et al., 2013; Hennebel et al., 2015; Dunbar, 2017; Sapsford, Cleall and Harbottle, 2017) with very little consideration of the extent of ecological and cultural resources on such sites and their collective role in a 'mining landscape'. To date, research has focussed on the development of technologies to extract resources from wastes, for example, using microbial processes (e.g. Johnson, 2014; Dunbar, 2017; Hennebel et al., 2015), with this being seen as welcome advancement to increase the security of supply, particularly of metals, reuse land and reduce environmental degradation, or on the benefits of restored or unrestored mines as individual sites or across relatively small geographical areas (e.g. Tropek et al., 2012; Blaen et al., 2016; Wilker et al., 2016). This study examines the ecological, geological and cultural value of former mineral extraction sites in England and Wales as a means of evaluating the opportunities and risks from resource recovery. This work builds on that in Crane et al. (2017), which examined the extent to which metal mines in Wales and the south west of England are protected for their ecological, geological and cultural value. To the author's knowledge this is the first time such a study has been conducted at a national scale, across a range of minerals and ages of mine, and it will deepen our understanding of the contribution such sites make to society. It will also inform the debate on the future of former mineral extraction sites and the feasibility of different options for the long-term management of abandoned, restored and newly exploited sites. Former extraction sites have first been categorised by the mineral type, and their associated restoration practices, after uses, land cover and ecological, geological and cultural designations are then presented and discussed.

Material and methods

The ecological, geological and cultural value of mineral extraction sites was assessed using spatial analysis. The co-location of mine sites with areas protected for their geological, ecological or cultural importance was then determined. Spatial data on the location of mineral extraction sites from the British Geological Survey BRITPITS database (Figure 1) was used with data for main geological, ecological and cultural designations (e.g. Sites of Special Scientific Interest (SSSIs), Areas of Outstanding Natural Beauty (AONBs), and Scheduled Monuments) in England and Wales (Table 1).

[Insert Figure 1 near here]

[Insert Table 1 near here]

These designations were selected as they meet at least one of the following criteria: they are ‘specified’ ecological receptors under Part 2A of the Environmental Protection Act (1990) (DEFRA, 2012) and therefore should be protected from pollution from mine wastes, they are have been reported to be associated with past mining activity, and there are spatial data available for them. The split between geological and ecological, and cultural designations is arbitrary in some cases. Some designations have a clear basis in nature conservation (e.g. Local Nature Reserves (LNRs), Special Areas of Conservation (SACs)) or heritage (e.g. Scheduled Monuments) whereas others are more nuanced (e.g. National Parks). The decision was taken for cultural designations to include those where landscape and/or recreation as opposed to wildlife conservation is a primary objective (e.g. AONBs, National Parks) (Gaston et al., 2006).

The BRITPITS database details all known mine locations in Great Britain as point data categorised by the commodity (e.g. coal, copper, lead, gravel), type of mine (e.g. underground, open pit), status (e.g. active, ceased) geological age (e.g. Carboniferous, Permian), lithostrat (e.g. Alluvium, West Maria Lode) as well as address and operator information. Co-ordinates are for the location of the open cast mine or entrance to the underground mine (tolerance of 5 m) (Cameron, 2012). There are around 170,000 entries in the complete database, but there is duplication where the same mine has been exploited for multiple commodities. Commodities have been grouped into broad mineral groups (Department of the Environment, 2000) but are discussed by individual commodity when appropriate. These groups are: *Sand, gravel* (e.g. sand and gravel, silica sand, silica rock, sand); *Igneous rock, sandstone; Chalk, dolomite, limestone; Clays* (e.g. ball clay, fireclay, clay, china clay, slate); *Anhydrite, gypsum, salt; Coal; Iron Ore;* and *Vein minerals* (metals including arsenic, copper, gold, lead, silver, tin and zinc, as well as barytes, calcite, and fluorspar).

The analysis was carried out in ArcMap 10.1. The data were first limited to those that were mine locations (as opposed to associated infrastructure such as rail depots and wharfs) and those that were non-active (ceased, inactive, dormant and historic). This resulted in 128,337 non-active mines in England and 27,124 in Wales. The spatial joining function in ArcMap was used to identify which mine sites are co-located with the geological, ecological and

cultural designations from Natural England, Historic England or Natural Resources Wales (Table 1; Figure 2). Here, the spatial data for each designation was ‘joined’ onto the spatial data for the mines, so that each mine that fell within the boundary of a designation included the attributes (e.g. name, size, boundary) of that designation. For example, the row containing the attributes of an individual mine (e.g. commodity, type of mine) now contained the attributes of every designation that this mine fell within (e.g. SSSI, National Park).

[Insert Figure 2 near here]

Mines have been left abandoned or restored to, most commonly, agriculture, amenity or forestry. The land cover at each mine location was also analysed as a way of examining the dominant vegetation types associated with mineral extraction. Again the spatial joining function was used to assign the land cover to each mine from the 25m Land Cover Map 2007.

The spatial analysis provided a broad picture of the types of designations associated with the mines. Evidence from restoration policy, guidance and research was then used to examine the potential impacts of resource recovery on nature conservation and cultural heritage on mineral extraction sites in England and Wales.

Results and discussion

Co-location of mine sites with environmental designations

Looking first at the overall extent to which mine sites are co-located with ecological, geological and cultural designations, Table 2 demonstrates that over half the sites exploited for *Igneous rock, sandstone* (52.9%); *Chalk, dolomite, limestone* (58.7%); and *Vein minerals* (84%) in England are co-located with some form of designation. At least a quarter of all other mineral types in England and Wales are co-located with some form of designation.

[Insert Table 2 near here]

Generally, the proportion of mines co-located with designations is greater in England than in Wales and there is variation between the mineral types. In particular, 84% of *Vein mineral* sites are co-located with more than one designation in England but only 51% in Wales. Whereas around 20% of *Sand, gravel* quarries across England and Wales have some form of co-location.

Looking specifically at the type of designation co-located with mineral extraction some clear patterns are present (Table 3). For ecological/geological designations the most common is ‘priority habitats’, and this may explain the greater overall co-location observed in England,

because these data were not available for Wales. Here all types of mineral, with the exception of *Sand, gravel*, had more than 18% co-location with priority habitats. Although not a statutory designation, these habitats should be protected and enhanced as part of the planning process. Their co-location suggests that these mines are either already contributing to these habitats, for example as a result of restoration, or that opportunities exist to create these habitats during any restoration of abandoned sites, or during ongoing management. The Royal Society for the Protection of Birds have highlighted the opportunity for mineral extraction sites to provide connectivity and enhancement of priority habitats, by identifying 55,794 ha on 1100 sites undergoing mineral extraction in 2006 (Davies, 2006).

[Insert Table 3 near here]

More than 10% of *Igneous rock, sandstone; Clays; Coal and Vein mineral* sites in Wales and *Iron ore* sites in England are co-located with Ancient Woodlands. These are likely to be older, smaller sites and the Ancient Woodland status incidental to the mining activity. In fact, for some mineral types (e.g. *Coal and Vein minerals*) the mining activity may be posing a risk to these designations due to toxicity of any waste materials still present (Milton, Johnson and Cooke, 2002).

The only type of mineral extraction with a substantial proportion of sites co-located with ecological designations is *Vein minerals*. More than 20% and 13% of such sites are co-located with SSSIs and (p)SACs respectively in England and Wales, and 13% of (p)SPAs in England. Many metal mines are abandoned as the extraction took place prior to any legislation enforcing restoration and their wastes are common features of mining landscapes. Indeed the co-location found here is predominantly with SACs and SSSIs in the lead mining areas of the Pennines and North Wales and the tin-copper mines of Cornwall. These sites are well known for their important ecological and geological characteristics including mosses and lichens with evolved toxicity for elevated metal concentrations (Batty, 2005). Their importance is also recognised in the Calaminarian Grasslands priority habitat (BRIG, 2008) where 13% and 5% of *Vein mineral* sites are associated with this habitat in England and Wales respectively. Similarly, *Chalk, dolomite, limestone* quarries have a relatively high level of co-location with SSSIs, with older and smaller examples of these sites being colonised with orchids and gentians over several decades (Bradshaw and Chadwick, 1980; Lundholm and Richardson, 2010). Although the proportions are relatively low, the absolute number of *Sand, gravel*, and *Igneous rock, sandstone* mines co-located with ecological/geological

designations is substantial. For example, 1784 *Sand, gravel*, 2786 *Igneous rock, sandstone* and 2448 *Chalk, dolomite, limestone* quarries, and 674 *Vein mineral* sites are co-located with SSSIs. There is likely to be significant overlap between these SSSIs and the SAC/SPA designations as all terrestrial SACs and SPAs are also SSSIs. It is not possible from this high-level analysis to discern whether the designations are due to the mineral extraction or to any subsequent restoration, or indeed are coincidental to it, but Davies (2006) reported that over 600 SSSIs in England had been designated in closed quarries. Crane et al. (2017) reported that of the fourteen abandoned metal mine waste sites in England and Wales they examined that were SSSIs and SACs the designation was always directly related to the mining activity. It was often due to the presence of metal-tolerant bryophytes. Some indication may be gained through an inspection of the co-location with Open Mosaic Habitats on Previously Developed Land (Lush, Kirby and Shephard, 2013) which may provide some idea of the proportion of SSSIs designated due to the mining activity. In this case there are 73 *Sand, gravel*, 261 *Igneous rock, sandstone* and 396 *Chalk, dolomite, limestone* quarries, and 56 *Vein mineral* sites in England are co-located with both SSSIs and Open Mosaic Habitats (data not shown) suggesting that 5-16% of SSSIs on these mines may be due to the mining activity. Other mines may be co-located with a few very large designations in areas with significant mining activity, for example, Exmoor Heath SAC (10,000 ha) and Berwyn SSSI (24,000 ha).

Turning to cultural designations, very few mine sites were co-located with Country Parks, Scheduled Monuments or Park and Gardens (Table 3). In contrast, more than 10% of *Sand, gravel; Igneous rock, sandstone; Chalk, dolomite, limestone; Clays*, and *Vein mineral* mines are co-located with National Parks and AONBs in England and/or Wales (Table 3). This is not surprising as these are extremely large designations in many of the regions with a strong mining heritage; for example Peak District National Park (143,700 ha), Cornwall AONB (95,800 ha). Whilst not specifically awarded for their mining heritage these designations do recognise the cultural and industrial heritage of the area of which mining may be an important component (e.g. Cornwall AONB, 2011). However, although such landscapes are highly valued by the public (Swanwick, 2009; Howley, 2011), preference is often given to those that are perceived as ‘unspoilt’ or ‘natural’ (Damigos and Kaliampakos, 2003; Swanwick, 2009; Svobodova et al., 2012). This means that abandoned mines or other obvious signs of past mineral extraction may be felt to be degrading the designated area (English Heritage, 2008).

In Wales, substantial numbers of mine sites are co-located with Natural Resources Wales' Landscapes of Historic Interest (Table 3). Again, these designations recognise many facets of cultural and industrial heritage, including mining (Cadw et al., 2007). Only *Vein minerals* in England have a relatively large proportion of mines in World Heritage Sites (15%). These are primarily the tin-copper mines in the Cornwall and West Devon Mining Landscape World Heritage Site. There are also former coal mines in the Blaenavon Industrial Landscape World Heritage Site in South Wales and coal, iron, clay and limestone mines in Ironbridge Gorge World Heritage Site. These designations have been granted for the global significance of the technological advances exhibited in the areas.

The spatial analysis demonstrates that former mineral extraction sites have substantial ecological, geological and cultural value (some examples are shown in Figure 3) that should be considered alongside their potential for resource recovery or future uses. Although such designations would be considered when changes to the sites were proposed (e.g. through planning or remediation) this analysis demonstrates the extent of these associations at a national level and contributes to our understanding of the practical implications of resource recovery.

[Insert Figure 3 near here]

Restoration, land use and land cover

Many former mineral sites in England and Wales have been restored to a 'soft' end use (Figure 3). The Town and Country Planning (Minerals) Act 1981 sets out the requirement for a restoration strategy, which allows for three after uses: agriculture, forestry and amenity. Between 1988 and 2000 in England 36,610 ha of mineral sites were restored; 54% to agriculture, 6% to forestry, and 31% to amenity (Department of the Environment, 1994a, 2000). Again, there is substantial variation between the different mineral types. For example, restoration to agriculture varied between 42% on *Clays* to around 90% on *Iron ore* and *Vein mineral* sites (although these were relatively small areas at 115 ha and 179 ha respectively; Department of the Environment, 1994a, 2000). Proportions restored to forestry were relatively low at less than 5% on all types except *Igneous rock, sandstone* (13%) and *Coal* (8%). A substantial proportion were restored to amenity ranging from 5% on *Iron ore* to 43% on *Clays* (Department of the Environment, 1994a, 2000). No comparable data were available for Wales. The area of land restored to these different uses is in broad agreement with the land cover associated with the mine sites based on the spatial analysis (Table 4). Agriculture

generally relates to the *Arable and Horticulture*, and *Improved Grassland* land covers, although there will be some overlap in *Improved Grassland* with amenity use. Similarly, forestry relates to *Broadleaved Woodland* and *Coniferous Woodland* but there is likely to some overlap, particularly for the former, with amenity after-uses (Figure 3). The *Suburban* land cover is also likely to include some sites restored for amenity uses. The most common land covers were *Improved Grassland* across all mineral types in both England and Wales, ranging from 18% to 41% of mine sites. This is followed by *Arable and Horticulture* in England (12% to 34%) and *Broadleaved Woodland* in England and Wales (9% to 22%) and *Rough Grassland* in Wales (11 to 16%). *Sand, gravel*; and *Clays* in England are also associated with *Suburban* areas as are *Coal* sites in both countries. Centres of population have tended to develop in close proximity to these resources as they provide construction materials and energy.

[Insert Table 4 near here]

Restoration practice in England and Wales has primarily focussed on agriculture as an after use and, to a lesser extent, forestry and amenity (Davies, 2006). Although amenity use nominally included nature conservation the majority of sites have been restored to public open space, outdoor sports facilities and water sports facilities (in flooded open-cast pits). However, in recent years the importance of mineral sites for nature conservation has been recognised in both academic literature and policy (e.g. Batty, 2005; Tropek et al., 2012; Wilker et al., 2016). This, coupled with the realisation that an opportunity exists to use nature-based restoration to enhance existing habitats and the connectivity between them (Davies, 2006), has shaped restoration policy. This now explicitly includes the creation of new habitats as an after use along with agriculture, forestry and recreational activities (Department for Communities and Local Government, 2014). The focus on ‘soft’ end-uses for mineral extraction sites means that it is likely they are providing multiple benefits to people and nature depending on if, and how, they have been restored (Larondelle and Haase, 2012; Blaen, MacDonald and Bradbury, 2016; Wilker et al., 2016; Van Ree and van Beukering, 2016).

Limitations to the spatial analysis

There are a number of limitations to the spatial analysis. Crane et al. (2017) found that in some cases the location of mine ‘entrances’ as is reported in BRITPITS may be just outside the boundary of the designation. This is particularly important where the mine waste is the

subject of the designation, and on smaller designations such as SSSIs and Open Mosaic Habitats on Previously Developed Land. The high-level analysis presented here is therefore probably a conservative estimate of the designations linked to mining activity and detailed site-specific analysis would need to be undertaken before drawing any firm conclusions for individual sites. Some ecological and cultural designations have not been included in this study as no national level datasets are available and the impact of mine wastes on water quality and any downstream ecological receptors have not been considered (Mayes et al., 2009). In order to assess these it is likely that a range of stakeholders including those from the local area would need to be consulted (Howard, Kinsey and Carey, 2015; Selman, 2009).

Opportunities and risks from resource recovery

The restoration and land cover data, along with the ecological/geological and cultural designations associated with the mineral types are summarised in Table 5.

[Insert Table 5 near here]

This suggests that former mineral extraction sites provide opportunities for a range of benefits or ‘ecosystem services’ beyond the agricultural, forestry and amenity land uses. As well as providing places for physical activity, rest and recreation, food growing and timber production, these sites are directly contributing to the cultural heritage and nature conservation (Blaen, MacDonald and Bradbury, 2016). In some cases this is providing a contribution to the local economy, for example even before its World Heritage Site designation the Devon and Cornwall mining landscape generated an estimated £120 million per year to the local economy from visitors to mining attractions (Atlantic Consultants, 2003). Many are also providing important areas for nature conservation often in a wider landscape that due to development or agriculture have suffered from habitat loss or fragmentation (Davies, 2006; Lundholm and Richardson, 2010). Similarly, many are in or close to urban areas and provide an important component of the wider green infrastructure network. They also provide educational and research opportunities through the exposure or creation of unusual geology, and the habitats they support.

Therefore rather than the presumption that mineral extraction sites have no inherent value they have the potential to provide a range of benefits and this should be considered in their management. This applies to both unrestored, abandoned sites when their options for their long-term management are being considered, and for sites undergoing restoration now and in

the future. The opportunities to maximise the current or potential benefits should inform the debate on future management of such sites.

However, many sites, particularly those used for metal and coal extraction may be adversely affecting the natural environment and human health. For example, if acid mine waters or elevated metal concentrations are negatively impacting water quality, ecosystems or human health (Mayes et al., 2009). Similarly, unrestored sites or inappropriate restoration can be to the detriment of both nature conservation and landscape quality (Batty, 2005; English Heritage, 2008). These could result in the degradation of designations or landscapes (Damigos and Kaliampakos, 2003) not dependent on the mining heritage with negative consequences for the local economy, for example visitors to the Cornwall AONB have been estimated to generate £1.5 billion (Cornwall AONB, 2011). Where multiple receptors are at risk from the site this could strengthen the case for remediation. So, the restoration and management of former mine sites requires careful consideration and the priorities of a range of stakeholders need to be balanced (English Heritage, 2008; Selman, 2009; Swanwick, 2009; Howard, Kinsey and Carey, 2015).

[Insert Table 6 near here]

This study demonstrates that balancing these priorities is particularly challenging given the overlapping designations that exist on many of the sites (Table 6). As highlighted above some designations will be either wholly or partially dependent on the former mining activity whilst others will be coincidental to it. If resource recovery of metals, for example, can be combined with the remediation of sites that pose a risk to water quality or nearby ecological receptors should this be prioritised even if sensitive ecological or cultural designations are put at risk? Similarly, where there is significant demand for housing and former mineral sites can be used for development should this be prioritised even where they are providing a resource for nature conservation and amenity, perhaps greater than that provided by farmland? Currently, pollution from such sites is often managed with little or no disturbance to the waste, and restoration activities have left the waste relatively intact, with some regrading and possibly a cover material prior to planting. However, any resource recovery be it for metals, coal or making the land suitable for development is likely to result in significant disturbance to the waste and loss of habitats or cultural assets. As Table 6 demonstrates, these potentially contradictory designations are not found on the majority of sites, however, they are common

enough on *Igneous rock, sandstone; Chalk, dolomite, limestone;* and *Vein minerals* to warrant acknowledgement of the tensions associated with the management of former mineral sites.

Conclusions

Despite their dramatic impact on the environment, former sites of mineral extraction can result in areas of high ecological, geological, educational and cultural value. Many sites in England and Wales provide unique habitats, species assemblages, geology and heritage settings that have a direct positive contribution to nature conservation and the cultural heritage of the area. This demonstrates, first, that existing restored and abandoned sites need to be reconsidered in terms of the benefits that they provide and, second, that these sites and those where mineral extraction has been completed should be restored and managed sensitively to maximise the services and reduce their negative effects. Their contribution to nature conservation and cultural heritage means that mineral sites should be viewed as a resource and this balanced against other opportunities for resource recovery from the sites. This will require careful consideration of the biotic, abiotic, amenity and aesthetic characteristics of the site and its surrounding landscape with a range of stakeholders.

Acknowledgements

The study was carried out through the Natural Environment Research Council /Economic and Social Research Council-funded 'INSPIRE: IN Situ Processes In Resource Extraction from waste repositories' project (Grant Reference NE/L013916/1). I appreciate the helpful comments from Professor Katie Williams and two anonymous reviewers.

References

Atlantic Consultants. 2003. *Cornish Mining World Heritage Site Bid: Economic Impact Assessment Final Report*. Truro: Cornish Enterprise.

Batty, L C. 2005. "The Potential Importance of Mine Sites for biodiversity." *Mine Water and the Environment* 24: 101-103. doi: <https://doi.org/10.1007/s10230-005-0076-0>

Bellenfant, G., A-G. Guezennec, F. Bodénan, P. D'Hugues, and D. Cassard. 2013. "Re-Processing of Mining Waste: Combining Environmental Management and Metal Recovery?" *Mine Closure 2013*, September 2013, Cornwall, United Kingdom. pp. 571-582.

Blaen, P. J., M. A. MacDonald, and R. B. Bradbury. 2016. "Ecosystem Services Provided By a Former Gravel Extraction Site in the UK Under Two Contrasting Restoration States." *Conservation and Society* 14 (1): 48-56.

Bradshaw, A. 2000. "The Use of Natural Processes in Reclamation – Advantages and Difficulties." *Landscape and Urban Planning* 51: 89-100. doi: [https://doi.org/10.1016/S0169-2046\(00\)00099-2](https://doi.org/10.1016/S0169-2046(00)00099-2)

Bradshaw, A. D., and M. J. Chadwick. 1980. *The Restoration of Land: The Ecology and Reclamation of Derelict and Degraded Land*. Berkeley Los Angeles: University of California Press.

BRIG. 2008. "Calaminarian Grasslands." In *UK Biodiversity Action Plan Priority Habitat Descriptions*, edited by A Maddock. Peterborough: JNCC.

Cadw, Welsh Assembly Government, Countryside Council for Wales. 2007. "Caring for Historic Landscapes." http://cadw.gov.wales/docs/cadw/publications/Caring_for_Historic_Landscapes_EN_CY.pdf.

Cameron, D G. 2012. *Use Guide for the BRITPITS GIS Dataset*. Open Report OR/13/016. British Geological Survey.

Cornwall AONB. 2011. "Cornwall Area of Outstanding Natural Beauty: Safeguarding Our Landscape's Beauty & Benefits for Future Generations. Management Plan 2011-2016." <http://www.cornwallaonb.org.uk/managementplan/>.

Crane, R. A., D. E. Sinnett, P. J. Cleall, and D. J. Sapsford. 2017. "Physicochemical Composition of Wastes and Co-located Environmental Designations at Legacy Mine Sites in South West England and Wales: Implications on Resource Potential." *Resources, Conservation and Recycling*, 123, 117-134. doi: <http://dx.doi.org/10.1016/j.resconrec.2016.08.009>

Damigos, D., and D. Kaliampakos. 2003. "Assessing the Benefits of Reclaiming Urban Quarries: a CVM Analysis." *Landscape and Urban Planning* 64: 249-258. doi: [https://doi.org/10.1016/S0169-2046\(02\)00243-8](https://doi.org/10.1016/S0169-2046(02)00243-8).

Davies, A. M. 2006. *Nature After Minerals: How Mineral Site Restoration Can Benefit People and Wildlife*. Sandy, Bedfordshire: Royal Society for the Protection of Birds.

DEFRA. 2012. *Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance*. London: The Stationery Office.

Department of the Environment. 1989. *Mineral Planning Guidance 7: Reclamation of Mineral Workings*. London: Department of the Environment.

Department of the Environment. 1994a. *Survey of Mineral Land 1994*. London: Department of the Environment.

Department of the Environment. 1994b. *The Reclamation and Management of Metalliferous Mining Sites*. London: Department of the Environment.

Department of the Environment. 1996. *The Reclamation of Mineral Workings to Agriculture*. London: Department of the Environment.

Department of the Environment. 2000. *Survey of Mineral Land 2000*. London: Department of the Environment.

Dunbar, W.S. 2015. "Biotechnology and the mine of tomorrow." *Trends in Biotechnology* 35 (1): 79-89. doi: <http://dx.doi.org/10.1016/j.tibtech.2016.07.004>

English Heritage. 2008. *Mineral Extraction and the Historic Environment*. London: English Heritage.

Gaston, K. J., K. Charman, S. F. Jackson, P. R. Armsworth, A. Bonn, R. A. Briers, C. S. Q. Callaghan, et al. 2006. "The Ecological Effectiveness of Protected Areas: The United Kingdom." *Biological Conservation* 132: 76-87. doi: <https://doi.org/10.1016/j.biocon.2006.03.013>.

Hennebel, T., N. Boon, S. Maes, and M. Lenz. 2015. "Biotechnologies for critical raw material recovery from primary and secondary sources: R&D priorities and future perspectives". *New Biotechnology* 32 (1): 121-127. doi: <http://dx.doi.org/10.1016/j.nbt.2013.08.004>.

Howard, A. J., M. Kinsey, and C. Carey. 2015. "Preserving the Legacy of Historic Metal-Mining Industries in Light of the Water Framework Directive and Future Environmental Change in Mainland Britain: Challenges for the Heritage Community." *The Historic Environment: Policy & Practice* 6 (1): 3-15. doi: <https://doi.org/10.1179/1756750514Z.00000000061>.

- Howley, P. 2011. "Landscape Aesthetics: Assessing the General Publics' Preferences Towards Rural Landscapes." *Ecological Economics* 72: 161-169. doi: <https://doi.org/10.1016/j.ecolecon.2011.09.026>.
- Johnson, D. B. 2014. "Biomining - biotechnologies for extracting and recovering metals from ores and waste materials." *Current Opinion in Biotechnology* 30: 24-31. doi: <http://dx.doi.org/10.1016/j.copbio.2014.04.008>.
- Larondelle, N., and D. Haase. 2012. "Valuing Post-Mining Landscapes Using an Ecosystem Services Approach – An Example from Germany." *Ecological Indicators* 18: 567-574. doi: <https://doi.org/10.1016/j.ecolind.2012.01.008>.
- Lundholm, J. T., and P. J. Richardson. 2010. "Habitat Analogues for Reconciliation Ecology in Urban and Industrial Environments." *Journal of Applied Ecology* 47: 966-975. doi: [10.1111/j.1365-2664.2010.01857.x](https://doi.org/10.1111/j.1365-2664.2010.01857.x).
- Lush, M, P. Kirby, and P. Shephard. 2013. *Open Mosaic Habitat Survey Handbook*. Powys: exeGesIS SDM Ltd.
- Mayes, W. M., D. Johnston, H. A. B. Potter, and A. P. Jarvis. 2009. "A National Strategy for Identification, Prioritisation and Management of Pollution from Abandoned Non-Coal Mine Sites in England and Wales. I. Methodology Development and Initial Results." *Science of the Total Environment* 407: 5435-5447. doi: <https://doi.org/10.1016/j.scitotenv.2009.06.019>.
- Milton, A, M. S. Johnson, and J. A. Cooke. 2002. "Lead within Ecosystems on Metalliferous Mine Tailings in Wales and Ireland." *Science of The Total Environment* 299 (1-3): 177-190. doi: [https://doi.org/10.1016/S0048-9697\(02\)00253-X](https://doi.org/10.1016/S0048-9697(02)00253-X).
- Palumbo-Rose, B., and T. Colman. 2010. *The Nature of Waste Associated with Closed Mines in England and Wales*. British Geological Survey Open Report, OR/10/14. 98pp.
- Sapsford, D. J., P. Cleall, and M. Harbottle. 2017. In situ Resource Recovery from Waste Repositories: Exploring the Potential for Mobilization and Capture of Metals from Anthropogenic Ores. *Journal of Sustainable Metallurgy* 3(2), 375-392. doi: <http://dx.doi.org/10.1007/s40831-016-0102-4>.
- Selman, P. 2009. "Conservation Designations – Are They Fit for Purpose in the 21st Century?" *Land Use Policy* 26S: S142-S153. doi: <https://doi.org/10.1016/j.landusepol.2009.08.005>.

Sinnett, D., L. Carmichael, K. Williams, and P. Miner. 2014. *From wasted space to living spaces: The availability of brownfield land for housing development in England*. Technical Report. London: Campaign to Protect Rural England.

Svobodova, K., P. Sklenicka, K. Molnarova, and M. Salek. 2012. "Visual Preferences for Physical Attributes of Mining and Post-Mining Landscapes with Respect to the Sociodemographic Characteristics of Respondents." *Ecological Engineering* 43: 34-44. doi: <https://doi.org/10.1016/j.ecoleng.2011.08.007>.

Swanwick, C. 2009. "Society's Attitudes to and Preferences for Land and Landscape." *Land Use Policy* 26S: S62-S75. doi: <https://doi.org/10.1016/j.landusepol.2009.08.025>.

Tropek, R., T. Kadlec, M. Hejda, P. Kocarek, J. Skuhrovec, I. Malenovsky, S. Vodka, et al. 2012. "Technical Reclamations are Wasting the Conservation Potential of Post-Mining Sites. A Case Study of Black Coal Spoil Dumps." *Ecological Engineering* 43: 13-18. doi: <https://doi.org/10.1016/j.ecoleng.2011.10.010>.

Van Ree, C.C. D.F., and P. J. H. van Beukering. 2016. "Geosystem Services: A Concept in Support of Sustainable Development of the Subsurface." *Ecosystem Services* 20: 30-36. doi: <https://doi.org/10.1016/j.ecoser.2016.06.004>.

Wilker, J., K. Rusche, A. Benning, M. A. MacDonald, and P. Blaen. 2016. "Applying Ecosystem Benefit Valuation to Inform Quarry Restoration Planning." *Ecosystem Services* 20: 44-55. doi: <https://doi.org/10.1016/j.ecoser.2016.06.003>.

Worrall, R., D. Neil, D. Brereton, and D. Mulligan. 2009. "Towards a Sustainability Criteria and Indicators Framework for Legacy Mine Land." *Journal of Cleaner Production* 17 (16): 1426-1434. doi: <https://doi.org/10.1016/j.jclepro.2009.04.013>.

Table 1 Ecological and cultural designations included in the study

Designation	Summary and protection
<i>Geological and ecological</i>	
Local Nature Reserve (LNR)	Designated because of their nature conservation and/or geological interest under the National Parks and Access to the Countryside Act (1949) and the Natural Environment and Rural Communities Act (2006).
National Nature Reserve (NNR)	Sites of biological and geological interest with a strong research and educational remit, most are publicly accessible. Designated under the National Parks and Access to the Countryside Act (1949) but also receive protection under the Wildlife and Countryside Act (1981).
Site of Special Scientific Interest (SSSI)	Sites of biological and geological interest in the UK designated under the Wildlife and Countryside Act (1981). They often overlap with other designations including LNRs, NNRs, SACs and SPAs.
Special Area of Conservation (SAC)	Designated for their internationally significant habitats and species under the 1992 Habitats and Species Directive and the Conservation of Habitats and Species Regulations (2010). Together with SPAs they are known as Natura 2000 sites, all terrestrial SACs and SPAs are also SSSIs.
Special Protection Area (SPA)	Designated to protect threatened or engaged internationally significant bird species under the 1979 Birds Directive and the Conservation of Habitats and Species Regulations (2010).
Ancient Woodland (AW)	Defined as woodland that has been present since 1600AD. They take hundreds of years to develop and are irreplaceable. They are not protected by specific legislation, but under planning policy.
Priority Habitats (PH)	Published through the Natural Environment and Rural Communities Act (2006). They are not specifically protected but local planning policies should provide opportunities for their preservation and enhancement.
Open Mosaic Habitat on Previously Developed Land (OMH)	A relatively new priority habitat in acknowledgement of the ecological significance of many previously developed (brownfield) sites. An inventory of potential OMH sites has recently been published.
<i>Cultural</i>	
Area of Outstanding Natural Beauty (AONB)	Designated solely for their landscape qualities, including natural and cultural features, under the National Parks and Access to the Countryside Act (1949).
National Park (NP)	Also designated under the National Parks and Access to the Countryside Act (1949) their purpose is to promote education and recreation as well as conservation of landscape, wildlife and cultural heritage.
Country Park (CP)	Designated under the Countryside Act (1968) to provide access to the natural environment close to where people live,
Scheduled Monument (SM)	Designated under the Ancient Monuments and Archaeological Areas Act (1979) for their archaeological character.
World Heritage Site (WHS)	Designated by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) for their natural or cultural features of international significance.
Landscape of Historic Interest (LHI)	A non-statutory recognition of the special or outstanding historic character of landscapes in Wales. There is an expectation that they are considered as part of the planning process (Cadw et al., 2007).
Registered Parks and Gardens (PG)	Non-statutory designation of parks and gardens in England with a special historic interest, registration should be considered in the planning process.

Table 2 Total number (and percentage) of non-active mines co-located with designations in England (n=128,337) and Wales (n=27,124)

	Country	Total number of designations			
		0	1	2	1+
Sand and gravel	England	14470 (61.1)	5698 (24.1)	1848 (7.8)	9205 (38.9)
	Wales	1231 (73.4)	329 (19.6)	71 (4.2)	447 (26.6)
Igneous rock, sandstone	England	14795 (47.1)	9479 (30.2)	3885 (12.4)	16624 (52.9)
	Wales	5791 (69.0)	2154 (25.7)	324 (3.9)	2602 (31.0)
Chalk, dolomite, limestone	England	14492 (41.3)	13145 (37.4)	4699 (13.4)	20624 (58.7)
	Wales	1285 (55.5)	634 (27.4)	260 (11.2)	1032 (44.5)
Clays	England	15591 (66.8)	5402 (23.1)	1602 (6.9)	7745 (33.2)
	Wales	3160 (64.0)	1380 (28.0)	229 (4.6)	1775 (36.0)
Anhydrite, gypsum, salt	England	172 (60.4)	81 (28.4)	19 (6.7)	113 (39.6)
	Wales				
Coal	England	7296 (71.2)	1857 (18.1)	810 (7.9)	2951 (28.8)
	Wales	4696 (73.0)	1501 (23.3)	195 (3.0)	1733 (27.0)
Iron ore	England	1698 (60.0)	581 (20.5)	305 (10.8)	1134 (40.0)
	Wales	162 (70.7)	46 (20.1)	10 (4.4)	67 (29.3)
Vein minerals	England	301 (16.0)	695 (36.9)	412 (21.9)	1584 (84.0)
	Wales	1515 (48.8)	867 (27.9)	391 (12.6)	1592 (51.2)

Note: Many mines are exploited for multiple minerals so the total number of mines is not equal to the sum of the different types of mineral.

Sand and gravel=sand and gravel, silica sand, silica rock, sand; Clays=ball clay, fireclay, clay, china clay, slate; Coal=coal, peat, lignite;

Vein minerals=As, Ag, Au, Cu, Pb, Sn, Zn, barytes, calcite, fluorspar. Sources: mine data from BRITPITS Licence No. 2014/098BP ED

British Geological Survey © NERC. All rights reserved.

Table 3 Number (and percentage) of non-active mines co-located with ecological, geological and cultural designations in England (n=128,337) and Wales (n=27,124)

Mineral	Country	Total	Number (percentage) of mines co-located with													
			AW	SSSI	(p)SAC	(p)SPA	NNR	LNR	PH	OMH	NP	CP	AONB	SM	LHI	WHS
Sand and gravel	England	23675	533 (2.3)	1784 (7.5)	923 (3.9)	958 (4.0)	102 (0.4)	237 (1.0)	5622 (23.7)	852 (3.6)	1490 (6.3)	269 (1.1)	2785 (11.8)	72 (0.3)	56 (0.2)	358 (1.5)
	Wales	1678	80 (4.8)	109 (6.5)	62 (3.7)	15 (0.9)	5 (0.3)	5 (0.3)		11 (0.7)	226 (13.5)	8 (0.5)	96 (5.7)	11 (0.7)	301 (17.9)	5 (0.3)
Igneous rock, sandstone	England	31434	1832 (5.8)	2786 (8.9)	1989 (6.3)	1807 (5.8)	69 (0.2)	230 (0.7)	9897 (31.5)	1572 (5.0)	3909 (12.4)	181 (0.6)	5453 (17.3)	139 (0.4)	483 (1.5)	438 (1.4)
	Wales	8393	999 (11.9)	310 (3.7)	114 (1.4)	36 (0.4)	15 (0.2)	21 (0.3)		389 (4.6)	903 (10.8)	43 (0.5)	332 (4.0)	26 (0.3)	1191 (14.2)	51 (0.6)
Chalk, dolomite, limestone	England	35116	1420 (4.0)	2448 (7.0)	843 (2.4)	420 (1.2)	166 (0.5)	218 (0.6)	9455 (26.9)	1584 (4.5)	4367 (12.4)	98 (0.3)	10507 (29.9)	253 (0.7)	307 (0.9)	482 (1.4)
	Wales	2317	220 (9.5)	353 (15.2)	170 (7.3)	6 (0.3)	18 (0.8)	21 (0.9)		123 (5.3)	240 (10.4)	17 (0.7)	375 (16.2)	32 (1.4)	419 (18.1)	30 (1.3)
Clays	England	23336	615 (2.6)	680 (2.9)	250 (1.1)	306 (1.3)	33 (0.1)	135 (0.6)	4324 (18.5)	784 (3.4)	1105 (4.7)	89 (0.4)	2596 (11.1)	32 (0.1)	144 (0.6)	185 (0.8)
	Wales	4935	561 (11.4)	337 (6.8)	180 (3.6)	103 (2.1)	19 (0.4)	9 (0.2)		120 (2.4)	937 (19.0)	18 (0.4)	116 (2.4)	10 (0.2)	1055 (21.4)	10 (0.2)
Anhydrite, gypsum, salt	England	285	3 (1.1)	18 (6.3)	5 (1.8)	5 (1.8)	3 (1.1)	11 (3.9)	80 (28.1)	27 (9.5)	0 (0.0)	1 (0.4)	9 (3.2)	7 (2.5)	0 (0.0)	1 (0.4)
	Wales	0														
Coal	England	10247	291 (2.8)	217 (2.1)	170 (1.7)	158 (1.5)	10 (0.1)	145 (1.4)	2039 (19.9)	839 (8.2)	315 (3.1)	93 (0.9)	163 (1.6)	41 (0.4)	155 (1.5)	22 (0.2)
	Wales	6429	674 (10.5)	118 (1.8)	40 (0.6)	1 (0.0)	4 (0.1)	47 (0.7)		728 (11.3)	193 (3.0)	69 (1.1)	12 (0.2)	30 (0.5)	641 (10.0)	91 (1.4)
Iron ore	England	2832	340 (12.0)	114 (4.0)	92 (3.2)	56 (2.0)	2 (0.1)	37 (1.3)	638 (22.5)	138 (4.9)	230 (8.1)	14 (0.5)	311 (11.0)	76 (2.7)	5 (0.2)	20 (0.7)
	Wales	229	16 (7.0)	15 (6.6)	11 (4.8)	5 (2.2)	0 (0.0)	3 (1.3)		25 (10.9)	18 (7.9)	0 (0.0)	3 (1.3)	1 (0.4)	95 (41.5)	7 (3.1)
Vein minerals	England	1885	49 (2.6)	390 (20.7)	273 (14.5)	254 (13.5)	8 (0.4)	6 (0.3)	752 (39.9)	199 (10.6)	774 (41.1)	6 (0.3)	432 (22.9)	164 (8.7)	290 (15.4)	8 (0.4)
	Wales	3107	351 (11.3)	674 (21.7)	414 (13.3)	95 (3.1)	31 (1.0)	3 (0.1)		30 (1.0)	606 (19.5)	12 (0.4)	470 (15.1)	75 (2.4)	1159 (37.3)	0 (0.0)

Note: Many mines are exploited for multiple minerals so the total number of mines is not equal to the sum of the different types of mineral. Sand and gravel=sand and gravel, silica sand, silica rock, sand; Clays=ball clay, fireclay, clay, china clay, slate; Coal=coal, peat, lignite; Vein minerals=As, Ag, Au, Cu, Pb, Sn, Zn, barytes, calcite, fluorspar. Caution should be used when using these figures as not all mines are represented in BRITPITS and the point locations are not necessary in the same location as mine wastes. Sources: mine data from BRITPITS Licence No. 2014/098BP ED British Geological Survey © NERC. All rights reserved. Local Nature Reserve (LNR), National Nature Reserve (NNR), Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC), Special Protection Area (SPA), Ancient Woodland (AW), Priority Habitat (PH), Open Mosaic Habitat on Previously Developed Land (OMH), Area of Outstanding Natural Beauty (AONB), National Park (NP) and Country Park (CP) data for England © Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2016. Scheduled Monument and World Heritage Site data for England © Historic England 2016. Contains Ordnance Survey data © Crown copyright and database right 2016. The Historic England GIS Data contained in this material was obtained on 29th June 2015. The most publicly available up to date Historic England GIS Data can be obtained from HistoricEngland.org.uk. All other data © Natural Resources Wales copyright. Contains Ordnance Survey data © Crown copyright and database right 2016.

Table 4 Number (and percentage) of non-active mines co-located with different land cover in England (n=128,337) and Wales (n=27,124)

	Country	Broadleaved woodland	Coniferous woodland	Arable and horticulture	Improved grassland	Rough grassland	Acid grassland	Heather grassland	Suburban
Sand and gravel	England	3693 (15.6)	616 (2.6)	6274 (26.5)	5662 (23.9)	1127 (4.8)	147 (0.6)	292 (1.2)	3123 (13.2)
	Wales	169 (10.1)	61 (3.6)	162 (9.7)	693 (41.3)	269 (16.0)	106 (6.3)	35 (2.1)	86 (5.1)
Igneous rock, sandstone	England	5864 (18.7)	1358 (4.3)	4695 (14.9)	8425 (26.8)	1813 (5.8)	2365 (7.5)	1659 (5.3)	2514 (8.0)
	Wales	1341 (16.0)	513 (6.1)	493 (5.9)	2783 (33.2)	1162 (13.8)	993 (11.8)	229 (2.7)	514 (6.1)
Chalk, dolomite, limestone	England	5800 (16.5)	540 (1.5)	12017 (34.2)	9503 (27.1)	1991 (5.7)	1148 (3.3)	507 (1.4)	2049 (5.8)
	Wales	468 (20.2)	43 (1.9)	299 (12.9)	624 (26.9)	293 (12.6)	193 (8.3)	33 (1.4)	209 (9.0)
Clays	England	3293 (14.1)	456 (2.0)	7612 (32.6)	5449 (23.4)	808 (3.5)	297 (1.3)	122 (0.5)	2931 (12.6)
	Wales	852 (17.3)	369 (7.5)	299 (6.1)	1586 (32.1)	554 (11.2)	550 (11.1)	198 (4.0)	163 (3.3)
Anhydrite, gypsum, salt	England	62 (21.8)	6 (2.1)	81 (28.4)	59 (20.7)	21 (7.4)	1 (0.4)	0 (0.0)	15 (5.3)
	Wales								
Coal	England	945 (9.2)	323 (3.2)	1910 (18.6)	2456 (24.0)	623 (6.1)	412 (4.0)	520 (5.1)	1918 (18.7)
	Wales	1211 (18.8)	455 (7.1)	421 (6.5)	1469 (22.8)	1108 (17.2)	627 (9.8)	81 (1.3)	693 (10.8)
Iron ore	England	512 (18.1)	126 (4.4)	739 (26.1)	806 (28.5)	167 (5.9)	34 (1.2)	20 (0.7)	247 (8.7)
	Wales	29 (12.7)	21 (9.2)	9 (3.9)	43 (18.8)	41 (17.9)	31 (13.5)	5 (2.2)	25 (10.9)
Vein minerals	England	234 (12.4)	70 (3.7)	232 (12.3)	531 (28.2)	77 (4.1)	190 (10.1)	227 (12.0)	62 (3.3)
	Wales	369 (11.9)	389 (12.5)	293 (9.4)	644 (20.7)	411 (13.2)	467 (15.0)	169 (5.4)	75 (2.4)

Note: Fen, marsh and swamp, Montane habitats, Saltwater, Supra-littoral rock, Supra-littoral sediment, Littoral rock, Littoral sediment, Saltmarsh all <1%. Neutral grassland, Calcareous grassland, Inland rock all <5%. Heather, Bog, Freshwater, Urban all <10%. Sources: mine data from BRITPITS Licence No. 2014/098BP ED British Geological Survey © NERC. All rights reserved. Land Cover Map 2007, Great Britain 25m [TIFF geospatial data], Scale 1:250000, Tiles: GB, Updated: 18 July 2008, CEH, Using: EDINA Environment Digimap Service, <<http://digimap.edina.ac.uk>>, Downloaded: 2015-08-17 12:14:09.596.

Table 5 Summary of restoration, land cover and use, and designations associated with mineral extraction sites in England and Wales

	Type of mine, waste and impact of waste	Restoration and use	Association with ecological and cultural designations	Dominant land cover
Sand and gravel (E=WM, EM, EE, SE, N&E; W)	Open cast mining with shallow working. Overburden and fines. Often used in restoration. Droughty, stony, low pH, N & P deficient. Non-hazardous; visual impact prior to restoration.	Generally restored to some productive use. Progressive restoration common. Wet pits allowed to flood to become artificial lakes, with regrading and planting for amenity or nature conservation . Dry pits can have rapid colonisation to heathland. Agriculture (56%): Top soil cover and fertiliser; amenity or forestry (3%): Fertiliser, cultivation, grasses, legumes, trees. Amenity on both wet and dry pits (35%).	Co-located with SSSIs, SACs, SPAs, PHs incl. OMHs, NPs, AONBs . Around 20% co-located with some designation	Broadleaved woodland (16%; 10%), Arable and horticulture (27%; 10%), Improved grassland (24%; 41%).
Igneous rock, sandstone (E=N&W, NE; W=N&W)	Open cast mining. Variable amount of waste, often very little waste overburden. Oversize blocks and very fine particles. Low pH, P deficient. Non-hazardous; visual impact prior to restoration.	Progressive restoration difficult, little waste means restoration often restricted to quarry floor. Wet pits allowed to flood to become artificial lakes, with regrading and planting for amenity or nature conservation . Dry pits: Cultivate hard or consolidated surfaces, or blasting, regrading to provide benches, soil or organic amendment, fertiliser. Grasses, legumes, trees and shrubs. After-uses include agriculture (54%), forestry (13%) and amenity (20%).	Co-located with ancient woodlands, SSSIs, SACs, SPAs, PHs incl. OMHs, NPs, AONBs . Around 30% in England and 20% in Wales co-located with some form of designation.	Broadleaved woodland (19%; 16%), Arable and horticulture (15%; 6%), Improved grassland (27%; 33%).
Chalk, dolomite, limestone (E=EM, NE, NW, S&E, N&W; W=N&W)	Open cast mining with deep excavation. Variable amount of waste, often very little waste overburden. Used in restoration. High pH, stony, droughty, N (P, K on chalk) deficient, heavy textures, waterlogging and compaction. Non-hazardous; visual impact prior to restoration	Smaller, older quarries colonised, but can take 50 years. Important habitats : gentians, orchids and wildlife refuges. Progressive restoration difficult, little waste means restoration often restricted to quarry floor. Wet pits allowed to flood to become artificial lakes, with regrading and planting for amenity or nature conservation. Dry pits: Difficult to restore; cultivate hard or consolidated surfaces, or blasting, regrading to provide benches, incorporate fine material, soil or organic amendment, fertiliser. Grasses, legumes, trees and shrubs adapted for calcareous soils. After-uses include agriculture (62%), forestry (3%) and amenity (24%).	Co-located with ancient woodlands, SSSIs, SACs, PHs incl. OMHs, NPs, AONBs . Around 35% in England and 25% in Wales co-located with some form of designation.	Broadleaved woodland (17%; 20%), Arable and horticulture (34%; 13%), Improved grassland (27%; 27%).
Clays (E=SW, SE NW, NE, M; W=SW, M, NW)	Open cast with some underground mining. China clay : Coarse sand and rock waste; fine slurry. Slate : Large fragments, fines washed down. Clay : Overburden, clay and sand; relatively little waste. Low pH, droughty, nutrient deficient. Clays: heavy textures, waterlogging and compaction. Non-hazardous, visual impact of conical tips of china clay waste, slate waste tips.	China clay : Natural regeneration can take up to 100 years: sparse vegetation builds to full cover of grasses and shrubs; then heathland in exposed areas, acid oak woodland in less exposed areas. Slate : Some colonisation of moss and birch, more on quarry floors (e.g. scrub, acid grassland and acid oak woodland. Restoration includes remodelling to reduce visual impact, fertiliser and lime, revegetation e.g. grasses and legumes, woodland. If no fine material trees are the only option with a pocket of water absorbent material. After-uses include agriculture (42%), forestry (4%) and amenity (43%).	Co-located with ancient woodlands, PHs incl. OMHs, NPs, AONBs . Around 20% co-located with some form of designation.	Broadleaved woodland (14%; 17%), Arable and horticulture (33%; 6%), Improved grassland (23%; 32%).
Anhydrite, gypsum, salt (E=M, NW, SE)	Open cast : Temporary waste used in restoration. Underground : Very little waste. Non-hazardous.	Progressive restoration common and often effectively blended into surrounding landscape. Restored to agriculture (81%), forestry (0%) and amenity (8%).	Co-located with PHs . Around 27% in England co-located with some form of ecological designation.	Broadleaved woodland (22%), Arable and horticulture (28%), Improved grassland (21%).
Coal (E=NE, NW, M; W=S)	Underground : very large tips, especially post-1950s. Shaly material, heavy textures. Open cast : 90% used in restoration. Sandy, pebbly to dense clays, fine to coarse texture. Low pH, droughty, stony, waterlogging, compaction, N, P deficient, salinity. Mainly inert, some with acid mine drainage, visual impact.	Underground : Older tips inspected and remediated but often only for stability, but restoration programmes in 1980s and 1990s means that most wastes now restored. Natural colonisation possible especially on wastes with higher pH. Often situated near people; restored for development (e.g. industrial estates) and amenity (29%). Remodelling to reduce visual impact (and instability), cultivation, lime, fertiliser, sometimes with top soil or SFMs (e.g. MSW). Grasses, legumes or trees. Open cast : Progressive restoration common and often effectively blended into surrounding landscape. Restored to agriculture (51%) and forestry (8%), often to original quality. Cultivation and fertiliser addition. May need to control acid mine water on underground and open cast.	Co-located with PHs incl. OMHs, WHS, LHI . Around 20% co-located with some form of ecological designation.	Broadleaved woodland (9%; 19%), Arable and horticulture (19%; 7%), Improved grassland (24%; 23%), Suburban (19%; 11%).
Iron ore (E=NW, NE, EM, SE; W=S)	Underground and open cast mining, with shallow workings until 20 th Century. Mainly 18 th and 19 th century, waste often removed for construction (e.g. where limestone) or used in restoration but substantial areas abandoned. Waste often left underground.	Colonisation of flora able to tolerate extreme conditions. Pre-20 th century, restored to agriculture , then deeper mining and decline of agriculture resulted in more abandoned waste in 'hill and dale' topography. 1920s to 1950s blocks of woodland planted without levelling. Ironstone Restoration Fund resulted in most sites being restored in 1950s and 1960s. Some development (e.g. industrial estates). Mainly restored to agriculture (93%) with some amenity (5%): levelling of hill and dale, cultivation, sometimes with top soil, fertiliser.	Co-located with PHs incl. OMHs, AONBs . Around 20% co-located with some form of designation.	Broadleaved woodland (18%; 13%), Arable and horticulture (26%; 4%), Improved grassland (28%; 19%).

	Heavy clay, limestone lumps. High pH, P, K deficiency.			
Vein minerals (E=SW, NE, NW; M; W=M).	Underground with limited open cast mining. Mainly 18 th and 19 th century; abandoned wastes. Changed over time; larger pieces to smaller particles (more likely to retain water, oxidise pyrite, support plant growth, lower metal concentration). Some reprocessing of waste or removed for construction. Droughty, N, P deficient. Acid mine drainage, elevated metal concentrations, impacting on soil and water quality, radon in SW.	Natural colonisation of higher plants, mosses, liverworts and lichens with evolved tolerance; wildlife refuge (e.g. bats in underground mines, newts and toads in washing pools). Many restored in 1980s and 1990s but substantial number still unrestored, often restoration degraded historical landscape . Restoration practices evolved: Initially soil cover used but upwards migration of metals, then used infertile capping material (e.g. colliery spoil, rock waste; 50-60 cm or 2 m for trees) with top soil or SFM, then membrane or clay seal used to prevent movement of metals. Can plant directly on waste (not near water or grazing) using metal tolerant cultivars or encourage natural colonisation where low metal concentrations. Cultivation, fertiliser and lime, planting with grasses and legumes. After-uses include agriculture (90%) and amenity (10%).	Co-located with ancient woodlands , SSSIs , SACs , SPAs , PHs incl. OMHs , NPs , AONBs , LHIs , WHS . Around 40% in England and 30% in Wales co-located with some form of designation.	Broadleaved woodland (12%; 12%), Improved grassland (28%; 21%), Acid grassland (10%. 15%).

Percentage of after-use refer to the proportion of sites restored to that use between 1988 and 2000. References: Bradshaw and Chadwick, 1980; Department of the Environment, 1989, 1994a, 1994b, 1996, 2000;

Lundholm and Richardson, 2010; Palumbo-Rose and Colman, 2010.

Table 6 Number (and percentage) of non-active mines co-located with multiple designations in England and Wales, for those mineral groups where more than 10% of mines are co-located with multiple designations

	Country	Designations	Designations		
			NP	AONB	PHI
Igneous rock, sandstone	England	SSSI	1105 (3.5)	956 (3.0)	2478 (7.9)
	Wales		123 (1.5)	47 (0.6)	-
Chalk, dolomite, limestone	England	SSSI	527 (1.5)	903 (2.6)	2021 (5.8)
	Wales		95 (4.1)	75 (3.2)	-
Vein minerals	England	SSSI	277 (14.7)	79 (4.2)	336 (17.8)
	Wales		157 (5.1)	214 (6.9)	-
Igneous rock, sandstone	England	OMH	267 (0.8)	228 (0.7)	515 (1.6)
	Wales		2 (0.0)	2 (0.0)	-
Chalk, dolomite, limestone	England	OMH	134 (0.4)	456 (1.3)	614 (1.7)
	Wales		18 (0.8)	10 (0.4)	-
Vein minerals	England	OMH	64 (3.4)	60 (3.2)	751 (4.6)
	Wales		0 (0.0)	17 (0.5)	-
Igneous rock, sandstone	England	SM	41 (0.1)	67 (0.2)	54 (0.2)
	Wales		11 (0.1)	1 (0.0)	-
Chalk, dolomite, limestone	England	SM	47 (0.1)	47 (0.1)	150 (0.4)
	Wales		21 (0.9)	3 (0.1)	-
Vein minerals	England	SM	120 (6.4)	71 (3.8)	109 (5.8)
	Wales		7 (0.2)	5 (0.2)	-

Note: Many mines are exploited for multiple minerals so the total number of mines is not equal to the sum of the different types of mineral.

Sand and gravel=sand and gravel, silica sand, silica rock, sand; Clays=ball clay, fireclay, clay, china clay, slate; Coal=coal, peat, lignite;

Vein minerals=As, Ag, Au, Cu, Pb, Sn, Zn, barytes, calcite, fluorspar. Sources: mine data from BRITPITS Licence No. 2014/098BP ED

British Geological Survey © NERC. All rights reserved.

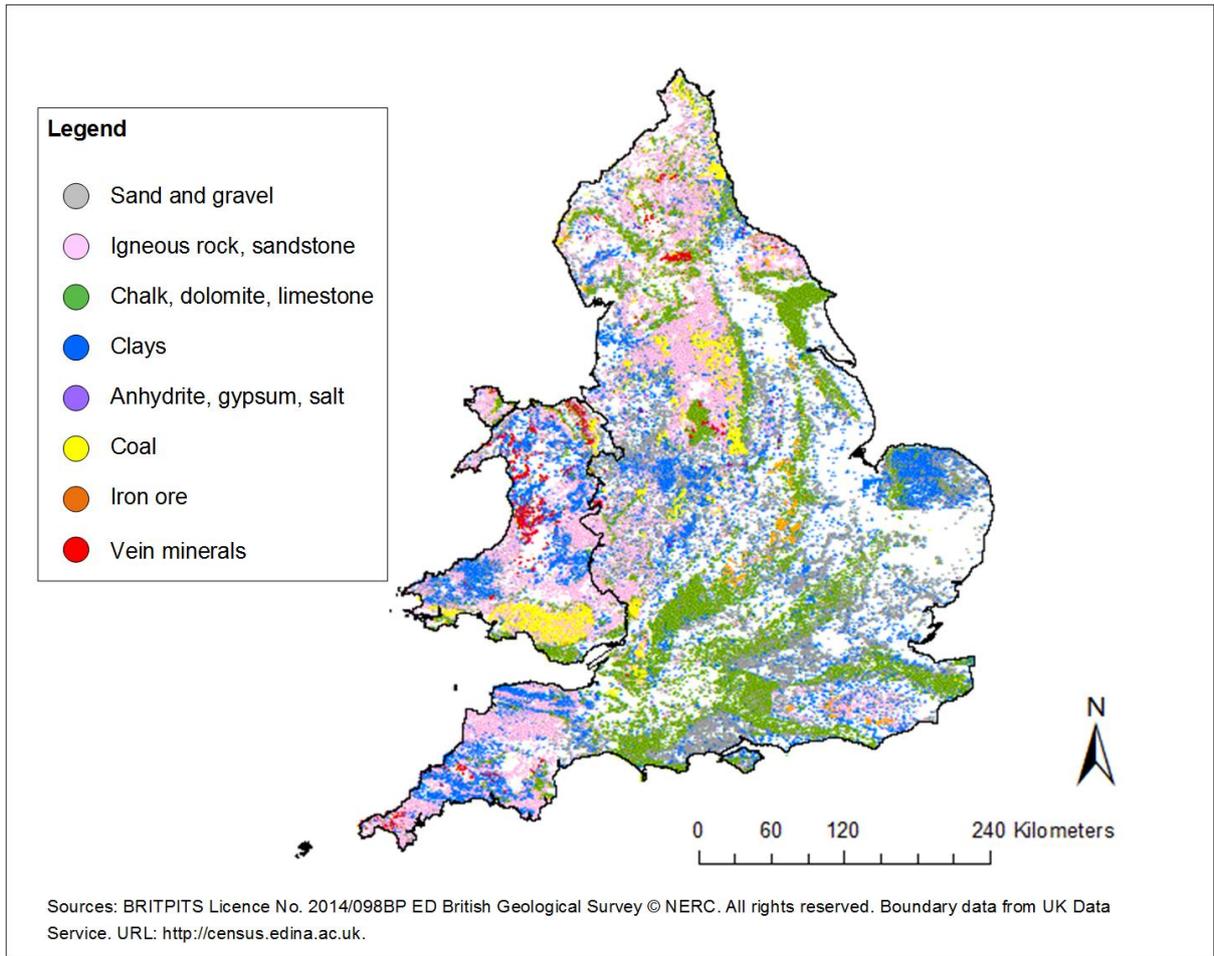


Figure 1 Location of mines in England and Wales (n=157,285)

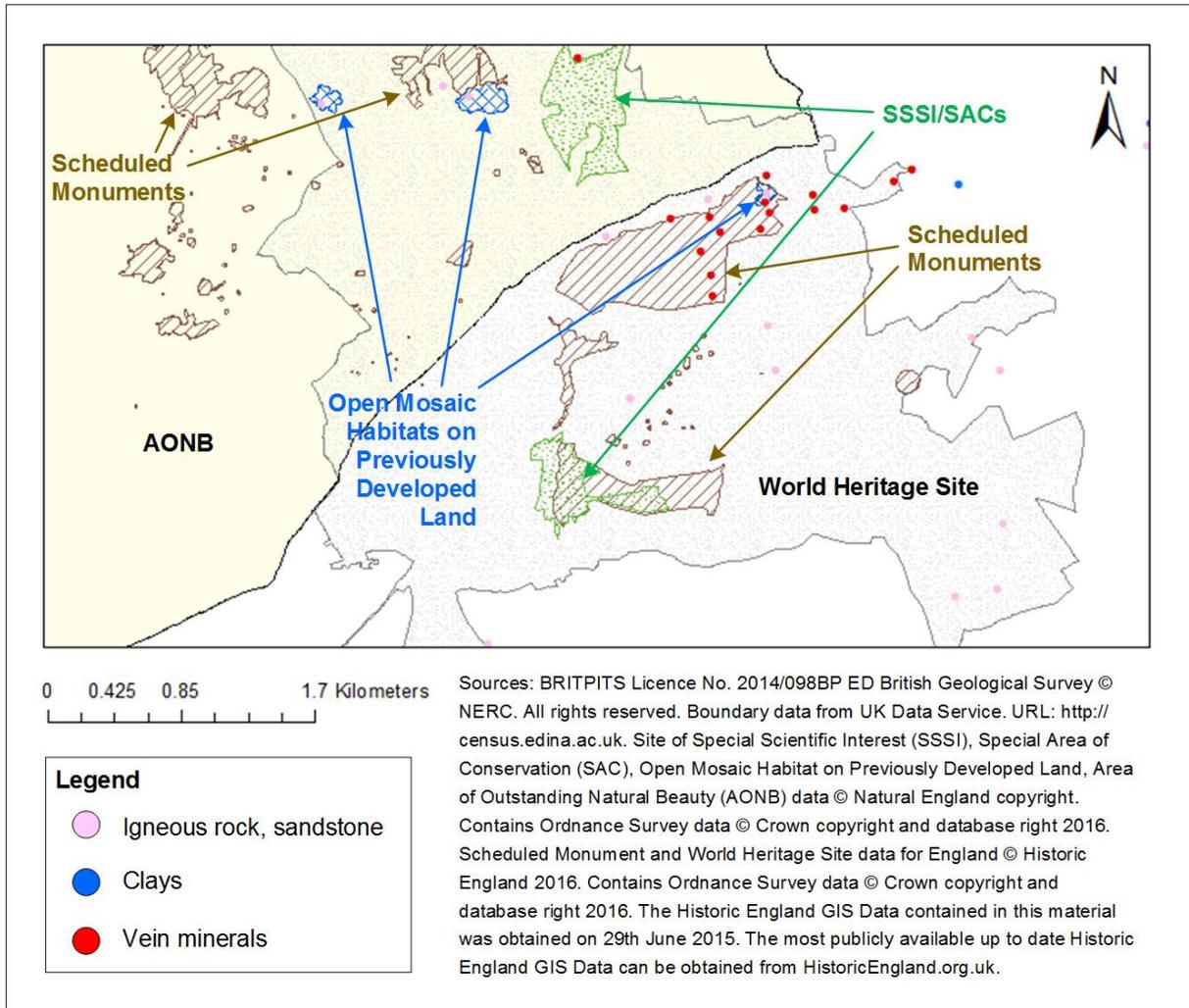


Figure 2 Example of the multiple ecological, geological and cultural designations that exist in the Cornish mining landscape



a) Tree planting and natural regeneration at a sand and gravel quarry in the Thames Basin Special Protection Area, Hampshire.



b) Community greenspace establishment at the former Bentley colliery, Yorkshire



c) The unrestored Parys Mountain copper mine, Anglesey; includes scheduled monuments and Sites of Special Scientific Interest (Credit: Rich Crane).



d) Regeneration of South Crofty copper and tin mine, Cornwall, within the World Heritage Site, combines new housing with community facilities.

Figure 3 Examples of restored and unrestored mines in England and Wales