Recolonisation and recovery of soil invertebrate assemblages at an inactive coal mine in southern New Zealand

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Abstract

The natural recovery of soil invertebrate assemblages was investigated at an old coal mine in southern New Zealand. Natural successional processes had been occurring for the last 50-60 years, giving rise to variable levels of vegetation recovery. For final rehabilitation, large amounts of self-colonised shrublands were cleared. Substrate cores were collected from six study sites to identify if measurements of invertebrate assemblages provided information to detect habitats with different revegetation histories. Three sites on waste rock, three sites on unmined loess substrate and a mature forest remnant were included in the study. Twenty-one cores were collected from each site during spring in 2004. Invertebrates were heat extracted as live specimens and identified to taxonomic order/family. Numbers of Collembola were high at all sites but their dominance decreased from waste rock to loess to mature forest, as numbers of other invertebrates, particularly Acari, increased. Site differences were also apparent in taxonomic richness, composition, and stability, with loess sites being more similar to those in mature forest than waste stacks. Barriers to some taxa establishing on waste rock were most likely linked to habitat unsuitability. The assemblages produced by natural rehabilitation were slower to form compared to anthropogenic rehabilitation but they showed high resilience.

Keywords: invertebrates – substrate cores – waste rock – loess — coal mine – biological recovery – rehabilitation.

Introduction

The re-establishment of vegetation is a key objective in modern mine site rehabilitation (Bradshaw 1997). Planting and seeding mine sites, usually with the addition of a soil-like cover, is by far the most commonly used approach for re-establishing plant cover, and has gained significant research attention for both indigenous and non-indigenous vegetation (e.g., Bradshaw 1997; Davis *et al.* 1997; Bell 2001; Holl 2002). In longer-term rehabilitation programmes there has also been considerable focus on documenting development and recovery at the ecosystem level, of which invertebrates have understandably been a major focus (e.g., Greenslade & Majer 1993; Majer & Nichols 1998; Topp *et al.* 2001; Wanner & Dunger 2002; Andersen *et al.* 2003). Far less is known about rates of invertebrate community recovery using other revegetation techniques, such as translocation of habitat clumps (cf. Ross *et al.* 2000) and natural regeneration from nearby seed sources ("spontaneous succession"; Hodačová & Prach 2003). The process of natural, as opposed to actively managed, mine site recovery has been investigated from a plant perspective for some time (e.g., Bramble & Ashley 1955; Johnson *et al.* 1982; Titlyanova & Mironycheva-Tokareva 1990), and it has been advocated as a preferable option for land rehabilitation in some settings (Hodačová & Prach 2003). However, studies of mine waste have shown that invertebrate numbers are usually significantly lower in plots with naturally established versus deliberately planted/seeded vegetation, and this is usually attributed to comparably poor plant cover (Majer & Nichols 1998; Kielhorn *et al.* 1999; Pižl 2001; Watts *et al.* 2008). Consequently, there is little information on what happens to invertebrate populations when the natural plant cover increases to similar levels as surrounding vegetation.

At the Wangaloa coal mine in south Otago, natural successional processes have been allowed to occur with minimal anthropogenic interference for the last 50-60 years. Shrublands, dominated by gorse (*Ulex europaeus*), manuka (*Leptospermum scoparium*), and kanuka (*Kunzea ericoides*), have naturally established at the mine site, including on unameliorated waste stacks. An earlier investigation on one waste stack showed that the complexity of soil- and litter-dwelling invertebrate assemblages was positively correlated to the amount of shrubland cover, whereas abundance was not because Collembola numbers were proportionately higher under low cover (Craw *et al.* 2007). Although that finding contributes to understanding the long-term temporal scale of invertebrate community recovery in a natural rehabilitation setting, a wider perspective is lacking. For example, how does waste rock recovery compare to that on other substrates over a similar time frame, and how close are their faunas to approaching the diversity and structure of invertebrate assemblages in less disturbed habitat?

This paper presents a second study of soil animals at the Wangaloa coal mine undertaken to investigate invertebrate recovery over a wider spatial scale than has been undertaken so far. The aim of the study was to identify if measurements of soil invertebrate assemblages changed in local habitats with different revegetation histories. Invertebrates mediate many soil processes that determine successful establishment of vegetation, and this makes them a target group for assessing rates of biological recovery. This paper presents data on the extent to which waste rock and non-waste rock faunas were converging with the fauna of a mature forest site so as to provide a detailed evaluation of local rates of natural ecosystem development on highly disturbed land.

Methods

General setting

The Wangaloa opencast coal mine (169°54'E; 46°17'S) is near the township of Kaitangata in south-east Otago, New Zealand, and although it covers 252 ha, not all of the land has been directly impacted by mining (Figure 1). Located 2.5 km from the coast, the local area

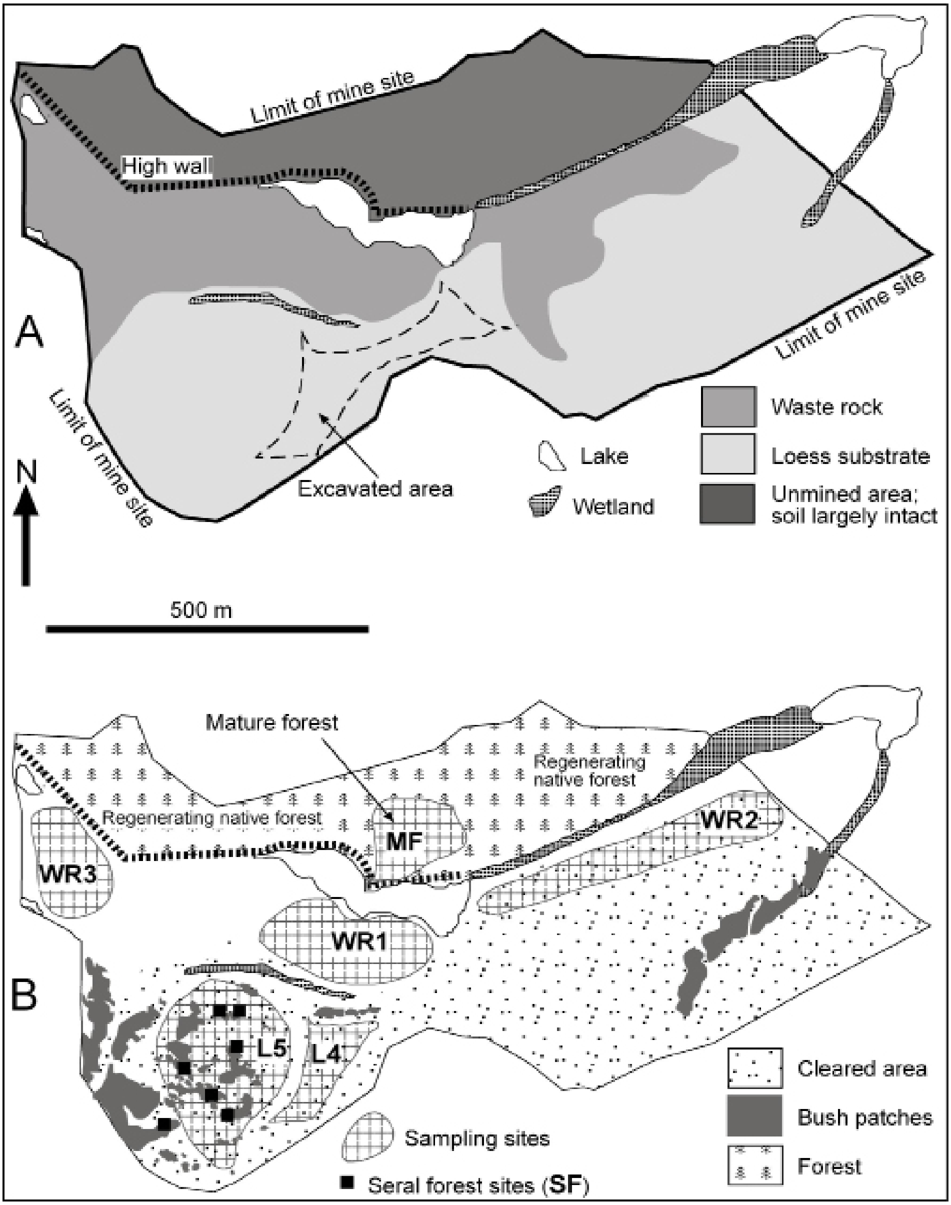

Figure 1. Map of the Wangaloa coal mine showing invertebrate sampling areas within different substrate-natural revegetation units.

has a cool temperate maritime climate with a mean annual temperature of around 12°C and 700-1000 mm of rainfall per year. The coal mine exists in a landscape of agriculture and plantation forestry that contains local patches of indigenous vegetation at various stages of regeneration. The coal mining period lasted for 44 years between 1945 and 1989. The substrates above the coal seam were stripped (topsoil, Quaternary loess, late Cretaceous Taratu Formation) and dumped to form multiple waste stacks (Figure 1). Due to the dumping technique, the surfaces of waste stacks are without soil or loess. Instead, a poorly consolidated, quartz pebble conglomerate exists that is highly prone to erosion

(Craw *et al.* 2007). Loess remains at the surface on land adjacent to the waste stacks that were not stripped (Figure 1).

Over time, the nature of the vegetation has changed significantly at the mine site. Aerial photographs show conversion of pasture to shrubland in areas where waste rock was not dumped. Some of the bare waste rock also developed a complete or partial shrub cover, with minimal rehabilitation effort by the mining company. In 2002, a final rehabilitation project for the mine was initiated by Solid Energy New Zealand Limited. The aim of rehabilitation is to re-establish native ecosystems among some mine site features, to form a public recreational area. Over 100,000 New Zealand native seedlings have been planted in an effort to replace the shrubs, including wilding *Pinus radiata* trees that had self-colonised. All of the pine trees and much of the shrubland was cleared late in 2002, and the substrate deep-ripped in preparation for planting. Where gorse was uncommon, the natural shrublands were retained (Figure 1). Amelioration techniques were used sparingly, although minor liming of some waste rock was undertaken.

The nutrient status of the coal mine soil is generally low compared to typical New Zealand soils although loess has higher total N and P than the waste stacks (Todd *et al.* 2009). The general pH range for the mine site rock and soil is around 4-4.5 but there are some locally acidic areas (pH <3) on waste rock with high coal and/or pyrite content. For the most part, the loess and waste rock are relatively benign and no toxicity issues have been identified (Todd *et al.* 2009). However, when waste rock contains very high coal content, boron levels can be strongly elevated and it is possible that these have a negative effect on plant establishment at the mine site (Craw *et al.* 2006).

Sampling sites

Invertebrates were sampled from seven locations selected within the coal mine using a combination of aerial photographs and information on their management. Six of these study sites represented a range of disturbance histories and ages since natural shrubland establishment. A brief description of each site is summarised in Table 1. The seventh site was an area of mature kamahi forest (MF), with around 50 plant species, that represented the expected vegetation on the local soil type. The kamahi forest remnant was 93,000 m^2 in size, and was located above the high wall (Figure 1).

Mineral soil was absent from all sites except MF but a thin layer of organic soil was evident at the loess sites and WR2. Three sampling sites, WR2, L4 and L5, occurred within the cleared areas, where bare ground was mixed with some gorse regeneration and *Holcus lanatus* at the time of invertebrate sampling. WR3 and SF occurred where the natural shrubland had been retained: 1-2m tall *Leptospermum scoparium* and *Erica lusitanica* at WR3, and 4-5 m tall *L. scoparium* and *Kunzea ericoides* at SF. The remaining study site, WR1, was on a waste stack recently rebuilt for rehabilitation. It was initially left unvegetated but hydroseed applications of adventive grasses and legumes were made later. Planted native seedlings were a minor component of waste rock and loess study sites, due to their small size and recent introduction. Where possible, study sites were chosen for their proximity to one another to reduce the effect of location on invertebrate assemblage patterns. The positions of individual sampling points were selected at random and their location recorded using a Trimble GeoXT differential GPS.

Table 1. Summary descriptions for the seven study sites from which soil invertebrates were sampled at the Wangaloa coal mine. * Includes native and adventive self-colonised species (see text).

Code	Description
WR1a	Waste stack constructed in 2002; initially sampled 2003 when unvegetated
WR1b	As above; re-sampled 2004 within imported hydroseed
WR2	50-60 year old waste rock stack; full natural revegetation cover* cleared for rehabilitation in 2002
WR3	40 year old waste rock stack; partial natural revegetation cover* left intact
L4	Loess excavated 40-50 years ago; full natural revegetation cover* cleared for rehabilitation in 2002
L5	In situ loess; full natural revegetation cover* cleared for rehabilitation in 2002
SF	In situ loess; 'islands' of tall seral native forest left intact (*Leptospermum scoparium* and *Kunzea ericoides*)
MF	Original soil: mature kamahi native forest (*Weimannia racemosa*)

Invertebrate sampling

Invertebrates were sampled in spring 2004. In September, October, and November seven samples were collected from each site. In the previous year (2003), 30 samples had been collected from WR1 when the waste stack was still unvegetated. They are also considered here. In total, 177 invertebrate samples were examined. Collection and processing techniques followed those trialed and used by Rufaut *et al.* (2006) in an earlier study. Thus, substrate cores (7 cm diameter, 5 cm depth) were collected from the field within a two hour period at a similar period of the day each month (10am - 12pm). Vegetation on top of cores was trimmed to ground level so that the focus was on collecting near surface-dwelling invertebrates. For SF and MF, superimposed leaf litter was also reduced to a depth of about 2 mm. Cores were stored outside in paper bags for 1-3 days before processing, which involved two stages. Firstly, large invertebrates were removed by hand as the core material was broken up; secondly, smaller specimens were heat extracted from soil placed on a 2 mm-mesh grid within a funnel using a 60 W light bulb for 48 hours. White plastic discs (5 cm diameter) were placed inside collection jars (measuring 6 cm x 10 cm height) positioned beneath each funnel and filled ¾ with water (Rufaut *et al.* 2006). The plastic discs acted as 'counting rafts' and accumulated the majority of extracted invertebrates. The water in collection jars was also checked for specimens.

Invertebrates were counted live and insects were identified to order or family. Most non-insect groups were identified to class, or in the case of Annelida, Nematoda and Platyhelminthes to phylum.

Data analysis

It was possible to count the specimens (*N*) of most taxa but not for the more abundant Onychiuridae (Collembola) and Nematoda, for which abundance classes were used instead. An estimate of taxonomic richness was obtained from Margalef's index (*d*), with *T* (number of taxa) substituting for *S* (number of species) in the formula $d = (T\text{-}1)/\log_e N$. The index *d* was generated for each sample in the multivariate program PRIMER-5 (Clarke & Warwick 1994). The non-parametric Kruskal-Wallis test was used to look for significant differences in *d* and *N* among the 2004 sites with

Mann-Whitney tests being used for post-hoc multiple comparisons. The mid-point of number classes was used in calculations of median values of *N* for Onychiuridae and Nematoda. Mean (± 95% confidence intervals) values for *d* and *N* are graphically presented and were within 0.1 of median values. Differences among assemblages at the different study sites in 2004 were investigated using non-metric multidimensional scaling (NMDS) ordination in PRIMER-5. Abundance data were pooled for each month at each site. The data were $\log_{10}$(x + 1) transformed and the Bray-Curtis measure of association used to create a similarity matrix. Sites lying closest to each other in the ordination plot are most similar. The Bray-Curtis similarity matrix was also used to calculate average percentage similarity values (*S*') in assemblage composition between the mature forest and individual waste rock and loess sites. Values for *S*' ranges between 0-100%; the latter occurring when two pairs of samples have identical distributions of *N* among the same taxa.

Results

The approximately 7750 invertebrate specimens collected belonged to 18 higher taxa (orders or higher). The majority belonged to the collembolan family Onychiuridae (about 68%) with Nematoda the second most abundant group (about 14%). The remaining taxa had a combined total of 1436 individuals, of which Acari made up 50%, followed by non-Onychiuridae Collembola (20%), Coleoptera (7%), and Annelida (6%). The number of taxa represented at the different sites increased successively from those on waste rock, to loess, to mature forest (Table 2). In 2004 a significant difference in taxonomic richness (Margalef's *d*) was found between each of the three waste rock sites and loess sites ($p<0.01$; Figure 2). Differences among the latter were not significant but WR2 had significantly higher richness than WR1 ($p = 0.01$; Figure 2). Invertebrate richness at the mature forest site was significantly higher than at each of the waste rock sites ($p < 0.01$ respectively)

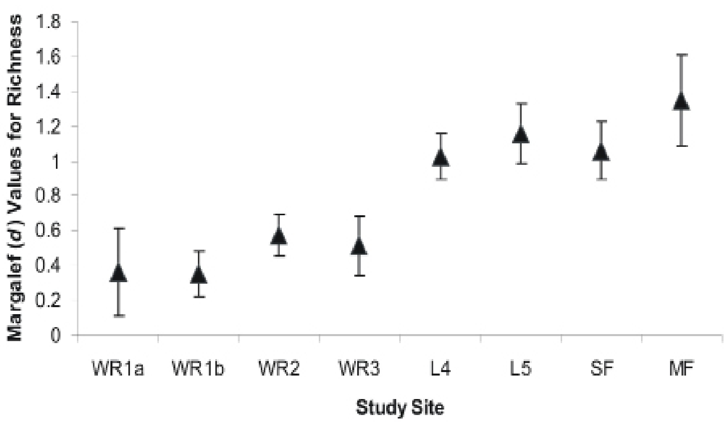

Figure 2. Average Margalef richness values (± 95% C.I.) for soil invertebrates at study sites in 2004 and WR1a in 2003.

Table 2. Abundance classes for Nematoda and Onychiuridae (Collembola) and full counts for other invertebrate taxa from different sites at the Wangaloa coal mine. * Denotes counts for adults only (larval counts are shown in Figure 4).

Community	Study Sites							
	Waste rock					Loess		Soil
	WR1a	WR1b	WR2	WR3	L4	L5	SF	MF
Nematoda	10-50	10-50	250-300	50-100	100-150	250-300	100-150	100-150
Collembola								
Onychiuridae	10-50	1500-1550	750-800	350-400	500-550	300-350	1250-1300	400-450
Entomobryiidae		6	26	1	9	23	18	9
Sminthuridae		14	10		6	28	3	6
Other Collembola			1	2	1	115	7	3
Coleoptera*	3	13	8	3	14	29	26	9
Diptera*	14	1	2	4	3	9	5	8
Hemiptera	5		7	4			2	
Heteroptera					1	2	1	1
Hymenoptera	1			1	1		2	2
Annelida			15	1	11	10	35	15
Platyhelminthes								3
Chilopoda					1	5	5	2
Diplopoda				1	2	2	5	8
Gastropoda					7	8		
Amphipoda					2	3	9	20
Isopoda								5
Aranneae	2	2	6	1	10	19	8	6
Acari	5	24	69	14	125	62	175	252
Opiliones		1	2	1		1	3	3
Pseudoscorpiones								1
No. taxa	8	9	12	13	16	16	17	19
No. individuals[1]	90	1616	1196	483	843	916	1704	902
No. individuals[2]	30	41	109	30	177	150	276	334

[1] = from mid-point values for Onychiuridae and Nematoda
[2] = excluding Collembola and Nematoda.

but not the loess sites ($p > 0.05$; Figure 2). All taxa found in the waste rock samples were also found at the loess sites and in mature forest, although Hemiptera were more common on waste rock (Table 2). In contrast, three groups (Heteroptera, Chilopoda, Amphipoda) were recorded on loess and in mature forest but not in waste rock samples (Table 2).

In 2004, average *N* was lowest at WR3 and in the mature forest, and highest at SF and WR1b. Significant differences in *N* were found between SF and MF, L4, L5, and WR3, respectively ($p < 0.01$), but no sites showed significant differences in abundance with WR1b, which had high intra-sample variation (Figure 3). On waste rock, *N* was significantly higher at the vegetated WR2 than at the partially vegetated WR3 ($p = 0.01$; Figure

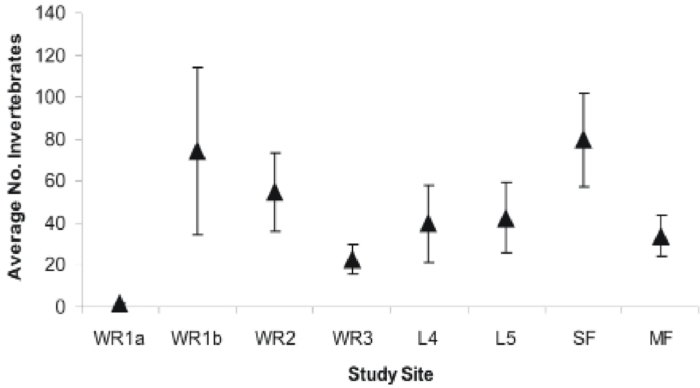

Figure 3. Average number (± 95% C.I.) of soil invertebrates at the study sites in 2004 and WR1a in 2003.

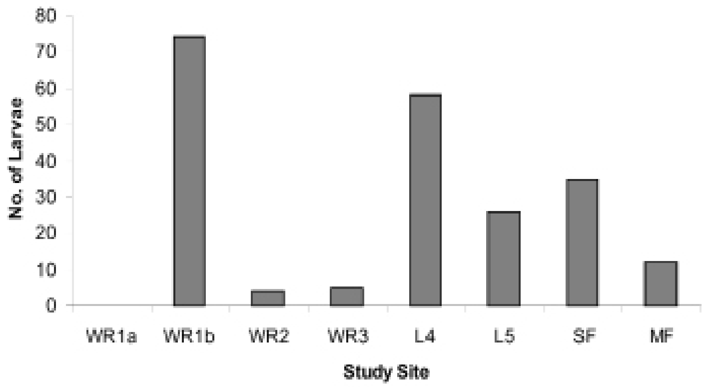

Figure 4. Total counts for larval Diptera and Coleoptera combined at the study sites.

3). The large error bars seen in Figure 3 for most sites, reflect dense aggregations of Collembola and Nematoda, specifically. When the latter groups are omitted, a strong trend of increasing *N* from the waste rock sites, to loess, to the mature forest was found (Table 2). This trend was due mainly to increases in Acari. Within substrate categories, WR2 had higher non-Collembola and Nematoda abundance than WR1b and WR3, and SF had higher non-Collembola and Nematoda abundance than L4 and L5.

At WR1, when recontoured surfaces were devoid of vegetation in 2003, average *N* was <2 individuals per core and invertebrates were absent from 42% of the cores. However, after hydroseed establishment (2004), average *N* increased nearly 40 times and only 5% of cores contained no invertebrates (Figure 3). A high proliferation of Onychiuridae accounted largely for this temporal change in *N* at WR1 (Table 2).

Larval Coleoptera and Diptera differed in their distributions among sites. In 2004, larval counts were lowest at WR2 and WR3 and highest at WR1b, despite no larvae being recorded at the latter in 2003 (Figure 4). Larval counts among the loess sites showed higher consistency, suggesting they provided generally more stable breeding sites than waste rock.

Initially two ordination analyses were

performed, one with and one without Onychiuridae and Nematoda. The latter ordination gave clearer differentiation among sites (Figure 5). The sample points had a distinct wedge-shaped configuration on the scatterplot, with minimal degree of overlap among sites (Figure 5). Samples from the mature forest were closely grouped to the left of the scatterplot and showed high similarity between months. To the right, waste rock samples were widely separated and reflected strong variations in invertebrate composition (Figure 5). Samples from the loess sites were positioned between the mature forest and waste rock sites (Figure 5).

The site identified as converging most closely with the mature forest was SF followed by L4/L5, WR2, WR1 and WR3 (Figure 5). This sequence was also reflected in the average percentage similarity values (*S*') between the mature forest and individual waste rock and loess sites. The lowest *S*' values obtained (<40% for WR1 and WR3) show how different the invertebrate faunas of these two sites were, compared to the mature forest assemblage (Table 3).

Table 3. Average Bray-Curtis similarity (*S*′) of invertebrate assemblages between the mature forest and individual waste rock and loess sites at Wangaloa coal mine.

Study sites	Similarity (%)
WR1	38.6
WR2	54.7
WR3	37.1
L4	61.8
L5	58.8
SF	70.4

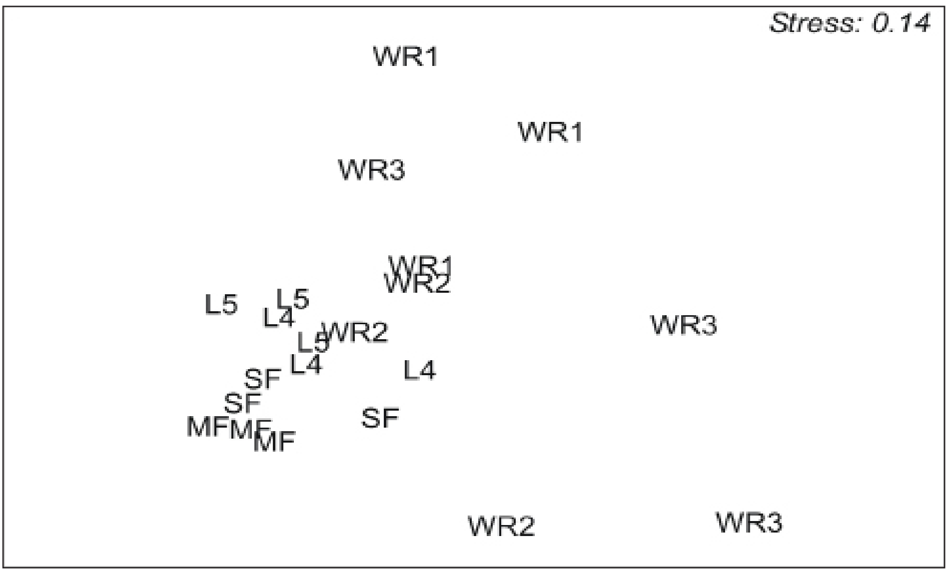

Figure 5. NMDS ordination plot of study sites based on quantitative invertebrate data (excluding Nematoda and Onychiuridae) for three months, shown as separate points. Stress value indicates that the plot provides good visual representation of inter-sample relationships in the original data matrix.

Discussion

This study found that local variations in natural plant community recovery were reflected in changes to invertebrate abundance and composition in the soil fauna at an old coal mine site. Natural successional processes had occurred on waste rock and loess substrates for 50-60 years, with virtually no anthropogenic interference. The main difference between the two substrates was that biological communities had arisen from primary colonisation processes on unameliorated waste stacks, but secondary colonisation processes on the loess, as shrublands reinvaded pasture. The rate of revegetation by natural shrubland was therefore faster at the loess sites L4 and L5 than at the waste rock sites WR2 and WR3. Seral shrublands established before the mining era represented the oldest natural shrublands at the mine site, occurring also on loess (SF sites).

Differences in richness and composition of the invertebrate higher taxa (families and above), and the abundance of less dominant taxa reflected a positive association with vegetation age. In contrast, estimates for total invertebrate abundance did not, because numbers of Collembola and Nematoda showed no site trend. In particular, Onychiuridae counts were highly variable, although the very high numbers at WR1b, showed they were rapid colonisers of previously unvegetated, young waste rock that had been recently covered with hydroseed. Members of two other herbivorous collembolan families (Entomobryiidae and Sminthuridae) also colonised WR1 but not to the same degree as Onychiuridae. Collembola are well known to be among the first colonisers of rehabilitated mine waste (Greenslade & Majer 1993; Wanner & Dunger 2002). Their abundance can also increase significantly, if high levels of disturbance coincide with an increase in resource availability (Cole *et al.* 2008). In the current study, the irregular patterns of Collembola abundance may have been a response to recent rehabilitation, although pre-disturbance data would have been needed to establish such an effect.

Future monitoring of the study sites may elucidate the impacts that vegetation clearance and ground layer disturbance have had on certain invertebrate taxa but the historical patterns of assemblage development still appear to be evident. An interesting finding of the study was the identification of Acari as a potential indicator group for monitoring New Zealand invertebrate communities at mine sites. Abundance and capture frequency of mites reflected changes in the vegetation and showed a successional response. Discrimination of taxa within the Acari may reveal more detailed habitat relationships, as has been shown at some mine sites overseas (e.g., Wanner & Dunger 2002).

A strength of the current investigation was that all comparisons, including those with the mature forest reference site, were made within a single coal mine locality, ensuring that the findings are not confounded by geographical factors. Interpretation of the invertebrate assemblage patterns therefore provided a reliable evaluation of long-term invertebrate succession in self-colonised vegetation after catastrophic disturbance, i.e. opencast mining. Keesing & Wratten (1998) state that animal community research is under-represented in restoration ecology in New Zealand, and we are unaware of another mine site study that has examined soil invertebrates.

As indicated above we found that the recovery of invertebrates on fully revegetated waste rock (WR2) remained 'behind' recovery levels on similarly revegetated loess (L4 and L5). This was apparent in the ordination scatterplot where invertebrate composition and stability of the L4/L5 assemblage converged more closely with the mature forest community than did WR2. Revegetation of waste rock at the coal mine began with direct establishment of shrubs, around which 'plant islands' developed (Rufaut & Craw 2009) and there was an estimated lag period of 15 years between the initial colonization of shrubs at WR2 and L4/L5. In an earlier study we showed that the degree of cover by 'plant islands' was correlated positively to invertebrate richness and non-collembolan abundance (Rufaut *et al.* 2006). Similar findings at waste rock sites WR2 and WR3 in the present study indicate positive relationships between the degree of plant and invertebrate assemblage recovery are a robust ecological pattern at the coal mine.

Although it had been dumped 40-50 years ago, no members of some invertebrate groups (e.g., Chilopoda, Amphipoda, Gastropoda) were taken in samples from waste rock. While the partial vegetation cover on WR3 could explain an absence of such later successional taxa (Topp *et al.* 2001), potential reasons are unclear for WR2, which had been fully vegetated for the last 20 years. Some unknown aspect of site unsuitability is more likely to be the cause than habitat isolation (e.g., Watts & Didham 2006) as all of the study sites were located close to one another and to surrounding source populations. It is possible that some of these invertebrate groups were present before rehabilitation and that the changed in habitat from closed shrubland to open, cleared surfaces resulted in their decline or loss (Pik *et al.* 2002).

Long-term natural invertebrate succession on unameliorated mine waste has rarely been described in the literature in contrast to accounts following organic amendments to mine waste sites (Topp *et al.* 2001). However, examination of entirely natural assemblages can provide interesting base-line information on the natural process of converting mine waste to healthy soil. At the Wangaloa coal mine, much of the dumped waste rock appears to have been reorganised into a biologically active and sustainable substrate by natural processes within about 40 years. This time frame of recovery is considerably longer than has been documented for anthropogenic-assisted rehabilitation at other mine sites overseas (e.g., Majer & Nichols 1998; Dunger & Wanner 2001) and in New Zealand. For example, at a peat bog mine on the Hauraki plains, Watts & Didham (2006) found that all the major invertebrate orders colonised the foliage of potted plant specimens within just 6 weeks of being experimentally introduced onto mine surfaces devoid of vegetation. Furthermore, strong evidence was found at the same peat mine for pit-fall trapped beetle assemblages on restored surfaces to converge in composition with the assemblages of undisturbed peat bogs within 8 years (Watts *et al.* 2008).

Rehabilitation technology has repeatedly been demonstrated to fast-track development of the invertebrate fauna (e.g., Majer & Nichols 1998; Wheater *et al.* 2000; Watts *et al.* 2008) and can also artificially elevate their densities (Topp *et al.* 2001). At the Wangaloa coal mine, this was demonstrated in the proliferation of Collembola on the youngest waste rock stack following an unprecedented introduction of hydroseed. Although the anthropogenic rehabilitation has interfered with the natural process of invertebrate development, the extent that the invertebrate fauna at the mine site still reflected historical differences in vegetation development conveys resilience of their assemblages. The permanence of biological communities that form via natural succession compared to technical reclamation is a key outcome for advocates of the former approach to site restoration (e.g., Hodačová & Prach 2003).

In conclusion, inherent differences in soil invertebrate assemblages could be detected for study sites that had reached different stages of natural revegetation at an old coal mine. The trends of increased taxonomic richness and compositional stability, decreased dominance of Collembola, and increased presence of meso- and macro-invertebrates was shown to resemble a successional pattern associated with the age and rate of natural revegetation, over a 50-60 year time period. The invertebrate assemblages developed by natural succession showed comparably slower rates of recovery in self-colonised shrublands on waste rock than on loess substrate. Spatial changes in the fauna, arising from the re-colonisation process, are believed to be due to variations in habitat suitability rather than isolation, although environmental relationships were not quantified. Compared to anthropogenic rehabilitation of mine waste, this entirely natural approach to rehabilitation seemed to produce longer recovery periods for invertebrates, but the assemblages formed showed high resilience. We suggest that in the future, greater consideration be given to natural patterns of biological recovery before earthworks commence for site rehabilitation.

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