SOIL ORGANISMS Volume 83 (3) 2011 pp. 433–450

ISSN: 1864-6417

Auditing revegetated catchments in southern Australia: decomposition rates and collembolan species assemblages

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Abstract

Major government funds have been allocated to revegetation of degraded catchments in Australia in order to enhance biodiversity, protect stock and improve water quality. However, the success or otherwise of the different restoration practices used has not been assessed. To redress this deficiency we audited these practices by measuring biotic and abiotic variables in two field surveys, one at a landscape scale and the second at a local scale. The landscape survey comprised 21 sites in western Victoria, a third of the sites were revegetated and were between 8 and 12 years old, a third carried remnant native vegetation and a third were degraded and not revegetated. In the local survey the results of the landscape survey were tested by sampling sites within a small area using the same methods but including pine plantations as an untreated site. Here we report on density and species composition of soil and surface active fauna, native and exotic Collembola and decomposition rates as measured with bait laminae. Fifty seven species of Collembola were found on the landscape survey and 47 on the local survey. Densities ranged from 17,000 to 45,000 m^{-2} in soil. In both the surveys we found decomposition was directly related to soil moisture and in the landscape survey exotic Collembola (*Hypogastrura* and *Ceratophysella* spp) to abundance of exotic grass species. MDS analysis of soil Collembola in the landscape survey placed remnant sites separate from the revegetated sites and untreated sites, which tended to cluster together. A suite of nine native Collembola species were found exclusively on remnant sites in the landscape survey. In the local survey, the revegetated sites, here with a ground cover of native not exotic grasses, were found to have nine characterising species, four of which were the same indicators as in the landscape survey. The pine plantations were dominated by acidophil exotic Collembola species. MDS analysis of pitfall data in local survey placed all sites in the same space, except for one remnant because of domination by the same exotic species as in the landscape survey. In contrast, MDS of the soil-core data separated all three treatments with the revegetated sites occupying the space between the remnants and the pines as in the landscape survey. When exotic species were removed, there was spatial separation of each treatment. We conclude that, in some circumstances, soil fauna of revegetated sites can develop characteristics of remnant sites in terms of native Collembola even after only 8 to 12 years. The bait lamina method must be used with caution as it is strongly influenced by soil moisture.

Keywords: Hypogastruridae, bait lamina, exotic species, native species, pine plantations

1. Introduction

For over 220 years, from the time of first European settlement, the original cover of native vegetation in Australia has been progressively cleared. Australian catchments, in particular, are known to have been damaged (Gale & Haworth 2005, Gell et al. 2005). Most significantly, the last 50 years of intensive human-induced activities have altered the health of ecosystems to an even greater extent, and more rapidly, than at any other comparable period and this has been particularly severe in the south of Victoria where less than five per cent of the original vegetation remains. Degradation has been caused by a *per capita* increase in resource use, coupled with population growth and a changing climate (Millennium Ecosystem Assessment 2005). Remediation is considered essential to restore damaged ecosystems (Wilson 1992). In response to this need, ecological restorative activities are now being applied and are among the most expensive natural resource conservation activity undertaken across Australia (Holl et al. 2003). Extensive revegetation has been achieved in the last two decades mainly because the Australian government has invested in restoration projects nation-wide. In 2000–01 alone, $36.4 million was spent in establishing native vegetation and in providing appropriate habitat for wildlife (Wilkins et al. 2003). Despite this investment, little or no monitoring of revegetated sites has been undertaken to assess whether any ecological benefits have resulted. The benefits expected were: protection of catchments, restoration of biodiversity, an increase in carbon storage, improvement in water quality by reducing erosion and pollution from stock and reduction of stock loss. Brooks & Lake (2007) reported that, of the 2,247 restoration projects undertaken in four catchments in Victoria, only 14% included some form of monitoring and these were largely only photographic. Even simple measures, such as the relative performance of broadcasted seed and planted seedlings, or the level of natural recruitment of indigenous species, are rarely made.

Funds to plant native vegetation, usually trees only, were largely spent by farmers and Land Care groups channelled via Catchment Management Authorities (CMAs), but vegetation work by farmers in particular lacked audits on the effectiveness in achieving the stated aims. Because of this, the University of Ballarat has undertaken an audit to measure biotic and abiotic characteristics of over 120 sites in south western Victoria. The specific objectives of the overarching project are: to audit restoration activities by comparing the proposed and apparent outcomes of restoration activities, to compare the quality, with regard to diversity and vegetation structure, of restoration sites of different age classes with corresponding remnant vegetation sites. The variables measured should reflect the internal resilience of the site and to what degree established reserves act as sources for species colonisation of restored sites. Since revegetation should also aim to restore ecological function (Hobbs & Norton 1996), ecological processes should also be measured on remnant, restored and untreated sites and compared. All the measured variables included not only vegetation type and structure, floristics, soil seed store and seed fall, water quality, species richness of birds and soil invertebrates, soil moisture, decomposition rates but also a range of other abiotic attributes. This range of attributes complies with Ruiz-Jaen & Aide's (2005) suggested requirements for evaluating restoration success. As the plant species and sites selected for revegetation were chosen for the most part without any consideration of ecological appropriateness or provenance of seeds on these sites, it was not expected that revegetated sites would have achieved high biodiversity values.

We report here on soil faunal recovery, with reference to Collembola and decomposition rates and examine whether our data are able to measure the 'success' of the revegetation efforts. The following hypotheses are examined: decomposition will be slowest on youngest or untreated sites, exotic species will be more abundant on youngest or untreated sites, species richness will be highest on remnant sites, at least of natives, indicators of the integrity of remnant sites will comprise a suite of native species and pine plantations will have a higher number of exotic species than remnants or revegetated sites.

2. Materials and methods

Problems with measuring the effects of impacts in the field are, if sites are sampled at a landscape scale, variability both within these large sites and between them can be so great as to mask any signal from the impact. The number of samples needed to overcome this ‘noise’ is impossible to achieve. Alternatively, small plots have the advantage of minimising site variability, but here edge effects can dominate and mask any effect of impact. We have attempted to minimise this problem and provide a balanced sampling programme by conducting surveys at both a large landscape scale (CMA) sites and a small, local (Wilson's Reservoir) scale, and by comparing results from both. If results from both surveys are similar, our conclusions are strengthened.

Stream riparian zones were chosen as the focus of this study as they are: ecotones capable of hosting high species richness and diversity, subject to bank erosion and in need of stabilisation by means of rehabilitation, sources of sediment and clay-bound phosphate and so are critical in mitigating water quality decline and have become highly disturbed and in need of weed and pest management.

2.1. Landscape study

2.1.1. Site selection

The first field survey was conducted on 21 sites on riparian zones within an area of approximately 60 km by 60 km south of Ballarat, south western Victoria (Fig. 1), a region of predominately sheep farming and a wheat/canola rotation. The restoration sites for the landscape survey were selected from the Catchment Activities Management System data base of all works that have been done by Catchment Management Authorities in Victoria. They were all between 8 and 12 years old and revegetated mainly with *Eucalyptus* species. The six untreated sites had a cover of mainly exotic grasses with some weeds. Eight sites were in native, undisturbed vegetation, mainly in parks and reserves. The six revegetated sites were all on farm land and were aged from 5 to 12 years old with one being 60 years old (Tab. 1). More remnants were sampled than revegetated and untreated sites because some data had to be discarded because of interference from foxes or people. The revegetated and untreated sites were long and narrow, between 5 and 20 m wide, while the remnant sites were considerably larger and were usually several hundred hectares in area.

2.1.2. Sampling methods

Pitfall traps were used to collect surface active fauna, soil cores were taken to measure abundance in soil and bait laminae to measure decomposition rates in soil as recommended by Keplin & Hüttl (2000) and Römbke et al. (2006). At each site, five pitfall traps, diameter 1.8 cm, were inserted in a line about one metre apart three quarters filled with a high concentration of alcohol (Greenslade 2007) and left for seven days. Five soil cores were taken (5 cm diameter and 5 cm deep) approximately one metre away from each pitfall, crumbled and spread evenly on sieves inserted in simple plastic funnels of 20 cm diameter. If the soil was dry on collection the sample was moistened for 24 hours to activate fauna. The extraction continued over

Tab. 1 Data for sites sampled on the landscape survey in the Corangamite Catchment region: treatment, age, mean soil temperatures and moisture content.

Site number	Latitude	Longitude	Treatment	Age [years]	Mean soil temperature [°C]	Mean soil moisture [%]
1	37.49592	143.29540	revegetated	11	10.0	6.8
2	37.49936	143.29780	untreated	unknown.	16.0	13.5
3	38.01907	143.20274	remnant grassland	>100	18.0	28.1
4	37.56372	143.23076	revegetated	8	16.4	4.0
5	37.56160	143.23360	untreated	unknown.	24.1	19.9
6	37.?	143.22678	revegetated	8	25.3	14.4
7	37.51500	143.21000	untreated	unknown	27.5	26.3
8	37.50039	143.29941	revegetated	60	25.0	1.2
9	37.42900	143.53500	revegetated	9	16.4	1.7
10	37.42900	143.53500	untreated	unknown	15.0	9.0
11	37.47916	143.54843	remnant	>100 yrs	20.7	0.4
12	37.51310	143.55300	remnant	>100 yrs	25.6	0.1
13	37.48283	143.58503	revegetated	9	19.5	5.7
14	37.48411	143.58644	untreated	unknown	29.9	6.5
15	37.38590	143.53800	remnant	>100 yrs	13.8	2.4
16	37.35264	143.54003	remnant	>100 yrs	14.6	5.3
17	37.33240	143.53688	untreated	unknown	19.0	36.9
18	37.43526	144.05735	remnant	>100 yrs	16.7	6.7
19	37.42658	144.05645	remnant	>100 yrs	15.9	3.1
20	37.46212	143.44217	remnant	>100 yrs	12.4	15.9
21	37.46196	143.44235	remnant	>100 yrs	15.2	16.0

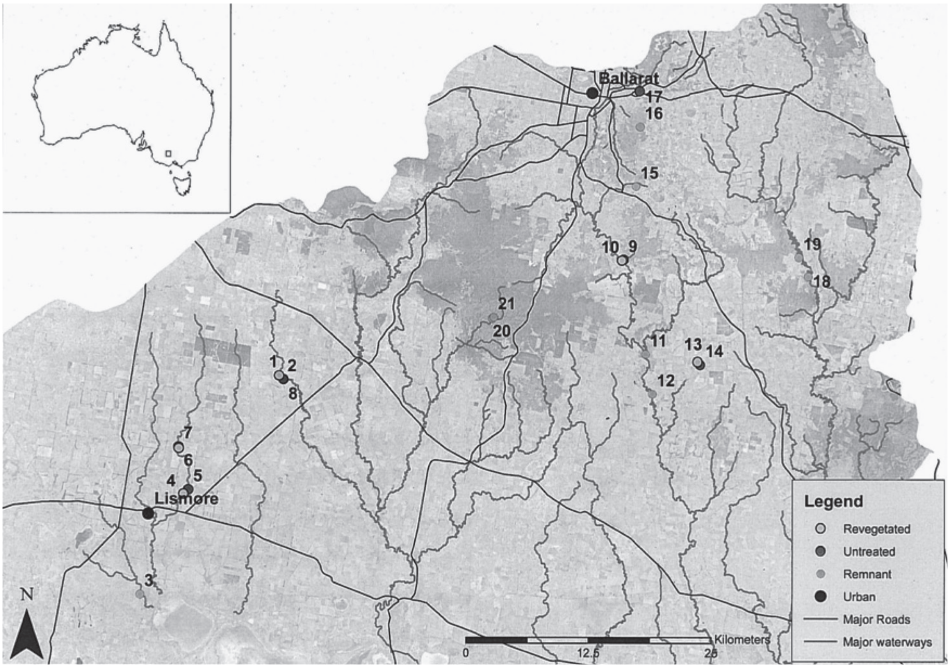

Fig. 1 Map showing locations of landscape survey sites in south-eastern Victoria. Insert shows location within Australia.

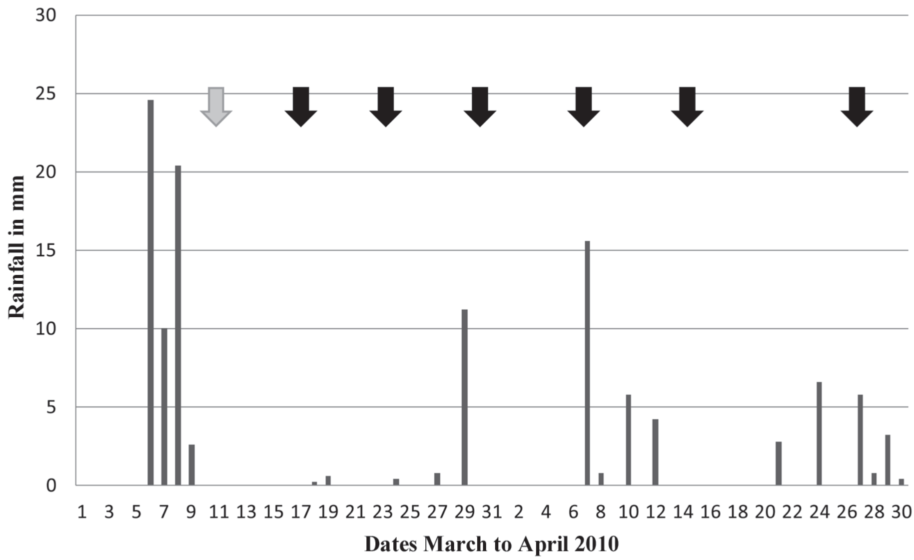

Fig. 2 Daily rainfall records in mm for the months of March and April from Bannockburn for the landscape survey sampling period. Initial sampling date denoted by grey arrow, subsequent sampling dates by black arrows.

alcohol for one week until dryness. No heat was applied so as to maximise extraction. Two bait lamina strips were inserted into the soil near each pitfall. The bait laminae openings were filled with a wet mixture of finely ground starch, activated charcoal and processed bran in the ratio of 70:27:3 (*terraprotecta* GmbH, 1999). The pitfalls and bait lamina were left in place for seven days. The digging-in effect is the same for all sites so is uniform over all the results. In addition, at each site two measures of soil moisture near each pitfall using a MPM160 Moisture Probe Meter (ICT International Pty Ltd) and one of soil temperature were made. Vegetation, dominant plant species, slope, aspect, stone and leaf litter cover and depth, abundance of coarse woody debris, and distance from creek were recorded for each site and photographs were taken. The coordinates and altitude were also recorded. All field work was carried out during autumn, 2010 (March to April). The weather was initially dry, but 81.6 mm rain fell mainly during the last two weeks of sampling (Fig. 2).

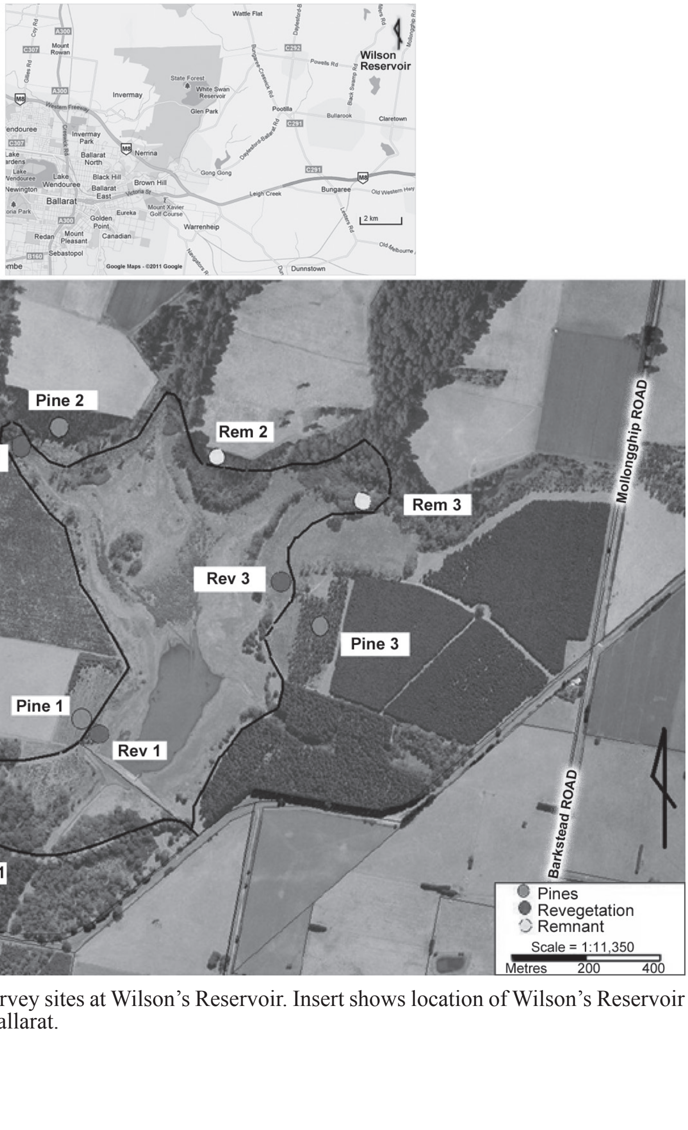

Fig. 3 Map of local survey sites at Wilson's Reservoir. Insert shows location of Wilson's Reservoir in relation to Ballarat.

2.2. Local study

2.2.1. Site selection

Sites of the local survey were all located within two kilometers of each other around a domestic water supply storage facility with a capacity of 1013 ML 15 km NE of Ballarat, southern Australia, managed by Central Highlands Water (CHW) (Fig. 3) and in a water reserve. Here three *Pinus radiata* plantations, three remnant vegetation and three revegetated sites were selected under the guidance of CHW staff around the reservoir and within 100 m or less of high water mark (Fig. 3). The revegetated sites were the same age as those in the landscape survey (Tab. 2). Pine plantations were included because they have been used in the past to protect water catchments, but previous studies have shown that *P. radiata* and other coniferous species increase soil acidity, have less ability to store carbon and reduce nutrient availability, resulting in reduced plant productivity in the long term (Noble et al. 1999). All sites were long and narrow, with a maximum width of about 50 m except for pine sites 2 and 3 and remnant 1 where the width was 200 m.

2.2.2. Sampling methods

The sampling regime was identical to that of the landscape survey except that four bait laminae were inserted at each pitfall site with one removed and read every week for four weeks. The same abiotic variables were measured at each of the nine sites as before. Midway through the sampling period, multiple soil cores were taken to a maximum depth of 20 cm from within a 1-metre radius of a soil core or pitfall trap. These soil cores were pooled, mixed and subsamples of approximately 400 g taken for chemical analyses. Twenty eight soil chemical properties were analysed. The most relevant soil chemical properties reported here include: soil organic carbon, phosphorus (Olsen) mg/kg, Phosphorus Buffer Index (PBI), pH (1:5 Water), aluminium (meq/100g), EC (dS/m) and ammonium nitrate. All samples were taken in winter and very early spring, from August to September 2010 when weather was wetter and 227.8 mm rain fell from August 1st to September 9th (Fig. 4).

2.3. Faunal analyses

Collembola were identified and counted in all samples to species or morphospecies except for the pitfalls from the landscape survey. Only exotic Hypogastruridae, *Hypogastrura* and *Ceratophysella* species, were counted (*H/C*) in these samples.

For both surveys, differences in species composition and abundance of soil-core Collembola between treatments were compared, as well as for pitfalls in the local survey, using Multi-dimensional Scaling (MDS) with PRIMER (6.1) based on the Bray–Curtis dissimilarity coefficient without transformation. This analysis was repeated for native species only excluding exotics in the local survey. A non-parametric Mann Whitney test of species richness between treatments was carried out. The indicator values of significant native species were calculated using a modified version of IndVal. Spearman Rank Correlations (Wessa 2011) were done of leaf litter depth, percentage of exotic grasses and soil moisture against log of abundance, i.e. numbers of individuals of the exotic *Hypogastura/Ceratophysella* collected in pitfalls in the landscape survey. For the local survey, data was tested for normality and, based on the results, Spearman Rank Correlation test was used (Wessa 2011) to investigate relationships between species richness and abundance of Collembola found on the three treatments with soil chemical properties (N, P, organic C etc., see Tab. 4) and soil moisture. The rate of decomposition (as measured by bait lamina 'feeding activity') was compared with soil moisture using the same non-parametric method as for the landscape survey.

Tab. 2 Data for sites sampled on the local scale around Wilson's Reservoir: treatment, vegetation, age, mean weediness, mean soil moisture and mean soil temperature.

Treatment	Latitude	Longitude	Dominant vegetation	Age of vegetation	weediness (%)	Mean soil moisture (%)	Mean soil temperature (ºC)
Pine Plantation 1	37.51363	144.01467	*P. radiata* *Poa* sp.; broadleaf weeds	6 yrs	10	29.5	7.2
Pine Plantation 2	37.50595	144.01557	*P. radiata* Exotic grass	21 yrs	10	36.1	7.6
Pine Plantation 3	37.51038	144.02275	*P. radiata* Exotic grass; broad leaf weeds	23 yrs	10	33.7	7.5
Revegetation 1	37.51401	144.01484	*Eucalyptus, Acacia* & *Poa* spp Exotic grass; broadleaf weeds	6 yrs	15	30.4	7.8
Revegetation 2	37.50688	144.01524	*Eucalyptus, Acacia* & *Poa* spp *Pteridium esculentum*; exotic grass	6 yrs	30	24.6	7.6
Revegetation 3	37.50947	144.02171	*Eucalyptus, Acacia* & *Poa* spp *Pteridium esculentum;* broad leaf & woody weeds	6 yrs	20	42.0	7.2
Remnant 1	37.51605	144.1234	*Eucalyptus, Acacia* & *Poa* spp Exotic grass; woody weeds	>100 yrs	35	40.6	7.7
Remnant 2	37.50353	144.02059	*Eucalyptus, Acacia* & *Poa* spp *Pteridium esculentum*; broad leaf weeds	>100 yrs	10	37.4	7.7
Remnant 3	37.50517	144.02514	*Eucalyptus, Acacia* & *Poa* spp *Pteridium esculentum*	>100 yrs	15	32.9	8.3

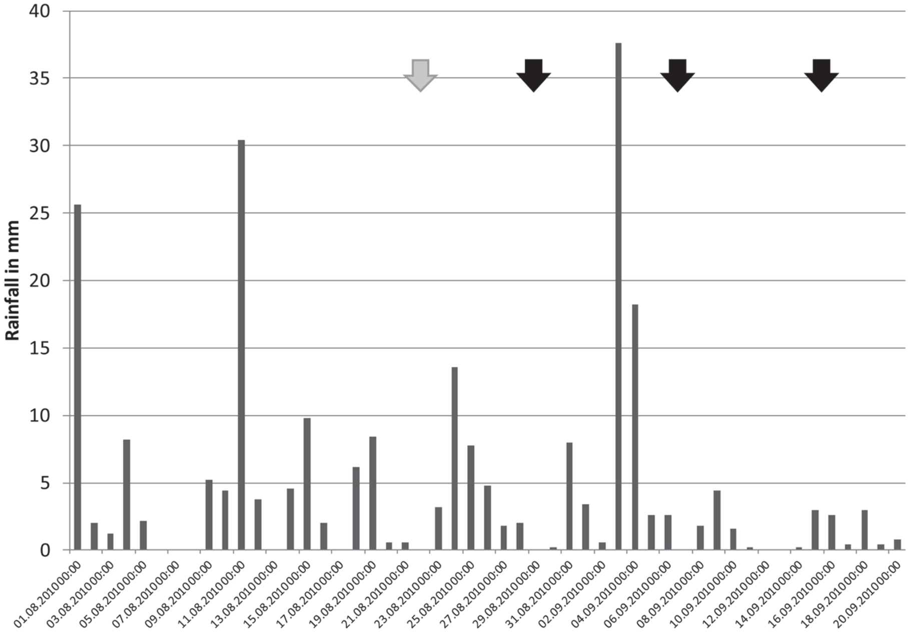

Fig. 4 Daily rainfall in mm at Wilson's Reservoir during the sampling period. Initial sampling date denoted by grey arrow, subsequent sampling dates by black arrows.

3. Results

3.1. Landscape survey

In the landscape survey, decomposition, as measured by the bait lamina, showed that rates varied between treatments with remnant sites showing lowest rates and revegetated sites the highest. Untreated sites were intermediate apart from one outlier (site 5), which was heavily impacted by foxes. As expected, rates were strongly correlated with soil moisture and not related to density or activity of the soil fauna (Fig. 5).

Soil cores taken from the 21 landscape survey sites contained 11,220 individual Collembola, which were identified as belonging to 57 species and 47 genera. Total mean density of Collembola was 54,000 m^{-2} for all 21 sites combined based on 105 cores, but varied between treatments from 22,300 m^{-2} on remnants, 42,671 m^{-2} on untreated sites, and 44,690 m^{-2} on revegetated sites. The cumulative species curves for the three treatments (Fig. 6) shows that the sampling collected only a subset of the total fauna for all treatments, but most noticeably for remnants. Figure 6 also shows that the total number of species collected from each treatment differed as did the mean species richness in soil cores per site, which was 15 (range 8 to 19) for remnants, 8 (range 5 to 11) for revegetated and 7 (range 1 to 8) for untreated sites, with considerable variability between sites within treatments. The Mann Whitney test showed that this difference was significant for remnants versus untreated sites and for remnants versus revegetated sites (0.1% likelihood that the faunas represented a single population). Using the same test, no significant difference was found between species richness of revegetated sites and untreated sites, but almost twice as many individuals of native species (mean 103 per site) were found in soil cores on the revegetated sites compared to the untreated sites (74 per site). Log species abundance curves for the three treatments did not differ significantly and there was no extreme dominance of one or two species on the disturbed sites. Also, treatments differed in the uniqueness of their faunas with 26 (56%) of the 57 species only found on remnant sites, 2 found only on untreated sites and 4 found only on revegetated sites. Indicator values were calculated for all species exclusive to remnant sites (Tab. 3). One species was

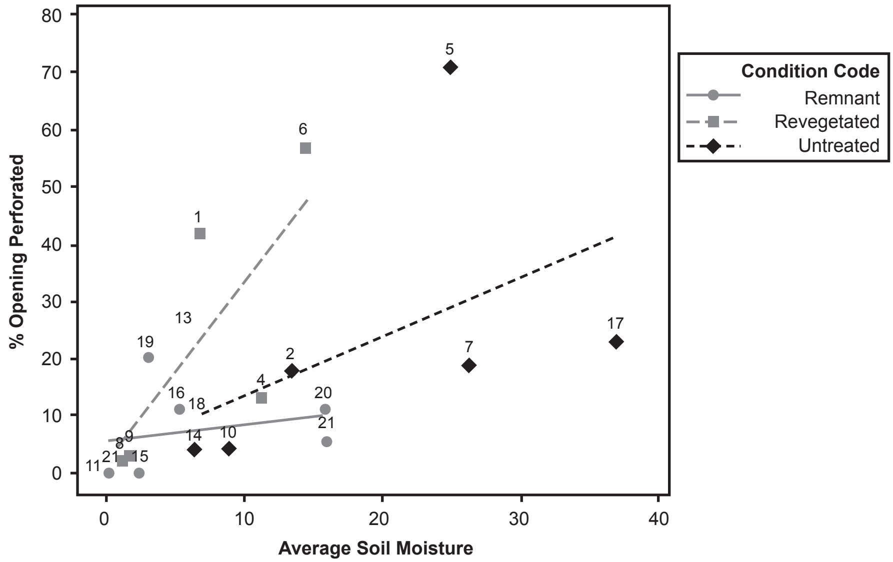

Fig. 5 Scatter graph of average soil moisture and mean percentage of empty holes in bait lamina for each plot for the landscape survey.

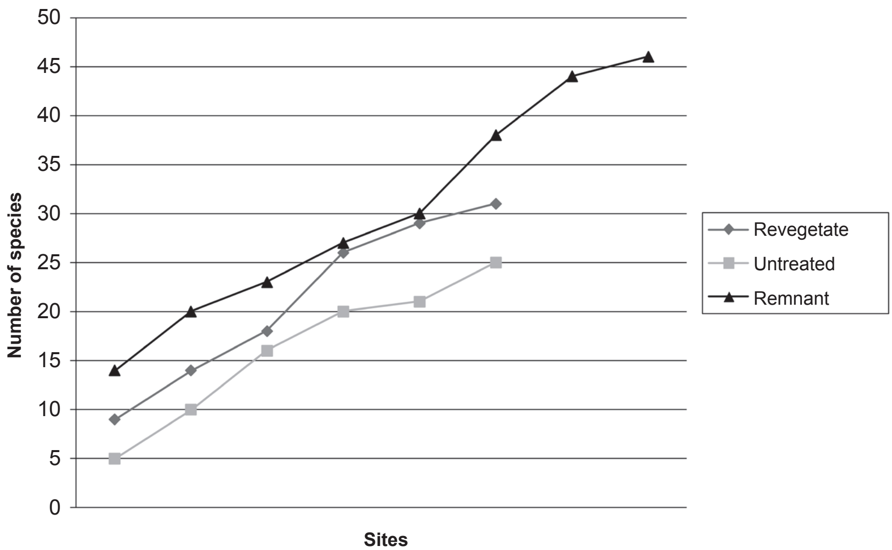

Fig. 6 Cumulative species curve for each treatment of the landscape survey.

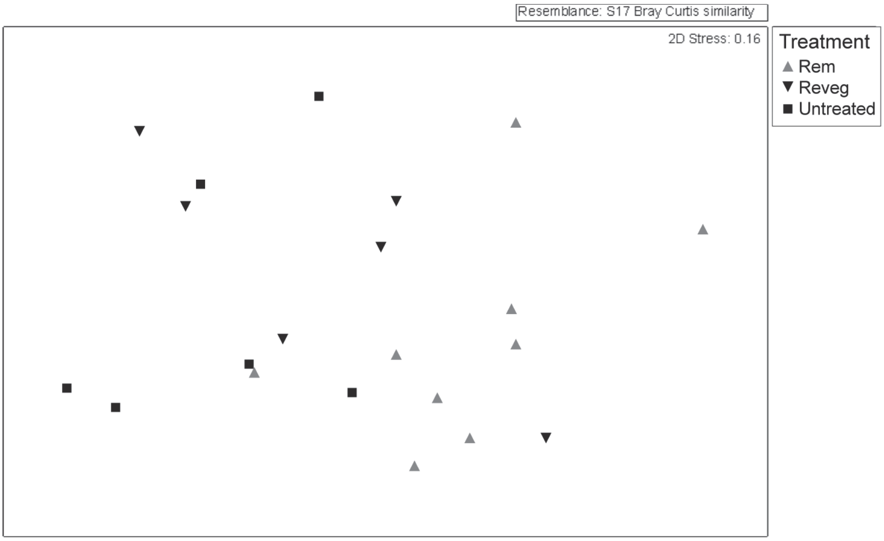

Fig. 7 MDS of Collembola species abundance in soil for all sites in the landscape survey.

Tab. 3 Native species (excluding those represented by single specimens) on remnants of the landscape survey sites with indicator values > 0.5 and presence on the remnants of the local survey (P - pines, RV - revegetation, RM - remnant). Native species on local survey sites of significant indicator value in bold.

Taxon	IndVal for landscape survey	Local survey
***Isotopenola* sp.**	**23.2**	RM RV P
Parisotoma raffi	**3.2**	absent
***Pseudachorutes* sp.**	2.3	RV RM
Cryptopygus antarcticus grp	1.3	P RV RM
Folsomia loftyensis	1.1	absent
***Cephalachorutes* sp.**	0.9	RV RM
Folsomides sp.	0.8	absent
Odontellidae	0.7	P RV RM
Neanuridae indet.	0.6	**RM**
Lepidocyrtus sp. 2	absent	**RM**
Tullbergia sp.	absent	**RV RM**
Dinaphorura sp.	absent	**RM**
Isotomiella sp.	absent	RM P
Sinella sp.	absent	RM

found to have a high value with a further eight with significant values. The ordination of soil Collembola (Fig. 7) placed remnant sites somewhat separated from untreated sites, but with an outlier (site 3), in an intermediate space. This was the only remnant carrying no trees but with predominately native grasses. One revegetated site clustered with the remnants (site 4, aged 8 years), indicating a better trajectory in faunal recovery here than on the other revegetated sites. There were few weeds on this site. Without these outliers, the revegetated and untreated sites occupied approximately the same space.

Landscape-scale pitfall traps collected invasive exotic hypogastrurids in large numbers on untreated and revegetated sites but few on the remnants; untreated sites generally had twice as many invasive hypogastrurid individuals than revegetated sites (Fig. 8). Two revegetated sites had few exotic grasses, one was treated annually with herbicide and the other was approximately 60 years old carrying only well-grown *Eucalyptus cladocalyx* trees. Few exotic hypogastrurids were caught on either of these two sites. Even so, including the two revegetated sites with few exotic grasses, the percentage of exotic grasses, recorded as an environmental variable, was positively correlated to the abundance of invasive hypogastrurids ($r = 0.60$, $p = 0.009$). There was a weaker relationship between the abundance of invasive hypogastrurids and soil moisture ($r = 0.48$, $p = 0.04$), and a negative relationship with leaf litter depth ($r = -0.51$, $p = 0.029$).

3.2. Local survey

The total number of Collembola collected on the local survey in both soil cores and pitfall traps was 3409 represented by 47 species. Numbers of individuals in pitfalls did not differ significantly between treatments, although pitfalls in pine had the highest total numbers (total catch in pitfalls of 692 in pines, 378 in revegetated sites and 476 in remnants). Density in soil cores were also similar (24,800 m^{-2} in pines, 17,000 m^{-2} in revegetated sites and 21,300 m^{-2} in remnants). Collembola species richness was highest on the remnant (30 species) and pine (28 species) sites and lowest on the revegetated sites (22).

Bait lamina results for the local survey indicated that soil decomposition increased with time and did not differ between the three treatment types after four weeks, but a slight, non-significant difference was evident after one and two weeks with pine sites showing a faster rate of decomposition. After 29 days, nearly 50% of the baits were consumed on all treatments. Soil moisture and baits consumed showed a small, not statistically significant positive relationship (Fig. 9) with the remnant sites showing the greatest response and pines no response to increasing moisture. As expected Spearman rank correlation analysis revealed that there was a strong, positive correlation between the number of days exposed and the percentage of holes perforated and approx. 95% of the variation can be explained by the number of days exposed.

For both sampling methods, pine sites had the greatest number of Collembola individuals caught in traps and higher densities in soil than the other two treatments, partly due to the dominance of three exotic species: *Ceratophysella* spp and two acidophil species, *Mesaphorura* spp and *Parisotoma notabilis.* Although the pine sites registered overall a lower pH than the other two treatments at a mean of 4.75 for the two oldest sites compared to 5.75 for remnant sites and 6.12 for revegetated sites, this difference was not significant. Individuals from the two target invasive genera (*Ceratophysella* and *Hypogastrura* species) dominated all sites, accounting for over 70% of all Collembola fauna caught in traps. Excluding records of single individuals, three native taxa were found exclusively on the local survey remnant sites, but only in low numbers except for *Lepidocyrtus* sp. 2 and a further five were found more abundantly on remnants compared to the other two treatment types (Tab. 3).

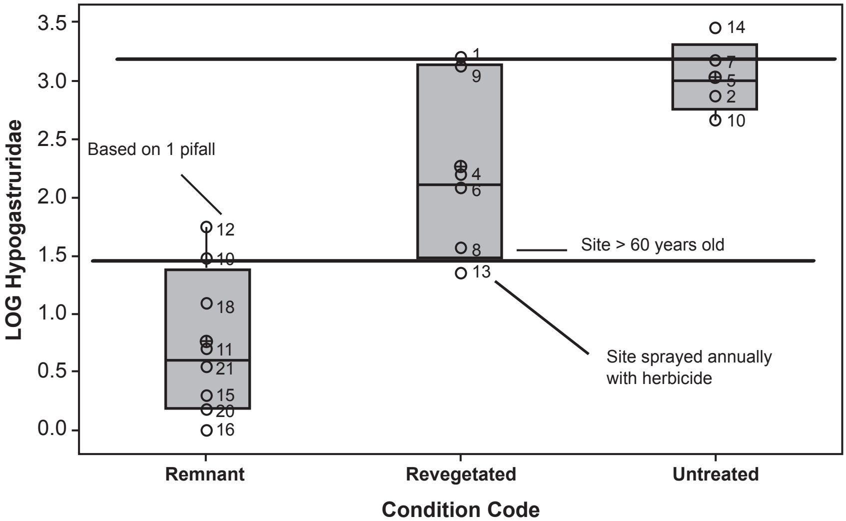

Fig. 8 Boxplot of LOG Hypogastruridae (pitfalls only) in landscape survey.

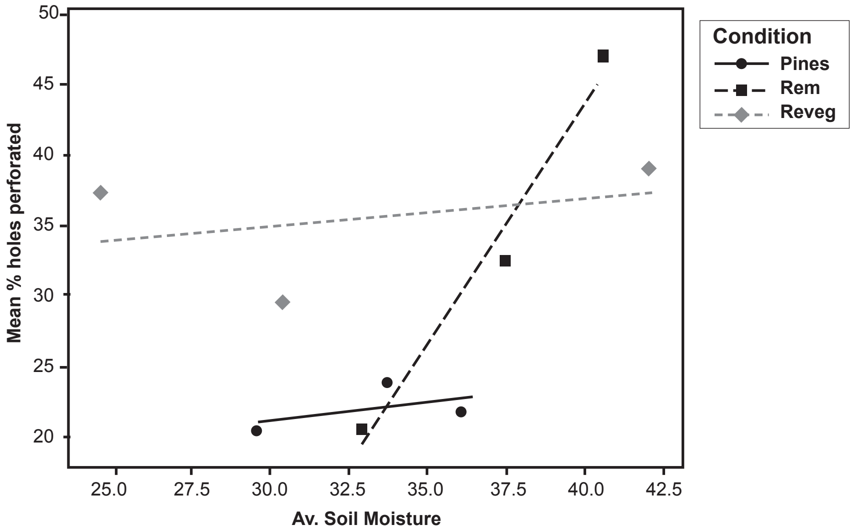

Fig. 9 Scatter plot of holes perforated on the bait lamina on each plot against soil moisture in the local survey sites.

Tab. 4 Results of soil analyses of the local survey sites at Wilson's Reservoir.

	Pines			Revegetation			Remnant		
Soil Property	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
pH (1:5 Water)	6.1	5.7	5.6	6.1	6.3	6	6.1	6.1	5.4
Organic carbon [%]	4.7	4.3	3.4	5.5	7	5.1	6.8	7.4	5.9
Cation exchange capacity [meq/100g]	15.8	10.8	6.68	15.3	21.2	14.5	20.9	17.6	8.2
Nitrate nitrogen (NO_3) [mg/kg]	1	1.2	1	2.1	7.7	1	22	3.9	1
Ammonium nitrogen (KCl) [mg/kg]	11	8.5	4.5	16	22	13	19	16	17
Phosphorus (Olsen) [mg/kg]	33.3	38.6	14	28.6	52.4	6.14	28	5	5
Phosphorus Buffer Index [PBIcol]	830	820	450	780	1100	440	420	1010	350
EC [ds/m]	0.08	0.07	0.06	0.07	0.09	0.08	0.17	0.09	0.09
Aluminium (KCI) [meq/100g]	0.1	0.53	0.85	0.1	?	0.1	?	0.1	0.89

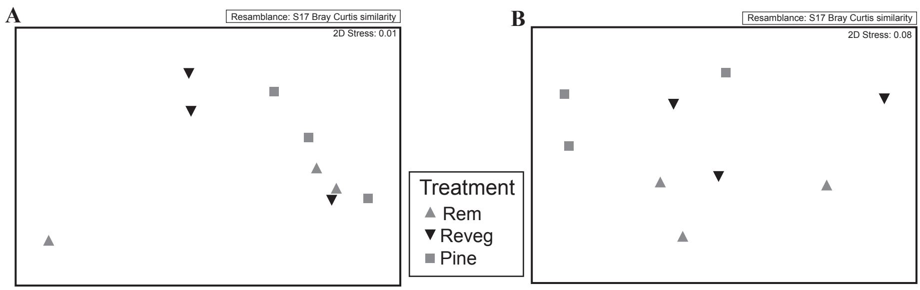

Fig. 10 MDS for Collembola found on the local survey sites. **A**: pitfall data, **B**: soil data.

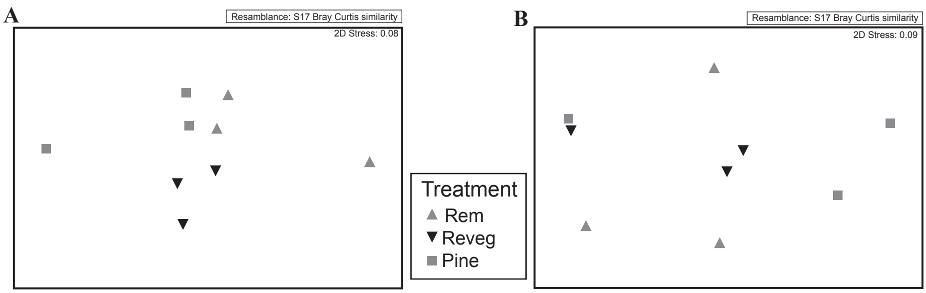

Fig. 11 MDS for Collembola excluding exotic species collected in the local survey sites. **A**: pitfall data, **B**: soil data.

Results of soil analyses are given in Tab. 4, but significant relationships between soil parameters and treatment or fauna were few. Soil organic carbon was highest within remnant sites and lowest in the pine plantation, being 4.1%, 5.9% and 6.7% in the pine, revegetation and remnants sites, respectively. Spearman rank correlation revealed a positive correlation between soil organic carbon and two soil-living taxa, *Neanuridae* spp ($p = 0.039$ and *Tullbergia* sp. ($p = 0.001$). *Neanuridae* spp were five times more abundant in the remnant sites than the pine sites, whilst *Tullbergia* sp. was not recorded on any pine site. *Mesaphorura* sp. was significantly correlated with ammonium nitrogen ($r = 0.56$) and this variable explained 47% of the abundance of this genus while *P. notabilis* was significantly correlated with pH at $r = 0.62$.

The MDS of pitfall data from the local survey showed some clustering of the different treatments except for one remnant site (Fig. 10A). This is because the exotic *H/C*, which were collected more numerously in pitfalls than in soil, were fairly abundant on remnant site 1. In the MDS of Collembola from soil cores, the remnants clustered together well separated from the pine sites. Revegetated sites generally occupied an intermediate space (Fig. 10B). When the test was repeated after removing the data for exotic species (*H/C* only), the treatments were better separated for both soil and pitfall data and occupied different spaces almost exclusively (Figs 11A and 11B). An exception was one remnant site that was badly infested with weeds. Even the pine sites were well separated from the revegetated sites, indicating that native species composition differed between pine and revegetated treatments not only in abundance and presence of exotics, probably because the soil-living acidophil *Mesaphorura* sp. and *P. notabilis* were mainly found in pine soils.

4. Discussion

Unlike many other studies of arthropods in restoration (Longcore 2003) or when comparing native eucalypt forest and pine plantations (Robson et al. 2009), our study identified one Class of arthropods to species and two complementary methods were used by collecting fauna both in leaf litter by means of pitfalls and in soil, thus providing two sources of data on impacts especially as they were conducted at different seasons. As species in the same genus may have different habitats and functions (Greenslade and Smith 2010), identification to this level is essential to understanding subtle differences between treatments and in identifying 'indicator' taxa for restoration progress. We found congruence between the taxa considered characteristic of remnants, that is native sites, in both the landscape and local surveys as the same six taxa occurred on them in both the landscape and local surveys. The presence and abundance of these species can be used to measure the trajectory toward improved site condition. As part of the current increasing interest in restoration ecology (Roberts et al. 2009), invertebrates as well as vegetation attributes are being used to monitor the progress of revegetation especially after mining (Orabi et al. 2010 and included references). Collembola are considered particularly valuable in these studies because of their ubiquity, abundance, species richness and sensitivity to environmental disturbance (Greenslade & Majer 1993; Zeppelini et al. 2009). Our study capitalised on the results of previous studies on this group in Australia (Greenslade & Smith 2010), which identified taxa characteristic of old growth vegetation. It also attempted to measure restoration of ecosystem functioning as exemplified by decomposition rates of baits in laminae designed for this purpose by von Törne (1970).

Because we conducted investigations at both large (landscape) and small (local) scales, results that are similar at both scales reinforce their wider relevance. The bait lamina results are an example as results from both the landscape and local sites showed that if soil moisture is sufficiently high, decomposition rates were not strongly affected by site condition nor related to faunal density. Andre et al. (2009) also found soil moisture affected results from bait laminae, but Gongalsky et al. (2008) found temperature had a greater influence on perforation loss than soil moisture in a laboratory trial. It is assumed that microbial activity is responsible for decomposition of this bait type as reported by Gestel et al. (2003). Holly et al. (2011) showed that the microbial fauna under exotic grass differs in composition and activity to that under a native grass, resulting in faster decomposition under the exotics. These authors suggest that this is the mechanism by which invasive plants can alter an ecosystem process and Harris (2003) noted that composition of microbial fauna provides valuable information for restoring degraded land. In the local survey there was an indication that feeding on baits was greater under pines in the short term than on sites with native vegetation. As the baits consisted of exotic plant material, it is possible that they were more palatable to the microbial fauna there. Our data suggest that there are several draw backs to the use of bait lamina to measure decomposition rates and that soil moisture and rainfall must also be measured. Different types of baits should also be tested, as vegetation cover determines the amount of moisture reaching the soil and microbial populations differ under different vegetation types.

Soil temperatures were considerably higher in autumn during sampling of the landscape survey than during late-winter sampling of the local survey (Tabs 1, 2), which may account for the lower densities of Collembola found in winter (August/September). Also, moisture varied considerably between sites in the landscape survey and over time in the local survey as heavy rain fell before the fourth sampling date in the latter. However there was no evidence that either the temperature or moisture content of soils influenced the species composition of the Collembola collected. Greenslade (1986) showed that in southern South Australia the species active in autumn and spring are similar, while different faunas are active in winter and different again in summer.

The abundance of the genera *H/C* was assumed from previous data (King et al. 1986) to provide a measure of the integrity of remnants and of the trajectory of revegetated sites towards a native state. A strong positive relationship between exotic grasses and *H/C* species was found on the landscape scale sites while at local survey their relatively high abundance provided a measure of the poor quality of one of the remnants, which was not obvious from a study of the vegetation alone. This result is significant as indicators must provide information on impacts (treatments) not easily obtainable by other means. Unlike the landscape scale sites, remnants in the local survey were small and narrow with considerable edge effects. Significantly, hypogastrurid abundance here was lowest on the revegetated sites in the local survey, suggesting some ‘success’ of the revegetation.

Species richness and density of Collembola found here were similar to numbers found on other sites in Australia. Collembola densities in eucalypt forest are between 5,000 and 13,000 m^{-2} animals, but in improved pastures it may rise to 60,000 m^{-2} and numbers of species normally range from 20 to 60 per site depending on vegetation type (Greenslade 2007). Of the nine species considered characteristic for native sites on the small scale survey, six were also found to be characteristic for remnant sites in the landscape survey. This underpins the results from the ordinations, which suggests that the revegetated sites in the local survey were more similar to remnants than the revegetated sites were to remnants sampled in the landscape survey. The ordinations support this conclusion in particular in reinforcing the influence on exotic species in assessing success of revegetation efforts. In the local survey, the revegetated sites had been planted with a greater range of native trees and shrubs and a native *Poa* species had naturally colonised the ground layer. Our results emphasise the benefit of revegetating with more than just one or two species of tree and shrubs and including ground layer plants.

For more than a century Parks Victoria has been the principal overseer of biodiversity conservation in Victoria. They have a particular interest in the degree to which their reserves contribute to the broader matrix of natural habitat in the region and also in how their estate acts as a source of individuals and species that may colonise appropriately restored pieces of the landscape. Many smaller reserves play an important role in regional biodiversity conservation and our results here from reserves show that native biodiversity, in terms of Collembola species, is well represented in them.

Although these surveys were limited in scope, some management recommendations that are indicated reinforce the increasing view that, firstly, restoring habitat for invertebrate conservation cannot be achieved, even in the long term, if only trees are planted and, secondly, that controlling exotic weeds does not improve native invertebrate biodiversity values if there is no effort given to plant native ground-layer species. We suggest also that the width of revegetated strips at, on average, 10 to 20 m are too narrow and suffer from edge effects such as invasion of weedy species. In addition, because of the high acidity of the soil under pines, high populations of exotic acidophil species of Collembola can develop and native grasses and shrubs are excluded. It is recommended that pine plantations be phased out and replaced with native plant species that have added benefits in improving carbon storage.

5. Acknowledgements

We thank the Australian Research Council, Corangamite and Glenelg Hopkins Catchment Management Authorities, Parks Victoria and Central Highlands Water for funding. We are grateful to numerous land owners for access to their land; J. Groves and W. Cloke of the University of Ballarat assisted with field work and equipment respectively.

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Accepted 28 November 2011