LOW COST QUARRY MANAGEMENT PRODUCING HIGH GAIN BIODIVERSITY: USING GIS TO QUANTIFY EFFECTIVE QUARRY MANAGEMENT REGIMES

G. R Lucas[1], *P. Michell*[1] *and N. Williams*[2]

[1] *Edge Hill University, Department of Geography and Geology, St Helens Road, Ormskirk, Lancashire L39 4QP.*

[2] *Quarry Manager (retired) Castle Cement (now Hanson Cement), Cefn Mawr Quarry, Cadole, Flintshire CH7 5EA, Wales.*

Abstract

A large scale biodiversity study of Cefn Mawr quarry, Mold, North Wales provided a scientific database for the operator. The project aimed to develop a set of 'biodiversity indicators' that would inform sustainable mineral operations at mineral extraction sites whilst simultaneously protecting ecological and landscape interests. The results helped fashion the production of the corporate guideline 'Promotion of biodiversity at the mineral extraction sites of HeidelbergCement'.

Cefn Mawr quarry is a Carboniferous limestone quarry providing feedstock for the nearby Padeswood Hanson Cement plant. At the time of the survey it was operated by Castle Cement.

A range of ecological surveys were carried out over a six month period (covering late spring, summer and early autumn 2008). They included a JNCC Phase 1 Habitat survey, butterfly and dragonfly surveys and an assessment of water bodies for amphibians. Any habitats not categorised by the JNCC Phase 1 Habitat survey were described as 'Partial Living Spaces' and were incorporated within the GIS model and used to assess the biodiversity of the site. They added significantly to the biodiversity count and biodiversity indicators. The authors argue that Partial Living Spaces should become part of biodiversity audits at mineral extraction sites because of their contribution to the quantification of biodiversity.

Data recorded were analysed within ESRI ArcGIS. The analysis considered the range of habitats and levels of floral diversity found within different zones (operational, restoration and buffer) of the quarry.

Wildlife was found to be thriving in the most disturbed parts of the quarry with evidence of a range of species found in the operational zone. Around 300 species of flora were identified on the site. The density of flora (species per hectare) found in the operational and restoration zones of the quarry, together were greater than that in the buffer zone. The buffer zone was considered to be an analogue for the surrounding upland countryside. Statutorily-protected and 'Nationally Scarce' species were also present. The analysis demonstrated that a continuous cycle of disturbance is a key factor in increasing the levels of biodiversity within the quarry. The GIS proved to be an effective tool in recording and analysing the variety of habitats and their species. The quarry had not employed any sophisticated or costly procedures to foster biodiversity. Restoration had been conducted using low cost in-house techniques that had been designed to be cost effective and promote biodiversity. The GIS demonstrated that these techniques had been successful. A number of management approaches were suggested to enhance the biodiversity and are now employed by the quarry as part of the Quarry Biodiversity Management Plan.

Lucas, G. R., Michell, P. and Williams, N. 2014. Low cost quarry management producing high gain biodiversity: Using GIS to quantify effective quarry management regimes. Pp. 135-146 in Hunger, E., Brown, T. J. and Lucas, G. (Eds.) Proceedings of the 17th Extractive Industry Geology Conference, EIG Conferences Ltd. 202pp.
e-mail: Lucasg@edgehill.ac.uk

Introduction

The main aim of the Cefn Mawr project was to collect a number of datasets of British biodiversity in a hard rock quarrying operation that would contribute to the development of a set European wide 'biodiversity indicators' that could be used to inform the sustainable mineral extraction operations of the HeidelbergCement corporation (HeidelbergCement, 2010).

Biodiversity, or biological diversity, is important because it matters to people and is an indispensable part of a sustainable world. It typically describes the variety, quantity and distribution of the components of life whether they are species or ecosystems.

Biodiversity can be measured and is often presented in the form of biodiversity indicators. They are not perfect measures of ecological wellbeing, but they are good enough to show which way some of the key components of biodiversity are heading. The crucial issue in developing biodiversity indicators is to be clear on the specific question about biodiversity that the measuring system is designed to answer. In particular there are biodiversity indicators that measure important concerns such as population trends, the extent of different habitats, trends in the status of nationally rare or threatened species and the total area of natural habitats under protection or potential threat. (European Academies Science Advisory Council, 2005). This project followed most of the approach elucidated by the latter organisation. The indicators were tailored to the site conditions and statutory obligations of the quarry operation at Cefn Mawr. The final document has now become part of the group guideline applicable at all HeidelbergCement European extraction sites.

The Cefn Mawr data were collected, stored, analysed and presented as an ESRI ArcView GIS database as well as a written report. A GIS database was necessary to collate and analyse a dataset of significant volume captured over an area of 139.6ha.

The approach developed, and the observations made, are applicable to many other mining and quarrying sites with appropriate adjustments to take into account local site conditions.

Cefn Mawr was chosen for the experiment because the site had successfully developed and executed a two decade long novel and low cost restoration scheme involving piecemeal habitat translocation and transient on-site nurseries using quarry staff on downtime.

This paper is divided into five parts;

- The first part briefly reviews previous work and identifies that quarries can have both negative and positive impacts on biodiversity.
- The second part provides the context of the site which is based in North Wales in an Area of Outstanding Natural Beauty (AONB) on Carboniferous limestones.
- The third part presents the methodology used in this study. The data was collected and stored using GIS. The Joint National Conservation Committee (JNCC) Phase 1 methodology was followed but the study was also extended to incorporate habitats the authors defined as Partial Living Spaces.
- Part four presents the results in text, table and a GIS based map.
- The final part is a discussion and concludes that active quarries are rich in biodiversity. Accurate measurement is made possible by using GIS databases. These ensure that all habitats are fully recorded allowing spatial query to reveal quantitative patterns. This demonstrates that quarrying can promote biodiversity by its disturbance. The role of disturbance and biodiversity is well understood but in this study the authors analysed the extent of its contribution within a mineral extraction site.

Previous Studies

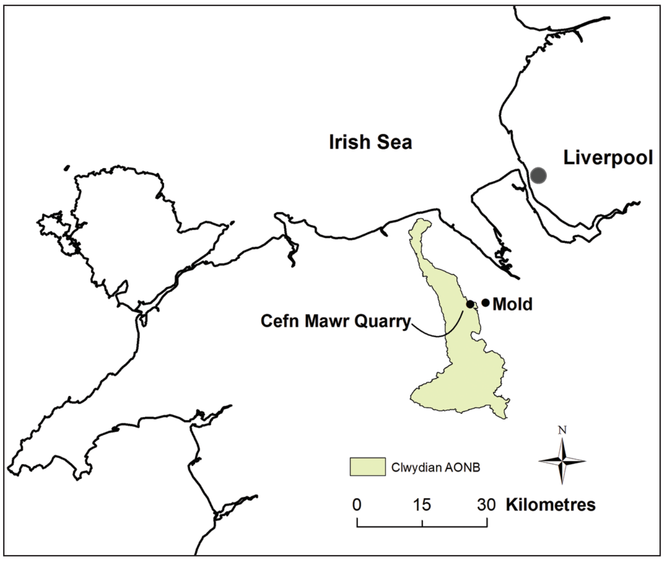
Quarrying is traditionally viewed as having a negative impact on the environment. Concern regarding visual impact and negative effects on biological communities by large scale mineral extraction are evident at planning consultation and inquiries. The academic literature has often mirrored this concern indicating that mineral extraction activities generally inflict heavy impact at regional and local levels affecting communities, species, habitats and their interconnections (Thornton, 1996; Milgrom, 2008; Sponsel, 2013). In contrast, many studies in recent years have demonstrated the ecological value of quarry sites after mineral extraction. These studies demonstrate the positive value that quarrying can have on biodiversity because abandoned workings act as safe undisturbed havens for plant and animal communities and can often help to foster the establishment and enhancement of species of national and international concern (Jefferson, 1984; Benes et al, 2003; Bétard, 2013).

Quarries, and especially hard rock quarries, normally have large footprints and lengthy scales of operation. They produce, as a consequence of extraction and restoration, a variety of geomorphological units (slopes, faces, piles etc.). This heterogeneity of landform provides a diversity of ecological niches which in turn results in a rich biodiversity (Bétard, 2013). Such observations mirror research beyond the mineral extraction environment. Burnet et al (1998) tested the hypothesis of landform heterogeneity and biodiversity in a GIS based project in the eastern deciduous forest of Rhode Island (USA). Here they consistently found a greater number of species, shrub coverage and overall diversity in areas that had geomorphic heterogeneity. Quarries are disliked by as much as 90% of human populations who view them as intrusive and destructive (Quarry Management, 2008). Studies that can demonstrate that mineral extraction positively contribute to the environment can only be of advantage to the industry and be illuminating for the wider population.

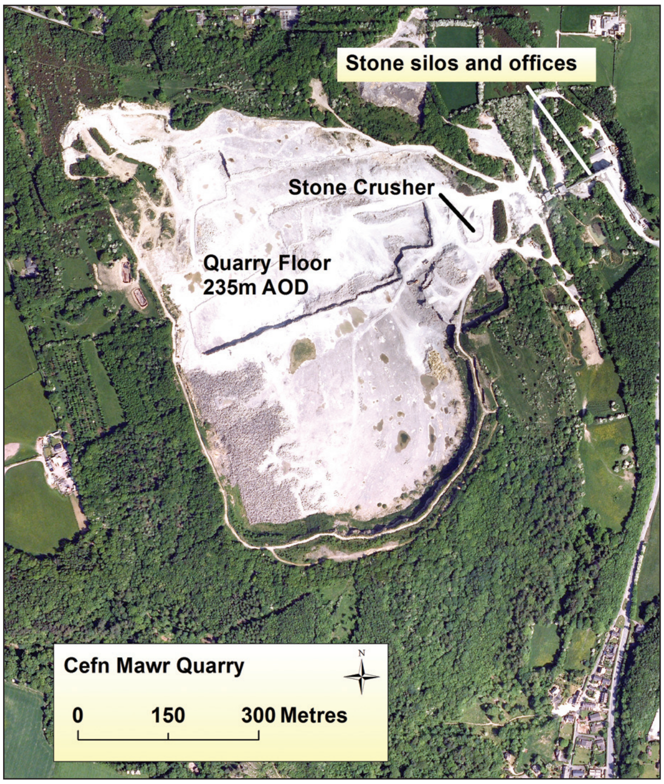
Location And Site Description

Cefn Mawr quarry is located to the west of Mold in North Wales (Figure 1). The quarry lies in the Clwydian Mountains, an Area of Outstanding Natural Beauty (AONB) of North Wales. Locally the site is surrounded by the Mold Golf Course, the Loggerheads Country Park, a number of dwellings and small settlements, with sheep grazing on grass pasture and swathes of ash/hawthorn woodlands. The Clywdian Range is underlain by Lower Carboniferous limestones (Cefn Mawr and Loggerheads Limestone Formations). These rocks are extensively quarried, with 13 current or recently closed sites located along their strike. The environmental load in a relatively small area is therefore high and of some concern to the local population.

The central operation area of the quarry consists of a 300 x 400m floor footprint. At the time of survey three, 12m rock faces and benches surrounded the open floor at approximately 235mAOD. To the east of the quarry is the stone crusher, sheds, and offices (Figure 1b). A series of lead/zinc veins cross the site and lead mining has been commonplace in the area. A number of abandoned mine shafts are still found scattered around the site today. Spoil



a



b

Figure 1. *Location of Cefn Mawr quarry; 1a shows the quarry in its regional context, 1b shows an aerial image of the quarry and immediate surroundings.*

heaps produced from small scale mining are present outside old shaft entrances. All of these geologic / geomorphological / anthropogenic artifacts contribute to the biodiversity of the site by providing a mosaic of ecological niches and substrates.

Following mineral extraction the quarry faces have been restored using low cost methods. The southern perimeter of the site has undergone a specialised type of restoration involving habitat translocation using soils and vegetation removed from areas that are being stripped for extraction. In addition, onsite nurseries help to produce additional restoration resources. All work is completed by the workforce during downtime or slow periods. There is little or no management carried out after habitat translocation restoration. The slopes and benches are abandoned and left to succeed. The western edge had been re-profiled with imported topsoil and planted with native trees after a face collapse. The quarrying and restoration produce a multitude of landforms that develop diverse vegetation communities and thus respective habitats. These communities vary in structure and species and range from primary colonisation to fixed vegetation. These semi-natural (indigeneous flora and fauna with some human transformation – i.e. close to their original character (Ratcliffe, 1977)) habitats range from older broadleaved woodland to unimproved grassland and dense stands of established scrub, while habitats of relatively more recent origin include woodland plantations and man-made ponds. Vehicle tracks within and around the quarry, including the haul roads, were surveyed and proved to be important habitats, albeit in many places perhaps short lived. The operational parts of the site are in a constant state of flux and are subject to localised rapid and unpredictable changes. Nevertheless, they offer potential wildlife habitats and subsequently proved to be important in the biodiversity count.

Study Methodology

An initial desktop study gathered pre-existing biological data for the survey site. This included locations of any statutorily-protected sites including Special Areas of Conservation (SAC), Special Protection Areas (SPA), Sites of Special Scientific Interest (SSSI) and Ramsar Convention Wetland Sites (Ramsars) or sites of local significance such as Local Nature Reserves (LNR) and Local Wildlife Sites (LWS). Biological records (e.g. protected species, UK and local Biodiversity Action Plan (BAP) species) of no more than three years length were collected from a range of sources; Flintshire County Council, Countryside Commission for Wales and Gwasnaeth Gwybodaeth Amgylcheddol Gogledd Cymru (the North Wales Environmental Information Service) (COFNOD).

Following this, baseline surveys of habitats, water bodies, flora, butterflies and dragonflies were carried out between May and September 2008 using a GPS enabled tablet computer (installed with ESRI ArcPad and a Bluetooth microGPS - Holux unit providing nominal accuracy of up to 3-7m). The survey layers consisted of a surveyors site topography, a 2 year old colour aerial photograph (at 25cm per pixel resolution) and OS Mastermap Topography layers.

Field surveys conducted by ecologists were transferred into a PC based GIS system (ESRI's ArcMap) on completion. In addition to these base layers new layers were generated to depict and record the ecology found during the field surveys. These layers (shapefiles) are shown in Table 1. A shapefile is the proprietary ESRI ArcGIS data format for features such as polygons (areas on a map), lines (linear geometries such as roads) and points (specific sites on a map).

The survey area was divided into three zones; the

JNCC Phase 1 Habitats and Partial Living Spaces	Polygons, points or line data as appropriate
Butterfly (Lepidoptera) transects	line data
Target Notes	point data with hyperlinks for dynamic viewing of images or documents on screen
Floral Lists	point data
Plants of Conservation Concern	point data
Water bodies	points or polygons as appropriate
Dragonflies (Odonata) counts	point data
Butterflies	point data
Photographs	point data with hyperlinks for dynamic viewing on screen

Table 1. *GIS survey layers generated from field survey data.*

operational (quarry) zone, the restoration zone and a 250metre encircling buffer zone (Figure 2) that was outwith the extraction site but within the quarry estate. A 500m buffer was initially considered but later discarded as it covered too large a footprint to be accommodated by the project's financial and time resources. The zones were given equal treatment in terms of ecological survey and were fundamental to the spatial query and analysis of the biodiversity in the GIS.

Floral and insect surveys were carried out using established surveying methods. Habitats were classified using the UK based JNCC Phase 1 categorisation (JNCC, 1990). The method is used to categorise habitats on a broad scale (Table 2) which are then further sub-divided. JNCC recognise 155 specific habitat types each having its own name, alpha-numeric code, description and mapping colour. For example 'woodlands' can be categorised as 'semi-natural broadleaved woodland' or 'mixed plantation'. Grasslands are sub-divided into 'unimproved', 'semi-improved' or 'improved' depending on past treatment and their substrates, for instance, calcareous, neutral or acid. Each subdivided habitat is given a unique alphanumeric code to assist in a more detailed classification (e.g. Coniferous Woodland plantation - A1.2.2).

It was necessary to extend the broad level JNCC classification to ensure that all of the diversity in the quarry and restoration zones was counted. These habitats were identified and mapped by a combination of walkover surveys and analysis of aerial photographs. Any quarry habitat that did not conform to categories within the JNCC Phase 1 Habitat Survey were recorded as 'Partial Living Spaces' and these features were recorded as polygons, lines or points as appropriate depending upon their geomorphology. The identification of Partial Living Spaces enhanced the biodiversity record of the site by extending the range and nature of habitats providing living spaces for plant or animal species.

A: Woodland and scrub
B: Grassland and marsh
C: Tall herb and fen
D: Heathland
E: Mire
F: Swamp, marginal and inundation
G: Open water
H: Coastland
I: Exposure and waste
J: Miscellaneous

Table 2. *JNCC Phase 1 broad categories.*

In our definition Partial Living Spaces are temporally and/or spatially restricted habitats (polygons/areas, lines or points) that exist in quarries. They result from the normal everyday working practices and/or from restoration or abandonment practices. Partial Living Spaces exist for short or medium periods of times (days, months or even decades in some instances). They can be isolated in location and can sometimes be small in size (c.2m^2). Examples include soil piles, stockpiles, wheel ruts, roadways, abandoned equipment, buildings, faces, benches, joints, bedding planes etc. In the past they have not been specifically mapped as potential sites for biodiversity in quarries. The Partial Living Spaces provide important colonisation sites and refuges for plant and animal species albeit in somewhat restricted circumstances. For example, in the JNCC classification many of these sites are designated at coarse levels such as; (I): Exposure and waste, or, (J): Miscellaneous (Table 2).

It was felt that these JNCC classifications were too broad and did not sufficiently register the habitat potential or possible biodiversity value of these variable sites. Within the JNCC Phase 1 survey method - used in most ecological appraisals of mineral sites, quarry environments are placed in the general purpose alphanumeric category 'I2.1 Quarry' which encompasses the extraction areas, works and site buildings. There are no further subdivisions of this category. However, in this study, the JNCC code I2.1 has been expanded to provide a unique code suitable for a term the authors call Partial Living Spaces that may be found within quarries, as shown in Table 3. The Partial Living Spaces in Table 3 have been identified by surveying Cefn Mawr and a number of other hard rock quarry sites and represent the range of Partial Living Spaces that can exist in hard rock quarries. They were not all present at Cefn Mawr quarry during this survey or if they did exist they may not have registered as sites of wildlife.

There is scope to add or amend Table 3 based on further work. Photographs of some Partial Living Spaces are shown in Figure 3. Partial Living Spaces maybe recorded as polygons, lines or points depending upon their geomorphological complexity. Anthropogenic substrates (12.1.2 in Table 3) were recorded as polygons or points at Cefn Mawr. In this study 8 Partial Living Space habitats were recorded and were represented as 7 polygons and 2 points. The inclusion of these and their species in the geodatabase added significantly to the overall biodiversity count. In total they amounted to 84 separate and individual habitats over the site (7.5% of the total) and they covered 25% of the survey area (354,098m^2). These Partial Living Spaces provide connections, transient shelter, feeding habitat, breeding

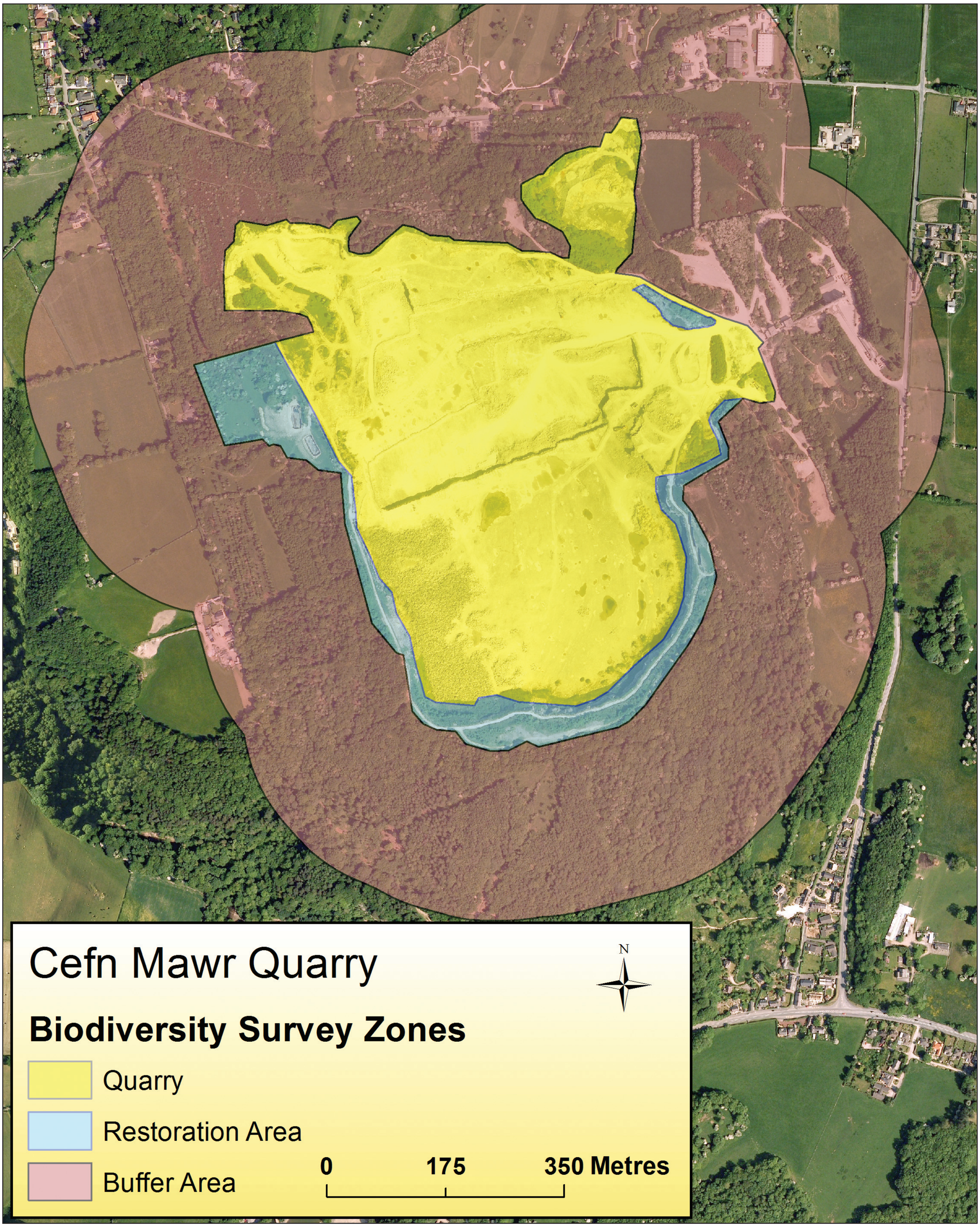


Figure 2. *The survey zones of the biodiversity study.*

habitat or areas for growth and development for wildlife during their life cycles. For example, the 'Nationally Scarce' grizzled skipper (Pyrgus malvae) had been previously reported in the quarry. They were not recorded in this 2008 survey. However, 2 years later a small colony was surveyed living for just a 2 week period on the side of a perimeter road (I2.1.7 in Table 3). This observation emphasises the transiency of species and the nature and value of Partial Living Spaces.

The term 'wanderbiotopes' has been used in German ecological literature to help explain the complexity of biodiversity in mineral extraction. They form when spatial changes in the extraction areas create microhabitats for plants and animals. These zones are of various ages, have different structures, and are closely connected to one another sometimes by proximity or topographical corridors such as roads. Whenever mineral extraction occurs in one of these areas, a replacement site has already developed elsewhere for the disturbed species to migrate to. These biotopes, together with their animals and plants that are affected by quarrying and have emerged as a result of quarrying therefore 'wander' back and forth across the quarrying site (HeidelbergCement, 2010). Partial Living Spaces in some instances may be wanderbiotopes. Examples of a wanderbiotope at Cefn Mawr might be a 'dirt road' with its wheel ruts that house frog spawn or mosquito larvae that swifts / house martins / swallows will eventually feast upon. Such tracks migrate across the site as operations move into new areas.

New code	**Partial Living Space** *(may be represented as polygons, points or lines)*	Present at Cefn Mawr	Phase 1 code	Phase 1 Habitat category
I2.1.1	Waste dumps (overburden piles)	√	N/A	N/A
I2.1.2	Anthropogenic substrates (e.g. asphalt, building rubble)	√		N/A
I2.1.3	Operations building, production plant, machinery, plant	X	J3.6	Buildings
I2.1.4	Settlement area (unstable ground)	X		N/A
I2.1.5	Bench and faces (in active extraction zone or recently abandoned)	√		N/A
I2.1.6	Native soil dumps, ground movement	X	J4	Bare ground
I2.1.7	Dirt road (e.g. perimeter roads)	√		N/A
I2.1.8	Bunds (safety/screening)	√		N/A
I2.1.9	Rock faces with ledges, crags, fissure and crevices (with no or low erosion rates) exist on faces that have been restored.	√		N/A
I2.1.10	Conveyor belts, railway routes, gondola railways	X	J3.6	Buildings
I2.1.11	Perennial watercourse with shallow and deeper (profundal) zones	X	G1	Standing water
I2.1.12	Ephemeral watercourses (e.g. in runs, or grooves)	X	J2.6	Ditch
I2.1.13	Restored and temporarily restored areas (e.g. initial seedings, plantations, regraded slopes)	X	A1.3.2	Mixed plantation
I2.1.14	Slurry pits and lagoons	X		N/A
I2.1.15	Rock debris piles. Stockpiles	X		N/A
I2.1.16	Border of excavation site	X		N/A
I2.1.17	Quarry floors with oversized blocks, aggregate piles	√		N/A
I2.1.18	Rock faces with ledges of rocks, crag, fissure and crevice (with high erosion rates)	X		N/A
I2.1.19	Scree in front of restored/abandoned rock faces	√		N/A

Table 3. *Partial Living Spaces typical of hard rock quarries (based on the Cefn Mawr survey and in conjunction with recognised Heidelberg Wanderbiotopes). (N/A: Not Applicable. Top level Phase 1 codes shown in Table 2).*

Plate 1

Plate 2

Plate 3

Plate 4

Plate 5

Plate 6

Plate 1	Tadpoles in pool on active quarry floor I2.1.12
Plate 2	Ephemeral watercourses in ruts I2.1.12
Plate 3	Rock debris piles I2.1.15
Plate 4	Quarry floor with oversized blocks I2.1.17
Plate 5	Dirt (perimeter) road I2.1.7
Plate 6	Rock faces with ledges (low erosion) I2.1.9

Figure 3. *Plates showing examples of Partial Living Spaces.*

Plant lists were collated for each habitat type. Some of the more common bryophytes were also recorded. Floral data was stored in a botanical geodatabase. Different plants were recorded throughout the spring and summer season with a final site visit for late-flowering species carried out in late September. All vascular plant data within the GIS follows current nomenclature from Stace's Field Flora of the British Isles (1999). Some of the observed species fell into 'Plants of Conservation Concern' meaning that they had local or national significance and these were recorded on a separate GIS layer.

Water bodies suitable for amphibians were mapped according to the standard JNCC Phase 1 habitat survey (standing water, swamp etc.) and were also assessed for their potential to support amphibians. Each water body was assessed from its boundary and scored against a suitability checklist for amphibian life potential. No detailed amphibian surveys were undertaken, e.g. netting, trapping or egg searches, as this would have added to the cost of the project and diverted human resources. Later surveys conducted in 2011 for different purposes (quarry extension) confirmed these preliminary surveys which indicated that many of the water bodies contained amphibians including protected species (e.g. Great Crested Newts). The water bodies were also surveyed on three occasions for damselflies and dragonflies (Odonata). Ephemeral pools on the active quarry floors were not routinely visited during the Odonata survey because of vehicular movement, however, incidental records were mapped in other parts of the quarry outside of the survey visits and are included with the survey data in the GIS.

Target Notes are a feature of the Phase 1 Habitat Survey and were used to report any locations where evidence of faunal activity was found or indeed where there is the potential to support fauna, (e.g. buildings which might be suitable for roosting bats). They add momentary detail and are a good way of representing occasional biodiversity information to features.

Results

The desktop survey provided a significant amount of digital data stored in the geodatabase enabling analysis by spatial query. The biodiversity data is stored and displayed as three main types of data: areas (polygons), linear features and points. The database also contained background layers that added further value to the spatial query such as environmental designations, aerial photography, maps and the quarry survey zones.

The survey site is surrounded (within 1km) by a number of sites of conservation (1 statutory SSSI/SAC and 8 non-statutory sites). Faunal records from COFNOD within a 1km buffer over a period of the previous three years recorded observations of 3 terrestrial native reptiles listed in Schedule 5 of the Wildlife and Countryside Act (1981) as of national conservation concern. Of these only the common lizard was recorded despite reports by quarry personnel of adder and slow worm. A badger sett was recorded on the extraction site boundary. Other faunal species of concern noted during the survey either on site or with 1km of the site boundary included dingy skipper butterflies, stoat, and bullfinch. The importance of the observations beyond the site boundary indicates the range of the biodiversity in the general area. These records are important indicators and are of value to a qualitative assessment of biodiversity. However fauna by their very nature are mobile and their observation is serendipitous. In addition, there are problems of recording the presence of inherently mobile species in a GIS which is essentially a static instrument.

Conversely, habitats and floral species are fixed, at least during the period of survey, and more easily measured and represented on static maps. They provide measures of biodiversity in themselves and also act as proxies for fauna (e.g. water bodies for dragonflies or amphibians). In total 24 JNCC Phase 1 and 8 Partial Living Spaces habitats were identified across the 3 survey zones. The complexity of the biodiversity mosaic is apparent on the map shown in Figure 4 which is the JNCC Phase 1 Habitat map for the quarry with the authors additions in the form of Partial Living Spaces.

The complete Floral Lists (the species lists) for each habitat were stored within the GIS geodatabase and are not presented here for the sake of brevity. They have now been lodged with the North Wales local records repository (COFNOD). The complete list of biodiversity indicators also developed in conjunction with the Biodiversity Indicators of HeidelbergCement (HeidelbergCement, 2008) is shown in Table 4. These are formed by counts of features or ratios of the features compared to the area of the zone surveyed to give comparative measurements.

Discussion

The survey work, documented by the GIS, found that the quarry was biodiverse in both habitats and species. In total, 24 types of JNCC Phase 1 habitat polygons (including 53 water bodies) and 7 Partial Living Spaces polygons were mapped across the three survey zones. These polygon (area) measurements are in addition to 6 line and 4 point JNCC Phase 1 habitats and 2 Partial Living Space points. In total they contain at least 292 species of flora, at least 9 species of Odonata and at least 20 species of butterfly. Protected faunal species such as common lizard and badgers were observed. Three habitats (limestone pavement, upland calcareous grassland and ponds) are listed on the UK-BAP as being of priority conservation concern. Three habitats (hedgerows, lowland mixed deciduous woodland and upland mixed ash woods) are listed on both the UK-BAP and Flintshire BAP indicating their biodiversity importance at both a national and local level. In terms of Biodiversity Action Plan species, reptiles and bullfinch are listed on the UK-BAP while reptiles and badger are listed in the Flintshire BAP.

One of the main purposes of the study was to test biodiversity indicators of the site based on the HeidelbergCement model (HeidelbergCement, 2008) that could feed into a European wide system. The various habitat polygons, lines and points contribute a total 1136 individual habitats distributed over an area of 139.6 hectares. The map shown in Figure 4 illustrates the intricate complexity of this mix. Habitat mosaics of species, substrates and geomorphology provide a range of ecological niches which in turn support the substantial

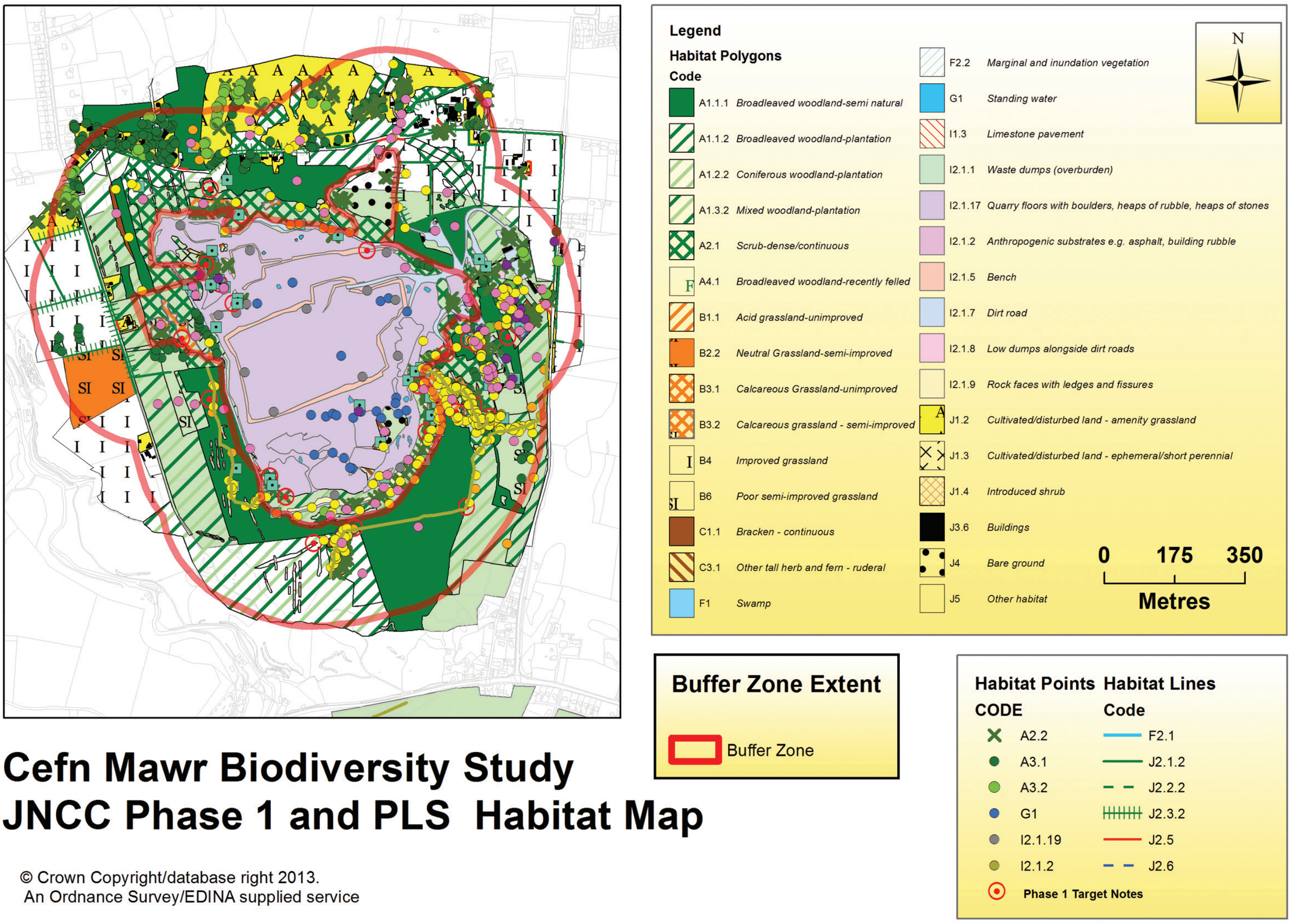


Figure 4. *The GIS based JNCC Phase 1 and Partial Living Spaces Habitat map for Cefn Mawr quarry 2008.*

counts of floral and faunal species. The habitats have been defined using the Phase 1 methodology which define them largely on vegetation categories. These vegetation categories are not always sharply delimited and different categories often grade into one another in response to environmental gradients so that transition zones exist that allow other species to migrate between them. Sites such as Cefn Mawr quarry with a highly varied mosaic structure provide for a range of meso- and microhabitats that are valuable for many other groups such as invertebrates, small mammals, reptiles.

Table 4 shows the distribution of the habitats. Although the majority of habitats (824) are located in the buffer zone (which is quarry estate but beyond the quarry - operational zone there are however significant numbers in the operational and restored zones (193 and 119 habitats respectively). In fact 17% of the total habitat mosaic is actually found in the operational quarry, the majority of these being Partial Living Spaces subject to possible destruction and/or movement over time. The restoration zone had the highest density per hectare of the 3 zones with 17.5 habitats per hectare.

The floral diversity across the three quarry zones shows one of the most interesting outcomes and is based on the observation of 292 species. Based on the number of species of flora per hectare the operational and restoration zones together contained more species (5.4 ha^{-1}) than the buffer zone that comprises the surrounding countryside (3.1 ha^{-1}). By disaggregating the statistics further, the restored zone is shown to contain 189 floral species in 6.8ha (27.8 floral species per hectare) and the operational quarry 165 floral species in 37.4 hectares (4.4 floral species per hectare). In other words, the quarry has more species per hectare than the buffer (4.4 versus 3.1 floral species per hectare). Further, the restored zone, produced by habitat translocation (and left to succeed on its own with limited if any management), has 8.96 times the biodiversity (27.8 versus 3.1 floral species per hectare) than the buffer zone. These comparisons illustrate the value of recording Partial Living Spaces in a GIS promoting quantification using the GIS function of spatial query. In addition, the statistics reflect the efficacy of the low intervention habitat translocation/transient nursery restoration procedures practiced in the quarry by Noel Williams (retired quarry manager).

In terms of floral species of national concern, a similar story is illustrated, with the quarry containing 19% of the species (albeit based on one type with 11 individuals). Nevertheless, the comparator of 3.4 individuals per hectare contrasts impressively with the larger and more mosaic buffer zone with 2.12 individuals per hectare. This illustrates the potential of operational zones to paint an even more colourful biodiversity picture of working quarries.

Together, the restoration and the operational zones are the 'working' areas of the quarry with activities ranging from a fairly low level of intensity, for example tree

General Information	Area of quarry (Operational) zone 37.4 ha Area of Restoration zone 6.8 ha Area of Buffer zone 95.4 ha
JNCC habitats in the three survey zones	24 polygons (area habitats) 6 lines (linear habitats) 4 points (single instance habitats)
Partial Living Spaces (PLS) *(of the 19 possible in hard rock quarries, 8 existed at Cefn Mawr during the survey)*	7 polygons (area habitats) 2 points (single instance habitats) *Note: Anthropogenic substrates (e.g. asphalt, building rubble) I2.1.2 (Table 3) were counted in some places as a polygon or a point depending on its geomorphology. This makes 9 GIS features – 7 polygons and 2 points totalling only 8 PLS habitats.*
Habitats	*(based on a GIS spatial search using intersect as the operator)*
Total number of JNCC and PLS habitats (habitat mosaic count) within the whole survey area	1136 individual habitats making up a complex mosaic
Quarry (Operational Zone)	193 – (17%) of the total habitat mosaic count averaging 5.2 habitats ha^{-1}
Restoration Zone	119 – (10%) of the total habitat mosaic count averaging 17.5 habitats ha^{-1}
Buffer Zone	824 – (73%) of the total habitat mosaic count averaging 8.6 habitats ha^{-1}
Floral Species	*(based on a GIS spatial search using intersect as the operator)*
Quarry	165 Floral Species averaging 4.4 species ha^{-1}
Restoration	189 Floral Species averaging 27.9 species ha^{-1}
Quarry and Restoration area together	236 Floral Species averaging 5.3 species ha^{-1}
Buffer	292 Floral Species averaging 3.1 species ha^{-1}
Special Floral Species	**Those of national or conservation concern** *(based on a GIS spatial search using intersect as the operator)*
Quarry	11 individuals; 19% of the species averaging 3.4 individuals ha^{-1} *Stinking hellebore*
Restoration	1 individual; 4% of the species averaging 0.14 individuals ha^{-1} *Pyramidal Orchid*
Buffer	45 individuals; 77 % of the species averaging 2.12 individuals ha^{-1} *Bluebell, Green Flowered Hellebore, Herb Paris, Deadly Nightshade*

Table 4. *Biodiversity Indicators for Cefn Mawr Based on HeidelbergCement Biodiversity Indicators (HeidelbergCement, 2008).*

planting or bund creation in the restoration area, to higher levels of disturbance such as blasting, stone extraction and regular vehicle movements. The level of disturbance therefore differs across the working areas of the site which in turn influences the nature of the habitats present, from ephemeral, weedy habitats, like those on the south quarry floor, to dense established scrub in more undisturbed locations. ‘Raw material extraction is linked with substantial interventions in nature and the landscape’ (HeidelbergCement, 2008:4). Such diversity of activity introduces a variety of geomorphological features that in turn provide ecological niches and therefore opportunities for wildlife. The disturbance factor is therefore likely to be producing a positive effect in terms of increasing biodiversity within the quarry by providing a variety of living spaces. Furthermore, it is accepted that in time natural succession will change these niches and that extraction activities will cause disturbance to some of these niches. It is likely that flora and fauna will probably migrate to new areas in the true sense of the term ’wanderbiotope’ used by European guideline for the promotion of Biodiversity at mineral extraction sites HeidelbergCement (HeidelbergCement, 2010). The Cefn Mawr study established that there is more biodiversity in the working zones of the quarry than might have been anticipated by casual overview. This has implications for biodiversity studies in other mineral extractions sites or indeed any industrial environment where they should not be ignored in the measurement of biodiversity. We have also attempted to classify the ecological niches associated with the working of the quarry even though they may appear small and transitory. We have named these Partial Living Spaces and have integrated them into to the JNCC Phase 1 list of habitats as an experiment. Further work is suggested in this area. JNCC Phase 1 Habitat surveys are typically the main tool used by ecologists in assessing the ecology for quarry planning matters in the UK. It would serve the interests of the industry if an extended JNCC classification could be used to record the significant biodiversity that exists within these apparently hostile Partial Living Spaces environments.

Some of the Partial Living Spaces offer significant ecological potential. In particular, the dirt roads (coded I2.1.7 in Table 3) around the perimeter of the quarry especially in the restored zone, act as wildlife ‘rides’ for a range of species. These tracks are secured by safety bunds and have developed a mixed vegetation of mainly ruderal herbs with scattered scrub. Roadways like these mimic the sunken lanes and associated high hedges found in southwest Britain. They are hot in the summer and sheltered during the winter, suiting butterfly and bird species and providing navigation routes for bats and other wildlife. Similarly the assessment of water bodies across the site, including the active extraction site, found that hundreds of tadpoles were present in isolated, unvegetated ‘pools’ on the quarry floors. There was no evidence on how they had become populated other than being introduced by birds or on vehicle tyres. These ephemeral water bodies are undoubtedly hostile environments prone to drying out and vehicular movements, yet developing tadpoles were still observed in the smallest amounts of water left behind after evaporation in the months of June and July. The assessment showed that any ephemeral pool within the operational zone therefore has the potential of being utilised by amphibians as a Partial Living Space during the spawning period. Likewise, a collection of oversized blocks mimic the natural habitat of limestone pavement, where water-worn grikes support ferns and geraniums. At Cefn Mawr male fern (*Dryopteris filix-mas*) was identified between gaps within the boulders and some of these gaps were large enough to provide living spaces for foxes. The location of the boulders provided easy access to the restored slopes that comprise a mosaic of habitats and thus provided foxes with varied foraging. Scrub and cut brash provide shelter and breeding sites while strewn limestone boulders and stone or log piles provide good basking or hiding locations.

The JNCC and Partial Living Spaces habitats identified on site provide important areas for small mammals and reptiles, as well as the diverse floral mix. The occurrence of a species, or the richness and composition of assemblages (biodiversity), depends not only on the characteristics of the site at which they were sampled, but also on its context in the land mosaic (Bennett et al, 2006). In this study area of 139.6 hectares the mosaic is particularly rich consisting of 1136 habitats represented as GIS features in the form of polygons lines or points.

Whilst the number of floral species per hectare gives a useful indication of the levels of biodiversity within the different zones of the quarry, the restored zone contains a significant amount of inaccessible habitat, such as rock faces, slopes and ledges that would likely increase its biodiversity value if investigated further. It is known, for example, that birds such as peregrine falcon use the rock ledges for nesting. The restored zone will, however, tend towards scrub and woodland as tree canopy establishes and will eventually reduce diversity to a level similar to that found in the surrounding buffer. It is therefore important that a management approach is followed so as maintain and promote biodiversity as well as permitting the quarry to follow its normal working practices. This appears to be the case at Cefn Mawr having been an approach adopted and developed over the preceding 20 year period.

The production and application of a Quarry Biodiversity Action Plan (QBAP) could provide the mechanism for maintaining, monitoring and enhancing flora and fauna whilst setting out specific actions for rarer species and habitats. The QBAP should seek to include actions on strengthening the biodiversity value of the operational zone in ways which would allow wildlife to complete their life cycles and successfully reproduce. For example, links between water bodies could be strengthened while new water bodies could be created or encouraged in storage areas. Refugia sites could be constructed away from vehicle or haulage routes. This would improve the potential of the operational zone to suit wildlife such as reptiles, amphibians and dragonflies and increase the type and number of Partial Living Spaces available.

Management of habitats within the restoration and buffer zones might largely be concerned with halting the development of scrub on grasslands and ephemeral and weedy habitats in order to maintain higher diversity. Otherwise, scrub invasion within these habitats would eventually reduce the biodiversity interest and threaten populations of wildflowers and butterflies that rely on the openness and shorter grass swards for their continued success. Additionally, the creation and maintenance of glades within the buffer zone could help improve the levels of biodiversity whilst maintaining the habitats required by more specialist species. A QBAP was instituted at Cefn Mawr in 2010.

Conclusion

The study has demonstrated four important conclusions.

Firstly, biodiversity measurement benefits from the significant storage, manipulation and display capacity of a GIS.

Secondly, Partial Living Spaces developed on patch scale geomorphological heterogeneity contribute to the overall biodiversity tally of a site and they deserve more attention in ecological surveying.

Thirdly, quarry management plans should take into account Partial Living Spaces and they should be included in a QBAP.

Finally, quarrying operations need not be a limiting factor on the development of biodiversity. Ironically even destructive operations can provide a range of opportunities for wildlife, even within the most active parts. Successful management of biodiversity interests can be achieved in conjunction with normal mineral operations.

Acknowledgements

Quarry personnel at Cefn Mawr, especially Tony Condren for logistics during the survey period. Kathryn Coffey for proof reading.

References

Benes, J., Kepka, P., and Konvicka, M., 2003. Limestone quarries as refuges for European xerophilous butterflies. Conservation Biology 17 pp1058-1069.

Bennet, A. F., Radford, J. Q., and Haslem, A., 2006. Properties of land mosaics: Implications for nature conservation in agricultural environments. Biological Conservation, 133 (2) pp 250-264.

Bétard, F., 2013. Patch-scale relationships between geodiversity and biodiversity in hard rock quarries:case study from a disused quartzite quarry in N W France. Geoheritage 5 pp 59-71.

European Science Academies Advisory Council, 2005. A users' guide to biodiversity indicators. European Parliament Committee on the Environment, Available through: http://www.europarl.europa.eu/comparl/envi/pdf/externalexpertise/easac/biodiversity_indicators.pdf. Accessed 7 November 2013.

Jefferson, R;G., 1984. Quarries and wildlife conservation in the Yorkshire Wolds, England. Biological Conservation 29 pp363–380.

JNCC, 1990. Handbook for Phase 1 habitat survey - a technique for environmental audit. http://jncc.defra.gov.uk/page-2468 Accessed 3 July 2013.

HeidelbergCement, 2008. Sustainable Development Indicators for Integrated Raw Material and Nature Conservation Management. Draft Report. http://www.heidelbergcement.com/NR/rdonlyres/00C2832C-4655-483C-9804-211E94C3EF32/0/Biodiversityi Accessed 3 July 2013.

HeidelbergCement, 2010. Promotion of Biodiversity at the mineral extraction sites of HeidelbergCement. 2nd Edition. http://ec.europa.eu/environment/biodiversity/business/assets/pdf/resources-center/HC_Guideline%20Biodiversity%20%28Europe%29-EN.pdf Accessed 3 July 2013.

Milgrom, T., 2008. Environmental aspects of rehabilitating abandoned quarries: Israel as a case study. Landscape and Urban Planning 87, (3) pp172-17.

Quarry Management, 2008. Care for the Community. May 2008. QMJ Publishing.

Ratcliffe, D.A., 1977. A Nature Conservation Review. Cambridge University Press.

Sponsel, L. E., 2013. Human impact on biodiversity Encyclopaedia of Biodiversity. 2nd edition. Pp 137-152.

Stace, C., 1999. Field Flora of the British Isles. Cambridge University Press, Cambridge.

Wildlife and Countryside Act, 1981 (c.69). London:HMSO.

Thornton., I., 1996. Impacts of mining on the environment; some local, regional and global issues. Applied Geochemistry 11 pp.355–36.