Notornis, 2007, Vol. 54: 65-70

South Island robin (*Petroica australis australis*) abundance and leaf-litter invertebrates in plantation and native forest

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Abstract We investigated whether the abundance of the South Is robin (*Petroica australis australis*) could be explained by the abundance, species richness, diversity, or evenness of leaf-litter invertebrates. We recorded robin abundance indices and collected leaf-litter invertebrates in 3 forest types: mature Douglas fir (*Pseudotsuga menziesii*); mature Monterey pine (*Pinus radiata*); and old growth kanuka-manuka (*Kunzea ericoides - Leptospermum scoparium*). Robins were attracted to stations using 5-min playbacks of robin full song in each forest type. Invertebrates were extracted from leaf-litter samples using 'Tullgren-type' heat extraction funnels. There was no significant difference between the numbers of robins detected in the Douglas fir (1.14 5 min count^{-1}), or kanuka-manuka forest (0.86 5 min count^{-1}), and no robins were detected in the Monterey pine forest. Kanuka-manuka forest had the greatest biomass and species richness of leaf-litter invertebrates, but the lowest evenness. We believe that the abundance of the South Is robin can not be sufficiently explained by the density or directly of leaf-litter invertebrates.

Borkin, K.M; Goodman, A.J.; Mayhew, K.; Smith, E. 2007. South Island robin (*Petroica australis australis*) abundance and leaf-litter invertebrates in plantation and native forest. *Notornis 54(2)*: 65-70.

Keywords South Island robin; *Petroica australis australis*; exotic plantation forest; native forest; invertebrate biomass; invertebrate diversity

INTRODUCTION

Fossil evidence suggests that the New Zealand robin (*Petroica australis*) was present throughout lowland New Zealand until large-scale deforestation in Polynesian and European times (Worthy & Holdaway 2002). Now the South Is robin (*Petroica australis australis*) has a disjunct distribution (Bull *et al*. 1985). Although occasionally found in exotic plantations that are contiguous with native forest, the species is generally found now within native forest (Webb & Duncan 1998). On the east coast of the South I there appear to be only 2 remnant populations of the South Is robin (Heather & Robertson 1996). One of these populations is in the forested areas of the Silverstream catchment and the plantation forests of Flagstaff, northwest of Dunedin (referred to here as the Silverstream population, following Webb & Duncan (1998)).

The Silverstream population is distributed unevenly between forest types (Webb & Duncan 1998). Several surveys by Otago Region Ornithological Society of New Zealand have shown that more robins were present in mature Douglas fir (*Pseudotsuga menziesii*) plantations than in other forest types in the area, including forest dominated by kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*), or radiata (Monterey) pine (*Pinus radiata*) plantations (unpubl. data, Ornithological Society of New Zealand (Otago); Webb & Duncan 1998).

Received 8 July 2006; accepted 16 November 2006
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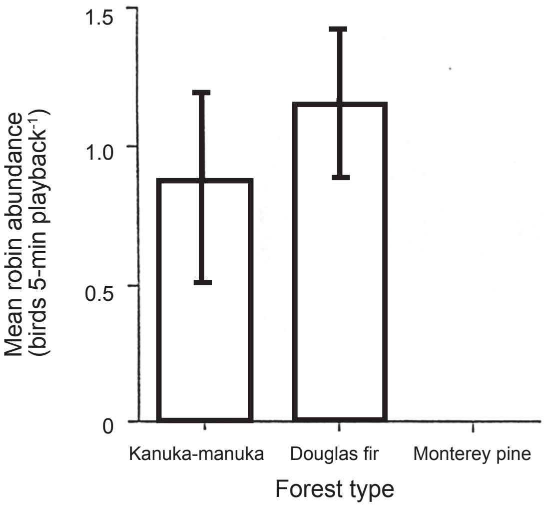

Fig 1. Mean abundance of South Is robins (5-min playback^{-1}; 95% confidence intervals) in early Apr 1998 in kanuka-manuka forest, Douglas fir plantation, and Monterey pine plantation .

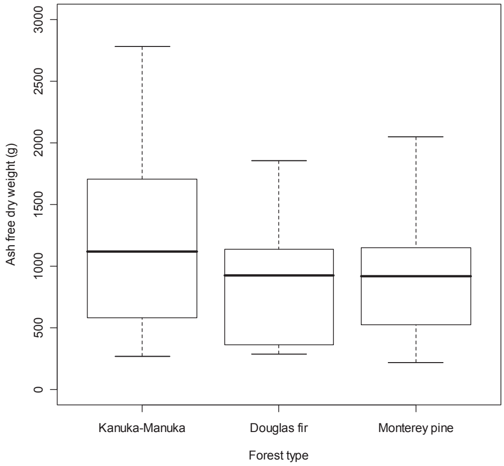

Fig 2. Biomass (mg m^{-2}) of leaf-litter invertebrates in the study area at Silverstream by forest type.

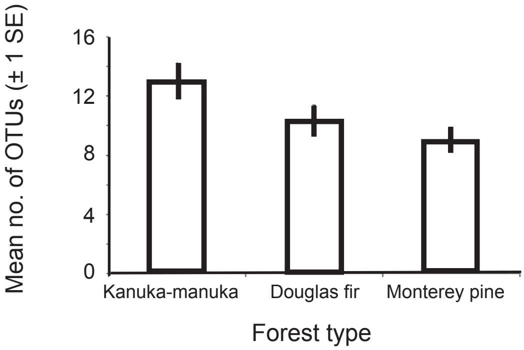

Fig 3. Leaf-litter species richness (number of OTUs in each plot) in the study area at Silverstream by forest type in Apr 1998.

Webb & Duncan (1998) identified 4 main factors that may influence the distribution of robins in the Silverstream area: social factors; predation pressure; food availability (specifically of leaf-litter invertebrates); and the availability of suitable foraging sites (open areas with apparently "high quality" leaf-litter). Our study aimed to examine the patchiness of the distribution of South Is robins in the Silverstream area; and their distribution in relation to parameters (leaf-litter invertebrate biomass, species richness, species evenness, diversity) of food availability.

METHODS

We investigated the distribution of robins and the abundance and diversity of leaf-litter invertebrates on 2-6 Apr 1998 in the native forests of the Silverstream catchment and the contiguous plantation forests of Flagstaff, northwest of Dunedin, South Island, New Zealand. This forest mosaic covers about 50 km^2 (Webb & Duncan 1998). The northern area is in old growth kanuka-manuka, whereas the southern area is a patchwork of exotic plantations dominated by varying aged stands of Monterey pine. Douglas fir, eucalyptus, and areas of clear fell cover the remaining areas under forestry practice.

Robin population indices

We recorded robin indices in 3 forest types: mature Douglas fir; mature Monterey pine; and old growth kanuka-manuka. Fieldwork was done between 0730 h and 1000 h on fine, still days. Robins were attracted to 10 randomly located sampling stations in each habitat type using 5-min playback of full robin song. Each station was sampled 5 times (once day^{-1}). We chose 5 min of playback because Webb & Duncan (1998) found that this duration of song attracted the most robins. Robins were counted after they had been identified by sight or their calls. Relative indices of robin numbers were calculated as number of robins detected 5-min playback^{-1}. An analysis of variance was used to examine robin indices.

Invertebrate analyses

Litter samples were taken at the same 10 randomly chosen sites as the robin counts, within each habitat type, again on 2-6 Apr 1998. A 500 mm × 500 mm quadrat was placed on the forest floor at each site, and all leaf-litter removed for the laboratory extraction of invertebrates. Leaf-litter samples were processed using 'Tullgren-type' heat extraction funnels using 150W light bulbs as the heat source. All invertebrates were measured (length) and grouped for convenience into operational taxonomic

Table 1 Shannon diversity indices and evenness of litter invertebrates in each forest type at the Silverstream study area in Apr 1998.

Forest type	Shannon index	*n*	OTUs	SE_{mean}	Evenness
Kanuka-manuka	2.1047 ± 0.0013	1412	36	0.0363	0.5873
Douglas fir	2.3732 ± 0.0018	800	32	0.0424	0.6848
Monterey pine	2.3361 ± 0.0022	512	26	0.0472	0.7170

Table 2 Comparisons (by Student's *t*) of Shannon diversity indices for litter invertebrates by forest type in Apr 1998 in the Silverstream study area.

Comparison	*t*	*df*	*P*
Kanuka-manuka v Douglas fir	4.81	1843	<0.0001
Kanuka-manuka v Monterey pine	3.88	1151	0.0001
Douglas fir v Monterey pine	0.59	1179	0.56

units (OTUs; see Appendix for list of abbreviations) rather than to individual taxa.

The dry weights of representatives of each OTU were measured, and these samples were then burned to obtain ash-free dry weights for each OTU. The ash-free dry weights (mg) were used as a measure of invertebrate biomass for each plot. Differences in total invertebrate biomass between habitat types were tested using ANOVA, and Kruskal-Wallis non-parametric ANOVA by ranks.

Species richness was defined as the number of OTUs within each plot. Species richness was tested using a General Linear Model and Kruskal-Wallis non-parametric ANOVA by ranks. Mean ranks were calculated to determine which habitat type had highest species richness.

Species diversity was represented by the Shannon Index, which takes into account species richness and evenness of the abundances of species (in this instance arbitrary operational taxonomic units OTUs; Magurran 1998). Evenness is constrained between 0 and 1; with 1 indicating that all species are equally abundant (Magurran 1998). Data from all 10 plots were pooled for this analysis, and differences were compared quantitatively using Student's *t*-tests, as in Magurran (1998).

RESULTS

There was a significant difference between the numbers of robins detected in the Douglas fir, Monterey pine, and kanuka-manuka forest ($F = 5.78$, $P = 0.012$). We detected the greatest numbers of robins in Douglas fir (mean = 1.14 5-min playback^{-1}). Kanuka-manuka forest had fewer robins (0.86 5-min playback^{-1}): no robins were detected in the Monterey pine plantation. Individual 95% confidence intervals for mean counts indicated that there was no significant difference between the numbers of robins detected within Douglas fir and kanuka-manuka forest (Fig. 1).

Although kanuka-manuka forest had the greatest biomass of leaf-litter invertebrates, there was no significant difference over all between the biomass in the 3 forest types (ANOVA: $F_{2, 27} = 1.01$, $P = 0.378$; Kruskal-Wallis $\chi^2 = 0.751$, $df = 2$, $P = 0.687$; Fig. 2)

There were significant differences in species richness between habitat types (i.e. mean number of OTUs in different forest types: $\chi^2_2 = 7.97$, $P = 0.018$; Kruskal-Wallis $\chi^2 = 8.6378$, $df = 2$, $P = 0.01331$). Greatest species richness was found in the kanuka-manuka forest (mean number of OTUs = 13.0), followed by Douglas fir (10.3), and Monterey pine (8.9; Fig. 3).

Invertebrate diversity, as measured by the Shannon Index (Table 1), differed significantly between kanuka-manuka forest and Douglas fir ($t = 4.81$; $P < 0.0001$; Table 2). Invertebrate diversity also differed significantly between Monterey pine plantation and kanuka-manuka forest ($t = 3.88$; $P = 0.0001$; Table 2). There was no significant difference between invertebrate diversity in Douglas fir and Monterey pine stands ($t = 0.59$; $P = 0.59$; Table 2).

The leaf-litter invertebrate samples from the kanuka-manuka forest were dominated by 3 OTUs which had very high numbers of individuals (dipt-lar-wr-br = 439; acari-blk = 364; dip-br-br = 251), which led to low evenness values (Table 1; Appendix 1). The invertebrate fauna in the kanuka-manuka forest had the lowest evenness (0.5873), in comparison to that in the Douglas fir (0.6848) or Monterey pine (0.7170) plantations.

DISCUSSION

The mean number of robins that we detected per count in each habitat type was similar to that detected by the Otago Branch of the Ornithological Society of New Zealand (unpubl. data) during their 23-month study of robins in this area. That survey detected, as we found, the greatest numbers of robins in Douglas fir plantations (3.4 robins km^{-1}) in the Silverstream-Flagstaff area, followed by native habitats (2.9 robins km^{-1}), and finally Monterey pine plantation (1.1 robins km^{-1}). Similarly Clout & Gaze (1984) found that in the Nelson region robins were common in relatively dense conifer stands, such as those of Douglas fir, but were rare or absent elsewhere.

Duncan *et al*'s. (1999) survey of South Island robins in the Silverstream catchment also found that the mean number of robins varied between habitats. As in our study, Duncan *et al.* (1999) found the greatest numbers of robins in Douglas fir (1.56 5-min $playback^{-1}$), followed by native forest (0.32 5-min $playback^{-1}$) , and Monterey pine (0.24 5-min $playback^{-1}$).

The small differences between our results and Duncan *et al.* (1999) may be explained by seasonal differences in robin distribution or density. Duncan *et al.* (1999) found higher numbers of robins in Monterey pine and Douglas fir plantations, and lower numbers in native forest than observed in our study. However, Duncan *et al.* (1999) surveyed robins over summer (Dec–Jan 1996), whereas our study took place in early autumn (Apr 1998).

We chose to measure only *leaf-litter* invertebrate biomass, species richness, and diversity as a measure of food availability. Powlesland (1981) showed that South Is robins in kanuka-dominated forest at Kaikoura spent 90% of their foraging time on, or within 2 m of, the ground, and that most (61.3%) of their foraging time was spent gleaning on the ground, so we believe that leaf-litter invertebrates provide most of the robin diet. This conclusion is reinforced by the low percentage of time robins at Kaikoura spent foraging above ground: vegetation gleaning (4.5%), hawking (0.3%), and fly-catching (0.1%) (Powlesland 1981).

Invertebrate biomass did not differ significantly between habitat types, so if robins are adaptable foragers, and will readily eat invertebrates (of the same energetic value as native leaf-litter invertebrates) in leaf-litter in exotic vegetation, we do not believe that invertebrate biomass will be a factor restricting robin distribution. Our results support those of Clout & Gaze (1984) who also suggest that conifer plantations are relatively good sources of invertebrate prey for this species.

Why should old-stand kanuka-manuka and Douglas fir plantation both be favourable habitat for South Island robin?

Webb & Duncan (1998) suggested that the distribution of South Island robins may be influenced by 4 main factors: social interactions; predation pressure; food availability (abundance of leaf-litter invertebrates); and the availability of suitable foraging sites (open areas with apparently "high quality" leaf-litter).

We found lower species richness of invertebrates in the Monterey pine plantation than in Douglas fir plantation or kanuka-manuka forest, which accords with Curry's (1991) suggestion that few local species of invertebrates are likely to be adapted to living in exotic plantations, that there is likely to be a paucity of flowering plants for nectivorous insects. On these premises, Curry (1991) believed that food for insectivores is probably restricted in plantation forests. If invertebrates important in robin diet are absent from Monterey pine plantations, or are in very low numbers there, robins may not be able to persist. We believe that more needs to be known about robin diet before the relative importance of these factors can be determined, especially because the species diversity of litter invertebrates was lower for native forest than in either the Monterey pine or the Douglas fir plantations. The greater ecological evenness, with no major groups dominating, of leaf-litter invertebrates within the Monterey pine plantation may have something to do with limiting the population of robins in pine plantations.

We found that some invertebrate OTUs that are abundant in kanuka-manuka associations are found in lower numbers in both Douglas fir and Monterey pine plantations (e.g., dip-br-br and acari-blk, Appendix 1) or are even absent there (e.g., dipt-lar-wr-br, Appendix 1). Other taxa, such as amphipods, were found in high numbers in Douglas fir plantations and in lower numbers elsewhere. Although amphipods have not been recorded as being eaten by robins, amphipods may be consumed if they were available rather than being hidden under leaf-litter (R. Powlesland, *pers. comm.* 2006). Amphipods are therefore one group of litter-dwelling invertebrates that may influence the distribution of South Is robin.

We believe that South Is robin abundance cannot be explained adequately by the abundance or species richness of leaf-litter invertebrates alone. Invertebrates that live in foliage and on tree trunks may play a more important role in robin diet than expected. If invertebrates in these situations are particularly important to robin diet, it may help explain robin distribution. However, in winter Powlesland (1981) found that South Is robins spent most of their foraging time in kanuka-dominated forest gleaning on the ground. The Douglas fir area we studied contained a high percentage of standing dead trees, and more often trees with rotting lateral branches (authors' pers. obs.). The greater percentage of rotting wood observed in the Douglas fir stands results from a lower frequency of pruning, as against the practice in Monterey pine plantations, as the trees are managed for applications such as structural timber for which.small knots formed by un-pruned branches are not important (Boyd 1983). Douglas fir also has a longer rotation time than pine plantations (Ministry of Forestry 1991). We infer that the rotting wood in the Douglas fir plantations may provide better habitat for a variety of invertebrates that are eaten by robins. The rough and stringy bark of kanuka is also well known as an important refugium for small invertebrates such as insect larvae and pupae (Henderson 1977; Powlesland 1981), which may be an important part of robin diet. These flightless stages of the insect life cycle may provide an additional and valuable food resource for South Island robins.

Robins favour structurally simple (monospecific) forest with dense and even canopies, and extensive areas of ground covered by leaf litter (Clout & Gaze 1984). This is matched most closely by the old-stand kanuka-manuka and Douglas fir areas we surveyed, which had relatively few plants in the understorey and contained the most robins. In comparison, the understorey of the Monterey pine plantation, where no robins were detected, was fairly well developed. An earlier study of this Otago robin population showed that there were fewer robins in Monterey pine plantations with extensive undergrowth than in those that had sparser undergrowth (Ornithological Society of New Zealand (Otago)). Forest structure may be a more significant factor in determining the distribution of South Island robins than expected.

Clout & Gaze (1984) suggested creating a mosaic of stands of varying age and type within large-scale plantation forests to facilitate colonization by species, such as the South Is robin, that have a poor ability to disperse so that stands of suitable ages are always available. This seems to be a reasonable strategy to adopt until the reasons for the uneven distribution of South Is robin populations in areas such as Silverstream area are better understood.

ACKNOWLEDGEMENTS

We thank Colin Ferguson and Rory Logan at AgResearch, Invermay, for their help with processing invertebrate samples; Eric Edwards, and Harald Steen for advice on methodology; Guy Forrester for statistical advice; Peter Webb and Petrina Duncan for providing taped robin song; Carlene Mitchell for teaching us skills in the lab; and Janine for getting us sorted out with equipment. Comments by Nick Poutu, Paul Scofield, Ralph Powlesland, and Andy Cox helped improve the manuscript.

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Appendix 1 Counts for invertebrate Operational Taxonomic Units (OTUs) in Silverstream area, by forest type.

	Vegetation type			
OTU	Douglas fir	Kanuka-manuka	Monterey pine	Total
acari-blk	34	364	71	469
amphipod	198	64	84	346
ann-rd	1	3	4	8
ant-rd		4		4
arac-br-blk	32	1	15	48
arac-br-or-stp	5	5	26	36
arac-br-sp	11	11	3	25
arac-br-stp			3	3
arac-sp	1	1		2

Appendix 1 (continued) Counts for invertebrate Operational Taxonomic Units (OTUs) in Silverstream area, by forest type.

	Vegetation type			
OTU	Douglas fir	Kanuka-manuka	Monterey pine	Total
bug-blk-rust-sp		22		22
bug-or	1	34		35
chil-or-ch	14	4	33	51
chil-or-tan	30	40	3	73
cole-blk-rust	3	2	2	7
cole-lar-br		6		6
cole-lar-gy	2	8		10
cole-lar-rust	1	18		19
cole-pitt	1	1	6	8
cole-rd-shine	9			9
cole-smoo-blk			1	1
cole-smoo-rd			1	1
dip-br-br	31	251	17	299
dip-br-ch	11	11	1	23
dip-gy		2		2
dipl-br-cm	6		1	7
dip-rd-gn	1		7	8
dip-rd-gr	4			4
dipt-ad		1	2	3
dip-tan-cr		15		15
dipt-lar-blk-cm			4	4
dipt-lar-cm-hr			2	2
dipt-lar-cr		15		15
dipt-lar-gn	2			2
dipt-lar-rd-fat	2			2
dipt-lar-wr-br		439		439
flatworm	2		2	4
geo		1		1
geo-rd-cr	1			1
hymen-red		2		2
iso-stp	21	7	20	48
lep-lar-blk-gn	3		3	6
lep-lar-br-spk		21		21
lep-lar-gn		1		1
lep-lar-gr-sp		1		1
lep-lar-rust		2	1	3
lep-rd-br	194		1	195
nem	1	6		7
nem-red-cm	72	3		75
opil-br-stp	11	14	121	146
slug-gy		8		8
wee-blk	83	24	78	185
wee-hairy-red	12			12
Total	800	1412	512	2724