RELOCATION AND RESTORATION IN LIMESTONE QUARRIES: IMPLICATIONS FOR INVERTEBRATE COMMUNITIES FOLLOWING TWO EXTREME FORMS OF MANAGEMENT[1]

W. Rod Cullen and C. Philip Wheater[2]

Abstract: Limestone quarrying often results in the need to protect existing ecosystems and restore abandoned quarries, and hence the development of appropriate management techniques. This study discusses the effects of two such, relocation and restoration blasting, on invertebrate communities. Invertebrates are important components of ecosystems that are frequently ignored during, or following, management. Following the relocation of part of a magnesian limestone grassland in County Durham, UK, the invertebrate fauna was examined in turfs relocated at different dates. Elements of these communities declined from the most recently relocated turfs, rising in the oldest plots. This may be due to an initial shock caused by disturbance, followed by recovery as the turfs establish and settle. Invertebrate recovery may be slower than for plants, due to direct or indirect (via changes in plant communities) influences. Restoration blasting in postworked quarries aims to produce landforms that can support ecosystems similar to those on natural dalesides. Comparisons between natural, abandoned and managed sites in the White Peak area of Derbyshire, UK, indicate that natural dalesides have more invertebrate orders than disused quarries, which have higher values than restoration blasted sites. The time communities have been developing may be important. The restoration blast piles have been effected by severe rabbit grazing, and the effects on the vegetation has repercussions on the associated invertebrate communities. These extreme forms of management may influence invertebrates to a greater extent than plants. It is, therefore, important to encourage an integrated approach to management, to take account of all the communities involved.

Additional Key Words: reclamation, restoration blasting, colonization, establishment.

Introduction

Limestone is an important raw material, used in the manufacture of a wide range of products. In Britain figures for 1988 estimated that 13,920 ha of land was affected by limestone quarries (Brown 1992). By 1987 annual production had risen to 124 million mt (Gunn and Bailey 1991) with a projected rise well into the 1990's. Often the occurrence of limestone coincides with some of Britain's most valuable ecological and scenic areas. Resulting conflicts have led to the development of several techniques for the protection and restoration of threatened or damaged areas, while enabling extraction to continue. In Britain planning permission for a new quarry or extension to an existing quarry requires the company to submit a reclamation strategy (Gunn and Bailey 1991). There is, therefore, a need for effective management both before and after quarrying, and several techniques are currently being used. We shall discuss some of the implications of two of the more extreme methods, one before extraction (relocation) and one following abandonment (restoration blasting).

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[2]W. Rod Cullen, Researcher, and C. Philip Wheater, Principal Lecturer in Ecology, Department of Environmental and Geographical Sciences, The Manchester Metropolitan University, Manchester, M1 5GD, UK.

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Relocation is an extreme form of management, potentially retaining a whole ecological unit. In England Byrne (1990) recorded 92 registered, existing or proposed, relocations, 48 of which were grasslands. To retain a magnesian limestone grassland threatened by quarrying, part of Thrislington Plantation, County Durham, UK, was relocated over 8 yrs. Such grasslands in northeast England are important ecological links between northern montane and southern lowland grasslands and are now limited in size and distribution (Park 1988). Thrislington Plantation SSSI (Site of Special Scientific Interest) is the most diverse, representative, and extensive area (22 ha) of the remnant magnesian limestone grasslands in the region (Richardson 1984). The relocation is fully described by Park (1988, 1989). Briefly, following removal of the topsoil from the receiver site, turfs 4.75 m by 1.75 m by 0.4 to 0.5 m deep were moved in the winter to prevent drying and splitting. Interturf gaps were infilled with overburden and soil from the donor site. For 2 yrs these gaps were leveled, and emergent weeds were controlled. After 2 yrs, the plots were flail mown annually to check scrub invasion. Relocations are not always successful (Byrne 1990), making it important to examine the apparent success at Thrislington. This study examines some of the effects of the relocation on the invertebrate fauna of one plant community (Festuca-Helianthemum) in plots relocated during the first 3 and last 2 yrs of the relocation program (1982-90). This enables comparisons to be made between the temporal extremes of the relocations.

Limestone quarries are often difficult to restore, being of coarse substrate, deficient in minerals, and often excessively drained (Bradshaw and Chadwick 1980). Such factors may provide habitats for early successional, species-rich plant communities similar to seminatural calcareous grasslands (Davis et al. 1985). Natural colonization and succession of quarries is often slow (Davis et al. 1985) and is no longer considered an acceptable reclamation technique (Bailey et al. 1991). Modern extraction methods produce harsher, more engineered landforms which evolve slower following abandonment than faces worked by the previous methods of manual and black powder blasting (Gagen and Gunn 1987). Most options for quarry after-use require treatment of the faces to reduce rock fall and improve the visual appearance (Bailey et al. 1991). Recently, the Limestone Research Group has developed a method of limestone quarry restoration, aiming to construct "daleside landform sequences" capable of supporting self-sustaining ecosystems (Bailey et al. 1991). Restoration blasting utilizes high explosives to produce landforms that replicate a natural daleside model (Gagen and Gunn 1987), Greatrocks Dale, which is classified as Festuca ovina-Avenula pratensis grassland, Dicranum scoparium subcommunity using the National Vegetation Classification (Ash 1981). Cover material, mainly limestone waste, is applied to the scree slopes prior to hydroseeding and tree planting to facilitate the development of vegetation (Bailey et al. 1991). The current study compares the invertebrate communities developing on recently created restoration blast piles with those on a natural daleside model and several naturally colonized abandoned quarries in the same locality.

Methods

Five sites at the temporal extremes of the Thrislington relocations were surveyed from June 29, 1990 to August 3, 1990 for vegetation using a 20-pin pinframe and for invertebrates using a 3 m by 3 m grid of 9 pitfall traps. The sites were relocated during the winters of 1982-83 (site A), 1983-84 (site B), 1984-85 (site C), 1988-89 (site G), and 1989-90 (site H). Diversities were calculated using the Shannon Index (H') using log base e (Magurran 1988).

During May 1992, five pitfall traps were placed on identifiable features in each of three restoration blasts, the natural daleside model, and seven disused quarries. Random vegetation surveys were carried out in April using two

0.25 m by 0.25 m quadrats on each feature. All sites were located within the White Peak area of Derbyshire and in close proximity to each other. The three restoration blasts were created in November 1988 (RB5), February 1989 (RB7), and April 1989 (RB8/9). Seven disused quarries, differing in age since abandonment (37 to 100 yrs), face length, face height, area, and method of extraction, were examined to compare restoration blasting with natural colonization. Comparisons among sites were made using a nonspecific, nonparametric analysis of variance (Meddis 1984).

Results-Relocation

Surveys recorded 11 species of grasses and sedges and 29 species of herbaceous and woody plants. Plant species number and diversity decreased slightly from the most recently relocated plots to the intermediate ones, rising again for the more established plots (fig. 1). The number of individual hits increased initially (between plots H and C), falling to plot A. Hits on bare ground were found only in plots G and H.

Table 1. Invertebrate orders found in pitfall traps per relocated plot.

Invertebrate orders	Plot				
	A	B	C	D	E
Opiliones	152	88	76	203	346
Acarina	185	114	216	66	136
Araneae	279	175	192	177	197
Isopoda	91	40	55	41	55
Julidae	15	22	12	2	4
Polydesmidae	0	0	0	1	2
Lithobiomorpha	5	4	14	15	3
Geophilomorpha	0	0	1	0	0
Pulmonata	19	54	9	9	1
Collembola	186	178	99	79	256
Orthoptera	16	11	19	6	10
Dermaptera	2	3	0	0	3
Hemiptera	79	74	21	66	80
Lepidoptera	10	13	7	4	7
Hymenoptera	282	138	100	106	215
Diptera	18	15	26	48	119
Coleoptera	158	69	175	200	634

[1]The figures indicate the numbers of animals found per site from a total of 9 pitfall traps per site and 5 weekly sample periods. For transplant dates of sites, see figures 2 or 3 or text.

All the plots contained similar invertebrate orders, with plot H having

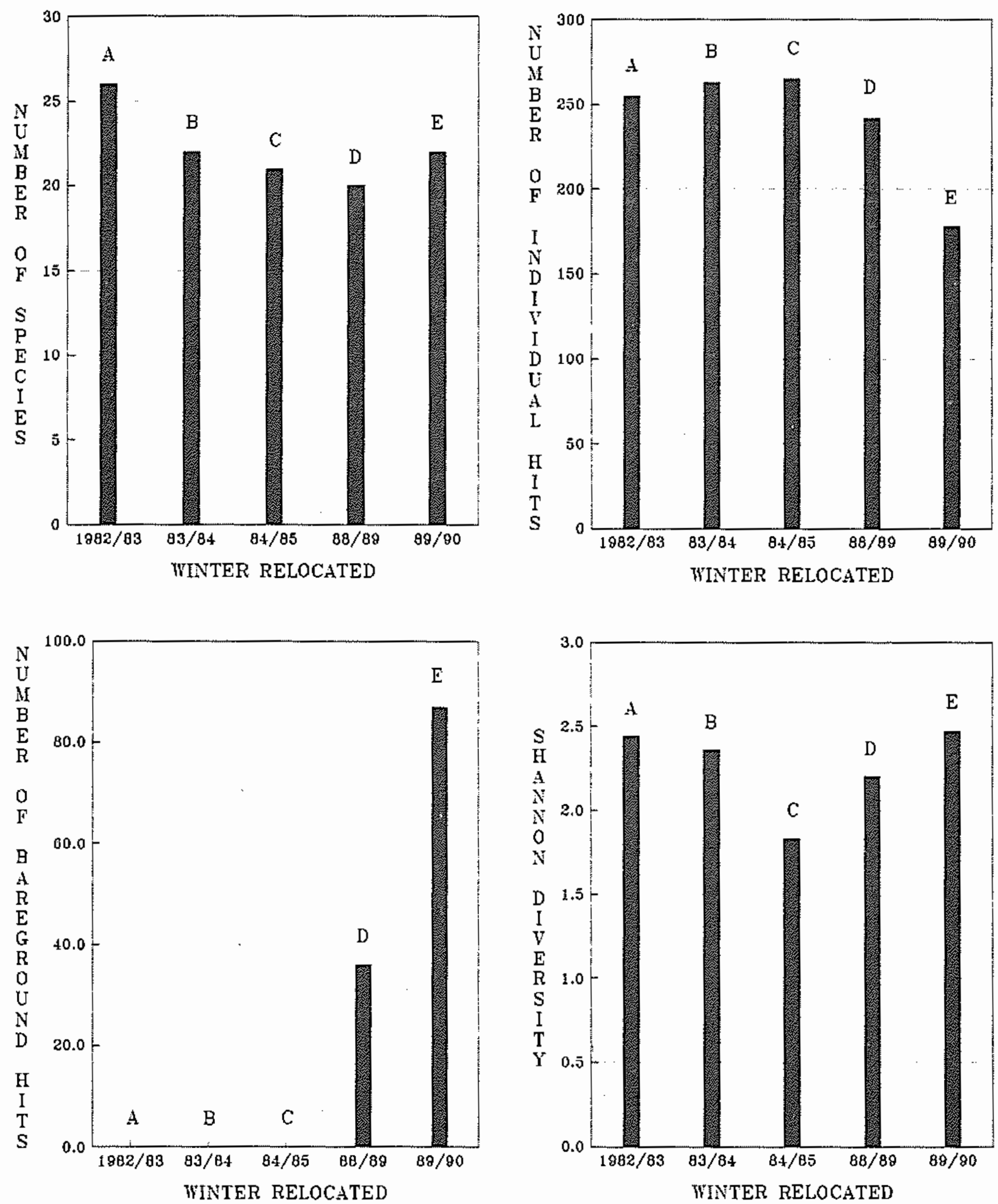

Figure 1. Floral changes with time since relocation. Letters indicate sites, see text for details.

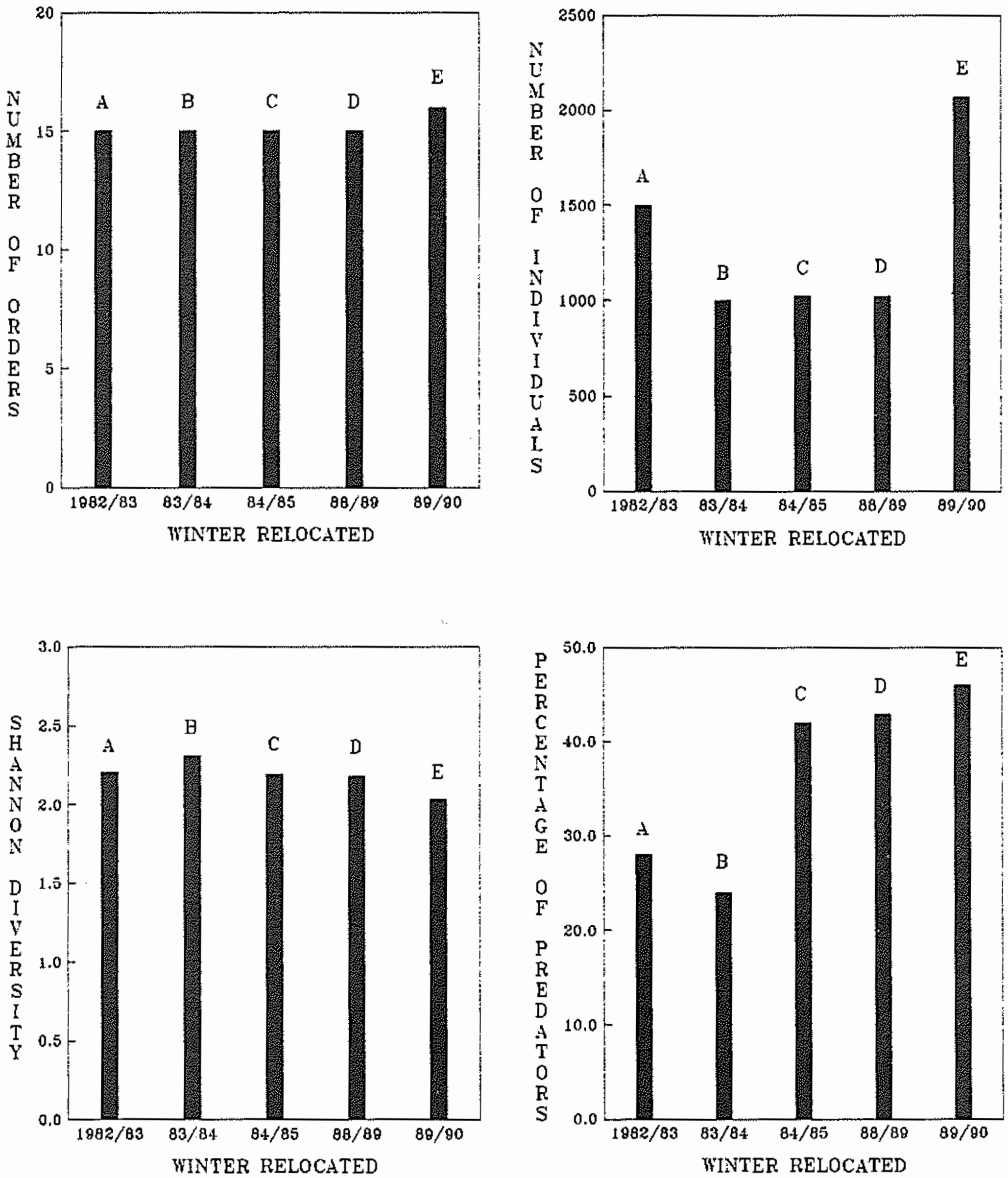

Figure 2. Invertebrate changes with time since relocation. Letters indicate sites, see text for details.

16 compared with the other plots' 15. The numbers of animals were greatest at plot H, followed by a decline to plot B and a rise to plot A (fig. 2). Of the eight insect orders recorded, all were found at the extremes (plots A, B, and H), and seven were found at the intermediate plots (table 1). Again an initial decline in the number of individuals from plot H occurred (to a minimum at plot C), followed by a rise to plot A. The diversities of invertebrate orders (fig. 2) were positively correlated with the time since relocation ($R_s = 0.8999$, $df = 3$, $p = 0.037$).

Discussion-Relocation

Most of the 40 vascular plant species found were typical of calcareous soils (Grime et al. 1990) and more species were found at the oldest relocated plot (fig. 1). Variation between plots may be due to different tolerances to disturbance or the exploitation of new areas (turf edges and gaps). Variation in the individual hits between plots (fig. 1) indicates, in plots A to C, repeat hits on the same plant by adjacent pins (which were not recorded), and in plots G and H repeat hits and hits on bare ground. Bare ground between turfs has been colonized in plots A, B, and C. The lower diversity at plot C may be due to dominant species such as *Carex flacca* (Glaucous Sedge), *Dactylis glomerata* (Cocksfoot) and *Helianthemum nummularium* (Common Rockrose).

The number of invertebrate orders varies little between plots (fig. 2). The number of individuals initially declines with age of turf, from plot H, rising to plot A. Sheppard (1990), in an earlier survey of the site, recorded a decline in species number during the first few years following relocation. The increase in diversity with time since relocation may reflect community stabilization following constancy of management and colonization of bare ground. The proportions of the major predator groups (Opiliones, Araneae, Chilopoda, Carabidae, and Staphylinidae) tend to decline with time since relocation (fig. 2). Pitfall catches increase with abundance and activity; the mobility of some species (Uetz and Unzicker 1976) and the vegetation around the traps (Greenslade 1964) influencing catches. The predators in plots G and H are highly active species; here gaps between the turfs may increase their activity and, thus, capture. Managing grasslands by cutting encourages new plant growth and maintains the sward, benefiting phytophages (Morris and Rispin 1988), which being less mobile than many predators are less likely to be caught in pitfall traps. However, Orthoptera, Lepidoptera larvae, and Pulmonata are more numerous in plots A-C (table 1). The fall and subsequent rise of some invertebrates may be due to initial changes caused by disturbance, followed by recovery with time. Such changes may result from the direct influence of the relocation, or as a consequence of changes in vegetation type and cover (e.g. the changes in the numbers of Hemiptera, which may reflect the availability of food plants).

Both the vegetation and invertebrates show changes in community structure with time since relocation. This may indicate an initial "shock" following relocation. For invertebrates the initial effects may be more traumatic than for plants. Such effects and the availability of new microhabitats (such as bare ground) may alter the community dominance (e.g. by enhancing predator activity). Changes in the vegetation may influence invertebrate herbivores and hence predators, leading to a longer time lag in recovery for invertebrates than for plants. Many such relocations show initial changes in vegetation structure and community dynamics, especially in infilled gaps between turfs (Byrne 1990). At Thrislington Plantation, where relocated turfs are large and limited disturbance is caused, recovery is possible. Some elements of the floral and invertebrate communities appear to have been initially effected by the relocation, although with possible subsequent recovery. At Thrislington Plantation these may be neither catastrophic nor persistent; with time the interturf gaps should be colonized and the area may develop similar communities to those prior to relocation.

Results - Restoration Blasting

Significant differences were found between the areas examined (restoration blast piles, natural daleside, and disused quarries) for vascular plant species number, cover and diversity, total plant cover, and the percentage cover of bare ground (table 2). Significant differences were found between the restoration blast piles for vascular plant and total plant cover (table 2). In both cases RB8/9 was significantly higher than either RB5 or RB7.

Table 2. Analysis of vegetation.

	DIFFERENCES BETWEEN AREA TYPE		DIFFERENCES BETWEEN RESTORATION BLAST PILES	
	Non specific p	Order	Non specific p	Order
Numbers of plant species	0.000	ND > RB > DQ	0.140	No significant difference
Vascular plant cover	0.000	ND > DQ > RB	0.005	RB8/9 > RB5 / RB7
Total plant cover	0.000	ND > DQ > RB	0.006	RB8/9 > RB5 / RB7
Plant diversity	0.038	ND > RB > DQ	0.219	No significant difference
Bare ground cover	0.000	RB > ND / DQ	0.120	No significant difference

The invertebrate data showed significant differences between the types of sites for all aspects except Araneae per trap (table 3). Except for Mollusca per trap, greater numbers were found on the natural daleside, fewer in the disused quarries, and fewer still on the restoration blast piles. This pattern was repeated for the numbers of individuals and orders per trap. The number of Mollusca per trap was significantly higher for both the natural daleside and disused quarries than for the restoration blast piles. Significant differences were found between the restoration blast piles for Isopoda per trap and total individuals per trap (table 3). RB8/9 had significantly more Isopoda per trap than either RB5 or RB7, but this was reversed for total individuals per trap.

Discussion-Restoration Blasting

Since the natural daleside is the oldest site, it may be expected to have the most vascular plant species and highest diversity (table 2). The disused quarries are older than the restoration blast piles but have fewer vascular plant species and lower diversities, possibly due to the blast piles having recently been seeded with a daleside seed mix. The pattern for vascular plant and total plant cover is slightly different. The natural daleside is again the highest, probably due to its age and development. Disused quarries have higher values than the restoration blast piles, possibly reflecting a richer, but more patchy, cover on the latter sites. This is reinforced by the restoration blast piles having the highest percentage cover of bare ground. Davis et al. (1985) recorded that rabbit grazing affects vegetation establishment on bare quarry floors and that levels of bare ground were greater where grazing was not prevented. The restoration blast piles have been subject to severe grazing by rabbits, which may account for the elevated levels of bare ground (table 2). However, the hydroseeding and the cover material used on the blast piles may also have had an influence. Significant differences were found between the restoration blast piles for vascular plant and total plant cover (table 2). RB8/9 have the highest values, probably reflecting the less severe grazing by rabbits here compared with RB5 and RB7.

Table 3. Analysis of invertebrates.

	DIFFERENCES BETWEEN AREA TYPE		DIFFERENCES BETWEEN RESTORATION BLAST PILES	
	Non specific p	Order	Non specific p	Order
Diplopoda/trap	0.002	ND > DQ > RB	0.051	No significant difference
Mollusca/trap	0.000	ND / DQ > RB	0.297	No significant difference
Isopoda/trap	0.000	ND > DQ > RB	0.010	RB8/9 > RB5 / RB7
Araneae/trap	0.161	No significant difference	0.628	No significant difference
Individuals/ trap	0.009	ND > DQ > RB	0.013	RB5 / RB7 > RB8/9
Total Orders	0.000	ND > DQ > RB	0.294	No significant difference

More orders per trap and more animals per trap (except Araneae) were found on natural dalesides than in disused quarries, with fewer still on restoration blast piles. This may be related to age or degree of establishment, the natural daleside being the oldest, most developed site. The communities on the disused quarries have been developing for 37 to 100 yrs, and the restoration blast piles are relatively new (4 to 5 yrs old). In contrast to the establishment of vegetation, which has been actively encouraged on the restoration blast piles, the invertebrates have colonized and established on their own. Time may, therefore, be important in the development of invertebrate communities on restoration blast piles. Several factors may determine the time scale for successful colonization, including proximity of suitable source areas, size of the available species pool, the mobility of animals, and the availability of suitable conditions and resources for the potential colonists. Araneae tend to be very mobile and active, and are often amongst the first predators attempting to colonize new sites (Gorman 1979). This mobility and the close proximity of the natural daleside and disused quarries to the restoration blast sites may account for the lack of significant differences in these animals between the areas. In comparisons of Isopoda between blast piles, RB8/9 had greater numbers per trap than RB5 and RB7, which have a reduced height of standing vegetation as a result of severe rabbit grazing. This has occurred to a lesser extent on RB8/9; the increased cover (table 2) and thus detritus may account for the higher levels of Isopoda here. RB8/9 was also significantly lower in total numbers of individuals per trap than either RB5 and RB7, possibly due to being the youngest site and hence having had less time to recruit animals.

General Conclusions

Grassland management for conservation is often geared to the requirements of plant species or vegetation types rather than those of invertebrates (Rushton 1988). This is certainly the case at Thrislington Plantation. Byrne (1990) stated that little attention was paid to the invertebrate communities at relocated sites. Thrislington Plantation is unusual in the level of monitoring that has taken place during and following relocation. Since the effects of relocations and subsequent management may be greater on the invertebrate communities than on the vegetation, we suggest that future programs monitor both components and consider implementing management strategies to enhance invertebrate conservation. It is also important to recognize that in all cases of extreme management, time considerations are important. This may be especially true for organisms, including invertebrates, that are usually neither introduced nor encouraged by the initial management process. Literature regarding the colonization of disused quarries and restored ecosystems by invertebrates is scant. This is in no small part due to the prevailing attitude that animals play little part in the reconstruction of a properly functioning ecosystem, considering that the first trophic level is the crucial element in any ecosystem. It is hoped that this, and similar, work will encourage a more integrated approach to ecosystem protection and restoration, catering for the necessary interactions between plants and animals during ecosystem development.

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Literature Cited

Ash, H. 1981. Limestone quarry restoration: Report 1: Soils and vegetation. Department of the Environment.

Bailey, D.E., J. Gunn, J. Handley, and S. Shaw. 1991. The construction of limestone ecosystems on quarried rock slopes. p. 13-25. In Proceedings of the Environmental Workshop 1991.(Australian Mining Industry Council, Perth).

Bradshaw, A.D. and M.J. Chadwick. 1980. The restoration of the land. Blackwell Scientific Publications, London.

Brown, A. 1992. The UK environment. HMSO, London.

Byrne, S. 1990. Habitat transplantation in England: A review of the extent and nature of the practice and the techniques employed. England Field Unit Project No. 104, English Nature, Peterborough.

Davis, B.N.K., K.M. Lakhani, M.C. Brown, and D.G. Park. 1985. Early seral communities in a limestone quarry: An experimental study of treatment effects on cover and richness of vegetation. J. of App. Ecol. 22:473-490. http://dx.doi.org/10.2307/2403179

Gagen, P.J. and J. Gunn. 1987. Restoration blasting in limestone quarries. Explosives in Eng. 1(1):14-15.

Gorman, M. 1979. Island ecology. Chapman and Hall, London

Greenslade, P.J.M. 1964. Pitfall trapping as a method of studying populations

of Carabidae (Coleoptera). J. Anim. Ecol. 33:301-310.
http://dx.doi.org/10.2307/2632

Grime, J.P., J.G. Hodgson, and R. Hunt. 1990. The abridged comparative plant ecology. Unwin Hyman, London.

Gunn, J., and D.E. Bailey. 1991. Limestone quarrying and limestone quarry reclamation in Britain. In V. Sauro, A. Bordesan, and M. Meneghel. (eds.), Proceedings of the International Conference on Environmental Changes in Karst Areas. (University Di Padova, Italy).

Magurran, A.E. 1988. Ecological diversity and its measurement. Croom Helm, London.

Meddis, R. 1984. Statistics using ranks: a unified approach. Blackwell, Oxford.

Morris, M.G. and W.E. Rispin. 1988. A beetle fauna of oolitic limestone grassland and the responses to conservation management by different cutting regimes. Biological Conservation 43:87-105.
https://doi.org/10.1016/0006-3207(88)90084-5

Park, D.G. 1988. Limestone grassland relocation technique and practice. M & Q Environment 2(4):18-22.

Park, D.G. 1989. Relocating magnesian grassland. p 264-280. In G.P. Buckley (ed.), Biological habitat reconstruction. Bellhaven Press, London.

Richardson, J.A. 1984. Some pioneer investigations with Professor Harrison on pit heaps and magnesian limestone sites in County Durham. Vasculum 69:25-35.

Rushton, S.P. 1988. The effects of scrub management regimes on the spider fauna of chalk grasslands, Castor Hanglands National Nature Reserve, Cambridgeshire, UK. Biological Conservation 46:169-182.
http://dx.doi.org/10.1016/0006-3207(88)90066-3

Sheppard, D.A. 1990. Changes in the fauna of magnesian limestone grassland after transplantation: Preliminary observations at Thrislington Plantation. p 171-172. In S.H. Hillier, D.W.H. Walton, and D.A. Wells (eds.), Calcareous grasslands ecology and management. Bluntisham Books, Huntingdon.

Uetz, G.W. and J.D. Unzicker. 1976. Pitfall trapping in ecological studies of wandering Spiders. J. of Arachnol. 3:101-111.