

Ecological restoration of sandstone quarry sites: a systematic review of literature

Barnaby Letheren, School of the Environment and Natural Resources,
Bangor University

Supervisor: Dr John R. Healey

Project Manager: Dr Fergus L. Sinclair (f.l.sinclair@bangor.ac.uk)



Sponsored by



SYSTEMATIC LITERATURE REVIEW

DOES THE ACTIVE REHABILITATION OF SANDSTONE QUARRY SITES OFFER GREATER BENEFITS FOR BIODIVERSITY THAN NATURAL SUCCESSION?

This systematic review was undertaken by Barnaby Letheren as part of his MSc at Bangor University, a study of options for ecological restoration of sandstone quarry sites in Rajasthan commissioned by Marshalls. Barnaby attended a module run by the Centre for Evidence-Based Conservation (CEBC) at Bangor and subsequently completed the review using their methodology, under the supervision of Dr John R. Healey. Some of the text of this version has been edited to ensure consistency amongst project documents.

Reviewer:	Barnaby Letheren
Supervisor:	Dr John R. Healey
Postal address:	School of the Environment and Natural Resources Bangor University Deiniol Road Bangor Wales LL57 2UW
Project contact:	Dr Fergus L Sinclair (f.l.sinclair@bangor.ac.uk)

CONTENTS

1. BACKGROUND.....	2
2. OBJECTIVE OF THE REVIEW	5
2.1 Primary question.....	5
2.2 Review methods employed	6
2.2.1 Literature searching	6
2.2.2 Search strings.....	6
2.2.3 Study inclusion criteria.....	6
2.2.4 Study quality assessment	7
2.2.5 Data extraction strategy	7
2.2.6 Data synthesis	7
3. RESULTS	7
3.1 Review statistics	7
3.2 Discussion of results.....	8
3.2.1 Landscaping	8
3.2.2 Soil management and additions.....	9
3.2.3 Organic matter application.....	12
3.2.4 Mycorrhizal studies	15
3.2.5 Planting of seeds and seedlings	16
3.2.6 Natural succession	19
3.2.7 Faunal colonisation.....	21
3.2.8 Other studies	23
4. CONCLUSIONS.....	24
APPENDIX I - SYSTEMATIC REVIEW PROTOCOL DATA EXTRACTION SHEET	28

1. BACKGROUND

Rajasthan, in north-west India, has a long history of anthropogenic pressure on its flora and fauna (Gupta, 1968; RPCB, 2007). Agriculture, grazing, clearance of vegetation cover and the gathering of fuelwood and fodder have all caused significant declines in biodiversity (Chopra and Gulati, 1998; RPCB, 2007).

Extractive industries such as mining and quarrying also have a long history in Rajasthan including the oldest lead and zinc mines in the world located at Zawar. The area of land affected by extraction operations is likely to increase as the state has the second richest mineral deposits in India (after Bihar) but currently ranks only fifth in total extraction. Sandstone is a major resource in the area and extraction from Rajasthan accounts for about 70% of India's total production (Rajasthan Government, 2008). The area affected by this industry is substantial and growing. In the Bijolia region of Rajasthan sandstone quarrying only covered an area of around 0.84 km² in 1971, this increased to 12.04 km² in 1984 and 30.83 km² in 1991. Forest area and the quality of forest habitat in the region decreased proportionally during the same period (Sinha *et al.*, 2000).

The environmental impacts of quarry operations can be large and far-reaching. For example, an assessment of sandstone mining in Jodpur found large impacts on the hydrology of an extensive area arising from mining operations (Bhadra *et al.*, 2007). But the most obvious and dramatic impacts are usually the disturbance to vegetation at the quarry site leading to loss of habitat for local flora and fauna. Since it is not possible to avoid destroying habitat during the mining operation, options for mitigation lie in protection of alternative areas or rehabilitation of sites after operations cease. Quarry sites usually operate for something between two and about 20 years, and rehabilitation offers a way of returning abandoned sites to a more desirable ecological state. Rehabilitation is defined by Walker and del Moral (2003) as any manipulation of a successional sequence that enhances its rate or deflects its trajectory towards a specified goal.

Rehabilitation is a prerequisite of being granted an extraction licence in India (National Mineral Policy 1993 sections 7.13.2 and 7.13.3) although this is rarely, if ever, enforced and is broadly ignored by extraction companies. However, with the increasing public and political interest in environmental matters, and the growing shortage of land retaining natural ecological functionality, there is growing pressure for rehabilitation to be undertaken.

Habitat restoration and the rehabilitation of degraded land is complex, difficult and subject to numerous stochastic factors, including climate. There have been several attempts to produce broad protocols for rehabilitation (e.g. Aronson *et al.*, 1993; Hobbs and Harris 2001; Martínez and López-Barrera, 2008) as well as many scientific articles and several scientific journals dedicated to rehabilitation research. The results of these studies are varied and often site- and species-specific.

The present critical review of existing literature aims to give a good indication of the strategies that have the best chance of success in the area of interest. The review forms part of a study into possible rehabilitation strategies for sandstone quarry sites near the town of Kota in south-east Rajasthan. These quarries are located in a semi-arid area and so the review will focus on rehabilitation of degraded land, especially land degraded through quarrying and mining, in semi-arid zones. Conclusions from the review will be combined with environmental information collected at the site to inform restoration action.

REFERENCES

- Aronson, J., Floret, C., LeFloc'h, E., Ovalle, C. and Pontanier, R. (1993). Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the South. *Restoration Ecology* **1**: 8-17.
- Bhadra, B.K., Gupta, A.K., Sharma, J.R. and Choudhary, B.R. (2007). Mining activity and its impact on the environment: Study from Makrana marble and Jodhpur sandstone mining areas of Rajasthan. *Journal of the Geological Society of India* **70**: 557-570.
- Chopra, K. and Gulati, S.C. (1998). Environmental degradation, property rights and population movement: hypothesis and evidence from Rajasthan (India). *Environment and Development Economics* **3**: 35-57.
- Gupta, R.K. (1968). Anthropogenic influences on the vegetation of Western Rajasthan. *Plant Ecology* **16**: 79-94.
- Hobbs, R.J. and Harris, J.A. (2001). Restoration ecology: repairing the Earth's ecosystems in the new millennium. *Restoration Ecology* **2**: No. 2: 239-246.
- Martínez, M.L. and López-Barrera, F. (2008). Special issue: Restoring and designing ecosystems for a crowded planet. *Ecoscience* **15**: No. 1: 1-5.
- Rajasthan Government. (2008). www.rajasthan.gov.in/rajgovresources. Last accessed 30/04/2008.
- RPCB. (2007). Rajasthan State Pollution Control Board. State of the environment report for Rajasthan: 2007. <http://rpcb.nic.in/>. Last accessed 04/05/2008
- Sinha, R.K., Pandey, D.K. and Sinha, A.K. (2000). Mining and the environment: a case study from Bijolia quarrying site in Rajasthan. *The Environmentalist* **20**: 195-203.

Walker, L.R. and del Moral, R. (2003). Primary succession and ecosystem rehabilitation.
Cambridge University Press.

2. OBJECTIVE OF THE REVIEW

2.1 Primary question

This review focuses on the question: does the active rehabilitation of sandstone quarry sites offer greater benefits for biodiversity than natural succession? This means that a series of potential interventions are reviewed in relation to desirable outcomes (Table 1).

Table 1. Interventions and outcomes considered in the review.

Subject	Intervention	Outcomes
Disused sandstone quarry sites in semi-arid environments	<p>Soil</p> <ul style="list-style-type: none"> • Addition of top soil • Soil ripping • Organic matter addition • Fertiliser application • pH control <p>Planting</p> <ul style="list-style-type: none"> • Direct seeding • Other planting • Leguminous species • Nurse species/facilitators <p>Invasive species control</p> <ul style="list-style-type: none"> • Herbicide application • Manual control <p>Disturbance regulation</p> <ul style="list-style-type: none"> • Grazing exclusion • Grazing regulation • Human access regulation <p>Landscaping</p> <ul style="list-style-type: none"> • Micro habitat creation • Cliff face blasting • Water capture/retention measures <p>Propagules</p> <ul style="list-style-type: none"> • Provision of soil with seed bank • Addition of propagule laden vegetation 	<p>Vegetation</p> <ul style="list-style-type: none"> • Biomass accumulation • Species richness and diversity • Structural complexity <p>Ecological functionality</p> <ul style="list-style-type: none"> • Soil formation • Soil nutrient enrichment • Water interception/retention • Erosion control • Species turnover

2.2 Review methods employed

2.2.1 Literature searching

The following on-line data-bases of peer reviewed journals were searched.

ISI Web of Knowledge:

ISI Web of Science; Science Citation Index and Social Science Index. All years.

ISI Proceedings; Science and Technology Proceedings

Science and Technology (STP), 1990-present

2.2.2 Search strings

The following search strings were used to identify articles.

1. (quarry OR mine) AND (restor* OR rehab*)
2. (quarry OR mine) AND (restor* OR rehab*) AND (semiarid OR semi-arid OR steppe)
3. (quarry OR mine) AND soil AND (organic matter OR fertilize*)
4. (quarry OR mine) AND (nurse speci* OR facilitat*)
5. (quarry OR mine) AND (afforestation OR plant* OR vegetat*)
6. (quarry OR mine) AND (soil rip* OR compact*)
7. (quarry OR mine) AND (ph OR acid* OR alkal* OR base) AND soil*
8. (quarry OR mine) AND conservation
9. (quarry OR mine) AND environment
10. (quarry OR mine) AND invasive*
11. (quarry OR mine) AND (graze* OR disturb*)
12. (quarry OR mine) AND (landscaping OR habitat)
13. (quarry OR mine) AND (seed bank OR propagule)

2.2.3 Study inclusion criteria

The articles were initially scanned by title and abstract by the reviewer for general relevance after export to Endnote Web. Those identified by this initial screening were then read fully. Studies on rehabilitation of any land degraded to the point where no biological legacy remains were considered, with particular emphasis given to sandstone quarry/mine sites in semi-arid regions. Ideal comparators would be primary succession (without intervention) on homogeneous areas.

Outcomes of the studies include the RESTORATION of desirable ecological processes such as; vegetative community diversity and/or rarity, vegetation structure, species turnover, water retention, erosion control, habitat provision and the time taken (or predicted) for these

processes to become self sustaining. Less weight was given to studies concerned with acid and heavy metal contamination as these are not relevant to the type of quarrying that is of interest to this study.

Heterogeneity is a potential problem as sites vary in climactic conditions and local environmental factors such as the distance from the nearest seed source, hydrological and edaphic factors, grazing pressure, availability of seed dispersers and pollinators, etc. Also as primary succession and rehabilitation occur over relatively long time scales, stochastic factors become increasingly important in causing variation between sites.

2.2.4 Study quality assessment

All the studies were assessed for quality by the reviewer. For studies where there was uncertainty the reviewer sought a second opinion.

2.2.5 Data extraction strategy

Identified studies were read and the data extracted by the reviewer. A data extraction form was created to allow recording. This form was checked for appropriateness and comprehensiveness by pilot usage. This was used to record information on rehabilitation strategies employed and their outcome.

2.2.6 Data synthesis

The data that was extracted was not suitable for meta-analysis due to the wide range of focus, methodology and results. The results of the data extraction are therefore qualitatively evaluated and discussed below.

3. RESULTS

The data extraction sheets summarising information in the reviewed articles are reproduced in Appendix 1. The numbers of articles on different aspects of the review are set out in Section 3.1 and a qualitative evaluation of their content by subject area is set out in Section 3.2.

3.1 Review statistics

The initial search returned 7 392 references (excluding duplicates). These were scanned by title for relevancy, leaving 960 references. Scanning by abstract reduced the number to 372.

These were read and a further 58 were eliminated, leaving 314 references included in the final review. Key information was extracted from these articles using the data extraction sheet (Appendix 1). The studies were too diverse in their focus and methodology to allow for meta-analysis so qualitative evaluation by subject area was completed.

The articles were allocated to a subject category according to their major focus to facilitate comparative analysis but there is some overlap amongst these categories because many articles dealt with more than one factor. The numbers of studies in each group were as follows:

- Landscaping- 11
- Soil management and additions- 91
- Organic matter application- 64
- Mycorrhizal studies- 41
- Planting of seeds and seedlings- 55
- Natural succession- 32
- Faunal recolonisation- 37
- Other studies- 26

The results are discussed under these headings below.

3.2 Discussion of results

The range of studies that have been conducted on mine sites is significant. They are highly diverse in their approach to rehabilitation and the methodologies applied. Natural succession on mine sites has also been intensively studied, however few direct comparisons between succession and rehabilitation exist. A more common strategy for studies of substrate amendments is to use a control site which does not receive the intervention being tested. For studies focusing on vegetation, the usual approach is to compare the sites being restored to reference areas with minimal anthropogenic impact.

3.2.1 Landscaping

Landscaping involves the shaping of the site under rehabilitation for a number of purposes. Landscaping can be done to re-contour the site to blend in with surrounding terrain for predominantly aesthetic reasons (Gunn and Bailey, 1993). It can also be done to reduce slope angle which can aid water and propagule capture and retention, control erosion and reduce leaching of any soil amendments.

Results of plant survival and establishment are somewhat mixed. Badia *et al.* (2007) found no effect on woody plant survival of slope and, although growth was restricted, it was similar to reference areas. Zeleznik *et al.* (1996) found results which were highly species-specific when comparing levelled and unlevelled sites. Jim (2001) found very low survival but this was blamed on shallow, nutrient poor soils.

Cullen *et al.* (1998) used blasting to create micro habitats and created vegetation communities similar to reference areas in two years. Gao *et al.* (1998) also found that landscaping, in combination with other restoration actions, had created a site comparable with reference areas within five years. Wheeler *et al.* (2000) found that blasted sites were floristically more similar to reference areas than unblasted sites, supporting an earlier study (Wheeler *et al.*, 1997) which found that blasted sites had lower richness and diversity than surrounding areas but were establishing well.

Contouring was found to aid establishment and germination (Windsor and Clements, 2001) and created vegetation communities that converged with reference areas (Hatton and West, 1987).

3.2.2 *Soil management and additions*

Studies on soils form the bulk of the work that has been done on rehabilitation. However this research is complicated by the high level of variability within mine soils (Dimitrakopoulos and Mackie, 2003).

Surprisingly few studies have focused on natural development of soils on mine sites. Yuan *et al.* (2006) found that soil formation was surprisingly rapid, with plant growth being significantly correlated with soil depth. Abakumov (2008) found that soil organic matter (SOM) and soil organic carbon (SOC) increased over time and were correlated with vegetative development. Baig (1992) found that soil structure and fertility improved even in harsh conditions over time. Li and Daniels (1994) studied a chronosequence to assess nitrogen availability and found high levels in all ages but increasing abundance of plant available forms in older sites. Mott and Zuberer (1991), working in arid areas, found that microbial levels recovered after around one and a half years. However Rao *et al.* (2000) working in a limestone quarry found that after five years microbial activity was still significantly lower than in reference areas and recommended waiting some time for natural recovery before implementing management action.

Soil compaction is a significant problem with mine soils and is a barrier to plant establishment and growth (Monterroso *et al.*, 1998; Graves *et al.*, 2000; Conrad *et al.*, 2002;

Burke, 2008). One method of reducing this problem is changing the way in which soils are handled (Ramsey, 1986). Another is soil ripping, which can benefit plant establishment and growth (Ashby, 1997; Koch *et al.*, 2004; Croton and Ainsworth, 2007) by improving soil structure (Fulton *et al.*, 2002; Fulton and Wells, 2005; Sinnott *et al.*, 2006) and water infiltration (Chong and Cowser, 1997). A problem with this technique is that mixing soils can reduce plant available nutrients (Bateman and Chanasyk, 2001). However Curtis and Claassen (2005) combined ripping with compost additions and found that plant available water doubled, in comparison with control sites, and plant biomass increased four-fold.

Replacement of topsoil is also well studied although the origin of the top soil and the way it is applied has a large impact on its structure and fertility. When soils are removed from mining areas and stockpiled they lose fertility rapidly (Harris and Birch, 1989; Ghose, 2004), viable seed banks are reduced (Koch, 1996), erosion and runoff increases (McIntosh and Barnhisel, 1993; Leavitt *et al.*, 2000), nitrogen levels and water retention reduce (Antonopoulos and Wyseure, 1998), compaction increases (Schwenke *et al.*, 2000) and mycorrhizal densities reduce (Reddell and Milnes, 1992). However Moynahan *et al.* (2002) found that topsoil applications had a great effect on microbial population recovery. Graham and Haynes (2004) measured a range of soil properties and found that stored soils had very low fertility, especially carbon, but that all measured properties, including organic matter and microfauna, recovered after 25 years. Martinez-Ruiz and Fernandez-Santos (2005) studied natural succession on a mine after topsoil application and found that revegetation was successful although species composition differed from reference areas. However Hatton and West (1987) found that although storage of topsoil slowed succession, the site converged floristically with reference areas over time.

Koch (2007) tried transferring soil from unmined areas to revegetate a mine site. Although 70% of the understory recovered, woody species did not establish well in the long term. Ward *et al.* (1997) investigated the best practices to transfer topsoil from unmined areas to preserve maximum seed bank viability. They found large differences with seasonality and different sites. They concluded that the ideal method was collecting topsoil post seed-set and spreading it as soon as possible prior to the wet season.

The depth of the topsoil used has a large effect with deeper soils being more fertile, retaining more water and supporting greater biomass although this can lead to lower diversity (Redente *et al.*, 1997; Holmes, 2001; Bowen *et al.*, 2005). Schladweiler *et al.* (2005) found that 30 cm of topsoil produced the greatest diversity but 56 cm supported the greatest biomass,

even exceeding reference areas. They recommended a range of depths for the best combination of diversity and biomass.

Many studies have attempted to improve mine soil with a range of amendments. As mentioned above, soil depth, structure and low fertility are significant barriers to plant establishment and growth. Jochimsen (2001) studied the effect of adding sand to mine sites, then fertilizing and sowing. The results were mixed and it was thought that local conditions had a greater effect than RECLAMATION actions, however there was a general improvement over time. Dudeney *et al.* (2004) had good results when sand was mixed with wetland sludge, suggesting that an organic matter component could be crucial.

Organic, mineral and chemical fertilizers have been used to attempt to increase fertility. Organic amendment will be dealt with in the next section but it is worth noting that the major difference between the three forms of nutrients seems to be their longevity of effectiveness. Chemical fertilizers have probably the strongest effect but without repeat applications the effects are short-lived (Gardiner, 1993; Wilden *et al.*, 1999; Wilden *et al.*, 2001). This may be due in part to the rapid leaching of these fertilizers from soils. Hartmann and Keplin (2003) compared chemical fertilizers and mineral fertilizers and found that the mineral fertilizers sustained higher levels of plant available nutrients over time although soil water was an influential factor. This contrasts with the findings of Reeder and Berg (1977) who compared nitrogen availability from chemical and mineral sources and found that chemical fertilizers provided higher levels of plant available nitrogen. Feagley *et al.* (1994) found that the high nutrient release of chemical fertilizers was essential for plant establishment.

Fertilizing has a definite positive effect on plant growth (Singh *et al.*, 2000; Singh and Singh, 2001): however this can be problematic as it can promote the growth of exotic species over more desirable native ones (O'Dell and Claassen, 2006a; O'Dell and Claassen, 2006b). Phosphorus additions aid plant establishment and nitrogen additions increase growth (Fierro *et al.*, 1999). A possible alternative to fertilizer is the use of bacteria (Grandlic *et al.*, 2008) or microbial inoculation (Petrisor *et al.*, 2004).

Fertilizer has also been used in combination with other restoration actions. Combinations of fertilizing, grazing exclusion and seeding were tested, showing positive effects of all the treatments, which increased when two were combined and were maximised with all three combined (Davis *et al.*, 1985; Davis *et al.*, 1993). Figge *et al.* (1995) tested the effect on germination of fertilizer combined with topically added (mixed into substrate) expanded clay (strong effect) and porous ceramic (less effect). A wide scale experiment was carried out by

Marsden (1987) using a combination of soil ripping, windbreaks, lime and fertilizer additions. This was successful after some ongoing modifications to the methodology.

Hydro-gel has also been used to attempt to improve soil water holding capacity. Rowe *et al.* (2005) found no benefit from hydro-gel applications. Clemente *et al.* (2004) had some success but results were species-specific and plant provenance was thought to be a more important factor. Kahl *et al.* (2000) used hydro-gel as part of an intensive restoration effort which was successful although the contribution of hydro-gel to its success is not clear.

Soil bacterial diversity increases according to the progress of RECLAMATION (Yin *et al.*, 2000). This increase is linked to the age of the site, with the build up of soil organic matter and nitrogen being the most important factors (Mummey *et al.*, 2002a). However plant establishment and rooting are important factors, so responses are species-specific with shrubs being particularly beneficial (Mummey *et al.*, 2002b).

Mine sites have also been identified as a possible carbon sink. Soil organic carbon builds up over time (Akala and Lal, 2000) and this could be a small but significant contribution to carbon fixation in light of climate change. Shrestha and Lal (2006) estimated that 16 Tg of CO₂ could be offset annually in the United States from land restoration using grassland and forest but reported that more research was needed.

3.2.3 *Organic matter application*

The problems of soil depth, structure, fertility and water holding capacity can all be reduced with the addition of organic matter to the soil (Reid and Neath, 2005a; Reid and Neath, 2005b). The length of time that various types of amendments have an effect for is variable, with compost>sewage sludge>fertilizer (Wilden *et al.*, 1991; Wilden *et al.*, 2001).

The most commonly tested form of organic matter addition is through biosolids or sewage sludge. These can have a beneficial effect on plant growth (Johnson, 1998; Kothari and McNearny, 1998; Thorne *et al.*, 1998; Brofas *et al.*, 2000; Kahl *et al.*, 2000; Han *et al.*, 2004; Felix *et al.*, 2008) although, as with fertilizer, this can negatively affect species richness (Moreno-Penaranda *et al.*, 2004) and diversity (Martinez *et al.*, 2003). Ye *et al.* (2001) found that mixing 50% (v/v) sewage sludge and mine tailing gave the greatest rate of growth and total biomass. The sludge provided carbon, nitrogen, phosphorus and potassium. Sydnor *et al.* (2002), however, compared biosolids and mushroom compost for effects on plant biomass accumulation and found that mushroom compost was more effective.

Bendfeldt *et al.* (2001) found a large positive effect on soil quality, with the application of sewage sludge in the first five years, but untreated soils had recovered to the same level after

sixteen years. Sewage sludge application improves soil aggregation although after the first year these effects decline rapidly (Sort and Alcaniz, 1999).

A potential problem with sewage sludge and biosolids is contamination with heavy metals and other pollutants. Alberici *et al.* (1989) found that heavy metal levels were within safe limits in soil, vegetation and voles on land reclaimed with biosolids. Almendro-Candel *et al.* (2007) found no problem with heavy metals although ammonium nitrate levels were high. Rate *et al.* (2004) and Evanylo *et al.* (2005) found that metals were higher in plant tissues but were within safe limits and were not detrimental to growth. Jordan *et al.* (2008) found no problems except for electrical conductivity, which was initially high although dropped rapidly. Soluble salts were found to inhibit plant growth without high levels of irrigation (Rodgers and Anderson, 1985). A leaching column experiment by Santibanez *et al.* (2007) found high levels of nitrate leaching although mixing and seeding reduced the problem. Seaker (1991) monitored zinc, copper, cadmium and lead levels, finding a small increase in plant tissue levels but no affect on ground water as metals remained mainly in the soil layer. Sopper (1992) also sampled vegetation, groundwater and soils for pH, nitrate and heavy metal contamination twelve years after restoration and found no significant levels. Tian *et al.* (2006) found an increase in ammonium levels in the catchment but these remained within safe limits.

Stehouwer *et al.* (2004) however found that pH decreased and nitrates and heavy metals in leachates were a significant problem at least in the short term. Molina *et al.* (2000) measured levels of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F) pollution in mine soils amended with sewage sludge and found persistently high levels. Zhang *et al.* (2008) experimented with stabilizing sewage sludge with fly ash and found that at a ratio of 1:1 pH tended towards neutrality and heavy metal concentrations were kept low. This may represent a possible way of controlling potential problems.

As with plant diversity Andres (1999) found that low application rates of sewage sludge promoted micro-arthropods but high levels reduced diversity. Moynahan *et al.* (2002) also found an increase in soil microbiota with farmyard slurry applications, although top soil additions had a more beneficial effect. Ruzek *et al.* (2003), however, found that of the soil amendments tested sewage sludge gave rise to the highest soil carbon levels and microbiological activity. Tak and Rao (2001) showed that the effects are specific to different sites. On gypsum mines sewage sludge gave rise to the highest levels of microbiological activity, while on limestone mines farmyard manure combined with top soil addition produced the best results. Plant growth was correlated with microbiological activity on all sites. Sites reclaimed with various forms of organic matter were sampled for ground beetle diversity by

Kielhorn *et al.* (1999). The highest rate of colonization was on sewage sludge sites followed in decreasing order by compost, mineral fertilizer and unameliorated sites.

Other forms of organic matter additions have also been tested. On a semi-arid site Barbera *et al.* (2005) compared mycorrhizal inoculation, planting in polypropylene tunnels, planting furrows and fresh and composted organic matter for effects on the growth of *Pinus halepensis*. They found that fresh and composted organic matter applications were the only effective treatment. Curtis and Claassen (2005) found that combining soil ripping and composting had a large positive effect on plant establishment and growth by improving soil water capacity. Composting also improved plant cover and biomass of native seeded grasses (Noyd *et al.*, 1995a; Noyd *et al.*, 1996). Mixing wetland sludge with sand had good results, promoting the growth of perennial ryegrass, compared to weathered sludge or wood chippings as the later decomposed slowly (Dudeney *et al.*, 2004). However Schoenholtz *et al.* (1992) found that woodchips increased soil nitrogen and carbon and enhanced plant growth over three years. Schuman and Belden (1991) also found that buried litter bags with woody residue decomposed rapidly. Woodchips were found to enhance the establishment of grasses by van Rensburg and Morgenthal (2004), although concerns were raised about long term C:N ratios, and composting before application was recommended. Responses of plants were species-specific but, as with other amendments, mid-range levels of application supported the highest levels of diversity, cover and biomass. High levels generally benefited exotic species over native ones (Smith *et al.*, 1985; Smith *et al.*, 1986).

Grant *et al.* (2002) found beneficial effects of using mulch on the survival and growth of plants on mine tailings. A strong positive effect on plant establishment and growth from adding paper de-inking sludge to an abandoned sandpit has been recorded (Fierro *et al.*, 1997; Fierro *et al.*, 1999). Green and Renault (2008) also recorded a large benefit for plant growth when paper mill sludge was combined with fertilizer. Camberato *et al.* (2006) found an improvement in soil structure and water-holding capacity when paper mill by-products were added but found that nitrogen and phosphorus immobilization was problematic. Feagley *et al.* (1994) found this could be overcome by adding fertilizer along with the sludge.

Sewage sludge mixed with green manure were shown to be effective at controlling leaching, erosion and soil hydrology by Harris (2001) and Harris and Megharaj (2001). Lunt and Hedger (2003) used organic matter in the form of leaf mulch which improved growth and nutrient uptake in oak seedlings.

Hay mulch was successful at kick starting the accumulation and activity of soil microbes (Machulla *et al.*, 2005). Walker and Powell (2001) mixed straw with various substrates, to

attempt to improve water holding capacity of the substrates, but did not find any significant difference from straw additions in their results.

Sharma *et al.* (2000) combined legume planting with planting of native plants, rainwater harvesting and manure application and the results were good levels of growth of planted species supported by natural succession. Pig slurry combined with straw was effective in promoting plant establishment and growth even though soil crusting was observed (Salazar *et al.*, 2002). Fisher *et al.* (2000) combined lime with organic matter to raise soil pH on an acidic site: all the treatments showed some increase in pH, leading to soils better able to support plants. Walker (2003) noted that the incorporation of composted organic matter inhibited growth of *Pinus jeffreyi* and caused high seedling mortality. Poor water relations were thought to be the cause.

3.2.4 Mycorrhizal studies

Mine soils, especially if they have been stockpiled, often have a low occurrence of mycorrhizal fungi (Diaz and Honrubia, 1993; Diaz and Honrubia, 1994; Azcon-Aguilar *et al.*, 2003). These fungi can be beneficial, sometimes essential, for plant growth especially in harsh and dry environments (Bellgard, 1991; Jha *et al.*, 1995; Pattanaik *et al.*, 1995; Reddell *et al.*, 1999; Rao and Tak, 2001; Rao and Tak, 2002; Chen *et al.*, 2008).

However, mycorrhizal survival and root infection, and its effects on plant establishment and growth, are variable and it is clear that careful selection of mycorrhizal strains and timing of application are needed (Dodd and Thompson, 1994; Corbett *et al.*, 1996; Thorne *et al.*, 1998; Bell *et al.*, 2003).

Beckjord and McIntosh (1984) found a significant effect from inoculation on clear felled sites but no effect on mine soils. Barbra *et al.* (2005) also found no benefit from inoculation on mine sites. Frost *et al.* (2001) found no effect from inoculation but sampling over fourteen years noted that as soil structure improved, mycorrhiza colonized naturally. Gould *et al.* (1996) also found low survival after inoculation but after one year levels of infection were increasing rapidly. Comparing early and late stage successional plants on mine spoil, Johnson (1998) and Kasowska (2002) found low levels of mycorrhizal association in early stages but high levels in late stages of succession. In an experiment combining landscaping, fertilizing, sowing and inoculation, Gao *et al.* (1998) found that the vegetation of the site approximated that of the reference area after around five years. Jasper *et al.* (1988) found a strong response in plant growth to mycorrhizal inoculation when combined with additions of phosphorus. Nitrogen became the limiting factor over time.

Combining inoculation with the addition of organic matter can greatly enhance the success rate (Biro *et al.*, 1993; Lunt and Hedger, 2003). In a range of experiments testing the effects of fertilizer, compost and inoculation with arbuscular mycorrhiza, little effect was found on plant growth from inoculation except to extend root growth (Noyd *et al.*, 1995a; Noyd *et al.*, 1995b; Noyd *et al.*, 1996). Walker (2003) found no effect on plant survival or growth; poor water relations were thought to be responsible. White *et al.* (1992) found no increase in the rate of root colonization by mycorrhiza with fertilization, although irrigation, while not affecting density of mycorrhiza, did increase levels of colonization. Inoculating soils on Mt St Helens had no effect on plant survival or growth when early successional species were planted (Titus and del Moral, 1998).

Using mycorrhiza of local provenance increases their survival in soils. They also colonize local plant species more readily. Rydlova and Vosatka (2001) found low colonization and little effect on plant growth from inoculation, although native mycorrhizal strains performed better than exotics. Using soils taken from revegetated areas as a source of inoculum worked effectively, although plant species covering the revegetated areas were an important factor (Mehrotra, 1996).

Ruzek *et al.* (2003) found that inoculation encouraged microbiological activity. Brundrett *et al.* (1996) compared disturbed and reference areas and found that mycorrhizal associations showed some correlation with improvements in soil structure. McEwan *et al.* (1999) found that the survival and inoculation levels of mycorrhiza in planted *Frankia* were very low but increased in the presence of *Alnus rubra*.

Natural colonization of mycorrhiza can be rapid and beneficial for plant growth without management (Mehrotra, 1998). Pushel *et al.* (2008) compared artificial inoculation with natural colonization and found that development was rapid in both treatments but responses were plant species-specific. Tarafdar and Rao (1997) also found several functional groups of mycorrhiza in naturally colonized mine spoils although they suggested that inoculation could be effective as a restoration strategy. Ganesan *et al.* (1991) surveyed coal, calcite and lignite mine spoils that had been colonized naturally and found high levels of mycorrhizal fungus present and infecting plants.

3.2.5 *Planting of seeds and seedlings*

Species selection

The ultimate aim of most restoration projects is to establish a sustainable vegetation cover on mine sites. The type of vegetation depends on the goals of the restoration project and is usually

one of two options. One is to produce a commercially valuable species, often timber, an agricultural crop or forage for grazing. The second is to produce a vegetative assemblage of conservation value. A direct way to promote either of these options is to plant seeds or seedlings of the desired species, although varying degrees of success have been achieved with this approach.

A crucial factor for the success of establishing vegetation is to identify suitable species to plant (Sharma *et al.*, 2000; Halofsky and McCormick, 2005b). Native plants are often tolerant of the local environmental conditions (Skeel and Gibson, 1996; Siniscalco *et al.*, 1998; Smith *et al.*, 2005; Singh and Singh, 2006; Wu *et al.*, 2008). These can be identified from analysis of nearby undisturbed or less disturbed vegetation or naturally colonizing species (Sharma and Sunderraj, 2005; Brune *et al.*, 2007). A review paper on phytostabilization in arid and semi-arid environments concluded that local adaptation was the most important factor influencing success (Mendez and Maier, 2008).

Planting options

Various methods for re-vegetating areas have been tested. Fyles *et al.* (1985) seeded an area and found that it approached reference area levels of soil and vegetation development after six years, although they noted that soil organic matter build up was slow. Gao *et al.* (1998) combined seed sowing with other reclamation strategies and found the site approximated reference conditions after around five years. Holmes (2001) also found seeding to be viable, with sufficient depth of top soil, for revegetating a mine site. Gardiner (1993) combined seed drilling with additions of fertilizer but with mixed levels of plant survival and growth. Muzzi *et al.* (1997) found no improvement on vegetation cover from hydro-seeding. Martinez-Ruiz *et al.* (2007) used a commercial seed mix applied by hydro-seeding. They found an initial increase in diversity but only for two years. They recommended natural succession as a better rehabilitation alternative. Kirmer and Mahn (2001) amended soils with plant clippings and compared them with un-amended areas. Both developed over time but vegetation accumulation was faster on amended sites.

Planting is more commonly used to produce woodland, often for commercial crop production, as it is more effective than seeding (Torbert *et al.*, 1995). Gorsira and Risenhoover (1994) compared woodland planting with natural woodland and suggested that twenty-seven years would be needed for a comparative vegetation to form due to low survival and stem density. In a similar study Groninger *et al.* (2006) found that planted mine areas had lower

productivity than natural areas. Kumar *et al.* (1998) showed that reclaimed areas planted with trees and shrubs had higher richness and diversity than unreclaimed areas. Pensa *et al.* (2004) compared tree plantations with natural succession and noted that planted stands had greater biomass but lower diversity.

Li *et al.* (2005a) combined planting with various soil amendments, they were highly successful. Messina and Duncan (1993) found irrigation in the first year had a beneficial effect on planted trees and shrubs. In a series of experiments using Jeffrey pine trees (*Pinus jeffreyi*) it was found that liming to control soil pH had a negative effect on survival and growth (Walker, 2002a). Fertilizing did not affect survival but had a strong positive effect on growth over three years, enhancing foliar macronutrients, although some micronutrients were suppressed (Walker, 2002b; Walker, 2002c; Walker, 2005). Walker *et al.* (2004) found that colonization of mycorrhiza had a strong effect, although was dependent on soil nutrient status.

Protection

Grazing can be a significant factor on both planted and naturally colonizing sites (Wood *et al.*, 2005). Grazing is often cited as a detrimental factor to planted shrubs and trees (Muzzi and Fabbri, 2007; Koch *et al.*, 2004) that can be controlled by excluding grazing animals (Davis *et al.*, 1985; Davis *et al.*, 1993). Schuman and Belden (2002) noted that shrubs survived better when combined with high rates of grass seeding as this reduced grazing pressure on the shrubs. Koch *et al.* (2004) found that nurse species aided growth in the presence of grazing but impeded it if grazing was excluded. Others have also found that plant density and nurse/competitor relationships are important (Jefferson, 2004). Contrary to the expected outcome, competition was the dominant factor affecting survival of transplanted succulents in an arid environment (Blignaut and Milton, 2005). Huxtable *et al.* (2005) found that on mine spoils native grasses did well but were out-competed by exotics when topsoil was added. Schuman *et al.* (2005) found that competition with seeded grasses reduced survival and growth of seeded shrubs. Halofsky and McCormick (2005a) left unseeded strips on mine sites and found an increase in the colonization of natural woody species on these strips.

Plant-soil interactions and soil formation

The effects of plant establishment on soils are generally beneficial (Singh *et al.*, 1999; Shukla *et al.*, 2007) and especially good with leguminous species (Jha *et al.*, 1995; Singh *et al.*, 2006;

Brune *et al.*, 2007). Chiti *et al.* (2007) found a large positive effect on pedogenesis and growth of oak trees when nitrogen-fixing plants were planted in the area. Soil microbial biomass and activity can be enhanced by planting, although effects are dependent on tree species and litter quality (Sourkova *et al.*, 2005a). Rosario *et al.* (2007) compared planting and fertilizing for effects on soil bacteria getting positive results. However they found no effect from fertilizer, suggesting planting was the more influential factor. Nyamadzawo *et al.* (2008) found that soil enhancement was greatest when the site was initially seeded with grasses followed by subsequent planting of trees. Planting bamboo also has a positive effect on soil nutrient status and microbial biomass (Singh and Singh, 1999). Areas managed as either forest, hay or pasture were measured over twenty-eight years for effects on soils (Shrestha and Lal, 2007; Shrestha and Lal, 2008). The results showed that soil carbon and nitrogen were highest under pasture then hay and lowest under woodland, although hay enriched the soil with the highest levels of plant available nutrients. Bulk density, water infiltration, cone index and water stable aggregates improved most under hay and forest although still lower than undisturbed forest soils.

3.2.6 *Natural succession*

As was stated above (section 3.2.5) there are two main aims for the revegetation of mine sites, commercial crop production or conservation. If the desired outcome is for conservation then species native to the region, as well as being more tolerant to local environmental conditions, are likely to be of greater conservation value. Allowing plants to establish naturally is a possible way to develop a vegetative assemblage which is more closely matched to the surrounding vegetation (Ursic *et al.*, 1999; Rafaut *et al.*, 2006; Tomlinson *et al.*, 2008).

Frenedozo-Soave (2003) found increasing diversity over a 1-40 year old chronosequence. Lyngdoh *et al.* (1992) surveyed spoil heaps and found increasing richness and diversity with age, although assemblages remained significantly different to unmined areas. Surveying natural succession on an abandoned limestone quarry, Thompson and McKinney (2006) found a diverse species assemblage including two rare species, but invasive species were also abundant. Novak and Prach (2003) monitored succession in a number of disused quarries. They recorded several rare species but concluded that around twenty years was needed to produce a semi-natural vegetative assemblage at their study site. Distance from natural habitat was a significant factor affecting the ability and rate of species to colonize. Sampling mine areas being colonized naturally can also identify species that are suited to the

environmental conditions and which can be utilized for planting or seeding (Guevara *et al.*, 2005).

Environmental factors affect the trajectory and time for succession to occur. Wilcox *et al.* (2005) found that a shallow water table favoured succession to woodland while a deeper water table favoured scrub. Skousen *et al.* (1994) found a large effect of soil pH. Singh *et al.* (1997) found that grass biomass was correlated with canopy cover. Khater *et al.* (2003) compared levels of degradation and the resulting communities. They found that less degraded sites favoured woody shrubs and perennial herbs while more degraded sites favoured annual plants. Soil compaction, pH and salinity were shown to limit succession (Sieg *et al.*, 1983). Duan *et al.* (2008) concluded that soil organic matter, soil structure and moisture were the most influential factors. Yuan *et al.* (2006) listed soil depth and volume, organic matter, nitrogen and phosphorus as factors controlling succession. Craw *et al.* (2007) found that siltstone areas were colonized well but quartz pebble areas resisted colonization.

Burke (2007) sampled a wide range of sites and found that species richness was comparable to reference areas after around thirty years. Seed availability was thought to be the limiting factor. Carrick and Kruger (2007) found very little natural colonization due to arid conditions.

Soil structure and fertility have been shown to improve with time and vegetative development (Baig, 1992) in a self-reinforcing positive-feedback process. This can be especially effective with leguminous species (Atallah *et al.*, 2008). Adding topsoil to a mine site and allowing natural colonization was successful in revegetating a mine area, although the resulting communities were different to succession on areas not affected by mining (Martinez-Ruiz and Fernandez-Santos, 2005). Fertilizing during succession was shown to have a beneficial effect on tree growth although ground cover responses were varied (Rowe *et al.*, 2006).

Comparing the effectiveness of natural establishment and planting has produced varied results. Wali (1999) compared a chronosequence of naturally colonized sites with areas that were reclaimed and found that species richness and abundance increased with time but after forty-five years there were still large differences between the reference areas and the naturally colonized and planted mine sites. He also showed that vegetation on reclaimed areas recovered faster in soil properties and vegetation development. Hall *et al.* (2003) found successional communities were significantly different from surrounding areas but suggested that ongoing planting would be effective at steering the communities to a more desirable state.

Strong (2000) monitored successional change on initially revegetated mine lands and found that it was progressing towards reference sites.

Pietrzykowski and Krzaklewski (2007) compared energy accumulation and soil carbon in reclaimed and natural successional areas and found that they were two-fold higher in reclaimed areas. Pensa *et al.* (2004), comparing planted areas with naturally colonized areas, found greater biomass in planted sites but greater diversity in naturally colonized sites.

Holl (2002) suggested that planting had inhibited natural colonization and impeded the vegetation structure and diversity on the study site compared with reference areas. Hodacova and Prach (2003) found that natural succession produced greater diversity and naturalness over long time scales when compared with technical RECLAMATION.

3.2.7 Faunal colonisation

The aim of conservation is often to recreate wildlife habitat, and faunal communities are often a fundamental component of sustainable ecosystem functioning. Studies have been conducted to assess the colonization and habitat usage of various animal species on reclaimed land.

Anthony *et al.* (1991) found that several species of ant colonized a reclaimed mine site in Texas but an invasive species was the most successful. Replanted sites in Brazil were surveyed for ant colonization and were found to be rapidly progressing towards reference levels (Majer, 1992; Majer, 1996). Ottonetti *et al.* (2006) found that ant species richness and diversity did not differ significantly between reclaimed and reference areas. There was a difference in functional groups although specialist species were increasing. Pereira *et al.* (2007) surveyed planted and natural successional areas on a sand mine and found a richer and more diverse ant assemblage on the natural successional areas. Majer and Nichols (1998) found seeding with mixed species gave rise to the most similar ant assemblage to reference areas. All treatments improved over time although differences with reference areas persisted.

Holl (1996) found that lepidopteran communities converged with reference areas but noted that some, possibly open habitat, species declined. Majer *et al.* (2007) found that invertebrate species assemblages became more similar to reference areas over time in a review study. Moir *et al.* (2005) sampled plant and arthropod populations over a chronosequence of restored mine sites and found that arthropod assemblages followed a similar pattern to that of plants. Parmenter *et al.* (1991) also found a strong correlation with arthropod and vegetation recovery although noted large differences with reference areas after six years. This correlation with botanical diversity was also recorded by St John *et al.* (2002) studying mite (Acari) richness and diversity. This seemingly intuitive link is challenged to some

extent by Picaud and Petit (2007) who noted that sites with topsoil showed correlation between the plant and Orthoptera communities but sites without topsoil, while having no difference in Orthoptera communities, had limited plant succession. Rafaut *et al.* (2006) also found that species richness of invertebrates was highest in areas where plants had colonized well, but populations were higher on less vegetated areas.

Galan (1997) sampled the herpetofauna colonizing a mine site reclaimed with fertilizer and a seed mix. Colonization of the site was rapid in the first few years with the community becoming increasingly similar to the reference site.

Chamberlin *et al.* (2004) showed that the Allegheny woodrat (*Neotoma magister*) used revegetated mine spoils, especially where revegetation had been particularly successful. Dooley and Murray (2006) found that the vole *Microtus pennsylvanicus* used reclaimed sites but that time since reclamation was not a significant factor in habitat usage. Sieg *et al.* (1986) assessed the use of reclaimed areas by a number of small mammals and their results indicated that several pioneer species used the site for foraging but not burrowing. Soil compaction and lack of vegetation structure were given as probable reasons for this. Hambler *et al.* (1985) and Dixon and Hambler (1993) assessed the effects of rabbit (*Oryctolagus cuniculus*) grazing on a reclamation site. They determined that the input of nutrients and creation of heterogeneity was beneficial although they noted that damage to rare plants or those favoured by rabbits could be problematic. The recolonization of wildlife on a strip mine was investigated by Ireland *et al.* (1994). They found that richness and diversity were lower than reference areas. Lack of woody debris and micro habitats were given as reasons.

Armstrong and Nichols (2000) found all the sites they studied supported increasing bird diversity with increasing age. Seeded sites recovered more quickly however. DeVault *et al.* (2002) also found diverse bird communities on reclaimed grasslands that were comparable to native bird assemblages, including some rare species. Galligan *et al.* (2006) compared undisturbed and reclaimed areas for nesting success and found no significant difference. A similar study by Little *et al.* (2006) had similar results, although they noted that proximity to current mining activities was a significant negative factor. Passell (2000) compared reclaimed, unreclaimed and reference areas and found that unreclaimed sites had little colonization by birds, restored areas were colonized, although significantly less than reference areas after three years. Scott *et al.* (2002) assessed a site reclaimed with native grass and legumes and recorded a bird community comparable to natural areas. Scott and Lima (2004) investigated usage of exotic grass species by birds on a reclaimed site. Usage was high although thought to be comparable to native species. Vukovich and Ritchison (2008) assessed foraging behaviour

of two raptor species on reclaimed mine land and found that hunting methods and rate of success were comparable to unmined areas. The ongoing management of reclaimed areas is influential as mowing can be detrimental to bird populations (Ingold, 2002).

A number of studies have focused on specific species of conservation interest. Henslow's sparrows (*Ammodramus henslowii*) were recorded in significant numbers on mine sites reclaimed to grassland, although vegetative structure was important (Bajema and Lima, 2001; Bajema *et al.*, 2001). Monroe and Ritchison (2005) also investigated the behaviour and ecology of Henslow's sparrows and recorded that prey numbers were higher on reclaimed areas, where territories were smaller than on reference areas, although no difference in nesting success was found. Vukovich and Ritchison (2006) recorded successful nesting of Northern Harriers (*Circus cyaneus*) on reclaimed grasslands. Red-shouldered hawks (*Buteo lineatus*) were also shown to be using reclaimed habitat (Balcerzak and Wood, 2003). Boisvert *et al.* (2005) noted small differences in range size but otherwise similar ecology for Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) when comparing a reclaimed mine to a conservation area. Dickcessels (*Spiza americana*) were also shown to be nesting successfully on reclaimed land (Dixon *et al.*, 2008).

3.2.8 Other studies

Various studies that do not fall into any of the above categories are discussed here. Several of these have studied the hydrological effects of mining and mine rehabilitation. Bengson (1977) studied the effect of drip irrigation and found it to be highly successful at revegetating slopes in an arid environment. Carey *et al.* (2005) measured evaporation from waste rock surfaces and found that moisture loss through evaporation without vegetation was very high. Guebert and Gardner (2001) measured runoff and erosion and found that with increasing soil development and age since reclamation, runoff reduced and infiltration increased. Revegetating mine sites has been shown to increase infiltration, reduce runoff and improve soil water-holding capacity (Loch and Orange, 1997; Loch, 2000a; Loch, 2000b).

Remote sensing and geographical information systems (GIS) can be employed to monitor and predict impacts of mining activities. Bhadra *et al.* (2007) used satellite data combined with GIS to track effects on the hydrology and forest cover of a wide area resulting from mining. They recorded large changes in river flow and a reduction in forest cover from both clearance and degradation. Honda *et al.* (1993) used GIS with global positioning system (GPS) data to monitor succession and predicted around 200 years would be needed for vegetation to recover. By controlling erosion with planting the time was halved.

Invasive species are often a problem on denuded ground and especially when amendments such as fertilizer are added (O'Dell and Claassen, 2006a; O'Dell and Claassen, 2006b). An experiment by MacDonald *et al.* (2003) attempted to control invasive species and encourage native ones on a site infested by invasives. They used a combination of sewage sludge and herbicides. However their results were mixed with some combinations favouring invasive species and some native.

Koch and Hobbs (2007) combined multiple measures of restoration success using both vegetation structure and ecosystem function. Looking at the results of their study they were able to conclude which properties had been successfully restored and which were still developing. Cummings *et al.* (2005) tried adaptive restoration. After their initial efforts largely failed they reassessed their restoration strategy and amended their original plan. On re-implementation they achieved a much greater level of success.

Alexander and Kidd (2000) noted that a state-run rehabilitation scheme had largely failed to improve soils on disturbed areas. They employed local knowledge from farmers about how they managed soils and were able to create a much more successful strategy. Botha *et al.* (2008) also employed local knowledge to inform rehabilitation strategy. The results raised several issues that were recommended for further research.

Cloke *et al.* (1996) investigated socio-economic factors arising from rehabilitation after mining. The expected regeneration of the local economy was not observed. The reasons given were ongoing mining in the area and predominantly private ownership of the forested area.

4. CONCLUSIONS

Research on ecological restoration of quarry sites has generally been site-, species- and treatment-specific, making it difficult to marshal evidence for comparative conclusions about what treatments work best in what environmental conditions. A network of factorial experiments with different treatments replicated across a range of site types would be required to develop this evidence base. In addition to what works ecologically, the cost of implementing treatments needs to be carefully considered in relation to the site and objectives involved to arrive at a cost / benefit ratio for their implementation. There is, however, a great deal of varied experience in getting vegetation established on quarry sites that can inform decision taking.

Landscaping through blasting and contouring is of limited benefit to the establishment of vegetation although it can reduce the visual impact of mining. Soil can develop naturally on

quarry sites and this process is enhanced by recovering vegetation where pioneer species take hold. Ripping soils is likely to be beneficial when stockpiled soils are re-spread over a quarry area. Spreading topsoil can be an effective strategy to enhance revegetation rates but the origin of the topsoil and the timing of application need to be considered carefully to avoid displacement of environmental impact from the site where the soil is obtained.

Adding fertilizer can kick-start vegetation establishment but care is needed when invasive plants are a potential problem. More technical reclamation through the use of hydro-gel, expanded clay, porous ceramic and mineral fertilizers can enhance vegetation establishment in particular circumstances, but combinations need testing in the area to be rehabilitated prior to adoption. These remediation strategies can be expensive, so attention needs to be given to whether the benefit of their use outweighs their cost. A set of simple trials at new locations is recommended prior to widescale adoption.

Organic matter applications are generally beneficial. These often represent a cheap and effective method for enhancing soil and vegetation development. Heavy metal contamination is unlikely to be a major problem in the Kota area, but monitoring would be advisable if sewage sludge or biosolids were used.

The effectiveness of mycorrhizal inoculation has been highly variable across sites and species. It can be effective as a rehabilitation strategy, but needs pilot trials to identify strains that are effective in the local environment and that will colonize desired plant species. Combining inoculation with organic matter applications can be synergistic and enhance the effectiveness of organic matter application.

The need for planting seeds or seedlings depends on the goals of the reclamation project. It can be an effective strategy where there are clear productive goals for plantations established on quarry sites or where particular native species can be identified. Candidate species can be identified by botanical survey of vegetation in the area surrounding quarry sites. This ensures selection of species which are tolerant of local environmental conditions.

Promoting natural succession is likely to be more effective than planting when aiming at a vegetative community of conservation value. However, local conditions and especially sources of plant propagules need to be considered. Careful planting can be used to kick-start and steer largely natural succession. This is a promising strategy for quarry site rehabilitation but little research has been done to date.

The range of studies on wildlife shows that viable habitat can be created for many animal species over time. Colonization is rapid for many species and with developing habitat, communities become more similar to reference areas. Managing succession can also create

suitable habitat for target species of conservation value. A critical requirement for setting restoration goals is scoping of existing priorities for habitat and species conservation in the area concerned.

Overall, the evidence suggests that ecological restoration is possible in most incidences but the choice of appropriate methods requires the goals of the project to be clear. In general, combinations of best bet methods based on consideration of environmental conditions, local vegetation and the restoration goals should be trialled at new locations before widespread adoption.

APPENDIX I - SYSTEMATIC REVIEW PROTOCOL DATA EXTRACTION SHEET

Data extraction sheet

Author(s) and year of publication	Title and source	Intervention/research	Results
Abakumov, E. V. (2008)	<i>Accumulation and transformation of organic matter in different-aged dumps from sand quarries. Eurasian Soil Science, 41, 844-851.</i>	Pedogenesis/vegetative development	SOM and SOC increased along with time and vegetative development
Akala, V. A. & Lal, R. (2000)	<i>Potential of mine land reclamation for soil organic carbon sequestration in Ohio. Land Degradation & Development, 11, 289-297.</i>	Soil C sequestration	SOC increased with time
Alberici, T. M., Sopper, W. E., Storm, G. L. & Yahner, R. H. (1989)	<i>Trace-metals in soil, vegetation, and voles from mine land treated with sewage-sludge. Journal of Environmental Quality, 18, 115-120.</i>	Addition of sewage sludge	Trace metals were monitored but did not become a problem
Alexander, M. J. & Kidd, A. D. (2000)	<i>Farmers' capability and institutional incapacity in reclaiming disturbed land on the Jos Plateau, Nigeria. Journal of Environmental Management, 59, 141-155.</i>	Local knowledge employed after problems with rehabilitation	Local activities were more successful than 'state' ones at creating fertile soil
Almendro-Candel, M. B., Jordan, M. M., Navarro-Pedreno, J., Mataix-Solera, J. & Gomez-Lucas, I. (2007)	<i>Environmental evaluation of sewage sludge application to reclaim limestone quarries wastes as soil amendments. Soil Biology & Biochemistry, 39, 1328-1332.</i>	Addition of sewage sludge	Problems with ammonium nitrates but not heavy metals
Andres, P. (1999)	<i>Ecological risks of the use of sewage sludge as fertilizer in soil restoration effects on the soil microarthropod populations. Land Degradation & Development, 10, 67-77.</i>	Addition of sewage sludge on microarthropods	Low doses were beneficial but higher rates caused loss of diversity
Anthony, C. D., Formanowicz, D. R. & Brodie, E. D. (1991)	<i>Effect of mine reclamation on ant community structure in eastern Texas. Texas Journal of Science, 43, 261-272.</i>	Ant colonization of reclaimed mine land	Several species colonized but an invasive was most successful
Antonopoulos, V. Z. & Wyseure, G. C. L. (1998)	<i>Modelling of water and nitrogen dynamics on an undisturbed soil and a restored soil after open-cast mining. Agricultural Water Management, 37, 21-40.</i>	Replacement of top soil and N additions	N and water retention were lower in restored soil

Armstrong, K. N. & Nichols, O. G. (2000)	<i>Long-term trends in avifaunal recolonisation of rehabilitated bauxite mines in the Jarrah forest of south-western Australia. Forest Ecology and Management, 126, 213-225.</i>	Seeded, soil only and bare ground surveyed for birds	Seeded site recovered most quickly but all sites supported increasing diversity with age
Ashby, W. C. (1997)	<i>Soil ripping and herbicides enhance tree and shrub restoration on stripmines. Restoration Ecology, 5, 169-177.</i>	Soil ripping and herbicide use	Positive effect from ripping and herbicide although some damage to target plants, herbivory problems
Atallah, T., Rizk, H., Cherfane, A., Daher, F. B., El-Alla, R., De Lajuide, P. & Hajj, S. (2008)	<i>Distribution and nodulation of spontaneous legume species in grasslands and shrublands in Mediterranean Lebanon. Arid Land Research and Management, 22, 109-122.</i>	Leguminous species and root nodulation investigated	Annual legumes and inoculated perennial legumes are recommended
Azcon-Aguilar, C., Palenzuela, J., Roldan, A., Bautista, S., Vallejo, R. & Barea, J. M. (2003)	<i>Analysis of the mycorrhizal potential in the rhizosphere of representative plant species from desertification-threatened Mediterranean shrublands. Applied Soil Ecology, 22, 29-37.</i>	AM fungal potential assessed	Beneficial for shrub growth and soils but low occurrence and diversity in disturbed soil
Badia, D., Valero, R., Gracia, A., Marti, C. & Molina, F. (2007)	<i>Ten-year growth of woody species planted in reclaimed mined banks with different slopes. Arid Land Research and Management, 21, 67-79.</i>	Effect of slope on growth and survival of woody species planted on spoil heaps assessed	No effect on survival, growth less on steeper slopes but similar to comparable areas
Baig, M. N. (1992)	<i>Natural revegetation of coal-mine spoils in the Rocky-Mountains of Alberta and its significance for species selection in land restoration. Mountain Research and Development, 12, 15285-300.</i>	Soils and vegetation assessed in a harsh environment	Soil structure and fertility improved with age. Naturally colonizing species performed well as well adapted
Bajema, R. A., DeVault, T. L., Scott, P. E. & Lima, S. L. (2001)	<i>Reclaimed coal mine grasslands and their significance for Henslow's sparrows in the American Midwest. Auk, 118, 422-431.</i>	Reclaimed mine grasslands assessed for Henslow's sparrows	Significant population recorded indicating useful habitat has been created
Bajema, R. A. & Lima, S. L. (2001)	<i>Landscape-level analyses of Henslow's sparrow (Ammodramus henslowii) abundance in reclaimed coal mine grasslands. American Midland Naturalist, 145, 288-298.</i>	Reclaimed mine grasslands assessed for Henslow's sparrows	Structure of vegetation on reclaimed land important
Balcerzak, M. J. & Wood, P. B. (2003)	<i>Red-shouldered hawk (Buteo lineatus) abundance and habitat in a reclaimed mine landscape. Journal of Raptor Research, 37, 188-197.</i>	Various reclaimed land surveyed for Red-shouldered hawk	Hawks were recorded using reclaimed landscape

Barbera, G. G., Martinez-Fernandez, F., Alvarez-Rogel, J., Albaladejo, J. & Castillo, V. (2005)	<i>Short- and intermediate-term effects of site and plant preparation techniques on reforestation of a Mediterranean semiarid ecosystem with Pinus halepensis Mill. New Forests, 29, 177-198.</i>	Mycorrhizal inoculation, composting, planting furrow, polypropylene tunnel planting	Addition of fresh and composted organic matter fertilizer was the only effective treatment tested.
Bateman, J. C. & Chanasyk, D. S. (2001)	<i>Effects of deep ripping and organic matter amendments on Ap horizons of soil reconstructed after coal strip-mining. Canadian Journal of Soil Science, 81, 113-120.</i>	Deep ripping and OM additions assessed for effects on surface soil	Particle size reduced and loss of nutrients due to mixing no significant effect on water holding but infiltration improved
Beckjord, P. R. & McIntosh, M. S. (1984)	<i>Growth and fungal persistence by quercus-rubra inoculated with ectomycorrhizal fungi and planted on a clear-cutting and strip mine. Canadian Journal of Botany-Revue Canadienne De Botanique, 62, 1571-1574.</i>	Inoculation with Ectomycorrhizas	Significant effect on clear felled area but not on mine area
Bell, J., Wells, S., Jasper, D. A. & Abbott, L. K. (2003)	<i>Field inoculation with arbuscular mycorrhizal fungi in rehabilitation of mine sites with native vegetation, including Acacia spp. Australian Systematic Botany, 16, 131-138.</i>	AM and phosphate fertilizer	Little benefit seen, possible seasonal limitation
Bellgard, S. E. (1991)	<i>Mycorrhizal associations of plant-species in Hawkesbury sandstone vegetation. Australian Journal of Botany, 39, 357-364.</i>	Sandstone soil mycorrhizal associations examined	Mycorrhizas shown to be important for many species
Bendfeldt, E. S., Burger, J. A. & Daniels, W. L. (2001)	<i>Quality of amended mine soils after sixteen years. Soil Science Society of America Journal, 65, 1736-1744.</i>	OM inputs of sawdust, sewage sludge on soil	OM inputs made a large difference in the first 5 years but after 16 years unamended soils had caught up.
Bengson, S. A. (1977)	<i>Drip irrigation to re-vegetate mine wastes in an arid environment. Journal of Range Management, 30, 143-147.</i>	Drip irrigation compared with other methods	Drip irrigation was highly successful on slopes
Bhadra, B. K., Gupta, A. K., Sharma, J. R. & Choudhary, B. R. (2007)	<i>Mining activity and its impact on the environment: Study from Makrana marble and Jodhpur sandstone mining areas of Rajasthan. Journal of the Geological Society of India, 70, 557-570.</i>	GIS and satellite used to monitor mining impacts	Large effects on the hydrology of the area as well as forest area and quality
Biro, B., Voros, I., Kovespechy, K. & Szegi, J. (1993)	<i>Symbiont effect of rhizobium-bacteria and vesicular-arbuscular mycorrhizal fungi on pisum-sativum in recultivated mine spoils. Geomicrobiology Journal, 11, 275-284.</i>	Inoculation and treatment with various forms of OM	Inoculated plants performed better than un-inoculated but addition of OM as well had a much greater effect

Blignaut, A. & Milton, S. J. (2005)	<i>Effects of multispecies clumping on survival of three succulent plant species translocated onto mine spoil in the Succulent Karoo Desert, South Africa. Restoration Ecology, 13, 15-19.</i>	Succulent species taken from planned mine area were transplanted to abandoned mine individually and in clusters	Competition had more effect and individual plants had greater survival than mixed clumps
Boisvert, J. H., Hoffman, R. W. & Reese, K. P. (2005)	<i>Home range and seasonal movements of Columbian sharp-tailed grouse associated with conservation reserve program and mine reclamation. Western North American Naturalist, 65, 36-44.</i>	Columbian sharp-tailed grouse ecology compared in a conservation area and reclaimed mine	Minor differences in range size but otherwise similar ecology
Botha, M. S., Carrick, P. J. & Allsopp, N. (2008)	<i>Capturing lessons from land-users to aid the development of ecological restoration guidelines for lowland Namaqualand. Biological Conservation, 141, 885-895.</i>	Local residents asked for information about restoration possibilities	Results used to inform areas for further research
Bowen, C. K., Schuman, G. E., Olson, R. A. & Ingram, L. J. (2005)	<i>Influence of topsoil depth on plant and soil attributes of 24-year old reclaimed mined lands. Arid Land Research and Management, 19, 267-284.</i>	Soil fertility and water holding and plant diversity and biomass compared for different soil depths	Deeper soils were more fertile and held more water and supported greater biomass but lower diversity
Brofas, G., Michopoulos, P. & Alifragis, D. (2000)	<i>Sewage sludge as an amendment for calcareous bauxite mine spoils reclamation. Journal of Environmental Quality, 29, 811-816.</i>	OM additions in the form of sewage sludge	Increase in plant growth and associated species but decrease over time some issues with heavy metals
Brundrett, M. C., Ashwath, N. & Jasper, D. A. (1996)	<i>Mycorrhizas in the Kakadu region of tropical Australia .2. Propagules of mycorrhizal fungi in disturbed habitats. Plant and Soil, 184, 173-184.</i>	Association of mycorrhizal fungi compared on disturbed and reference areas	Some evidence of improved soil characteristics but high variance between sites
Brune, B., Domergue, O., Maure, L., Brahic, P., Galiana, A., Josa, R., De Lajudie, P., Attallah, T., Risk, H., El-Hajj, S. & Cleyet-Marel, J. C. (2007)	<i>Potential of nitrogen-fixing symbiotic systems for revegetation strategies of degraded land sites in Mediterranean conditions. Cahiers Agricultures, 16, 324-329.</i>	Plants grown in a nursery identified from natural colonizers inoculated with rhizobial partners	Good levels of establishment shrubs especially good at forming relationships and for soil enrichment
Burke, A. (2007)	<i>Recovery in naturally dynamic environments: A case study from the Sperrgebiet, southern African arid succulent karoo. Environmental Management, 40, 635-648.</i>	Species richness and cover compared over a range of sites including reference areas	Species richness was comparable after ~30 years. Seed availability thought to be limiting
Burke, A. (2008)	<i>The effect of topsoil treatment on the recovery of rocky plain and outcrop plant communities in Namibia. Journal of Arid Environments, 72, 1531-1536.</i>	Depth of excavation, soil additions, ripping and seeding compared	Deep excavations only benefited through soil additions, shallow excavations had good levels of recruitment even without additions

Camberato, J. J., Gagnon, B., Angers, D. A., Chantigny, M. H. & Pan, W. L. (2006)	<i>Pulp and paper mill by-products as soil amendments and plant nutrient sources. Canadian Journal of Soil Science, 86</i> , 641-653.	OM in the form of paper mill by products added	Increased OM and water holding and physical properties of soil but N and P immobilization a problem
Carey, S. K., Barbour, S. L. & Hendry, M. M. (2005)	<i>Evaporation from a waste-rock surface, Key Lake, Saskatchewan. Canadian Geotechnical Journal, 42</i> , 1189-1199.	Evaporation measured	Very high levels of evaporation from unplanted rock
Carrick, P. J. & Kruger, R. (2007)	<i>Restoring degraded landscapes in lowland Namaqualand: Lessons from the mining experience and from regional ecological dynamics. Journal of Arid Environments, 70</i> , 767-781.	Rehabilitation investigated	Very little natural revegetation found due to harsh environmental conditions
Chamblin, H. D., Wood, P. B. & Edwards, J. W. (2004)	<i>Allegheny woodrat (Neotoma magister) use of rock drainage channels on reclaimed mines in southern West Virginia. American Midland Naturalist, 151</i> , 346-354.	Use of reclaimed land by the Allegheny woodrat was investigated	It was shown to use former mine sites, especially where vegetative restoration had been particularly successful
Chen, Y., Yuan, J. G., Yang, Z. Y., Xin, G. R. & Fan, L. (2008)	<i>Associations between arbuscular mycorrhizal fungi and Rhynchelyrum repens in abandoned quarries in southern China. Plant and Soil, 304</i> , 257-266.	Rhynchelyrum repens association with AM fungi investigated	Survival and growth strongly enhanced by association, inoculation recommended
Chiti, T., Certini, G., Puglisi, A., Sanesi, G., Capperucci, A. & Forte, C. (2007)	<i>Effects of associating a N-fixer species to monotypic oak plantations on the quantity and quality of organic matter in minesoils. Geoderma, 138</i> , 162-169.	Using an N fixing species to facilitate growth	Large difference in both oak growth and pedogenesis found
Chong, S. K. & Cowsert, P. T. (1997)	<i>Infiltration in reclaimed mined land ameliorated with deep tillage treatments. Soil & Tillage Research, 44</i> , 255-264.	Soil ripping at 20, 40, 60 and 80 cm depths evaluated for infiltration	Little difference between 20, 40 and 60 cm but 80cm significantly better
Clemente, A. S., Werner, C., Maguas, C., Cabral, M. S., Martins-Loucao, M. A. & Correia, O. (2004)	<i>Restoration of a limestone quarry: Effect of soil amendments on the establishment of native Mediterranean sclerophyllous shrubs. Restoration Ecology, 12</i> , 20-28.	Gel polymer, fertilizer and mycorrhizal inoculation effects on plant growth on limestone quarry	Some benefit from fertilizer and gel but species specific. Provenance of plants thought to be more important
Cloke, P., Milbourne, P. & Thomas, C. (1996)	<i>From wasteland to wonderland: Opencast mining, regeneration and the English National Forest. Geoforum, 27</i> , 159-174.	Afforestation of former mine sites and socio-economic factors	Limited success attributed to on going mine activities and private ownership of land
Conrad, P. W., Sweigard, R. J., Graves, O. H., Ringe, J. M. & Pelkki, M. H. (2002)	<i>Impacts of spoil conditions on reforestation of surface mined land. Mining Engineering, 54</i> , 39-46.	Effect of soil compaction on tree survival rate tested	Close correlation between level of compaction and tree survival

Corbett, E. A., Anderson, R. C. & Rodgers, C. S. (1996)	<i>Prairie revegetation of a strip mine in Illinois: Fifteen years after establishment. Restoration Ecology, 4, 346-354.</i>	Mycorrhizal inoculum potential on prairie revegetation measured for invasive and prairie species	Invasive and prairie species did not differ significantly. Area patchiness thought more important than plant cover
Craw, D., Rufaut, C. G., Hammit, S., Clearwater, S. G. & Smith, C. M. (2007)	<i>Geological controls on natural ecosystem recovery on mine waste in southern New Zealand. Environmental Geology, 51, 1389-1400.</i>	Succession seres on a naturally recovering mine waste investigated	Differences attributable to geology, quartz pebbles resisted colonization while siltstone colonized well
Croton, J. T. & Ainsworth, G. L. (2007)	<i>Development of a winged tine to relieve mining-related soil compaction after bauxite mining in Western Australia. Restoration Ecology, 15, S48-S53.</i>	Deep soil ripping	Shown to benefit tree survival
Cullen, W. R., Wheeler, C. P. & Dunleavy, P. J. (1998)	<i>Establishment of species-rich vegetation on reclaimed limestone quarry faces in Derbyshire, UK. Biological Conservation, 84, 25-33.</i>	Blasting to create a range of micro habitats and seeding	Created vegetation similar to undisturbed sites in 2 years although grazing by rabbits was and issue
Cummings, J., Reid, N., Davies, I. & Grant, C. (2005)	<i>Adaptive restoration of sand-mined areas for biological conservation. Journal of Applied Ecology, 42, 160-170.</i>	Adaptive restoration used	Proved successful after initial failures. Removal of competitive invasive, grazing exclusion and OM additions worked well
Curtis, M. J. & Claassen, V. P. (2005)	<i>Compost incorporation increases plant available water in a drastically disturbed serpentine soil. Soil Science, 170, 939-953.</i>	Ripping and composting	Ripping and composting together was highly effective (2XPAW, 4Xbiomass)
Davis, B. N. K., Lakhani, K. H. & Brown, M. C. (1993)	<i>Experiments on the effects of fertilizer and rabbit grazing treatments upon the vegetation of a limestone quarry floor. Journal of Applied Ecology, 30, 615-628.</i>	Fertilizing and grazing exclusion effects on plant growth	Exclusion and exclusion of fertilizing combined had greatest effect. All treatments had benefits over control areas
Davis, B. N. K., Lakhani, K. H., Brown, M. C. & Park, D. G. (1985)	<i>Early seral communities in a limestone quarry - an experimental-study of treatment effects on cover and richness of vegetation. Journal of Applied Ecology, 22, 473-490.</i>	Grazing exclusion, fertilizing and seeding effects of plant growth	All had a positive effect, rising when two were combined and maximised with all three combined.
DeVault, T. L., Scott, P. E., Bajema, R. A. & Lima, S. L. (2002)	<i>Breeding bird communities of reclaimed coal-mine grasslands in the American midwest. Journal of Field Ornithology, 73, 268-275.</i>	Bird communities on reclaimed grasslands assessed	Diverse communities supported that are native to grasslands including some rare species
Diaz, G. & Honrubia, M. (1993)	<i>Infectivity of mine soils from southeast Spain .2. Mycorrhizal population-levels in spoilt sites. Mycorrhiza, 4, 85-88.</i>	Mine soils assessed for mycorrhizal inoculum potential	Inoculum potential and mycorrhizal populations were very low is mined soils
Diaz, G. & Honrubia, M. (1994)	<i>A mycorrhizal survey of plants growing on mine wastes in southeast Spain. Arid Soil Research and Rehabilitation, 8, 59-68.</i>	Mycorrhizal infection of plants in disturbed soil according to degradation and season measured	More degraded soils had fewer mycorrhizal associations with plants. Seasonal variation also high

Dimitrakopoulos, R. & Mackie, S. (2003)	<i>Stochastic simulation for the quantification of mine spoil variability and rehabilitation decision making.</i>	Mine spoil variability assessed over sites to assist restoration	Variability shown to be high and an important factor in restoration
Dixon, J. M. & Hambler, D. J. (1988)	<i>Coexistence, stress, and catastrophe, in grassy vegetation established in a hard-limestone quarry. Environmental Conservation, 15, 223-238.</i>	Plant communities measured on limestone quarry site	A community of moss and sown grass became stable
Dixon, J. M. & Hambler, D. J. (1993)	<i>Wildlife and reclamation ecology - rabbit middens on seeded limestone quarry-spoil. Environmental Conservation, 20, 65-73.</i>	The effect of rabbits on soil and plants assessed in a reclamation project	Soil nutrients were higher around middens and vegetation benefited. Overall rabbits seen as beneficial.
Dixon, T. P., Lopez, R. R., Peterson, M. J., McCleery, R. A. & Silvy, N. J. (2008)	<i>Field-level spatial factors, associated edges, and dickcissel nesting ecology on reclaimed lands in Texas. Landscape and Urban Planning, 86, 60-65.</i>	Nesting ecology of disturbance dependent bird on reclaimed sites assessed	Dickcissels shown to be nesting successfully on reclaimed land
Dodd, J. C. & Thomson, B. D. (1994)	<i>The screening and selection of inoculant arbuscular-mycorrhizal and ectomycorrhizal fungi. Plant and Soil, 159, 149-158.</i>	Mycorrhizal fungal selection and use for sustainable plant growth investigated	Results and discussion show that they are effective if selected carefully and use appropriately
Dooley, J. L. & Murray, A. L. (2006)	<i>Population responses of Microtus pennsylvanicus across a chronological sequence of habitat alteration. Ohio Journal of Science, 106, 93-97.</i>	Population and ecology of a common vole on a chronosequence of reclaimed site studied	Age since reclamation was not a significant factor but site were used suggesting reclamation success
Duan, W. J., Ren, H., Fu, S. L., Wang, J., Yang, L. & Zhang, J. P. (2008)	<i>Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences-China, 20, 476-481.</i>	Natural succession surveyed on abandoned quarry site to measure development of seres	Soil OM, moisture and bulk density thought to be the most important factors
Dudeney, A. W. L., Tarasova, II & Tyrologou, P. (2004)	<i>Co-utilisation of mineral and biological wastes in mine site restoration. Minerals Engineering, 17, 131-139.</i>	Mineral and biological waste used to create artificial soils for mine restoration	Sand and wetland sludge showed good results, shale, woodchips and weathered sludge showed little decomposition
Dunger, W. & Voigtlander, K. (2005)	<i>Assessment of biological soil quality in wooded reclaimed mine sites. Geoderma, 129, 32-44.</i>	Soil OM and fauna measured across a chronosequence of afforested mine sites	Both OM and faunal composition improved with the age since reclamation
Dunger, W., Wanner, M., Hauser, H., Hohberg, K., Schulz, H. J., Schwalbe, T., Seifert, B., Vogel, J., Voigtlander, K., Zimdars, B. & Zulka, K. P. (2001)	<i>Development of soil fauna at mine sites during 46 years after afforestation. Pedobiologia, 45, 243-271.</i>	Microfauna, mesofauna and macrofauna measured at afforested mine sites and compared to earlier results	Around 10-20 years after afforestation the soil fauna approaches that of undisturbed forest but some development continues
Dutta, R. K. & Agrawal, M. (2003)	<i>Restoration of opencast coal mine spoil by planting exotic tree species: a case study in dry tropical region. Ecological Engineering, 21, 143-151.</i>	Biomass accumulation and net primary productivity of exotic species planted on mine spoils assessed	Above and below ground biomass increased although results were species specific

Dutta, R. K. & Agrawal, M. (2005)	<i>Development of ground vegetation under exotic tree plantations on restored coal mine spoil land in a dry tropical region of India. Journal of Environmental Biology, 26, 645-652.</i>	Vegetative structure and biomass of ground flora assessed on planted mine spoils	Species richness and evenness increased with age of spoil. Exotics out performed native species
Evanylo, G. K., Abaye, A. O., Dundas, C., Zipper, C. E., Lemus, R., Sukkariyah, B. & Rockett, J. (2005)	<i>Herbaceous vegetation productivity, persistence, and metals uptake on a biosolids-amended mine soil. Journal of Environmental Quality, 34, 1811-1819.</i>	Slope reduction, amelioration with biosolids and seeding with grasses and herbaceous species	Metal uptake was not detrimental but soil depth and compaction affected survival. Xeric plants fared best
Feagley, S. E., Valdez, M. S. & Hudnall, W. H. (1994)	<i>Paper-mill sludge, phosphorus, potassium, and lime effect on clover grown on a mine soil. Journal of Environmental Quality, 23, 759-765.</i>	Lime, fertilizer and paper sludge amended soils used to grow clover	No vegetation without fertilizer but fertilizer plus paper sludge gave best results
Felix, E., Tilley, D. R., Felton, G. & Flamino, E. (2008)	<i>Biomass production of hybrid poplar (Populus sp.) grown on deep-trenched municipal biosolids. Ecological Engineering, 33, 8-14.</i>	Municipal biosolids used to fertilize degraded tree plantation	Success in improving biomass
Fettweis, U., Bens, O. & Huttli, R. F. (2005)	<i>Accumulation and properties of soil organic carbon at reclaimed sites in the Lusatian lignite mining district afforested with Pinus sp. Geoderma, 129, 81-91.</i>	Carbon accumulation in afforested reclaimed soils investigated	SOC uptake was shown to be of similar amounts to undisturbed soils although total C was lower
Fierro, A., Angers, D. A. & Beauchamp, C. J. (1999)	<i>Restoration of ecosystem function in an abandoned sandpit: plant and soil responses to paper de-inking sludge. Journal of Applied Ecology, 36, 244-253.</i>	Paper sludge and N and P addition with seeding	Sludge had large effect on biomass, P aided establishment and N further increased biomass with sludge
Fierro, A., Norrie, J., Gosselin, A. & Beauchamp, C. J. (1997)	<i>Deinking sludge influences biomass, nitrogen and phosphorus status of several grass and legume species. Canadian Journal of Soil Science, 77, 693-702.</i>	Sand and mineral soil used with paper sludge and N and P additions	Sludge worked well when combined with N and P
Figge, D. A. H., Hetrick, B. A. D. & Wilson, G. W. T. (1995)	<i>Role of expanded clay and porous ceramic amendments on plant establishment in minespoils. Environmental Pollution, 88, 161-165.</i>	Effects of expanded clay and porous ceramic and fertilization on germination and biomass of a grass grown on mine tailings	When the clay and to a less extent porous ceramic were added topically increased rates of germination occurred
Filcheva, E., Noustorova, M., Gentcheva-Kostadinova, S. & Haigh, M. J. (2000)	<i>Organic accumulation and microbial action in surface coal-mine spoils, Pernik, Bulgaria. Ecological Engineering, 15, 1-15.</i>	OM accumulation and microbial activity assessed on afforested spoil slopes	Increase in SOC and microbial activity compared with unvegetated site
Fisher, K. T., Brummer, J. E., Leininger, W. C. & Heil, D. M. (2000)	<i>Interactive effects of soil amendments and depth of incorporation on Geyer willow. Journal of Environmental Quality, 29, 1786-1793.</i>	Lime, OM and lime + OM assessed at various depths for soil amendment	Greater depth of planting improved growth but all treatments showed some benefit

Frenedo-Soave, R. D. (2003)	<i>Phytosociological studies on natural establishment of vegetation in an unreclaimed limestone mining. Brazilian Archives of Biology and Technology, 46, 259-269.</i>	1-40 year old chronosequence studied for natural succession by vegetation community and plant diversity	Diversity increased with age, legumes were important early on but all ages linked to environmental conditions
Frost, S. M., Stahl, P. D. & Williams, S. E. (2001)	<i>Long-term reestablishment of arbuscular mycorrhizal fungi in a drastically disturbed semiarid surface mine soil. Arid Land Research and Management, 15, 3-12.</i>	AM fungus was added to plantings to aid establishment of vegetative cover assessed 14 years later	AM fungal inoculation made no difference although as soils ameliorated naturally AM fungal colonization happened naturally
Frouz, J., Elhottova, D., Pizl, V., Tajousky, K., Sourkova, M., Picek, T. & Maly, S. (2007)	<i>The effect of litter quality and soil faunal composition on organic matter dynamics in post-mining soil: A laboratory study. Applied Soil Ecology, 37, 72-80.</i>	Soil from mine tailings treated with litter from natural vegetation and from an alder plantation plus various soil fauna combinations from the two sites	Litter removal and C accumulation was faster in the reclaimed alder site. Earth worms were the most effective at litter removal
Fulton, J. P. & Wells, L. G. (2005)	<i>Evaluation of a mechanical system for reconstructing soil on surface mined land. Applied Engineering in Agriculture, 21, 43-51.</i>	Soil ripping	Ripping improved the bulk density of reclaimed soils and reduced compaction
Fulton, J. P., Wells, L. G. & Smith, T. D. (2002)	<i>A mechanical system for soil reconstruction. Applied Engineering in Agriculture, 18, 517-524.</i>	Soil ripping	Ripping improved the bulk density of reclaimed soils and reduced compaction
Fyles, J. W., Fyles, I. H. & Bell, M. A. M. (1985)	<i>Vegetation and soil development on coal-mine spoil at high elevation in the Canadian Rockies. Journal of Applied Ecology, 22, 239-248.</i>	Grass and legume seeding over 0-6 year period compared with natural succession and reference site	Soil and vegetation on the seeded site approached the reference site over the six years except soil OM which was lacking
Galan, P. (1997)	<i>Colonization of spoil benches of an opencast lignite mine in northwest Spain by amphibians and reptiles. Biological Conservation, 79, 187-195.</i>	Fertilizer and seed mix reclaimed site compared to reference areas for herpetofauna	Colonization was rapid in the first few year becoming more similar to reference areas with age
Galligan, E. W., DeVault, T. L. & Lima, S. L. (2006)	<i>Nesting success of grassland and savanna birds on reclaimed surface coal mines of the midwestern United States. Wilson Journal of Ornithology, 118, 537-546.</i>	Nesting success of birds compared for natural and reclaimed areas	Little difference found between sites suggesting that the reclaimed areas functioned well as habitat
Ganesan, V., Ragupathy, S., Parthipan, B., Rani, D. B. R. & Mahadevan, A. (1991)	<i>Distribution of vesicular-arbuscular mycorrhizal fungi in coal, lignite, and calcite mine spoils of India. Biology and Fertility of Soils, 12, 131-136.</i>	Coal, calcite and lignite spoils naturally colonized by vegetation compared for mycorrhizal fungus presence and infection	All sites showed presence and infection of fungus
Ganihar, S. R. (2003)	<i>Nutrient mineralization and leaf litter preference by the earthworm Pontoscolex corethrurus on iron ore mine wastes. Restoration Ecology, 11, 475-482.</i>	Iron ore mine waste amended with cattle dung tested for effects of earthworm activity	Worms significantly increased OM and soil nutrients. Survival of worms was improved by OM from dung
Gao, L., Miao, Z. W., Bai, Z. K., Zhou, X. Y., Zhao, J. K. & Zhu, Y. M. (1998)	<i>A case study of ecological restoration at the Xiaoyi Bauxite Mine, Shanxi Province, China. Ecological Engineering, 11, 221-229.</i>	Landscaping, fertilizing sowing and mycorrhizal inoculation	Plant and soils had reached reference site condition after ~5 years

Gardiner, D. T. (1993)	<i>Revegetation status of reclaimed abandoned mined land in western north-Dakota. Arid Soil Research and Rehabilitation, 7, 79-84.</i>	Seed drilling and NPK fertilizer applications	Mixed success. NPK did improve first year growth but helped subsequently
Ghose, M. K. (2004)	<i>Effect of opencast mining on soil fertility. Journal of Scientific & Industrial Research, 63, 1006-1009.</i>	The effect of removal and stockpiling on soil fertility investigated	Soil fertility in soil dumps shown to drastically reduce in first and subsequent years
Gorman, J. M., Sencindiver, J. C., Horvath, D. J., Singh, R. N. & Keefer, R. F. (2000)	<i>Erodibility of fly ash used as a topsoil substitute in mineland reclamation. Journal of Environmental Quality, 29, 805-811.</i>	Fly ash and wood chips used as substrate plus vegetation effects on erosion	Fly ash erodes very quickly, wood chips slow the rate as does ground cover
Gorsira, B. & Risenhoover, K. L. (1994)	<i>An evaluation of woodland reclamation on strip-mined lands in east Texas. Environmental Management, 18, 787-793.</i>	Mine areas reclaimed to woodland compared with natural woodland	Suggested that 27 years would be needed for vegetative structure to become comparable low planting survival and stem density found
Gould, A. B., Hendrix, J. W. & Ferriss, R. S. (1996)	<i>Relationship of mycorrhizal activity to time following reclamation of surface mine land in western Kentucky .1. Propagule and spore population densities. Canadian Journal of Botany-Revue Canadienne De Botanique, 74, 247-261.</i>	Seeding and mycorrhizal inoculation for rehabilitation tested for mycorrhizal population and infection	A very low population density of mycorrhiza following seeding but small population survives. After one year population and infection increases rapidly
Graham, M. H. & Haynes, R. J. (2004)	<i>Organic matter status and the size, activity and metabolic diversity of the soil microflora as indicators of the success of rehabilitation of mined sand dunes. Biology and Fertility of Soils, 39, 429-437.</i>	SOM, soil C and soil microfauna assessed over a 25 year time sequence following the replacement of stored soils	Stored soils had low fertility especially very low soil C all measured attributes improved with time approximating reference soils after 25 years
Grandlic, C. J., Mendez, M. O., Chorover, J., Machado, B. & Maier, R. M. (2008)	<i>Plant growth-promoting bacteria for phytostabilization of mine tailings. Environmental Science & Technology, 42, 2079-2084.</i>	Adding bacteria to mine soils in combination with reduced amounts of fertilizer to normal assessed	Responses were highly species specific. Bacteria were shown to aid some plants with less or no fertilizer added
Grant, C. D., Campbell, C. J. & Charnock, N. R. (2002)	<i>Selection of species suitable for derelict mine site rehabilitation in New South Wales, Australia. Water Air and Soil Pollution, 139, 215-235.</i>	Tailings, mulch and mulch/tailings used to test suitability of plants for rehabilitation	Mulch treatments produced the greatest survival and growth. Suitable species identified by greenhouse trials
Graves, D. H., Ringe, J. M., Pelkki, M. H., Sweigard, R. J. & Warner, R. (2000)	<i>High value tree reclamation research.</i>	Effects of soil compaction and ripping of establishment of growth of planted trees	Compaction shown to affect both establishment and growth of trees
Green, S. & Renault, S. (2008)	<i>Influence of papermill sludge on growth of Medicago sativa, Festuca rubra and Agropyron trachycaulum in gold mine tailings: A greenhouse study. Environmental Pollution, 151, 524-531.</i>	SOM inputs in the form of paper mill sludge and fertilizer tested for effects on plant growth	Large positive effect shown especially for combined sludge/fertilizer although species response differed

Groninger, J. W., Fillmore, S. D. & Rathfon, R. A. (2006)	<i>Stand characteristics and productivity potential of Indiana surface mines reclaimed under SMCRA. Northern Journal of Applied Forestry, 23, 94-99.</i>	Sites reclaimed to forest cover assessed against natural areas	Reclaimed areas showed far lower productivity than natural areas
Guebert, M. D. & Gardner, T. W. (2001)	<i>Macropore flow on a reclaimed surface mine: infiltration and hillslope hydrology. Geomorphology, 39, 151-169.</i>	Runoff and related erosion assessed	Infiltration and reduced runoff found with increasing time and pedogenesis
Guevara, R., Rosales, J. & Sanoja, E. (2005)	<i>Pioneer vegetation on rocks, a biological potential for revegetation of degraded areas by iron-ore mining. Interciencia, 30, 644-652.</i>	Naturally colonized mine disturbed area sampled for soils and vegetation	Naturally adapted species identified for soil conditions for use in restoration
Gunn, J. & Bailey, D. (1993)	<i>Limestone quarrying and quarry reclamation in Britain. Environmental Geology, 21, 167-172.</i>	Blasting faces to match surrounding landscape and planting with locally adapted species	Visual impact reduced
Haering, K. C., Daniels, W. L. & Roberts, J. A. (1993)	<i>Changes in mine soil properties resulting from overburden weathering. Journal of Environmental Quality, 22, 194-200.</i>	Hard rock overburden used as artificial substrate	Mine soils formed rapidly from weathering of the overburden
Hall, A. R., du Preez, D. R. & Campbell, E. E. (2003)	<i>Recovery of thicket in a revegetated limestone mine. South African Journal of Botany, 69, 434-445.</i>	Soil from surrounding desirable vegetation areas used to enhance natural succession	Natural recruitment gave rise to communities very different to surrounding vegetation although it is suggested that continuing planting would be effective
Halofsky, J. E. & McCormick, L. H. (2005a)	<i>Effects of unseeded areas on species richness of coal mines reclaimed with municipal biosolids. Restoration Ecology, 13, 630-638.</i>	The effect of leaving un-seeded strips on areas amended with biosolids on promoting woody planted species assessed	Low survival but species richness and natural colonization was highest on un-seeded strips
Halofsky, J. E. & McCormick, L. H. (2005b)	<i>Establishment and growth of experimental grass species mixtures on coal mine sites reclaimed with municipal biosolids. Environmental Management, 35, 569-578.</i>	Assessment made of various grass species seed mixes with biosolids that give adequate cover for nutrient cycling and erosion control but allow greatest natural succession	Seeding species mix identified that gave suitable cover but allowed for greatest species richness and succession of wood species
Hambler, D. J., Dixon, J. M. & Hale, W. H. G. (1995)	<i>Ten years in rehabilitation of spoil: Appearance, plant colonists, and the dominant herbivore. Environmental Conservation, 22, 323-334.</i>	Effects of rabbit grazing on plants and soil on spoil heaps	Heterogeneity of soils and plants through grazing and middens has benefited diversity although damage to rare or favoured plants can be a problem
Han, S. H., Lee, J. C., Jang, S. S. & Kim, P. G. (2004)	<i>Composted sewage sludge can improve the physiological properties of Betula schmidtii grown in tailings. Journal of Plant Biology, 47, 99-104.</i>	Effects of composted sewage sludge on woody species establishment and growth assessed	Results were mixed but generally beneficial when sewage sludge was used

Harris, J. A. & Birch, P. (1989)	<i>Soil microbial activity in opencast coal-mine restorations. Soil Use and Management, 5, 155-160.</i>	Soil store, reclaimed areas and undisturbed areas compared for microbial activity and N cycling	Stored and newly replace soils had lowest levels along with poor water holding, general improvement seen with age
Harris, M. A. (2001)	<i>The effect of sewage sludge and green manure on the erodibility of two mine tailings materials. Environmental Geology, 40, 1367-1376.</i>	The effects of green manure, sewage sludge and a combination of the two were assessed for control of erosion and leaching	Green manure alone was most successful at controlling erosion and runoff but it also stabilized sewage sludge
Harris, M. A. & Megharaj, M. (2001)	<i>The effects of sludge and green manure on hydraulic conductivity and aggregation in pyritic mine tailings materials. Environmental Geology, 41, 285-296.</i>	The effects of green manure, sewage sludge and a combination of the two were assessed for affects on hydrology of soils in spoil heaps	Sewage sludge combined with green manure showed the best results by a clear margin
Hartmann, R. & Keplin, B. (2003)	<i>Nutrition and early growth of Pinus sylvestris L. on extensively meliorated sandy mine spoil soils. Forstwissenschaftliches Centralblatt, 122, 205-218.</i>	Amelioration of sandy soils with heavy inputs of fertilizer is shown to be of limited use as they leach very quickly. Slow release silicate rock powder is offered as an alternative	Soil fertility was generally higher over an extended time period. Soil water was thought to be the most important factor
Hartmann, R., Schneider, B. U., Gast, C., Keplin, B. & Huttli, R. F. (1999)	<i>Effects of N-enriched rock powder on soil chemistry, organic matter formation and plant nutrition in lignite-poor sandy mine spoil in the forest reclamation practice. Plant and Soil, 213, 99-115.</i>	N enriched rock powder addition effects on pine seedlings	High rates of N addition caused low levels of N in pine trees probably through competition from stimulated ground layer
Hatton, T. J. & West, N. E. (1987)	<i>Early seral trends in plant community diversity on a recontoured surface mine. Vegetatio, 73, 21-29.</i>	Surface recontouring, planting density and storage of topsoil	All plots converged floristically over time but topsoil storage and planting affected early succession
Hodacova, D. & Prach, K. (2003)	<i>Spoil heaps from brown coal mining: Technical reclamation versus spontaneous revegetation. Restoration Ecology, 11, 385-391.</i>	Technical reclamation compared with natural succession	Natural succession provided greater naturalness and diversity over longer timescales
Holl, K. D. (1996)	<i>The effect of coal surface mine reclamation on diurnal lepidopteran conservation. Journal of Applied Ecology, 33, 225-236.</i>	Diurnal lepidopteran and vegetation communities compared across reclaimed and reference sites	Lepidopteran communities converged on reference site structure over time however some (probably open habitat specialists) declined
Holl, K. D. (2002)	<i>Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. Journal of Applied Ecology, 39, 960-970.</i>	Vegetation on reclaimed and reference sites compared	Structure and diversity approaching reference sites but significant differences even after long time scales. Also suggested that planting has inhibited colonization of some species that occur naturally

Holl, K. D. & Cairns, J. (1994)	<i>Vegetational community-development on reclaimed coal surface mines in Virginia. Bulletin of the Torrey Botanical Club, 121, 327-337.</i>	Vegetation on reclaimed and reference sites compared	Structure and diversity increase but limited conservation value as community structure differs from reference sites. Herbaceous layer similar but woody species differ.
Holmes, P. M. (2001)	<i>Shrubland restoration following woody alien invasion and mining: Effects of topsoil depth, seed source, and fertilizer addition. Restoration Ecology, 9, 71-84.</i>	Top soil depth from stored soil, seeding and fertilizer application effects on plant establishment.	Top soil depth was effective for plant establishment especially at deeper depths. Fertilizer application encouraged invasive species
Honda, K., Murai, S. & Shibasaki, R. (1993)	<i>Prediction of vegetation restoration by erosion control works in Asio-copper-mine, Japan.</i>	GIS and GPS used to track and predict vegetation recovery	~200 years predicted for recovery in unmanaged areas. Erosion control by planting halved the predicted time
Huxtable, C. H. A., Koen, T. B. & Waterhouse, D. (2005)	<i>Establishment of native and exotic grasses on mine overburden and topsoil in the Hunter Valley, New South Wales. Rangeland Journal, 27, 73-88.</i>	Native and exotic grasses sown in un-amended spoil and topsoil amended spoil	Native grasses performed better on raw spoil due to absence of competition, on soil they were out competed by exotics
Ingold, D. J. (2002)	<i>Use of a reclaimed stripmine by grassland nesting birds in east-central Ohio. Ohio Journal of Science, 102, 56-62.</i>	Reclaimed grasslands surveyed for birds and on going management in the form of mowing evaluated	Reclaimed grasslands were used extensively although mowing was detrimental to most species
Ireland, T. T., Wolters, G. L. & Schemnitz, S. D. (1994)	<i>Recolonization of wildlife on a coal strip-mine in Northwestern New-Mexico. Southwestern Naturalist, 39, 53-57.</i>	Ground features, vegetation and wildlife communities compared for reclaimed and reference areas	Reclaimed habitat was used but richness and diversity were lower. Lack of woody debris and other micro habitat was blamed
Jasper, D. A., Robson, A. D. & Abbott, L. K. (1988)	<i>Revegetation in an iron-ore mine - nutrient-requirements for plant-growth and the potential role of vesicular-arbuscular (va) mycorrhizal fungi. Australian Journal of Soil Research, 26, 497-507.</i>	P additions and mycorrhizal inoculation tested	Strong plant response to inoculation and P additions. N became the limiting factor after these additions
Jefferson, L. V. (2004)	<i>Implications of plant density on the resulting community structure of mine site land. Restoration Ecology, 12, 429-438.</i>	Plant interaction investigated to assess survival in seed mix	Interactions, especially density and nurse/competitor, shown to be important in seed mix
Jha, P. K., Nair, S., Gopinathan, M. C. & Babu, C. R. (1995)	<i>Suitability of rhizobia-inoculated wild legumes <i>Argyrolobium flaccidum</i>, <i>Astragalus graveolens</i>, <i>Indigofera gangetica</i> and <i>Lespedeza stenocarpa</i> in providing a vegetational cover in an unreclaimed limestone quarry. Plant and Soil, 177, 139-149.</i>	Sowing and seeding of legumes with mycorrhizal inoculation	Increase in germination, survival and biomass from inoculation compared to un-inoculated controls. Legumes were beneficial for soils and naturally colonizing legumes also established
Jim, C. Y. (2001)	<i>Ecological and landscape rehabilitation of a quarry site in Hong Kong. Restoration Ecology, 9, 85-94.</i>	Blasting and landscaping to match surrounding area, soil cap and OM added for leguminous trees	Very low establishment and survival blamed on shallow soils low soil nutrient and water holding capacity

Jochimsen, M. E. (2001)	<i>Vegetation development and species assemblages in a long-term reclamation project on mine spoil. Ecological Engineering, 17, 187-198.</i>	Sand and fertilizer applications and sowing on mine spoils	Highly mixed results, possibly dependent more on local conditions than reclamation but general development over time
Johnson, N. C. (1998)	<i>Responses of Salsola kali and Panicum virgatum to mycorrhizal fungi, phosphorus and soil organic matter: implications for reclamation. Journal of Applied Ecology, 35, 86-94.</i>	Mycorrhizal inoculation and P enrichment and soil OM	OM produced good results, mycorrhizal inoculation aided growth but mainly of late successional species. OM additions suggested as effective and cost effective method
Jordan, M. M., Pina, S., Garcia-Orenes, F., Almendro-Candel, M. B. & Garcia-Sanchez, E. (2008)	<i>Environmental risk evaluation of the use of mine spoils and treated sewage sludge in the ecological restoration of limestone quarries. Environmental Geology, 55, 453-462.</i>	Sewage sludge remediated stored soils assessed for leachates when applied to un-vegetated mine spoils	Measured levels for all parameters were within acceptable limits except electrical conductivity which reduced quickly
Kahl, L., Kluge, R. & Thomas, S. (2000)	<i>Evaluation of an attempt to cultivate shrubs and trees on a heap of a potash mine. Landscape and Urban Planning, 51, 109-112.</i>	Intensive management in the form of planting containers, hydro-gel and sewage sludge used for planting of seedlings	Planting was successful in these conditions
Kasowska, D. (2002)	<i>Mycorrhizal status of plants in two successional stages on spoil heaps from fireloam mining in Lower Silesia (SW Poland). Acta Societatis Botanicorum Poloniae, 71, 155-161.</i>	Early and late stage successional plant communities compared for mycorrhizal associations	Relatively low levels of mycorrhizal association found in early succession but domination by inoculated plants in late succession
Khater, C., Martin, A. & Maillet, J. (2003)	<i>Spontaneous vegetation dynamics and restoration prospects for limestone quarries in Lebanon. Applied Vegetation Science, 6, 199-204.</i>	Natural succession surveyed for areas with different levels of degradation	Annuals dominate on highly degraded land while woody shrubs and perennial herbs on less degraded land. Survey identified species useful for restoration
Kielhorn, K. H., Keplin, B. & Huttli, R. F. (1999)	<i>Ground beetle communities on reclaimed mine spoil: Effects of organic matter application and revegetation. Plant and Soil, 213, 117-125.</i>	Sewage sludge, compost and mineral fertilizer used to ameliorate sandy mine spoil. Sown grass and planted pines compared with control with no rehabilitation	Sewage sludge sites were most colonized with beetles followed by compost, mineral fertilizer and un-ameliorated sites.
Kirmer, A. & Mahn, E. G. (2001)	<i>Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany. Applied Vegetation Science, 4, 19-27.</i>	Soil amended with plant clippings compared with unamended soils. Seed rain also measured	Both treated and untreated treatments developed over time but the rate of succession on the treated plots was higher
Koch, J. M. (2007)	<i>Restoring a jarrah forest understorey vegetation after bauxite mining in Western Australia. Restoration Ecology, 15, S26-S39.</i>	Direct transfer of topsoil from unmined areas	Approximately 70% of unmined area understory richness returned however woody species did not establish well in the long term

Koch, J. M. & Hobbs, R. J. (2007)	<i>Synthesis: is Alcoa successfully restoring a jarrah forest ecosystem after bauxite mining in Western Australia? Restoration Ecology, 15, S137-S144.</i>	Multiple measurements of restoration success used to assess restoration success	Ecosystem function and vegetative structure was considered to either be restored or developing successfully
Koch, J. M., Richardson, J. & Lamont, B. B. (2004)	<i>Grazing by kangaroos limits the establishment of the grass trees Xanthorrhoea gracilis and X-preissii in restored bauxite mines in Eucalypt Forest of Southwestern Australia. Restoration Ecology, 12, 297-305.</i>	Soil ripping used to aid establishment of plants and grazing exclusion tested	Grazing was shown to be a significant factor affecting growth. Nursery plants aided growth in grazed areas but inhibited growth when grazing was excluded
Koch, J. M., Ward, S. C., Grant, C. D. & Ainsworth, G. L. (1996)	<i>Effects of bauxite mine restoration operations on topsoil seed reserves in the jarrah forest of Western Australia. Restoration Ecology, 4, 368-376.</i>	Effects of soil handling and storage on soil seed bank assessed	Storage in soil dumps greatly reduced viable seed numbers. Ripping was shown to aid seed germination
Kothari, R. R. & McNearny, R. L. (1998)	<i>Revegetation of a mine tailings impoundment using municipal biosolids in a semi-arid environment, Utah, USA, two years of results.</i>	Soil amendment with biosolids tested for plant and soil effects	Soil characteristics and plant biomass shown to be greatly enhanced by application of biosolids. This trend continued over time
Kumar, S., Sharma, K., Sharma, B. K. & Gough, L. P. (1998)	<i>Richness, diversity and evenness of vegetation upon rehabilitation of gypsum mine spoiled lands in the Indian arid zone. Annals of Arid Zone, 37, 139-145.</i>	Shrub and tree planting, water harvesting and protection used to establish vegetation	Rehabilitated sites were shown to have higher levels of richness and diversity than unreclaimed sites
Leavitt, K. J., Fernandez, G. C. J. & Nowak, R. S. (2000)	<i>Plant establishment on angle of repose mine waste dumps. Journal of Range Management, 53, 442-452.</i>	Mine soil, mine soil with fertilizer, cover soil and cover soil and fertilizer combined assessed for plant establishment promotion	Seeds established naturally on cover soil treatment but erosion was significant. Plantings were successful on all treated slopes.
Li, F. P., Liu, R. Y., Zhang, J. R., Guo, Q. Z. & Wang, H. X. (2005a)	<i>Land reclamation pattern of iron mine in Tangshan. Transactions of Nonferrous Metals Society of China, 15, 151-155.</i>	Soil amendments and direct planting used to reclaim areas	Treatments reported as highly successful
Li, R. S. & Daniels, W. L. (1994)	<i>Nitrogen accumulation and form over time in young mine soils. Journal of Environmental Quality, 23, 166-172.</i>	Chronosequence studied for N accumulation, distribution and component change	Young soils dominated by leguminous species had high N but in forms unavailable to plants. Hardwood dominated older soils had increased levels of available N.
Little, I. T., Little, R. M., Jansen, R. & Crowe, T. M. (2005)	<i>Winter bird assemblages, species richness and relative abundance at a re-vegetated coal mine in the Middelburg district, Mpumalanga province, South Africa. South African Journal of Wildlife Research, 35, 13-22.</i>	Bird assemblages compared on reclaimed and un-mined sites	Age of site had little effect. Proximity to current mining activities was far more influential

Loch, R. J. (2000a)	<i>Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the Meandu Mine, Tarong, Queensland. Australian Journal of Soil Research, 38, 299-312.</i>	Rainfall was simulated on a 15% slope with varying degrees of vegetative cover to test effects on runoff and erosion	Increasing vegetative cover had an increasing level of infiltration and reduction in runoff
Loch, R. J. (2000b)	<i>Using rainfall simulation to guide planning and management of rehabilitated areas: Part I. Experimental methods and results from a study at the Northparkes Mine, Australia. Land Degradation & Development, 11, 221-240.</i>	Rain fall simulated to test the effects of vegetation on infiltration, runoff and erosion	Increasing vegetative cover had an increasing level of infiltration and reduction in runoff
Loch, R. J. & Orange, D. N. (1997)	<i>Changes in some properties of topsoil at Tarong coal Meandu mine coalmine with time since rehabilitation. Australian Journal of Soil Research, 35, 777-784.</i>	Vegetated and unvegetated mine spoil compared for soil hydrology	Vegetation shown to greatly improve the infiltration and soil water holding capacity
Lunt, P. H. & Hedger, J. N. (2003)	<i>Effects of organic enrichment of mine spoil on growth and nutrient uptake in oak seedlings inoculated with selected ectomycorrhizal fungi. Restoration Ecology, 11, 125-130.</i>	OM added as leaf mulch and inoculation with mycorrhiza tested	OM had a significant effect. Inoculation had no effect on its own but combined with OM addition in enhanced growth
Lyngdoh, T., Tripathi, R. S. & Das, A. K. (1992)	<i>Vegetation dynamics on coal-mine spoils of Jaintia hills in Meghalaya (northeast India) undergoing natural recovery. Acta Oecologica-International Journal of Ecology, 13, 767-775.</i>	Natural colonization of spoils assessed	Richness and diversity of plants increased with spoil age but the assemblages were significantly different to unmined sites
MacDonald, N. W., Koetje, M. T. & Perry, B. J. (2003)	<i>Native warm-season grass establishment on spotted knapweed-infested gravel mine spoils. Journal of Soil and Water Conservation, 58, 243-250.</i>	Sewage sludge and herbicides used to control invasive species and encourage natives	Interactions were not clear cut. Sludge increased native grasses and herbicide was effective at controlling invasive but some combinations of sludge and herbicides favoured invasive
Machulla, G., Bruns, M. A. & Scow, K. M. (2005)	<i>Microbial properties of mine spoil materials in the initial stages of soil development. Soil Science Society of America Journal, 69, 1069-1077.</i>	Hay mulch seeding treatment without topsoil or fertilizer application. Microbial C and activity measured	Microbial mass and activity increased with time of reclamation compared to reference site
Majer, J. D. (1992)	<i>Ant recolonization of rehabilitated bauxite mines of pocos-de-caldas, brazil. Journal of Tropical Ecology, 8, 97-108.</i>	Various planting treatment compared for ant species recolonisation	Ant recolonisation was rapid on both treatments. Species assemblages were progressing towards reference areas
Majer, J. D. (1996)	<i>Ant recolonization of rehabilitated bauxite mines at Trombetas, Para, Brazil. Journal of Tropical Ecology, 12, 257-273.</i>	Various planting treatment compared for ant species recolonisation	Ant recolonisation was rapid on both treatments. Species assemblages were progressing towards reference areas

Majer, J. D., Brennan, K. E. C. & Moir, M. L. (2007)	<i>Invertebrates and the restoration of a forest ecosystem: 30 years of research following bauxite mining in Western Australia. Restoration Ecology, 15, S104-S115.</i>	Invertebrate assemblages measured by review in restored mining areas	All species progressed towards reference areas over time
Majer, J. D. & Nichols, O. G. (1998)	<i>Long-term recolonization patterns of ants in Western Australian rehabilitated bauxite mines with reference to their use as indicators of restoration success. Journal of Applied Ecology, 35, 161-182.</i>	Planted, mixed species seeded and unvegetated mine site compared for invertebrate community establishment	Mixed species seeding produced communities most similar to reference areas followed by the planted site. All plots improved over time although differences with reference area persisted
Malik, A. & Scullion, J. (1998)	<i>Soil development on restored opencast coal sites with particular reference to organic matter and aggregate stability. Soil Use and Management, 14, 234-239.</i>	Soil OM and aggregate stability measured in restored sites with a range of management strategies	Results were not clear. Restored soils were generally better but changes over time were complex. 5 years did not produce soils of the desired structure and fertility
Marsden, D. D. (1987)	<i>The vegetating of mine-residue deposits on the Witwatersrand. Journal of the South African Institute of Mining and Metallurgy, 87, 189-194.</i>	Ripping, wind breaks, revegetation, fertilizer additions and liming	After wide scale trial gold mine tailings were successfully revegetated
Martinez, F., Cuevas, G., Calvo, R. & Walter, I. (2003)	<i>Biowaste effects on soil and native plants in a semiarid ecosystem. Journal of Environmental Quality, 32, 472-479.</i>	Biosolids and municipal wastes applied and soil and plants surveyed	Zn and Cu higher in municipal waste treatments. Soil nutrients and plant biomass increased with applications but diversity decreased.
Martinez-Ruiz, C. & Fernandez-Santos, B. (2005)	<i>Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecologica-International Journal of Ecology, 28, 231-238.</i>	Topsoil added to mine spoils and natural succession recorded	Revegetation was successful although species composition was different to undisturbed site succession. Differing levels of exposure affected timing of succession but not direction
Martinez-Ruiz, C., Fernandez-Santos, B., Putwain, P. D. & Fernandez-Gomez, M. J. (2007)	<i>Natural and man-induced revegetation on mining wastes: Changes in the floristic composition during early succession. Ecological Engineering, 30, 286-294.</i>	Hydro seeding of commercial seed mix	Hydro seeding increased establishment and diversity but only for two years. Natural succession is suggested as a better alternative
McEwan, N. R., Gould, E. M. O. & Wheeler, C. T. (1999)	<i>The competitiveness, persistence and dispersal of Frankia strains in mine spoil planted with inoculated Alnus rubra. Symbiosis, 26, 165-177.</i>	Mycorrhizal inoculation of planted Frankia tested with and without the presence of alder	Without alder as a host survival and inoculation of fungal mycorrhiza was very limited
McIntosh, J. E. & Barnhisel, R. I. (1993)	<i>Erodibility and sediment yield by natural rainfall from reconstructed mine soils. Soil Science, 156, 118-126.</i>	Top soil, subsoil and mine spoil compared for erosion, runoff and sediment yield	Erosion was greatest in sub soil then mine spoil then topsoil. However slope and aspect were of greater significance than substrate
Mehrotra, V. S. (1996)	<i>Use of revegetated coal mine spoil as source of arbuscular mycorrhizal inoculum for nursery inoculations. Current Science, 71, 73-77.</i>	Soils taken from revegetated mine sites used as a source of mycorrhizal inoculum for nursery planting	Soils used improved plant growth significantly but results were dependent on species covering mine soils used

Mehrotra, V. S. (1998)	<i>Arbuscular mycorrhizal associations of plants colonizing coal mine spoil in India. Journal of Agricultural Science, 130, 125-133.</i>	Mine soils sampled from areas re-vegetating naturally	High levels of mycorrhizal infection found showing that colonizers could support and benefit from mycorrhiza naturally
Mendez, M. O. & Maier, R. M. (2008)	<i>Phytostabilization of mine tailings in arid and semiarid environments - An emerging remediation technology. Environmental Health Perspectives, 116, 278-283.</i>	Literature review of phytostabilization of mine tailings in arid and semi-arid environments	Local adaptation proved to be the most important factor
Messina, M. G. & Duncan, J. E. (1993)	<i>Establishment of hardwood tree and shrub species on a Texas lignite mine using irrigation, mulch and shade. Landscape and Urban Planning, 25, 85-93.</i>	Hardwood tree and shrub species planted with irrigation, mulch and shade and irrigation only	First year irrigation was shown to have a positive effect. Subsequent irrigation and mulch and shade had no effect
Moir, M. L., Brennan, K. E. C., Koch, J. M., Majer, J. D. & Fletcher, M. J. (2005)	<i>Restoration of a forest ecosystem: The effects of vegetation and dispersal capabilities on the reassembly of plant-dwelling arthropods. Forest Ecology and Management, 217, 294-306.</i>	Chronosequence of restored mines and surrounding forest sampled for arthropods and plants	Vegetation found to reach a plateau of richness below that of natural forest although structure converges. Arthropod populations follow a similar pattern with generalist species colonizing quickly but overall being limited by vegetation dynamics
Molina, L., Diaz-Ferrero, J., Coll, M., Marti, R., Broto-Puig, F., Comellas, L. & Rodriguez-Larena, M. C. (2000)	<i>Study of evolution of PCDD/F in sewage sludge-amended soils for land restoration purposes. Chemosphere, 40, 1173-1178.</i>	Pollutant levels tested in mine soils amended with sewage sludge	Pollution was detected at persistently high levels
Monroe, M. S. & Ritchison, G. (2005)	<i>Breeding biology of Henslow's Sparrows on reclaimed coal mine grasslands in Kentucky. Journal of Field Ornithology, 76, 143-149.</i>	Behaviour and ecology of Henslow's sparrows compared on reclaimed and unmined sites	Prey numbers were higher on reclaimed sites and territories were smaller. No differences were recorded in nesting success
Monterroso, C., Macias, F., Bueno, A. G. & Caballero, C. V. (1998)	<i>Evaluation of the land reclamation project at the As Pontes Mine (NW Spain) in relation to the suitability of the soil for plant growth. Land Degradation & Development, 9, 441-451.</i>	Reclaimed mine site compared for plant growth	Soil properties especially compaction were considered the most important factor
Moreno-Penaranda, R., Lloret, F. & Alcaniz, J. M. (2004)	<i>Effects of sewage sludge on plant community composition in restored limestone quarries. Restoration Ecology, 12, 290-296.</i>	Sewage sludge mixed with soils compared with stored soils	Bio mass and plant cover increased as a result of sewage sludge application however species richness was lower
Mott, J. B. & Zuberer, D. A. (1991)	<i>Natural recovery of microbial-populations in mixed overburden surface-mine spoils of Texas. Arid Soil Research and Rehabilitation, 5, 21-34.</i>	1-10 year old mine soils analysed for soil micro flora and fauna	Soil microbes recovered in around 1.5 years after revegetation but algal and fungal densities increased but remained low

Moynahan, O. S., Zabinski, C. A. & Gannon, J. E. (2002)	<i>Microbial community structure and carbon-utilization diversity in a mine tailings revegetation study. Restoration Ecology, 10, 77-87.</i>	Revegetated mine spoils either untreated, with top soil, various degrees of ripping, slurry and lime additions sampled for microbes	Soil microbiota increased across all plots but top soil additions had the greatest effect
Mummey, D. L., Stahl, P. D. & Buyer, J. S. (2002a)	<i>Microbial biomarkers as an indicator of ecosystem recovery following surface mine reclamation. Applied Soil Ecology, 21, 251-259.</i>	Mine reclamation plots of various ages sampled for microbiota	All plots showed an increase towards reference sites with age SOM and N levels thought to be the most important factors
Mummey, D. L., Stahl, P. D. & Buyer, J. S. (2002b)	<i>Soil microbiological properties 20 years after surface mine reclamation: spatial analysis of reclaimed and undisturbed sites. Soil Biology & Biochemistry, 34, 1717-1725.</i>	Mine reclamation plots of various ages sampled for microbiota	Low levels of recovery and shallow rooting by established plants found. Shrubs played a key role in ecological development
Muzzi, E. & Fabbri, T. (2007)	<i>Revegetation of mineral clay soils: Shrub and tree species compared. Land Degradation & Development, 18, 441-451.</i>	Various planted shrub and tree species growth on otherwise unmanaged quarry land	Responses were highly species specific. Also grazing was shown to be a considerable factor
Muzzi, E., Roffi, F., Sirotti, M. & Bagnaresi, U. (1997)	<i>Revegetation techniques on clay soil slopes in northern Italy. Land Degradation & Development, 8, 127-137.</i>	Hydro-seeding and tillage, hydro-seeding on sod, cover with jute mats and various combinations of fertilizer. Ground cover, species and runoff and erosion measured	No effect from hydro-seeding. Covering and tilling reduced erosion. Fertilization aided plant growth but effects were mixed
Novak, J. & Konvicka, M. (2006)	<i>Proximity of valuable habitats affects succession patterns in abandoned quarries. Ecological Engineering, 26, 113-122.</i>	Age and distance to valuable habitat tested for effects on succession	Age, size and distance from desired habitat had a large effect on the establishment of valuable habitat
Novak, J. & Prach, K. (2003)	<i>Vegetation succession in basalt quarries: Pattern on a landscape scale. Applied Vegetation Science, 6, 111-116.</i>	Succession in disused quarries studied	Rare species found to establish. Semi-natural vegetation found after ~20 years. Distance from desirable habitat shown to be a significant factor
Noyd, R. K., Pflieger, F. L. & Norland, M. R. (1996)	<i>Field responses to added organic matter, arbuscular mycorrhizal fungi, and fertilizer in reclamation of taconite iron ore tailing. Plant and Soil, 179, 89-97.</i>	Compost, fertilizer and AM mycorrhiza added to tailings seeded with native grasses	All three treatments increased plant cover and biomass
Noyd, R. K., Pflieger, F. L., Norland, M. R. & Sadowsky, M. J. (1995a)	<i>Native prairie grasses and microbial community responses to reclamation of taconite iron-ore tailing. Canadian Journal of Botany-Revue Canadienne De Botanique, 73, 1645-1654.</i>	Compost, fertilizer and AM mycorrhiza added to tailings seeded with native grasses	All three treatments increased plant cover and biomass although effects of mycorrhizal inoculation was limited
Noyd, R. K., Pflieger, F. L. & Russelle, M. P. (1995b)	<i>Interactions between native prairie grasses and indigenous arbuscular mycorrhizal fungi - implications for reclamation of taconite iron-ore tailing. New Phytologist, 129, 651-660.</i>	Mycorrhizal inoculation of green house grown plants on mine spoil	Mycorrhizal inoculation did not affect growth positively except to extend root growth in some instances.

Nyamadzawo, G., Shukla, M. K. & Lal, R. (2008)	<i>Spatial variability of total soil carbon and nitrogen stocks for some reclaimed minesoils of Southeastern Ohio. Land Degradation & Development, 19, 275-288.</i>	Soil C and N assessed in a chronosequence of mine soils seeded with grasses and some planted with tree species	Soil enhancement was most effective when initially seeded with grass followed by subsequent planting of tree species
O'Dell, R. E. & Claassen, V. P. (2006a)	<i>Relative performance of native and exotic grass species in response to amendment of drastically disturbed serpentine substrates. Journal of Applied Ecology, 43, 898-908.</i>	Growth of native and exotic species compared on mine soils amended with NPK, gypsum and mulch	Treatment greatly promoted growth but favoured invasive over native species
O'Dell, R. E. & Claassen, V. P. (2006b)	<i>Vertical distribution of organic amendment influences the rooting depth of revegetation species on barren, subgrade serpentine substrate. Plant and Soil, 285, 19-29.</i>	Growth of native and exotic species compared on mine soils amended with NPK, gypsum and mulch	Treatment greatly promoted growth but favoured invasive over native species
Ottonetti, L., Tucci, L. & Santini, G. (2006)	<i>Recolonization patterns of ants in a rehabilitated lignite mine in central Italy: Potential for the use of Mediterranean ants as indicators of restoration processes. Restoration Ecology, 14, 60-66.</i>	Ant populations on reclaimed areas studied	Species richness and diversity were not greatly different but the functional groups were. Increases in specialist species showed good response to reclamation
Parmenter, R. R., Macmahon, J. A. & Gilbert, C. A. B. (1991)	<i>Early successional patterns of arthropod recolonization on reclaimed Wyoming strip mines - the grasshoppers (orthoptera, acrididae) and allied faunas (orthoptera, gryllacrididae, tettigoniidae). Environmental Entomology, 20, 135-142.</i>	Revegetated mine sites sampled for arthropods	All sites showed some colonization but after 6 years little similarity to reference areas was noted. Strong correlation was found with vegetation recovery
Passell, H. D. (2000)	<i>Recovery of bird species in minimally restored Indonesian tin strip mines. Restoration Ecology, 8, 112-118.</i>	Bird species richness compared for reference area, unreclaimed area and reclaimed mine areas	Unrestored sites showed little colonization, restored areas were colonized although significantly less than reference areas after 3 years
Pattanaik, R., Sahu, S., Padhi, G. S. & Mishra, A. K. (1995)	<i>Effect of inoculation of vesicular-arbuscular mycorrhiza on horsegram (macrotyloma-uniflorum) grown in soil in iron-mine area. Indian Journal of Agricultural Sciences, 65, 186-190.</i>	Greenhouse experiment using mine soils to grow plants with and without mycorrhizal inoculation	Inoculation had a strongly positive effect of plant growth
Pensa, M., Sellin, A., Luud, A. & Valgma, I. (2004)	<i>An analysis of vegetation restoration on opencast oil shale mines in Estonia. Restoration Ecology, 12, 200-206.</i>	Various tree plantations compared with natural succession	Planted stands had the greatest biomass but natural succession gave the most diverse assemblages
Pereira, M. P. D., Queiroz, J. M., Valcarcel, R. & Mayhe-Nunes, A. J. (2007)	<i>Ant fauna as a tool for the monitoring of a rehabilitated sand mine at Ilha da Madeira, Itaguaí, RJ. Ciencia Florestal, 17, 197-204.</i>	Natural succession and plantations on mine soil compared for ant fauna	Natural succession produces a richer and more diverse ant species assemblage

Petrisor, I. G., Dobrota, S., Komnitsas, K., Lazar, I., Kuperberg, J. M. & Serban, M. (2004)	<i>Artificial inoculation - Perspectives in tailings phytostabilization. International Journal of Phytoremediation, 6, 1-15.</i>	Greenhouse study of native plant growth on mine spoils with chemical fertilizer or microbial inoculation	Microbial inoculation produced better growth in all treatments than fertilization. Microbial activity was also low in fertilized treatments
Picaud, F. & Petit, D. P. (2007)	<i>Primary succession of Orthoptera on mine tailings: role of vegetation. Annales De La Societe Entomologique De France, 43, 69-79.</i>	Plant and Orthoptera communities measured on mine sites with and without added topsoil	With topsoil plant and Orthoptera communities developed roughly in parallel. Without topsoil insect succession was unaffected but plant succession was limited
Pietrzykowski, M. & Krzaklewski, W. (2007)	<i>An assessment of energy efficiency in reclamation to forest. Ecological Engineering, 30, 341-348.</i>	Energy accumulation assessed in natural succession and reclaimed areas	Energy content of plant biomass and soil C was around 2 fold higher in reclaimed systems
Pushel, D., Rydlova, J. & Vosatka, M. (2008)	<i>Does the sequence of plant dominants affect mycorrhiza development in simulated succession on spoil banks? Plant and Soil, 302, 273-282.</i>	Mycorrhizal infection compared in inoculated and naturally colonizing sites	Mycorrhizal development was very rapid in all treatments although dependent on the plant species present
Ramsay, W. J. H. (1986)	<i>Bulk soil handling for quarry restoration. Soil Use and Management, 2, 30-39.</i>	Soil handling and transport to minimise damage investigated	Use of excavators and dump trucks reduce compaction and loss of cohesion allowing improved plant growth
Rao, A. V. & Tak, R. (2001)	<i>Effect of rhizobial inoculation on Albizia lebbeck and its rhizosphere activity in mine spoils. Arid Land Research and Management, 15, 157-162.</i>	Inoculation effects on plant growth investigated	Inoculation had a large positive effect on plant growth and soil properties
Rao, A. V. & Tak, R. (2002)	<i>Growth of different tree species and their nutrient uptake in limestone mine spoil as influenced by arbuscular mycorrhizal (AM) -fungi in Indian arid zone. Journal of Arid Environments, 51, 113-119.</i>	Inoculation effects on plant growth investigated	Inoculation had a large positive effect on plant growth and soil properties
Rao, A. V., Tarafdar, J. C. & Tak, R. (2000)	<i>Improvement in the microbiological productivity of limestone mine spoils with time. Agrochimica, 44, 171-179.</i>	Microbial activity measured in limestone spoil heaps	After 5 years levels of microbial activity were still lower than in reference areas. Some time for natural systems to start up before further management recommended
Rate, A. W., Lee, K. M. & French, P. A. (2004)	<i>Application of biosolids in mineral sands mine rehabilitation: use of stockpiled topsoil decreases trace element uptake by plants. Bioresource Technology, 91, 223-231.</i>	Biosolid amended mine spoil used in green house experiment with top soil and liming additions	Heavy metal concentrations in soils and plants increased with rate of biosolid application. Lime and topsoil reduced levels but in all treatments levels of heavy metals were within safe limits

Reddell, P., Gordon, V. & Hopkins, M. S. (1999)	<i>Ectomycorrhizas in Eucalyptus tetrodonta and E-miniata forest communities in tropical northern Australia and their role in the rehabilitation of these forests following mining. Australian Journal of Botany, 47, 881-907.</i>	Effect of ectomycorrhizal inoculation investigated	Very low levels of mycorrhiza found in mine soils. Inoculation found to be highly beneficial to growth
Reddell, P. & Milnes, A. R. (1992)	<i>Mycorrhizas and other specialized nutrient-acquisition strategies - their occurrence in woodland plants from Kakadu and their role in rehabilitation of waste rock dumps at a local uranium-mine. Australian Journal of Botany, 40, 223-242.</i>	Stockpiled soils, undisturbed soils and newly forming mine soils compared.	Stockpiled soils had very low levels of mycorrhiza, new soils slightly higher. Mycorrhizal inoculation had a strong positive effect
Redente, E. F., McLendon, T. & Agnew, W. (1997)	<i>Influence of topsoil depth on plant community dynamics of a seeded site in northwest Colorado. Arid Soil Research and Rehabilitation, 11, 139-149.</i>	Top soil depth, ripping and fertilization tested for effects on plant growth	Deeper soils supported grass dominated communities while shallower soils encouraged more diversity and shrubs
Reeder, J. D. & Berg, W. A. (1977)	<i>Plant uptake of indigenous and fertilizer nitrogen from a cretaceous shale and coal-mine spoils. Soil Science Society of America Journal, 41, 919-921.</i>	N uptake from fertilizer and mineral N compared in a greenhouse experiment	N from fertilizer was more readily available to plants than mineral N
Reid, N. B. & Naeth, M. A. (2005a)	<i>Establishment of a vegetation cover on tundra kimberlite mine tailings: 1. A greenhouse study. Restoration Ecology, 13, 594-601.</i>	Various forms of OM and fertilizer were used in a greenhouse experiment.	Plant growth and soil properties were enhanced by soil amendments and structural improvements
Reid, N. B. & Naeth, M. A. (2005b)	<i>Establishment of a vegetation cover on tundra kimberlite mine tailings: 2. A field study. Restoration Ecology, 13, 602-608.</i>	Various forms of OM and fertilizer were used in a field experiment.	Plant growth and soil properties were enhanced by soil amendments and structural improvements
Rodgers, C. S. & Anderson, R. C. (1995)	<i>Plant-growth inhibition by soluble salts in sewage sludge-amended mine spoils. Journal of Environmental Quality, 24, 627-630.</i>	Grasses grown in chamber with mine soil and various levels of sewage sludge or fertilizer or fresh soil	There was a linear increase in biomass accumulation with increasing sewage sludge. High levels of irrigation were needed to avoid inhibition by soluble salts
Rodrigue, J. A. & Burger, J. A. (2004)	<i>Forest soil productivity of mined land in the midwestern and eastern coalfield regions. Soil Science Society of America Journal, 68, 833-844.</i>	Forest grown on mine sites and non-mined sites compared for productivity	12 of the 14 mined sites had no significant difference with un-mined areas. The differences on the other site were attributed to soil depth and composition
Rodrigue, J. A., Burger, J. A. & Oderwald, R. G. (2002)	<i>Forest productivity and commercial value of pre-law reclaimed mined land in the eastern United States. Northern Journal of Applied Forestry, 19, 106-114.</i>	Forest grown on mine sites and non-mined sites compared for productivity	12 of the 14 mined sites had no significant difference with un-mined areas. The differences on the other site were attributed to soil depth and composition. Commercial forestry value was higher on planted mine sites

Rosario, K., Iverson, S. L., Henderson, D. A., Chartrand, S., McKeon, C., Glenn, E. P. & Maier, R. M. (2007)	<i>Bacterial community changes during plant establishment at the San Pedro River mine tailings site. Journal of Environmental Quality, 36, 1249-1259.</i>	Plants transplanted onto mine tailings with and without fertilizer and an unplanted control. Assessed for plant survival and soil bacteria	>80% survival on all planted plots. No treatment effect from fertilizer on soil bacteria suggesting planting rather than fertilizing is important
Rowe, E. C., Healey, J. R., Edwards-Jones, G., Hills, J., Howells, M. & Jones, D. L. (2006)	<i>Fertilizer application during primary succession changes the structure of plant and herbivore communities. Biological Conservation, 131, 510-522.</i>	Effects of fertilization on primary succession on slate waste assessed for tree growth, ground flora and foliar invertebrates	Tree growth was enhanced as did ground cover although responses were varied. Invertebrates were favoured by more palatable foliage although diversity was unaffected
Rowe, E. C., Williamson, J. C., Jones, D. L., Holliman, P. & Healey, J. R. (2005)	<i>Initial tree establishment on blocky quarry waste ameliorated with hydrogel or slate processing fines. Journal of Environmental Quality, 34, 994-1003.</i>	Compost filled pocket planting, hydro gel and slate processing fines used to try and enhance tree growth	Effects of slate processing fines were beneficial but hydro gel had no effect.
Rufaut, C. G., Hammit, S., Craw, D. & Clearwater, S. G. (2006)	<i>Plant and invertebrate assemblages on waste rock at Wangaloa coal mine, Otago, New Zealand. New Zealand Journal of Ecology, 30, 311-319.</i>	Natural succession on waste rock tested for plant and invertebrate assemblages	Plants were predominantly native woody species although community differences were evident on different areas of the heap. Invertebrates were richest on high plant areas but total numbers highest on quartz rich areas
Rumpel, C., Kogel-Knabner, I. & Huttli, R. F. (1999)	<i>Organic matter composition and degree of humification in lignite-rich mine soils under a chronosequence of pine. Plant and Soil, 213, 161-168.</i>	C accumulation and degree of humification over a chronosequence of mine soils with pine trees assessed	C and humification increased with soil age becoming comparable with undisturbed forest soils after 32 years.
Ruzek, L., Vorisek, K., Vrablikova, J., Strnadova, S. & Vrablik, P. (2003)	<i>Chemical and biological characteristics of reclaimed soils in the Most region (Czech Republic). Plant Soil and Environment, 49, 346-351.</i>	Soil C and microbiological characteristics measured for soils sown with legumes and grasses and amended with pulp and sewage sludge and mycorrhizal inoculation	Amendments with pulp and sewage gave rise to the greatest levels of soil C and microbiology activity. Inoculation also encouraged microbiology.
Rydlova, J. & Vosatka, M. (2001)	<i>Associations of dominant plant species with arbuscular mycorrhizal fungi during vegetation development on coal mine spoil banks. Folia Geobotanica, 36, 85-97.</i>	Plants tested in the field and pot experiments for associations with mycorrhiza	Very low levels of infectivity found in all field tests. Some grasses seemed to be facultative mycotrophs. Native mycorrhiza colonized more readily than exotic but still little effect on growth
Salazar, M., Poch, R. M. & Bosch, A. D. (2002)	<i>Reclamation of steeply sloping coal spoil banks under Mediterranean semi-arid climate. Australian Journal of Soil Research, 40, 827-845.</i>	Various mine slopes amended with pig slurry and straw and seeded	Crusting caused some problems with emergence especially on steep slopes however plants established and grew well. Erosion was problematic on steep slopes but controlled by vegetation

Santibanez, C., Ginocchio, R. & Varnero, M. T. (2007)	<i>Evaluation of nitrate leaching from mine tailings amended with biosolids under Mediterranean type climate conditions. Soil Biology & Biochemistry, 39, 1333-1340.</i>	Leaching column experiments for bio solid amended mine spoils (surface applied or mixed) with or without grass seeding	Leachates were high initially. Mixing and seeding reduced the problem
Schladweiler, B. K., Vance, G. E., Legg, D. E., Munn, L. C. & Haroian, R. (2005)	<i>Topsoil depth effects on reclaimed coal mine and native area vegetation in northeastern Wyoming. Rangeland Ecology & Management, 58, 167-176.</i>	Effect of topsoil depth on plant growth compared with reference areas	30cm depth produced the greatest diversity, 56cm produced the greatest biomass exceeding reference areas. Reference areas had the greatest diversity. Varied soil depth recommended
Schoenholtz, S. H., Burger, J. A. & Kreh, R. E. (1992)	<i>Fertilizer and organic amendment effects on mine soil properties and revegetation success. Soil Science Society of America Journal, 56, 1177-1184.</i>	Wood chips, native soil and fertilizer tilled into newly exposed mine soils, spread with fertilizer and seeded with cover crop	Wood chips increased soil N and C and resulted in highest rate of plant growth over 3 years. Fertilizer improved only first season growth
Schuman, G. E. & Belden, S. E. (1991)	<i>Decomposition of wood-residue amendments in revegetated bentonite mine spoils. Soil Science Society of America Journal, 55, 76-80.</i>	Buried litter bags with wood residue and N fertilizer	Woody residue decomposed rapidly and was aided by N fertilizer however. Decomposition appears to be effective despite harsh conditions
Schuman, G. E. & Belden, S. E. (2002)	<i>Long-term survival of direct seeded Wyoming big sagebrush seedlings on a reclaimed mine site. Arid Land Research and Management, 16, 309-317.</i>	Long term survival (8years) checked for a target shrub species direct seeded onto reclaimed land	Highest survival rates found on heavily grass seeded areas as the grass is thought to relieve grazing pressure on the shrub
Schuman, G. E., Vicklund, L. E. & Belden, S. E. (2005)	<i>Establishing Artemisia tridentata ssp wyomingensis on mined lands: Science and economics. Arid Land Research and Management, 19, 353-362.</i>	Direct seeding of target shrub species along with grass seeding	Lower rates of grass seeding give rise to higher survival and increased biomass of shrubs
Schwenke, G. D., Ayre, L., Mulligan, D. R. & Bell, L. C. (2000)	<i>Soil stripping and replacement for the rehabilitation of bauxite-mined land at Weipa. II. Soil organic matter dynamics in mine soil chronosequences. Australian Journal of Soil Research, 38, 371-393.</i>	Fresh and stockpiled soils, native tree/shrub, forestry or pasture combinations compared with reference areas	Reference areas were superior in all measured attributes, stored soils were the most compacted and lowest in fertility and structure. OM accumulated in all plots although higher levels of naturally colonizing grass speeded improvements
Scott, P. E., DeVault, T. L., Bajema, R. A. & Lima, S. L. (2002)	<i>Grassland vegetation and bird abundances on reclaimed midwestern coal mines. Wildlife Society Bulletin, 30, 1006-1014.</i>	Vegetation characteristic and bird abundance on mine areas seeded with grasses and legumes	Native colonizing legumes and grasses accounted for much of the plant community. Heterogeneity in the plant community supported a variety of bird species comparable with natural areas
Scott, P. E. & Lima, S. L. (2004)	<i>Exotic grasslands on reclaimed midwestern coal mines: An ornithological perspective. Weed Technology, 18, 1518-1521.</i>	Reclaimed, predominantly exotic grass, mine site data reviewed for bird habitat use	High levels of usage of exotic grasses by many species. Native grasses thought to be as effective but may be less resistant to succession to woody assemblages

Seaker, E. M. (1991)	<i>Zinc, copper, cadmium, and lead in minespoil, water, and plants from reclaimed mine land amended with sewage-sludge. Water Air and Soil Pollution, 57-8, 849-859.</i>	Sewage sludge applied to mine wastes and monitored for groundwater, plant tissue and soils monitored for heavy metals	Metals remained mainly in the soil layer, ground water was unaffected, plant tissue showed some increase but within acceptable levels
Sharma, D. & Sunderraj, S. F. W. (2005)	<i>Species selection for improving disturbed habitats in Western India. Current Science, 88, 462-467.</i>	Mine spoils and mine soils surveyed for vegetation to assess the suitability of plants for restoration	Trees and shrubs identified that should prove well adapted to restoration by surveying
Sharma, K. D., Kumar, P., Gough, L. P. & Sanfilippo, J. R. (2004)	<i>Rehabilitation of a lignite mine-disturbed area in the Indian Desert. Land Degradation & Development, 15, 163-176.</i>	Backfilling and topsoil application, collection of rainwater, soil management and planting used	The effects of the combined management activities was successful at restoring the area shown by colonization of desirable species
Sharma, K. D., Kumar, S. & Gough, L. P. (2000)	<i>Rehabilitation of lands mined for limestone in the Indian desert. Land Degradation & Development, 11, 563-574.</i>	Manure application and legume planting along with rainwater harvesting and selection of appropriate plants	Rehabilitation was a success with planted species being complemented with natural succession giving good diversity and evenness
Shrestha, R. K. & Lal, R. (2006)	<i>Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. Environment International, 32, 781-796.</i>	Soil C sequestration and storage investigated	Mine site identified as a possible source of C sequestration although further research needed
Shrestha, R. K. & Lal, R. (2007)	<i>Soil carbon and nitrogen in 28-year-old land uses in reclaimed coal mine soils of Ohio. Journal of Environmental Quality, 36, 1775-1783.</i>	Various land uses (forest, hay and pasture) compared for effects on soil chemistry in reclaimed mine sites	Both soil C and N were highest under pasture followed by hay then forests. However hay was considered the best land use for providing plant available nutrients.
Shrestha, R. K. & Lal, R. (2008)	<i>Land use impacts on physical properties of 28 years old reclaimed mine soils in Ohio. Plant and Soil, 306, 249-260.</i>	Various land uses (forest, hay and pasture) compared for effects on soil structure in reclaimed mine sites	Bulk density and water infiltration, cone index and water stable aggregates were best under hay and forest although still less than undisturbed forest soils
Shukla, M. K., Lal, R. & VanLeeuwen, D. (2007)	<i>Spatial variability of aggregate-associated carbon and nitrogen contents in the reclaimed minesoils of Eastern Ohio. Soil Science Society of America Journal, 71, 1748-1757.</i>	Undisturbed soils compared with grass seeded reclaimed areas and a grass and tree planted area	All reclaimed site improved in structure and nutrient content over time but there was a high degree of variability within and between sites
Sieg, C. H., Uresk, D. W. & Hansen, R. M. (1983)	<i>Plant-soil relationships on bentonite mine spoils and sagebrush-grassland in the northern high-plains. Journal of Range Management, 36, 289-294.</i>	An unreclaimed area, a newly reclaimed area, an older reclaimed area and a reference area compared	Plant cover and biomass were highest on the undisturbed area. Soil compaction and acid and salinity limited mine soils
Sieg, C. H., Uresk, D. W. & Hansen, R. M. (1986)	<i>The value of bentonite mine spoils in Southeastern Montana as small mammal habitat. Northwest Science, 60, 218-224.</i>	Mine spoils assessed for small mammal habitat	Soils were used for foraging by several pioneer species but not as burrow sites. This was attributed to soil compaction and lack of vegetation structure

Singh, A., Jha, A. K. & Singh, J. S. (1997a)	<i>Influence of a developing tree canopy on the yield of Pennisetum pedicellatum sown on a mine spoil. Journal of Vegetation Science, 8, 537-540.</i>	Shoot and root biomass of grasses measured from under canopy, canopy edge and open land on mine soils	Grass biomass was greatest in open land then canopy edge and lowest under canopy
Singh, A., Jha, A. K. & Singh, J. S. (2000)	<i>Effect of nutrient enrichment on native tropical trees planted on Singrauli Coalfields, India. Restoration Ecology, 8, 80-86.</i>	Effect of NPK fertilizer on native trees grown on mine spoil tested	All species increased in height and diameter with increasing fertilizer application however effects were less for leguminous species although these out performed non legumes
Singh, A. & Singh, J. S. (2001)	<i>Comparative growth behaviour and leaf nutrient status of native trees planted on mine spoil with and without nutrient amendment. Annals of Botany, 87, 777-787.</i>	Effect of NPK fertilizer on native trees grown on mine spoil tested	All species increased in height and diameter with increasing fertilizer application however effects were less for leguminous species although these out performed non legumes
Singh, A. N., Raghubanshi, A. S. & Singh, J. S. (2004a)	<i>Comparative performance and restoration potential of two Albizia species planted on mine spoil in a dry tropical region, India. Ecological Engineering, 22, 123-140.</i>	Growth and effects on soil development were compared for two leguminous tree plantations, one with <i>Albizia lebbbeck</i> and <i>A. procera</i>	Both species performed well but <i>Albizia lebbbeck</i> was slightly better
Singh, A. N., Raghubanshi, A. S. & Singh, J. S. (2004b)	<i>Impact of native tree plantations on mine spoil in a dry tropical environment. Forest Ecology and Management, 187, 49-60.</i>	Growth and effects on soil development were compared for two leguminous tree plantations, one with <i>Albizia lebbbeck</i> and <i>A. procera</i> and a non leguminous tree	All species showed an improvement although both legumes significantly out performed the non-legume.
Singh, A. N. & Singh, J. S. (1999)	<i>Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. Forest Ecology and Management, 119, 195-207.</i>	The effects of bamboo planted on a mine spoil were investigated	Soil chemistry and nutrient status improved with age as did microbial biomass
Singh, A. N. & Singh, J. S. (2006)	<i>Experiments on ecological restoration of coal mine spoil using native trees in a dry tropical environment, India: A synthesis. New Forests, 31, 25-39.</i>	17 indigenous species grown on mine spoil	All 17 grew effectively after plantation although there was species variation depending on slope. All planting benefited soils over time
Singh, A. N., Zeng, D. H. & Chen, F. S. (2006)	<i>Effect of young woody plantations on carbon and nutrient accretion rates in a redeveloping soil on coalmine spoil in a dry tropical environment, India. Land Degradation & Development, 17, 13-21.</i>	Leguminous woody species planted on mine sites and the soil chemistry monitored	All species had a large positive effect although there was variability between species
Singh, K. P., Singh, P. K. & Tripathi, S. K. (1999)	<i>Litterfall, litter decomposition and nutrient release patterns in four native tree species raised on coal mine spoil at Singrauli, India. Biology and Fertility of Soils, 29, 371-378.</i>	Several species planted on mine spoils compared for inputs to soil nutrient	Effects were species specific but more close correlation with rainfall was found for decomposition

Siniscalco, C., Reyneri, A., Ciotti, A., Peyron, A. & Pala, S. (1998)	Use of wild plant herbaceous species for revegetation. <i>Symposium on Plant Biotechnology as a Tool for the Exploitation of Mountain Lands</i> (ed [^] (eds S. Scannerini, A. Baker, B. V. Charlwood, C. Damiano, C. Franz & S. Gianinazzi), pp. 371-377.	A comparison was made between seeding with a commercial seed mix of grasses and legumes, the same seed mix with but with native plants added and no seeding	The seeding including wild species produced a more diverse and stable vegetation assemblage and allowed the establishment of woody species
Sinnett, D., Poole, J. & Hutchings, T. R. (2006)	<i>The efficacy of three techniques to alleviate soil compaction at a restored sand and gravel quarry. Soil Use and Management</i> , 22 , 362-371.	Soil surface ripping compared with complete cultivation	All treatments improved soil structure but the ripping left only a shallow amendment possibly limiting rooting depth. Complete cultivation had a deeper effect
Skeel, V. A. & Gibson, D. J. (1996)	<i>Physiological performance of Andropogon gerardii, Panicum virgatum, and Sorghastrum nutans on reclaimed mine spoil. Restoration Ecology</i> , 4 , 355-367.	3 species of native grasses grown on mine spoil were surveyed for physiological performance	All three performed well suggesting that they would be preferable to exotic species
Skousen, J. G., Johnson, C. D. & Garbutt, K. (1994)	<i>Natural revegetation of 15 abandoned mine land sites in West-Virginia. Journal of Environmental Quality</i> , 23 , 1224-1230.	Natural succession was assessed at 15 sites of varying ages	All site recolonized however the type of vegetation was influenced by soil pH. Invasion from surrounding areas was an important factor
Smith, B. M., Diaz, A., Winder, L. & Daniels, R. (2005)	<i>The effect of provenance on the establishment and performance of Lotus corniculatus L. in a re-creation environment. Biological Conservation</i> , 125 , 37-46.	Cuttings collected from various areas and planted in quarry soils and sites amended with top soil	Local plants had the highest rates of survival on treated plots but there was little variation on untreated plots however overall the differences were small
Smith, J. A., Deput, E. J. & Schuman, G. E. (1986)	<i>Wood residue and fertilizer amendment on bentonite mine spoils .2. Plant-species responses. Journal of Environmental Quality</i> , 15 , 427-435.	Seed mix applied to various quantities of wood residue and fertilizer	Responses were highly species specific however there was a general benefit from amendments. High level of amendment benefited exotics over natives however
Smith, J. A., Schuman, G. E., Deput, E. J. & Sedbrook, T. A. (1985)	<i>Wood residue and fertilizer amendment of bentonite mine spoils .1. Spoil and general vegetation responses. Journal of Environmental Quality</i> , 14 , 575-580.	Various quantities of wood residue and fertilizer used to amend mine soils	Mid levels of application resulted in highest rates of density, cover and biomass
Smyth, C. R. (1997)	<i>Early succession patterns with a native species seed mix on amended and unamended coal mine spoil in the Rocky Mountains of Southeastern British Columbia, Canada. Arctic and Alpine Research</i> , 29 , 184-195.	Native soils and mine spoil substrates seeded or unseeded monitored for early succession	Native soils always performed better. Unseeded areas colonized from surrounding vegetation although convergence was noted with all treatments

Sopper, W. E. (1992)	<i>Rapid ecological restoration of mine land using municipal sewage-sludge.</i>	Two mine sites reclaimed with sewage sludge were re-sampled 12 years after reclamation with backfilling and re-contouring	Vegetation, ground water and soils sampled for pH, nitrate and heavy metals. No significant contamination was found
Sorensen, D. L. & Fresquez, P. R. (1991)	<i>Nitrification potential in reclaimed coal-mine spoils and soils in the semiarid southwest. Journal of Environmental Quality, 20, 279-285.</i>	N cycling tested in reclaimed sites with and without topsoil applications	N cycling was measurable in all sites but highest in older reclaimed areas
Sort, X. & Alcaniz, J. M. (1999)	<i>Effects of sewage sludge amendment on soil aggregation. Land Degradation & Development, 10, 3-12.</i>	Varying doses of sewage sludge were applied to quarry soils and tested for effects on soil aggregation	There was a positive effect in the first year but this rapidly declined
Sourkova, M., Frouz, J., Fettweis, U., Bens, O., Huttli, R. F. & Santruckova, H. (2005a)	<i>Soil development and properties of microbial biomass succession in reclaimed post mining sites near Sokolov (Czech Republic) and near Cottbus (Germany) Geoderma, 129, 73-80.</i>	Alder plantations and Scotch pine/Red oak plantation sampled for microbial activity in soils	Vegetation type and litter quality had a greater impact on microbial activity than substrate
Sourkova, M., Frouz, J. & Santruckova, H. (2005b)	<i>Accumulation of carbon, nitrogen and phosphorus during soil formation on alder spoil heaps after brown-coal mining, near Sokolov (Czech Republic). Geoderma, 124, 203-214.</i>	A chronosequence of 19 spoil heaps studied for C, N and P	Rapid accumulation of C,N and P after 15 years however P remained limiting in even 40 year old sites
Srivastava, S. C., Jha, A. K. & Singh, J. S. (1989)	<i>Changes with time in soil biomass c, n and p of mine spoils in a dry tropical environment. Canadian Journal of Soil Science, 69, 849-855.</i>	Soil biomass C,N and P determined for an unmined clear felled, native forest and a chronosequence of mine spoils	Soil microbial C,N and P were positively correlated with site age on reclaimed sites
Srivastava, S. C. & Singh, J. S. (1991)	<i>Microbial-c, microbial-n and microbial-p in dry tropical forest soils - effects of alternate land-uses and nutrient flux. Soil Biology & Biochemistry, 23, 117-124.</i>	Savannah, crop field and mine spoil microbial C,N and P compared	Microbial C,N and P were related to plant biomass both above and below ground comparison with native forest showed large declines in all land uses
St John, M. G., Bagatto, G., Behan-Pelletier, V., Lindquist, E. E., Shorthouse, J. D. & Smith, I. M. (2002)	<i>Mite (Acari) colonization of vegetated mine tailings near Sudbury, Ontario, Canada. Plant and Soil, 245, 295-305.</i>	Mite colonization and soil features compared on a chronosequence of mine tailings	Soil pH and OM improved over time and this and mite richness and diversity was positively correlated with botanical diversity
Stehouwer, R., Day, R. L. & Macneal, K. E. (2006)	<i>Nutrient and trace element leaching following mine reclamation with biosolids. Journal of Environmental Quality, 35, 1118-1126.</i>	Sites amended with biosolids applied at standard and maximum rates monitored for effects on water courses	Biosolid applications decreased pH and had high inorganic N and heavy metals in leachate. This decreased over time but results indicate possible contamination problems

Stolt, M. H., Baker, J. C., Simpson, T. W., Martens, D. C., McKenna, J. R. & Fulcher, J. R. (2001)	<i>Physical reconstruction of mine tailings after surface mining mineral sands from prime agricultural land. Soil Science, 166, 29-37.</i>	Unamended tailings, topsoil treated tailings and compost treated tailings compared for soil properties	Compost treated tailings had lower bulk density, higher plant growth and better water infiltration and holding. Top soil had a high bulk density and low infiltration
Strong, W. L. (2000)	<i>Vegetation development on reclaimed lands in the Coal Valley Mine of western Alberta, Canada. Canadian Journal of Botany-Revue Canadienne De Botanique, 78, 110-118.</i>	Revegetated mine lands sampled for vegetation	Revegetation was found to be progressing well in a similar pattern to that expected from surrounding land. Canopy closure was thought important in establishing natural understory vegetation
Sydnor, M. E. W. & Redente, E. F. (2002)	<i>Reclamation of high-elevation, acidic mine waste with organic amendments and topsoil. Journal of Environmental Quality, 31, 1528-1537.</i>	Mushroom compost and biosolids and stockpiled and non-stockpiled soil used to reclaim waste rock piles	OM significantly increased biomass with mushroom compost being more effective than biosolids. Top soil increased trace element uptake including stock piled soil when amended with lime
Tak, R. & Rao, A. V. (2001)	<i>Microbiological productivity of mine spoils as influenced by the incorporation of organic amendments. Agrochimica, 45, 67-73.</i>	Gypsum and limestone mine spoils treated with various different types of OM	Sewage sludge gave the greatest improvement in micro biological activity on gypsum while soil additions with OM gave best results on limestone. Plant productivity also increased with microbial activity
Tarafdar, J. C. & Rao, A. V. (1997)	<i>Mycorrhizal colonization and nutrient concentration of naturally grown plants on gypsum mine spoils in India. Agriculture Ecosystems & Environment, 61, 13-18.</i>	Mine spoils assessed for plant colonization and mycorrhizal infection	Several functional groups found with high degree of infection. Results suggest that inoculation could be an effective reclamation strategy
Thompson, R. L. & McKinney, L. E. (2006)	<i>Vascular flora and plant habitats of an abandoned limestone quarry at Center Hill Dam, DeKalb County, Tennessee. Castanea, 71, 54-64.</i>	Abandoned limestone quarry surveyed for vascular flora	Wide range of species found including two rarities. Invasive species were also found in high numbers though
Thorne, M. E., Zamora, B. A. & Kennedy, A. C. (1998)	<i>Sewage sludge and mycorrhizal effects on Secar bluebunch wheatgrass in mine spoil. Journal of Environmental Quality, 27, 1228-1233.</i>	Composted sewage sludge mixed with sand and mycorrhizal fungi used to restore mine soils	Above and below ground biomass increased with increasing levels of sewage sludge. Fungal colonization was beneficial but varied with type used
Thum, J., Wunsche, M., Laves, D. & Vogler, E. (1990)	<i>Humus formation on cultivated dump loam. Archiv Fur Acker Und Pflanzenbau Und Bodenkunde-Archives of Agronomy and Soil Science, 34, 855-864.</i>	Accumulation of OM and soil structural changes reported	OM, water holding capacity, density and permeability develop over years but sub soil structure deteriorates mainly due to compaction

Tian, G., Granato, T. C., Pietz, R. I., Carlson, C. R. & Abedin, Z. (2006)	<i>Effect of long-term application of biosolids for land reclamation on surface water chemistry. Journal of Environmental Quality, 35</i> , 101-113.	Biosolids were injected as liquid fertilizer and added as solid and the catchment was monitored for water quality	Ammonium levels increased compared to controls but were within safe limits. Other effects were minor.
Titus, J. H. & del Moral, R. (1998)	<i>The role of mycorrhizal fungi and microsities in primary succession on Mount St. Helens. American Journal of Botany, 85</i> , 370-375.	Mycorrhiza added to soils and micro-sites tested for effects on growth of planted known colonizer species	Mycorrhiza had no effect on plant growth but micro-sites had a strong effect
Todd, M. C. L., Adams, M. A. & Grierson, P. F. (2000a)	<i>Mineralisation of nitrogen in a chronosequence of rehabilitated bauxite mines. Australian Journal of Soil Research, 38</i> , 435-451.	A chronosequence of rehabilitated mine sites, planted with fast growing trees and fertilized, assessed for N availability and transformations	Rates of N mineralization were lower in the rehabilitated sites than the reference sites. Water availability was the most important factor
Todd, M. C. L., Grierson, P. F. & Adams, M. A. (2000b)	<i>Litter cover as an index of nitrogen availability in rehabilitated mine sites. Australian Journal of Soil Research, 38</i> , 423-433.	Litter cover and N availability were measured in a 9 year old rehabilitated mine	N availability was correlated with litter cover. This was related to plant cover and micro-topography. Heterogeneity of the topography will encourage plant colonization and N availability
Tomlinson, S., Matthes, U., Richardson, P. J. & Larson, D. W. (2008)	<i>The ecological equivalence of quarry floors to alvars. Applied Vegetation Science, 11</i> , 73-U68.	Natural succession in quarry floors compared with limestone pavement for plant community	High degree of correlation found suggesting that naturally recolonized quarries can use limestone pavement as a restoration goal
Topp, W., Simon, M., Kautz, G., Dworschak, U., Nicolini, F. & Pruckner, S. (2001)	<i>Soil fauna of a reclaimed lignite open-cast mine of the Rhineland: improvement of soil quality by surface pattern. Ecological Engineering, 17</i> , 307-322.	Soil fauna surveyed in relation to micro-topography of the soils	Heterogeneous soils with crests and troughs had an increased soil fauna in the troughs. This lead to better soil structure and nutrient status. Faunal diversity shown to be beneficial
Torbert, J. L., Burger, J. A. & Probert, T. (1995)	<i>Evaluation of techniques to improve white-pine establishment on an Appalachian minesoil. Journal of Environmental Quality, 24</i> , 869-873.	Mine spoil planted or seeded with trees treated with two seeded ground cover mixes, with or without fertilizer	No difference with fertilizer treatment or different ground covers. Planting produced better results than seeding for trees
Totola, M. R. & Borges, A. C. (2000)	<i>Growth and nutritional status of Brazilian wood species Cedrella fissilis and Anadenanthera peregrina in bauxite spoil in response to arbuscular mycorrhizal inoculation and substrate amendment. Brazilian Journal of Microbiology, 31</i> , 257-265.	Plant growth in bare spoil, spoil plus topsoil or compost or just topsoil, with or without inoculation by various types or mycorrhizal fungi compared	Inoculation was generally beneficial but the interactions between plant species, mycorrhizal species and substrate were complex and variable
Ursic, K. A., Kenkel, N. C. & Larson, D. W. (1997)	<i>Revegetation dynamics of cliff faces in abandoned limestone quarries. Journal of Applied Ecology, 34</i> , 289-303.	Revegetation dynamics on cliff faces of a known chronosequence related to biotic and abiotic factors	Age of site and density and proximity of trees were the most influential factors. Initial diversity is high but drops when surrounding vegetations starts to shade out. Similarity to reference site is high and succession is recommended as a means of rehabilitation

Ussiri, D. A. N. & Lal, R. (2005)	<i>Carbon sequestration in reclaimed minesoils. Critical Reviews in Plant Sciences, 24, 151-165.</i>	SOC sequestration reviewed for reclaimed mine soils	Grass lands had higher initial rates of sequestration than forests. Increasing vegetative cover and soil chemical and physical properties enhances sequestration
Ussiri, D. A. N., Lal, R. & Jacinthe, P. A. (2006)	<i>Post-reclamation land use effects on properties and carbon sequestration in minesoils of southeastern Ohio. Soil Science, 171, 261-271.</i>	SOC and total N determined for mine soils reclaimed to grass land under meadow, hay, grazing or grazing-feeding	Soil structure was better in ungrazed areas. SOC was not highly variable between sites but root mass was considered the more important factor
Vacher, C. A., Loch, R. J. & Raine, S. R. (2003)	<i>Effect of polyacrylamide additions on infiltration and erosion of disturbed lands. Australian Journal of Soil Research, 41, 1509-1520.</i>	Three mine site were amended with polyacrylamide gel	Infiltration was improved, surface hardness lessened and erosion was reduced. Clay content of the soil had an impact on the effectiveness
van Rensburg, L. & Morgenthal, T. (2004)	<i>The effect of woodchip waste on vegetation establishment during platinum tailings rehabilitation. South African Journal of Science, 100, 294-300.</i>	Wood chips used to ameliorate mine tailings	Initial establishment of grasses was improved by wood chip amendments although some concern was raised about long term N:C ratios so composting beforehand may be a better solution
Vetterlein, D., Bergmann, C. & Huttli, R. F. (1999a)	<i>Phosphorus availability in different types of open-cast mine spoil and the potential impact of organic matter application. Plant and Soil, 213, 189-194.</i>	P availability was tested for mine soils with or without amendment by sewage sludge or compost	P immobilization was high leading to low levels of plant available P. Adding OM increased the amount of available P.
Vetterlein, D., Waschkies, C. & Weber, E. (1999b)	<i>Nutrient availability in the initial stages of surface mine spoil reclamation - Impact on plant growth. Journal of Plant Nutrition and Soil Science-Zeitschrift Fur Pflanzenernahrung Und Bodenkunde, 162, 315-321.</i>	Availability of N,P and K to plants was tested by additions of chemical fertilizer	N and P were found to be the major limiting factors to plant growth. Application of fertilizer ameliorated this to some extent but it was dependent on the substrate
Vukovich, M. & Ritchison, G. (2006)	<i>Nesting success and behavior of Northern Harriers on a reclaimed surface mine grassland in Kentucky. Journal of Raptor Research, 40, 210-216.</i>	Reclaimed grasslands surveyed for nesting success of Northern Harriers	Results suggest that harriers can use the habitat successfully
Vukovich, M. & Ritchison, G. (2008)	<i>Foraging behavior of short-eared owls and northern harriers on a reclaimed surface mine in Kentucky. Southeastern Naturalist, 7, 1-10.</i>	Foraging behaviour of two raptor species on reclaimed grassland assessed	Hunting methods and success was comparable to that found in unmined areas
Waggoner, P. J. & Zuberer, D. A. (1996)	<i>Response of nitrification and nitrifying bacteria in mine spoil to urea or ammonium sulfate. Soil Science Society of America Journal, 60, 477-486.</i>	Spoil heaps were fertilized with urea or chemical nitrogen fertilizer	Sites improved with age. The two amendments did not differ significantly.

Wali, M. K. (1999)	<i>Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. Plant and Soil, 213, 195-220.</i>	Natural succession in a chronosequence compared to sites with topsoil, fertilizing and topsoil addition	Species richness and abundance increased with age however after 45 years there was still a large difference between mined and reference areas. Rehabilitated areas recovered faster for plant and soil characteristics
Walker, L. R. & Powell, E. A. (2001)	<i>Soil water retention on gold mine surfaces in the Mojave Desert. Restoration Ecology, 9, 95-103.</i>	Three different substrates mixed with straw and a growth medium applied to the spoil heap. Rock mulch then applied to half the plots	Soil water was monitored and showed that the treatments did not have a significant effect on soil water retention
Walker, R. F. (2002a)	<i>Fertilization and liming effects on the growth and nutrition of bareroot Jeffrey pine outplanted on an eastern Sierra Nevada surface mine. Western Journal of Applied Forestry, 17, 23-30.</i>	Pine trees planted on a surface mine treated with two types of fertilizer and limed	Liming had a negative effect of survival and growth. Fertilizing had no effect on survival but a strong effect on growth over 3 years
Walker, R. F. (2002b)	<i>Growth and nutritional responses of bareroot Jeffrey pine on a Sierra Nevada surface mine to minisite applications of fertilizer and lime. New Forests, 24, 225-238.</i>	Pine trees planted on a surface mine treated with two types of fertilizer and limed	Liming had a negative effect of survival and growth. Fertilizing had no effect on survival but a strong effect on growth over 3 years
Walker, R. F. (2002c)	<i>Responses of Jeffrey pine on a surface mine site to fertilizer and lime. Restoration Ecology, 10, 204-212.</i>	Pine trees planted on a surface mine treated with two types of fertilizer and limed	Liming had a negative effect of survival and growth. Fertilizing had no effect on survival but a strong effect on growth over 3 years
Walker, R. F. (2003)	<i>Comparison of organic and chemical soil amendments used in the reforestation of a harsh Sierra Nevada site. Restoration Ecology, 11, 466-474.</i>	Composted OM, fertilizer and mycorrhizal inoculation compared for planted pine survival and growth	OM and inoculation caused high seedling mortality, OM suppressed growth while inoculation had no effect. Fertilizer did not affect survival but promoted growth. Water relations were blamed for poor performance of OM and inoculation
Walker, R. F. (2005)	<i>Growth and nutrition of Jeffrey pine seedlings on a Sierra Nevada surface mine in response to fertilization three years after planting. Western Journal of Applied Forestry, 20, 28-35.</i>	Pine seedling planted 3 year previously were treated with varying levels of fertilizer	Applications had a large positive effect on growth, increasing with higher rates of application. Foliar nutrients were high for macro nutrients although some micro nutrients were suppressed
Walker, R. F., McLaughlin, S. B. & West, D. C. (2004)	<i>Establishment of sweet birch on surface mine spoil as influenced by mycorrhizal inoculation and fertility. Restoration Ecology, 12, 8-19.</i>	Birch seedlings inoculated with various mycorrhizas and planted. Various nutrient solutions were applied	Colonization of mycorrhiza was varied depending on the nutrient status of the soil however those that colonized had a strong positive effect

Wanner, M. & Dunger, W. (2002)	<i>Primary immigration and succession of soil organisms on reclaimed opencast coal mining areas in eastern Germany. European Journal of Soil Biology, 38, 137-143.</i>	Colonization and immigration of soil organisms tested on sites of various age and soil chemistry	Immigration and colonization is species specific but it is shown that fresh substrate can be colonized effectively
Ward, S. C. & Koch, J. M. (1996)	<i>Biomass and nutrient distribution in a 15.5 year old forest growing on a rehabilitated bauxite mine. Australian Journal of Ecology, 21, 309-315.</i>	Above ground biomass and litter fall measured on a 15.5 year old mine reclamation site	Biomass and litter mass were around a quarter that of the reference area. N levels were higher and litter fall was similar
Ward, S. C., Koch, J. M. & Grant, C. D. (1997)	<i>Ecological aspects of soil seed-banks in relation to bauxite mining. 1. Unmined jarrah forest. Australian Journal of Ecology, 22, 169-176.</i>	Soil seed banks measured for viable seed	Large differences found in different sites and with season. Top soil should be collected post seed set and spread as soon as possible prior to the wet season
Wheater, C. P. & Cullen, W. R. (1997)	<i>The flora and invertebrate fauna of abandoned limestone quarries in Derbyshire, United Kingdom. Restoration Ecology, 5, 77-84.</i>	Natural succession in an unmanaged quarry and hydro seeding in a quarry blasted to fit the surrounding landscape compared to a reference area	The blasted site had lower richness and diversity of plants and animals however they seemed to be establishing well although rabbit grazing was caused problems
Wheater, C. P., Cullen, W. R. & Bell, J. R. (2000)	<i>Spider communities as tools in monitoring reclaimed limestone quarry landforms. Landscape Ecology, 15, 401-406.</i>	Landform sites created by blasting compared for vegetation and spider communities	Blasted sites are more similar in vegetation community to unmined sites than unblasted sites. Spider communities highlighted differences in structure
White, J. A., Depuit, E. J., Smith, J. L. & Williams, S. E. (1992)	<i>Vesicular-arbuscular mycorrhizal fungi and irrigated mined land reclamation in South-western Wyoming. Soil Science Society of America Journal, 56, 1464-1469.</i>	Colonization by mycorrhizal fungi was tested for effects of fertilization and irrigation	Fertilization had no significant effect but irrigation while having no effect of density did increase colonization of plant roots
Wilcox, C. A., Chun, Y. M. & Choi, Y. D. (2005)	<i>Redevelopment of black oak (Quercus velutina lam.) savanna in an abandoned sand mine in Indiana Dunes National Lakeshore, USA. American Midland Naturalist, 154, 11-27.</i>	Development of vegetative communities was measured	There was a large divergence in trajectory attributed to the depth of the water table. Shallow water table promotes woodland while the deeper water table produces scrub
Wilden, R., Schaaf, W. & Huttl, R. F. (1999)	<i>Soil solution chemistry of two reclamation sites in the Lusatian lignite mining district as influenced by organic matter application. Plant and Soil, 213, 231-240.</i>	Mineral fertilizer, sewage sludge and compost compared for effects on soil chemistry	The main difference between the treatments was the longevity of the effect. The fertilizer had a strong but short term effect, sewage sludge was longer and compost the longest
Wilden, R., Schaaf, W. & Huttl, R. F. (2001)	<i>Element budgets of two afforested mine sites after application of fertilizer and organic residues. Ecological Engineering, 17, 253-273.</i>	Mineral fertilizer, sewage sludge and compost compared for effects on soil chemistry	The main difference between the treatments was the longevity of the effect. The fertilizer had a strong but short term effect, sewage sludge was longer and compost the longest

Windsor, D. M. & Clements, A. M. (2001)	<i>A germination and establishment field trial of Themeda australis (kangaroo grass) for mine site restoration in the central tablelands of New South Wales. Restoration Ecology, 9, 104-110.</i>	Time since soil preparation, contour, slope, irrigation and rate of seed/mulch application effects on establishment of grass	Newly contoured substrate produced a greater rate of germination, irrigation increased germination but was not essential, mid contour had greatest cover until a storm
Wood, M. K., Buchanan, B. A. & Skeet, W. (1995)	<i>Shrub preference and utilization by big game on new-Mexico reclaimed mine land. Journal of Range Management, 48, 431-437.</i>	Naturally colonizing and planted shrubs on a mine site assessed for grazing impacts	Results showed that the site is used for grazing by several animal species
Wu, C. Q., Lai, S. H., Xu, Y. Y., Xu, T. & Lei, J. L. (2008)	Application of 17 wild plant species in afforesting the abandoned quarry. <i>Proceedings of the International Symposium on Asian Plants with Unique Horticultural Potential</i> (ed [^] (eds D. Zhang, J. M. Lee & R. Tao), pp. 501-508.	17 species of native wild plants were planted on and abandoned quarry and assessed for survival and growth	Species were shown to be well adapted to the conditions although response was specific to micro habitat
Ye, Z. H., Yang, Z. Y., Chan, G. Y. S. & Wong, M. H. (2001)	<i>Growth response of Sesbania rostrata and S-cannabina to sludge-amended lead/zinc mine tailings - A greenhouse study. Environment International, 26, 449-455.</i>	Green house study of growth of legumes planted in mine tailings ameliorated with varying rates of sewage sludge application	50% (v/v) of sewage sludge provided the best results for biomass and growth rates. Sewage sludge had a positive effect increasing C,N,P and K
Yin, B., Crowley, D., Sparovek, G., De Melo, W. J. & Borneman, J. (2000)	<i>Bacterial functional redundancy along a soil reclamation gradient. Applied and Environmental Microbiology, 66, 4361-4365.</i>	Soil samples collected and analyzed for bacterial functional redundancy from bare mine soil, below primary colonizers, revegetated soil near pristine forest and pristine forest	Functional redundancy increased according to the level of reclamation
Yuan, J. G., Fang, W., Fan, L., Chen, Y., Wang, D. Q. & Yang, Z. Y. (2006)	<i>Soil formation and vegetation establishment on the cliff face of abandoned quarries in the early stages of natural colonization. Restoration Ecology, 14, 349-356.</i>	Soil formation and vegetation establishment and growth measure over several years in abandoned quarries	Soil formation was surprisingly rapid. Vegetation established and increased in cover and abundance. Vegetation was highly correlated with soil depth and volume and N, P and OM
Zeleznik, J. D. & Skousen, J. G. (1996)	<i>Survival of three tree species on old reclaimed surface mines in Ohio. Journal of Environmental Quality, 25, 1429-1435.</i>	Survival and growth of planted trees measured at levelled and unlevelled mine sites	Tree survival was low although with some naturally colonizing species a closed canopy formed after 46 years
Zhang, H. L., Sun, L. & Sun, T. H. (2008)	<i>Solubility of ion and trace metals from stabilized sewage sludge by fly ash and alkaline mine tailing. Journal of Environmental Sciences-China, 20, 710-716.</i>	Sewage sludge stabilized by fly-ash at various ratios	At a ratio of 1:1 the pH tended towards neutrality. Heavy metals were kept at low concentrations