Received: 29 July 2021 | Accepted: 8 December 2021

DOI: 10.1002/2688-8319.12121

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

Assessing the state of New Zealand's garden birds from national to local scales

Catriona J. MacLeod[1] | Peter Green[1,3] | Simon Howard[2] | Andrew M. Gormley[2] | Angela J. Brandt[1] | Eric B. Spurr[2]

[1] Manaaki Whenua—Landcare Research, Dunedin, Otago, New Zealand

[2] Manaaki Whenua—Landcare Research, Lincoln, New Zealand

[3] AgResearch, Palmerston North, Manawatu-Wanganui, New Zealand

Correspondence
Catriona J. MacLeod, Manaaki Whenua – Landcare Research, Dunedin, New Zealand.
Email: macleodc@landcareresearch.co.nz

Funding information
Ministry for Business Innovation and Employment: Building Trustworthy Biodiversity Indicators, Grant/Award Number: C09X1308; Strategic Science Investment Fund for Crown Research Institutes; Ministry for the Environment, Grant/Award Number: (Contract No. 21135)

Handling Editor: Max Lambert

Abstract

1. Better biodiversity indicators are needed to address information gaps, describe trends accurately and robustly and be useful for decisionmakers. Citizen science's potential to help address these challenges often goes unrealized, despite promises by organizers to deliver such information.
2. This paper addresses these challenges by demonstrating the powerful utility of citizen science results for improving our knowledge of the state of New Zealand's garden birds, from the national to the local scale. For 14 species and three annual assessments, we: (a) calculate changes in bird counts over the medium to short term (over 10 and 5 years, respectively); (b) use an alert system to identify trends of interest or concern and collate the assessments in an online interactive tool; and (c) apply the results to address management questions.
3. Seven species have declined nationally in gardens in the medium term, but the population trends of six of these have improved in the short term (the declines of three have been reversed). For Otago, as a regional example, a wider range of medium-term alerts was initially raised, and positive short-term changes were also more evident. Performance differed across Otago's districts: positive increases were muted in Dunedin City, while Waitaki had the highest number of increasing species and Central Otago more species rapidly increasing.
4. For 54 neighbourhoods managed by Predator Free Dunedin, as a local example, the baseline medium-term assessment detected rapid declines in two species, moderate to shallow declines in five species and increases in three species.
5. Based on these findings, managers could improve benefits for biodiversity by using: (a) trends, to direct and evaluate policy investments; (b) benchmarks, to provide social incentives; and (c) targets, to give management purpose and direction.
6. Our case study highlights how citizen science can address biodiversity information gaps and make powerful management contributions at scale by delivering metrics that are robust and comparable across time and space, showing decisionmakers

how to readily access and interpret information of interest, building trust and value and highlighting how spatially hierarchical assessments can facilitate multiple end-user benefits.

KEYWORDS
alert, benchmark, biodiversity, citizen science, decision making, interactive, target, trend

1 | INTRODUCTION

Biodiversity loss is an ongoing global concern, which international policy commitments have failed to address (Diaz et al., 2019). Poor progress in meeting the Convention on Biodiversity's Aichi Biodiversity Targets by 2020 was, in part, linked to a lack of clear goal definition and operational indicators (Tittensor et al., 2014). Hence, there is a need for better indicators to describe biodiversity trends as accurately and robustly as possible, while being useful and understandable for decisionmakers (Fraixedas et al., 2020; Gregory et al., 2005).

Birds are good indicators for monitoring environmental change, even though they comprise only a small fraction of animal species (Pereira & Cooper, 2006). They are targeted because birds are relatively easy to observe and identify, they are an iconic and popular component of biodiversity and they are good indicators for assessing other taxa and ecosystem services (Devictor et al., 2008; Furness & Greenwood, 1993; Newton, 1998; Pereira & Cooper, 2006). With many ongoing monitoring programmes in place and many volunteers willing to contribute, birds are often selected as target taxa for global and regional monitoring schemes (Pereira & Cooper, 2006). However, despite their popularity, a recent review of bird indicators highlighted strong spatial, seasonal and habitat biases in their composition: most indicators are derived from census data gathered in Europe, within the breeding season and within farmland and forest habitats (Fraixedas et al., 2020). This shows that indicators need to be expanded to address these shortcomings. Urban birds are a notable gap, as they are not only useful indicators of environmental change in these landscapes (Chamberlain et al., 2018; Evans et al., 2008; Strochbach et al., 2009), but also provide well-being benefits to humans, who are increasingly becoming concentrated in cities (Cox & Gaston, 2015; Fuller et al, 2007; Keniger et al., 2013; Ratcliffe, et al., 2013).

Filling these information gaps cannot rely on professionals alone, as there are too few ecologists, who are also limited in their geographical and taxonomic scope (Sutherland et al., 2015). As a result, there are growing calls to capitalize on the positive—but often unrealized—contributions that citizen science can offer (Bonney et al., 2014). Many citizen science initiatives promise to use the data gathered to inform science and environmental management, yet in practice very few achieve these goals (Theobald et al., 2015). This is partly due to differences in perceptions about what constitutes scientific evidence (Cooper et al., 2014). Thus, to enable citizen science to produce reliable and useful information for scientists, policymakers and the public, Bonney et al. (2014) recommend: (1) applying advances in statistical tools and computational techniques to remove barriers to compiling and analysing complex citizen science datasets; (2) capitalizing on recent technological development to increase the functionality, visibility and accessibility of citizen science for different users; and (3) exposing citizen science to the same peer review as conventional science to build trust and confidence in its value.

This paper uses a case study to demonstrate how to address these issues. Specifically, it assesses the state of New Zealand's garden birds at national to local scales, based on an analysis of winter counts gathered by citizen scientists participating in the New Zealand Garden Bird Survey (NZGBS; Spurr, 2012). Focusing on 14 common species, it: (1) calculates changes in bird counts for national, regional and local scales over three medium-term and two short-term periods; (2) uses a standardized alert system to identify trends of interest or concern; and (3) illustrates the powerful utility of the results to address different management questions at each scale. The results are then reviewed to consider mechanisms for improving their future uptake in decision-making by policymakers and practitioners.

2 | MATERIALS AND METHODS

2.1 | Raw data

Bird count data were gathered by citizen scientists participating in the NZGBS, an annual nationwide event that has run for 9 days in midwinter since 2007 (Spurr, 2012). Participants selected a day and recorded in a garden, park or school for an hour the maximum number of birds per species they saw or heard at any one time. The data were collected via an online form (which included automated data validation rules) or, for paper forms, by post and edited using standardized protocols (MacLeod et al., 2019a; MacLeod, Howard, Green et al., 2019; Spurr, 2012).

Five subsets of survey records for gardens only were used as a basis for three assessments of the state of New Zealand's garden birds. Medium- and short-term changes in bird counts were calculated using standardized 10 year and 5 year timeframes. These timeframes not only aligned with well-established protocols for internationally recognized bird indicators (Baillie & Rehfisch, 2006; Woodward et al., 2020) but also ensured the derived metrics were comparable among the different assessments. Furthermore, an early warning of an impending improvement or deterioration in bird counts for a given species could be detected by comparing its medium- and short-term trends. The 2017 assessment evaluated medium-term changes in bird counts (2007–2017: 31,679 records; MacLeod et al., 2018a, 2018b; MacLeod, Howard, Green et al., 2019), while the 2018 and 2019 assessments considered both medium-term periods (2008–2018: 34,686 records; 2009–2019: 35,786 records) and short-term periods (2013–2018: 20,274 records; 2014–2019: 19,912 records; Brandt et al., 2020a, 2020b; MacLeod et al., 2019a, 2019b, 2019c).

To demonstrate the potential value of our approach, our analyses focussed on 14 garden birds, selected because they are common and widespread species that occupy a diversity of foraging niches (from aerial to ground feeders). They included five native species: bellbird/korimako (*Anthornis melanura*), fantail/pīwaiwaka (*Rhipidura fuliginosa*), New Zealand pigeon/kererū (*Hemiphaga novaeseelandiae*), silvereye/tauhou (*Zosterops lateralis*) and tūī/kōkō (*Prosthemadera novaeseelandiae*). The remainder were introduced species: blackbird/manu pango (*Turdus merula*), chaffinch/pahirini (*Fringilla coelebs*), dunnock (*Prunella modularis*), goldfinch (*Carduelis carduelis*), greenfinch (*Carduelis chloris*), house sparrow/tiu (*Passer domesticus*), myna/maina (*Acridotheres tristis*), song thrush (*Turdus philomelos*) and starling/tāringi (*Sturnus vulgaris*). Note that the myna is only found in the North Island of New Zealand. Common widespread species tend to be more statistically powerful indicators of environmental change than rare species (Gaston, 2010; Gregory et al., 2005, 2008; Schmeller et al., 2018).

2.2 | Trend analysis

For each species and period, a generalized linear mixed model (Bates et al., 2015) was fitted to test for a linear trend in bird counts while accounting for repeated measures gathered from spatially nested gardens (MacLeod et al., 2019a; MacLeod, Howard, Green et al., 2019). A binomial response was specified for most species, with low counts converted into presence-absence data. For four species (blackbird, house sparrow, silvereye and starling), which had zero-inflated but also some skewed high counts, a Poisson response was specified, and an overdispersion term was included in the model (Harrison, 2014). Survey year and an interaction term for garden type (urban vs. rural) and bird feeding (yes/no) were specified as fixed effects. To account for variation in bird counts and trends at each spatial level, all models included random intercepts for four spatially nested variables and a random slope (with respect to year) for three spatial scales; thus, effectively also accounting for any spatial and temporal variation in survey effort. Note that for each assessment, spatial units were derived using the most current geopolitical boundary layers (as defined by Statistics New Zealand), which resulted in some finer-scale variation in the spatial unit classifications (i.e. region, urban areas and area unit layers for the 2017 assessment; region, territorial authority and urban rural layers for the 2018 and 2019 assessments; for more detail see MacLeod et al., 2019a; MacLeod, Howard, Green et al., 2019). The error term in the model accounted for any other sources of variance not explicitly specified in our models (e.g., time of day; species identification; weather; Bird et al., 2014).

To account for the unbalanced design of the NZGBS (i.e., spatial variation in the number of gardens surveyed; MacLeod & Spurr, 2019), fitted trend estimates were weighted for each neighbourhood (i.e., a cluster of gardens in close proximity of each other within a given location within a city, town or rural area) in relation to the number of gardens available for surveying (as a proportion of the national total). Weighted trend estimates for all other spatial scales and locations were calculated as the weighted average for the respective subset of neighbourhoods. Parametric bootstrap ($n = 1001$ replicates) was used to estimate uncertainties (or confidence intervals) in weighted trend estimates by simulating new data from the fitted base model (Canty & Riple, 2020; Davison & Hinkley, 1997), refitting the mixed-effects model, and recalculating the weighted estimates. The percentage change in bird counts for each period and spatial scale was calculated for each of the weighted bootstrap runs (e.g., Figure 1a). All analyses were undertaken using R (R Core Team, 2020).

2.3 | Alert system

A standardized protocol (MacLeod et al., 2019a; MacLeod, Howard, Green et al., 2019) was then used to classify the weighted estimates of trend direction as equivalent to rapid, moderate and shallow declines (colour coded red, amber and light amber respectively), as well as shallow, moderate and rapid increases (dark green, light and dark blue respectively), and little or no change (light green) over 10 or 5 years (Figure 1b). The signal strength of each colour-coded alert was ranked from insufficient or very weak to very strong; these ranks were based on the distribution of the bootstrap estimates in relation to specified trend threshold criteria and/or whether they overlapped zero (Figure 1c). Species with smaller variance will have stronger signals. The resulting alert category classifications (Figure 1d) were undertaken using purpose-built R functions.

2.4 | National to local applications

To demonstrate the utility of the species alerts, the results were used to address management questions at three spatial scales: national, regional and local. Supporting graphics summarising the results from the three assessments (2017, 2018 and 2019) were collated into an online interactive tool (MacLeod et al., 2021). The tool was built using R and deployed using the package Shiny (Chang et al., 2020), hosted by RStudio (Rstudio Team, 2020). The graphics were colour coded in relation to the six alert classes and the five strength-of-alert signal categories. The data visualizations ranged from community-level summaries through to detailed matrices for each assessment and spatial unit specifying the species-level median and 80% confidence intervals for the bootstrap estimates, as well as dot plots visualizing the distribution of bootstrap estimates in relation to alert class and their signal strength categories (MacLeod & Scott, 2021).

At the national scale we evaluated, across the three assessments, medium- to short-term changes in: (1) the distribution of the 14 focal species among the six alert classes and the five strength-of-alert signal categories; and (2) alerts raised for individual species nationally and

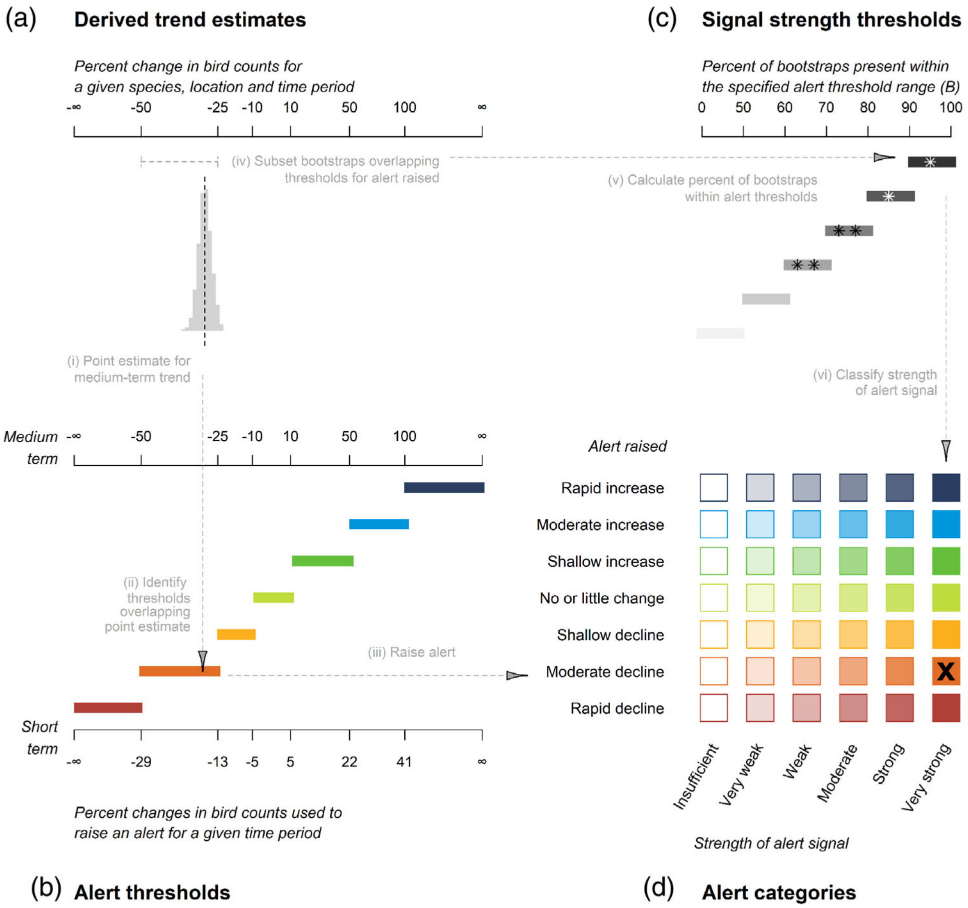

FIGURE 1 Alert classification process for New Zealand's garden bird trends, where the derived point and bootstrap estimates (black dotted line and grey histogram, respectively, in (a) for each species, location and time period are independently overlaid on standardized alert and signal strength thresholds (b and c, respectively) to identify their relevant alert category and colour code (d). Note if the 10%–90% quantile range for the bootstrap estimates included zero, the strength of alert signal was downgraded for very strong or strong classes to a weak one (as denoted by * in c) and for moderate or weak classes to a very weak one (** in c). (Also note that the short-term or 5-year thresholds are calculated based on the same rate of annual change as used for the medium-term or 10-year period.)

across the regions, taking into consideration the strength of the alert signals.

Using the Otago region as an example, we evaluated medium- to short-term changes in 13 focal species across the whole region, using alert information from each of the three available assessments. Then, based on the 2018 assessment alone, we assessed the state of garden birds across the five districts within the Otago region: Central Otago, Clutha, Dunedin City, Queenstown–Lakes and Waitaki. In both cases we explored spatial and temporal changes in: (1) the distribution of species numbers among the six alert classes and the five strength-of-alert signal categories; and (2) alerts raised for individual species, taking into consideration the strength of the alert signals.

At the local scale we focused on Predator Free Dunedin, a community-led initiative to eradicate stoats (*Mustela erminea*), possums (*Trichosurus vulpecula*) and rats (*Rattus* spp.) from 31,000 ha of urban and rural land centred on the city of Dunedin (Predator Free Dunedin, n.d., a). It overlaps 54 neighbourhoods (MacLeod et al., 2021) and encompasses three areas at different stages of implementation. The Otago Peninsula Biodiversity Group was established in 2008 (almost 10,000 ha, 10 neighbourhoods); the Halo was initiated in 2011 (12,500 ha north of the city surrounding Orokonui Ecosanctuary, seven neighbourhoods); and the City Sanctuary was initiated in 2020 (spanning 8,000 ha, 37 neighbourhoods). Drawing on the 2017 assessment as a baseline, we evaluated medium-term changes in 13 focal species by calculating the percentage of neighbourhoods within each alert class, and evaluating the strength of those signals, across all 54 neighbourhoods and in each of the three areas.

3 | RESULTS

3.1 | National assessment

National declines were identified for half of the 14 garden bird species evaluated in the 2017 medium-term assessment (Figure 2); alerts were raised for a moderate decline in four species and for a shallow decline

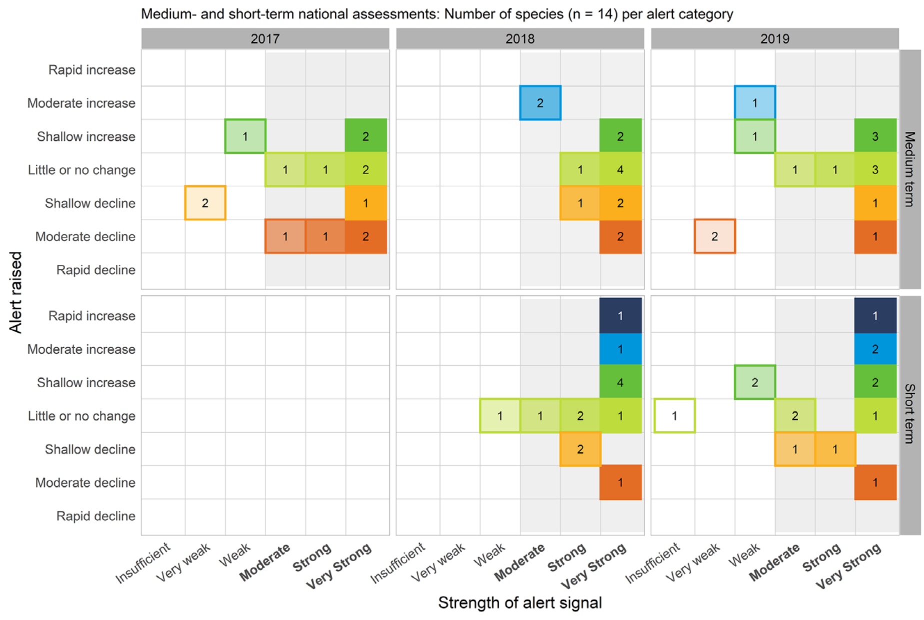

FIGURE 2 Number of garden bird species ($n = 14$) per alert category for three national assessments (MacLeod et al., 2018a, 2019; Brandt et al., 2020). Alert categories with one or more species present (as specified by the numbers in boxes) are colour-coded as a visual aid (where the colours reflect the trend alert raised (y-axis) and the depth of shading the strength of the alert signal (x-axis); Figure 1). Alerts were evaluated over the medium term (2007–2017: 31,679 survey records gathered by the New Zealand Garden Bird Survey (Spurr, 2012); 2008–2018: 34,686 records; 2009–2019: 35,786 records) and short term (2013–2018: 20,274 records; 2014–2019: 19,912 records). Grey shading indicates alert categories where the signal strength was classified as moderate to very strong (Figure 1)

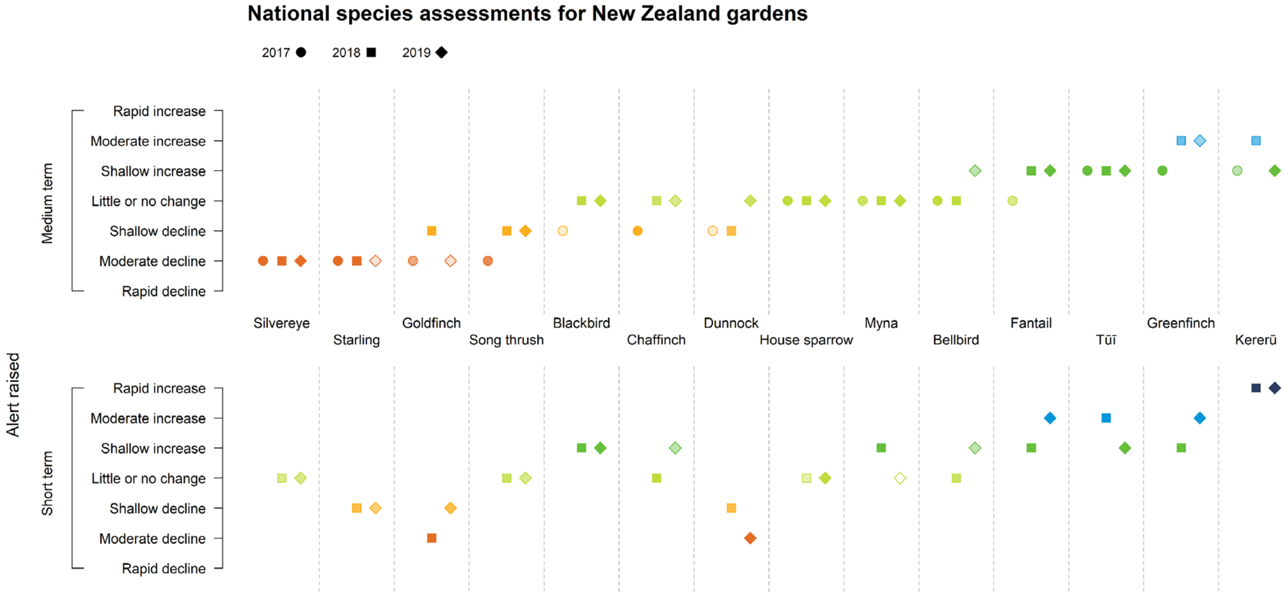

FIGURE 3 National alerts raised for 14 garden bird species in New Zealand over the medium and short term. Shading is proportional to the strength of evidence for the trend (Figure 1). Trends in bird counts were evaluated over the medium term (2007–2017: 31,679 survey records gathered by the New Zealand Garden Bird Survey (Spurr, 2012); 2008–2018: 34,686 records; 2009–2019: 35,786 records) and short term (2013–2018: 20,274 records; 2014–2019: 19,912 records)

in the other three (albeit with a very weak signal for two). A shallow increase was flagged for three species (but weakly in one case), while little or no change was observed for the remaining four species. Subsequent national assessments (2018, 2019) signalled improvements overall. In the medium term the proportion of species declining dropped to roughly a third, five species showed little or no change, and the remainder signalled either a shallow or a moderate increase (Figure 2). The short-term assessments indicated at least six species were increasing, with very strong signals for moderate or rapid increases in at least two species.

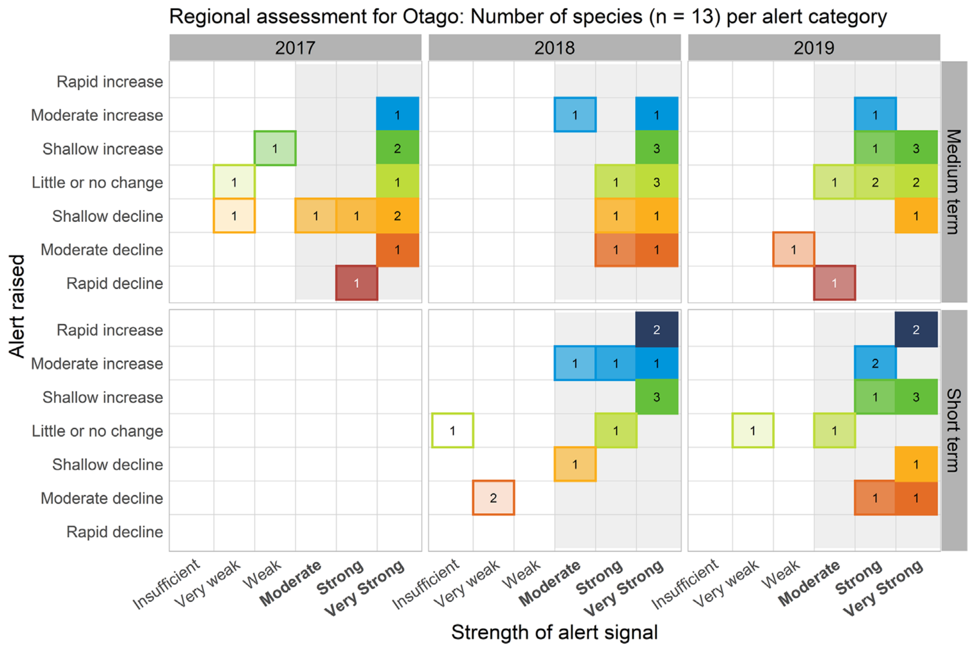

FIGURE 4 Number of garden bird species ($n = 13$) per alert category for three regional assessments for Otago (MacLeod et al., 2018a, 2019a; Brandt et al., 2020a). Alert categories with one or more species present (as specified by the numbers in boxes) are colour-coded as a visual aid (where the colours reflect the trend alert raised (*y*-axis) and the depth of shading the strength of the alert signal (*x*-axis); Figure 1). Alerts were evaluated over the medium term (2007–2017: 4316 survey records gathered by the New Zealand Garden Bird Survey (Spurr, 2012); 2008–2018: 4927 records; 2009–2019: 2493 records) and short term (2013–2018: 5191 records; 2014–2019: 2602 records). Grey shading indicates alert categories where the signal strength was classified as moderate to very strong (Figure 1)

Three of the four species that raised medium-term amber alerts (>25% decline over 10 years) in the 2017 national assessment signalled improvements in their status in the latest assessment (i.e., amber alert signals weakened or shifted to a light amber alert; Figure 3). These improvements were associated with regional changes in species' alert status (see maps in MacLeod et al., 2021). The number of regions signalling an amber alert for starling dropped from nine (distributed across the country) to five (all in the North Island) and, for song thrush, from seven (across the country) to one (in the South Island). For goldfinch, the strength of amber alert signals generally weakened across the regions. Silvereye, which had a strong signal for an amber alert in all three medium-term assessments, flagged red alerts in six regions across the country initially but only in the two southernmost regions in the latest assessment. Early warnings (>10% decline over 10 years) were also flagged initially for chaffinch and, with a weak signal, for blackbird and dunnock; however, the status of all three species later improved (classified as 'little or no change') nationally and regionally (Figure 3; MacLeod et al., 2021). For all seven species identified as declining in the 2017 medium-term assessment, a slowing, halting or reversing of those declines was signalled in the short term for all species (Figure 3), except dunnock, which raised an amber alert (for 2014–2019).

Overall, little or no change was observed nationally (and in most regions) for house sparrow, myna and, possibly, bellbird, which weakly signalled shallow increases and only flagged a decline in one region in the latest assessment (compared to four regions initially; Figure 3; MacLeod et al., 2021). National increases were detected for three native and one introduced species. For fantail, shallow or moderate increases were identified in the two most recent assessments as their performance improved across the regions. Shallow increases were consistently signalled nationally for tūī, which also increased moderately in two or more regions and rapidly in the Canterbury region. Kererū signalled positive changes nationally and (almost) consistently across all regions; in the latest assessment it achieved shallow or moderate increases in the medium term and rapid increases in the short term. Greenfinch shifted from a shallow to a moderate increase, with some rapid increases detected at the regional level, particularly in the short term.

3.2 | Regional assessment

For the Otago region, the 2017 medium-term assessment signalled declines in seven of the 13 garden bird species evaluated (Figure 4), with one species raising a red alert (silvereye) and another an amber alert (song thrush; Figure 5). Positive changes were detected for four species initially: three with a shallow increase (house sparrow, tūī and, with a weak signal, dunnock) and one with a moderate increase (greenfinch). Medium-term improvements were detected in the subsequent assessments, where the strength-of-alert signals were also generally enhanced (Figure 4). While silvereye wavered between an amber and red alert status, the number of declining species roughly halved as the earlier shallow declines slowed to little or no change for blackbird, chaffinch and starling, and reversed to a shal-

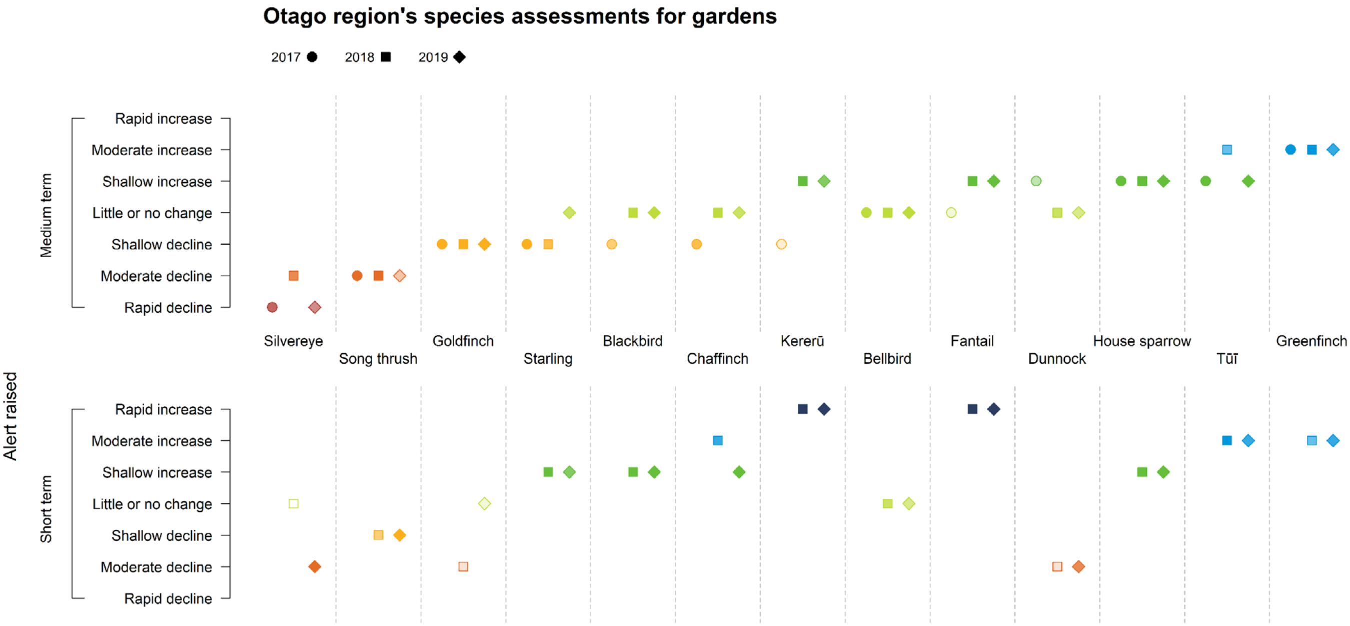

FIGURE 5 Regional alerts raised for 13 garden bird species in Otago over the medium and short term. Shading is proportional to the strength of evidence for the trend (Figure 1). Three assessments evaluate trends in bird counts over the medium term (2007–2017: 4316 records; 2008–2018: 4927 survey records gathered by the New Zealand Garden Bird Survey (Spurr, 2012); 2009–2019: 2493 records), and two assessments over the short term (2013–2018: 5191 records; 2014–2019: 2602 records)

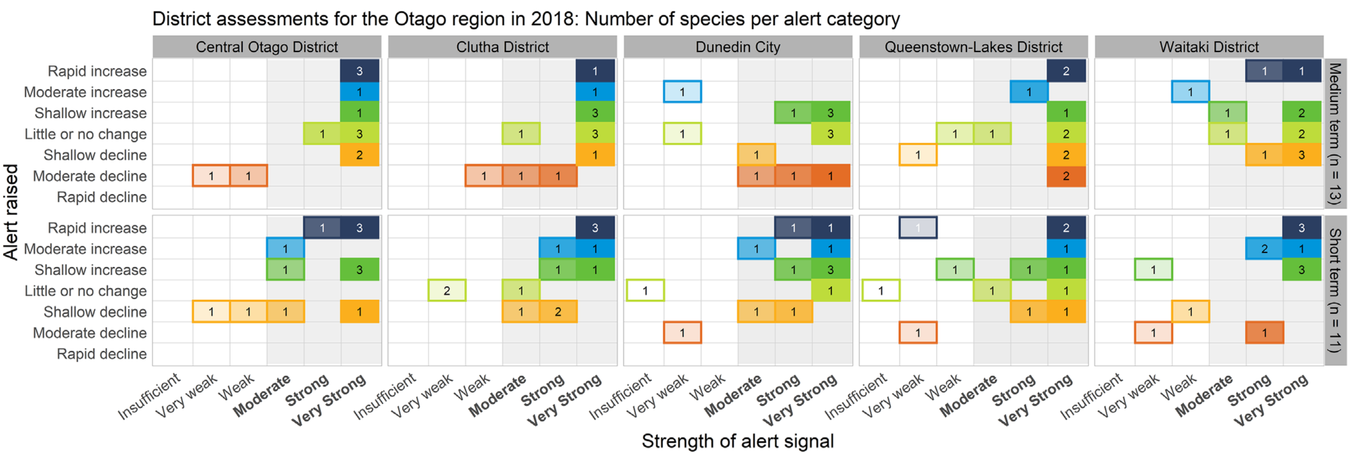

FIGURE 6 Number of garden bird species (medium term, $n = 13$; short term, $n = 11$) per alert category for the 2018 local assessment for five districts (or territorial authorities) within the Otago region (MacLeod et al., 2019a). Alert categories with one or more species present (as specified by the numbers in boxes) are colour-coded as a visual aid (where the colours reflect the trend alert raised (*y*-axis) and the depth of shading the strength of the alert signal (*x*-axis); Figure 1). The 2018 assessment evaluates trends in bird counts over the medium term (2008–2018: Central Otago, 341 survey records gathered by the New Zealand Garden Bird Survey (Spurr, 2012); Clutha, 306 records; Dunedin City, 3534 records; Queenstown–Lakes, 359 records; Waitaki, 387 records); and short term (2013–2018: Central Otago, 191 records; Clutha, 158 records; Dunedin City, 1716 records; Queenstown–Lakes, 202 records; Waitaki, 226 records). Grey shading indicates alert categories where the signal strength was classified as moderate to very strong (Figure 1)

low increase for kererū (Figure 5). Overall, medium-term increases were shallow. Positive changes were signalled in the short term for eight species, including moderate increases for greenfinch and tūī, and rapid increases for fantail and kererū. Deviating from its medium-term trend for little or no change, the dunnock raised an amber alert in the short term.

Within Otago, alert patterns varied among the five districts based on the 2018 assessments alone (Figure 6). All districts raised at least two amber alerts in the medium term (for song thrush, silvereye or goldfinch; MacLeod et al., 2021), except Waitaki District, which had the highest number of increasing species. Central Otago was the only district where rapid increases were signalled in the medium term for three

FIGURE 7 Percentage of neighbourhoods within three Predator Free Dunedin areas classified alert category. Alert categories with one or more percent of neighbourhoods (as specified by the numbers in boxes) are colour-coded as a visual aid (where the colours reflect the trend alert raised (*y*-axis) and the depth of shading the strength of the alert signal (*x*-axis); Figure 1). Results are based on the 2017 local assessment of medium-term trends (2007–2017; 2597 survey records in total; MacLeod et al., 2018a, 2018b) in bird count data gathered by the New Zealand Garden Bird Survey (Spurr, 2012). Grey shading indicates alert categories where the signal strength was classified as moderate to very strong (Figure 1)

species (Figure 6)—greenfinch, tūī and kererū—and in the short term for the same species plus fantail (MacLeod et al., 2021). In Dunedin City, positive changes in the medium term were relatively muted compared to other districts, being limited to a shallow increase for four species (house sparrow, tūī, fantail and kererū) and for a moderate increase, albeit with a very weak signal, in greenfinch (Figure 6; MacLeod et al., 2021).

3.3 | Local assessment

Within Predator Free Dunedin, seven species were identified as declining in the medium term, based on the 2017 assessment (Figure 7). Four species were declining across the whole locality. For silvereye and song thrush, rapid declines were flagged in at least 80% of neighbourhoods overall and were most likely to occur on the Otago Peninsula; however, signals for silvereye's rapid declines were weak in 43% of the Halo neighbourhoods. For goldfinch, moderate declines were signalled in 76% of all neighbourhoods (but most likely within the City Sanctuary). For chaffinch, shallow declines were detected in all neighbourhoods. Shallow or moderate declines were also identified in c. 85% of all neighbourhoods for starling and kererū, but with one neighbourhood on the Otago Peninsula signalling a shallow increase for kererū. Shallow declines were detected in 29% of neighbourhoods and across all three areas for blackbird.

Bellbird was the only species to show little or no change across Predator Free Dunedin, with the five remaining species increasing in most neighbourhoods (Figure 7). Shallow increases were detected across all three areas and in most neighbourhoods for dunnock and, albeit with a weaker signal, for fantail. Shallow increases were signalled for tūī in 70% of neighbourhoods overall, with most other neighbourhoods experiencing moderate increases. For greenfinch, the signals for individual neighbourhoods were split roughly equally between shallow and moderate increases in all areas. House sparrow was most likely to flag a moderate or rapid increase overall, but with rapid increases being least likely in the City Sanctuary.

4 | DISCUSSION

4.1 | Using citizen science to inform a biodiversity information gap

Our case study, which evaluates the state of New Zealand's garden birds, provides new and valuable insights into medium and short term changes in bird counts for 14 common and widespread species. Thus, it helps to address key global gaps in the availability of bird indicators (Fraixedas et al., 2020), by fulfilling geographic (New Zealand), spatial (national to local), seasonal (winter) and habitat (urban and rural garden landscapes) gaps. With the application of modern statistics and objective scientific methodology, the trends presented here are more robust that those usually drawn from more traditional survey methods (such as 5 min bird counts, which are frequently analyzed without correcting for sources of error; Bird et al., 2014). They could thus be used as one way of assessing the accuracy of those more traditional approaches.

Common and widespread species can be useful indicators of the general state of nature and how it is changing (Gaston, 2010; Gregory et al., 2005, 2008; Schmeller et al., 2018). However, until relatively recently, most bird monitoring efforts in New Zealand focussed on rare and threatened species that typically live on offshore islands or in remote locations. While monitoring of rare species is important for informing on the status of a key component of biodiversity, they often require more intensive survey efforts to detect changes in their status, differ systematically in their ecology and are more likely to be subject to beneficial management interventions. As New Zealand's common and widespread species were not systematically monitored in the past, evaluations of their trends often relied on site-specific and intermittent observations typically gathered in forest habitats on conservation land by short-term projects undertaken by professionals (Elliott et al., 2010; Harper, 2009; Hartley, 2012).

In 2011, New Zealand initiated the rollout of a national biodiversity monitoring programme, which aims to provide objective reporting at the national scale (Bellingham et al., 2020) and includes a breeding bird survey implemented by professionals (MacLeod et al., 2012). However, the geographic coverage of this system is still currently limited, being mainly applied to public conservation land (which only makes up about 30% of the total land area; Bellingham et al., 2020) or areas with native land cover (e.g., Griffiths et al., 2021), as most regional government agencies are slow or reluctant to adopt and apply it on private land (i.e., urban and farming landscapes), likely partly due to the high costs of monitoring. Even if the monitoring programme was implemented nationally, it is unlikely to provide the resolution of information required to inform management at finer spatial scales of interest (e.g., restoration initiatives by community-led groups).

4.2 | Addressing recommendations to help realize citizen science's potential

Many projects struggle to meet the stringent requirements of decision-makers who are sceptical about the quality of citizen science data, as these can be prone to greater variability than information gathered by professionals (Bird et al., 2014; Parrish et al., 2018). One mechanism to improve the quality of citizen science data is to develop protocols and procedures for improving how the data are collected (Thornhill et al., 2021). The New Zealand Garden Bird Survey, the data source for our case study, is unique among local citizen science initiatives in being the only one to implement an annual survey monitoring multiple species nationwide at a standardized time of year and using a standardized protocol. Other initiatives either provide snapshots of information (e.g., Bull et al., 1985; Robertson et al., 2007), focus on a single species (e.g., the Great Kererū Count; Hartley, 2020), or gather ad hoc records or localized surveys motivated by individuals (e.g., Sullivan, 2012). Through the application of a standardized protocol for monitoring birds, the NZGBS has thus removed one source of error that can make detecting trends difficult.

Data quality can also be improved post collection, through standardized data validation and editing protocols to remove obvious anomalies (as employed in the NZGBS; MacLeod et al., 2019a; MacLeod, Howard, Green et al., 2019; Spurr, 2012) as well as through the application of modern statistical methods to account for many types of error and bias in citizen science data, including uneven sampling effort (Bird et al., 2014). With the aim of delivering reliable and useful information to policymakers and practitioners, our case study addresses three recommendations for helping to realize the potential contributions of citizen science (Bonney et al., 2014; Theobald et al., 2015). First, by applying advanced statistical tools and computational power we have removed previous barriers to compiling and analyzing a complex citizen science database, increasing its inferential power. Second, by using a standardized alert system (Figure 1) and an online interactive tool (MacLeod et al., 2021) we have capitalized on recent technological developments to increase the functionality, visibility and accessibility of citizen science results. Third, by regularly and actively inviting participating citizen scientists (MacLeod & Scott, 2021), as well as local policymakers, practitioners, bird experts and researchers, to review our progress, we have helped build trust and confidence in its value, a process we aim to consolidate through an international peer review of this paper.

4.3 | Driving continuous improvement in biodiversity outcomes

Organizers often highlight the value of citizen science data for informing management as a key motivation for people to engage, and, in doing so, have responsibility to ensure the citizen science results are actively used in management decisions (Parrish et al., 2018). However, despite broad calls for better uptake of the available evidence in conservation decision making, this is often challenging to achieve in practice (Sutherland & Wordley, 2017). This challenge arises, at least partly, because conservation practitioners and policymakers, including those who intend to adopt evidence, may not have the mental roadmaps required to enact their goals (Travers et al., 2021; World Bank, 2015). Here we highlight how our hierarchical assessments across scale can be applied to facilitate benefits for multiple end-users, by linking the derived biodiversity measures to trends, benchmarks or targets. Furthermore, by providing resources that can be tailored for use at multiple scales, our study highlights clear pathways to help stakeholders leverage place-based motivations for improving the impacts of citizen science and, ultimately, conservation decision making (Newman et al., 2017).

4.3.1 | Trends

Trends help signal whether we are gaining or losing ground towards improving biodiversity outcomes. They allow the user to compare previous and current performance, and to determine if what they are doing is making a difference (Fraixedas et al., 2020; Gregory et al., 2005). They also help practitioners and policymakers make decisions about whether they are investing enough, and when they can ease off an intervention.

There are three ways in which our assessments can help. First, the community overview for each assessment allows swift evaluation of the number of species that are declining, increasing or showing little or no change, and can assess the distribution of species among the alert classes and the signal strength categories. For example, in the initial national assessment, seven of the 14 species considered were declining, three were increasing, and four were showing little or no change (Figure 2). Four of the declines were moderate and the remainder shallow, while all three increases were shallow. The alert signals were moderate to very strong for 11 species, including all those experiencing moderate declines.

Second, comparing the community overviews across multiple assessments allows evaluation of whether the species status and the strength-of-alert signals are generally improving or diminishing over time. For example, the alert status of the 14 species has generally improved in the latest medium-term national assessments, compared to the initial one, but signal strengths were strongest overall for the middle assessment (Figure 2). Strength-of-alert signals could also be used to direct the NZGBS campaigns towards increasing survey effort in specific regions and neighbourhoods with weak signal strengths, where there may either be a low proportion of gardens surveyed or only a few gardens present.

Third, community patterns observed in the medium term can be verified against those in the short term, where early warnings might also be signalled. For example, positive changes were signalled for at least six species nationally in both short-term assessments, with two or more species having strong signals for moderate or rapid increases (Figure 2). The medium-term trend for improvements was thus supported at the community level, but also indicated potential for positive trends to accelerate in the future.

Such information could direct national policy to where it is most needed and demonstrate whether those policies were delivering improvements. Gaining clarity on key trend signals of concern and celebrating the successful biodiversity outcomes could be used to motivate increased participation in citizen science campaigns.

4.3.2 | Benchmarks

Benchmarking compares performance at different spatial scales to help policymakers and practitioners evaluate themselves compared to their peers. This is the most common and simplest way for people to determine how well they are doing.

The community overviews in our interactive reports can help benchmark performance spatially. For example, a wider range of medium-term alerts was initially raised for the Otago region (Figure 4), compared to the matched national assessment (Figure 2), as silvereye flagged a red alert for a rapid decline and greenfinch signalled a moderate increase (Figure 5). Similarly, for the short-term assessments, positive changes were more evident in Otago, as more species were classified as moderately or rapidly increasing (Figure 4). Differences in performance were also detected across districts within Otago (Figure 6). Positive increases were most muted in Dunedin City, while Waitaki had the highest number of increasing species and Central Otago more species exhibiting rapid increases.

Drilling down to our species-level information can also provide valuable insights. For example, the species overview for Otago gardens shows that silvereye raised a red alert in two of the three medium-term assessments, with weak evidence for improvements in its status in the short term (Figure 5). Furthermore, the regional maps show this species' decline is most severe and persistent in the southernmost regions of the South Island, including Otago (see MacLeod et al., 2021). This suggests any management strategy reducing national silvereye declines in gardens should invest most support in these areas and investigate their underlying drivers. Within the Predator Free Dunedin footprint, this species raised red alerts in over 70% of neighbourhoods in each of its three management areas (Figure 7; MacLeod et al., 2021), suggesting that if predator control is beneficial for silvereye, those benefits are still to be realized. However, weak signals suggest possible positive changes in the Halo area relative to the other two management areas, as a higher proportion of neighbourhoods raised a moderate decline or weaker signals for a rapid decline. These changes should be closely monitored in subsequent assessments to see if they show continued improvements.

Such information would support practice improvement (Byerly et al., 2018; Davis et al., 2018; Farrow et al., 2017; Travers et al., 2021) as: (1) peer pressure is a powerful motivator for change; (2) it helps decisionmakers identify where to invest the most support and help or, as a last resort, apply regulations or sanctions; (3) it identifies leaders that other parties can see and learn best practice from; and (4) it creates a 'learning escalator' by changing social norms—as the laggards lift their game, previous leaders may work hard to regain their top spots, so slowly everyone lifts their performance.

4.3.3 | Targets

Targets give direction and purpose for performance. They are the main way we judge whether performance is good enough and, when well chosen, they can accelerate continuous improvement (Mace et al., 2010; Perrings et al., 2011).

Biodiversity targets could readily be informed by our species overviews and detailed metrics (MacLeod et al., 2021). To illustrate with a hypothetical example, consider a management target that aimed to achieve national increases in the medium term (10 years) for all five native species. Our three assessments (2017, 2018 and 2019) show that two species consistently failed to meet this target: silvereye declined, and bellbird showed little or no change overall (Figure 3). However, if the aim was to achieve national increases in the medium term for at least three native species and positive change in the short term for two native species, then this target would have been met. Increases were strongly signalled for three native species in the medium and short terms, with fantail exhibiting shallow increases in the two latest assessments, tūī consistently maintaining a shallow increase, and kererū having shallow to moderate increases in the medium term but rapid increases in the short term. Positive changes were also weakly indicated for bellbird, with shallow increases in the latest medium- and short-term assessments. While silvereye persistently raised an amber alert nationally in the medium term, its short-term trend is for little or no change, which should be closely monitored to see if it materializes in the medium term.

Species alerts for fine spatial scales could also be used to help inform targets at coarse scales. To illustrate, consider a hypothetical management target for the four species signalling moderate declines nationally in the 2017 medium-term assessment (silvereye, song thrush, starling and goldfinch), aiming to reduce within 2 years the number of regions within each species' most severe decline alert category by at least half. This hypothetical target would have been achieved for two out of the four species: silvereye (dropping from six regions to two with a rapid decline) and song thrush (dropping from eight regions to one with a moderate decline; MacLeod et al., 2021). Positive changes were also signalled for starling, albeit at a slower rate, as the number of regions with moderate declines for this species was reduced from nine to five (with very weak signals in three regions). For these three species, these alerts also became more localized, while goldfinch showed little change.

Such information could accelerate continuous improvement through: (1) setting goals for change; (2) pointing to critical thresholds or tipping points that decisionmakers need to get past or avoid to safeguard biodiversity; (3) identifying trigger points where decisionmakers predetermine that they will intervene to avoid danger; and (4) highlighting distance to target so that decisionmakers can adjust their investments to achieve their goals in time (Mace et al., 2010; Perrings et al., 2011).

5 | CONCLUSIONS

Our case study has highlighted how citizen science can help address biodiversity information gaps and make powerful contributions to management at multiple scales. It achieved this in four steps:

1. By applying advances in statistical techniques to noisy data, it delivered metrics for 14 common garden bird species that are robust and comparable across time and space. Thus, it directly recognizes and accounts for issues of error and bias associated with variation in survey effort over space and time often present in citizen science and other monitoring data, using hierarchical analyses (Bird et al., 2014; Fraixedas et al., 2020). It also supports others to leverage place-based motivations for improving the impacts of citizen science and, ultimately, conservation decision making (Newman et al., 2017).
2. By using an alert system and collating the hierarchical assessments into an online interactive tool, it showed how decisionmakers can readily access and interpret information of interest to them.

Furthermore, it explicitly tackles the challenge of communicating uncertainty in these alert classifications (Fraixedas et al., 2020) and detecting early warning signals to better inform and enable proactive conservation responses (Schmeller et al., 2018).

3. By inviting peer review of our approach and resources, it sought to build trust and value. This process involved not only ensuring the resources were useful and meaningful to the citizen scientists themselves (MacLeod & Scott, 2021), but also responding to calls for citizen science results to be subjected to the same peer review protocols that are applied to professional science (Bonney et al., 2014; Theobald et al., 2015).
4. By linking biodiversity measures to trends, benchmarks or targets, it highlighted how these hierarchical assessments can be applied to facilitate continuous biodiversity improvements and multiple end-user benefits. In effect, it has set out a range of mental models to help decisionmakers better envisage how these citizen science results meet their specific biodiversity reporting and management needs (Travers et al., 2021; World Bank, 2015).

Thus, this case study has helped the New Zealand Garden Bird Survey to start to fulfil its responsibility to meet one of its goals: assist local authorities with planning and management of their biodiversity responsibilities (Spurr, 2012). This process is already yielding positive results. For example, working with a local conservation collective to develop the interactive State of New Zealand's Garden Birds resource (MacLeod et al., 2021) has catalyzed a discussion about how the emerging results for their location can be used to help demonstrate the biodiversity outcomes of their management actions. Specifically, this collective seeks to motivate more people within the community to engage with and support their initiative by integrating local species' alert maps into their own online interactive dashboard (Predator Free Dunedin, n.d., b).

However, as changing behaviour is complex, provision of these resources and mental models alone is unlikely to be sufficient to achieve uptake of citizen science results and deliver the desired conservation impacts on the ground. Hence, the next challenge will be carefully crafting marketing strategies that are attentive to diverse interests and issues to reach and engage target audiences (Smith et al., 2020; Wright et al., 2015). This will need to include thinking strategically about how to frame key messages to emphasize the things that matter to the target audiences (Kusmanoff et al., 2020).

ACKNOWLEDGEMENTS

We thank the NZGBS participants and many other stakeholders (including Predator Free Dunedin) who contributed data and helped refine our resources. Henrik Moller provided useful insights, which were influential in shaping this work. The research was funded by the Ministry for Business, Innovation and Employment (Building Trustworthy Biodiversity Indicators C09X1308) and the Ministry for the Environment (Contract No. 21135). NZGBS campaigns and this paper were funded by the Ministry for Business, Innovation and Employment's Strategic Science Investment Fund for Crown Research Institutes.

CONFLICTS OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

CJM, PG, SH, AG and ES conceived the ideas and designed the methodology. CJM led the project and writing of the manuscript. All authors contributed to either data editing, analysis, interpretation or visualization, as well as commenting critically on the drafts and giving final approval for publication.

DATA AVAILABILITY STATEMENT

Supporting reports and data available via the Manaaki Whenua – Landcare Research DataStore. State of New Zealand Garden Birds 2017: https://doi.org/10.7931/vkex-8543 (MacLeod et al., 2018a), https://doi.org/10.7931/h44e-wh90 (MacLeod et al., 2018b), https://doi.org/10.7931/n3n0-0g92. (MacLeod et al., 2019). State of New Zealand Garden Birds 2018: https://doi.org/10.7931/8sa9-zh19 (MacLeod et al., 2019a), https://doi.org/10.7931/vkex-8543 (MacLeod et al., 2019b), https://doi.org/10.7931/7mqz-sw15 (MacLeod et al., 2019c). State of New Zealand Garden Birds 2019: https://doi.org/10.7931/1ds9-tv95 (Brandt et al., 2020a), https://doi.org/10.7931/eqg5-y240 (Brandt et al., 2020b).

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/2688-8319.12121

ORCID

Catriona J. MacLeod https://orcid.org/0000-0002-8435-410X
Angela J. Brandt https://orcid.org/0000-0001-5980-9128

REFERENCES

Baillie, S. R., Rehfisch, M. M. (2006). National and site-based alert systems for UK birds. BTO Research Report No. 226, Thetford. (BTO).

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using LME4. *Journal of Statistical Software*, *67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Bellingham, P. J., Richardson, S. J., Gormley, A. M., Allen, R. B., Cook, A., Crisp, P. N., Forsyth, D. M., McGlone, M. S., McKay, M., MacLeod, C. J., van Dam-Bates, P., & Wright, E. F. (2020). Implementing integrated measurements of Essential Biodiversity Variables at a national scale. *Ecological Solutions and Evidence*, *1*(2), e12025. https://doi.org/10.1002/2688-8319.12025

Bird, T. J., Bates, A. E., Lefcheck, J. S., Hill, N. A., Thomson, R. J., Edgar, G. J., Stuart-Smith, R. D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J. F., Pecl, G. T., Barrett, N., & Frusher, S. (2014). Statistical solutions for error and bias in global citizen science datasets. *Biological Conservation*, *173*, 144–154, https://doi.org/10.1016/j.biocon.2013.07.037

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*, 1436–1437. https://doi.org/10.1126/science.1251554

Brandt, A. J., MacLeod, C. J., Howard, S., Gormley, A. M., & Spurr, E. B. (2020a). *State of NZ Garden Birds 2019 | Te Āhua o ngā Manu o te Kā I Aotearoa*. Manaaki Wheuna – Landcare Research. https://doi.org/10.7931/1ds9-tv95

Brandt, A. J., MacLeod, C. J., Howard, S., Gormley, A. M., & Spurr, E. B. (2020b). *NZGBS 2019 | Trend estimates*. Manaaki Wheuna – Landcare Research DataStore. https://doi.org/10.7931/eqg5-y240

Bull, P. C., Gaze, P. D., & Robertson, C. J. R. (1985). *The atlas of bird distribution in New Zealand*. Ornithological Society of New Zealand.

Byerly H., Balmford A., Ferraro P. J., Wagner C. H., Palchak E., Polasky S., Ricketts T. H., Schwartz A. J., & Fisher B. (2018). Nudging pro-environmental behavior: Evidence and opportunities. *Frontiers in Ecology and Environment*, *16*(3), 159–168. https://doi.org/10.1002/fee.1777

Canty, A., & Riple, B. (2020). *boot: Bootstrap R (S-Plus) Functions*. R package version 1.3-25. [Computer software.]

Chamberlain, D., Kibuule, M., Skeen, R. Q., & Pomeroy, D. (2018) Urban bird trends in a rapidly growing tropical city. *Ostrich*, *89*(30), 275–280. https://doi.org/10.2989/00306525.2018.1489908

Chang, W., Cheng, J., Allaire, J. J., Xie, Y., & McPherson, J. (2020). *Shiny: web application framework for R*. R package version 1.5.0. [Computer software.] https://CRAN.R-project.org/package=shiny

Cooper, C. B., Shir, J., & Zuckerberg, B. (2014). The invisible prevalence of citizen science in global research: Migratory birds and climate change. *PLoS One*, *9*, e106508. https://doi.org/10.1371/journal.pone.0106508

Cox, D. T. C., & Gaston, K. J. (2016). Urban bird feeding: Connecting people with nature. *PLoS ONE*, *11*(7), e0158717.

Davis, T., Hennes, E. P., & Raymond, L. (2018). Cultural evolution of normative motivations for sustainable behaviour. *Nature Sustainability*, *1*, 218–224. https://doi.org/10.1038/s41893-018-0061-9

Davison, A. C., & Hinkley, D. V. (1997). *Bootstrap methods and their applications*. Cambridge University Press.

Devictor, V., Julliard, R., Couvet, D., & Jiguet, F. (2008). Birds are tracking climate warming, but not fast enough. *Proceedings of the Royal Society Series B*, *275*, 2743–2748.

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., , Balvanera, P., Brauman, K. A., Butchart, S. H. M., Chan, K. M. A., Garibaldi, L. A., Ichii, K., Liu, J., Subramanian, S. M., Midgley, G. F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., … Zayas, C. N. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, *366*(6471), eaax3100. https://doi.org/10.1126/science.aax3100

Elliott, G. P., Wilson, P. R., Taylor, R. H., & Beggs, J. R. (2010). Declines in common, widespread native birds in a mature temperate forest. *Biological Conservation*, *143*, 2119–2126. https://doi.org/10.1016/j.biocon.2010.05.022

Evans, K. L., Newson, S. E., & Gaston, K. J. (2008). Habitat influences on urban avian assemblages. *Ibis*, *151*, 19–39. https://doi.org/10.1111/j.1474-919X.2008.00898.x

Farrow, K., Grolleau, G., & Ibanez, L. (2017). Social norms and pro-environmental behavior: A review of the evidence. *Ecological Economics*, *140*, 1–13. https://doi.org/10.1016/j.ecolecon.2017.04.017

Fraixedas, S., Lindén, A., Piha, M., Cabeza, M., Gregory, R., & Lehikoinen, A. (2020). A state-of-art review on birds as indicators of biodiversity: Advances, challenges, and future directions. *Ecological Indicators*, *118*, 106728. https://doi.org/10.1016/j.ecolind.2020.106728

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, *3*, 390–394. https://doi.org/10.1098/rsbl.2007.0149

Furness, R. W., & Greenwood, J. J. D. (1993). *Birds as monitors of environmental change*. Chapman & Hall.

Gaston, K. J. (2010). Valuing common species. *Science*, *327*, 154–155. https://doi.org/10.1126/science.1182818

Gregory, R. D., van Strien, A., Voříšek, P., Gmelig Meyling, A. W., Noble, D. G., Foppen, R. P. B., & Gibbons, D. W. (2005). Developing indicators for European birds. *Philosophical Transactions of the Royal Society Series B*, *360*, 269–288. https://doi.org/10.1098/rstb.2004.1602

Gregory, R. D., Voříšek, P., Noble, D. G., van Strien, A., Klvaňová, A., Eaton, M., Gmelig Meyling, A. W., Joys, A., Foppen, R. P. B., & Burfield, I. J. (2008). The generation and use of bird population indicators in Europe. *Bird Conservation International*, *18*, S223–244. https://doi.org/10.1017/S0959270908000312

Griffiths, G. J. K., Khin, J., Landers, T. J., Lawrence, G., Ludbrook, M. R., & Bishop, C. D. (2021). *Ecological integrity of forests in Tāmaki Makaurau /Auckland 2009–2019*. State of environment reporting. Auckland Council technical report, TR2021/01.

Harper, G. A. (2009). The native forest birds of Stewart Island/Rakiura; patterns of recent declines and extinctions. *Notornis*, *56*, 63–81.

Harrison, X. A. (2014). Using observation-level random effects to model overdispersion in count data in ecology and evolution. *PeerJ*, *2*, e616. https://doi.org/10.7717/peerj.616

Hartley, L. J. (2012). Five-minute bird counts in New Zealand. *New Zealand Journal of Ecology*, *36*(3), 268–278. https://newzealandecology.org/nzje/3041

Hartley, S. (2020). *Great Kererū Count 2020*. Annual report. Centre for Biodiversity and Restoration Ecology. Te Herenga Waka – Victoria University of Wellington.

Keniger, L. E., Gaston, K. J., Irvine, K. N., & Fuller, R. A. (2013). What are the benefits of interacting with nature? *International Journal of Environmental Research and Public Health*, *10*, 913–935. https://doi.org/10.3390/ijerph10030913

Kussmanoff, A. M., Fidler, F., Gordon, A., Garrard, G. E., & Bekessy, S. A. (2020). Five lessons to guide more effective biodiversity conservation message framing. *Conservation Biology*, *34*(5), 13–1141. https://doi.org/10.1111/cobi.13482

Mace G. M., Cramer W., Díaz S., Faith D. P., Larigauderie A., Le Prestre P., Palmer M., Perrings C., Scholes R. J., Walpole M., Walther B. A., Watson J. E. M., & Mooney H. A. (2010). Biodiversity targets after 2010. *Current Opinion in Environmental Sustainability*, *2*, 3–8. https://doi.org/10.1016/j.cosust.2010.03.003

MacLeod, C. J., Green, P., Howard, S., Gormley, A. M., Brandt, A. J., & Spurr, E. B. (2021). *State of NZ garden birds interactive | Proof of concept*. Version 1.0. Shiny app. https://landcare.shinyapps.io/sogb-concept/

MacLeod, C. J., Greene, T. C., MacKenzie, D. I., & Allen, R. B. (2012). Monitoring widespread and common bird species on New Zealand's conservation lands: A pilot study. *New Zealand Journal of Ecology*, *36*, 300–311.

MacLeod, C. J., Howard, S., Gormley, A. M., & Spurr, E. B. (2019a). *NZ Garden Bird Survey 2018: Data editing, analysis and interpretation methods*. Manaaki Whenua – Landcare Research Contract Report LC3484 for the New Zealand Garden Bird Survey. https://doi.org/10.7931/8sa9-zh19

MacLeod, C. J., Howard, S., Gormley, A. M., & Spurr, E. B. (2019b). *State of NZ Garden Birds 2018 | Te Āhua o ngā Manu o te Kā i Aotearoa*. Manaaki Whenua – Landcare Research. https://doi.org/10.7931/vkex-8543

MacLeod, C. J., Howard, S., Gormley, A. M., & Spurr, E. B. (2019c). *NZGBS 2018 | trend estimates*. Manaaki Whenua – Landcare Research DataStore. https://doi.org/10.7931/7mqz-sw15

MacLeod, C. J., Howard, S., Green, P., Gormley, A. M., Brandt, A. J., Scott, K., & Spurr, E. B. (2019). *NZ Garden Bird Survey 2017: data editing, analysis, interpretation, visualisation and communication methods*. Manaaki Whenua – Landcare Research Contract Report LC3461. https://doi.org/10.7931/n3n0-0g92

MacLeod, C. J., & Scott, K. (2021). Mechanisms for enhancing public engagement with citizen science results. *People & Nature*, *3*, 32–50. https://doi.org/10.1002/pan3.10152

MacLeod, C. J., & Spurr, E. B. (2019). *NZ garden bird survey 2018: spatial coverage and trends in garden records*. Manaaki Whenua Landcare Research Contract Report LC3470. https://doi.org/10.7931/t5mr-ny03

MacLeod, C. J., Spurr, E. B., Brandt, A. J., & Green, P. (2018a). *State of NZ Garden Birds 2017 | Te Āhua o ngā Manu o te Kāri i Aotearoa*. Manaaki Whenua – Landcare Research. https://doi.org/10.7931/vkex-8543

MacLeod, C. J., Spurr, E. B., Brandt, A. J., & Green, P. (2018b). *NZGBS 2017 | Trend estimates*. Manaaki Whenua – Landcare Research DataStore. https://doi.org/10.7931/h44e-wh90

Newman G., Chandler M., Clydec M., McGreavy B., Haklay M., Ballard H., Gray S., Scarpino R., Hauptfeld R., Mellor D., & Gallo J. (2017). Leveraging the power of place in citizen science for effective conservation decision making. *Biological Conservation*, *208*, 55–64. https://doi.org/10.1016/j.biocon.2016.07.019

Newton, I. (1998). *Population limitation in birds*. Academic Press Limited.

Parrish, J. K., Burgess, H., Weltzin, J. F., Fortson, L., Wiggins, A., & Simmons, B. (2018). Exposing the science in citizen science: Fitness to purpose and intentional design. *Integrative and Comparative Biology*, *85*, 150–160.

Pereira, H. M., & Cooper, D. (2006). Towards the global monitoring of biodiversity change. *Trends Ecology and Evolution*, *21*(3), 123–129. https://doi.org/10.1016/j.tree.2005.10.015

Perrings, C., Naeem, S., Ahrestani, F. S., Bunker, D. E., Burkill, P., Canziani, G., Elmqvist, T., Fuhrman, J. A., Jaksic, F. M., Kawabata, Z., Kinzig, A., Mace, G. M., Mooney, H., Prieur-Richard, A. H., Tschirhart, J., & Weisser, W. (2011). Ecosystem services, targets, and indicators for the conservation and sustainable use of biodiversity. *Frontiers in Ecology Environment*, *9*, 512–520. https://doi.org/10.1890/100212

Predator Free Dunedin (n.d. a) Predator Free Dunedin. https://www.predatorfreedunedin.org/

Predator Free Dunedin (n.d. b) *New Zealand Garden Bird Survey interactive map*. Predator Free Dunedin. https://newzealandgardenbirdsurvey.glitch.me/

Core Team R. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology*, *36*, 221–228. https://doi.org/10.1016/j.jenvp.2013.08.004

Robertson, C. J. R., Hyvönen, P., Fraser, M. J., & Pickard, C. R. (2007). *Atlas of bird distribution in New Zealand 1999–2004*. Ornithological Society of New Zealand.

rStudio Team. (2020). *rStudio: Integrated development environment for R*. rStudio, PBC. http://www.rstudio.com/

Schmeller, D. S., Weatherdon, L. V., Loyau, A., Bondeau, A., Brotons, L., Brummitt, N., Geijzendorffer, I. R., Haase, P., Kuemmerlen, M., Martin, C. S., Mihoub, J. B., Rocchini, D., Saarenmaa, H., Stoll, S., & Regan, E. C. (2018). A suite of essential biodiversity variables for detecting critical biodiversity change. *Biological Reviews*, *93*, 55–71. https://doi.org/10.1111/brv.12332

Smith, R., Salazar, G., Starinchak, J., Thomas-Walters, L., & Veríssimo, D. (2020). Social marketing and conservation. In W. Sutherland, P. Brotherton, Z. Davies, N. Ockendon, N. Pettorelli, & J. Vickery (Eds.), *Conservation Research, Policy and Practice* (Ecological Reviews, pp. 309–322). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108638210.019

Spurr, E. B. (2012). New Zealand Garden Bird Survey – analysis of the first four years. *New Zealand Journal of Ecology*, *36*(6), 287–299.

Strohbach, M. W., Haase, D., & Kabisch, N. (2009). Birds and the city: Urban biodiversity, land use, and socioeconomics. *Ecology and Society*, *14*(2)31. https://doi.org/10.5751/ES-03141-140231

Sullivan, J. J. (2012). Recording birds in real time: A convenient method for frequent bird recording. *New Zealand Journal of Ecology*, *36*, 416–424.

Sutherland, W. J., Roy, D. B., & Amano, T. (2015). An agenda for the future of biological recording for ecological monitoring and citizen science. *Biological Journal of the Linnean Society*, *115*, 779–784. https://doi.org/10.1111/bij.12576

Sutherland, W. J., & Wordley, C. F. R. (2017). Evidence complacency hampers conservation. *Nature Ecology & Evolution*, *1*, 1215–1216.

Theobald E. J., Ettinger A. K., Burgess H. K., DeBey L. B., Schmidt N. R., Froehlich H. E., Wagner C., HilleRisLambers J., Tewksbury J., Harsch M. A., & Parrish J. K.. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation*, *181*, 236–44. https://doi.org/10.1016/j.biocon.2014.10.021

Thornhill, I., Cornelissen, J. H. C., McPherson, J. M., MacBride-Stewart, S., Mohamad, Z., White, H. J., & Wiersma, Y. F. (2021). Towards ecological science for all by all. *Journal of Applied Ecology*, *58*(2), 206–213. https://doi.org/10.1111/1365-2664.13841

Tittensor, D. P., Walpole, M., Hill, S. L., Boyce, D. G., Britten, G. L., Burgess, N. D., Butchart, S. H., Leadley, P. W., Regan, E. C., Alkemade, R., Baumung, R., Bellard, C., Bouwman, L., Bowles-Newark, N. J., Chenery, A. M., Cheung, W. W., Christensen, V., Cooper, H. D., Crowther, A. R., … Ye Y. (2014). A mid-term analysis of progress toward international biodiversity targets. *Science*, *346*, 241–244. https://doi.org/10.1126/science.1257484

Travers, H., Walsh, J., Vogt, S., Clements, T., & Milner-Gulland, E. J. (2021). Delivering behavioural change at scale: What conservation can learn from other fields. *Biological Conservation*, *257*, 109092. https://doi.org/10.1016/j.biocon.2021.109092

Vohland, K., Weißpflug, M., & Pettibone, L. (2019). Citizen science and the neoliberal transformation of science – An ambivalent relationship. *Citizen Science: Theory and Practice*, *4*(1), 25. https://doi.org/10.5334/cstp.186

Woodward, I. D., Massimino, D., Hammond, M. J., Barber, L., Barimore, C., Harris, S. J., Leech, D. I., Noble, D. G., Walker, R. H., Baillie, S. R., & Robinson, R. A. (2020). *BirdTrends 2020: trends in numbers, breeding success and survival for UK breeding birds*. Research Report 732. BTO, Thetford. www.bto.org/birdtrends

World Bank. (2015). *World development report 2015: Mind, society, and behavior*. World Bank. https://www.worldbank.org/en/publication/wdr2015

Wright, A. J., Veríssimo, D., Pilford, K., Parsons, E. C. M., Ventre, K., Cousins, J., Jefferson, R., Koldewey, H., Llewellyn, F., & McKinley, E. (2015). Competitive outreach in the 21st century: Why we need conservation marketing. *Ocean & Coastal Management*, *115*, 41–48. https://doi.org/10.1016/j.ocecoaman.2015.06.029

How to cite this article: MacLeod, C. J., Green, P., Howard, S., Gormley, A. M., Brandt, A. J., & Spurr, E. B. (2022). Assessing the state of New Zealand's garden birds from national to local scales. *Ecological Solutions and Evidence*, *3*, e12121. https://doi.org/10.1002/2688-8319.12121