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# Measuring occupancy for an iconic bird species in urban parks

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**Abstract:** Urbanisation is a significant and increasing threat to biodiversity at the global scale. To maintain and restore urban biodiversity, local communities and organisations need information about how to modify green spaces to enhance species populations. 'Citizen science' initiatives monitoring the success of restoration activities also require simple and robust tools to collect meaningful data. Using an urban monitoring study of the bellbird (*Anthornis melanura*), we offer advice and guidance on best practice for such monitoring schemes. Three independent surveys were undertaken across 140 locations in Christchurch's urban parks. Detection probabilities (estimated from six repeat five-minute point counts at each location per survey) were used to calculate unbiased occupancy estimates for the second and third surveys. A single five-minute count had c. 60% chance of detecting bellbirds at a location where they were present, while the cumulative detection probability increased to almost one after five repeat counts per survey. Bellbird detection probabilities varied between surveys (albeit weakly) but not with environmental conditions. Occupancy, which declined slightly over the study period, was highest in parks with more native woody vegetation, less paved areas and close to the Port Hills (which were mostly Riverbank/Conservation parks). Robust estimates of bellbird occupancy require at least three repeat counts per location per survey within a short time frame, with multiple locations ideally surveyed concurrently.

**Keywords:** bellbird; detectability; distribution; habitat; restoration

## Introduction

Urbanisation, one of the globe's fastest-growing land uses, is considered a significant and increasing threat to biodiversity (e.g. McKinney 2002, 2006; Mcdonald et al. 2008). Habitat loss and degradation, high levels of pollution, disturbance and predation, lack of nesting cover for birds and predominance of alien plant species are some of the factors driving urban biodiversity declines (e.g. Cannon et al. 2005; Goddard et al. 2010). Thus, urban ecology has an important role to play in informing management actions to reverse this trend.

Green space (non-built-up areas) in urban landscapes is vital for both biodiversity maintenance and restoration and the provision of ecosystem services and quality of life (physical and mental health) for the resident human population (Gaston et al. 2005). Green space also educates and engages people in habitat management and conservation (McKinney 2002), while its aesthetic appeal enhances market values of neighbouring properties (Savard et al. 2000). Local government organisations are coming under increasing pressure to actively manage and enhance biodiversity in green spaces, and require information about how to modify these areas to provide important resources for some species (e.g. Cannon et al. 2005).

However, such organisations often have limited financial resources to run biodiversity restoration and monitoring programmes, so rely on local community involvement. To ensure these 'citizen science' initiatives provide meaningful data that can inform management, development of robust monitoring tools that can easily be implemented by the public is a priority. Potential issues include observers only sampling particular species, areas or seasons of interest, or only recording species presence but not absence, and omitting information on sampling effort (e.g. Voříšek et al. 2008). However, large-scale and cost-effective monitoring programmes can be established by providing the public with simple and robust sampling methods and frameworks that allow unbiased estimates of species occupancy and abundance to be calculated (e.g. Chamberlain et al. 2004; Gregory et al. 2004, 2005; Cannon et al. 2005).

Here we use an urban monitoring study of the bellbird (*Anthornis melanura*) to offer advice and guidance on best practice for such monitoring schemes. The bellbird is a forest-dwelling honeyeater that breeds in and around some of New Zealand's cities (Higgins et al. 2001; Spurr et al. 2010; van Heezik & Seddon 2012). To enhance this iconic endemic species' population in Christchurch, the local council has

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recently implemented predator control programmes in nearby native bush patches and actively encouraged community participation in planting native species in the city's parks. 'Citizen science' has played an important role in monitoring subsequent changes in the abundance and distribution of the bellbird population within the city boundary, with ad hoc observations across the city recorded using online tools such as the New Zealand Biodiversity Recording Network (Sullivan 2012) and eBird (Scofield et al. 2012). Anecdotal evidence suggests that, in the winter, some bellbirds move from their breeding habitat on the outskirts of the city into urban parks and gardens to feed (Spurr et al. 2008, 2010; Sullivan 2012). However, to date, no systematic monitoring of the distribution of bellbirds among different habitats or seasons has been published; hence, it is not clear whether these ad hoc observations provide an accurate measure of temporal and spatial changes in bellbird distribution in the urban landscape that could be used to determine the impact of the local council's predator control and restoration initiatives.

Our study aims to: (1) develop a simple, cost-effective survey design for monitoring changes in bellbird distribution among Christchurch's urban parks, by investigating how bellbird detection probabilities vary in relation to sampling effort, time and environmental conditions; (2) identify habitat features that could account for variation in bellbird occupancy among parks, informing restoration management within the city boundary; (3) use the best-fit model to provide unbiased estimates of bellbird occupancy of Christchurch's parks, which can be used as baseline information for monitoring the impact of future restoration efforts; and (4) use this case study to provide advice and guidance on best practice for such monitoring schemes in general.

## Methods

### Field surveys

In 2009, three independent bellbird surveys were undertaken by the same trained observer across 140 survey locations in Christchurch's urban parks. The city's c. 800 parks are categorised by the local council into five main types according to their facilities, vegetation composition and management intensity (Table 1). Within each type, a list of c. 70 potential park survey locations (≥ 200 m apart) were randomly generated using the geographic information software ArcMap and HawthsTools.

In the first survey (21 April – 5 June), a single point count lasting 5 min was carried out at each sampling location between 0900 and 1300 hours. In the second and third surveys (25 June – 25 August; 31 August – 2 November), six five-minute counts were completed at each sampling location over two consecutive days; on the first day in each area, three five-minute

**Table 1.** Description of different types of urban parks (excluding the 12 cemetery parks) in the city of Christchurch, New Zealand.

| Local council park classification | Park code | Description | All parks | | | | Surveyed parks | | | Sampling locations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (*N*) | Area (ha) Total | Mean | SE | (*n*) | Area (ha) Mean | SE | (*n*) Total | Mean | SE |
| Garden/Heritage | Garden | Emphasis on conserving and maintaining historical character. Intensive management overseen by a trust. | 47 | 86 | 1.83 | 0.65 | 19 | 2.5 | 1.1 | 27 | 1.42 | 0.26 |
| Local/Community | Local | Neighbourhood parks, with open spaces and no restrictions on planting. Regular maintenance (including mowing). | 538 | 356 | 0.66 | 0.05 | 29 | 1.7 | 0.5 | 31 | 1.07 | 0.07 |
| Regional | Regional | Often wilderness areas (including native and exotic vegetation), with emphasis on wildlife conservation and revegetation. Managed independently by an assigned ranger. | 57 | 4630 | 81.23 | 20.9 | 10 | 205.8 | 90.5 | 24 | 2.40 | 0.69 |
| Riverbank/ Conservation | River | Protection and restoration of native habitats, which often form corridors. Waterways and grass areas managed only. | 77 | 410 | 5.32 | 0.86 | 18 | 19.5 | 3.9 | 28 | 1.56 | 0.17 |
| Sports | Sports | Amenities provided, with grass areas intensively managed for particular sports. No restrictions on planting but community boards consulted about woody vegetation management. | 106 | 1302 | 12.28 | 2.07 | 15 | 12.3 | 2.9 | 30 | 2.00 | 0.28 |

counts were undertaken at each survey location (between 0900 and 1500 hours), with 5 min intervals between counts. The same process was repeated on the second day, but with the order in which locations were surveyed reversed. Such repeat surveys within a period allow detection probabilities and, therefore, unbiased estimates of occupancy to be calculated (MacKenzie et al. 2002). A full set of six surveys per location was occasionally not completed because counts were not carried out in rain or strong winds (survey two: $n = 2$; survey three: $n = 4$). All bellbirds heard or seen within each five-minute count were recorded irrespective of the distance from the observer.

The observer visited a given locality within the city boundary each day in survey one and for two consecutive days in surveys two and three. The order that different sampling locations were visited was determined by randomly rearranging the list of parks between surveys (with no location surveyed more than once per survey). The aim was to maximise the number of locations sampled while retaining a similar total number of locations within each park type (Table 1). As a result, within each park type, the number of surveyed parks and locations per park varied in relation to their area (i.e. the number of parks surveyed decreased as the area of the parks increased, while the number of locations per park decreased as the park area decreased). In addition, a small subset of inaccessible locations (mean total locations per park type ± SE; 4 ± 1.4) were excluded (mainly those located within tidal zones along the coast or waste disposal areas).

For all counts, noise and wind conditions were recorded (following Dawson & Bull 1975), with amount of sun immediately overhead also noted (0 = no sun, 1 = sun visible at times, 2 = sun visible throughout). Three habitat features within a 25-m radius of each survey location were also recorded: (1) the main utilities present in the park (e.g. sports field, playground, flowerbed); (2) the relative cover of parkland versus other land-use types (e.g. built-up areas, farmland, water-bodies); (3) the relative cover of four structural tiers of vegetation (following Hurst & Allen 2007) in relation to their broad composition (Table 2). The habitat survey was restricted to 25-m radius primarily due the practical constraints associated with gaining access to private property over a wider area. A principal components analysis (PCA) of all the sampling locations and habitat features listed in Table 2 was used to characterise each location's habitat composition according to its position on the first five principal components (each accounted for ≥ 5% of the variance). The magnitude and sign of the coefficients of each of the habitat variables were used to determine their relative contribution to each of the five principal components and to identify key habitat gradients across survey locations and park types.

**Modelling detectability and occupancy**

State - space occupancy models (MacKenzie et al. 2002; Royle & Dorazio 2008) were used to analyse data obtained from repeated sampling of locations ($i = 1, 2, ..., S$). Locations were each sampled in the primary survey periods ($t = 1, 2,$ or $3$), with repeated counts performed in $k$ secondary periods ($k = 1, 2, ..., 6$) within each primary period. When bellbirds were detected at location $i$ during primary period $t$, the true occupancy $z_{it} = 1$, and 0 otherwise. This is modelled as a random draw from a Bernoulli trial with probability $\psi_{it}$, the occupancy probability of location $i$ at time $t$: $z_{it} \sim \text{Bern}(\psi_{it})$. However, the values for $z_{it}$ are only partially observed: $z_{it} = 0$ could be due to either

**Table 2.** Correlation coefficients relating each habitat feature to the first five principal component axes (PC1–PC5) for those variables included in the principal components analysis (see text). Bold highlights habitat features most strongly correlated with each principal component.

| Type | Feature | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|---|
| Built-up areas | Commercial | 0.00 | 0.00 | 0.01 | 0.04 | −0.03 |
| | Industrial | 0.00 | −0.01 | 0.02 | 0.01 | −0.01 |
| | Path/road/rail | −0.06 | 0.04 | 0.04 | 0.52 | −0.17 |
| | House | −0.01 | −0.01 | 0.04 | 0.15 | 0.04 |
| | Garden | −0.01 | 0.01 | 0.01 | 0.05 | −0.01 |
| Other land use | Farm | 0.02 | −0.01 | −0.02 | 0.00 | −0.01 |
| Waterbody | Lake | −0.01 | −0.01 | 0.01 | 0.00 | −0.01 |
| | River | 0.00 | 0.01 | 0.00 | 0.06 | 0.00 |
| | Stream/ditch | 0.01 | −0.02 | 0.01 | 0.02 | −0.03 |
| | Coastal | 0.01 | 0.00 | 0.06 | −0.02 | 0.04 |
| Tiers 1–3 (> 5 m) | Exotic | −0.23 | **0.79** | **−0.51** | 0.06 | −0.11 |
| | Native | 0.01 | 0.03 | 0.15 | −0.04 | **−0.51** |
| Tier 4 (2–5 m) | Exotic | −0.03 | 0.05 | −0.12 | 0.11 | −0.06 |
| | Native | 0.04 | 0.03 | 0.18 | −0.17 | **−0.73** |
| Tier 5 (30 cm – 2 m) | Exotic shrub | 0.06 | 0.11 | −0.09 | −0.06 | 0.07 |
| | Flax | 0.01 | −0.01 | 0.03 | 0.00 | −0.08 |
| | Native shrub | 0.03 | 0.00 | 0.03 | −0.01 | −0.20 |
| | Native grass | −0.02 | 0.00 | 0.02 | 0.00 | −0.02 |
| | Tussock | 0.07 | 0.01 | −0.04 | −0.08 | 0.10 |
| Tier 6 (< 30 cm) | Bare | 0.12 | **0.46** | **0.47** | **−0.57** | 0.18 |
| | Herbaceous weeds | 0.06 | −0.02 | −0.04 | 0.00 | −0.01 |
| | Intense grass | **−0.78** | −0.30 | −0.22 | −0.43 | −0.06 |
| | Rough pasture | **0.55** | −0.20 | **−0.62** | −0.36 | −0.13 |
| | Shrub | −0.01 | 0.05 | 0.03 | 0.03 | −0.17 |
| | Tussock | 0.04 | 0.01 | 0.00 | 0.00 | 0.06 |
| | Woody debris | 0.01 | 0.05 | 0.00 | −0.02 | 0.01 |

non-occupancy at the location, or non-detection at an occupied location. The repeated sampling enables us to differentiate probabilistically between these. The observed data are given by $y_{itk} = 1$ indicating at least one bellbird was detected (heard or seen) at location $i$ during secondary sample $k$ of primary sample $t$, and 0 otherwise. This is modelled as: $y_{itk} \sim \text{Bern}(z_{it} \times p_{itk})$, where $p$ is the probability of detection conditional on the location being occupied.

Variations of the model allow for occupancy and/or detection probability to be constant or time dependent among sampling periods, or as a function of one or more covariates. Alternative models were compared using a version of the Deviance Information Criterion (DIC); this is a Bayesian method for model comparison and a generalisation of AIC for hierarchical models. In general terms, the model with the lowest DIC is the most parsimonious model, i.e. a trade-off between the model with the best fit and the model with the fewest number of parameters. A number of explanatory variables were considered a priori for detection probability (noise, sun and wind) and occupancy (park type, PCA scores of habitat composition, and distance from the Port Hills summit). PCA scores and distance were standardised to have a mean of zero and standard deviation of one. Modelling was carried out in two stages (sensu Lebreton et al. 1992): first, comparing the effect of covariates on detection, conditional on a time-varying model for occupancy, denoted $\psi\{t\}$; and second, comparing the effect of covariates on occupancy, using the best model for detection found previously.

## Results

### Habitat composition

Overall, the local council park classification corresponded well with our own observations of the primary park utility at each sampling location (Fig. 1a; Table 1). Ornamental gardens were predominantly associated with both Garden/Heritage and Local/Community parks, with the latter often also providing some recreation facilities (mainly playgrounds). However, recreation areas (e.g. walking and cycling trails) were mostly associated with Regional parks, which also provided other services rarely observed in other park types (e.g. plantation forestry and farming). Most restoration activity was observed in the Riverbank/Conservation parks. As park sizes varied both within and among park types (Table 1), other land uses (primarily farming) were often present within a 25-m radius of the sampling location (Fig. 1b). Built-up areas were a predominant feature in Garden/Heritage and Local/Community parks but mostly absent from Regional parks. Waterbodies and farmland, on the other hand, were mainly associated with Riverbank/Conservation parks. Mature tree canopy cover (> 5 m tall; Tiers 1–3) was greatest in Garden/Heritage parks and least in Local/Community parks (Fig. 1c), while immature tree and shrub cover (2–5 m tall; Tier 4) was predominantly associated with Riverbank/Conservation parks. Ground cover was highest in Sport parks and lowest in Regional ones.

The habitat composition of the sampling locations was well summarised by the first five principal components (Table 2; total variation explained = 80%). The first principal component, which explained 33% of the variation, had higher scores positively associated with rough grassland and negatively associated with intensively managed grassland. The second and third components, which accounted for 22% and 14% of

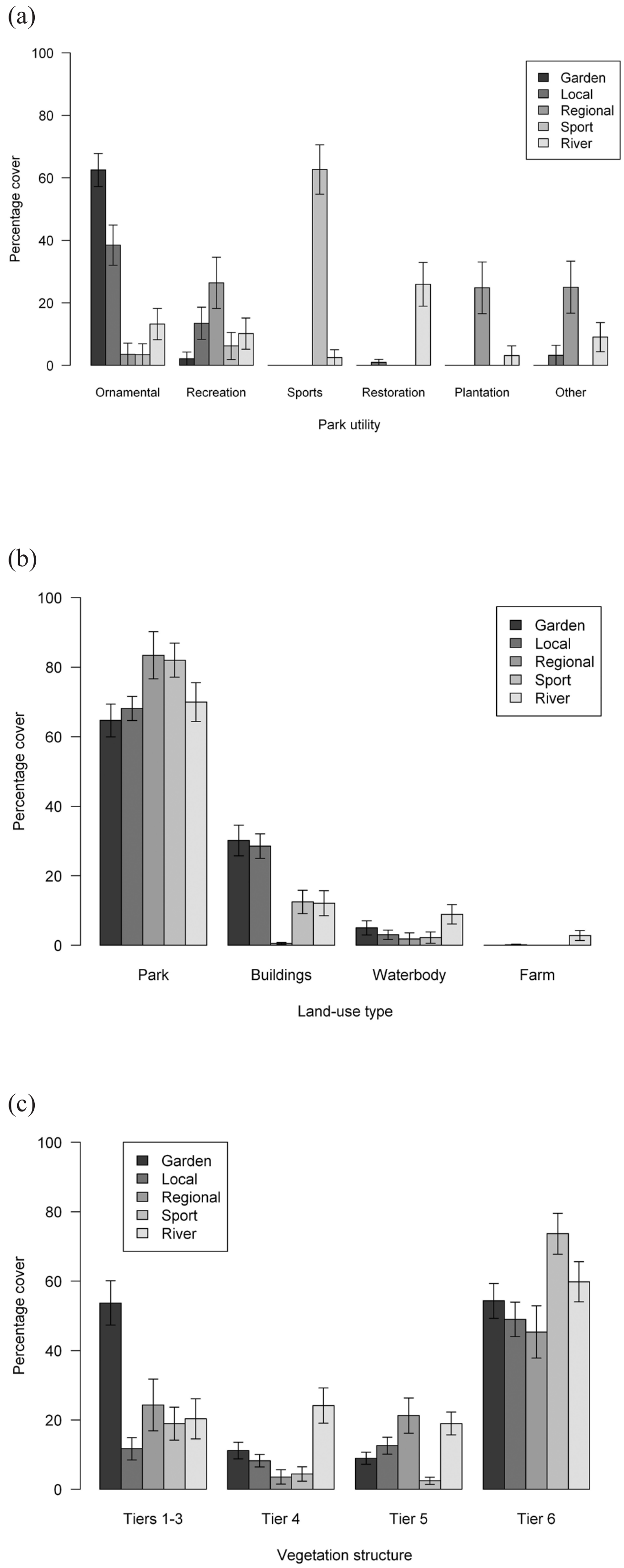


**Figure 1.** Mean (±SE) percentage cover of the primary (a) park utility ('ornamental', typically included intensively managed flowerbeds; 'recreation' included playgrounds or walking/cycle tracks; 'sports' included intensively managed playing fields; 'other' included farmland, a tree nursery and landfill areas), (b) land-use types and (c) vegetation tiers within 25 m of the sampling location in relation to park type.

the variation respectively, had higher scores associated with mature exotic trees (> 5 m tall) in the second component and bare ground in both components (low scores in the third component were associated with mature exotic trees and rough pasture). The fourth and fifth components accounted for 7% and 5% of the variation respectively; high scores were associated with paving and roads in the fourth component, and low cover of native vegetation (> 2 m high) in the fifth component.

### Detection and occupancy probabilities

Most bellbirds (99%; $n$ = 278 records) were detected using aural cues; only 7% were detected within 25 m of the count station and 39% were > 100 m away. Environmental conditions (noise, sun and wind) appeared to have little effect on an observer's probability of detecting bellbirds (conditional on time-varying occupancy; Table 3) with only wind having a moderate (positive) effect. Of the time-varying and constant detection models considered (Table 3), an intermediate model ($\psi\{t\}p\{2{:}3\}$) had the lowest DIC. Here the detection probability for $t$ = 1 was restricted to be the average for $t$ = 2 and 3, rather than a survey-specific estimate, as no repeat counts were undertaken in this survey period. Detection probabilities for $t$ = 3 (August–November) were slightly greater than for $t$ = 2 (June–August), but because detection for time 1 is based on estimates from time 2 and 3, the estimate of occupancy for this time period should be treated with care. The parameterisation of $p\{2{:}3\}$ was used for further models.

From the estimates of detection probability, a single five-minute count had c. 60% chance of detecting bellbirds at a location where they were present (Fig. 2a). Assuming that each five-minute count per survey was independent, the cumulative detection probability increased and was almost 1 after five counts (Fig. 2a). Thus, mean occupancy estimates varied in relation to the number of replicate counts per location (Fig. 2b). For all three surveys, occupancy estimates based on a single five-minute count were consistently much lower than those calculated using the time-varying detection and occupancy model ($\psi\{t\}p\{2{:}3\}$) and including all six replicate counts. For the latter two surveys, occupancy estimates based on three replicates (for Day 1 and Day 2) were lower than those calculated using all six replicates, but this difference was not statistically significant (paired $t$-tests: $P > 0.05$). Occupancy estimates for Day 1 and Day 2 (based on the three replicates) were comparable for each survey (paired $t$-tests: $P > 0.05$).

When comparing a time-varying occupancy model to the model that assumes constant occupancy, DIC values decreased by one (Table 4). The estimates of time-varying occupancy show a slight decline in occupancy over the study period, but because detection at Time 1 is an average of Time 2 and 3, estimates of occupancy at Time 1 may be unreliable (Fig. 2b).

Including park-type alone resulted in DIC decreases of 10 (Table 4), with lowest and highest occupancy probabilities observed in Local/Community and Riverbank/Conservation parks respectively (Fig. 3a). Including distance from the Port Hills also resulted in a decrease in DIC of 10 relative to the constant-occupancy model, with estimated occupancy of 0.38 near the hills compared with 0.08 at a distance of 19 km (Fig. 3b). However, these results are probably confounded by the spatial distribution of park-type, as Riverbank/Conservation parks are generally situated closer to the Port Hills (Fig. 3c).

Including the principal component measures of habitat composition decreased DIC values by 25–30 compared with the constant-occupancy model (Table 4). Thus, these habitat variables (but PC1, PC4 and PC5 in particular) were better indicators of bellbird presence than park-type. Both PC4 and PC5 had negative relationships with occupancy, whereas PC1 had a positive relationship (Fig. 3d). Thus, bellbird occupancy is positively correlated with native woody vegetation, bare ground and possibly rough pasture, but negatively correlated with paved areas and possibly intense grass (Table 2).

A model that allows the relationship between distance from the Port Hills and occupancy to differ for each time period shows a strong negative relationship at time periods 2 and 3 only (Fig. 3e), but the DIC is larger than models with habitat composition (Table 4). However, including distance and habitat (PC4 and PC5) resulted in a decrease of 45 from the constant-occupancy model, indicating both variables are important factors influencing bellbird distribution (Table 4; Fig. 4). (Note: PC1 was removed from the model because the PC1 coefficient showed no relationship between PC1 and occupancy when distance was included, probably due to being confounded with distance.) The effects of time and park type were also present, but relatively less important (Table 4).

Baseline estimates of bellbird occupancy for Christchurch's urban parks shown in Fig. 4 are based on the simplest best-fit model (distance from the Port Hills and habitat [PC4 and PC5]). Highest occupancy probabilities are associated with parks close to the Port Hills, particularly Riverbank/Conservation and Regional parks, which had greater native woody vegetation cover.

**Table 3.** Results from models with differing parameterisations of detection probability ($p$) conditional on time-varying occupancy ($\psi\{t\}$), where $\beta$ denotes parameter estimates (mean and 95% Confidence Intervals, CI) for continuous variables (see Methods) and $p_t$ is the estimate (mean and 95% Cls) for detection probability for survey period $t$.

| Description | Model | DIC | Parameters | Mean (95% CI) |
|---|---|---|---|---|
| Noise | $\psi\{t\}p\{noise\}$ | 811.2 | $\beta_{noise}$ | −0.11 (−0.47 – 0.23) |
| Sun | $\psi\{t\}p\{sun\}$ | 811.6 | $\beta_{sun}$ | 0.02 (−0.21 – 0.26) |
| Wind | $\psi\{t\}p\{wind\}$ | 809.2 | $\beta_{wind}$ | 0.21 (−0.05 – 0.48) |
| Constant detection | $\psi\{t\}p\{.\}$ | 806.4 | $p_1 = p_2 = p_3$ | 0.65 (0.60 – 0.71) |
| Time-varying detection | $\psi\{t\}p\{t\}$ | 808.1 | $p_1$ | 0.45 (0.16 – 0.94) |
| | | | $p_2$ | 0.61 (0.54 – 0.68) |
| | | | $p_3$ | 0.73 (0.65 – 0.81) |
| Time-varying detection | $\psi\{t\}p\{2{:}3\}$ | 806.2 | $p_1 = (p_2 + p_3)/2$ | 0.67 (0.61 – 0.72) |
| | | | $p_2$ | 0.61 (0.53 – 0.67) |
| | | | $p_3$ | 0.73 (0.64 – 0.81) |

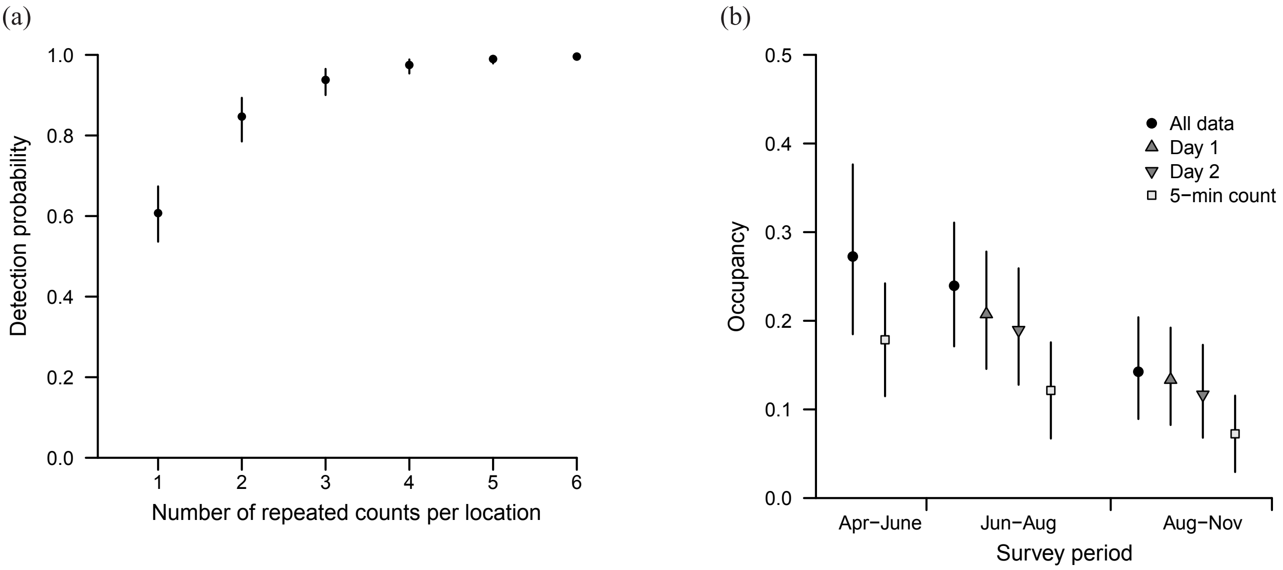


**Figure 2.** Testing the effects of varying sampling effort using the time-varying detection and occupancy model (*ψ{t}p{2:3}*): (a) shows cumulative estimates of detection probability (mean ± 95% Credible Interval; CI) in relation to the number of repeat counts at each location; and (b) shows occupancy estimates (mean ± 95% CI) for each survey period based on the *ψ{t}p{2:3}* model calculated using six repeat counts (All data) and only three replicates (for Day 1 and Day 2 independently), relative to those calculated using a single five-minute point count (which is based on the assumption that detection is equal to 1).

**Table 4.** Results from models with differing parameterisations of occupancy (ψ), with time-varying detection modelled as *p{2:3}*. Note 'distance' is the distance of each location from the Port Hills' summit, PC is the principal component used to measure habitat composition (see Table 2) and time (*t*) is the primary survey periods (see Methods).

| Description | Model | DIC | Δ DIC |
|---|---|---|---|
| Constant | *ψ{.}* | 807.2 | 48.4 |
| Time | *ψ{t}* | 806.2 | 47.4 |
| Park type | *ψ{park}* | 796.3 | 37.5 |
| Habitat | *ψ{habitat=All}* | 782.1 | 23.3 |
| | *ψ{habitat=PC1, PC4, PC5}* | 779.5 | 20.7 |
| Distance | *ψ{distance}* | 795.4 | 36.6 |
| Distance, with the relationship varying by time period | *ψ{distance*time}* | 793.6 | 34.8 |
| Park type and time | *ψ{park+time}* | 795.4 | 36.6 |
| Park type and time, with a random effect (that allows the temporal effect to differ for each park-type) | *ψ{park+time+ random effect}* | 797.3 | 38.5 |
| Habitat and time | *ψ{habitat=[PC1, PC4, PC5]+time}* | 777.6 | 18.8 |
| Habitat and distance | *ψ{habitat+distance[PC4, PC5]}* | 761.1 | 2.3 |
| Habitat and distance and time | *ψ{habitat+distance[PC4, PC5]+time}* | 758.8 | 0 |
| Habitat and distance with the relationship varying by time period | *ψ{ habitat[PC4, PC5]+distance*time}* | 760.1 | 1.3 |
| Habitat, park type and distance | *ψ{habitat[PC4, PC5]+park+distance}* | 760.5 | 1.7 |

# Discussion

## Survey design

To obtain unbiased estimates of species occupancy from bird counts, detection probabilities should be quantified (MacKenzie et al. 2002; MacKenzie & Royle 2005). For bellbirds within Christchurch's urban parks, we recommend using at least three repeat surveys per location within a relatively short time-frame to minimise the risk of recording false absences (MacKenzie & Royle 2005). In this study, an observer's ability to detect a bellbird (where present) was only 60% when a single five-minute point count was carried out at each location, but increased to c. 90% with three replicate counts and almost 100% with five counts (Fig. 2a). Occupancy estimates calculated using three replicate counts were lower, but not statistically different, than those based on six replicates (Fig. 2b). This suggests that the lower level of sampling effort will yield similar results. However, as the true level of occupancy is not known for our study area, we cannot assess the relative accuracy of these occupancy estimates, or whether the observed difference is important from an ecological perspective.

For the purposes of our study, we assumed that each five-minute count within a given survey period was an independent

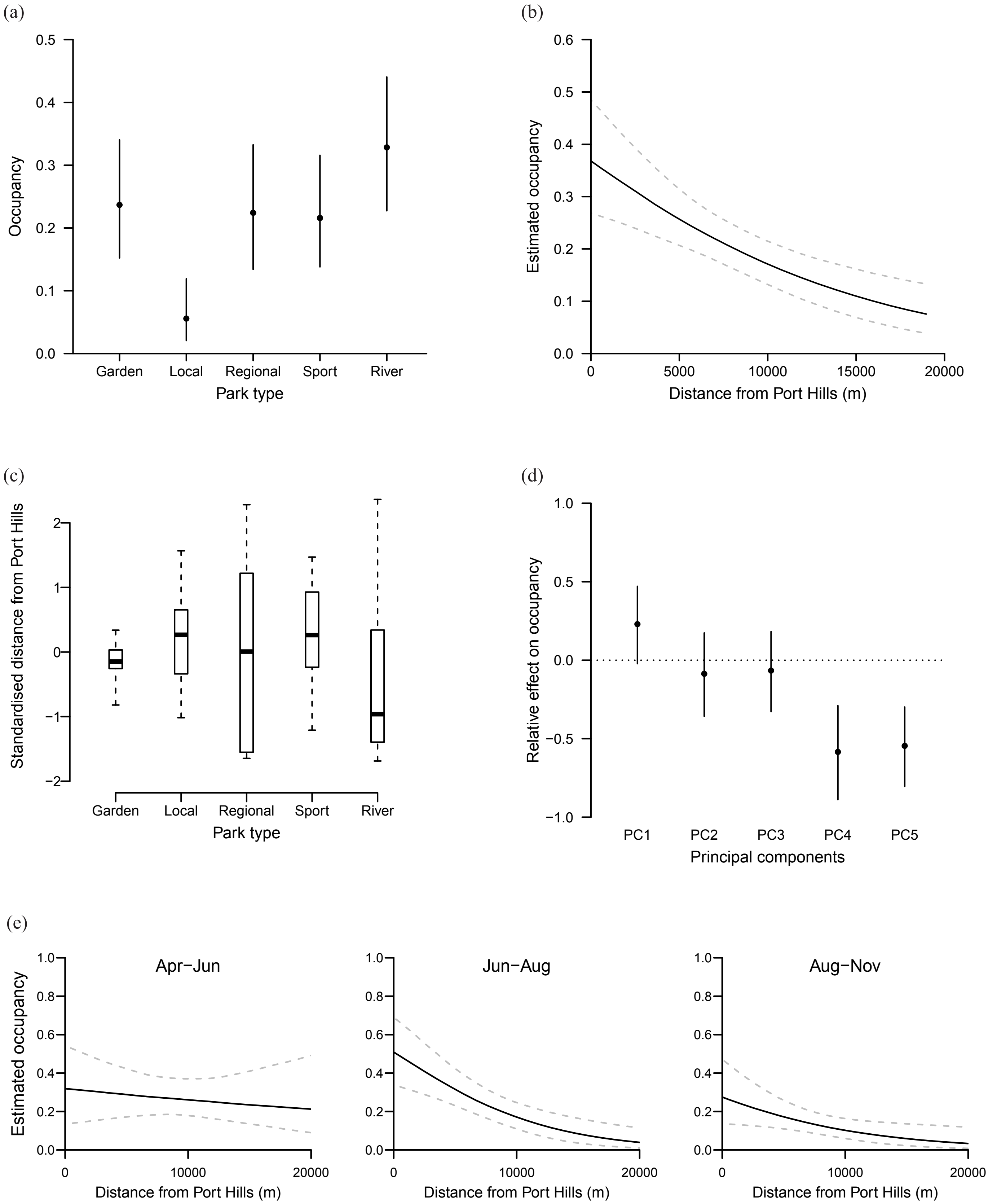


**Figure 3.** (a) Occupancy estimates (mean ± 95% CI) for each park type; (b) occupancy (solid line, with 95% CI indicated by dotted lines) in relation to distance from the Port Hills; (c) box-plots showing distribution of (standardised) distance of different park types from Port Hills; (d) occupancy (mean ± 95% CI) in relation to habitat composition (based on principal component scores; see Table 2); and (e) occupancy (solid line, with 95% CI indicated by dotted lines) in relation to distance from the Port Hills and survey period.

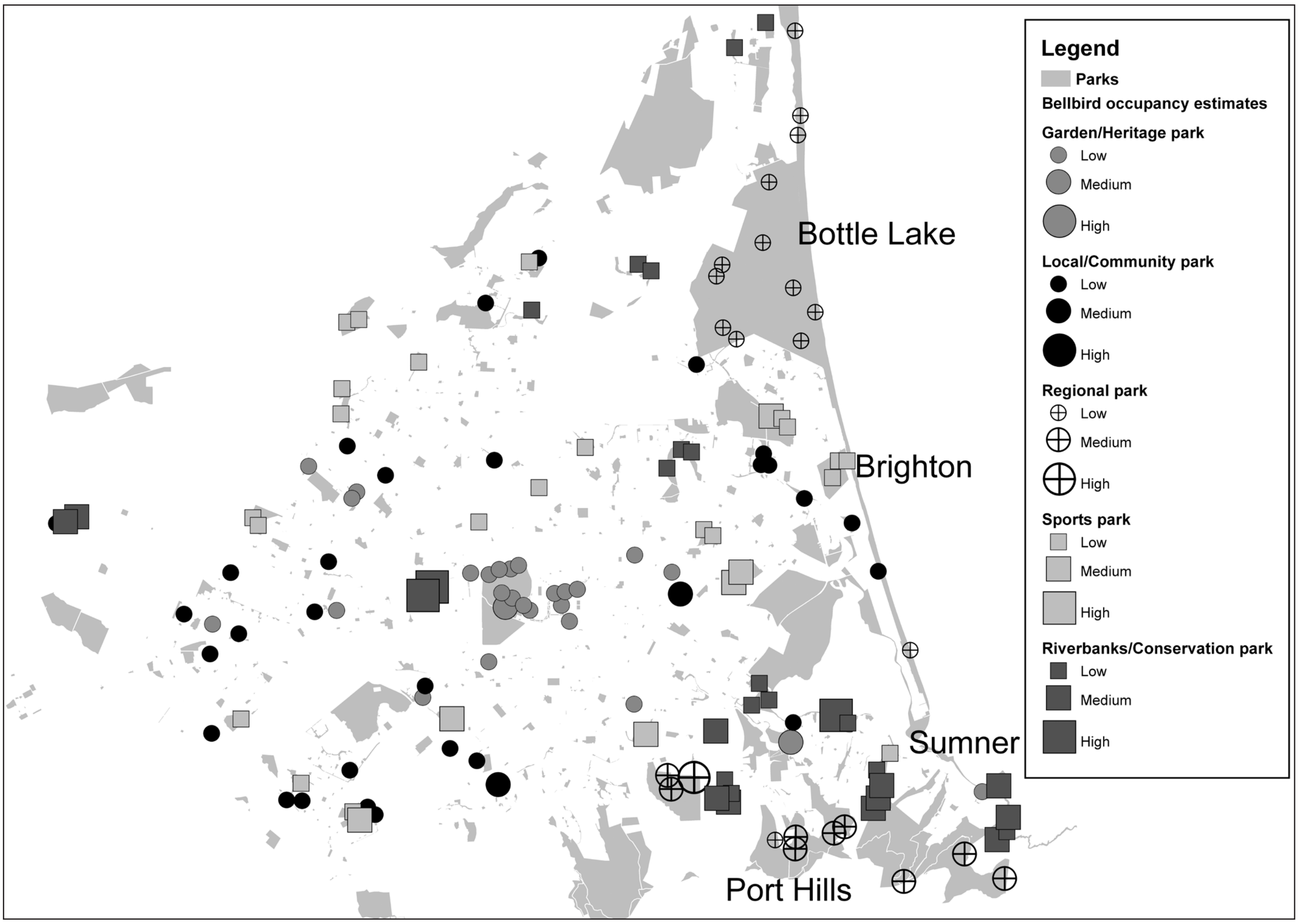


**Figure 4.** Bellbird occupancy estimates (Low = 0.01–0.32; Medium = 0.33–0.62, High = 0.63–0.94) extracted from the best-fit model (which included variables for habitat composition and distance from the Port Hills, *ψ{habitat [PC4, PC5]+distance}*) in relation to park type.

survey. A 5 min interval between repeat counts on the same day was selected based on practical considerations, where we aimed to optimise the number of repeat counts per location and the number of locations sampled on any given day. To determine whether the duration of the bird counts and interval between counts are appropriate, more detailed information on the call rates of individual bellbirds present at a location is required.

Ideally, all locations should be surveyed concurrently to acquire robust estimates of bellbird occupancy and distribution for a given survey period (MacKenzie & Royle 2005). This is because estimation methods assume that the sampling locations are closed to changes in occupancy for the duration of the repeated surveys. However, this assumption may be relaxed if changes in occupancy status of sampling locations occur at random. Prolonging the time taken to complete a survey of all locations increases the risk of bird movement occurring, and thus a shift from measuring occupancy to ‘use’. This is important, as the proportion of area ‘used’ by a species over time is often larger than the proportion of the area where it physically occurs at any given point in time. In the current study, a single observer took 2 months to sample all 140 locations within a survey period, primarily due to the time constraints associated with travelling among locations. For the latter two survey periods, bellbird activity did not appear to change markedly at each survey location between Day 1 and Day 2, as occupancy estimates for each day (based on three replicate counts) were comparable. However, if the frequency of bellbird movements among locations was high within each 2-month survey period, it is possible that our surveys measured bellbird ‘use’ of parks rather than occupancy. While reducing the number of repeat counts to three (all completed on the same day) should halve the time required for a single observer to survey all locations, coordinating a team of volunteers or using automated acoustic recorders to survey several locations concurrently over a 1- or 2-day period would be preferable.

It is standard practice to record the environmental conditions (weather and noise) during five-minute bird counts (Dawson & Bull 1975). Yet, these variables appeared to have little effect on the observer’s ability to detect bellbirds in the current study, perhaps because rain and strong winds were avoided. A weak trend for a decline in bellbird detection probabilities was detected over the study period; the significance of this may have been underestimated as a survey-specific detection probability could not be calculated for the initial survey (when no repeat counts were undertaken). Hence, if measuring seasonal changes in bellbird distribution among urban parks is a key study objective, repeat counts should be carried out at each location during each season to allow more accurate estimates of detection probabilities.

**Key predictors of occupancy**

To inform management aiming to enhance bellbirds in Christchurch's urban parks, the main habitat features influencing their distribution need to be identified. Bellbird occupancy varied among the five park types, with highest estimates observed in Riverbank/Conservation parks and lowest ones in Local/Community parks (Figs 3a & 4). While this classification of parks (used by the local council to account for differences in management intensity, utility and vegetation composition) is potentially useful for planning, other measures may be more sensitive for prioritising management actions targeting bellbirds. For example, bellbird occupancy in Riverbank/Conservation may be enhanced, relative to other park types, because native woody vegetation restoration activity is concentrated in these areas (Fig. 1) or they are close to the Port Hills, where this species breeds in the native bush patches on the outskirts of the city (Figs 3 & 4; Spurr et al. 2010). Our measures of habitat composition (PC4 and PC5) and spatial location (distance from Port Hills) were stronger predictors of bellbird occupancy than park type (Table 4), with highest occupancy estimates observed in parks with more native woody vegetation and less paved areas close to the Port Hills. This suggests that habitat composition and proximity are important features of the landscape influencing bellbird distribution among parks. The main habitat of bellbirds nationally is dense diverse native vegetation (Higgins et al. 2001), and particularly middle and upper tiers of forests (Spurr et al. 1992; Warburton et al. 1992; O'Donnell & Dilks 1994). Thus, habitat restoration (planting native woody vegetation) for bellbirds should initially target parks near to the source population of bellbirds on the Port Hills but then progressively shift across the city to encourage this species to utilise other areas within the city boundary.

There was some evidence (albeit weak) of a temporal change in bellbird occupancy over the study period, with highest occupancy estimates in the initial survey period (April–June; Fig. 2b) when birds were also most evenly distributed across the city (Fig. 3e). However, our confidence in these results is limited by our study design, as only a single five-minute point count was carried out at each location in the initial survey. This again highlights the importance of repeat surveys at each location within each survey period.

## Conclusions

Selection of sampling locations within the study area should be random but may be stratified depending on the scheme's objectives. If the scheme aims to measure seasonal changes in the distribution of a species, then multiple surveys through the year will be required. Alternatively, if the objective is to measure long-term trends in occupancy, then annual surveys of the same locations at a particular time of year will be sufficient. Schemes aiming to measure occupancy, rather than 'use', should also aim to survey all sampling locations either concurrently or within as short a time frame as possible to minimise the risk of bias associated with non-random bird movements among locations. Accounting for imperfect detection is necessary to obtain unbiased estimates of occupancy. Information from repeated counts at each sampling location within a short time frame can be used to estimate detection probabilities and so should be an integral part of any bird occupancy monitoring scheme. Thus, citizen-science research initiatives aiming to monitor temporal changes in species occupancy and richness (Zipkin et al. 2010) could be enhanced using repeated counts to obtain more accurate estimates that will increase their statistical power to detect change. The New Zealand Garden Bird Survey, which involves multiple observers recording bird observations concurrently nationwide (Spurr 2012), is a prime example where repeated measures could be used to enhance the value and accuracy of the data collected. Future research should aim to identify the optimal number and timing of repeat counts by taking species' behavioural traits such as mobility and calling frequency into account.

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