

## Persistence of biodiversity in a dryland remnant within an intensified dairy farm landscape

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**Abstract:** The lowland Canterbury Plains of New Zealand have been extensively modified since human occupation, but with recent conversions to irrigated dairy farming very few remnants of native dryland vegetation remain in the region. We investigated soil chemistry, plant distribution and soil invertebrates along transects in Bankside Scientific Reserve, a small (2.6 ha) remnant. The vegetation is a mosaic of native woody shrubs, predominantly *Kunzea serotina* (kanuka, Myrtaceae) and *Discaria toumatou* (matagouri, Rhamnaceae), and dry grassland. Changed soil conditions appear to have made the reserve less conducive for native species, but better suited to invasion by exotic plants. Compared with detailed surveys before the dairy conversion, only 31% of the original 65 native vascular plant species were recorded in the present study and 27 new exotic species had arrived since the original survey. Soil nutrient concentrations and pH were lower in the reserve than in surrounding farmland; peaks of nitrate and ammonium were recorded at the boundary. Soil phosphate was elevated in lower-lying areas within the reserve, an effect associated with natural drainage channels and evident up to 20 m into the reserve. Four species of native megascolecid earthworms were found in the reserve but not in neighbouring pasture, whereas the diversity and abundance of beetles and spiders in the reserve was similar to that observed at least 10 m into surrounding farmland. This study highlights the importance of the soil environment in sustaining biodiversity. We conclude that this remnant retains valuable communities of native species, but is apparently being impacted by phosphate encroachment and habitat fragmentation. This does not appear to be an intractable management issue for the interface between agricultural systems and conservation sites within a dairy landscape mosaic. We suggest that attention is required to maintain buffer zones adjacent to small, isolated and vulnerable remnants of original biota that are surrounded by intensive agriculture.

**Keywords:** conservation; kanuka; *Kunzea*; nutrient enrichment; threatened species; earthworms

### Introduction

The conversion of natural ecosystems to agricultural land is one of the main causes of native biodiversity loss (Tilman et al. 2001). New Zealand is now the world's largest dairy exporter, with dairy products accounting for 60% of New Zealand's agricultural exports (Thorburn et al. 2012). There has been a significant conversion from dryland sheep farming to irrigated dairy farming in recent years, particularly on the Canterbury Plains of South Island. This province contains 20% of New Zealand's farmland, with an increase of 194 000 dairy cattle between 2011 and 2012 (Agriculture and the New Zealand Economy, 2014).

Lowland Canterbury has a temperate climate and moderate rainfall (c. 630 mm). Shallow, stony, well-drained soils are an important feature of the landscape (Molloy 1998). Drier areas, including the present study site, typically support tussock grassland (*Festuca novae-zelandiae*) and *Danthonia* grassland with a few species of woody shrubs (Ward et al. 1964; Molloy 1970). By the end of the 19th century, most of the Canterbury Plains had been ploughed and sown in crops or pasture (Winterbourn et al. 2008). The region has been described as the most modified and biologically depauperate lowland environment in New Zealand due to the prevalence

of agriculture (Brockerhoff et al. 2008); less than 0.5% of the original vegetation type remains within the Low Plains Ecological District (Ecroyd & Brockerhoff 2005) and this dry scrubland/grassland mosaic is now an acutely threatened land habitat (Walker et al. 2006; Head & Given 2001; Meurk 2008). Most of the natural remnants that exist are considered too small, fragmented and isolated to maintain the biodiversity that was once present (Meurk et al. 1995; Bretherton & Given, 2002; Meurk 2008). Extensive and rapid conversion to centre pivot spray irrigation and more intensive farm management systems has also raised environmental concerns about water use, fertiliser input, waste management and nitrogen and phosphorus enrichment of water bodies (Di & Cameron 2002; Houlbrooke et al. 2004; Clark et al. 2007; Ballantine & Davies-Colley 2013). There is now considerable interest in restoration of native biodiversity within this landscape (Meurk & Swaffield 2000). For example, the importance of invertebrates to ecosystem services in agricultural landscapes is becoming better appreciated, including their value in facilitating soil structure, functionality, pollination, biocontrol and seed dispersal (Keesing & Wratten 1998). However, the residual and continuing impact of adjacent agronomic practices on the few remaining remnants of the original dryland habitat in Canterbury is largely unknown.

The aims of the present study were to (i) identify the current conservation value of one of the few dryland reserves remaining on the lowland Canterbury Plains, (ii) assess the persistence of native biodiversity within this small (2.6 ha) nature reserve within an agricultural matrix, and (iii) evaluate the effects of the likely infringement of irrigation water and nutrients from adjacent farmland.

## Materials and methods

### Site description

Bankside Scientific Reserve (−43.730°S 172.156°E; 65–69 m asl.) consists of a 2.6-ha remnant of dryland vegetation and is one of only a few dryland reserves remaining on the lowland Canterbury Plains (Meurk et al. 1995). The original vegetation was probably subjected to burning by Māori for hundreds of years, then reseeded and fertilised by European settlers and subsequently sheep-grazed from the mid-19th century until recent decades. The Bankside site was designated a scientific reserve in 1969 and was purchased by the Crown in 1971 (Voice 1980; Williams 2005).

The reserve (Fig. 1) is adjoined by an unsealed road on the eastern side and otherwise is surrounded by irrigated dairy pasture. Soils in this region have developed on river floodplain gravel fans with undulating relief that includes stone and sand ridges, flat areas and depressions that represent abandoned stream channels (Voice 1980). The shallow Eyre soils are very

stony, nutrient poor, well-drained sandy loams that are prone to drought (Molloy 1970, 1998). The site supports a vegetation cover of dry grassland consisting of mixed assemblages of exotic and indigenous species interspersed with areas of xerophytic woody shrubs, mostly *Kunzea serotina* (kānuka, Myrtaceae) and *Discaria toumatou* (matagouri, Rhamnaceae). The flora of this site has been studied twice previously: Molloy (1970) provided a detailed catalogue of the flora, listing 66 native vascular plant species, and Jenson & Shanks (2005) completed a one-day reassessment of the site, but recorded only 14 native species. The adjacent dairy pasture is a ryegrass/white clover mix and is fertilised with sulphur superphosphate, urea, potash, lime, and cattle slurries.

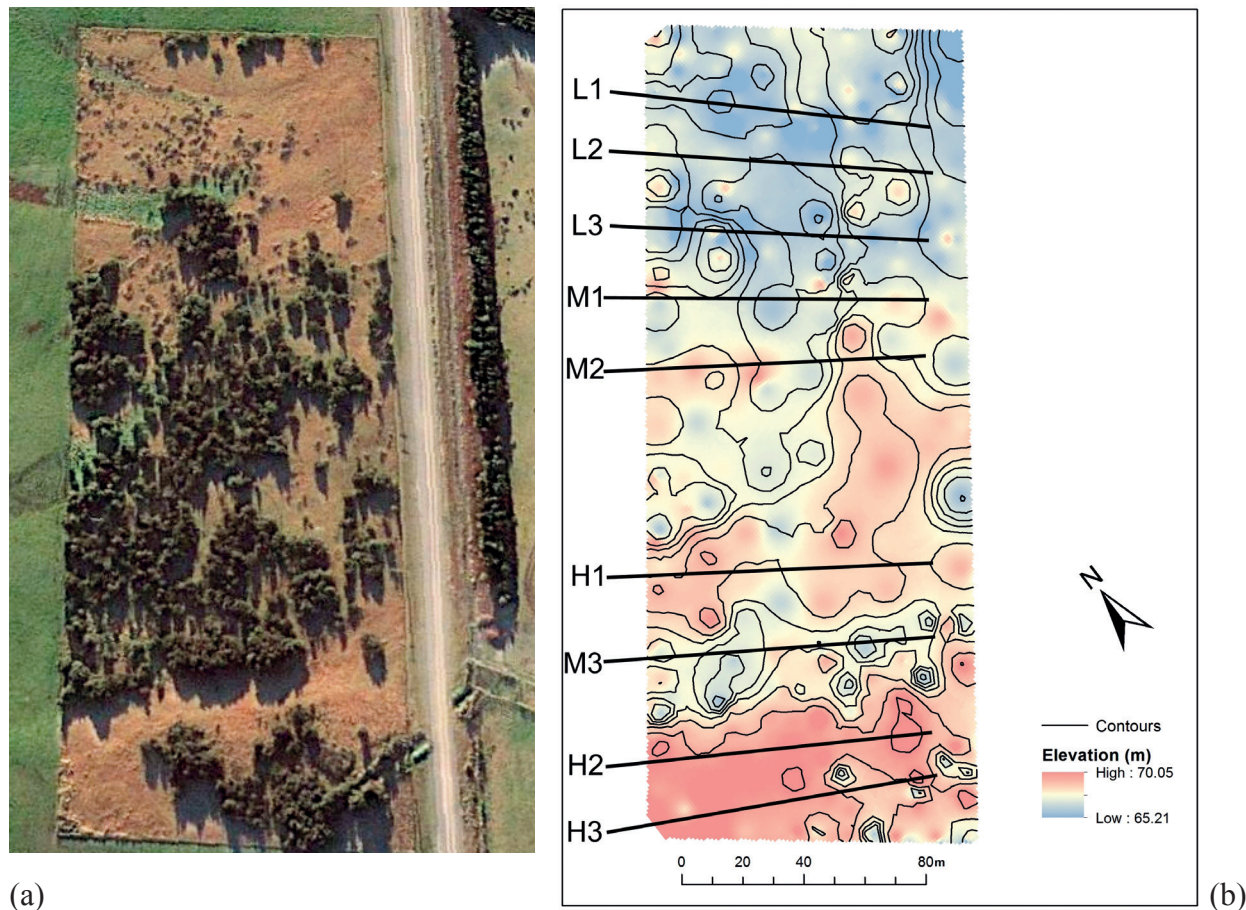
### Sampling transects

Nine transects extending from the pasture into the reserve were aligned to provide three transects each on land of three elevations: low-lying (mean altitude 65 m asl.), intermediate (67 m asl.) and higher (69 m asl.) (Fig. 1). Topography was measured at each sampling point using a Trimble Differential GPS. Along each of the nine transects, sampling points ranged from 10 m within the dairy paddock, then into the reserve at distances of 0, 2.5, 5, 10, 20, 40, 60, 80 m from the fence-line. Transects were 15 m or more apart.

### Soils and plants

Three soil cores (15 mm diameter × 10 cm depth) were extracted within 1 m<sup>2</sup> of each sampling point and bulked for

**Figure 1.** Aerial photograph of Bankside Scientific Reserve showing dominant kānuka, matagouri dotted at the north end and greener low-lying areas draining from pasture (a) and elevation map and location of sampling transects (b).



later chemical analysis. Using fresh soil, pH, KCl-extractable nitrate and ammonium, and Olsen P were analysed by Analytical Services in the Department of Soil and Physical Sciences at Lincoln University, using standard methodologies (see Blakemore et al. 1987).

The percent ground cover to 1 m in height was estimated using a 50 x 50 cm quadrat centred on each sampling point. A plant species inventory was recorded within a 5-m diameter of each sampling point in three height categories (<1 m, 1–2 m, >2 m). In addition to these plots, the whole reserve was surveyed to account for different species' phenologies and record as many plant species as possible over 15 days between April and December 2012, taking in excess of 100 person-hours. Plant species encountered by Molloy (1970) and Jenson and Shanks (2005) were compared with the current study to estimate changes in flora over time. The Jenson and Shanks (2005) plant survey corresponds to an eight person-hour search undertaken on 24th May 2005. Plant nomenclature follows that used by Molloy (1970), apart from where names are known to have changed.

### Invertebrates

Soil cubes (20 × 20 × 20 cm), including the vegetation and leaf litter, were dug with a spade at each sampling point and then carefully sorted on plastic sheets, separating all earthworms, beetles and spiders for later identification.

Earthworms were initially identified as exotic (Lumbricidae) or endemic (Megascolecidae) based on external morphology (Lee 1959) and then classified into different recognisable taxonomic units (RTUs) (Boyer & Wratten 2010). Tissue samples were collected from representatives of each RTU and molecular analyses conducted to obtain species names using a classical DNA barcoding approach (Boyer et al. 2011). DNA was extracted using the GF-1 tissue DNA extraction kit (Vivantis Technologies) following the manufacturer's recommendations. DNA amplification was performed using the GoTaq<sup>®</sup> Green Master Mix (Promega) following the protocol described by Lefort et al. (2012), using the universal COI primers of Folmer (1994). Each 10 µl PCR reaction contained 5 µl GoTaq<sup>®</sup> Green Master Mix, 0.5 µl of forward and reverse primers (10 µM), 1.5 µl of DNA template, and 3 µl of nuclease-free water. Many New Zealand earthworms have not been morphologically described, and only few species have been barcoded before (Boyer et al. 2011). Any megascolecid earthworm for which the DNA sequence had no match in Genbank and in our local library (Waterhouse et al. 2014) was considered an unknown endemic and was classified in a Molecular Taxonomic Unit (MOTU) grouping.

Beetles were identified to the level of family using May (1993) and family richness was calculated for each sample. We used beetle diversity as a simple metric for comparison of invertebrate biodiversity within and outside the reserve; use of higher taxonomic richness has been advocated as a valuable and rapid surrogate for biodiversity when specimens cannot be identified easily to species level (Balmford et al. 1996; Hodge & Frampton 2001). Spiders were identified using Paquin et al. (2010) and Vink (2002) and by comparison to specimens in the Lincoln University Entomology Research Museum. The only spider obtained in numbers suitable for subsequent statistical analysis was the native wolf spider *Anoteropsis hilaris*.

### Statistical Analyses

Data were analysed using Genstat v14 software, with most

response variables being analysed by nested ANOVA, with the primary explanatory factors defined as ground elevation and sample location ('inside' or 'outside') the reserve. None of the response variables exhibited clear linear relationships, or standard non-linear relationships, with distance from the fence-line. Therefore, distance into the reserve was treated as a categorical explanatory factor, nested within sample location.

Soil nutrient measurements, exotic earthworm abundance, beetle abundance and beetle diversity were transformed as  $\log_{10}(x + 1)$  to help meet the requirements of the analysis, such as normality of residuals and homogeneity of variances. Similarly, species richness and ground cover of native and exotic plants in each quadrat were transformed as  $\log_{10}(x + 1)$ . The data for native earthworms and native shrubs were dominated by zero counts and were therefore transformed to binary presence/absence data and analysed using generalised linear models.

## Results

### Soil properties

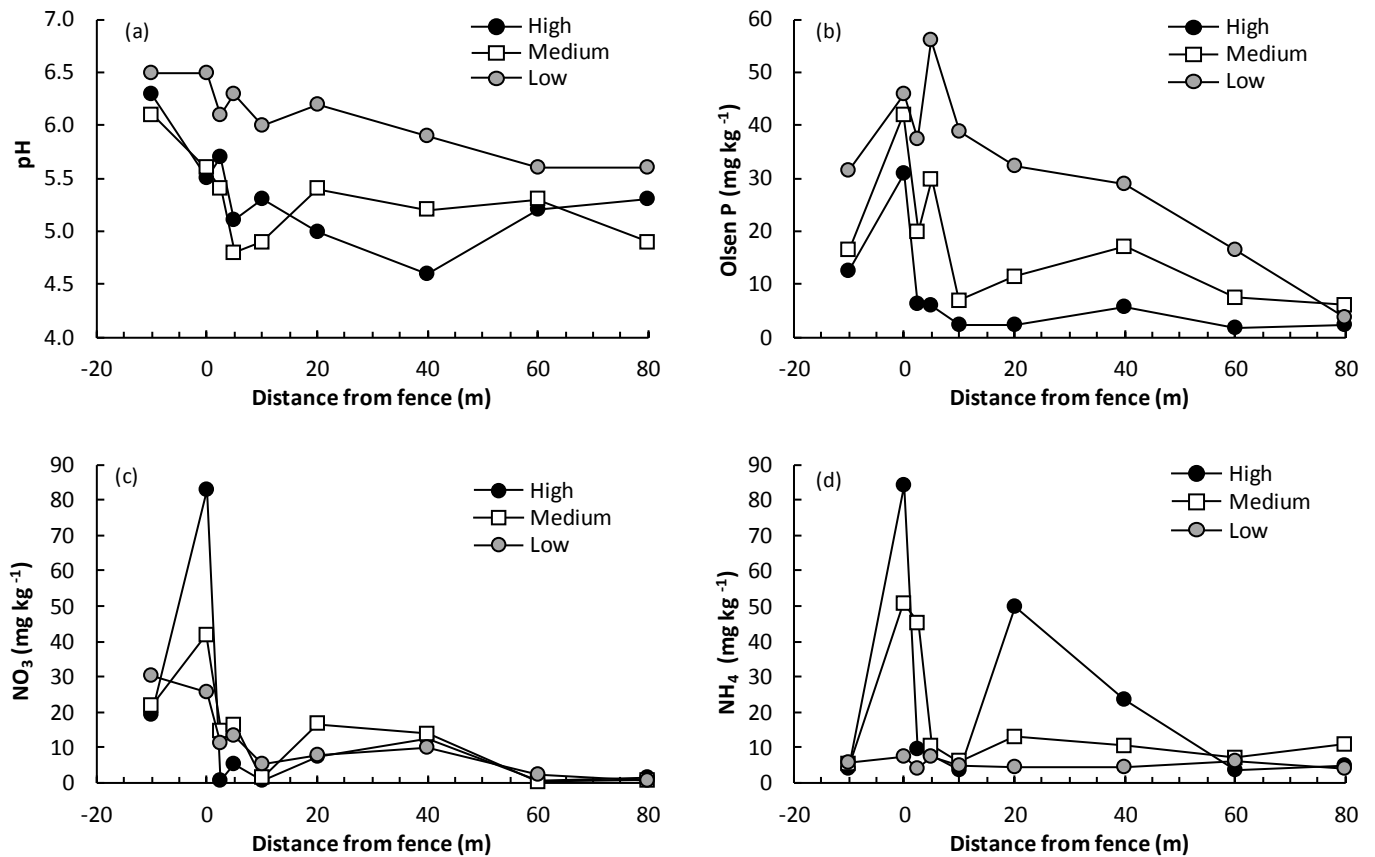
The pH of the soil samples ranged between 4.30 and 6.91, and pH was significantly lower within the reserve (mean  $5.4 \pm 0.6$  SD) than in the pasture paddock (mean  $6.1 \pm 0.5$  SD) ( $F_{1,54} = 27.47$ ;  $P < 0.001$ ). Soils in the lower-lying transects tended to be less acidic than those in higher levels (Fig. 2A,  $F_{2,54} = 22.47$ ;  $P < 0.001$ ).

Mean soil phosphate concentrations (Fig. 2B) were much higher in soil samples taken outside the reserve ( $F_{1,54} = 15.79$ ;  $P < 0.001$ ), with concentrations decreasing with distance from the fence-line, and with the lower-lying transects containing the highest values of the three elevations ( $F_{2,54} = 14.18$ ;  $P < 0.001$ ).

Extractable nitrate concentrations (Fig. 2C) were considerably higher in the pasture ( $F_{1,54} = 44.20$ ;  $P < 0.001$ ), decreasing in the reserve with distance from the fence-line ( $F_{7,54} = 2.31$ ;  $P = 0.039$ ), but neither nitrate nor ammonium (Fig. 2D) were affected by the ground level of transects ( $F_{2,54} = 1.39$ ;  $P = 0.257$  and  $F_{2,54} = 2.38$ ;  $P < 0.102$ ).

### Plant diversity

The dairy pasture was dominated by the exotic grass *Lolium perenne*, with some *Agrostis capillaris* and clover (*Trifolium repens*), and no native species apart from small patches of the mosses *Hypnum cupressiforme* and *Breutelia pendula* (Table 1). Only 31% of the native vascular plant species recorded in 1970 were found again in our surveys. More than half of the exotics originally recorded were found again, but 27 new exotic species were observed in the current surveys (Table 1). Four mosses *Breutelia pendula*, *Hypnum cupressiforme*, *Racomitrium pruinosum* (or *R. lanuginosum*) and *R. ptycophyllum* and two lichens, *Cladina aggregata* and *C. confusa* were also recorded. Percentage cover of exotic species was high in the reserve (Fig. 3), primarily due to the exotic grass *Anthoxanthum odoratum*. Beyond the first 10 m into the reserve, no statistically significant trends of species richness were found along transects ( $F_{7,54} = 1.13$ ;  $P = 0.360$ ). There is an obvious buffer zone (0–20 m wide) between the paddock and reserve. Ground elevation did not affect native species richness ( $F_{2,54} = 1.07$ ;  $P = 0.351$ ) and percentage ground cover ( $F_{2,54} = 1.65$ ;  $P > 0.202$ ). However, exotic species richness ( $F_{2,54} = 5.53$ ;  $P = 0.007$ ) and percentage ground cover



**Figure 2.** Soil properties along transects from an adjacent dairy pasture (−10m) into Bankside Scientific Reserve, at varying distances from the fence-line of a neighbouring dairy farm (0 m) and in the higher, intermediate and lower elevation transects for (a) pH, (b) Olsen P, (c) nitrate NO<sub>3</sub>, (d) ammonium NH<sub>4</sub>. (mean; n = 3).

**Table 1.** Number of plants recorded in the three botanical surveys (1970–2013) of Bankside Scientific Reserve.

|                          | Year of survey |      |      | Apparent number (and %) remaining from 1970 in the two later surveys |
|--------------------------|----------------|------|------|--|
|                          | 1970           | 2005 | 2013 |  |
| <b>Indigenous plants</b> |                |      |      |  |
| No. of families          | 30             | 11   | 10   | 13 (43%)   |
| No. of species           | 65             | 13   | 13   | 20 (31%)   |
| <b>Adventive plants</b>  |                |      |      |  |
| No. of families          | 20             | 13   | 9    | 10 (50%) <sup>b</sup>  |
| No. of species           | 36             | 39   | 20   | 20 (56%) <sup>a</sup>  |
| <b>Moss &amp; Lichen</b> |                |      |      |  |
| No. of species           | 48             | -    | 6    | 6 (13%)  |

<sup>a</sup>27 species (<sup>b</sup>7 families) of exotic plants were recorded in the latter two surveys that were not recorded in the 1970 survey. Species and family listings are provided in Supplementary Information.

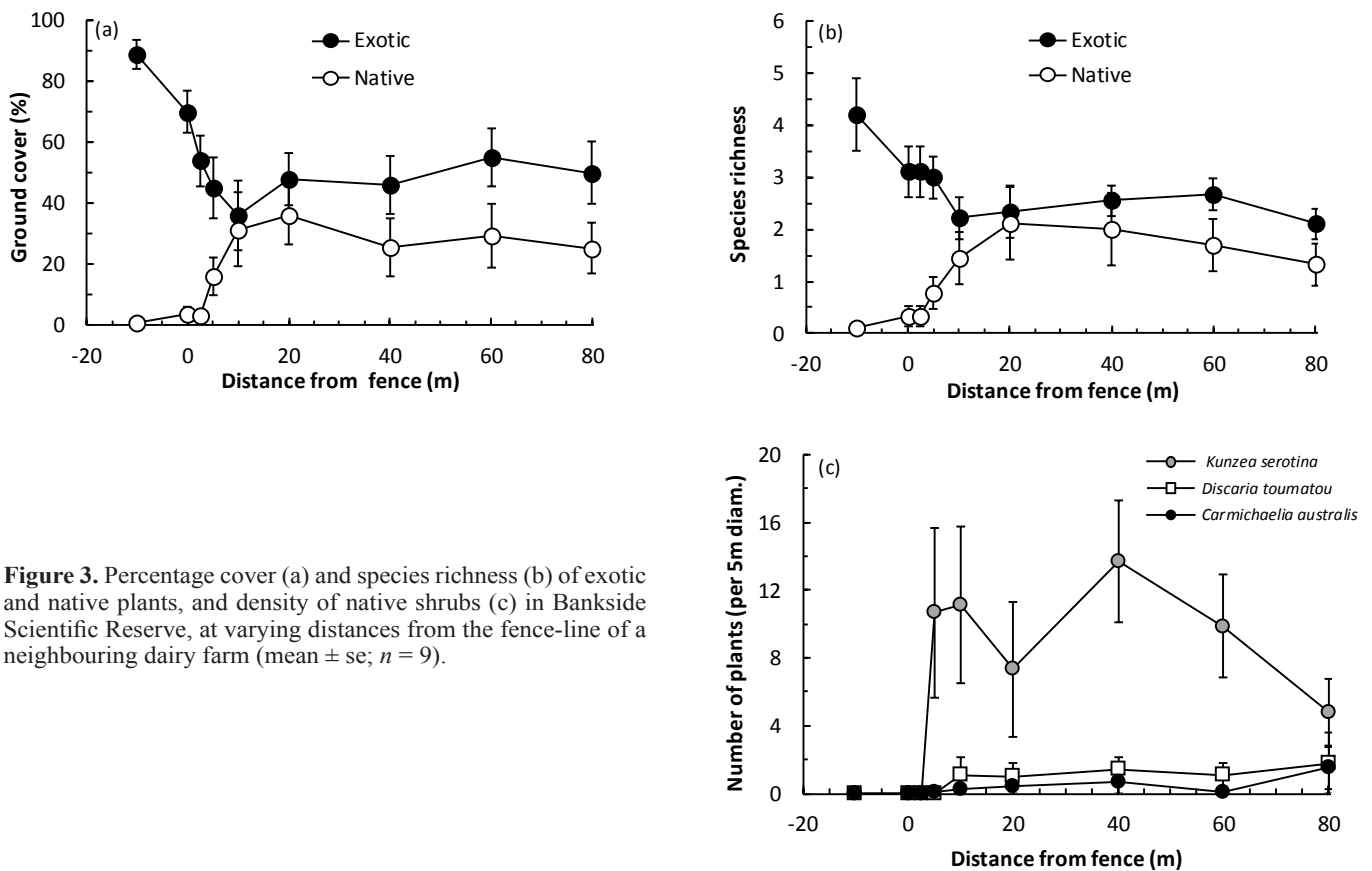
( $F_{2,54} = 5.64$ ;  $P = 0.006$ ) were significantly higher in the lower elevation transects.

Of the three common native shrubs in the reserve, kānuka was by far the most abundant (Fig. 3), and was even present just inside the fence-line. Indigenous broom (*Carmichaelia australis*) was not affected by ground level (GLM deviance ratio, DR = 1.77; d.f. = 2;  $P = 0.78$ ), whereas matagouri showed a tendency to occur in the lower ground transects (DR = 4.36; d.f. = 2;  $P = 0.013$ ) and kānuka was most commonly found in the middle and high ground and avoided the lower areas (DR = 7.68; d.f. = 2;  $P < 0.001$ ). This absence of kānuka from the

lower levels of the reserve can be clearly seen in the aerial photograph (Fig. 1).

**Earthworms**

Ten species of earthworms were recorded in the current study, including six exotic lumbricid species (Table 2). A number of incomplete worms were also collected but could not be identified. By far the most abundant species was the exotic *Aporrectodea caliginosa*, which accounted for 386 (70%) of all specimens collected. Exotic earthworms were affected by distance from the fence-line, being most abundant close to the



**Figure 3.** Percentage cover (a) and species richness (b) of exotic and native plants, and density of native shrubs (c) in Bankside Scientific Reserve, at varying distances from the fence-line of a neighbouring dairy farm (mean ± se; n = 9).

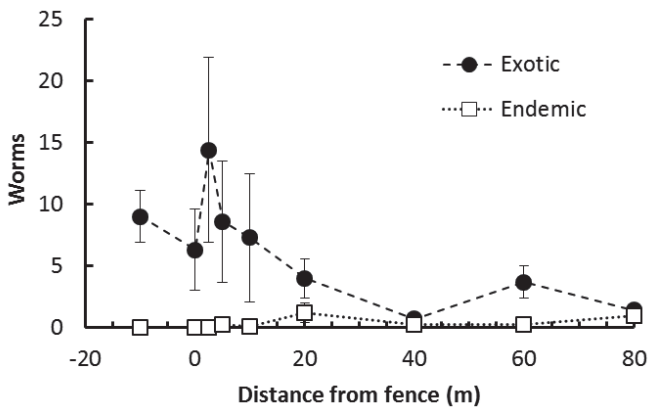
**Table 2.** Distribution of earthworms in Bankside Scientific Reserve in relation to proximity to the fence-line of a neighbouring dairy farm. Values are total counts in nine 20cm<sup>3</sup> soil samples. All Megascolecidae were genetically close to known endemic species (less than 3% difference based on COI primers) and were therefore classified as endemic earthworms and given a Molecular Taxonomic Unit (MOTU) code. A number of incomplete worms were also collected but could not be identified and were classified as ‘Unidentified’. The bottom row indicates species richness at distances from fence-line.

|                            |                                 | Distance from fence-line (m) |    |     |    |    |    |    |    |    |       |
|----------------------------|---------------------------------|------------------------------|----|-----|----|----|----|----|----|----|-------|
| Species                    |                                 | -10                          | 0  | 2.5 | 5  | 10 | 20 | 40 | 60 | 80 | Total |
| Exotic<br>(Lumbricidae)    | <i>Aporrectodea caliginosa</i>  | 59                           | 52 | 96  | 60 | 54 | 31 | 4  | 21 | 9  | 386   |
|                            | <i>Aporrectodea rosea</i>       | -                            | -  | -   | 1  | -  | 3  | 1  | -  | -  | 5     |
|                            | <i>Aporrectodea trapezoides</i> | 21                           | 1  | 11  | -  | 3  | -  | 1  | 6  | 1  | 44    |
|                            | <i>Dendrobaena octaedra</i>     | -                            | -  | 8   | 4  | 6  | -  | -  | -  | 1  | 5     |
|                            | <i>Lumbricus rubellus</i>       | 1                            | 4  | 11  | 10 | 3  | 2  | -  | 5  | 2  | 38    |
|                            | Unidentified Lumbricidae        | -                            | -  | 4   | 2  | -  | -  | -  | 1  | -  | 7     |
| Native<br>(Megascolecidae) | MOTU 1                          | -                            | -  | -   | -  | -  | 7  | -  | -  | -  | 7     |
|                            | MOTU 2                          | -                            | -  | -   | -  | -  | -  | 1  | -  | -  | 1     |
|                            | MOTU 3                          | -                            | -  | -   | 2  | 1  | 4  | 1  | 2  | 4  | 14    |
|                            | MOTU 4                          | -                            | -  | -   | -  | -  | -  | -  | -  | 5  | 5     |
|                            | Unidentified Megascolecidae     | -                            | 1  | 5   | 2  | 3  | 3  | 4  | 4  | 5  | 27    |
| Species richness           |                                 | 3                            | 4  | 6   | 7  | 6  | 6  | 6  | 6  | 7  |       |

fence-line with numbers decreasing further into the reserve ( $F_{7, 54} = 2.28$ ;  $P = 0.042$ ) (Fig. 4). Exotic earthworms were also significantly more abundant in the lower-lying ground areas compared to the middle and high ground ( $F_{2, 54} = 12.19$ ;  $P < 0.001$ ).

Only 26 individuals belonging to four native megascolecid earthworm species were recorded, and three of these species were each only observed in a single sample from the 81 soil samples. The data for the native earthworms were dominated

by zero counts, but the specimens were all found within the confines of the reserve ( $DR = 4.57$  for 1 d.f.;  $P = 0.037$ ) (Table 2). There was some indication that the presence of native species may be affected by ground level, being relatively infrequent in the low-lying ground ( $DR = 3.00$  for 2 d.f.;  $P = 0.058$ ). Overall earthworm species richness exhibited a positive relationship with distance from the fence-line, due to the combination of native and the more ubiquitous exotic species (Table 2).



**Figure 4.** Abundance of exotic and native earthworms in Bankside Scientific Reserve at varying distances from the fence-line of a neighbouring dairy farm (mean  $\pm$  se;  $n = 9$ )

**Ground invertebrates**

Overall, 112 specimens (mostly larvae) of Coleoptera were recorded belonging to six families: Carabidae, Chrysomelidae, Curculionidae, Elateridae, Scarabaeidae, and Staphylinidae. There were no significant relationships between Coleoptera abundance or taxonomic richness with ground level or location within the reserve (Table 3;  $P > 0.14$  in all cases). Three spider species were identified from the soil in the reserve: the golden brown jumping spider (*Trite auricomus*), the trap door spider (*Cantuarina dendyi*), and the native wolf spider (*Anoteropsis hilaris*), the last being the only species recorded in sufficient numbers to statistically analyse (30 specimens collected). The presence of this species was significantly affected by ground level, with no specimens recorded in low-lying transects (DR = 7.86 for 2 d.f.;  $P < 0.001$ ); however, there was no indication its occurrence was greater either within the reserve or the pasture (Table 3; DR = 0.74 for 1 d.f.;  $P = 0.391$ ). A single

immature specimen of ground wētā (*Hemiandrus* sp.) was also collected, but was too small to identify to species level.

**Discussion**

**Soil properties**

Prior to land clearance and conversion to agriculture, the shallow, well-drained and stony soils would have been of an acidic and low nutrient status. (McClaren & Cameron 1996; Molloy 1998), with pH probably c. 4.5, as seen in the higher elevations within the reserve. Typically, this had been raised to 6.3 in the farmed paddock through liming, and this has clearly impacted on the lower-lying areas of the reserve (Fig. 2A). This suggests a buffering effect through transport of solutes in drainage water, rather than from windblown fertilisers or other particulates.

Elevated soil nutrients at the fence-line, compared with 10 m into the pasture, were possibly due to cattle walking, excreting and defecating along the fence-line. Clearly there was marked transfer of phosphorus into the reserve (Fig. 2B). Phosphorus would normally be transported with eroded and mobile soil particles unless applied as soluble superphosphate formulations. Combinations of recycled slurries and superphosphate are common in New Zealand dairy systems. In agricultural terms, Olsen P concentrations measured in the reserve (0.65–67.5 mg kg<sup>-1</sup>) would suggest a fertile soil in all low elevation samples, except at 80 m. All medium elevation sampling points also clearly had elevated phosphorus fertility. Olsen P values of 20–30 mg l<sup>-1</sup> are the normal range for medium levels of fertility in agricultural soils in Canterbury (McDowell et al. 2002; Condrón & McDowell 2003). Mean concentrations only fell below this range from the sampling point 10 m into the reserve, gradually declining to 8.5 mg l<sup>-1</sup> at 80 m. However, individual soil samples (potentially representing hotspots) were found with Olsen P above 30 mg l<sup>-1</sup> at all distances into the reserve, apart from 80 m.

**Table 3.** Abundance of beetles (Coleoptera) and spiders (Araneae) collected in soil samples in Bankside Scientific Reserve in relation to distance from the fence-line.

| Family or species          | Distance from fence-line into reserve (m) |    |     |    |    |    |    |    |    | Total |
|----------------------------|---|----|-----|----|----|----|----|----|----|-------|
|                            | -10                                       | 0  | 2.5 | 5  | 10 | 20 | 40 | 60 | 80 |       |
| <b>BEEPLES</b>             |   |    |     |    |    |    |    |    |    |       |
| Staphylinidae              | -   | 1  | 5   | -  | 2  | -  | -  | 2  | -  | 10    |
| Carabidae <sup>1</sup>     | 3   | 1  | 4   | -  | -  | 1  | -  | 1  | 1  | 11    |
| Curculionidae <sup>2</sup> | 26  | 3  | -   | -  | 1  | -  | -  | 3  | -  | 33    |
| Elateridae <sup>3</sup>    | -   | 5  | 6   | 1  | 1  | -  | 3  | 10 | 1  | 27    |
| Chrysomelidae <sup>4</sup> | -   | 1  | -   | 5  | -  | 1  | -  | -  | 7  | 14    |
| Scarabidae <sup>5</sup>    | 4   | 1  | 4   | 1  | 2  | -  | 3  | 2  | -  | 17    |
| Total (beetles)            | 33  | 12 | 22  | 10 | 6  | 4  | 9  | 20 | 14 | 130   |
| Taxa (beetles)             | 3   | 6  | 5   | 4  | 4  | 3  | 3  | 6  | 4  |       |
| <b>SPIDERS</b>             |   |    |     |    |    |    |    |    |    |       |
| <i>Anoteropsis hilaris</i> | -   | 9  | 13  | -  | -  | 3  | 1  | 2  | 2  | 30    |
| Other spiders              | -   | 7  | 1   | -  | 1  | -  | 1  | 2  | 2  | 14    |

Main species identified from each family

<sup>1</sup>*Anisodactylus binotatus*, *Haplanister crypticus*

<sup>2</sup>*Listroderes delaigueti* or *L. bonariensis*

<sup>3</sup>Pyrophorinae indet.

<sup>4</sup>*Atrichatus aeneicollis*

<sup>5</sup>*Costelytra zealandica*

Differences between ground elevations would suggest this did not represent spray drift from phosphate fertiliser application. However, fertiliser granules (lime and/or superphosphate) were often found 20 m from the boundary in the top turf portion of soil samples collected for earthworm analysis, and are likely to be responsible for the gradual increase of pH towards the fence-line (Fig. 2A). Spreading of lime or superphosphate usually involves a cloud of fertiliser dust moving with the prevailing wind.

A somewhat surprising result was that there was no difference in nitrate or ammonium with ground level despite the apparent flow of water from the dairy paddock through the depressions that function as water channels into the reserve during wetter parts of the year (Fig. 2C, D). Aerial photographs showing the greening of the grasses in these areas indicate that occasional surface water flow occurs in these channels (Fig. 1). Nitrate ( $\text{NO}_3^-$ ) is the most soluble form of this element and might be expected to be most transferable to the reserve through lateral surface water flow. Downward movement of  $\text{NO}_3^-$  through this well-drained Eyre soil is also highly likely. A large proportion of the nitrogen will have been applied to the adjacent paddock directly from animals or indirectly through slurries; nitrification of  $\text{NH}_4$  from this source might be expected to result in increased concentration of  $\text{NO}_3^-$ . Disappearance rates through bacterial denitrification are normally associated with anoxic environments, which would be expected to occur only during short periods of winter waterlogging. While this may provide a partial explanation for lack of elevated nitrate in reserve soils, another explanation may be soil sampling during the summer in the present study. This was well after the main pasture growth period and there had been little recent transport of drainage water and nitrate from the paddocks. Soils were very dry and sufficient time may have passed for  $\text{NH}_4$  to have volatilised or to have been nitrified, and for  $\text{NO}_3^-$  to have leached from soils. Eyre soils are known to be vulnerable to high nitrogen leaching, and nitrogen retention in soils is related to particulate organic matter and coarse roots (Di & Cameron 2002; Franklin 2014), both of which are low in these sandy and gravelly soils. Changed soil conditions appear to have made the reserve less favourable for native species but better suited to invasion by exotic plants.

### Plant diversity

Only a third of the native vascular plants and 20% of the moss and lichen species recorded by Molloy (1970) were found in the current study and the one by Jensen & Shanks (2005). Native Asteraceae were particularly vulnerable, with none of the 14 original species found. In contrast, three of the 11 original adventive Asteraceae species were found in our study and we recorded six new species. Overall, the conditions present in the reserve appear to favour colonisation by exotic species.

The two most resilient indigenous species are kānuka and matagouri. Of these, the kānuka would be the most influential in terms of shading the grass and weedy species to encourage other native species to colonise. Unfortunately, the patchiness of kānuka, particularly at the northern end of the reserve, means that exotic grasses and weeds dominate over the less competitive indigenous species.

Our main vegetation sampling was restricted to the midsummer period, but was combined with significant searches at other times. Only 13 of the original 65 indigenous plant species identified by Molloy (1970) were found again, seven of which were also recorded by Jensen & Shanks (2005) (Table 1 and Tables S1–S3 in online supplementary material).

Combining records from the May sampling by experienced botanists (Jenson & Shanks 2005) with the current study, a total of 20 species identified by Molloy (31%) were found again in more recent years. Three new indigenous species were recorded in the two most recent surveys (a likely *Coprosma petriei* hybrid, *Juncus edgariae*, and *Pteridium aquilinum* var. *esculentum*). The combination of native plant diversity losses and exotic invaders, as well as a few new native species, represents what is termed by Knox & O'Connor (2008) as a 'novel or emerging ecosystem' and in dire need of conservation. Bankside Scientific Reserve is one of just a few drylands remaining on the Canterbury Plains of which <60 ha (0.5%) is protected and in need of targeted, innovative programmes to manage these emerging ecosystems so that native species within can survive, if not dominate (Pawson & Holland 2008).

The last 20 years have seen substantial restoration planting in this type of landscape (Hahner et al. 2014; Dickinson et al. 2014), and field margins with gorse hedgerows and riparian stands of willows are progressively being replaced with native plants (Price 1993; Washington 2002). Native hedgerows contain high native invertebrate biodiversity (Fukuda et al. 2011) and may also provide ecological corridors to and from natural remnants. A study on agrichemicals on field margins by Schmidt et al. (2014) concluded that prolonged use of fertilisers and pesticides caused significantly reduced species diversity, particularly in smaller and subordinate species, which were outcompeted by taller grass species. They found the impacts of these agrichemicals became stronger over time and led to changes in plant community composition.

### Earthworms

The persistence of native earthworms in a small isolated reserve is notable, in view of their rarity in New Zealand agricultural landscapes. The introduction of exotic grassland and crops, and the disturbance related to burning and ploughing are assumed to be the main causes of their demise (Lee 1961). However, little is known about co-existence or competition between endemic and exotic earthworms in New Zealand, nor of the capacity of exotic earthworms to colonise soils under native habitats. In this study, native species were never observed in the pasture although exotics had infiltrated the reserve, particularly in lower-lying ground. It would appear this is related to changed hydrology and soil chemistry; in wetter and more fertile soils, lumbricids are able to colonise and survive. It is not known whether exclusion of native species is related to competition from exotics or avoidance of modified soils. Although a relatively small number of native earthworms were recorded, they were present in areas least favourable for exotic earthworms, well within the reserve and on higher drier ground.

### Ground invertebrates

We found no indication that beetles and spiders were more abundant or diverse within the reserve. This may be due to the patchiness of the plants and the variable stony nature of the soil throughout the reserve. However, it may reflect insufficient sampling, especially in the number of specimens per sample unit (see Leather et al. 2014). Most of the taxa collected, such as *Anoteropsis hilaris* and the elaterid beetles, are typical of crop and pasture land in Canterbury (e.g. Sivasubramaniam et al. 1997; Bowie et al. 2003, 2014) and their presence in the reserve may be an artefact of their general abundance in the area.

### Conservation value of the nature reserve

Protection of the few remaining dryland ecosystems in Canterbury is critical for both the rare plants and native fauna reliant on this habitat. Several plant species listed by Molloy (1970) at Bankside are listed as 'At risk–Declining' (Townsend et al. 2008); these include *Pterostylis tristis*, *Muehlenbeckia ephedroides* and *Geranium sessiliflorum*. Of these, only *G. sessiliflorum* could be found there today, which highlights the need to conserve this and the few other remaining Canterbury Plains dryland remnants.

The Bankside Scientific Reserve provides above-ground habitat for a significant number of endemic insect species (Butcher et al. 1980; Emberson et al. 2011). Several interesting conservation finds in the reserve include the ground wētā (*Hemiandrus* sp.) and trap door spider (*C. dندی*). A recent survey by Emberson et al. (2011) also found the large rare Staphylinidae *Hadrotus wakefieldi* and several species of long-horn beetles (Cerambycidae), making this small reserve a significant remnant in terms of conserving indigenous invertebrates found in these rare dryland ecosystems (Emberson et al. 2011).

The majority of native earthworms sampled were immature and unsuitable for identification to species level based on morphological features. DNA barcoding revealed there were four native species, but these were not recognisable from existing databases. Finding new species is not unusual in New Zealand and adds weight to conservationists' fears that species could be lost before we know of their existence (Brockerhoff et al. 2008). Although not part of this study, skinks (*Leiopisma* sp.) noted by Molloy (1970), were still present and represent an important endemic component of this habitat.

### Recommendations for management of Bankside Scientific Reserve

Surrounded by farmland, Bankside Scientific Reserve is isolated from other remnants and has limited opportunity for import or export of native plant propagules by birds or wind. This lack of connectivity in the landscape is evidenced by the reduced number of native plant species since the first survey of the site. The formation of a bund wall would provide a barrier against drainage water and nutrient transfer, although a bund created by the neighbouring farmer attracted stock to the fence-line and was soon trampled to the same level as the paddock. Therefore, any bund between farmland and the reserve should be fenced (Hahner et al. 2014). Our findings suggest that a buffer zone would be of value around native vegetation remnants adjacent to dairy farms, and this should be at least 10–20 m wide to reduce the input of irrigation water and nutrients (effluent, urea, lime and superphosphate). Applying fertilisers only during periods with favourable winds, and planting buffer zones around remnants with native species would also be likely to help conserve the native plants and invertebrates within (Aarons & Gourley 2012).

Although we did not investigate the impact of exotic mammals at the site, some control of the pests observed at Bankside, such as hares (*Lepus europaeus*) and hedgehogs (*Erinaceus europaeus occidentalis*), should also be carried out to protect native flora and fauna such as wētā, earthworms, beetles and skinks. Similarly, continued control of woody weed species, such as gorse (*Ulex europaeus*) and European broom (*Cytisus scoparius*), would likely improve conditions for native plant species.

### Conclusions

Although the Bankside Scientific Reserve has lost most of the native plant community, it has conservation value for remnant populations of rare endemic earthworms and other invertebrates. The study highlights the importance of soil chemistry in sustaining native plant and invertebrate biodiversity; modification of soils adjacent to dairy farming systems has a clear impact on native plants and animals, while apparently also creating conditions more suited to invasive exotic species. Lime and phosphate fertilisers may represent the main threats to dryland nature reserves in irrigated dairy landscapes. There is no evidence of an influence of nitrogen in the present study, although increased nitrate mobility would be expected during winter and following wet periods. Although elevational differences between highest and lowest contours were <5 m in the present study, the higher areas are immensely significant in avoiding environmental modification from agricultural drainage and effluents, maintaining environmental conditions that most closely resemble the original habitat, and thus providing the most appropriate habitat for native plants and animals.

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## Supplementary Material

Additional supporting information may be found in the online version of this article:

**Table S1.** Native species of vascular plants recorded in the three surveys in Bankside Scientific Reserve.

**Table S2.** Adventive species of vascular plants recorded in the three surveys in Bankside Scientific Reserve.

**Table S3.** Moss and Lichen species recorded in the two surveys in Bankside Scientific Reserve.

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