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Advances in tools for bird population monitoring in New Zealand

Monitoring widespread and common bird species on New Zealand's conservation lands: a pilot study

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Abstract: Robust monitoring systems are required to improve the ecological outcomes of management actions aimed at preventing biodiversity loss. We present a pilot study that measured assemblages of widespread and common bird species at the national scale in New Zealand. Bird surveys were undertaken at 18 sampling locations (six per land cover class: forest, shrubland and non-woody) randomly selected from a national grid. The full sampling protocol (five count stations surveyed on each of two consecutive days) was implemented at 80% of sampling locations. Each survey consisted of a ten-minute bird count, with distance sampling carried out in the initial 5-min period and any new species recorded in the second 5-min period. Most observations were based on aural cues (particularly in forest and shrubland). On average, one additional species was recorded per sampling location in ten- versus five-minute counts. Analyses highlighted spatial heterogeneity as a major factor influencing detection probabilities both for species present and for individuals of those species at sampling locations. This issue is often overlooked when estimating bird population trends through time. Most endemic species were detected in forest, while native and introduced species were most frequently detected in shrub. Potential uses of the information collected, along with recommendations for improving the sampling protocols, are highlighted.

Keywords: abundance, detectability, five-minute bird count, occupancy, species richness

Introduction

Under the Convention on Biological Diversity 2002, world leaders committed to significantly reduce the rate of biodiversity loss by 2010. However, indicators of the state of global biodiversity (quantifying species' population trends, extinction risk, habitat extent and condition, and community composition) show no significant recent reductions in rate of loss (Butchart et al. 2010). Furthermore, pressures on biodiversity (including resource consumption, invasive alien species, nitrogen pollution, exploitation, and climate change impacts) have increased (Butchart et al. 2010). Thus, signatories of the Convention recently agreed to a new target – to 'take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services' (Herkenrath & Harrison 2011).

To improve the effectiveness of policy and management actions aiming to halt or reverse declines in biodiversity, sustained investment in coherent global biodiversity monitoring and indicators is required. Since the 2010 target was set, biodiversity indicator development has progressed substantially; however, there are still considerable gaps due to heterogeneity in the geographic, taxonomic and temporal range of available data (Butchart et al. 2010). Also, a lack of information about the background rates and direction of change in ecological systems makes it difficult to distinguish change that can be attributed to specific factors, such as anthropogenic impacts, from underlying natural change (Magurran et al. 2010). Thus, there is a growing need for long-term datasets, collected using robust and well-designed methods, to gauge changes in biodiversity through time as well as to assess and inform management actions.

Long-term national biodiversity monitoring programmes are generally lacking in New Zealand. For example, national bird monitoring schemes have been limited to atlases mapping species distributions (Bull et al. 1985; Robertson et al. 2007) and, more recently, the Garden Bird Survey (Spurr 2012) and the OSNZ eBird survey (Scofield et al. 2012). These bird surveys all rely on observations from volunteers. Consequently, the spatial distribution of sampling effort is biased towards particular

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regions or localities, especially those that are accessible or have specific species or habitats of interest. In addition, most published bird studies in New Zealand (usually investigating relationships between species distributions or abundance and pest, environmental and topographical parameters) use information collected from a limited number of sampling locations within a particular region and over a short time-frame (2–5 years; see review in Hartley 2012). Evidence of significant declines in New Zealand's common and widespread native species is lacking and primarily limited to site-specific data, with intermittent or anecdotal observations (e.g. Harper 2009; Elliott et al. 2010).

Approximately one-third of New Zealand's land area is administered by the Department of Conservation as conservation land, which is protected for scenic, scientific, recreational, historical or cultural reasons. To report on the effectiveness of its biodiversity management programmes in these areas, the Department of Conservation recently developed a natural heritage management system (NHMS; Lee et al. 2005). This system will provide a more rigorous approach than is currently available to quantify biodiversity and its threats on conservation land at both national and regional scales (Allen et al. 2009). It includes five indicators measuring (1) assemblages of widespread animal species (birds), (2) distribution and abundance of exotic weeds, (3) distribution and abundance of exotic pests, (4) size-class structure of canopy dominants, and (5) functional characteristics of plant and bird communities. These indicators will be used to address four key goals on conservation lands, with separate complementary indicators being developed for monitoring managed ecosystems and threatened species (Lee et al. 2005; Allen et al. 2009):

1) Reporting of biodiversity status and trend
2) Prioritising resource allocation for management actions
3) Assessing the effectiveness of management and policy
4) Providing an early-warning system for biodiversity.

Most of New Zealand's avian research and monitoring effort to date has focused on rare and endangered species, particularly those in forest habitats (Innes et al. 2010). However, monitoring changes in widespread and common bird assemblages is also important, as these species may help maintain key ecosystem services and functions (Gaston 2010). Thus, development of a bird indicator that aims to measure temporal shifts in assemblages of widespread and common bird species (Measure 5.1.2 in the Natural Heritage Management System; Lee et al. 2005) is timely. To fulfil this objective, bird monitoring techniques are required that can be implemented in a wide variety of habitats yet provide some flexibility for measuring temporal (and spatial) shifts in bird assemblages not anticipated at the outset.

Over the last forty years, the primary method for monitoring New Zealand's bird populations has been the five-minute bird count (5MBC; Dawson & Bull 1975; Hartley 2012), where the observer records all birds detected around an unbounded point. However, it is difficult to reliably assess and compare the status and trends of common and widespread bird species over time or across different habitat types using this method, as it does not allow for systematic changes in bird detectability over space or time (Gregory & Greenwood 2008). To facilitate the development of more robust measures for the NHMS, we test the feasibility of modifying the 5MBC approach to incorporate methods that explicitly measure and account for variation in species detection probabilities when estimating occupancy (MacKenzie et al. 2002; MacKenzie & Royle 2005) and abundance (Buckland et al. 2001; Thomas et al. 2010). Here, we consider the pros and cons of this modified approach, presenting the findings of a pilot study in light of its applicability in the field, the quality of data, and potential improvements. We also illustrate how this indicator could be used to address the NHMS's four goals, using our preliminary national estimates of species richness, occupancy, and density.

Methods

Sampling locations and timing

Bird surveys were carried out between 20 October and 23 December 2008 (during the breeding season) at 18 fixed sampling locations selected from a national 8 × 8 km grid overlaying all conservation land (n = 1311 possible locations). The grid is a modified version of the Ministry for the Environment's Land Use Carbon Accounting System grid (LUCAS; Payton et al. 2004) that excluded grid points with a slope > 65° (as derived from a high resolution digital elevation model; Barringer et al. 2002). To test the feasibility of implementing the bird survey method within different habitat types, we randomly selected six sampling locations from each of three broad land cover classes (forest, shrubland and non-woody), using a stratified sampling design at the national scale. Forest and shrubland locations were selected from existing 20 × 20 m vegetation plots, using LUCAS field classifications of land cover (Table 1). Non-woody vegetation sampling locations were identified and added using grid locations classified as 'tussock grassland' in the Land Cover Database (LCDB1; Thompson et al. 2004). As no vegetation plots existed within non-woody vegetation, new vegetation plots were established at the start of the study. To minimise the risk of bias arising from seasonal movements of some species and seasonal differences in detectability, surveys were undertaken over as short a period as possible, with field teams working roughly from north to south and east to west, accessing sampling locations as field conditions allowed.

Bird survey method

Each location was considered an independent sampling unit, at which species richness, occupancy, and density were estimated from a cluster of five count stations, one cluster centred on the vegetation plot and one located 200 m directly away from each plot corner (Fig. 1; ensuring a separation distance of c. 200 m between count stations). Surveys were carried out on each of two consecutive days at each of the five count stations for each sampling location. Surveys were not undertaken in heavy rain, strong winds or poor visibility. To minimise the effects of diurnal variation in vocalisation and to ensure comparability with historical 5MBC data (Hartley 2012), all counts were initiated at least one hour after the official sunrise time for the sampling location (hence surveying only diurnal species; sunrise times for each day and location were calculated using the 'sunriset' function in the 'maptools' package in R; Lewin-Koh et al. 2008). Field teams were asked to complete counts as quickly as possible but the timing of bird surveys was constrained because the same team also had to set up and check possum trap-lines (Allen et al. 2009).

For each replicate bird survey, a ten-minute bird count (10MBC) was used, with an observer and a recorder present at the count station. Distance-sampling procedures were incorporated into the first five minutes (5MBC) of each

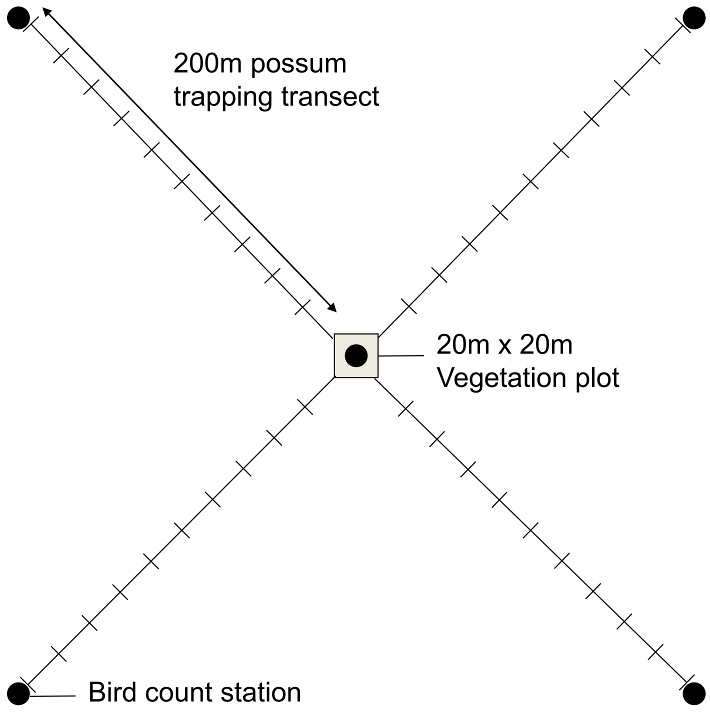

Figure 1. Position of bird count stations in relation to the layout of a vegetation plot and possum trapping transects at each sampling location.

10MBC, using a point-transect sampling approach (Buckland et al. 2001). During the 5MBC, the number of individuals detected (flock size) at each observation was recorded, in addition to whether individuals were initially heard or seen, and the horizontal radial distance from the count station to the point of first detection. Where it was not possible to accurately determine the distance, the observer was asked to identify in which distance-band the bird was located (0–50 m; 51–100 m; and >100 m from the count station). Birds only observed flying overhead (i.e. not associated with the sampling location) were also distinguished, except for skylark, for which the horizontal radial distance to the bird was recorded. Where birds in close proximity to the count station were obviously disturbed by the approach of the observer, care was taken to note the identity and, where possible, original location of those birds. The observer also recorded whether or not birds moved towards them. During the 6–10 min period of the 10MBC, observers only recorded any new species not observed in the initial 5MBC.

Species richness

To test whether species richness (measured here as total number of species detected) per sampling location increased when the count duration was extended, we compared matched estimates from the unbounded 5MBC and 10MBC datasets using a one-tailed paired *t*-test. To illustrate how these estimates (from unbounded 10MBC estimates) could be used to address the four NHMS goals (reporting, prioritisation, assessment of management actions and early warning), we classified species as endemic, native, or introduced (Heather & Robertson 2000) and according to their conservation threat category (Miskelly et al. 2008).

Species occupancy

Biased estimates of occupancy are obtained when species present at a given sampling location are not detected (i.e. false absences are recorded; MacKenzie 2005). This can result in incorrect inferences about the ‘value’ of different habitats, or temporal changes in species occurrence, range, and distribution (MacKenzie & Royle 2005; Tingley & Beissinger 2009). Unbiased occupancy or use estimates can be obtained by implementing methods that explicitly estimate detection probabilities using information from multiple surveys of the sampling location over a relatively short time-frame (e.g. MacKenzie & Royle 2005). We used a modelling approach that performed simultaneous logistic regression analyses on both occupancy and detection probabilities (MacKenzie et al. 2002). For each sampling location, we assumed that each bird survey at each count station was an independent repeat survey, providing 10 repeat surveys per sampling location. This level of sampling will be more than sufficient for most species of interest except for those with very low detection probabilities (<0.2), or those with low detection probabilities (c. 0.2) that are widely distributed (i.e. occupancy probabilities > 0.6; MacKenzie & Royle 2005).

We used these repeat surveys to calculate the effect of land cover class and varying sampling effort on estimates of occupancy and detection probabilities for six species (bellbird *Anthronis melanura*, chaffinch *Fringilla coelebs*, fantail *Rhipidura fuliginosa*, hedge sparrow *Prunella modularis*, rifleman *Acanthisitta chloris*, yellowhammer *Emberiza citrinella*), with different calling and behavioural traits likely to influence an observer’s ability to detect them. As the likelihood of detecting cryptic or inconspicuous species (that either call or move infrequently) increases with longer counts (Buckland et al. 2001; Greene et al. 2010), we tested the effects of increasing the duration of the bird count period from 5 min (Dawson & Bull 1975; Hartley 2012) to 10 min. For each species, four datasets were analysed: bounded 5MBC, unbounded 5MBC, bounded 10MBC, and unbounded 10MBC. The 5MBC datasets only included information collected during the 0–5 min period of 10MBC datasets, and bounded counts had a fixed radius of 100 m (note distance was only recorded for the 5MBC, so the area surveyed in the 6–10 min period of the 10MBC was always an unbounded area). Four models were then fitted to each dataset to test whether detection and occupancy probabilities varied in relation to land cover class (Appendix 1). The models were ranked according to AICc, and model averaging was used to estimate detectability and occupancy probabilities.

Species density

Distance sampling estimates the probability of detecting an individual bird as a function of distance from the observer, to produce unbiased measures of species density (Buckland et al. 2001). Note that detection probabilities in distance sampling are individual-based and are different from the species-level detection probabilities associated with occupancy estimation. We modelled variation in detection probabilities among species and habitats (using the Distance Version 6.0 software; Thomas et al. 2010). After excluding all observations taken > 100 m from the count station, all distance measures were subdivided into two distance bands (0–50 m and 51–100 m). Sampling effort was specified in the models as two surveys for each count station per sampling location. Models were constructed for the five species having greater than 50 observations across all counts (i.e. within the sample size threshold [40–60 detections] recommended for distance sampling analyses; Buckland et al. 2001): bellbird, chaffinch, grey warbler (*Gerygone igata*), silvereye (*Zosterops lateralis*) and tomtit (*Parus macrocephalus*). The best-fit detection function was identified using a two-stage process. Initially, we only fitted a base model with a half-normal key function without any series expansions, as other distributions available either do not allow the inclusion of covariates (uniform) or have an implausible shape (exponential). We then tested for heterogeneity in detectability (Marques et al. 2007) in relation to the detection cue (seen or heard) and land cover class by adding these covariates to the base model independently. Best-fit models were identified using Akaike's Information Criterion (AIC), excluding any poor-fitting models (those that failed to converge or that had very high coefficient of variances for density).

Results

Field implementation

Five count stations were set up at 16 of the 18 sampling locations, with four count stations established at the two remaining sampling locations (Table 1). The 200-m separation distance between count stations was not maintained at two sampling locations because physical barriers were encountered while setting up the possum trap-lines. The complete sampling protocol (five count stations, with the recommended 200-m separation distance between them) was, therefore, implemented at 80% of sampling locations. The LCDB classification of non-woody vegetation sampling locations was generally inaccurate, as field observations indicate these locations were not 'tussock grassland' but primarily depleted grasslands or gravel and rock (Table 1).

Table 1. Summary of sampling location information showing (a) the Land Use Carbon Accounting System (LUCAS; Payton et al. 2004) grid reference and New Zealand Transverse Mercator coordinates, (b) the land cover class according to land-cover database (LCDB1; Thompson et al. 2004) and field observations, along with the simplified classification used in our analyses, and (c) the number of count stations established and the distribution of the three observers among the locations.

Sampling location			**Land cover class**			**Bird survey**	
LUCAS grid reference	Easting	Northing	LCDB1	Field observations	Analysis	Number of count stations	Observer identity
CI76	1753972	5627170	Indigenous forest	Indigenous forest	Forest	5	1
AB144	1282007	5083211	Indigenous forest	Indigenous forest	Forest	5	2
BQ105	1610051	5395209	Indigenous forest	Indigenous forest	Forest	5	3
BJ109	1554073	5363210	Indigenous forest	Indigenous forest	Forest	5	1
BV99	1650032	5443173	Indigenous forest	Indigenous forest	Forest	5	1
DE66	1930002	5707328	Indigenous forest	Indigenous forest	Forest	5	3
L158	1153945	4970938	Shrubland	Shrubland	Shrubland	4	1
AU126	1433799	5227246	Shrubland	Shrubland	Shrubland	5	1
BS12	1625117	6138769	Shrubland	Shrubland	Shrubland	5	2
Z143	1266033	5091207	Indigenous forest	Shrubland	Shrubland	5	2
CR90	1826017	5515173	Indigenous forest	Regenerating indigenous forest (shrubland)	Shrubland	5	1
CZ73	1892465	5652641	Indigenous forest	Shrubland	Shrubland	5	3
BJ113	1554057	5331218	Tussock grassland	Alpine gravel & rock	Non-woody vegetation	4	2
AM142	1370085	5099240	Tussock grassland	Low producing grassland	Non-woody vegetation	5	1
BQ113	1610035	5331211	Tussock grassland	Depleted grassland	Non-woody vegetation	5	1
BN113	1586045	5331214	Tussock grassland	Depleted grassland/alpine gravel & rock	Non-woody vegetation	5	1
K165	1146005	4914816	Tussock grassland	Alpine gravel & rock	Non-woody vegetation	5	2
AD144	1298055	5083204	Tussock grassland	Alpine shrubland	Non-woody vegetation	5	2

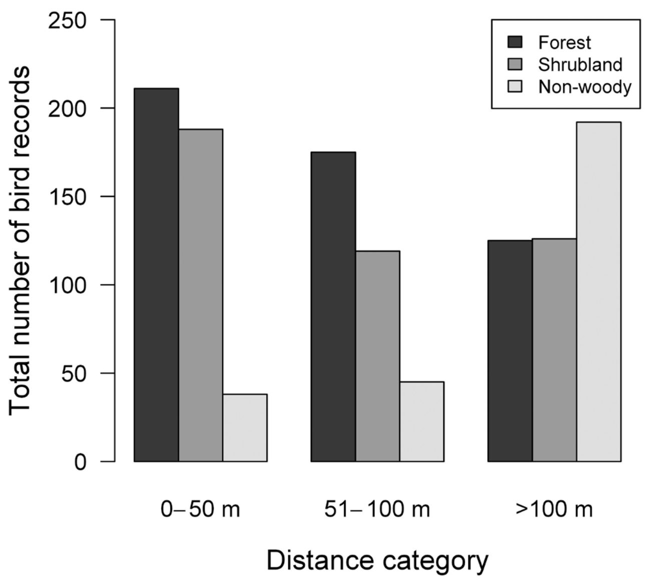

Figure 2. Distribution of bird observations (from unbounded 5MBC data) in relation to distance categories and land cover.

Count start-times ranged from 1 to 8 h after dawn, but the majority of counts occurred between 3 and 5 h after dawn (interquartile range). During the unbounded 5MBC, five species were recorded as moving towards the observer (percentage of records: kea *Nestor notabilis* 13%, tomtit 2%, fantail 8%, New Zealand robin *Petroica australis* 2% and banded dotterel *Charadrius bicinctus* 20%; for actual number of records see Appendix 2) but only one species away from the observer (redpoll *Carduelis flammea* 2%). For most species, observations were primarily based on aural cues rather than visual ones (mean ± SE percentage observations heard per species: 72 ± 5%). A higher amount of observations per species were based on aural cues in forest (93 ± 2%) and shrubland (79 ± 6%) sampling locations than in non-woody vegetation (58 ± 8%). Exact distance measures were only reported for approximately 40% of observations, with the remainder grouped into the three distance bands (0–50 m; 51–100 m; >100 m). The distribution of observations among the distance bands varied in relation to land cover class, with most observations in forest and shrubland sampling locations close to the count station, but the reverse pattern observed in non-woody vegetation (Fig. 2).

Species richness

On average 1.05 ± 0.24 SE more bird species were recorded per sampling location in the unbounded 10MBC than in the matched unbounded 5BMC (t = 4.49, d.f. = 17, P < 0.0002). Although fewer species were detected (per sampling location during unbounded 10MBCs) in non-woody vegetation (mean ± SE; 9.67 ± 1.31 species) than in forest (12.17 ± 0.95) and shrubland (12.50 ± 1.06), this pattern was not statistically significant (linear regression: $F_{2, 15}$ = 1.93, P = 0.18).

Most endemic species were detected in forest, while native and introduced species were most frequently detected in shrubland (Fig. 3a). Similar numbers of endemic and introduced species were detected in non-woody vegetation. The amount of species detected in shrubland and non-woody vegetation that were introduced (40 ± 4% and 39 ± 5%, respectively, per sampling location) was almost double that in forest (26 ± 2%).

Based on the conservation threat categories, more 'at-risk' and introduced species were detected in shrubland than forest and non-woody vegetation (Fig. 3b). 'Threatened' species were detected more frequently in non-woody vegetation relative to forest and shrubland, where 'not threatened' species were prevalent.

Species occupancy

For a given level of sampling effort, detection probabilities varied among the six focal species (Fig. 4). Bellbird and chaffinch were generally easier to detect relative to other species, particularly fantail. Detection probabilities varied among land-cover types irrespective of the count duration (5MBC vs 10MBC) or the area surveyed (bounded versus unbounded) for three species (rifleman, fantail and yellowhammer), but only for 5MBC for bellbirds and unbounded counts for hedge sparrows (Appendix 1; Fig. 4). For a subset of the focal species, detection probabilities increased slightly when the duration of the bird count increased (chaffinch and rifleman) and when an unbounded count, rather than a bounded one, was used (chaffinch, bellbird and hedge sparrow).

These models provide preliminary national estimates of occupancy for six focal species (Fig. 4), but should be interpreted with caution as only bellbird and chaffinch were detected in all three land cover classes. Occupancy estimates were consistently high for chaffinch (>0.8) and low for yellowhammer (<0.6). Occupancy only varied in relation to land cover for bellbird, fantail and hedge sparrow, but the effect size varied depending on the level of sampling effort (Appendix 1; Fig. 4). When unbounded rather than bounded counts were used, the precision of occupancy estimates decreased and the observed pattern of occupancy in relation to land use changed for bellbird and hedge sparrow (Fig. 4). The effect of varying the count duration on occupancy estimates and precision was variable within and among species.

Species density

Heterogeneity in detectability was identified for two of the five focal species when estimating density. Grey warbler was more likely to be heard than seen, while chaffinch was more easily detected in non-woody vegetation relative to forest and, particularly, shrubland. Of the five species considered, chaffinch was the most abundant and this was consistent across all three land cover classes (Fig. 5). Having accounted for any heterogeneity in detectability among the different land cover classes, densities for the five species also varied significantly among the land cover classes (linear regression: $p < 0.03$), with forest and shrubland sampling locations generally supporting highest densities.

While forest locations tended to consistently support higher densities of native species, the distribution of species varied among sampling locations (Fig. 6). For example, tomtit and silvereye densities in forest were inversely related to chaffinch densities at the same locations. In contrast, grey warbler densities corresponded broadly with chaffinch densities in both shrubland and forest. Highest densities of chaffinch, grey warbler and tomtit were all observed in shrubland but only at one or two locations.

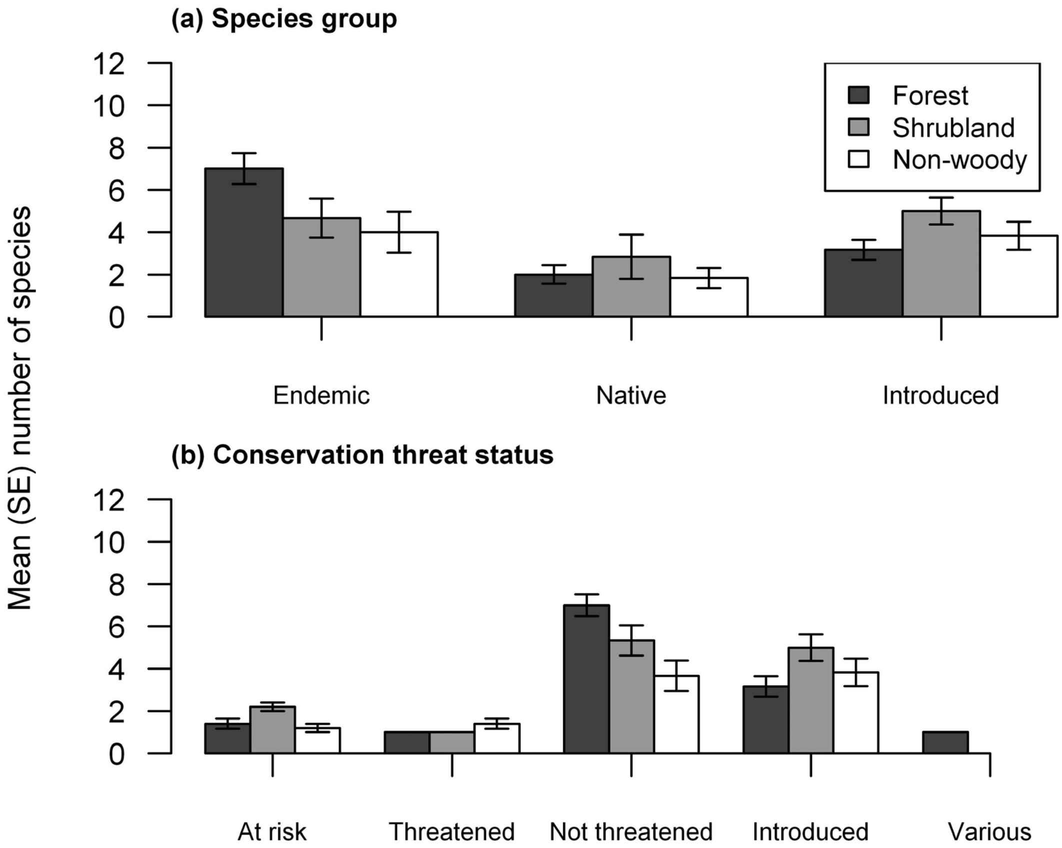

Figure 3. Mean (± SE) number of species per sampling location (a) for endemic, native and introduced species (Heather & Roberston 2000) and (b) classified according to conservation threat status (Miskelly et al. 2008) in relation to land cover class (n = 6 sampling locations per class), based on unbounded 10MBC. The 'Various' category in (b) was used for species groups where observers were unable to distinguish between specific species, in this case the parakeets (*Cyanoramphus* spp.).

Discussion

Advantages of the modified 5MBC

There were three clear advantages of modifying the traditional 5MBC (Dawson & Bull 1975). First, incorporating distance-sampling measures into the 5MBC allowed the area sampled around each station to be standardised (Fig. 2; Alldredge et al. 2007). This meant species richness, occupancy, and density estimates, with known confidence intervals, could be calculated. For unbounded counts, such estimates are less well defined as the area sampled is likely to vary for different land cover classes and topographies. Thus, we recommend that similar distance measures are also recorded for new species identified in the 6–10 min period of the 10MBC. Second, our distance and occupancy models calculated detection probabilities (Buckland et al. 2001; MacKenzie & Royle 2005; Thomas et al. 2010), which are often overlooked by 5MBC methodology (Dawson & Bull 1975). Although our analyses were based on few sampling locations (so had low statistical power to detect differences), heterogeneity in species detection probabilities was still observed in relation to distance from count station, or land cover classes, or detection cues. Distance sampling accounted for the probability of detecting individuals of the same species, while the occupancy models measured the probability of detecting a species given that it was present at a location. Future analyses should also account for species detection probabilities when estimating species richness (e.g. Zipkin et al. 2010). Third, increasing the duration of the recording period from 5 to 10 min increased the number of species detected at each sampling location, as the likelihood of detecting cryptic or inconspicuous species (e.g. kererū *Hemiphaga novaeseelandiae* and kākā *Nestor meridionalis*) that call or move infrequently increased (Buckland et al. 2001; Greene et al. 2010). The 10MBC was a cost-effective strategy for increasing sampling effort to measure species richness and occupancy, given the time constraints of navigating between stations at each location (Gregory & Greenwood 2008; Allen et al. 2009).

Independent repeat counts

For the purposes of our analysis, we assumed that the two surveys (of the five count stations) on consecutive days were independent. However, when the larger NHMS dataset becomes available, these surveys should not be treated as independent. It was also difficult to ensure that the repeat surveys of each location were independent for all species, as this depended on each species' mobility and their responsiveness to observers. For example, for highly mobile species with low levels of occupancy, a wider distribution of count stations may be desirable. However, this is unlikely to be practical or feasible given the costs associated accessing and navigating sampling

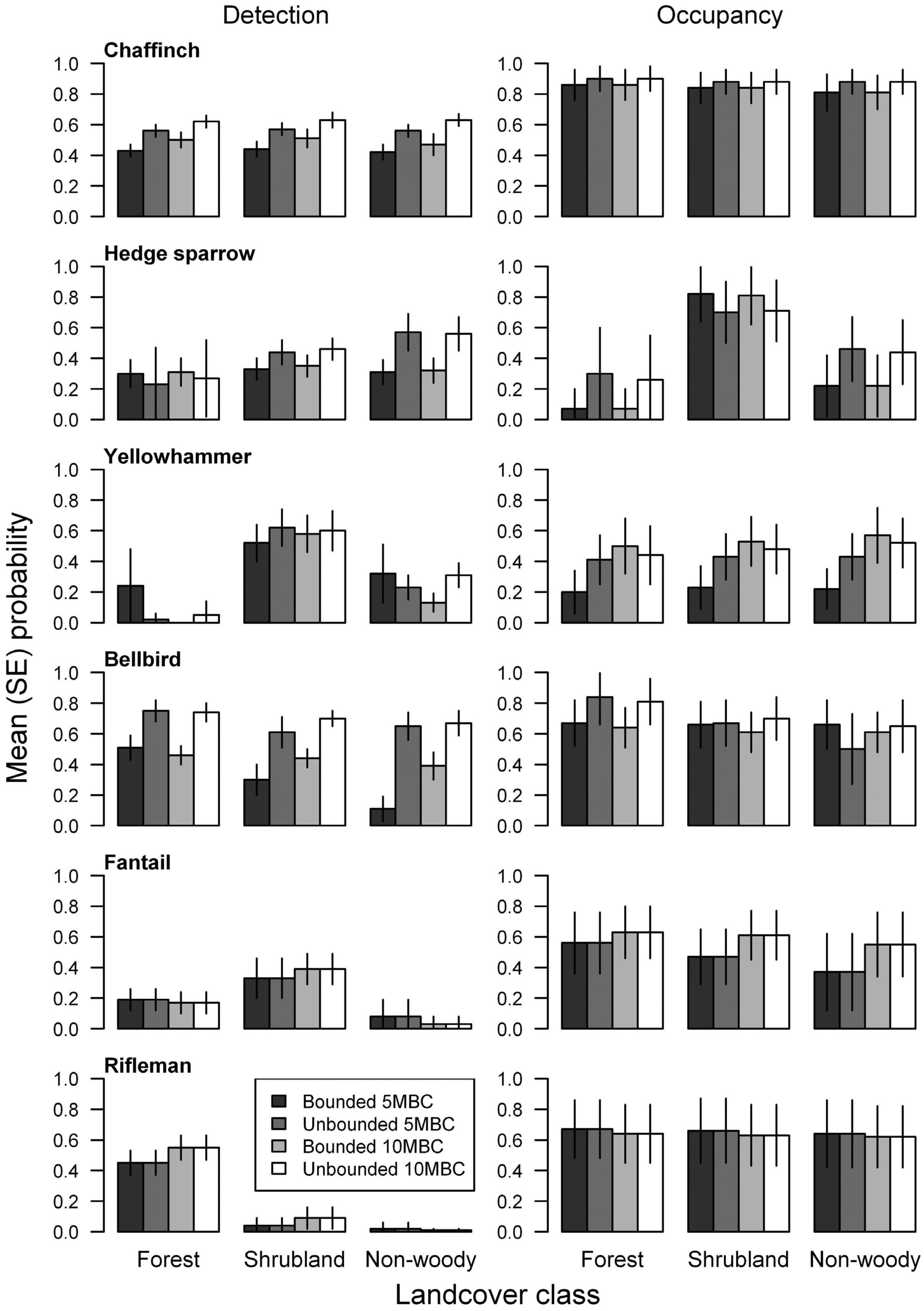

Figure 4. Model-averaged parameter estimates (±SE) for models fitted to four different datasets to test the effect of land cover class and sampling effort (varying the duration of the recording period and count station radius) on occupancy and or detection probabilities for six species (bellbird *Anthronis melanura*, chaffinch *Fringilla coelebs*, fantail *Rhipidura fuliginosa*, hedge sparrow *Prunella modularis*, rifleman *Acanthisitta chloris*, yellowhammer *Emberiza citrinella*). Note that fantail and rifleman were never seen in non-woody vegetation, rifleman were only once in shrubland, and hedge sparrow and yellowhammer were never seen in forest.

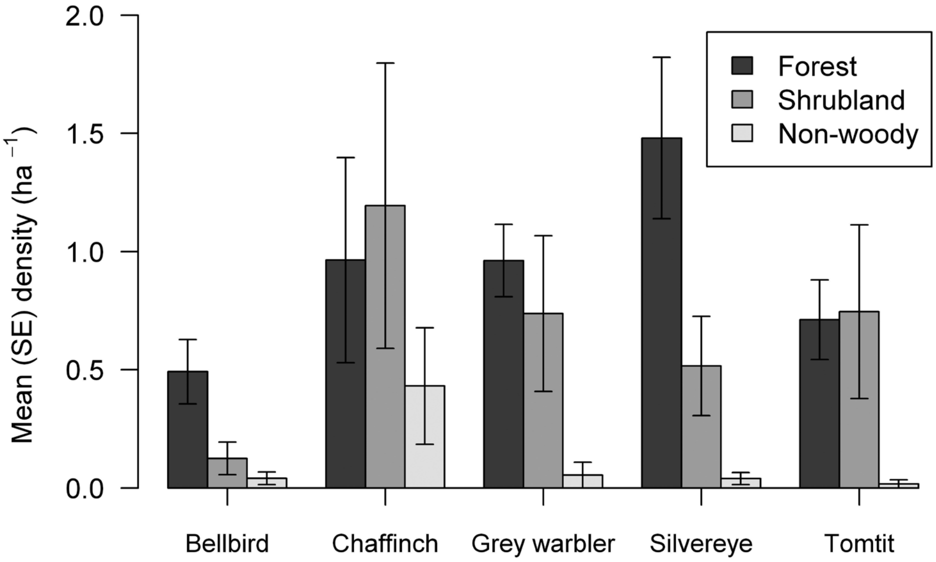

Figure 5. Mean (±SE) density (ha^{-1}) in relation to land cover class (n = 6 sampling locations per class) for five species (bellbird *Anthronis melanura*, chaffinch *Fringilla coelebs*, grey warbler *Gerygone igata*, silvereye *Zosterops lateralis,* tomtit *Parus macrocephalus*), extracted from the best-fit detection functions (modelled using Distance software) based on the bounded 5MBC (see Appendix 2 for number of observations per species).

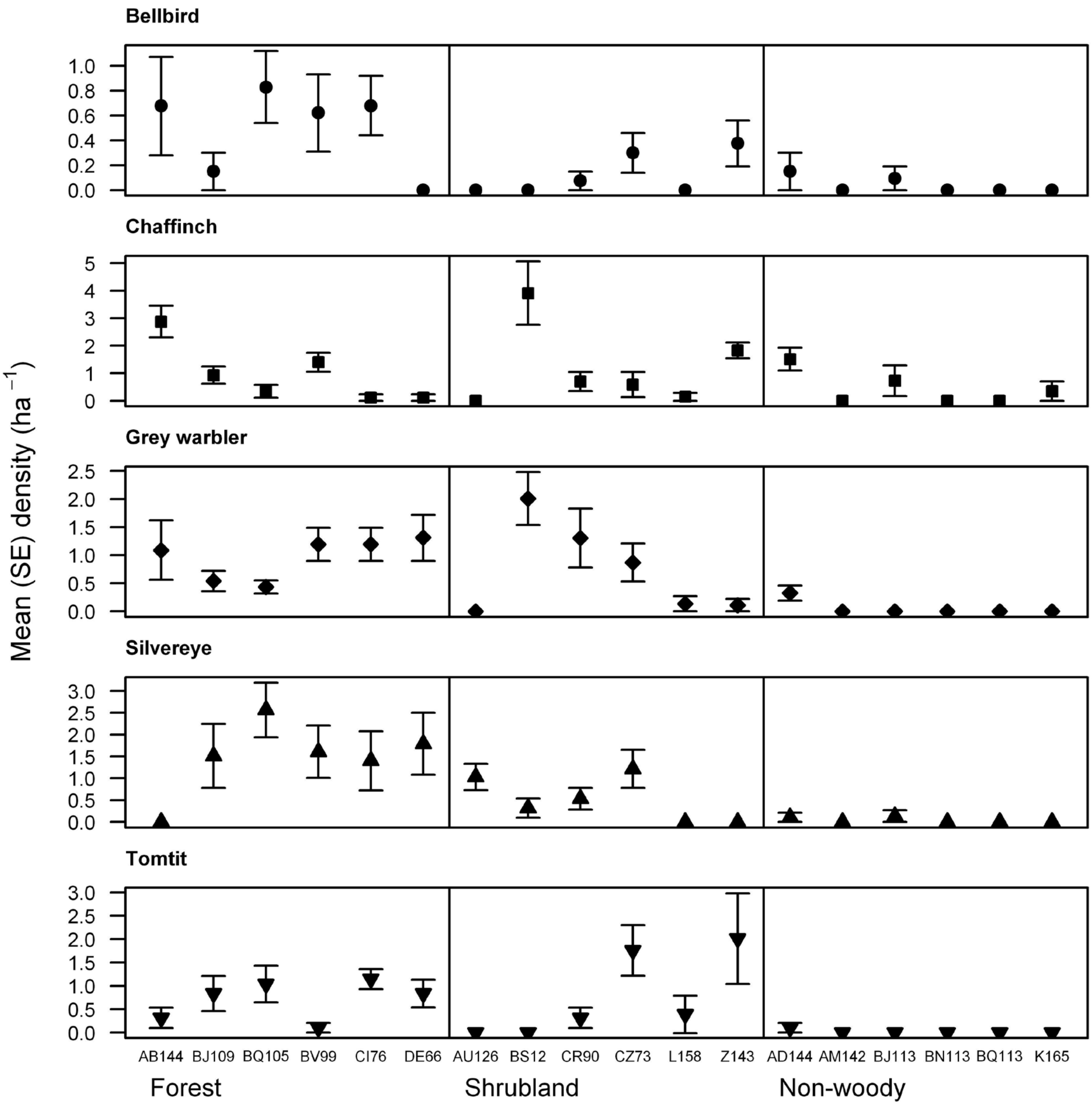

Figure 6. Land cover class and sampling locations for five species (see Fig. 5).

locations (Allen et al. 2009). MacKenzie and Royle (2005) recommend more intensive surveys of fewer sampling units for estimating occupancy for common species, but the reverse for rare species. The NHMS will have to balance the need for an intensive sampling effort per location with the number of sampling locations surveyed at the national scale. The 'best' design could be quite different depending on whether the main focus of the monitoring scheme is to get good density estimates or occupancy estimates for some key indicator species or to get good regional or national estimates of current biodiversity. Thus, maximising the number of sampling locations may not be a good idea, if there is insufficient sampling effort within locations to achieve the desired aim.

Measuring distance

As too few distance intervals were used in the pilot study, only single-parameter detection functions could be fitted to estimate density and the adequacy of model fit could not be tested (Buckland et al. 2001). We recommend grouping data into seven distance intervals with progressively wider bands away from the point, because distances further away are harder to measure accurately (especially for aural cues in dense vegetation) and provide less information for modelling (Buckland et al. 2001; Alldredge et al. 2007). Having more intervals provides some flexibility for truncating and amalgamating distance bands when fitting detection functions because some species will only be detected close to the count station (e.g. rifleman) while others will also be detected further away (e.g. bellbird), particularly in non-woody vegetation where they are more visible or likely to respond to observer presence. Using bounded counts will also minimise the risk of sampling bias associated with variation in sampling area and accuracy of distance measurements in different habitat types.

Responses to observer activity

Bird movement in response to the observer was detected for 14% of species but was probably underestimated for two reasons. First, recording was rarely initiated on arrival at the count station as the observer's ability to detect birds was impaired by the physical exertion of navigating difficult terrain. Second, disturbance in the vicinity of the count station was unavoidable while checking possum traps. We recommend observers approach count stations slowly and quietly, with minimal disturbance (i.e. working independently of other activities). We do not encourage the use of an acclimatisation period to allow birds to return to the original locations and settle (Johnson 2008, but also see Buckland 2006; Gregory & Greenwood 2008). For species known to respond to observer activity (e.g. Greene & Pryde 2012), occupancy, rather than abundance, may provide a more robust measure for monitoring.

Applicability

The NHMS sampling universe is currently defined as all sampling locations on lands administered by the Department of Conservation with slopes ≤ 65°. Implementing our sampling protocol should be feasible for at least 80% of those locations. Careful consideration will need to be given to systematic biases arising from having inaccessible or partially sampled locations (e.g. steep and challenging terrain in non-woody vegetation). While retrospective stratification may account for bias (by giving greater weight to data collected in under-sampled habitats), the sampling universe definition will need to be re-evaluated regularly (Gregory & Greenwood 2008).

Most bird observations in the pilot study were based on aural cues, emphasising the need for trained observers with good bird identification skills. Testing observers prior to each field season will identify potential biases in hearing ability and identification skills, while training should reduce the risk of observer bias. Ensuring these requirements are consistently met over time is important to reduce noise in the data. Retaining the same observers should also be a priority to ensure standardised sampling over time. Future research should determine measurement error (e.g. Alldredge et al. 2007) to quantify correction factors that can be incorporated into estimates.

Habitat information will be important not only for accounting for heterogeneity in detectability, but also for interpreting changes in bird assemblages over time (Gregory & Greenwood 2008). Thus, the broad topographic and vegetation characteristics (structure and cover) of each count station should be quantified using a standardised vegetation sampling protocol (Hurst & Allen 2007); in this pilot study the LCDB1 classification of land cover for each sampling location was generally inaccurate (Table 1; Coomes et al. 2002; Brockerhoff et al. 2008). In the future, other national vegetation classifications currently under development may also be informative (e.g. Wiser et al. 2011).

Development

While the NHMS development represents a significant first step towards meeting New Zealand's legal obligations to the Convention on Biological Diversity (Herkenrath & Harrison 2011), the system currently targets conservation land only. To demonstrate that no loss of biodiversity occurs at the national scale, the system will need to be extended nationally or carefully integrated with other monitoring schemes (e.g. MacLeod et al. 2012; Scofield et al. 2012; Spurr 2012). The system will also require cost-effective tools for checking, storing, processing and summarising large volumes of data (Voříšek et al. 2008). Development of simple, accurate, understandable and meaningful indicators for reporting will also be needed (e.g. Gregory et al. 2005; Butchart et al. 2010). Priority needs to be given to the latter, as it will determine the optimal field sampling design.

Designing a sampling methodology where all species fulfil its assumptions is difficult. However, while the NHMS focuses on measuring common and widespread species assemblages, it also has the potential to assist with the monitoring of threatened species (Fig. 3b). Thus, we recommend recording all species observed, rather than a subset of focal species, to retain some flexibility for measuring changes not anticipated at the outset. If currently rare species become common over time for example, the NHMS' power to detect those changes would be limited if only the focal species were monitored. A potential cost of recording all species is a reduction in the precision of density estimates, if observers are swamped recording detailed measures for each species. However, this was not identified as an issue in the pilot study.

In this study, we specified a 5-min recording period for the distance-sampling measures to facilitate comparisons with historical 5MBC data (Hartley 2012). While these historical 5MBC data were not originally recorded as part of a national monitoring programme (Hartley 2012), they may provide important baseline information for comparison with contemporary data (e.g. Tingley & Beissinger 2009). However, the validity of such comparisons is still to be determined, even though analytical tools that account for any temporal changes in detection probabilities (e.g. to changes in habitat structure) when calculating species richness and occupancy estimates are available (e.g. MacKenzie & Royle 2005; Tingley & Beissinger 2009; Tyre et al. 2003; Zipkin et al. 2010). Thus, we recommend retaining some flexibility to refine the field methods during the initial stages of implementing the NHMS. For example, a shorter recording period for some species (particularly highly mobile ones) may provide more precise estimates of abundance (e.g. Cassey et al. 2007), as an upward bias in abundance estimates may result if birds move into the area (Buckland et al. 2008). The optimal duration for recording for each species could be tested, if observers record which 1-min interval, in the 10MBC, each bird is first observed.

Focused methodological studies are also required to inform the survey design. For example, if unbiased estimates of density are considered a priority, then species responsive to observer activity can be estimated using more intensive sampling approaches (e.g. mark–recapture studies used to calculate correction factors to account for imperfect detection at the count location; Buckland et al. 2004).

Automated sound recordings, which are promoted for surveying species-rich populations when skilled observers are unavailable (e.g. Brandes 2008), may provide recordings of aural cues at several locations simultaneously. However, the ability of this technology to perform under a range of conditions still needs to be demonstrated to ensure that it is practically feasible to implement in the field at the national scale, without any systematic measurement biases arising (see review in Blumstein et al. 2011). Most automated sound recording devices are designed to provide indices of species abundance, occupancy and richness, and data processing costs are likely to be high. While significant technological and analytical advances in the use of automated sound recordings have been made to estimate density (Dawson & Efford 2009), these have only been demonstrated for one songbird species at one location.

The selection of occupancy versus abundance measures for NHMS reporting will not only depend on the species of interest and the amount of data available, but also on their sensitivity to change. For example, bellbird and chaffinch occupancy estimates were consistent across all land cover classes (based on bounded 5MBCs; Fig. 4), but these species were less abundant in non-woody vegetation than in forest or shrubland (Fig. 5). Thus, indicators monitoring these species' abundance, rather than their occupancy, may be more sensitive for assessing the effects of management actions in different land cover classes.

Value of data

The first NHMS goal is reporting of biodiversity status and trend (Lee et al. 2005; Allen et al. 2009). The public have a keen interest in the state of the nation's birds. Until now, the Department of Conservation has reported regularly on the status of populations of endangered endemic species such as kākāpō (*Strigops habroptilus*) and takahē (*Porphyrio hochstetteri*), which most members of the public are never likely to see in the wild. Yet there is good evidence that the public are just as interested in birds with which they are more familiar (e.g. Scofield et al. 2012; Spurr 2012; Sullivan 2012). The NHMS bird indicator will provide spatial information for a wider range of species. The pilot study indicates that most species located in shrubland and non-woody vegetation are at-risk and threatened, respectively (Fig. 3b). However, some shrubland locations also support high densities of common species, such as tomtits and grey warblers (Fig. 6). The NHMS will also provide time-series data to allow the public to see whether species' status or trends are unchanged, declining or improving.

The second NHMS goal is to prioritise resource allocation for management actions. For example, if introduced birds were identified as a major reservoir for avian disease (e.g. Sturrock & Tompkins 2008), then the pilot study indicates native and endemic species in shrubland and grassland habitats are most likely at risk, as the highest proportion of introduced bird species occurred in these habitats. Alternatively, if the chaffinch was identified as a significant reservoir for a disease threatening the grey warbler, then locations with high densities of both species could be targeted for management. The pilot study indicates management for this purpose could be limited to just 30% of locations in shrubland (Fig. 6).

The third NHMS goal is to assess the effectiveness of management and policy. The bird indicator will allow the Department of Conservation to answer public debate about whether its intensive management in local areas throughout New Zealand, including use of 1080 poison to control introduced mammalian predators (e.g. Parliamentary Commissioner for the Environment 2011), results in significant changes in bird species richness and abundance. Results from the pilot study indicate that prioritising forest habitat for pest management is appropriate, as more species and higher densities of endemic birds occurred in forests than in shrubland or non-woody vegetation (Fig. 5 & Fig. 3). Integrating NHMS bird data with the other NHMS indicators (e.g. measuring mammal pest and plant community composition) will allow the Department of Conservation to investigate the relative importance of different factors for maintaining bird populations at the national scale. Similarly, the NHMS bird data could be used to assess the effectiveness of different management actions, using spatial information about the habitat restoration efforts and predator control.

The fourth NHMS goal is to provide an early-warning system for biodiversity (Lee et al. 2005; Allen et al. 2009) that may be used to signal management responses or needs for research. For example, if national avifauna data had been collected in the past, this may have allowed an earlier management response to avert the decline in mohua (*Mohoua ochrocephala*; O'Donnell 1996). Similarly, although extensive reversion of grasslands to shrubland is likely to be motivated by a desire to provide services such as increased carbon sequestration (Payton et al. 2004), it could also provide increased opportunities for endemic and native birds.

Conclusions

This pilot study contributes towards the development of a standardised field survey technique that can be used to monitor New Zealand's bird assemblages within a wide range of habitats. It highlights the benefits of modifying the existing 5MBC method to produce more robust measures of species richness, occupancy and abundance, by quantifying and accounting for variation in species' detection probabilities. Recognising the limitations of the proposed methods and the small number of locations sampled in the pilot study, it also makes recommendations for future research to continue to refine the field protocols and analysis techniques. By providing unbiased and robust measures of bird assemblages on conservation land, this national-scale monitoring programme has the potential to monitor and inform both conservation management and policy actions, allowing New Zealand to demonstrate clearly that it is meeting its international obligations to halt biodiversity loss.

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