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A threatened species index for Australian birds

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Abstract

Quantifying species population trends is crucial for monitoring progress towards global conservation targets, justifying investments, planning targeted responses and raising awareness about threatened species. Many global indicators are slow in response and report on common species, not on those at greatest risk of extinction. Here we develop a Threatened Species Index as a dynamic tool for tracking annual changes in Australia's imperiled birds. Based on the Living Planet Index method and containing more than 17,000 time series for 65 bird taxa surveyed systematically, the index at its second iteration shows an average reduction of 59% between 1985 and 2016, and 44% between 2000 and 2016. Decreases seem most severe for shorebirds and terrestrial birds and least severe for seabirds. The index provides a potential means for measuring performance against the Convention on Biological Diversity's Aichi Target 12, enabling governments, agencies and the public to observe changes in threatened species.

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1 | INTRODUCTION

Biodiversity continues to decline (Butchart et al., 2010; Tittensor et al., 2014) despite global agreements to preserve it. Mechanisms such as the Convention on Biological Diversity (CBD) parties' UN Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets are designed to address biodiversity declines (CBD, 2010). However, few Aichi Targets are quantified (Tittensor et al., 2014), hampering efforts to report on the effectiveness of policies and actions aiming to recover species (Bjerke & Renger, 2017). One reason for poor quantification is that decision-makers currently lack timely, nuanced metrics and indicators for tracking change in threatened biodiversity. These metrics are necessary not only to support accountability against global targets, but also to inform management and policy at different spatial scales (Geijzendorffer et al., 2016; Pereira et al., 2013; Turak et al., 2017).

Aichi Biodiversity Target 12 states: “By 2020, the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained” (CBD, 2010). Reporting against this target requires metrics that provide an integrated overview of population trends for threatened species. Many available annual metrics track changes in individual species (e.g., the North American Breeding Bird Survey Regional Trend Analysis; <https://www.mbr-pwrc.usgs.gov/bbs/trend/tf15.shtml>; Link & Sauer, 2002) or their proxies (Garnett et al., 2018). Others focus on groups of common species (e.g., the UK Wild Bird Indicator [Gregory et al., 2005; Gregory, Skorpilova, Vorisek, & Butler, 2019; Gregory & van Strien, 2010]) or the Living Planet Index (Collen et al., 2009; Loh et al., 2005; McRae, Deinet, & Freeman, 2017)). While existing integrated metrics are effective tools for communication about biodiversity, most of them were not designed to monitor trends in threatened species and thus do not specifically report on their persistence and recovery. A notable exception, and precedent for the current study, is the Priority Species Indicator developed for threatened species in the United Kingdom (Eaton et al., 2015).

As evident in the uptake by the UK government of the Priority Species Indicator described by Eaton et al. (2015), for reporting on conservation progress (e.g., <https://jncc.gov.uk/our-work/ukbi-c4a-species-abundance/>), a consolidated index reporting on trends for currently imperiled species can also be an effective tool to catalyze and justify management resourcing, inform policy, increase political engagement with threatened species research, and stimulate a targeted response to environmental problems (Jones et al., 2011; Nicholson et al., 2012). Many countries carry

out monitoring of threatened species, but few have frameworks that integrate collected data into a tool for national and regional reporting.

Here, we present an approach for developing a national Threatened Species Index (TSX), building on the established trend aggregation methods of the Living Planet Index (LPI) (Collen et al., 2009; Loh et al., 2005; McRae et al., 2017). We demonstrate how to overcome some of the challenges associated with collating and incorporating data on trends that are often raw, unpublished and from many sources, into an index that is informed by the best available high-quality time series. We illustrate the TSX with Australia's currently imperiled birds. The resulting Threatened Bird Index was developed collaboratively by 42 research partners across 25 organizations from the research sector, civil society and government, and contains 46 datasets on 65 bird taxa (i.e., species and subspecies; see Methods). We summarize trends in imperiled bird taxa to answer three questions fundamental to reporting on conservation progress: (a) What is the mean change in index across currently threatened and near-threatened bird populations from 1985 or 2000 to the present (national-level changes)? (b) Where has the index of threatened and near-threatened bird taxa changed most and least (regional-level changes)? (c) Which bird groups have trends with the most severe index reductions and are hence most urgently in need of conservation action (bird group-level changes)?

The Threatened Species Index was developed on data contributed by all relevant government agencies, individuals and organizations involved in survey and monitoring of imperiled Australian birds. This dataset was reduced according to a set of criteria (see Methods) and is available for download via www.tsx.org.au (TSX, 2020) (select “Birds” under Index and hit the “Download csv” button under <https://tsx.org.au/tsx/#/> to download the data as a csv file and a data dictionary). The Living Planet Index approach (Collen et al., 2009; Loh et al., 2005; McRae et al., 2017) is used to estimate a yearly change in average bird taxa data in relation to a baseline year for which the index is set to 1. Changes in the index are proportional and are always relative to the reference year: a value of 0.5 indicates a 50% decrease relative to the baseline of 1 set at the reference year and a value of 1.5 indicates 50% relative increase. For the purpose of this analysis, we have used 1985 to showcase the results, as this is the earliest year for which consistent data are available. Calculations from a baseline year of 2000, when the availability of monitoring data substantially increased across many taxa, are provided for comparison as supplementary material (Supplementary Material, Figure S1, S2, and S3).

2 | METHODS

2.1 | Data collation

Sixty-five government agencies, individuals and organizations involved in monitoring threatened and near-threatened Australian bird taxa contributed 133,569 bird population time series for 96 taxa from a total of 1,444,510 single surveys conducted over 64 years. Full details of how data were collated, cleaned and processed are included in the Supplementary Material Appendix S1. Data include species to the level of ultrataxa, the terminal taxonomic unit of birds such as species or a subspecies (here referred to as “taxa”). We only included taxa considered nationally Near Threatened, Vulnerable, Endangered or Critically Endangered by one of either BirdLife Australia or the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) during some or all of the period 1985–2016. We use the term “imperiled” to include species and subspecies listed as Near Threatened or threatened. We include Near Threatened species in our index and analyzes as *ipso facto* these species are those most likely to become threatened in the time period over which we anticipate our index will be reporting, and we consider that ongoing monitoring and early reporting of trends for such species will be important for development and implementing conservation options for them.

Contributed data included counts of breeding pairs, prefledging chicks, nests, nests with eggs, recorded calls and nest occupancy rates, as well as systematic occupancy data measured as presences from a total number of surveys, converted to reporting rates (see Supplementary Material, Appendix S1, for a complete list of units of measurement and monitoring methods associated with the time series included). The database required to build time series contains the necessary metadata: unit of measurement, description of monitoring method, level of standardisation and consistency of monitoring continuity at one repeatedly monitored location. An online web interface for data capture by the database was developed and employed to import data submitted via a CSV data import template (accessible to data administrators and custodians at <https://tsx.org.au/tsx/#/import>).

2.2 | Time-series selection

A time series suitable for analysis is defined as longitudinal data for a taxon at a site repeatedly monitored over time using a consistent monitoring method to record the same unit of measurement. Time series are built of standardized population samples at two or more time points for the same fixed site, taxon, method and unit of measurement.

Of the initial collated database, 87% of records were removed because they did not meet a set of criteria for standardisation. For example, data were excluded if they contained incidental sightings, time series with no values other than zeros, time series with less than two years of monitoring, records from sites where monitoring methods and/or effort has changed, or time series where surveys were conducted at different sites rather than repeated for a set of predefined (fixed) sites over time. Owing to sensitivities around threatened species, much of the unpublished data included are subject to confidentiality agreements and are spatially de-identified to biogeographic subregions prior to public display and download.

2.3 | Calculation of multitaxon trends

All analyzes were performed using the software R version 3.6.2 (R Core Team., 2020). The *rlpi* package for R software used for Living Planet Index (LPI) was downloaded from: <https://github.com/Zoological-Society-of-London/rlpi> to calculate the multitaxon trends. The LPI method (Collen et al., 2009; Loh et al., 2005; McRae et al., 2017) calculates multitaxon trends using a geometric mean of trends for each taxon within a Generalized Additive Modeling framework. Where there are fewer than 6 data points, the chain method and log-linear interpolation is used to calculate the trends for a taxon. Following Collen et al. (Collen et al., 2009), we used bootstrapping to resample taxon trends 10,000 times, taking the bounds of the central 9,500 values per year to indicate the 95% confidence of the multitaxon composite relative to the baseline year. These confidence bounds indicate the heterogeneity among single-taxon trends relative to the baseline year used to build the composite. They are not intended to estimate the precision of the trend beyond the taxa and sites contained in the data set. The LPI method is a widely accepted method for measuring large-scale trends from aggregated data. Here we used the same settings as those used to produce the trends of the Living Planet Reports (WWF, 2018).

A workflow processing pipeline was developed using python programming language and all the data were managed in a MySQL database. Full documentation and a user guide on the workflows is available at <https://tsx.org.au/user-guide/>. We developed software routines which assisted with data upload and data quality assessment by enabling data from different monitoring programs to be classified, processed and analyzed depending on data type, temporal, and spatial aggregation (Supplementary Material, Figures S6 and S7). The scripts for the workflow and documentation can be downloaded from GitHub: <https://>

github.com/nesp-ts3-1/tsx and adjusted for the specific needs of the user.

2.4 | Sensitivity analyzes

We conducted sensitivity analyzes to identify the minimum data needed to reproduce trends of the full dataset. We examined the effect of (a) time-series length and (b) number of included taxa on the stability of the index by comparing how changes in time-series length or in the number of taxa affect the index slope.

Sensitivity analyzes suggested that the length of a time series did not have a significant impact on the index slope (Supplementary Material, Table S4). Thus, the trends shown here are produced based on time series with a length of at least 2 years (in alignment with the minimum time-series length requirement of the LPI method). Further analysis suggested that the minimum number of taxa needed to be at least 7 to produce results converging towards those when a full dataset is used and to reduce the variability by a factor of 2 (Supplementary Material, Figure S5).

The starting point for both sensitivity analyzes was a dataset containing 17,243 time series from standardized monitoring and 65 taxa with a time-series length of at least 2 years. The effect of time-series length on the index slope was investigated by producing Threatened Species Index trends based on a step-wise reduction of time-series length from 10 and more years: 10+, 9+, 8+, 7+, 6+, 5+, 4+, 3+ and 2+ years (Supplementary Material, Table S4). We then investigated the effect of the number of taxa included on the index slope when degrading the dataset by randomly selecting 2, 3, 4, 5, 6, 7, 8, 9 and 10 taxa to create subsets. Each degradation step for a dataset involved 100 simulations resulting in a new degraded dataset with reduced number of taxa. The mean of all slopes from trends produced by the degradation schedule were built with 95% confidence intervals and compared to the slope from the trend based on the overall dataset (Supplementary Material, Figure S4).

3 | RESULTS

3.1 | National-level changes

The Threatened Species Index compares relative multitaxon composite trends of imperiled Australian birds. It shows that the relative trend which included all data available decreased severely over the reporting period, with a mean change from 1 in 1985 to 0.41 in 2016, that is, a decrease of 59% relative to the baseline

year (Figure 1a). The slope is approximated as a linear regression with the index values and equals -0.02 , that is, a 2.1% decrease in index value per year. On average and over the reporting period 2000–2016, the index on imperiled birds decreased by 44% with a 2.5% reduction per year (Supplementary Material, Figure S1a and Table S2). The leverage of each individual taxon on the overall index is displayed in Figure S4 (Supplementary Material) by calculating the index after step-wise removing each taxon from calculation. The index includes 17,243 time series for 65 taxa (mean time-series length of 11.9 ± 8.3 years (mean $\pm$ SD) and with 7.6 ± 6.2 (mean $\pm$ SD) years sampled per time series).

Spatial representation of available data across the nation is uneven. Of all individual monitoring sites represented in the index, 61% come from the most populated eastern states and territories of mainland Australia (Queensland, New South Wales, Victoria, Australian Capital Territory) whereas only 13% are from the Northern Territory, South Australia and Western Australia (despite these states covering 66% of the continent), 24% from Australian external territories, and only 2% are from the island state of Tasmania (Figure 1b). Not all sites were consistently monitored over the entire time from 1985 to 2016 (Figure 1c). There was an increase in monitoring of taxa from 10 in 1985 to 56 in 2011, and of sites, from 1,267 time series in 1985 to 12,999 in 2011 (Figure 1d).

Intra- and inter-specific variation in trends was observed. Variability between the single-taxon trends that build the multitaxon composite manifests as an average decrease of between 70% and 44% for the time interval 1985 to 2016 (Figure 1a, gray cloud bounds).

3.2 | Regional-level changes

We broke down the national index to the subdivisions of the six Australian states, two territories and the Australian external territories (including the Australian Antarctic Territory, Christmas Island, Heard and McDonald Islands). The sub-national indices are therefore based on taxa that were monitored at sites located within each jurisdictional subdivision. It should be noted that taxa with monitoring data from one jurisdiction may also pertain to other jurisdictions. For some taxa, the primary cause of declines may be experienced beyond the area included in our datasets (e.g., migratory shorebirds [Studds et al., 2017]).

Between 1985 and 2016, index scores decreased most steeply in South Australia (83% average decrease) and New South Wales/Australian Capital Territory (83%) (Figure 2). Comparable trends were reported for the

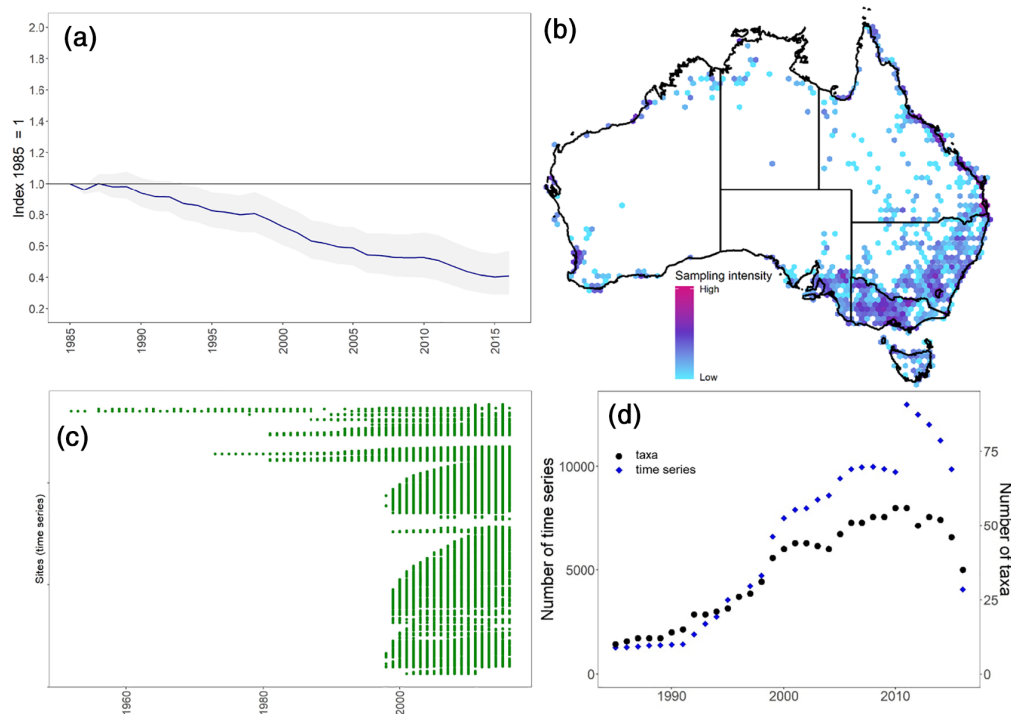
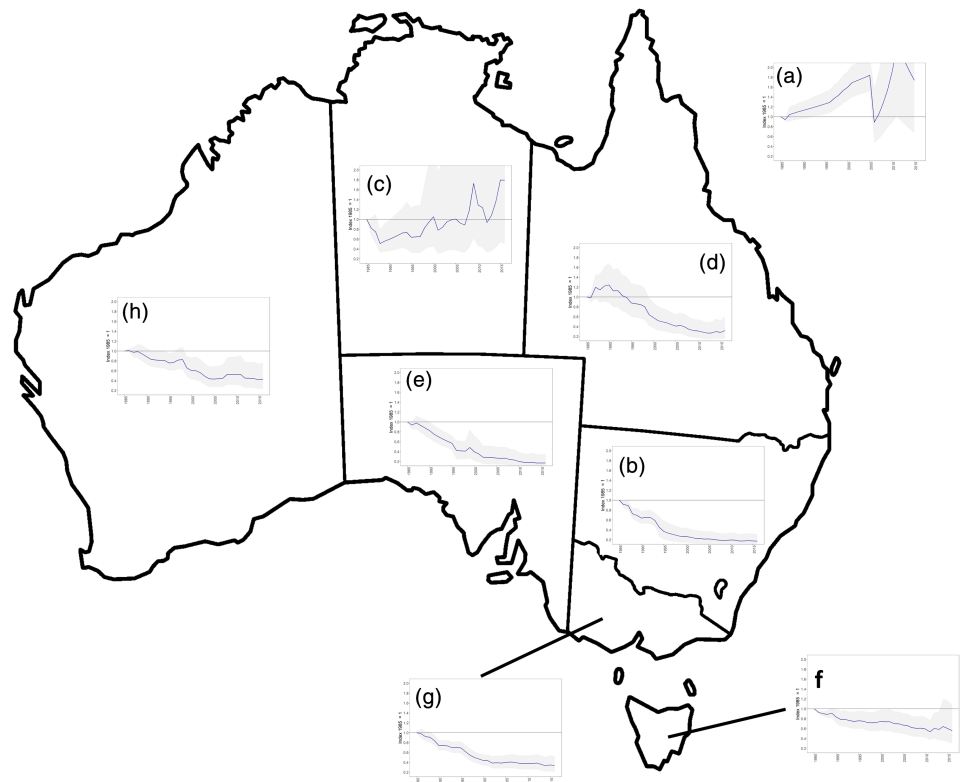


FIGURE 1 Threatened Species Index (TSX) created for 65 Australian bird taxa. (a) TSX between 1985 and 2016 based on bird taxa listed as threatened or Near Threatened. Proportions of the number of time series in the database for taxa listed under each threat category are: Critically Endangered (16.5%), Endangered (24.2%), Vulnerable (7.3%), and Near Threatened (52.0%). The composite multitaxon index is indicated by the blue line. The gray area represents the heterogeneity among single-taxon trends. (b) Spatial representation of sampling intensity of data included in the index. (c) Number of population time series for each taxon at each site surveyed repeatedly through time (green circles are superimposed due to the large number of time series in the database). (d) A summary of the number of taxa (in black circles) and number of time series (in blue diamonds) used to calculate the index for each year

FIGURE 2 Regional Threatened Species Indices for 65 threatened and near-threatened bird taxa surveyed in (a) Australian external territories (8 taxa, 4,101 time series), (b) New South Wales and Australian Capital Territory (30 taxa, 2,414 time series), (c) Northern Territory (13 taxa, 134 time series), (d) Queensland (23 taxa, 5,097 time series), (e) South Australia (23 taxa, 1,045 time series), (f) Tasmania (21 taxa, 356 time series), (g) Victoria (27 taxa, 3,031 time series), and (h) Western Australia (23 taxa, 1,065 time series). Composite multitaxon indices between 1985 and 2016 are indicated by the blue line. The gray area represents the heterogeneity between single-taxon trends



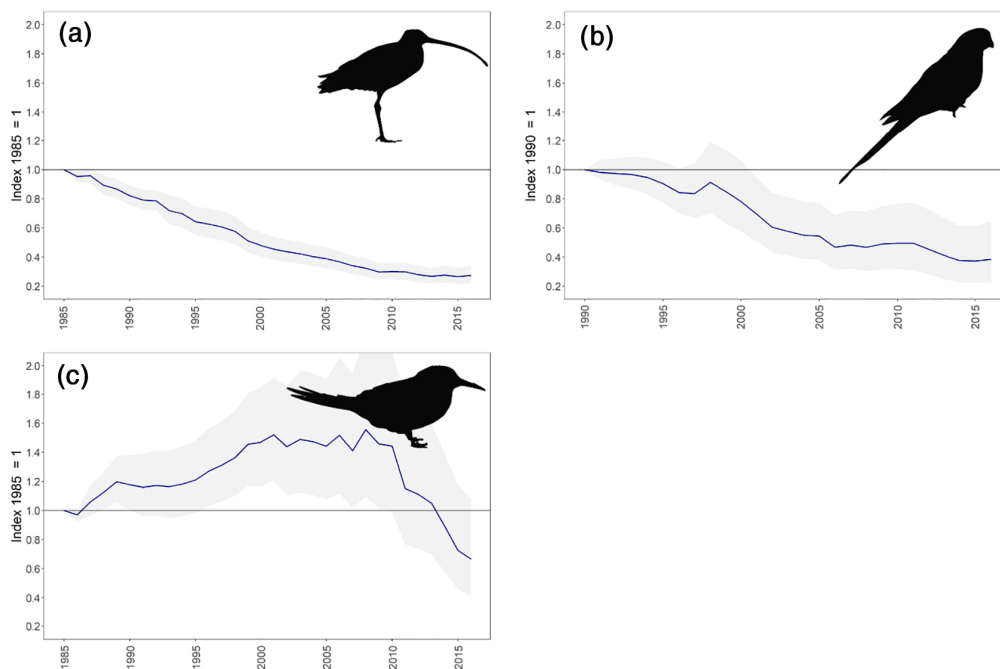


FIGURE 3 Threatened Species Index (TSX) for groups of Australian birds. (a) TSX for imperiled migratory shorebirds inhabiting the shoreline (10 taxa, 7,273 time series). (b) TSX for imperiled terrestrial birds (40 taxa, 9,175 time series) between 1990 and 2016. (c) TSX for imperiled marine birds/seabirds (13 taxa, 583 time series). Composite multitaxon indices between 1985 and 2016 are indicated by the blue line. The gray area represents the heterogeneity between single-taxon trends

period 2000–2016 (Supplementary Material, Figure S2). Increases were observed for the Northern Territory (79%) and the Australian external territories (74%), albeit with large variabilities in single-taxon trends (Figure 2).

3.3 | Comparisons among bird groups

Bird taxa were categorized into 'shoreline', 'marine', 'terrestrial', and 'wetland' groups depending on their natural habitat (*sensu* Garnett et al., 2015). The indices reporting on taxon group-level changes are based on data for 10 migratory shoreline, 13 marine, and 40 terrestrial taxa. Results from sensitivity analyzes indicated that sub-indices need to be calculated based on at least seven taxa to be representative (Supplementary Material, Figure S4), thus aggregated trends of the two wetland bird taxa are not calculated nor presented here. Other indices on bird groups of conservation interest are presented and updated annually in the online tool for public interrogation (www.tsx.org.au). Many more combinations of sub-indices are possible, assuming adequate numbers of taxa and data are available to populate the sub-index.

The TSX shows that the data subset on migratory shorebirds showed the greatest average decrease in index of 73% between 1985 and 2016 (Figure 3a), and 43% between 2000 and 2016 (Supplementary Material, Figure S3a). The terrestrial birds index decreased by 62% on average between 1990 and 2016, but there is more variability among taxa in trends over time (Figure 3b). Between 2000 and 2016, the 51% average index decrease in terrestrial birds exceeded that of shorebirds

(Supplementary Material, Figure S3b). Marine birds showed an overall increase in index from 1985 to 2007, which then declined, with a net 33% average decrease between 1985 and 2016 (Figure 3c) and a steeper index decrease of 55% between 2000 and 2016 (Supplementary Material, Figure S3c). None of the monitored bird taxa included in the TSX became extinct over the period 1985 to 2016.

4 | DISCUSSION

Here we present a Threatened Species Index (TSX), which has been developed for Australia's currently imperiled birds using the Living Planet Index methodology and data from more than 17,000 time series for 65 systematically surveyed bird taxa, from 46 monitoring programs. The TSX is based on raw data provided by multiple data custodians across Australia. Each individual dataset underwent a rigorous eligibility check (see 'Data quality control and vetting' in Supplementary Material, Appendix S1) to ensure that best practices for monitoring were followed. The TSX currently covers 27% of Australia's threatened and near-threatened bird taxa (Supplementary Material, Table S1) and may enable Australia to report on progress made against international commitments to improve the status of threatened species (i.e., Aichi Target 12 and Sustainable Development Goal 15). In 2019, the Australian Government adopted the index as an official performance criterion to report on changes in threatened birds annually (Australian Government, 2019). The dynamic,

reproducible approach presented here can be updated as new data become available and could potentially be adopted by other countries for similar reporting purposes on any taxonomic groups.

The results presented here are based on the second iteration of the TSX released in November 2019. The TSX compares relative trends and the method calculates a geometric mean across all taxon trends. This means that the TSX combines all taxa with equal weighting, even if some are rarer than others. This is appropriate for our application, as we were looking to determine the overall trend in threatened taxa regardless of how prevalent the taxa are across the continent. Using Australia's imperiled birds as a case study, we show an average reduction in composite trend of 59% between 1985 and 2016, and 44% between 2000 and 2016. Decreases are most severe for shorebird and terrestrial bird trends but are not pervasive for trends across all groups and locations. For some regions such as the Northern Territory and the Australian external territories, we detect an increasing trend. The index for marine birds is highly variable but also shows an overall increase between 1985 and 2007. If one or more taxa are increasing over time, this could produce a positive overall trend even though some taxa might still be decreasing in that group (e.g., terrestrial birds). These positive sub-trends provide modest grounds for encouragement in the face of the current global biodiversity crisis: Australia alone has lost 100 species over the last 230 years (Woinarski, Burbidge, & Harrison, 2015), 9 of which were birds (Woinarski et al., 2019) while global species extinctions are 1,000 times the background rate (Pimm et al., 2014).

Because a real population decline is a component of the criteria assessed for listing species as threatened (Vulnerable, Endangered and Critically Endangered) and Near Threatened (IUCN, 2017), there is some *ipso facto* reason for expecting a Threatened Species Index to show a decrease. However, imperiled species are often also the subject of targeted conservation management aimed at recovering those species, and recovery of threatened species is an explicit objective at an international level. Some of those recoveries might be visible when exploring the leverage of each individual taxon on the overall index (Supplementary Material, Figure S4). Thus an index of threatened and near-threatened species highlights whether policies and targeted conservation management aimed at recovering those species have been effective (Suckling, Mehrhoff, Beam, & Hartl, (2016)). Our approach also allows for inclusion of taxa that were formerly (i.e., at or subsequent to our baseline) listed as threatened but have recovered to a secure conservation status; however, while cases exist, none have been adequately monitored (Legge et al., 2018), and hence no such species were included in our index.

In our demonstration, the TSX for Australia's imperiled birds contains taxa with life histories ranging from small, sedentary passerines confined to highly specific habitats, to the largest seabirds on earth breeding in the sub-Antarctic. Due to many differences in the threats faced by these taxa, along with variability in their life history characteristics and responses to threats and their management, there is a high degree of variance in the threat environment and consequently in trends of populations across Australia (Legge et al., 2018). Furthermore, some highly imperiled taxa have been managed intensively and are showing signs of recovery [e.g., Helmeted Honeyeater (*Lichenostomus melanops cassidix*) and the Kangaroo Island Glossy Black Cockatoo (*Calyptorhynchus lathami halmaturinus*)] whereas others are either not managed or, even when managed, are not recovering (e.g., migratory shorebirds). For instance, the index for migratory shorebirds matches previous studies that used different methods (Clemens et al., 2016; Studds et al., 2017; Szabo, Butchart, Possingham, & Garnett, 2012) to document consistent declines across many taxa in this group. The low variability among single-taxon trends for the migratory shorebirds indicates that all taxa in this group are likely to be subject to much the same threat environments and are responding similarly (strongly decreasing). In contrast, the index for marine birds reflects marked inter-specific variation. This is likely due to the relatively low number of time series and the large increase in the number of taxa monitored over time. However, it may also be integrating the responses of disparate populations to threats and their management for example, population increases in some species following the eradication of introduced pests from Macquarie Island being offset by fishing-related declines in others (Springer, 2018).

All biodiversity indicators come with certain caveats and the TSX is no exception. One caveat is that we have included both abundance (12,149 time series) and occupancy (in the form of reporting rates from dividing the number of presences by the number of total surveys; 5,094 time series) data in the TSX because no abundance data were available for some large functional groups such as terrestrial birds. Van Strien et al. (2016) included occupancy data in their national butterflies' index and then show that the decline in occupancy is shallower than the decline in abundance using the same data (van Strien et al., 2019). This behavior was also observed by Eaton et al. (2015) for the status of UK's priority bird species (<https://jncc.gov.uk/our-work/ukbi-c4a-species-abundance/> vs <https://jncc.gov.uk/our-work/ukbi-c4b-species-distribution/>). As species populations decline, abundance and occupancy are expected to change at different rates, but their relationship is still unclear (Outhwaite et al., 2020). The relationship between

abundance and occupancy in some of Australia's bird groups needs to be explored once both types of data become available.

The availability of data is another limiting factor. As for all data-dependent indicators, our index is currently restricted to those Australian imperiled bird taxa for which adequate monitoring data are available. These data largely come from the more populous eastern states and the South Australian coast. Due to the relative paucity of data relative to the number of imperiled bird species, Western Australia, the Northern Territory and the arid Australian region are underrepresented. The data included comprise 27% of all Australian threatened and near-threatened bird taxa, suggesting that monitoring is inadequate for calculating long-term trends for most species. Thus, our index may not yet be representative of trends across all imperiled Australian bird taxa (Supplementary Material, Table S3). There is a potential for bias given the spatial distribution of monitoring in favor of more developed regions and given that much threatened species monitoring is targeted towards the species that are most imperiled (Legge et al., 2018). This is a common issue in ecological monitoring globally (Martin, Blossey, & Ellis, 2012) and within the Living Planet Index (McRae et al., 2017). However, in the absence of systematic sampling data, approaches outlined here can make effective use of the best quality data that are available.

Given their public profile, more monitoring data are likely to be available for birds than for other taxonomic groups (e.g., mammals or plants) of imperiled species, which may constrain the development and interpretation of indices for these other taxonomic groups. However, it would not preclude their inclusion in a national Threatened Species Index representing all taxa. In order to construct more fully representative indices for imperiled species, a strategic approach is likely to be needed that establishes monitoring programs for underrepresented locations and for particular species, for example, those undergoing responses to threats not captured by currently monitored species.

Without clear metrics linked to Aichi Biodiversity Targets, governments worldwide will be unable to monitor progress towards commitments made under the Convention on Biological Diversity (CBD, 2010). The approach we have demonstrated for developing a Threatened Species Index provides a practical solution for national and international reporting on trends of imperiled (threatened and near-threatened) taxa, capable of highlighting regional changes and identifying the taxonomic groups most in need of effective management response. The ability of the metric to track and visualise relative changes of imperiled species as a composite

makes it an effective tool for communicating biodiversity changes to end users at national and regional levels. The process of collating data for the development of a TSX can also help identify imperiled species and subspecies for which no data of sufficient quality to calculate trends are presently available or for which current monitoring is inadequate. It could hence stimulate the development of monitoring programs for such neglected species.

A commonly used approach for reporting on changes in the status of threatened (and non-threatened) species is the IUCN Red List Index (RLI) (Bubb et al., 2009). Like this study, previous applications of the RLI at a national scale showed declines in the status of Australia's birds between 1990 and 2010, and for both the TSX and the RLI the reductions were greatest in South Australia (Szabo et al., 2012). However, there are also discrepancies between the two indices at regional and temporal scales. For instance, bird taxa in Queensland showed the smallest declines in the RLI between 1990 and 2010 while they had some of the largest average decrease in the TSX in this period (85%). While the RLI was almost stable between 1990 and 2000 in Western Australia and Victoria, thus indicating few changes in bird conservation status, the TSX in both these states decreased by almost 30% (27% and 30%, respectively) during this time. These discrepancies are because the RLI assesses changes in the number of taxa crossing IUCN Red List thresholds whereas the TSX is measuring change in the abundance (and occupancy) of threatened taxa regardless of thresholds. The comparison highlights the value of the TSX. The RLI has value because it synthesises changes in conservation status of species but assessments of improvement in status have a built-in lag of five years between documented improvements and down-listing. The RLI is appropriate for reporting on changes that occur at long (e.g., decadal) time scales but the TSX is more sensitive and can allow for annual reporting. This difference is important where there is a need for regions or countries to report against short-term policy targets or for informing timely management decisions. For example, the 5-year target of the Australian National Threatened Species Strategy to improve populations trajectories of 20 threatened birds and mammals and 30 threatened plants by 2020 (Australian Government, 2015) could not be evaluated using IUCN Red-listing criteria as these species are unlikely to change in status over the target time period. In contrast, the TSX tool demonstrated here can report on annual changes in imperiled taxa, so long as those species have sufficiently frequent and appropriate monitoring. While its initial setup is time consuming, it has the advantage of being capable of dynamic update every year. In fact, the data presented here are from the second iteration of the TSX for birds released in

November 2019. Thus, we propose a TSX is a more appropriate tool than the Red List Index for time-sensitive applications, including the need for relatively quick detection and subsequent action in response to rapid declines in regions or groups of species such as presently experienced due to the bushfires in Australia.

National targets aimed at threatened species recovery are important. Yet, out of 83 nations that have formulated goals specifically for preventing threatened species extinctions under Aichi Biodiversity Target 12, only three are quantifying progress towards these goals. Norway has targets for threatened species population numbers, Bahrain has targets for percentage changes in population trends and Gambia aims to have prevented extinction for 35% of known threatened and rare species by 2020 (CBD, 2019). National threatened species indices could help encourage the setting of such national targets and aid reporting against these. They could also be used to measure the impacts of policies and decision-making just as quantitative economic indices such as the gross domestic product, unemployment rate or Dow Jones Index reflect the status of economies (Charles & Darne, 2014; Demirguc-Kunt & Levine, 1996). Like these socio-economic indices, some trends in our index are caused by factors operating at global rather than national scales (Clemens et al., 2016; Studds et al., 2017), allowing the index to highlight both national and international priorities for species conservation.

5 | CONCLUSIONS

We show that a national Threatened Species Index can be developed and be potentially used to monitor Australia's progress towards meeting international and national conservation targets. It has the potential to be integrated into reporting on imperiled taxa, for example, within State of the Environment reporting, and can be used as a powerful tool for communicating the state of threatened and near-threatened taxa to the public. The approach used in this index could readily be transferred to reporting globally and for other species groups of conservation concern. We encourage other countries with long-term monitoring programs and data to consider the TSX concept. Successful persistence of such a metric relies on: (a) continuation or enhancement of adequate monitoring for sufficient imperiled species; (b) adequate resourcing for index preparation; (c) hosting and management of raw source data; (d) engagement with data custodians, ensuring continuing data entry and index calculation; (e) an automated workflow pipeline which streamlines most data processing steps; and (f) ideally an online interface to enable others to upload, use, interrogate and download the data. The TSX can be an enduring

tool for tracking change in threatened and near-threatened species and subspecies over time and space, if collaborating agencies and other stakeholders continue to collect and contribute monitoring data. It can help stimulate broad community discussion of the state of threatened biodiversity. Ultimately, it has the potential to become a recognised metric for our performance in conserving biodiversity, and a valuable addition alongside other currently widely used measures of the health and prosperity of nations.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

EB, GE, AITT and HPP conceived the manuscript. EB analyzed the data. All authors interpreted the results. EB wrote the manuscript with the input from all authors.

ETHICS STATEMENT

Data custodians were surveyed under Human Ethics Approval number: 2018001572.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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