Appendix S1. Selecting additional sampling sites to supplement the Auckland Council monitoring program

Preliminary analyses of our initial set of 185 sampling sites, selected as part of Auckland Council's Terrestrial Biodiversity Monitoring programme, indicated that we had not sampled any landscapes with very low levels of forest cover, that sampling sites with no pest control only occurred in landscapes with relatively low forest cover, and that sampling sites under high-intensity rat and possum control were located within a small number of (often very large) forest patches. To extend the range over which forest cover was measured, reduce the confound between pest control category and forest cover, and increase the number of patches under high-intensity rat and possum control, we searched for additional sampling site locations that could fill these gaps in the Auckland Council monitoring program.

We used ArcGIS version 10.0 coupled with the New Zealand Land Cover Database version 2 to create a 'potential sampling site' at a randomly selected location within every forest patch in our search area, then calculated forest cover, patch size, and pest control category for each of these potential sampling sites using the methods described in the main text. We removed any potential sampling sites that were on privately-owned land, since in our study area there was no straightforward way to obtain the contact details of private landowners based on the mapped locations of forest patches. Exceptions were potential sampling sites on privately-owned land covenanted under the 'QE2 National Trust' program, since this program provided an avenue through which we could request the contact details of landowners.

Using this approach, we identified a large number of potential sampling sites in both Northland and Waikato that had very low levels of forest cover and no pest control. We selected the six of these that maximised the size of the forest cover gradient (i.e. had the lowest levels of forest cover) with the constraints that they should be (1) from both Waikato and Northland, to avoid inadvertently confounding forest cover and latitude, and (2) >2 km apart, to reduce the likelihood of spatial autocorrelation. We also identified two potential sampling sites, one in Northland and one in Waikato, which were in large forest patches, had very high levels of forest cover, and had no pest control. However, these potential sampling sites were >10 km from a walking trail or forest edge, so we randomly reselected their locations within each forest patch until they fell <2 h walk from a trailhead and <500 m from the trail. Trails within these forest patches typically ran perpendicular to the forest edge, so this reselection approach was unlikely to bias the location of sampling sites towards forest edges. We also selected an additional sampling site in one of these forest patches. This was because these two forest patches were the only locations throughout our entire search area which had high levels of forest cover and no pest control, and we wanted to increase the sample size for sampling sites with these characteristics. We randomly selected the location of this additional sampling site, with the constraints that it had to be (1) >2 km from the other sampling sites (to minimise spatial autocorrelation), and (2) <2 hrs walk from a trailhead and <500 m from the trail. Lastly, we identified a medium-sized forest patch (182 ha) under high-intensity rat and possum control, and we placed an additional sampling site in this patch. Ultimately, this approach resulted in an additional ten sampling sites, which together extended the range over which we measured native forest cover, removed the confounding correlation between the 'no control' pest control category and forest fragmentation, and increased the number of forest patches under high-intensity pest control.

Appendix S2. Relationship between pest control at the sampling site and pest control in the wider landscape.

Initially, we planned to measure the effects of pest control at both the site level (i.e. the category of pest control at the sampling site) and the landscape level (the proportion of forest in the surrounding landscape under each category of pest control). This was to account for the fact that some species of bird were likely to range beyond the immediate area of the sampling site, and so may have been affected by pest control (or lack thereof) in the wider landscape. However, we found that the category of pest control at each sampling site was closely related to the levels of pest control in the surrounding landscape. For sampling sites categorised as 'eradication', an average of 95% of native forest within a 1 km radius of the sampling site was also under eradication control. Similarly, for sampling sites categorised as 'HRP', 'LRP', 'PP', and 'NC', an average of 85%, 83%, 86%, and 91% of native forest within a 1 km radius of the sampling site was under the same pest control category, respectively. Therefore, we used category of pest control at the sampling site as our only metric of pest control.

Appendix S3. Identifying and accounting for potentially confounding variables

There were a number of variables aside from native forest cover and pest control category that could plausibly influence our measurements of bird richness or abundance. If correlated with native forest cover or pest control category, these variables might cause us to estimate spurious relationships between native forest cover, pest control, and bird richness or abundance if unaccounted for in our statistical models. We identified survey conditions during bird counts, local vegetation characteristics, climate and topography, level of urbanisation in the surrounding landscape, cover of pine plantations in the surrounding landscape, and latitude as potential confounds. We measured these variables at each of our sampling sites, examined whether they were correlated with native forest cover or pest control category (and therefore had the potential to cause spurious relationships), and if so included them in our statistical models to control for their effects.

Measuring survey conditions during bird counts

We measured the following survey conditions during each bird count: (1) date of survey (measured as number of days since 1 November); (2) identity of the surveyor; (3) minutes since dawn; (4) an estimate of the number of minutes of sunshine on the canopy during the count; (5) amount of noise on a four-point scale (0=none; 1=slight; 2=moderate; 3=significant); (6) amount of wind on the same scale as noise; and (7) amount of rain on a six-point scale (0=none; 1=foliage dripping; 2=drizzle; 3=light; 4=moderate; 5=heavy). We averaged variables 3–7 across counts to produce a single value for each sampling site.

Measuring local vegetation characteristics

We measured vegetation characteristics at each sampling site using a 20 × 20 m vegetation plot. The plot was orientated to align with the main slope of the terrain, with the sampling site forming its bottom left corner when looking up slope. Where sites were located on flat ground the plot was orientated so its borders ran north–south and east–west.

We quantified vegetation characteristics within each vegetation plot with the following variables: (1) maximum diameter at breast height (DBH) of trees, where 'breast height' was 1.35 m above ground, and trees were defined as any woody plant or treefern with a DBH >2.5 cm; (2) average canopy height, estimated to the nearest metre; (3) canopy cover (percent cover of all vegetation >1.35 m above ground), estimated to the nearest 10%; (4) density of trees (i.e. number per 400 m2 plot; and (5) the proportion of tree species that were native. Variables 1–4 were selected to characterise differences in vegetation structure among sampling sites, while variable 5 was selected because it has previously been shown to influence the richness of native forest birds in Auckland (Stevens 2006).

We also categorised sampling sites by vegetation class, using categories that we believed would reflect major differences in resources for birds. Specifically, we distinguished between (1) kahikatea (*Dacrycarpus dacrydioides*) forest, where kahikatea forms a near-monoculture of very tall, open forest; (2) early successional scrub forest, consisting of relatively small trees dominated by kānuka (*Kunzea ericoides*) and mānuka (*Leptospermum scoparium*); and (3) late successional podocarp-broadleaf forest, generally containing a variety of podocarp and broadleaf species. We classified our sites based on the proportional contribution of these species to the total basal area of trees in each plot: sites in which kahikatea comprised >50% of total basal area were classed as 'kahikatea'; sites in which kānuka and mānuka combined comprised >30% of total basal area were classed as 'scrub forest'; and all other sites were classed as 'podocarp-broadleaf' forest. We used this lower cutoff for the 'scrub' category because kānuka and mānuka are relatively small trees, and so a 30% basal area was still likely to represent strong numerical dominance by these species. This value also roughly corresponded with the emergence of late successional podocarp-broadleaf forest species, which were generally rare where kānuka and mānuka comprised >30% of basal area, but common otherwise.

Measuring urbanisation and cover of pine plantations

We quantified urbanisation and cover of pine plantations using land cover data from the LCDB2. We categorised sampling sites as 'urban' if the forest patch they were in was bordered on at least three sides by the 'built-up' or 'urban parkland' categories of the LCDB2. Visual examination of aerial photographs of the study area indicated that this criterion effectively separated patches that were within urban areas from those that were not. We measured percent cover of pine plantations in a 1 km radius surrounding each sampling site, where pine was defined as the 'Pine – open canopy' and 'Pine – closed canopy' categories of the LCDB2.

Measuring climate and topography

We measured climate and topographical variables for each sampling station with ArcGIS v10.0, using underlying data layers from the Land Environments of New Zealand program (MfE 2002): (1) mean annual temperature; (2) mean minimum temperature of the coldest month; (3) altitude, measured from a 25 m digital elevation model; and (4) slope. These layers were obtained from the Landcare Research GIS portal (https://lris.scinfo.org.nz; accessed February 2014).

Preliminary analyses suggested that these variables were highly correlated, so we conducted a principal components analysis ('PCA'), using the 'prcomp' function of the base package of R version 3.0.2 (R Core Team 2015), to reduce the number of variables required to capture the variation in climate and topography among sampling stations. We used the first axis from this PCA in our statistical models, since a scree plot showed a 'levelling off' of variance explained with the inclusion of additional axes (Zuur et al. 2007). This axis (hereafter 'climate PCA') explained 75% of the variability in the original data, and increasing values were associated with increasing mean and minimum temperature and decreasing elevation and slope.

Relationships between potential confounds, native forest cover, and pest control category

We used linear mixed models to examine potential relationships between native forest cover and continuous potential confounds. We modelled each categorical potential confound as a function of native forest cover or pest control category using the 'lmer' function of the R package 'lme4', including patch identity as a random factor. We used the 'mixed' function of the 'afex' package (Singmann et al. 2014) to estimate p-values for each of these models, since they are not provided directly by lme4.

This exercise suggested that seven of our potential confounds were significantly related to either pest control category or native forest cover: four 'survey conditions' variables (noise, rain, survey date, and minutes since dawn), vegetation class, climate PCA, and urbanisation category (Table S1). We calculated variance inflation factors for these variables to test whether their inclusion in our statistical models would introduce unacceptable levels of multicollinearity. Variance inflation factors were acceptable for our 'survey conditions' variables and urbanisation category (i.e <2; Zuur et al. 2010), but were unacceptable for vegetation class and climate PCA (>2). Therefore, we included survey conditions and urbanisation category in our statistical models to control for their effects. We did not include vegetation class or climate PCA in our models, but we did conduct a sensitivity analysis in which we reran our models including these variables to check that their exclusion from our main analysis did not strongly influence results (Figure S2).

Table S1. Relationships between native forest cover, pest control category, and 16 potentially confounding variables that were potentially correlated with forest cover or pest control category and which might plausibly influence native forest bird communities. The table shows p-values of linear mixed models which regressed each potential confound against either pest control category or native forest cover. Where necessary, variables were transformed to normalise their distributions and linearise their relationships with forest cover. Each model also contained forest patch identity as a random effect to account for non-independence of sampling sites within patches. Significant p-values (≤0.05) are shown in bold.

Potential confound	**P-value**	
	Forest cover model	**Pest control model**
Survey conditions		
Days since November 1st	**0.044**	**0.050**
Minutes since dawn	**<0.001**	**0.028**
Sunshine	0.597	0.513
Noise	**0.001**	0.355
Wind	0.425	0.849
Rain	0.061	**0.017**
Vegetation variables		
Maximum DBH	0.218	0.142
Average canopy height	0.519	0.544
Percent canopy cover	0.322	0.076
Tree density	0.883	0.214
Percent native trees	0.156	0.406
Vegetation class	**0.003**	0.088
Other variables		
Urbanisation	**<0.001**	**0.021**
Latitude	0.550	0.625
Pine plantation cover	0.811	0.259
Climate PCA	**<0.001**	**<0.001**

Appendix S4. Alternative statistical analyses for the tomtit data

We were unable to fit valid GLMMs to the tomtit data using approaches described in the main text. Inspection of the raw data revealed a threshold relationship in which tomtits never occurred below c. 25% forest cover but were common above this level (Figure A1). We attempted a range of alternative methods to model the tomtit data (generalised additive mixed models, breakpoint regression, and transformation of native forest cover into a categorical variable), but none produced valid models. Ultimately, we removed all sites for which forest cover was <25%, and then used our subset of data (i.e. observations for which forest cover ≥25%, n=102) to model tomtit abundance using our original methods. We believe this loss of data is only a minor limitation, because the effects of forest cover and pest control at sites with <25% forest cover are clear from visually inspecting the data: the expected value for tomtit relative abundance is zero when forest cover is below 25%, and this does not vary with pest control category (Figure A1).

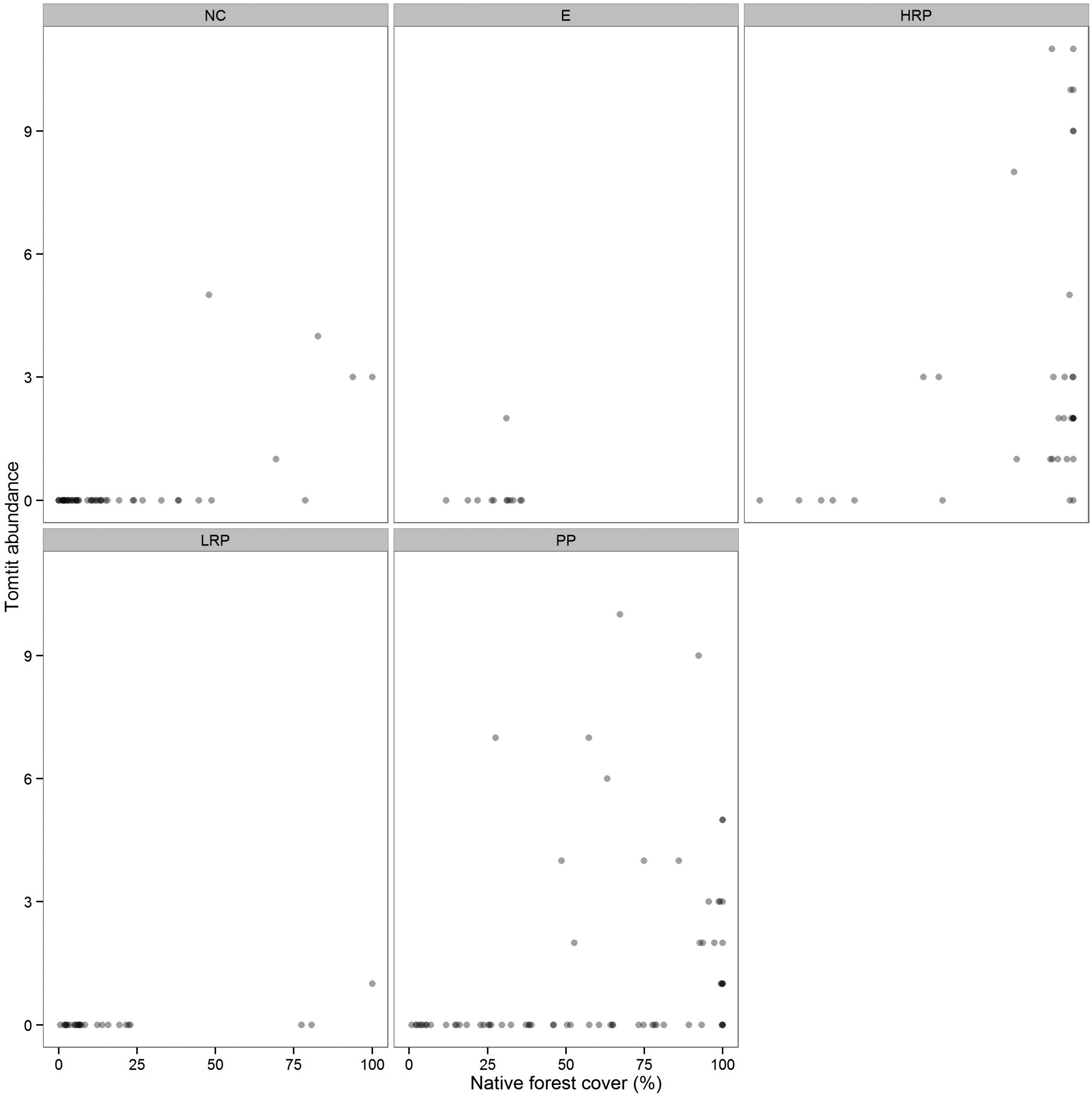

Figure A1. Tomtit abundance (individuals counted over three 5-minute counts) as a function of native forest cover and pest control category. Pest control categories are: E = eradication; HRP = high-intensity rat and possum control; LRP = low-intensity rat and possum control; PP = periodic possum control; NC = no control. The data are identical to those shown for the 'Tomtit' plot in Figure 2 of the main text, but are plotted separately for each pest control category to more clearly show that the threshold relationship between forest cover and tomtit abundance was consistent across pest control categories.

Supplementary Figure S1.

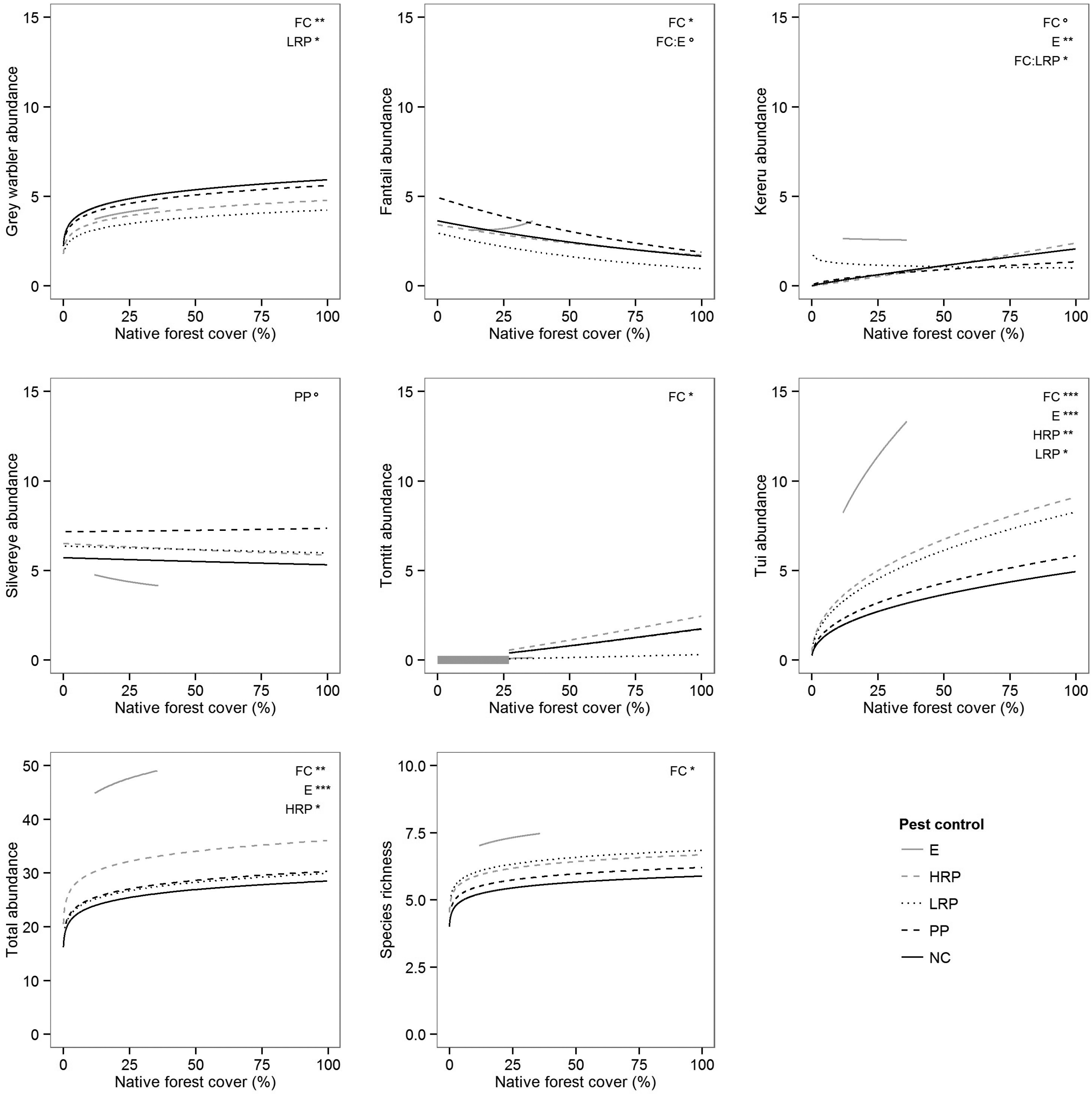

Figure S1. Model-predicted values for the effects of native forest cover and pest control category on native forest birds. Models were identical to those used in the main text, except that pest control category was defined by including only those operations that were >5 years old, rather than all operations. E = eradication; HRP = high-intensity rat and possum control; LRP = low-intensity rat and possum control; PP = periodic possum control; NC = no control. Truncated values for eradication predictions reflect the reduced range over which forest cover was measured for this pest control category. Lettering and asterisks at the top-right of each panel denote significant effects of forest cover (FC), pest control (E; HRP; LRP; and PP), and their interaction: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ^{o} $0.05 < p < 0.10$.

Supplementary Figure S2.

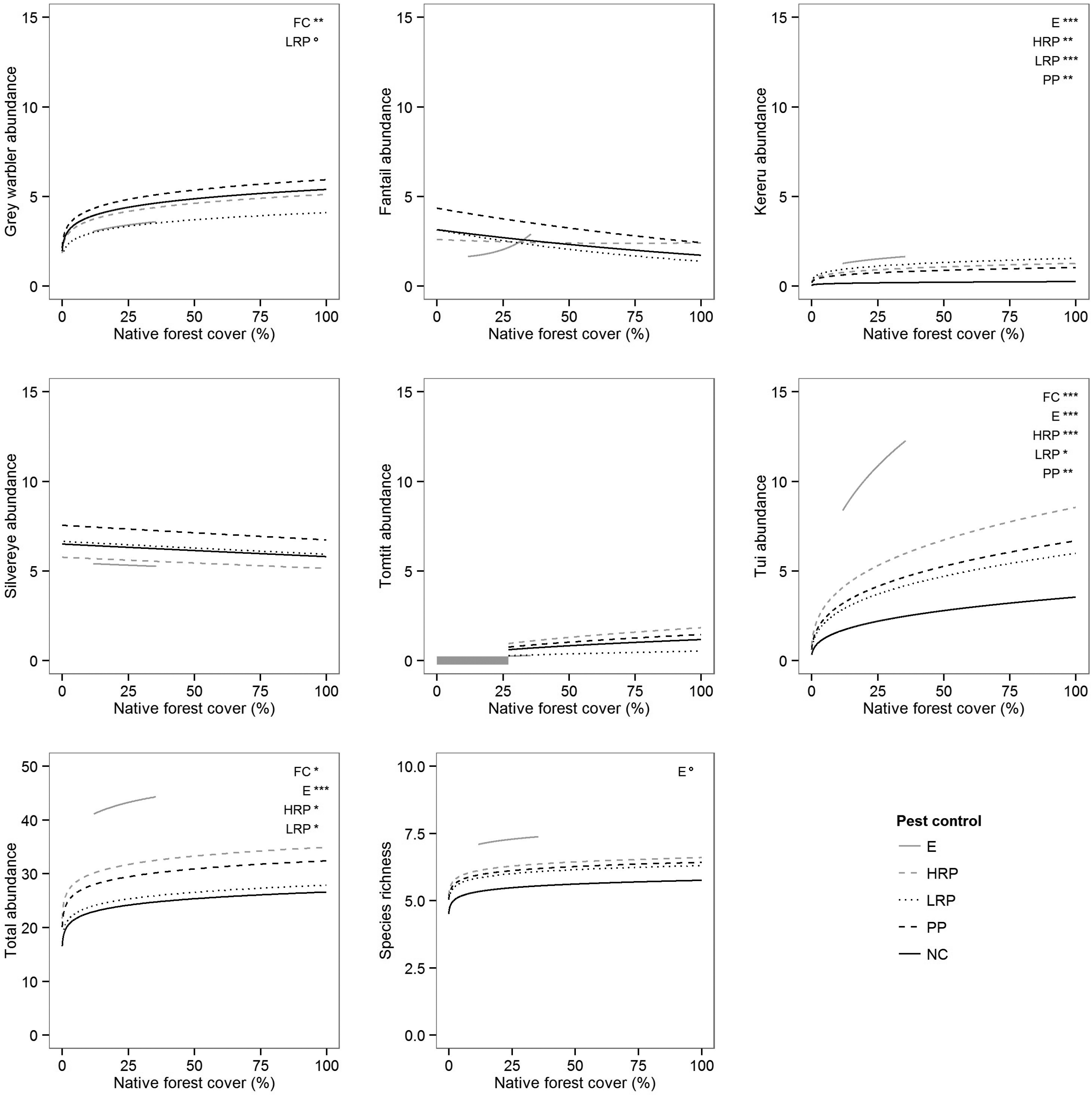

Figure S2. Model-predicted values for the effects of native forest cover and pest control category on native forest birds. Models were identical to those from the main analysis, except that they also included the ‘vegetation class’ and ‘climate PCA’ variables to control for their potentially confounding effects. These variables were excluded from the main analysis because they caused considerable variance inflation among other variables and therefore reduced our ability to accurately estimate effects. E = eradication; HRP = high-intensity rat and possum control; LRP = low-intensity rat and possum control; PP = periodic possum control; NC = no control. Truncated values for eradication predictions reflect the reduced range over which forest cover was measured for the eradication pest control category. Lettering and asterisks at the top-right of each panel denote significant effects of forest cover (FC), pest control (E; HRP; LRP; and PP), and their interaction: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ° $0.05 < p < 0.10$.

Supplementary Table S1.

Table S1. Native bird species recorded in our surveys, and whether we counted them as 'forest species' for our analysis.

Common name	Latin name
Forest species	
Grey warbler	*Gerygone igata*
Fantail	*Rhipidura fuliginosa*
Hihi	*Notiomystis cincta*
Kaka	*Nestor meridionalis*
Kererū	*Hemiphaga novaeseelandiae*
Morepork	*Ninox novaeseelandiae*
North Island robin	*Petroica longipes*
North Island kokako	*Callaeas cinereus*
Shining cuckoo	*Chrysococcyx lucidus*
Silvereye	*Zosterops lateralis*
Tomtit	*Petroica macrocephala*
Tūī	*Prosthemadera novaeseelandiae*
Whitehead	*Mohoua albicilla*
Non-forest species	
Black-backed gull	*Larus dominicanus*
Paradise shelduck	*Tadorna variegata*
Pūkeko	*Porphyrio porphyrio melanotus*
Red-billed gull	*Larus novaehollandiae*
Sacred kingfisher	*Todiramphus sanctus*
Spur-winged plover	*Vanellus miles*
Swamp harrier	*Circus approximans*
Variable oystercatcher	*Haemotopus unicolor*
Welcome swallow	*Hirundo neoxena*
White-faced heron	*Egretta novaehollandiae*
White-fronted tern	*Sterna striata*

Supplementary Table S2.

Table S2. Levels of support for candidate models which examined the best landscape size for quantifying the effects of native forest cover on native forest bird communities across our sampling sites. Each model was a Poisson GLM which modelled the relative abundance or richness of native forest birds as a function of native forest cover in the surrounding landscape, where landscapes were defined as either 500 m, 1000 m, 5000 m, or 15 000 m radius circles surrounding each survey point. ΔAIC gives a measure of change in the Akaike Information Criterion relative to the best model. Note that models differing by <2 AIC units are essentially indistinguishable in terms of how well they are supported by the data.

Species	Landscape radius	ΔAIC
Tūī	500 m	0.00
	1000 m	3.84
	5000 m	6.39
	15 000 m	8.55
Kererū	500 m	1.37
	1000 m	0.00
	5000 m	0.54
	15 000 m	13.18
Fantail	500 m	2.07
	1000 m	0.10
	5000 m	0.00
	15 000 m	0.76
Grey warbler	500 m	0.00
	1000 m	1.41
	5000 m	1.14
	15 000 m	2.19
Silvereye	500 m	0.00
	1000 m	0.89
	5000 m	3.98
	15 000 m	2.19
Species richness	500 m	2.24
	1000 m	0.00
	5000 m	2.92
	15 000 m	0.02

Supplementary Table S3.

Table S3. Estimated effects of native forest cover, pest control category ('PC'), and five additional variables (included to control for confounding) on native forest birds. Models also included estimates for an interaction between pest control category and forest cover, if specified by the AIC-best model(s) used for statistical inference (see Table 1 in main text). PC categories: E = eradication; HRP = high-intensity rat and possum control; LRP = low-intensity rat and possum control; PP = periodic possum control. Asterisks indicate significant effects: * p<0.05; ** p<0.01; *** p<0.001; º 0.05 < p < 0.10.

	Kererū abundance	**Tūī abundance**	**Grey warbler abundance**	**Fantail abundance**
Main effects				
Intercept[a]	-0.59 ± 0.46	0.66 ± 0.21 **	1.53 ± 0.13	0.93 ± 0.91 ***
ForestCover	0.60 ± 0.47	0.57 ± 0.12 ***	0.21 ± 0.07 **	-0.31 ± 0.17 º
PC_E	2.32 ± 0.55 ***	1.58 ± 0.32 ***	-0.06 ± 0.24	0.87 ± 0.82
PC_HRP	1.41 ± 0.85 º	0.97 ± 0.26 ***	-0.15 ± 0.16	-0.19 ± 0.35
PC_LRP	1.51 ± 0.52 **	0.63 ± 0.23 **	-0.30 ± 0.15 *	-0.14 ± 0.31
PC_PP	1.28 ± 0.50 *	0.67 ± 0.21 **	0.04 ± 0.13	0.25 ± 0.21
Interactions[b]				
ForestCover: PC_E	-0.66 ± 1.29	-	-	1.70 ± 1.92
ForestCover: PC_HRP	0.60 ± 1.03	-	-	0.21 ± 0.30
ForestCover: PC_LRP	1.15 ± 0.62 º	-	-	-0.17 ± 0.31
ForestCover: PC_PP	-0.31 ± 0.64	-	-	-0.01 ± 0.17
Confounding variables				
Urban_Yes	-0.82 ± 0.58	1.19 ± 0.23 ***	-0.08 ± 0.16	-0.19 ± 0.23
SurveyDate	-0.04 ± 0.17	0.07 ± 0.07	-0.09 ± 0.04 º	-0.02 ± 0.07
MinutesSinceDawn	-0.13 ± 0.16	-0.18 ± 0.08 *	0.01 ± 0.05	0.10 ± 0.09
Rain	-0.15 ± 0.12	-0.06 ± 0.07	0.01 ± 0.04	-0.02 ± 0.07
Noise	-0.33 ± 0.17 º	-0.08 ± 0.07	0.02 ± 0.05	-0.01 ± 0.09

[a]Represents the baseline level for each factor: 'PestControl_None and 'Urban_No'.
[b]Represents change in slope of the forest cover effect for each PC category, relative to PestControl_None, at the mean value of forest cover (22%).

Table S3. continued

	Silvereye abundance	**Tomtit abundance**[c]	**Total abundance**	**Species richness**
Main effects				
Intercept[a]	1.71 ± 0.15 ***	-1.26 ± 0.84	2.96 ± 0.10 ***	1.67 ± 0.08 ***
ForestCover	-0.16 ± 0.21	1.53 ± 0.80 º	0.11 ± 0.04 **	0.07 ± 0.04 º
PC_E	-0.51 ± 0.49	-1.32 ± 1.13	0.57 ± 0.14 ***	0.27 ± 0.13 *
PC_HRP	0.12 ± 0.28	0.67 ± 0.63	0.27 ± 0.11 *	0.15 ± 0.11
PC_LRP	0.02 ± 0.22	-0.78 ± 0.93	0.03 ± 0.10	0.10 ± 0.10
PC_PP	0.20 ± 0.20	0.36 ± 0.61	0.16 ± 0.09 º	0.10 ± 0.10
Interactions[b]				
ForestCover: PC_E	-0.52 ± 0.89	-	-	-
Forest cover: PC_HRP	0.08 ± 0.21	-	-	-
Forest cover: PC_LRP	0.04 ± 0.22	-	-	-
Forest cover: PC_PP	0.33 ± 0.29	-	-	-
Confounding variables				
Urban_Yes	0.47 ± 0.17 **	- [c]	0.32 ± 0.10 **	-0.10 ± 0.12
SurveyDate	-0.18 ± 0.05 *	0.29 ± 0.17 º	-0.04 ± 0.03	0.02 ± 0.03
MinutesSinceDawn	-0.14 ± 0.06 *	-0.01 ± 0.18	-0.07 ± 0.04	-0.02 ± 0.04
Rain	-0.15 ± 0.06 *	-0.25 ± 0.15 º	-0.06 ± 0.03 º	-0.02 ± 0.03
Noise	-0.04 ± 0.06	-0.31 ± 0.21	-0.07 ± 0.04 *	-0.03 ± 0.04

[a]Represents the baseline level for each factor: 'PestControl_None and 'Urban_No'.
[b]Represents change in slope of the forest cover effect for each PC category, relative to PestControl_None, at the mean value of forest cover (22%).
[c]Parameter estimates for the tomtit model only apply to sites with >25% forest cover. This meant that urban sites were excluded from the model.

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