Threatened Species Recovery Hub

National Environmental Science Programme

A Threatened Species Index for Australia: Interim Report Part 1 – Birds

January 2018

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Front cover: Photo of Eastern Regent Parrots kindly provided by G. Ehmke, BirdLife Australia.

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Electronic supplementary material
Supplementary material is available electronically from the TSR Hub project webpage:
www.nespthreatenedspecies.edu.au/projects/threatened-species-index

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Acknowledgements

Developing species population indices is inherently challenging given the mysterious ways of nature and much of the World's biological diversity. To develop an index for threatened species is to take on a long journey into the world of data while facing the hardest analytical challenges given the rarity of most threatened species, their crypsis, the vast distances over which they occur and the commitment it takes to monitor them over the long-term. Many attempts to empirically quantify threatened species population trends nationally have failed. This prospect has loomed as significant risk at all stages of this project. Indeed, the work presented here is only a first attempt and as such will require refinement and improvement over time if it is to evolve into a useful and widely adopted reporting tool to aid in the conservation of Australia's native flora and fauna.

To venture a task with such high likelihood of failure is not the norm in the modern and risk averse world. Convincing such a large number of people from around the nation to give this idea a go requires strong visionary leadership and enthusiasm. None has been more enthusiastic and instrumental in this initial effort to compile data and calculate the index than Hugh Possingham who's passion for the concept over more than a decade has been unwavering. Hugh has remained committed to this effort and has devoted much attention to it despite innumerable demands on a large proportion of his private time (now as Chief Scientist of The Nature Conservancy) and his mastery of highly complex problems solving. We hope Hugh will continue his lead and inspire the index team for many years to come.

Works such as this are only possible as a collaboration of many. The project has drawn on the collective efforts of innumerable highly dedicated and passionate people who devote much of their lives to helping threatened species. This initial effort featured a collaboration of far too many people from all Australian states and territories, non-government organisations, academia or simply concerned citizens in order to identify them all individually. The willingness of so many to assist this effort in highly substantial ways and often in their private time has been more than overwhelming. We would like to mention just a few of our collaborators that have been crucial for the development and success of the project. We have benefited enormously from the combined wisdom of John Woinarski (Charles Darwin University) for having the right instinct on directing the project, Stephen Garnett (Charles Darwin University) for sharing not only his in-depth knowledge on Australian birds but also his data, Ayesha Tulloch (University of Queensland and University of Sydney) for her help in planning for and executing the report as well as her guidance during processes requiring strategic finesse as a project co-leader, James O'Connor as our first contact for support and inspiring ideas at BirdLife Australia and Megan Barnes (University of Hawaii) for her knowledge of species population models and long coding nights. Elisa Bayraktarov would like to particularly thank James O'Connor for the encouragement and keeping the focus on making the dream of an index come true especially at stormy times for the project. Internationally, we also learned a great deal from Louise McRae who is managing the implementation of the Living Planet Index Reports at the Zoological Society of London. Louise has made her long way from rainy London to sunny Brisbane to introduce and teach us the Living Planet Index method and adjust it to fit the data on Australian threatened species.

Behind the scene of science and bright light of shiny headline graphs and numbers, work such as that on data collation and processing is often overlooked. However, those who are used to analysing monitoring data know that the bulk of work happens well before any results are produced. In this project, 90% of the day-to-day work was on data processing and collating which constituted an astronomic effort by our data wrangling team. The data from threatened species monitoring that we have dealt with came in from a large number of sources and in all imaginable shapes of format. It was truly a mammoth's job to process the vast diaspora of data formats into a consistent and logical database structure. We are especially indebted to the strenuous support and enthusiasm of Joris Driessen (BirdLife Australia) for the largest part of datasets but also to Rob Clemens (BirdLife Australia) for processing data on shorebirds. Once the data were reformatted and ready to go, our collaboration with the scientific workflow team became invaluable. In this project we presented the workflow team with tasks we thought would be impossible, or at the very least far too difficult to complete by our deadlines. However, thanks to the truly tireless dedication and efforts of Hoang Nguyen from UQ's Research Computing Centre, James Watmuff from Planticle Apps & Development along with Siddeswara Guru, aka 'Guru', from the Terrestrial Ecosystem Research Network - who came up with the idea that the index needed a workflow, our expectations were well and truly exceeded. The efforts of the workflow team are particularly important in providing a means to update and improve the index over time. There is little point in efforts such as these if they are not repeatable and largely automated. The workflow represents a landmark achievement in streamlining and automating tasks which would otherwise take months to complete for each index iteration, thus would render it a futile exercise in the light of the urgency for a need to report on our threatened species periodically.

To all those who have collected the data on threatened species, your efforts are unequivocally the most important part of this whole endeavour. Without you, a Threatened Species Index for Australia would never have been possible.

Much research, monitoring and conservation is conducted voluntarily. Certainly, much of the data used in this project have been collected by volunteers or professionals working well outside their immediate remit.

Often vast distances are travelled and expenses incurred in the name of elucidating 'How are our threatened species going?' The quality of monitoring research and consistency of effort over long periods, in the context of an increasing busy and demanding world, are truly laudable and will be essential to this and all conservation efforts in the future. We would like to emphasise our special gratitude to everyone who has provided data points stained by time, effort, money, sweat and care about our native flora and fauna.

This work was carried out with financial support of the Australian Government via the National Environmental Science Programme's Threatened Species Recovery Hub ($370,000), external support by the Ian Potter Foundation via BirdLife Australia ($120,000), the Terrestrial Ecosystem Research Network ($30,000) as well as an estimated in-kind contribution of $800,000 from our research partners. The views expressed herein are not necessarily the view of the Commonwealth or any other external funders, and theses do not accept responsibility for the information or advice contained herein.

We would like to thank our multitude of reviewers of this report who took their time to read through this >90 pages document. Most notably were the contributions by Jason Ferris and Nick MacGregor from the Department of the Environment and Energy. We are also thankful to Margaret Byrne from the Western Australian Department of Biodiversity, Conservation and Attractions, Mel Hardie from the Victorian Department of Environment, Land, Water and Planning, Allie Mokany from the Department of the Environment and Energy, David Lindenmayer from the Australian National University, Louise McRae from the Zoological Society of London, Rachel Morgain from the Australian National University, Stephanie Avery-Gomm from the University of Queensland, as well as members of our core team for the constructive comments which helped us to improve this report significantly and lit the fire of an exciting discussion around threatened species indices for the future to come.

Developing an Australian Threatened Species Index requires a broad representation of Australian stakeholders from all around the country. We are grateful and fortunate to be supported by at least one representative from each Australian state and territory, the Commonwealth Government, the Australian Wildlife Conservancy, Bush Heritage Australia, several research institutions, and most notably BirdLife Australia. We would like to acknowledge these (currently) 42 research partners who helped us develop this unique collaborative network among agencies and groups that collect monitoring data on threatened species, embarking towards the development of a coordinated index.

Communication with and between stakeholders has been instrumental not only for the identification and collection of data, but also to reach a common ground on what tool the end-user needs to have developed. We are indebted to the Communications Team at the Threatened Species Recovery Hub, Jaana Dielenberg, Mary Cryan, and David Salt but especially to Rachel Morgain who has communicated and often translated the messages between researchers and stakeholders. We are particularly thankful to the Director of the Hub, Brendan Wintle, the Hub's UQ Node Leader, Martine Maron, and the Hub's Leadership Group for their advocacy in strengthening the importance of this project. Many thanks also to Heather Christensen and Christine Fenwick for administrative support as well as to the Research Partnerships Office at the University of Queensland and Paul Sullivan from BirdLife Australia for dealing with multiple data sharing agreement in the most efficient manner.

Last but not least, we would like to thank the Friends of the Index – a list of potential end-users, supporters, and/or people from the wider public who just care about the state of Australia's threatened species. Your encouragement and endeavour to change the world towards our common dream of saving threatened species has been and truly continues to be an inspiration.

15th of January 2018

Elisa Bayraktarov
University of Queensland

Glenn Ehmke
BirdLife Australia

Figures

Tables

Glossary

Aggregation:	The process of grouping sighting records of individuals into defined spatial and temporal units used for analysis.
Aggregated data:	Aggregated data consist of >1 numerical data points that have undergone quality control, pre-processing, and been grouped into representative units suitable for analysis.
Arithmetic mean:	Sum of a collection of numbers divided by the number of numbers in the collection.
ASX 200	Australia's stock market index listed on the Australian Securities Exchange
Composite index:	An index that integrates trend information from multiple species into a single value per unit of time and includes information on the uncertainty around this value.
Data source:	The original data custodian who supplied raw data used in this project.
Functional bird group:	A grouping of bird taxa based on the environment they predominantly inhabit: Terrestrial, Marine or Shoreline (migratory or resident)
Functional bird subgroup:	Groupings of terrestrial bird taxa by their predominant association with major habitat types (as determined by aggregations of National Vegetation Information System types) and marine taxa according to taxonomic family
IBRA Subregion:	Interim Biogeographic Regionalisation for Australia (IBRA), Version 7 classifying Australia's landscapes into 89 large geographically distinct bioregions based on common climate, geology, landform, native vegetation and species information, and 419 subregions which are more localised and homogenous geomorphological units in each bioregion (Australian Government Department of the Environment and Energy and State Territory land management agencies 2012). In this report, spatial information of a species population time series is provided to the IBRA subregion level (i.e. latitude and longitude in WGS84 are given as centroids of IBRA subregions in which the species was monitored).
Geometric mean:	The central tendency or typical value of a set of numbers by using the product of their values (as opposed to the arithmetic mean which uses their sum). See 'Arithmetic mean'
Harmonic mean:	The reciprocal of the arithmetic mean of the reciprocals of the given set of observations. See 'Arithmetic mean'
Monitoring method:	A consistent, comparable way of collecting data for a threatened or Near Threatened species (see section A2.5.5 in the supplementary material for a complete list of monitoring methods)
Near Threatened:	A taxon assessed as Near Threatened by the BirdLife Australia Threatened Species Committee from 2016. The category 'Near Threatened' follows the IUCN Red List criteria for Australian species and subspecies
Raw data:	Raw data are a set of numerical measures of abundance or presences/absences linked to the full resolution geographical coordinates for a threatened or Near Threatened species at a specific time point with a specified monitoring method.
Search Type:	In terms of this report Search Type is a synonym for Monitoring method. See 'Monitoring method' (see section A2.5.5 in the supplementary material for a complete list of monitoring methods)
Site:	A discrete spatial entity in which species data are collected over time using a consistent monitoring method
Spatial representativeness:	Proportion of the available data to the total known distribution of a taxon
Species:	Species in this report refers to a taxon, i.e. it may be a species or subspecies. See 'Taxon'

Taxon, pl. taxa:	Taxon refers to ultrataxon (Schodde and Mason 1999). An ultrataxon is the terminal taxonomic unit of birds (i.e. a monotypic species or a subspecies). The term can be applied to any taxonomic group. This terminology is sensu the Action Plan for Australian Birds (Garnett et al. 2011).
Temporal aggregation:	See 'Aggregation'. The unit used for temporal aggregation in this report is one year.
Threatened species:	A taxon included in the Vulnerable, Endangered or Critically Endangered category of the list of threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* as at December 2017, and/or as meeting the IUCN Red List Criteria to be categorised as Vulnerable, Endangered, Critically Endangered, as judged by the BirdLife Australia Threatened Species Committee. The latter is referred to as BirdLife Australia Conservation Status (from 2016) and is consistent with the International Union for Conservation of Nature (IUCN) Red List. Seabird breeding and non-breeding populations are assessed separately.
Time series:	A time series is a sequence of population samples for a species at two or more time points that uses the same method of collection at the same location. At a minimum, a time series requires spatial information about the location, a description of the monitoring method, and the units of measurement.
Time-series evenness:	Variance of the length of gaps in the time series
Time-series length:	Time period between first year of a repeated measure at one site and the last year.
Time-series sample years:	Number of years between the initial and final year of a time series in which a sample was recorded.
TSX:	Threatened Species IndeX; an index calculated from processed and quality-controlled Australian threatened and Near Threatened species time-series data based on the Living Planet Index approach.
Unit of measurement:	Units used to quantify the abundance of a taxon recorded within the same monitoring method. Units of measurement can be actual count numbers of individuals, occurrences (presences/absences of individuals), or proxies. Different units of measurement cannot be directly compared (see section A2.5.4 in the supplementary material for a complete list of the units of measurement)
Ultrataxon:	The terminal taxonomic unit of birds (i.e. a monotypic species or a subspecies). See 'Taxon"
Index:	Index refers to a composite index (See 'composite index) which utilises information from multiple species to estimate the overall trend of a group of species populations. See 'TSX

List of Acronyms

ALA	Atlas of Living Australia
ANU	Australian National University
AWC	Australian Wildlife Conservancy
BHA	Bush Heritage Australia
CBD	Convention on Biological Diversity
CDU	Charles Darwin University
DBCA	Department of Biodiversity, Conservation and Attractions (Western Australian Government)
DES	Department of Environment and Science (Queensland Government)
DELWP	Department of Environment, Land, Water and Planning (Victorian Government)
DENR	Department of Environment and Natural Resources (Northern Territory Government)
DEWNR	Department of Environment, Water and Natural Resources (South Australian Government)
DoEE	Department of the Environment and Energy (Australian Government)
DPIPWE	Department of Primary Industries, Water and Environment (Tasmanian Government)
GAM	Generalised Additive Model
GLM	Generalised Linear Model
IBRA	Interim Biogeographic Regionalisation for Australia
IUCN	International Union for Conservation of Nature
LPI	Living Planet Index
MIT	Massachusetts Institute of Technology.
NESP	National Environmental Science Program
OEH	Office of Environment and Heritage (New South Wales Government)
RCC	Research Computation Centre
SoE Report	State of the Environment Report
SoS	Saving our Species
TERN	Terrestrial Ecosystem Research Network
TSR Hub	Threatened Species Recovery Hub
TSX	Threatened Species IndeX
UQ	University of Queensland
ZSL	Zoological Society of London

Executive Summary

The Goal

The overall goal of the NESP TSR Hub Threatened Species Index Project is to develop, test and deliver an index that provides reliable and robust measures of changes in the relative abundance of Australia's threatened and Near Threatened species at a national scale, and that can readily be interrogated and interpreted at a range of other scales and for individual groups of species. The index will eventually be freely available to anyone interested in learning about the trajectories of threatened and Near Threatened species, and their interpretation.

The NESP TSR Hub Threatened Species Index Project has seven associated/subsidiary aims:

1. To develop a collaborative network among agencies and groups that collect monitoring data on threatened species, and involve them in the development of a coordinated index.

2. To collect, vet, process, and collate existing annual time-series data (e.g. counts, abundance estimates or proxies) on threatened and Near Threatened species' populations from any reliable sources.

3. To critically evaluate, and thence refine, the robustness of the index depending on the credibility and representativeness of available data for threatened and Near Threatened species.

4. To provide reliable and robust measures of changes in the abundance of subsets of Australia's threatened and Near Threatened species (e.g. by state or territory, broad ecosystem type, threatening process, conservation status etc.).

5. To work with stakeholders on the development of a roadmap for continuation of the index as a legacy product beyond the life of the hub.

6. To provide a platform for a national 'conversation' about threatened and Near Threatened species, and thereby to increase community awareness and appreciation of our threatened biodiversity and create a mandate for investment in its protection.

7. To improve the quality and extent of threatened biodiversity monitoring in Australia by providing impetus in the form of a highly visible national index.

This interim report delivers on a project milestone – to complete a test case using Australia's threatened and Near Threatened birds. It also provides background information for a workshop to be held in Canberra in late January 2018 with the Department of the Environment and Energy to explore the workings and applicability of the index, and help refine the future direction of the project as a whole.

Why do it?

A credible Threatened Species Index is vital for understanding and reporting on overall biodiversity changes, for supporting the evaluation of large scale programs such as the Australian Government's first Threatened Species Strategy as well as threatened species programs in other jurisdictions, and for identifying priorities for ongoing investment. Repeatedly over several decades, government agencies and others have requested such an index.

Photo of Far Eastern Curlew kindly provided by G. Ehmke, BirdLife Australia.

What we did

Our initial focus has been on threatened and Near Threatened birds, selected to provide a proof-of-concept for the methodology and to explore reporting capabilities. The project team developed a collaborative network with all potential stakeholders undertaking monitoring of threatened and Near Threatened bird species, identified standards for acceptable monitoring programs and datasets, and developed collaborative contracts with custodians for the immediate use of those datasets. We explored the applicability and performance of a global range of comparable indices, and selected the Living Planet Index as a suitable approach.

The project team formed a research partners group of 42 representatives of government agencies and other groups (quarterly phone hook-ups), a *Friends of the Index* group of >95 people (regular emails), four workshops and three conference presentations, and leveraged $150,000 in cash co-funding from the Terrestrial Ecosystem Research Network ($30,000) and an Ian Potter Foundation grant to BirdLife Australia ($120,000). The NESP contribution has been $369,000 to date and we estimate the additional in-kind support to be $791,000 (see section A2.12 in the supplementary material for more information on the in-kind estimate).

To calculate a Threatened Bird Index for Australia, an aggregated database of 122,686 population time series (i.e. data from repeated monitoring at the same place over time) was collated from 66 data sources for 100 threatened or Near Threatened taxa (out of 236 possible species or subspecies assessed by BirdLife Australia/Threatened Species Committee and/or 130 bird taxa listed as threatened under the Environment Protection and Biodiversity Conservation Act 1999). When criteria for the suitability of data for trend analyses were applied, the database was culled to 72 taxa with at least one suitable time series, resulting in 11,772 time series for use in the index. Of these time series, 48% were for Near Threatened, 11% for Vulnerable, 18% for Endangered and 22% for Critically Endangered bird taxa. Data were accepted up until December 15th 2017, so the analyses presented here are indicative rather than comprehensive.

The analytical approach we used, based on the Living Planet Index, shows the relative change in abundance (across many species/subspecies) from one year to the next using an initial reference year. The index is cumulative and is always in reference to the baseline, as are the 95% confidence intervals around the index value (Figure 1 shows a snapshot based on the present data available). The index is highly dynamic, and both the trend and the confidence intervals may change after inclusion of new data.

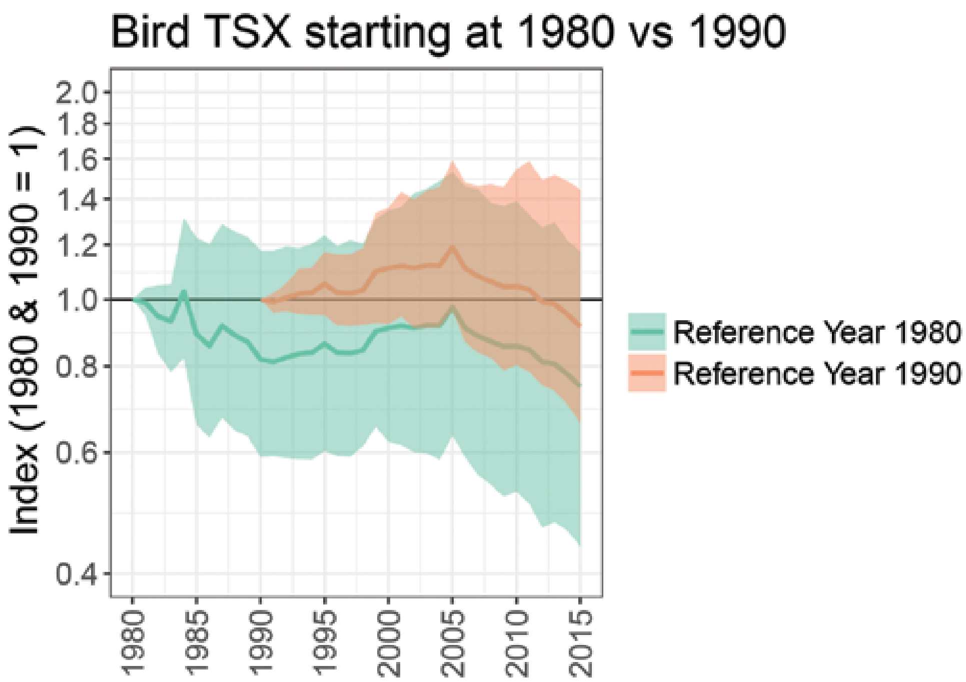


Figure 1: A Threatened Species Index (TSX) for threatened and Near Threatened Australian birds (72 taxa out of 236 taxa listed under BirdLife Australia/Threatened Species Committee - 2016 and/or EPBC Act - 2017). Here, the index value is set to 1.0 at a reference year of 1980 (green) vs 1990 (orange). Note that the pattern from a later reference is the same, but estimated decrease in the index value is linked to the reference year.

A novel aspect of the method has been to develop and utilise an automated workflow of processes to handle large volumes of data (many millions of data points such as those generated from big data citizen science monitoring programs) and apply the complex array of data processing and quality control tasks required to generate the index in a consistent and reproducible way. The distributed computing approaches are used to expedite the computing processes. The automated workflow system was developed using entirely open-source programming frameworks and web-applications. Applicable to any taxonomic group, the automated workflow allows for seamless incorporation of data as they are made available.

What we discovered

The 11,772 time series used to inform the index had an average length of 18.0 ± 8.8 years (mean ± SD) and an average number of sample years of 12.0 ± 7.0 (mean ± SD). The primary reason for rejecting 91% of the candidate data was because we accepted only time series that had at least five data points (Figure 2, green trend) and data collection was consistent from year to year in terms of method and surveying effort. Based on our acceptance criteria we will be able to identify species for which monitoring data are absent or inadequate. This will help guide the development of more suitable and applicable monitoring approaches to expand the scope of the index into the future.

Initial sensitivity analyses have been carried out to test the robustness of the index to varying data quantity or quality. For example, we tested the behaviour of the index using different reference (i.e. baseline) years (Figure 1) and minimum sample sizes of years with surveys per time series (Figure 2). These analyses will be complemented with more in-depth examination of data suitability for trend analyses after initial stakeholder feedback.

Based on these analyses we find that there are sufficient data to make robust and credible statements about aggregated trends in the abundance of Australia's threatened and Near Threatened birds.

Further, the Threatened Species Index is a feasible and transparent reporting tool toward the 5-year target of improving the trajectories of 20 priority birds (data on 12 taxa are available but vary in their suitability for trends), 20 mammals and 30 plants as delineated in the Australian Government's Threatened Species Strategy.

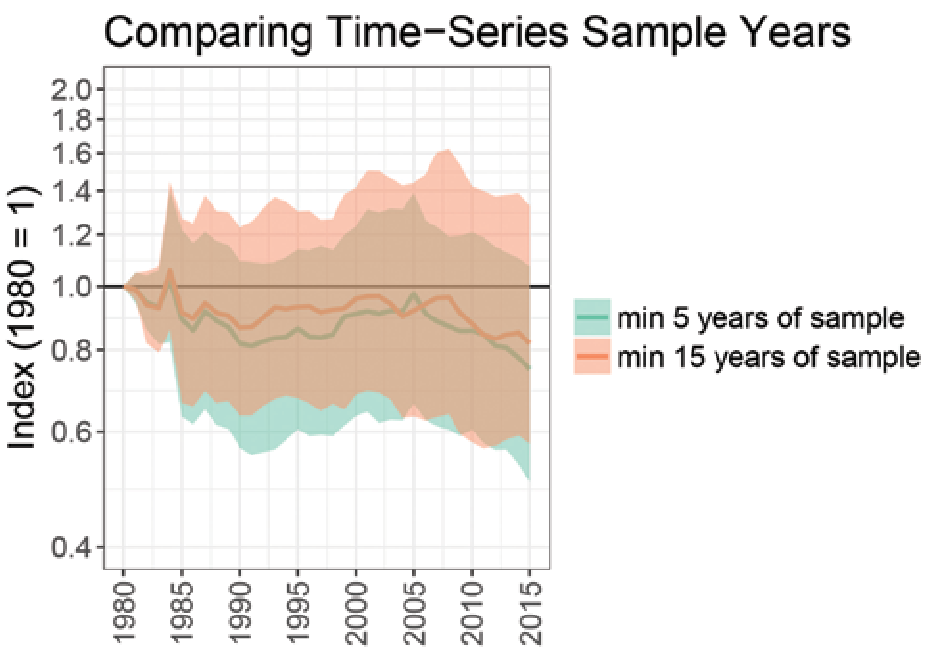


Figure 2: A Threatened Species Index (TSX) for threatened and Near Threatened Australian birds for which different number of survey years were used (minimum of 5 years of sample in green vs 15 years in orange). The index value is set to 1.0 at a reference year of 1980.

The Threatened Species Index estimates a decrease from 100% to 75% (with confidence limits of 122% at best and 53% at worst) relative to a baseline set to 1.0 in 1980 (Figure 1, in green). This means that our best estimate is that there may have been a 25% reduction in the abundance of threatened and Near Threatened birds in Australia since 1980 (for sampled taxa with the data available). Inspection of changes in specific geographic regions and groups is broadly consistent with other published literature and expert opinion.

The index can be used as a national headline indicator to report on overall changes in threatened species' populations, and can be an enduring tool for reporting on overall changes in populations of groups of threatened species in different regions over time. The aggregated datasets and code will all be freely available to the public, and the index can be readily updated by those with more monitoring data on trends of species, including through an automated data uploading portal, providing a foundational data processing service that saves agencies time and money. Users will be able to select the baseline, region and species groups of interest. The index, data and the automated workflow system have wide-ranging applicability, informing state of the environment reporting at national and sub-national scales, assessing national or state/territory threatened species strategies, reporting on international biodiversity commitments, or collating data that can support the development of environmental accounts.

What's next?

The project team plans to finalise the Threatened Bird Index by consulting intensively with the data custodians with respect to the observed trends, carrying out further sensitivity analyses and creating a prototype web-visualisation tool to allow interrogation. The next phase of the project, for which further funding is sought, will be to expand the approach to threatened and Near Threatened plants and mammals, and create a user-friendly web-visualisation tool for interrogation.

Thanks

Collating the database was only possible because of the generosity of more than 130 single data custodians, including research institutions, non-government organisations, state and territory agencies, recovery groups, citizen science projects, and private individuals. The effort in collecting high quality, scientifically planned data over many decades is inestimable but doubtlessly has involved thousands of volunteers, many of whom have self-funded travelling long distances to harsh environments to collect the data. The large in-kind contribution to this project greatly amplifies the resources committed by NESP and is a testimony to the broad interest in and support for the project.

Image: MalleeFowl Photo: Butupa Wikimedia Commons CC2.0

1. Introduction

1.1 Summary

Since European colonisation over 200 years ago, there has been an increase in the rate of environmental change and in the loss of biodiversity in Australia. Australian governments, non-government organisations and private individuals have responsibilities for the conservation of threatened species and have made major investments in threatened species recovery. Yet there is currently no fully effective means to report on changes in Australian biodiversity overall, for key groups or for threatened species (State of the Environment Committee 2011, Cresswell and Murphy 2017). Current widely-adopted measures of biodiversity change, such as numbers of species listed as threatened, provide only coarse and unreliable proxies for overall biodiversity trends. Furthermore, measures based on listing changes are in part a measure of the efficiency of the listing process rather than changes in the species themselves. The development of more detailed indices for trends in threatened species presence and abundance is therefore vital for understanding overall biodiversity changes at the temporal and spatial sensitivity needed to inform policy. Such indices will greatly improve evaluation of large scale programs such as the Australian Government's first Threatened Species Strategy and threatened species programs in other jurisdictions. They will aid in identifying priorities for further investment, and for reporting on progress towards Australia's international biodiversity commitments.

A key component of achieving the goal of halting and reversing threatened species declines and extinctions is having regularly reported headline indicators of the status of these species. Just as national indicators summarise the current state of Australia's unemployment, economic growth (gross domestic product) or market value of corporations (ASX 200), this project aims to develop a national indicator that reports on the state of threatened and Near Threatened species populations in Australia. The National Environmental Science Programme's Threatened Species Recovery Hub (NESP TSR Hub) Threatened Species Index Project 3.1 is trialling, developing and evaluating a Threatened Species Index to report on trends in threatened and Near Threatened species populations over time. The Threatened Species Index Project has been developed in collaboration with the Australian Government Department of the Environment and Energy, Australian state and territory governments, non-government organisations, national data repositories and a key international partner, the Zoological Society of London (see section A2.8 in the supplementary material for a list of partnering institutions). In particular, this project has worked in close collaboration with the Living Planet Index (LPI) Team at the Zoological Society of London, testing the feasibility of developing a Threatened Species Index for Australian birds using the LPI approach (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017) with time-series data on threatened and Near Threatened birds. Within this report, we show that delivering a Threatened Bird Index is realistic and achievable.

In this report we present the rationale and the results for an Australian Threatened Species Index, using Australia's threatened and Near Threatened birds as a proof-of-concept. Data on bird population trends were compiled from 66 data sources for 100 threatened/Near Threatened species, comprising 122,686 time series aggregated from a total of 502,419 surveys conducted over more than 45 years. After processing, aggregation and quality control, data from 43 sources and 72 species resulting in 11,772 time-series records or rows in an aggregated database were used for index calculation. Of these time series, 48% were for Near Threatened, 11% for Vulnerable, 18% for Endangered and 22% for Critically Endangered bird taxa. The index allows, for the first time, integrated reporting on and interrogating of population trends for Australia's threatened and Near Threatened species at national, state and territory levels, and for functional groups and subgroups of threatened birds.

1.2 Project Aims

The NESP TSR Hub Threatened Species Index Project 3.1 has seven associated/subsidiary key aims:

1. To develop a collaborative network among agencies and groups that collect monitoring data on threatened species, and involve them in the development of a coordinated index.
2. To collect, vet, process, and collate existing annual time-series data (e.g. counts, abundance estimates or proxies) on threatened and Near Threatened species' populations from any reliable sources.
3. To critically evaluate, and thence refine, the robustness of the index depending on the credibility and representativeness of available data for threatened and Near Threatened species.
4. To provide reliable and robust measures of changes in the abundance of subsets of Australia's threatened and Near Threatened species (e.g. by state or territory, broad ecosystem type, threatening process, conservation status etc.).
5. To work with stakeholders on the development of a roadmap for continuation of the index as a legacy product beyond the life of the hub.
6. To provide a platform for a national 'conversation' about threatened and Near Threatened species, and thereby to increase community awareness and appreciation of our threatened biodiversity and create a mandate for investment in its protection.
7. To improve the quality and extent of threatened biodiversity monitoring in Australia by providing impetus in the form of a highly visible national index.

The goal of the index is to support coherent and transparent reporting of changes in threatened and Near Threatened species' population trends across national, state and regional levels. The index also contributes to reporting on explicit quantitative targets. The project aims to incorporate trend information for all threatened and Near Threatened species, including all species listed as priorities under the Threatened Species Strategy for which data are available. Both the index and data have wide-ranging applicability, informing 'state of the environment' type reporting at national and sub-national scales, assessment of national or state/territory threatened species strategies, reporting on international biodiversity commitments or collating data that can support the development of environmental accounts. The end-goal is for a dynamic and credible Threatened Species Index calculated every year based on newly acquired and integrated data, thus enabling Australia to use the index as a national headline indicator to report on changes in overall threatened species populations.

Phase one of the project (from February 2016 to December 2017) has focused on developing an index for threatened and Near Threatened Australian birds. In this report, we demonstrate a proof-of-concept for the Threatened Bird Index, and examine the methods underpinning its development. These methods were developed with a wide range of species groups in mind, and are broadly applicable across taxa including plants, mammals, freshwater species and other groups with relevant trend information. Analysis and interpretation of integrated indices encompassing multiple taxonomic groups will be guided by the relative availability of trend data for these groups

Photo of Hooded Plover chicks with wings outstretched kindly provided by G. Ehmke, BirdLife Australia.

1.2.1 Why start with birds?

The initial two years of the Threatened Species Index Project focused on a proof-of-concept with threatened and Near Threatened birds. As a key stakeholder, BirdLife Australia had direct involvement in, working collaboration with, or knowledge of many existing Australian monitoring programs targeting threatened species in this group, and previous analyses of some of these datasets indicated that data suitable for trend analysis were available (Wilson et al. 2011). Many national-scale monitoring and trend analyses (Gregory et al. 2008, Gregory and van Strien 2010, North American Bird Conservation Initiative 2012, 2016, van Strien et al. 2016) have focused on birds for reasons such as high visibility, relative ease of monitoring efforts, and the extent of community engagement among bird groups and networks. The reasons why we chose birds as an initial taxonomic group for the Threatened Species Index include:

- Birds are highly visible, recognisable and generally better surveyed than most other taxonomic groups; but, as for threatened species generally, there is a wide divergence in monitoring effort, approach and duration for threatened birds. To some extent, monitoring of birds is likely to be more tractable (and hence there is likely to be more monitoring information available) than for other taxonomic groups (because birds are mostly diurnal, readily detected and identified, and have substantial public engagement). However, some bird species present formidable monitoring challenges (and hence there is very little monitoring information available for them) because they occur mostly in remote areas, are difficult to detect and/or are extremely rare. In contrast, monitoring may be much more tractable for threatened species in some other taxonomic groups (e.g. trees), so birds represent a reasonable test case for threatened species generally.
- There are good time-series data for a reasonably representative cross-section of threatened species within this group
- We have a high capacity national bird conservation and research organisation in BirdLife Australia, with a national monitoring program, good database infrastructure and management, and extensive partnerships with data holders
- BirdLife Australia has committed to long-term stewardship of threatened bird indices, and we can have confidence in them as a 116-year-old organisation
- BirdLife Australia has a history of sharing established data, vetting, processing, analysis and presenting bird indices, such as those used in their State of Australia's Birds reports (2015 Terrestrial Bird Headline Indices (Ehmke et al. 2015) – stateorbids.org.au)
- Threatened birds comprise a significant component (ca. 8%) of all Australia's listed threatened species
- Threatened birds occur widely across all regions of Australia; in marine, freshwater and aquatic environments; are affected by a wide range of threats; and have been subjected to highly variable conservation investment – so they should provide a reasonably representative context for trends for other threatened taxonomic groups

In collaboration with the Department of the Environment and Energy (DoEE), other state/territory agencies, and non-government organisations (NGOs), the project gathered existing time-series data on the occurrence, abundance or breeding of threatened bird species (e.g. data from recovery plans and projects, data held by state agencies and NGOs (especially BirdLife Australia), and citizen science data.

A close collaboration with BirdLife Australia was forged to progress the proof-of-concept of a Threatened Species Index using data on birds which includes:

1. identifying, testing and determining the methods to produce a Threatened Species Index,
2. establishing data sharing agreements between the University of Queensland (on behalf of the NESP TSR Hub), BirdLife Australia and >130 individual data custodians from >50 organisations and data collections,
3. creating a framework to assess whether data are suitable for trend analyses,
4. development of a scientific workflow to automate data processing and index calculation, which can be used for data from any other species group.

This initial work on birds has simultaneously set the conceptual foundation and the infrastructure for many other taxonomic groups to be included in an Australian multi-taxa index. Taxa to be added to the index will include plants and mammals, then freshwater species, and all other groups with relevant trend information. This project aims to fill key knowledge gaps on trends in other taxonomic groups (plants and mammals), and develop a way of combining information from different groups to report on multi-taxa trends across the nation.

1.3 The Need for an Australian Threatened Species Index

Despite the global agreement to preserve biodiversity through mechanisms such as the Convention on Biological Diversity (CBD) Parties' UN Strategic Plan for Biodiversity 2011–2010 and the Aichi Biodiversity Targets (CBD 2010), biodiversity continues to decline (Butchart et al. 2010, Tittensor et al. 2014). Extinction of species worldwide is most likely to be prevented through timely conservation interventions when species declines are identified and effectively managed in time to avoid extinctions (Martin et al. 2012). There are some good examples among Australian birds. The present decline of migratory shorebirds has resulted in the listing of several species as globally threatened (Clemens et al. 2016) and the implementation of several conservation action plans. Entire assemblages of birds such as Mallee-woodland species are now nationally recognised as threatened, and are the subject of active conservation measures (see stateofbirds.org.au).

In this project, we are collaborating with agencies and organisations across Australia to develop the Threatened Species Index as a national headline indicator reporting on changes in the overall state of threatened and Near Threatened species populations. Despite major efforts to conserve Australia's biodiversity by multiple stakeholders from the Australian Government, state and territory governments and the non-government sector, at present there is no overarching framework to integrate all data collected from species monitoring and to use it to report on trends in Australia's threatened species in any of these jurisdictions.

This means that Australia currently lacks the capacity to report holistically on the broad status of populations of threatened species. Furthermore, significant government investments, such the National Landcare Program, are premised on outcomes to improve the trajectory of Australia's threatened species. Evaluation against these outcomes requires a measure of overall change in the status of Australia's threatened species.

Quantifying trends for rare species is inherently challenging, and to date those challenges have remained unresolved. For instance, the Australian Government's State of the Environment (SoE) Report of 2011 stated that "Data on long-term trends in biodiversity are limited, making it difficult to interpret the state or trends of major animal and plant groups in most jurisdictions" ((State of the Environment Committee 2011), page 569). The SoE Report from 2016 reiterated this issue, stating that "The effectiveness of recovery planning for threatened species and communities is very difficult to assess because of a lack of long-term monitoring data" ((Cresswell and Murphy 2017), page 106). The Threatened Species Index Project is designed to address these challenges by drawing together available long-term monitoring data for threatened and Near Threatened species into a single, coherent framework.

National reporting on trends in Australia's threatened species using the index has major policy and management benefits. The index:

i. improves the Australian Government's ability to report on international conservation targets (such as the Aichi Target 12 and Sustainable Development Goals 15.5 under which economic growth no longer harms the environment);
ii. supports high-level and long-term reporting on the relative benefits of conservation investments and policies applied across different regions, taxonomic groups or times;
iii. creates capacity to report on or evaluate major government initiatives such as the Threatened Species Strategy;
iv. allows identification of investments to be directed to taxa and habitats that are currently the most pressing conservation priorities;
v. supports evaluation of species policy and recovery plans by informing on wider trends in taxonomic/functional groups against which trends in a species/assemblage can be viewed;
vi. ensures reporting is less likely to be fragmented (e.g. state-based) and more coherent; and
vii. provides robust indicators of biodiversity conservation that can be used to complement existing national economic and social indicators such as gross domestic product or unemployment rate.

The creation of trend indices will improve the capability for other stakeholders to contribute or be alerted to dramatic changes in trends. Current national reporting e.g. through SoE or National Biodiversity Strategy reporting, is forced to rely on less robust measures (such as number of species listed as threatened), and struggles with reporting on success of recovery plans and assessing changes in the conservation status of species.

A useful by-product of the Threatened Species Index is that it informs the coordination of threatened species monitoring, which is currently fragmented and largely insufficient for assessing population status and trend. The purpose of this report is not to inform how or where new monitoring programs might be developed, but once the index is established, it is likely that it will encourage further and more systematic and strategic monitoring through the identification of key information gaps, for example in locations and groups with low data availability.

1.4 The Threatened Species Index: A Solution to Reporting on Threatened Species Trends in Australia

1.4.1 How are we addressing the problem?

To create a Threatened Species Index for Australia, we first compared existing indices known as national headline indicators. Several indicators have been developed to track changes in species populations nationally (Fewster et al. 2000, Eaton et al. 2015, van Strien et al. 2016) and globally (Walpole et al. 2009, Butchart et al. 2010, Brummitt et al. 2017). On a global or national scale, rare species are hardly included in any national indices; e.g. the UK Wild Bird Index or the trends from the State of Canada's Birds in 2012 or State of North America's Birds 2016 reports specifically exclude rare and/or threatened species from their indices (Gregory and van Strien 2010, North American Bird Conservation Initiative 2012, 2016), although there are currently endeavours to progress these in the future. The Red List Index that is based on changes in the conservation status of species is the only index that specifically deals with threatened species. However, although already implemented for Australian birds (Szabo et al. 2012), it relies on changes in IUCN Red List status which tend to be too infrequent for the purposes of tracking annual change in populations.

Where data are available, the use of changes in population abundance as a metric is a superior choice to e.g. the stepped changes in risk perception underpinning the Red List Index, because measuring rates of change in population size is one of the most sensitive metrics for long-term measurement of biodiversity change (Balmford et al. 2003, Buckland et al. 2005, Pereira and Cooper 2006, Mace et al. 2010). Population abundance measures are also a good proxy for biodiversity at higher trophic levels, can be used to infer community change (Buckland et al. 2005) and are an excellent and direct indicator of extinction risk. We have chosen the Living Planet Index approach to develop a Threatened Species Index for Australia. The Living Planet Index is a global indicator that explicitly reports on changes in global vertebrate species populations and is able to integrate data from multiple sources and different monitoring methods (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017). It is able to calculate trends as soon as data are made available and are integrated into a database.

1.4.2 What is the Living Planet Index?

The Threatened Species Index uses the Living Planet Index approach (LPI), conceived by the World Wildlife Fund (WWF) in 1998 with further methodological development in partnership with the Zoological Society of London (ZSL) since 2006. The LPI was specifically designed to report changes in global vertebrate populations and was adopted as a biodiversity indicator which measures progress towards the Convention on Biological Diversity international biodiversity targets for 2010 and 2020. The approach uses a model that aggregates and interprets voluntarily supplied and disparate datasets on trends in species populations across most nations and environments. In 2016, the LPI database for Australia contained trend information for only 7 threatened bird and 24 threatened mammal taxa, indicating that a rigorous data collation exercise was needed for the present project. The LPI quantifies changes in vertebrate abundance through species population time series extracted and compiled from the published literature to provide an aggregated measure of relative change (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017) (see section A2.7 in the supplementary material for a detailed description of this method).

The LPI is a composite index. A composite index utilises information from multiple species to estimate the overall trend for a group of species populations. Composite indices cannot be disaggregated to specifically inform on single species trends – the whole is greater than the sum of its parts. A composite species index can be thought of in similar terms to stock market indices such as the ASX 200. The ASX 200 index captures the overall trend in the share price of a number of corporations, chosen to be representative of the stock market as a whole. There is variation across the trends of individual corporations' share prices, where some increase, others decrease, and the composite index captures the overall trend. One difference between the stock market and wildlife is that, whilst trends in corporations are easily measured continuously, information on threatened species comes from various and disjunct sources that need to be compiled in a meaningful way to derive overall trends.

Comparable indices are now well established and widely used elsewhere. Nations such as the UK and Canada have highly influential indicators of species' population trends (Gregory et al. 2008, Gregory and van Strien 2010). The UK Wild Bird Index for instance has been adopted as an official quality of life statistic by the UK government (https://data.gov.uk/dataset/wild_bird_populations). This index was instrumental in identifying a rapid and ongoing decline in farmland birds and prompted actions at national and European level to address the issue. While none of these indicators specifically focus on trends in threatened species, they use comparable methods and approaches to evaluate population trends more broadly.

1.5 Australian Commitments to Threatened Species

Internationally, the Australian Government has committed to global conservation targets such as the Aichi Biodiversity Target 12 (Strategic Goal C of the Convention on Biological Diversity) towards the "prevention of extinction of known threatened species by 2020" or the United Nations' Sustainable Development Goal 15.5 to "take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species".

More than 1,800 species of animals and plants are currently listed by the Australian Government as threatened and this number is likely to grow through the current Common Assessment process that seeks to better coordinate threatened species' listings across jurisdictions. The Government has commenced a wide range of significant national initiatives to reduce the risk of extinction and recover threatened species. The Threatened Species Strategy, launched in 2015, has committed to improving the trajectories of 20 priority threatened birds, 20 threatened mammals and 30 threatened plants by 2020. Other initiatives include the National Environmental Science Program's Threatened Species Recovery Hub and the Threatened Species Recovery Fund. National programs such as the National Landcare Program also include a core focus on recovering threatened species. See Table 1 for more details.

Most Australian states/territories as well as larger conservation non-government organisations have threatened species programs (see Table 1 for details). These other key players involved in threatened species monitoring are seeking to harmonise their reporting with the Australian Government.

Table 1: Major programs for biodiversity and threatened species recovery

Australian Government	
Australian Government, Department of the Environment and Energy (DoEE)	Since 2014, the Australian Government has mobilised more than $210 million for projects that support threatened species across the country through the Green Army, National Landcare Program and Commonwealth National Parks estate. In 2015, the Australian Government launched the first national Threatened Species Strategy committed to protect and recover Australia's threatened plants and animals. In 2015, the Threatened Species Recovery Hub (TSR Hub) was created based on $30 million funding from the National Environmental Science Program (NESP) matched by $30 million from contributions by 10 of the country's leading academic institutions and the Australian Wildlife Conservancy. The TSR Hub has been specifically established to provide research that directly supports decision-making and management of threatened species, including management of threats and improved recovery of threatened species through researchers working in collaboration with governments, management agencies and conservation groups. On the 7th of September 2016, the Australian Government announced a new $5 million Threatened Species Recovery Fund to support local communities in their efforts to recover rare and vulnerable animals and plants.
State/Territory Governments	
Australian Capital Territory, Environment, Planning and Sustainable Development Directorate	The Environment, Planning and Sustainable Development Directorate of the ACT Government has established Threatened Species Action Plans to help protect threatened species and ecological communities in the ACT. Each Action Plan outlines conservation, protection and on-ground management actions for the species or community concerned or proposals to minimise the effect of threatening processes. The primary objective is to maintain for the long term, viable, wild populations of each species (or samples of the ecological community) as components of the indigenous biological resources of the ACT. The Action Plans are first released as drafts for public comment before they are finally adopted. There are currently 37 plants, birds, mammals, reptiles and freshwater species listed under the Nature Conservation Act (2014) in ACT. The ACT is also pursuing an active program of species translocations in partnership with a number of agencies to assist recovery of species and communities.
New South Wales, Office of Environment and Heritage (OEH)	In NSW, the Saving our Species (SoS) Program was publicly launched in 2013 and expanded in 2016 with a $100 million funding commitment by the NSW Government for 5 years. The SoS Program aims to secure threatened plants and animals in the wild in NSW and has developed a Program-wide framework for monitoring and reporting on the outcomes of projects and actions for threatened species.
Northern Territory, Department of Environment and Natural Resources (DENR)	In the Northern Territory, the new Department of Environment and Natural Resources (DENR) has committed to manage and mitigate threats to regional communities and natural ecosystems and native flora and fauna through shared responsibilities and partnerships in their Strategic Plan 2017-2020. Action Plans for high priority species guide the research and management of threatened species in the Northern Territory.
Queensland, Department of Environment and Science (DES)	The Conservation & Sustainability Services Division within the Department of Environment and Science (DES) includes a number of teams that are involved in administering legislation, developing policy and facilitating and coordinating activities relating to the conservation and protection of threatened flora and fauna in Queensland. Through these teams DES collaborates with a range of different user groups and individuals within all levels of government, the community and industry sectors to undertake activities relating to threatened species.

South Australia, Department of Environment, Water and Natural Resources (DEWNR)	In South Australia, the Department of Environment, Water and Natural Resources (DEWNR), together with regional Natural Resources Management (NRM) Boards, work in partnership with other government and non-government organisations to assist with the conservation, management and recovery of threatened species. DEWNR are also working with the non-government sector to develop a new nature conservation strategy for South Australia.
Tasmania, Department of Primary Industries, Water and Environment (DPIPWE)	In Tasmania, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) works with partner organisations and individuals to protect Tasmania's unique flora and fauna. DPIPWE employs a range of teams that tackle threatened species conservation and management, notably the dedicated programs for Orange-bellied parrot and the Tasmanian Devil. The Tasmanian Government also administers state threatened species legislation and develops policies and procedures that guide management and protection of more than 700 threatened species.
Victoria, Department of Environment, Land, Water and Planning (DELWP)	In Victoria, the biodiversity plan 'Protecting Victoria's Environment – Biodiversity 2037' (Biodiversity 2037) was established in 2017 by the Victorian Government (Department of Environment, Land, Water and Planning – DELWP) to reverse the decline in biodiversity and achieve overall biodiversity improvements over the next 20 years. Biodiversity 2037 has a strong commitment in reporting of trends in threatened species. In addition, the Victorian Government has delivered $7.7 million for large-scale regional partnership projects to protect threatened plants and animals as part of the Biodiversity On-Ground Action initiative in 2017. The funding will support 26 large-scale projects that address major risks to threatened species and ecosystems and is part of a broader $25.7 million package to support native species through community action grants, support programs and regional partnerships.
Western Australia, Department of Biodiversity, Conservation and Attractions (DBCA)	The Western Australian Government introduced a new Biodiversity Conservation Act in 2016 that replaces the previous Wildlife Conservation Act and is administered by the Department of Biodiversity, Conservation and Attractions. The new Act introduces enhanced protection for threatened species in addition to new protection of threatened ecological communities. Changes to this Act compared with previous regulations include new maximum penalties for illegal taking of threatened species of up to $500,000 for an individual person or $2.5 million for a corporation.
National Environmental Management NGOs	
Australian Wildlife Conservancy	In addition to government incentives, there are a few large non-government organisations (NGOs) focused on the management of Australia's threatened species. The Australian Wildlife Conservancy (AWC) pursues a simple strategy to reverse the declines in wildlife by land acquisition, establishing feral-free sanctuaries and through partnerships with landholders. AWC then implements practical land management actions (e.g. feral animal control and fire management) informed by current science, on these lands.
Bush Heritage Australia	The NGO Bush Heritage Australia (BHA) is a national non-profit organisation conserving biodiversity in Australia by buying and managing land of outstanding conservation value, controlling or removing threatening processes and working in partnership with Traditional Owners on country. Bush Heritage protects native plants and animals on over 40 reserves encompassing over a million hectares throughout Australia. These reserves all represent ecologically important landscapes. BHA has many projects focusing on threatened species conservation including wildlife re-introduction, recovery and supplementation, removal and management of threatening processes in the landscape, in particular feral herbivores and predators, and wildfire, and long term monitoring of threatened plants, mammals, birds and freshwater species.
BirdLife Australia	BirdLife Australia, Australia's largest NGO focused on bird conservation, coordinates many research and conservation projects focused on learning about the ecology of and threats to threatened bird species and implementing actions to mitigate threats. These include dedicated recovery programs for threatened species such as the Regent Honeyeater, Carnaby's Black Cockatoo, Eastern Hooded Plover and the Red-tailed Black Cockatoo, and programs for suites of threatened birds such migratory shorebirds and south-eastern woodland birds. The NGO runs national-scale programs such as the Threatened Bird Network, a community based program aimed at encouraging participation in urgent conservation tasks for threatened birds. BirdLife Australia also hosts the monitoring program and data portal Birdata, aimed at collecting citizen science monitoring data to gain insight and protect Australia's birds, and produces the 'State of Australia's Birds' report series, which started in 2005, and most recently reported headline trends for terrestrial birds in 2015.

1.6 Milestones in the Development of the Threatened Species Index for Australian Birds

The development of the Threatened Species Index for Australian birds represents an extensive collaboration of agencies, spanning governments, non-government agencies, community organisations and the research sector across federal, and all state and territorial jurisdictions.

1.6.1 Collaborative Foundation

We started off by developing collaborative and legal arrangements across a wide set of stakeholders that undertake monitoring on threatened species in Australia (see section A2.10 in the supplementary material for a complete list of organisations that support this project with data). Participants at a workshop initiating the project in April 2016 included representatives from the Australian Government (Parks Australia), one or more representatives from all state and territory agencies, the Atlas of Living Australia (ALA), the Terrestrial Ecosystem Research Network (TERN), the Australian Wildlife Conservancy (AWC), Bush Heritage Australia, BirdLife Australia, the University of Queensland (UQ), Charles Darwin University (CDU), and Australian National University (ANU) (see section A2.8 in the supplementary material for a complete list of research partners). This first one-day workshop engaged with the Department of the Environment and Energy (DoEE), state/territory agencies, and major conservation non-government organisations. The workshop aimed to define what end-users and partners wanted from a Threatened Species Index, to ensure that the right tools were created for end-users and to decide on a strategy to achieve this. The workshop also discussed potential approaches for calculating an index which would satisfy the needs of all participating stakeholders. The delegates chose the Living Planet Index approach after discussing the benefits and disadvantages of the Red List Index (Bubb et al. 2009, Szabo et al. 2012), the Australian Bird Index (Ehmke et al. 2015), and the Bayesian Belief Networks' approach (Nicholson et al. 2011, Department of Environment Land Water and Planning 2016).

Within this workshop, we sought input from stakeholders about their specific needs for reporting on trends in threatened species. A large emphasis was placed on the facilitation of data transfer, data quality, establishment of an efficient platform for data sharing and management, and appropriate methods for indices reporting on Australia's threatened species. The outcomes of this workshop were to: identify the major custodians for threatened species data and create a collaborative data provider agreement together with BirdLife Australia, the ALA and collaborating TSR Hub projects regulating the access, handling and de-identification of raw bird population data received for this project. All major custodians were contacted at least twice by email and provided the opportunity to contribute data to the project (see section A2.1 in the supplementary material for a detailed information on the data collation process). The project team hopes that the small number of data custodians who did not share their data for delivering an Australian Threatened Bird Index will get on board once they are presented the results and gain trust in the process and outcome, and/or are able to allocate the time required for data sharing negotiation and minor re-formatting of their data. The index will become more robust and representative, with more data for existing and new taxa.

1.6.2 Developing Options for Data-sharing

The initial workshop was followed by a second virtual workshop in June 2016 focused entirely on data management. The workshop aimed to engage with ALA, TERN, BirdLife Australia and UQ's Research Partnerships Office to discuss options around data sharing, data-basing, metadata, curation, analysis, accessibility, and display of large and disparate datasets. The final focus of the workshop was on optimising data sharing agreements and dealing with data on sensitive species. The workshop was followed by several phone meetings allocated to smaller groups to address tasks related to data management.

1.6.3 Crafting a Decision Framework for Data Selection

The next step was to develop a decision framework that considers the fundamental principles of trend analyses in order to decide which data to keep and which to exclude from the index. We developed criteria to help identify the levels of suitability of data for the establishment of indices (see section A2.6 in the supplementary material for more details about suitability criteria). These criteria specifically enabled us to identify monitoring programs that provide adequate information to incorporate in national trend reporting.

1.6.4 Testing the Living Planet Index Method

Once a subset of data on threatened birds was collected and collated, a third workshop in March 2017 provided the methodological basis for developing an independent and credible index for Australian threatened and Near Threatened species. The workshop consisted of two parts: a two-day workshop to test methods with preliminary data on seabirds, shorebirds and a small suite of terrestrial birds, followed by a phone meeting for participants who could not join the workshop to discuss the index methods. Participants of this workshop were partners from UQ, CDU, TERN, BirdLife Australia, and ZSL in person, and Parks Australia (DoEE), DEWNR, DELWP and University of Melbourne on the phone. In this workshop, we provided an update on progress with bird data collection, decided on rules for data vetting and aggregation, demonstrated preliminary calculations of indices using the Living Planet Index method, discussed caveats of outputs, and planned deliverables (see section A2.7 in the supplementary saterial for a detailed description of the Living Planed Index method). The TERN committed to supporting the project with partners from UQ's Research Computation Centre (RCC). TERN provided an external cash contribution of $30,000 towards the development cost for a scientific workflow aimed at automating data processing and index calculation.

1.6.5 Collating the Data

Data predominantly representing threatened and Near Threatened species' abundances or occurrence were contributed by 69 agencies, individuals or organisations from April 2016 to December 2017. All bird taxa were included that were either listed as threatened on the EPBC Act as of December 2017 or assessed as Near Threatened, Vulnerable, Endangered, and Critically Endangered by the BirdLife Australia/Threatened Species Committee list from 2016 (see 'TaxonList' in the 'Data selection' folder of the electronic supplementary material). Abundance metrics included breeding pairs, count of pre-fledging chicks, nests, nests with eggs, recorded calls or nest occupancy rates as well as occupancy measured as presences and absences and converted into reporting rates (see section A2.5.4 in the supplementary material for a complete list of the units of measurement). These data were collated in a database containing the necessary metadata to identify the characteristics of each monitoring program and species, and enable broad headline population indices on threatened and Near Threatened Australian birds to be calculated as for the Threatened Species Index. As this database required the management of large data volumes comprising millions of species records, we started a collaboration with the TERN, UQ's RCC, and the software and web-app developer Planticle to create an online web interface for data ingestion into the database, and a scientific workflow to automate the processing. The scientific workflow assists with data quality assessment by enabling data from different monitoring programs to be classified, processed and analysed depending on data types, temporal and spatial aggregation. The workflow has been designed to deal efficiently with large volumes of data.

Once all available data on threatened birds for the prototype Threatened Species Index were collated, we developed and applied Threatened Species Indices to report on trends (and their significance) at varying scales and across alternative sets of species. Importantly, this index is not intended to report on the effectiveness of a given monitoring program for tracking change, nor is it intended to report on individual species. Rather, data are aggregated for functional groups of species, to inform on how multiple populations are changing over time. Different regions can be compared in terms of overall trends as well as overall representativeness of data for informing threatened species trends. This report outlines all protocols and standards for selection, sharing, storing and analysis of monitoring data as well as the derivation of relevant Threatened Species Indices.

Photo of Swift Parrot kindly provided by G. Ehmke, BirdLife Australia.

1.6.6. Engagement and Transparency through Communication

Project 3.1 has engaged with more than 130 individual custodians from over 50 institutions to collect existing data on threatened and Near Threatened birds. We have welcomed contributions of species monitoring data from Indigenous groups such as the Olkola, Wunambal Gaambera, and Dambimangari Rangers and are being supported by the Kowanyama Aboriginal Shire Council. We expect to involve more Indigenous custodians when moving to an index that includes plants, mammals and freshwater species. Every custodian who has provided data towards the development of the Threatened Species Index is appropriately acknowledged in the metadata to the database.

The Threatened Species Index project team holds regular stakeholder meetings and provides frequent email updates to a wide network (currently at 42 members), including members from the DoEE, all state and territory agencies, NGOs, and academia. Members of our project team made every effort to engage with all stakeholders throughout the life of the project and are determined to continue with these efforts to ensure that the development of Australia's Threatened Species Index remains a transparent and highly inclusive process. The project team holds multiple phone meetings (quarterly) and distributes update notes to communicate on progress and consult stakeholders on decisions required for advancing the project.

The team coordinates a *'Friends of the Index'* email list to which potential end-users, supporters, or people from the wider public can subscribe if they wish to receive updates on the project (see section A2.11 in the supplementary material for a list of the organisations currently subscribed to the *Friends of the Index* list). To ensure that the index received wide publicity amongst scientists and practitioners, various aspects of the index have also been presented at one international (ICCB 2016 in Cartagena/Colombia) and two national conferences (SCBO 2016 in Brisbane, EcoTAS in Hunter Valley 2017).

1.7 Caveats and Assumptions

To adequately judge the robustness of the Threatened Species Index (TSX) for birds and aid its interpretation, a few caveats and assumptions need to be taken into account:

i. An index can only be as robust in estimating relative changes in species groups as the underlying data. The present TSX is an initial trial of the Living Planet Index method where we were very inclusive of data in order to obtain a wide cross-section of species to build the index. Data used in this initial index vary from direct population abundance estimates gained from carefully planned scientific monitoring over decades to speculative proxies e.g. reporting rates of birds in large grid overlays using unstandardized data. Without incorporating various types of data, many species e.g. arid zone nomads would not be part of the index. It is important to highlight that these data still need to be examined whether they satisfy the statistical assumptions of trend analyses by a thorough and comprehensive sensitivity analysis.

ii. The robustness of the TSX as a good measure of relative changes in threatened and Near Threatened species groups will increase after the integration of more standardised monitoring data – especially for those species groups for which only unstandardized data are available.

iii. The TSX is highly dynamic. The trend represented by the TSX may change the more data are integrated. This interim report shows only a snapshot of the index consisting of data available in January 2018. The results are indicative rather than comprehensive and need to be evaluated by a sensitivity analysis.

iv. Because the Living Planet Index method is not designed to directly accommodate occupancy data, we have transformed presence/absence into continuous reporting rates in order to integrate these data. We acknowledge that traditional trend analyses for terrestrial birds in Australia use binomial statistical models for occupancy data (Cunningham and Olsen 2009, Ehmke et al. 2015). To our knowledge, using reporting rates with the Living Planet Index has not been tested previously; thus the results produced with this type of data should be dealt with carefully. Further testing and comparisons against existing and well established occupancy trend estimates is recommended.

v. The current index does not include all suitable data on threatened and Near Threatened birds taxa because some custodians 1) may have not been identified, 2) were not willing to share their data yet, or 3) committed to but did not deliver data and/or required agreements for data sharing.

vi. A thorough assessment of data suitability for trends will require a consultation with the data custodians for each trend produced in an expert elicitation survey.

vii. Australian birds, especially those in arid and semi-arid areas, are likely to show major fluctuations in abundance in response to rainfall conditions, and such variation may render it difficult to clearly discern longer-term population trajectories.

viii. The composite Threatened Species Index may inevitably suggest a decreasing trend because all threatened species in Australia are listed due to their declining populations. Species become de-listed once those trajectories recover, thus may be removed from the Threatened Species Index. However, this may not be true for trends which contain data on taxa that are non-representative of their overall populations. It is recommended to carefully inspect the spatial representativeness measure in order to avoid that a trend is driven by a particular area only but does not represent a minimum of the targeted groups' populations spatially.

ix. In some cases, populations or species may take many years or decades to recover following threat management; in other cases, recovery may be very rapid. There may be variable responses to conservation investment.

x. For at least some threatened species, there may be biases in monitoring, with possibly more likelihood of monitoring being undertaken at sites where recovery effort is invested rather than at sites where no recovery management is taking place.

xi. The index weights equally a decrease of e.g. 10% over a certain period for a species with a total population of 100 individuals at baseline as for a 10% decrease for a species with a total population of 100,000 individuals at the baseline, notwithstanding that these may represent different types and amounts of biodiversity loss, and may have different consequences for conservation status categorisation.

xii. Regarding indices for states and territories, it should be noted that the data reflect subsets of the total species complement and not of all taxa occurring in a state/territory.

2 Results

The following section introduces the four main Threatened Species Index (TSX) diagnostics used to support the robustness and interpretation of each index interrogation. The main results are presented thereafter.

2.1 Index Diagnostics and Characteristics

Consideration of data structure and characteristics is critical when interpreting trend indices, given the potential for factors such as the amount and quality of data to influence index results. Four basic diagnostics are presented in this report with each index produced to assess its robustness: (1) spatial representativeness of data used to calculate each index, (2) dot plots showing the distribution of surveys at sites, (3) time series vs species accumulation plots and (4) index summary tables. These diagnostics are the minimum information required for an initial evaluation of the index estimates. More information needs to be considered when evaluating the robustness of index estimates by examining:

- the units of measurements used to record monitoring data and how applicable they are to a certain species;
- rules for temporal aggregation of data (e.g. based on averages, maximum counts, or reporting rates);
- spatial aggregation of data (e.g. data collected at discrete sites vs data collected over large grids);
- standardisation of monitoring methods and effort;
- consistency of monitoring;
- time-series sampling evenness; and
- spatial representativeness of a data sample for the total area occupied by that species.

Further information on the aggregation methods and look-up tables can be found in sections A2.5 - A2.6 in the supplementary material, in the electronic supplementary material and upon request.

2.1.1 Spatial Representativeness: Maps of Sampling Intensity

To facilitate interpretation of the spatial representativeness of indices, maps showing the relative sampling intensity of data used in each index (across all years) are presented concurrent with each index produced. Trend data for all the populations of all threatened and Near Threatened species across their entire ranges are rarely available due to constraints on monitoring (e.g. accessibility), resulting in biases and gaps in the representativeness of monitoring across space. The Threatened Species Indices provide trends only for areas where monitoring data are available. Patterns and gaps in bird monitoring coverage and intensity are evident in all regions and should always be consulted when interpreting indices. Therefore, the spatial representativeness measure provided in the index summary table for each index produced can be examined.

The sampling intensity maps display the outputs of kernel density analysis of all data that were used for each index interrogation. For instance, examination of the dry sclerophyll woodland/forest bird index map shows that this index has good spatial coverage for Victoria, New South Wales and South Australia in relation to the extent of that habitat in those states. However, data for Western Australian dry sclerophyll woodland/forest birds are limited to areas surrounding metropolitan Perth and the index contains no data at all for Tasmanian dry sclerophyll woodland/forest birds. Therefore, this index may be considered broadly as spatially representative for dry sclerophyll woodland/forest birds of the south-eastern mainland, but provides a highly constrained basis for inference relating to dry sclerophyll woodland/forest birds in Tasmania or areas outside metropolitan Perth (Figure 3)

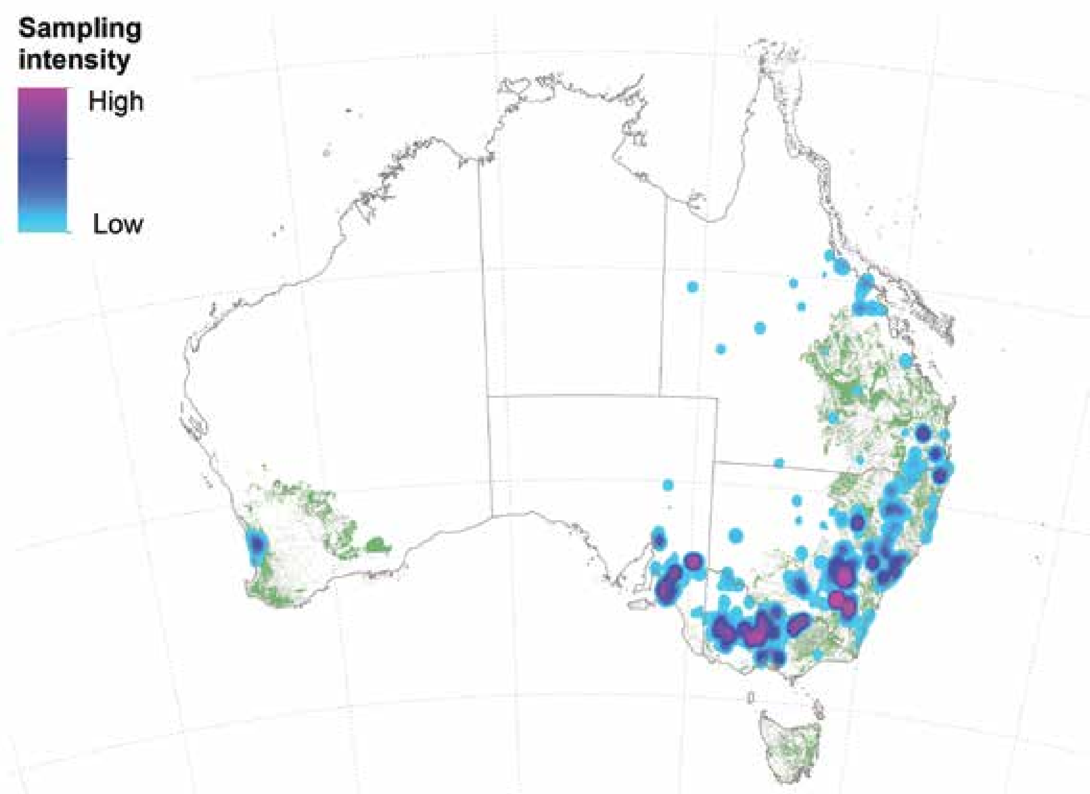


Figure 3: Example of spatial sampling intensity map for data used to produce the dry sclerophyll woodland/forest bird index shown. Dry sclerophyll woodland/forest habitat is indicated in green.

2.1.2 Spatio-temporal Representativeness: Dot Plots of Surveys at Sites and Time Series vs Species Accumulation Plots

There are two diagnostics for spatio-temporal representativeness included with each index which need to be consulted in conjunction with each other. (1) Dot plots (Figure 4a and c) display the distribution of surveys at consistent sites (vertical axis) over time (horizontal axis). (2) Time series vs species accumulation plots (Figure 4b and d) show the trend in the number of time series and the number of species across time. Where there is imbalance in sampling over time (e.g. Figure 4a and b) trend estimates might be erroneous.

To aid in interpreting the spatio-temporal representativeness of indices, dot plots showing patterns of data structure (i.e. surveys at consistent sites over time) are included with each index. Ideally monitoring site selection would follow a 'stratified random' experimental design and all sites in a region would be surveyed at equal time intervals for an observation period. This would result in a totally balanced dataset over time (e.g. Figure 4c and d). However, spatio-temporal patterns within monitoring datasets are usually apparent – e.g. an increase in monitoring effort over time. Statistical techniques accommodate much of this pattern (by only comparing data within individual sites). However, imbalance in monitoring data can result in trend estimates that reflect artefacts of data structure rather than real population trends, even if data are collected with the same methods through time. For instance, if species monitoring was conducted in highly degraded or marginally suitable habitats at the beginning of a monitoring period, and survey effort subsequently shifts to more suitable wilderness areas at the end of the period, trend estimates may reflect an increase in suitability of habitats surveyed rather than how the species population is behaving.

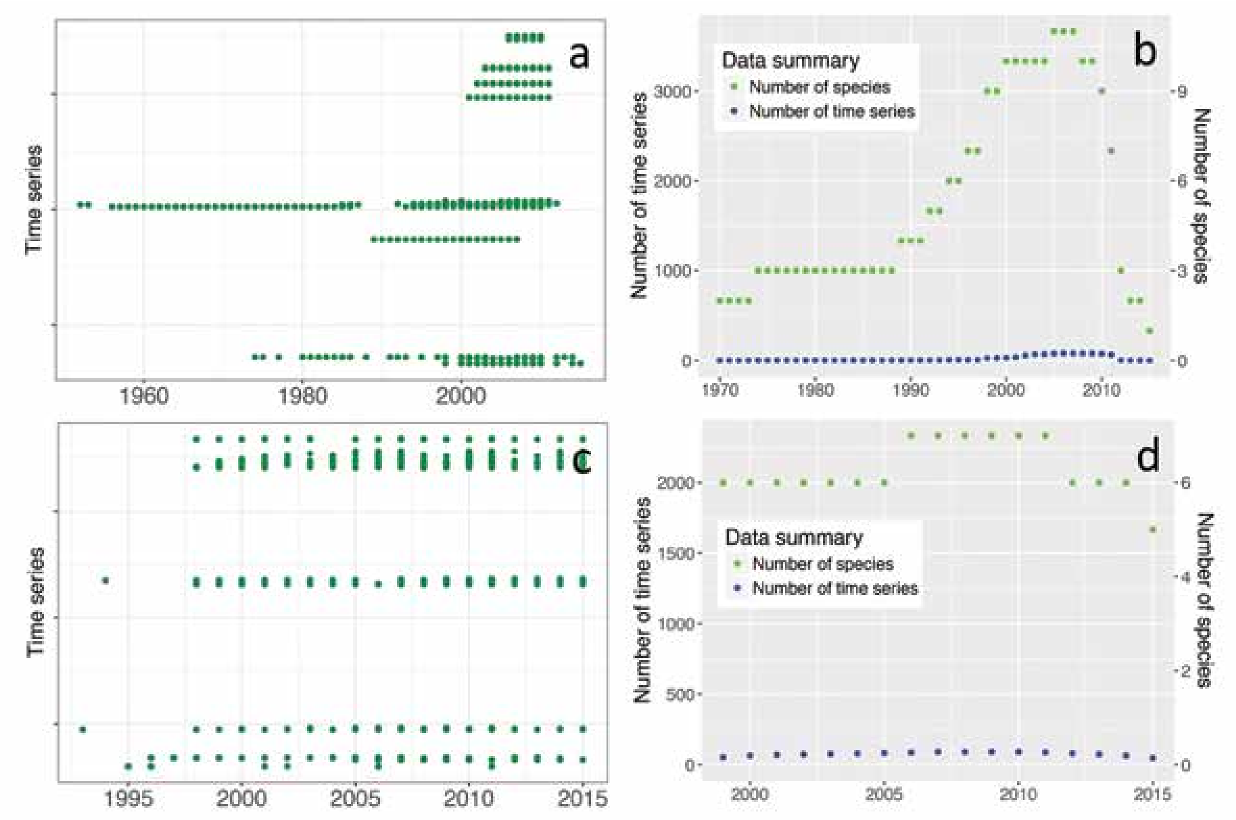


Figure 4: Spatio-temporal representativeness diagnostic presented with every index. Shown are dot plots of surveys at sites (vertical axis) over time (horizontal axis) (a and c) and number of time series (in blue, vertical axis) vs number of species (in green, secondary vertical axis) over time (horizontal axis) (b and d). Examples of unbalanced data structure (a and b) vs unbiased data structure (c and d) are shown here.

2.1.3 Taxonomic Representativeness: Index Summary Tables

To aid in interpreting the taxonomic representativeness of indices, index summary tables (Table 2 - 20) for each species group are included with each index. When evaluating indices for bird groups it is important to examine the species contributing to the composite index. Ideally, all species (or at least a balanced and representative set of species) in a group or region would be included in, and contribute to, the index, however there is often insufficient data to derive trends for some species. In particular, rare and cryptic species often do not have sufficient information for robust trends to be calculated. For instance, the index summary table for marine birds (Table 5) shows that the index is dominated by data for Albatrosses and Giant-Petrels (7 of the 11 species included in the index) and contains no data for Penguins.

Index summary tables include information on the number of time series per species, and importantly, the average time-series length. Time-series length varies widely across species and is an important factor when interpreting indices. For example, data for Light-mantled Sooty Albatross were available over a seven-year period whereas data for Wandering Albatross cover a >50 year span.

Spatial representativeness of data for each species included is also given in the index summary tables. Spatial representativeness was estimated by calculating the overall geographic range of a taxon (as determined by alpha hulls derived from all available records of a taxon), intersecting this with the taxon range for monitoring data used in the index, and calculating the proportion (in %) of the overall taxon range represented by the data used in the index. High values indicate that data in the index have been drawn from a high proportion of a taxon's range and are likely to better represent the population as a whole. For example, Black-eared Miners have a high spatial representativeness (>60%) indicating that data used in the index cover most of this species' range. In contrast, low values indicate that indices may not be effectively representing trends in the majority of a species' range, especially where habitat quality or threats vary across the extent of a species' range (species range layers are provided by Glenn Ehmke, BirdLife Australia, unpublished). For instance, although species such as Regent Honeyeater, Baudin's and Carnaby's Black-Cockatoo are included in several indices, data for these species are drawn from a comparatively low proportion (<3%) of these species' overall ranges. Spatial representativeness estimates for marine species were not calculated as data for these species were generally drawn from breeding colony monitoring of single locations.

2.1.4 Index Characteristics: Index Value, Baselines and Confidence Intervals

The index value is the average change in species' abundance from one year to the next based on a geometric mean. For any given year in the multi-species population time series, the index values are calculated from the average trend in that year compared to the previous year and they represent the cumulative trend since the baseline year which is set to a value of 1.0. The index is cumulative and is always in reference to the baseline, as are the 95% confidence intervals around the index value (see section A1.12 in the supplementary material explaining the confidence intervals). The baseline year for the Threatened Species Index depends on data availability and in most reporting here, we set the baseline (i.e. index of 1.0) to 1980. Setting the baseline to 1980 means that the trend will not consider any decrease or increase in those species' abundance which may have been recorded before 1980. The Threatened Species Index for birds calculated in 2017 ends at 2015 because of technical constraints within the software package, thus only data until 2015 were used in this interim report. This issue is currently being resolved by the Zoological Society of London so that data up to the present date can be used (see section A2.7 in the supplementary material for more information on the Living Planet Index methods that were applied in calculations for the Threatened Species Indices).

2.2 A Threatened Bird Index for Australia

To calculate a Threatened Bird Index for Australia, an aggregated database was collated with contributions from collaborating stakeholders of 122,686 species' population time series from 69 data sources for 100 threatened/Near Threatened species, from a total of 502,419 surveys and over more than 45 years. This represents >42% of all (236) listed threatened/Near Threatened bird taxa derived from the EPBC Act (2017) and/or the BirdLife Australia/Threatened Species Committee (2016). Collating this database was only possible because of the generosity of >130 single data custodians from state/territory agencies, non-government organisations, recovery groups, research institutions, private individuals, and citizen science groups. After applying data vetting and suitability criteria (see section A2.6 in the supplementary material for more information on the criteria used for data inclusion/exclusion), data from 43 sources and 72 species (>30% of all listed threatened and Near Threatened taxa) resulting in 11,772 time-series records or rows in the aggregated database were used for index calculation. A Threatened Species Index (TSX) for Australia was calculated (Figure 5) including five Functional Groups (Marine, Shoreline (migratory), Shoreline (resident), Terrestrial and Wetland). See Table 2 for a summary of all taxa included in this index. The TSX for Australian Threatened and Near Threatened birds included 11,772 time series with a time-series length of 18.0 ± 8.8 years (mean ± SD) and a number of sample years per time series of 12.0 ± 7.0 (mean ± SD). Due to a paucity of data available prior to 1980 (Figure 5c), the year 1980 was chosen as a baseline for this index. The index shows an overall trend of decrease of 25.2% relative to baseline set to 1.0 in 1980 (Figure 5a) with an overall slope of -0.003 (0.3% decrease in index value per year). The index value in 2015 is 0.748 with 95% confidence intervals between 0.531 and 1.216, indicating a decrease of 46.9 at worst and an increase of 21.6% at best between 1980 and 2015. The index is representative of most eastern states, but is marginal for Western Australia and the arid zone (Figure 5b).

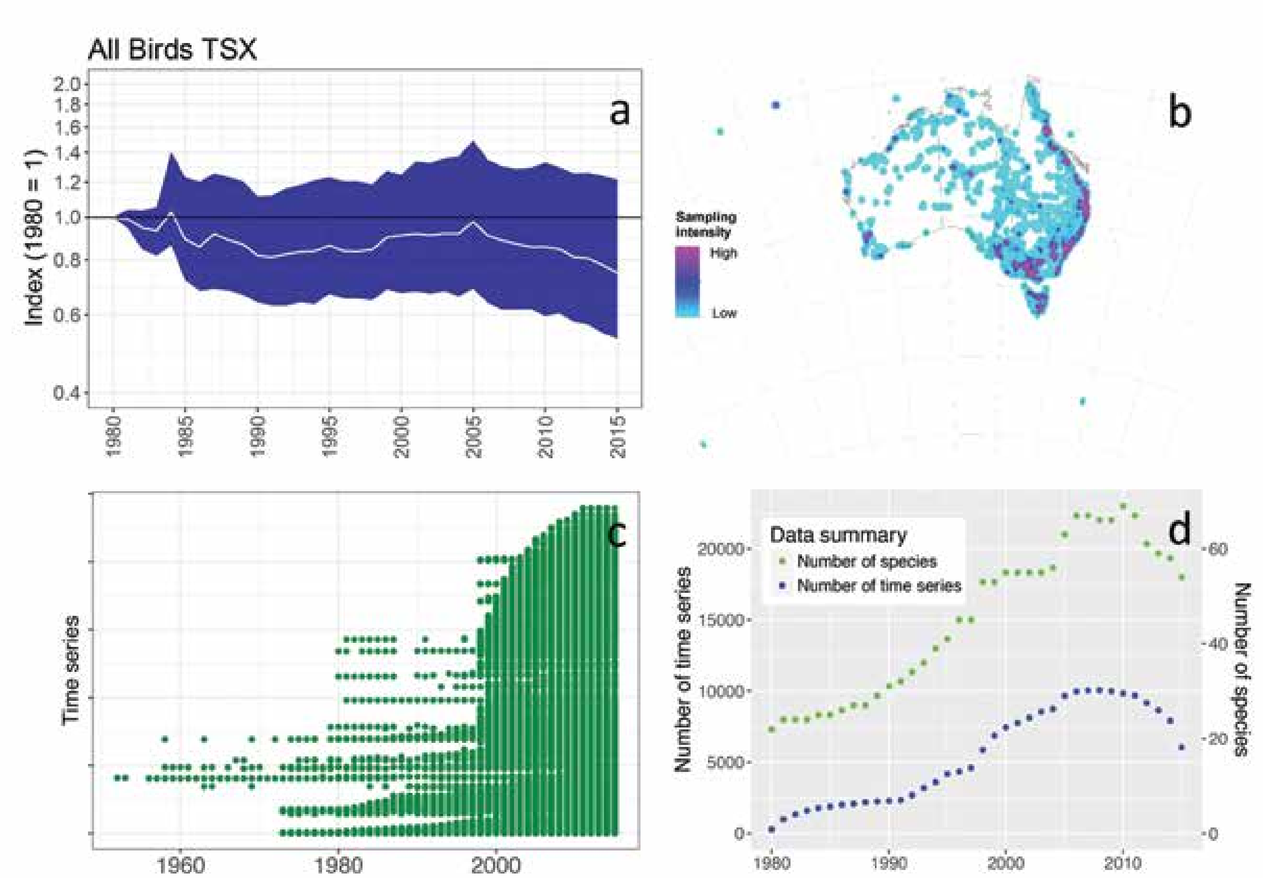


Figure 5: A Threatened Species Index (TSX) for all threatened and Near Threatened Australian birds. Panels indicate a) a TSX for all threatened and Near Threatened Australian birds with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary of the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

The marked 'early' (i.e. 1980 to 1990) decrease in the index value is based on relatively few time series included in the index at that time (Figure 5d, in blue). The composite trend stabilises more when a higher complement of time series are included after 1990 and even increases slowly until 2005 (coinciding with the introduction of the Commonwealth Endangered Species Protection Act in 1992 and the EPBC Act in 1999). There is an apparent drop in data after 2010 suggesting a decrease of structured monitoring at sites repeated through time.

Table 2: Summary table of data used to calculate the TSX for threatened and Near Threatened Australian birds can be downloaded from the 'Index Summary Tables' folder in the electronic supplementary material.

2.3. Threatened Species Indices for Functional Bird Groups

Threatened birds have highly diverse ecologies and life histories, and different ecological characteristics may predispose some species more than others to particular threats. Because of this, bird species were divided into broad 'Functional groups' and indices were calculated for these (see section A2.5.6 in the supplementary material for definition of Functional Bird Groups and Subgroups). Note that only a single resident shorebird species (Eastern Hooded Plover) and only three Wetland species (Table 2) had sufficient monitoring data to be included in the overall index.
While they are included in the overall trend index (Figure 5), we do not report separately on these two groups.

2.3.1 Terrestrial Birds

The TSX for Terrestrial Birds included 4,852 time series (41.0% of all records used for analyses, Figure 6c) on 46 taxa (Figure 6d) (representing 19.5% of all Australian threatened/Near Threatened birds) from 27 data sources with a time-series length of 14.2 ± 5.6 years (mean ± SD) and a number of sample years per time series of 10.0 ± 5.0 (mean ± SD) – see Table 3 for a summary of all taxa included in this index. Due to data availability, the year 1990 was chosen as a baseline for this index (Figure 6c). The trend shows a decrease of 16.6% relative to baseline set to 1.0 in 1990, with an overall slope of -0.003 (0.3% decrease in index value per year). However, although there is a decreasing overall trend, there are notable fluctuations in the index over this time. The index value in 2015 is 0.834 with 95% confidence intervals between 0.488 and 1.368 suggesting an increase of 36.8% at best and a decrease of 51.2% at worst between 1990 and 2015 (Figure 6a).

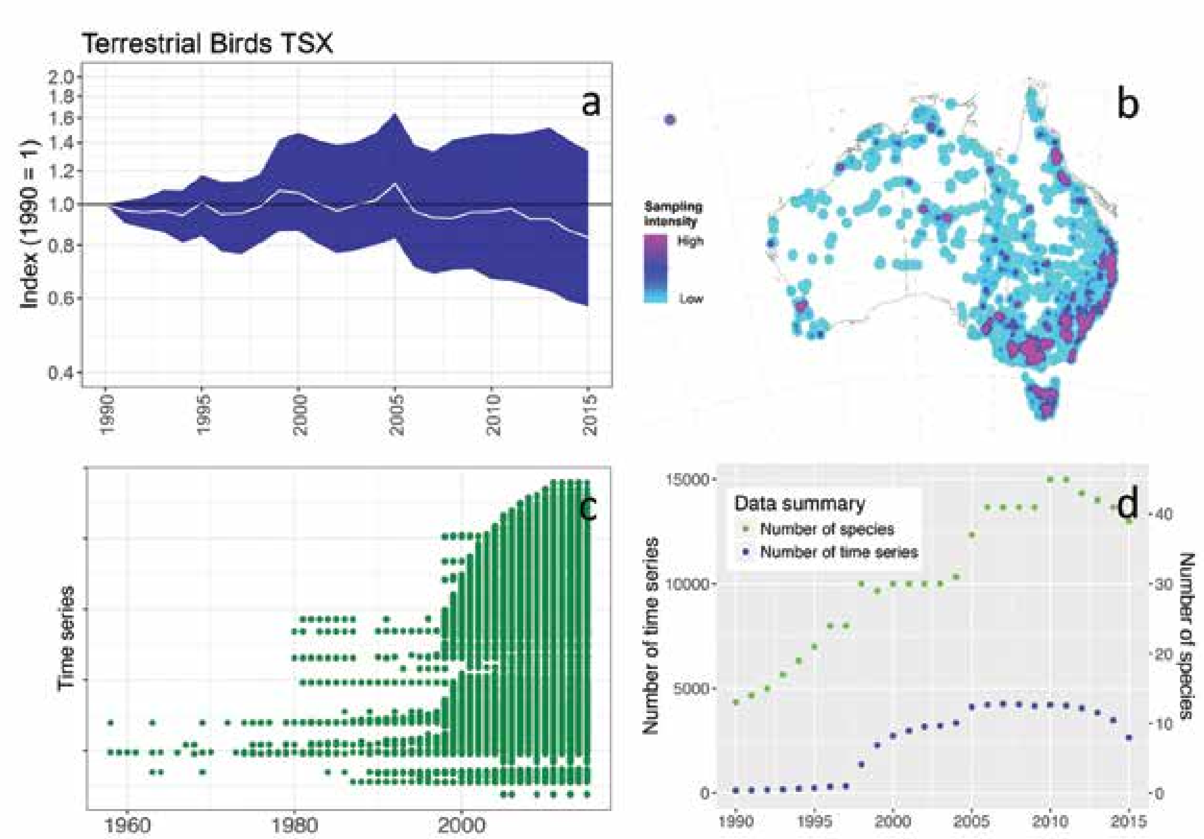


Figure 6: A Threatened Species Index (TSX) for Terrestrial Birds. Panels indicate a) a TSX for Terrestrial Birds with a base year set at 1990 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary of the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 3: Summary table of data used to calculate the TSX for Terrestrial Birds can be downloaded from the 'Index Summary Tables' folder in the electronic supplementary material.

2.3.2 Shoreline (migratory)/Migratory Shorebirds

The TSX for Migratory Shorebirds included 6,655 time series (56.5% of all records used for analyses) on 11 taxa (representing 4.7% of all Australian threatened/Near Threatened birds) from two data sources with a time-series length of 21.8 ± 9.6 years (mean ± SD) and a number of sample years per time series of 13.5 ± 7.8 (mean ± SD) – see Table 4 for a summary of all taxa included in this index. Due to data availability, the year 1980 was chosen as a baseline for this index (Figure 7a). The trend shows a clear decrease of 56.5% relative to the baseline set at 1.0 in 1980 (Figure 7a) with an overall slope of -0.023 (2.3% decrease in index value per year). The trend is almost entirely monotonic – i.e. there is little evidence of any fluctuation over time. The index value in 2015 is 0.435 with 95% confidence intervals between 0.350 and 0.562 indicating that the decrease between 1980 and 2015 is between 43.8% and 65.0% (Figure 7a).

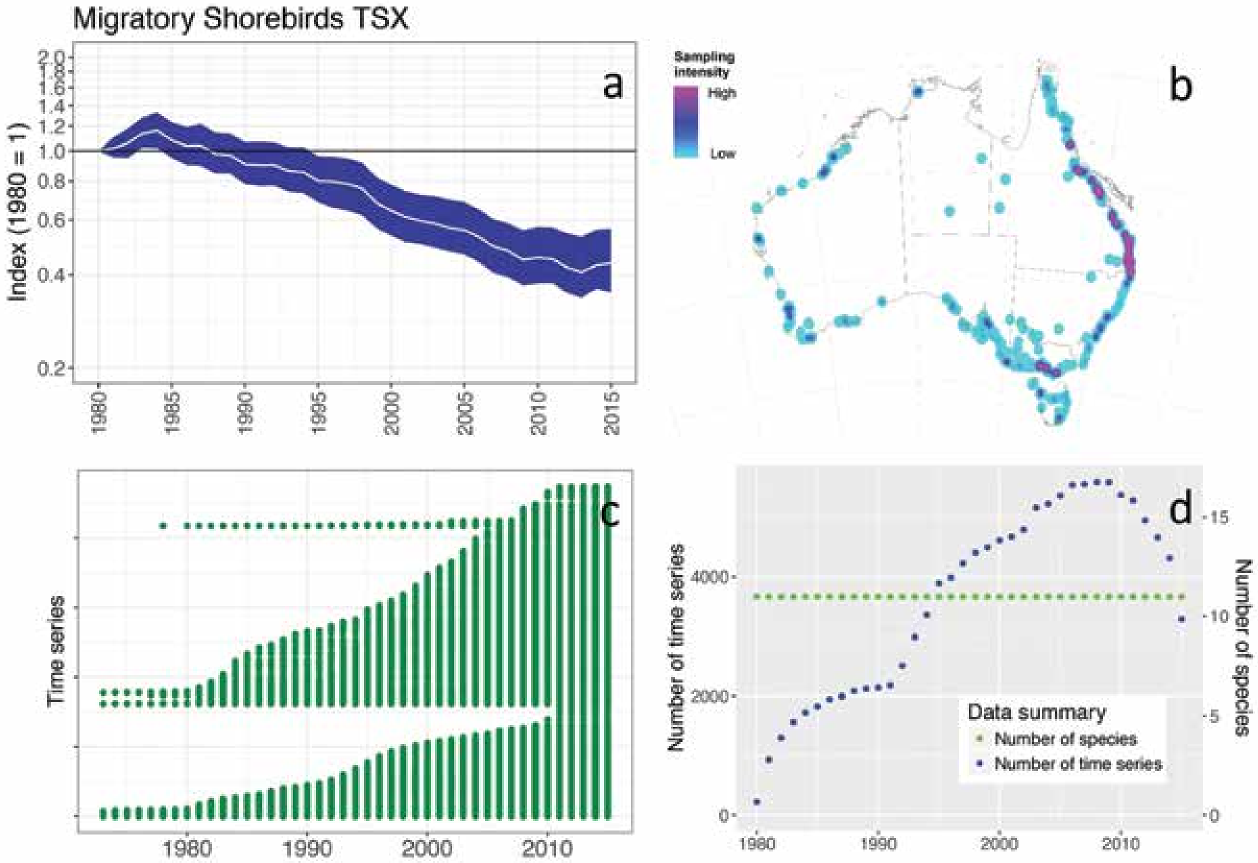


Figure 7: A Threatened Species Index (TSX) for Shoreline (migratory)/Migratory Shorebirds. Panels indicate a) a TSX for Migratory Shorebirds with a base year set at 1990 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary of the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 4: Summary table of data used to calculate the TSX for Shoreline (migratory)/Migratory Shorebirds. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 21.8 ± 9.6
Number of samples (years) per time series (mean ± SD): 13.5 ± 7.8
Number of data sources in Index: 2
Number of taxa in Index: 11

Taxon name	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in Index						
Asian Dowitcher	Near threatened		2	47	18.9	14.5
Eastern Siberian Black-tailed Godwit	Near threatened		2	404	20.5	13.0
Curlew Sandpiper	Critically Endangered	Critically Endangered	2	864	21.5	12.4
Eastern Curlew	Critically Endangered	Critically Endangered	2	916	19.9	11.8
Great Knot	Endangered	Critically Endangered	2	677	20.1	12.4
Mongolian Greater Sand Plover	Vulnerable	Vulnerable	2	480	19.5	13.1
Grey Plover	Near threatened		2	475	21.7	15.6
Lesser Sand Plover	Endangered	Endangered	2	590	20.3	
Red Knot	Endangered	Endangered	2	521	22.5	24.0
Red-necked Stint	Near threatened		2	1048	21.1	13.9
Palaearctic Ruddy Turnstone	Near threatened		2	633	21.2	14.3
Taxa not in Index						
Eastern Siberian Whimbrel	Near threatened		0	0	0	
Kamchatkan Lesser Sand Plover	Endangered		0	0	0	
Mongolian Lesser Sand Plover	Vulnerable		0	0	0	
New Siberian Islands Red Knot	Endangered		0	0	0	
North-eastern Siberian Red Knot	Endangered		0	0	0	
Northern Siberian Bar-tailed Godwit	Endangered	Critically Endangered	0	0	0	
Western Alaskan Bar-tailed Godwit	Vulnerable	Vulnerable	0	0	0	
Terek Sandpiper	Vulnerable		0	0	0	

2.3.3 Marine/Seabirds

The TSX for Marine/Seabirds included 47 time series (0.5% of all records used for analyses) on 11 taxa (representing 4.7% of all Australian threatened/Near Threatened birds) from 10 data sources with a time-series length of 12.2 ± 7.7 years (mean ± SD) and a number of sample years per time series of 9.4 ± 5.8 (mean ± SD) – see Table 5 for a summary of all taxa included in this index. Due to data availability, the year 1970 was chosen as a baseline for this index (Figure 8c). The trend shows an overall increase of 7.7% (Figure 8a) relative to the baseline set to 1.0 in 1970 with an overall slope of 0.030 (3.0% increase in index value per year). The index value in 2015 is 1.077 with 95% confidence intervals between 0.330 and 2.638 indicating a high uncertainty about whether Seabirds are on an increasing or decreasing trajectory. There is a strong correlation between the number of species for which data were available (Figure 8d) and the index trend indicating this trend may be confounded by data availability factors such as increasing effort over time (Figure 8c).

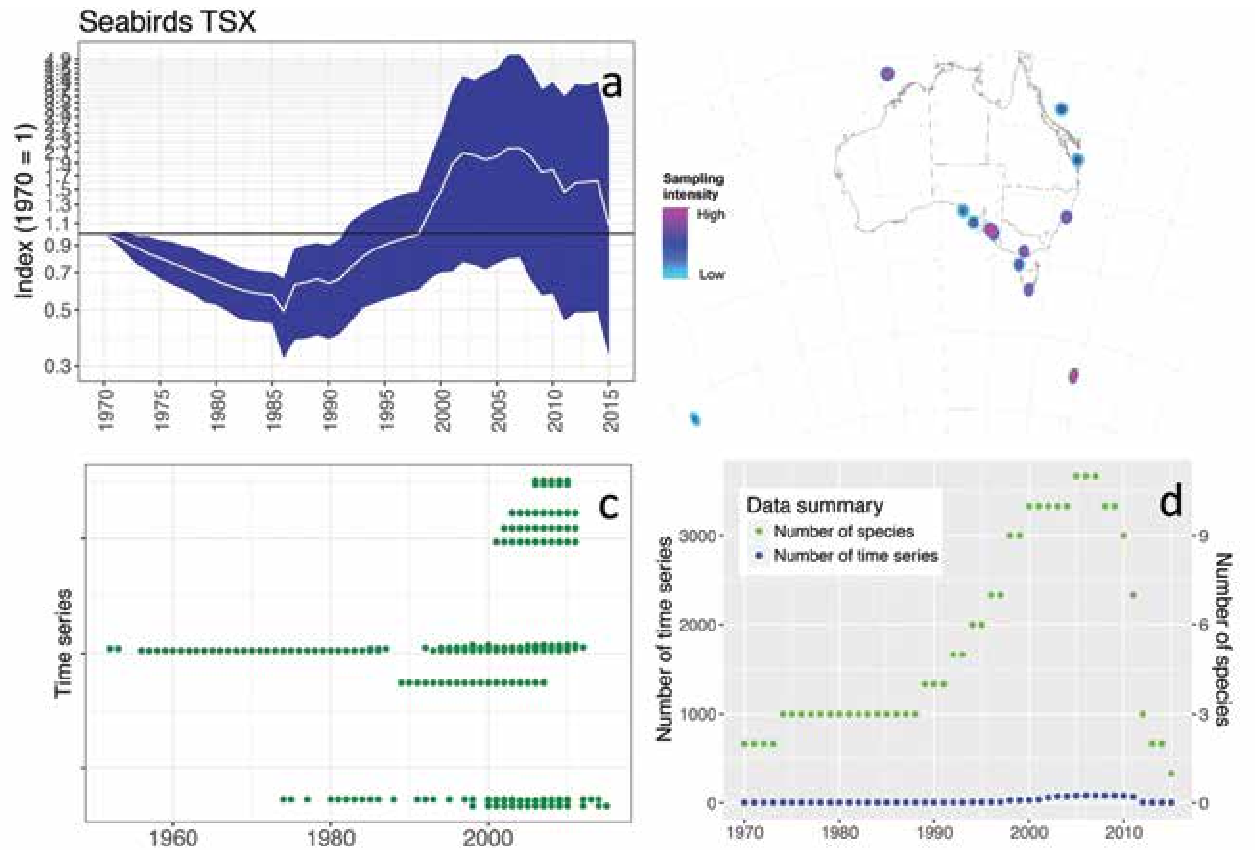


Figure 8: A Threatened Species Index (TSX) for Marine/Seabirds. Panels indicate a) a TSX for Seabirds with a base year set at 1970 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary of the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Photo of Australian Fairy Tern kindly provided by G. Ehmke, BirdLife Australia.

Table 5: Summary table of data used to calculate the TSX for Marine/Seabirds. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 12.2 ± 7.7
Number of samples (years) per time series (mean ± SD): 9.4 ± 5.8
Number of data sources in Index: 10
Number of taxa in Index: 11
** indicate taxa which do not breed in Australia*

Taxon name	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index						
Black-browed Albatross	Albatrosses and Giant-Petrels	Endangered	Vulnerable	2	2	33.5
Grey-headed Albatross	Albatrosses and Giant-Petrels	Critically Endangered	Endangered	1	1	18.0
Light-mantled Sooty Albatross	Albatrosses and Giant-Petrels	Near threatened		1	7	7.0
Northern Giant-Petrel	Albatrosses and Giant-Petrels	Least concern	Vulnerable	1	17	14.0
Shy Albatross	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	2	3	12.3
Southern Giant-Petrel	Albatrosses and Giant-Petrels	Least concern	Endangered	1	1	17.0
Wandering Albatross	Albatrosses and Giant-Petrels	Critically Endangered	Vulnerable	1	1	55.0
Australian Fairy Tern	Gulls Terns Noddies Skuas Jaegers	Vulnerable	Vulnerable	2	42	10.3
Australian Gould's Petrel	Petrels and Shearwaters	Vulnerable	Endangered	1	2	14.0
Indian Ocean Red-tailed Tropicbird	Tropicbirds Frigatebirds Gannets Boobies	Near threatened		3	5	11.4
Indian Ocean White-tailed Tropicbird	Tropicbirds Frigatebirds Gannets Boobies	Endangered		1	3	9.7
Taxa niot in Index						
Heard Island Black-faced Sheathbill		Vulnerable				
Heard Island Imperial Shag		Near threatened	Vulnerable			
Macquarie Island Imperial Shag		Vulnerable	Vulnerable			
* Amsterdam Albatross	Albatrosses and Giant-Petrels	Vagrant	Endangered			
* Campbell Albatross	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable			
* Chatham Albatross	Albatrosses and Giant-Petrels	Vagrant	Endangered			
* Gibson's Albatross	Albatrosses and Giant-Petrels	Endangered	Vulnerable			
* Indian Yellow-nosed Albatross	Albatrosses and Giant-Petrels	Endangered	Vulnerable			
* Northern Buller's Albatross	Albatrosses and Giant-Petrels	Near threatened	Vulnerable			
* Northern Royal Albatross	Albatrosses and Giant-Petrels	Endangered	Endangered			
* Salvin's Albatross	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable			
* Sooty Albatross	Albatrosses and Giant-Petrels	Endangered	Vulnerable			
* Southern Buller's Albatross	Albatrosses and Giant-Petrels	Near threatened				
* Southern Royal Albatross	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable			
* Tristan Albatross	Albatrosses and Giant-Petrels	Vagrant	Endangered			
* White-capped Albatross	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable			
Houtman Abrolhos Lesser Noddy	Gulls Terns Noddies Skuas Jaegers	Endangered	Vulnerable			
Indian Ocean Antarctic Tern	Gulls Terns Noddies Skuas Jaegers	Endangered	Vulnerable			
New Caledonian Fairy Tern	Gulls Terns Noddies Skuas Jaegers	Endangered				
New Zealand Antarctic Tern	Gulls Terns Noddies Skuas Jaegers	Endangered	Endangered			
Eastern Rockhopper Penguin	Penguins	Vulnerable				
Macaroni Penguin	Penguins	Near threatened				
Royal Penguin	Penguins	Near threatened				
Subantarctic Gentoo Penguin	Penguins	Near threatened				
Antarctic Prion	Petrels and Shearwaters	Endangered				
* Black Petrel	Petrels and Shearwaters	Vulnerable				
Blue Petrel	Petrels and Shearwaters	Critically Endangered	Vulnerable			
* Buller's Shearwater	Petrels and Shearwaters	Vulnerable				
Flesh-footed Shearwater	Petrels and Shearwaters	Near threatened				
Grey Petrel	Petrels and Shearwaters	Endangered				
Grey-backed Storm-Petrel	Petrels and Shearwaters	Endangered				
Herald Petrel	Petrels and Shearwaters	Vulnerable				
* Hutton's Shearwater	Petrels and Shearwaters	Endangered				
* Matsudaira's Storm-Petrel	Petrels and Shearwaters	Vulnerable				
* Mottled Petrel	Petrels and Shearwaters	Near threatened				
* New Caledonian Gould's Petrel	Petrels and Shearwaters	Vulnerable				
* New Caledonian Tahiti Petrel	Petrels and Shearwaters	Near threatened				
* Pacific Tahiti Petrel	Petrels and Shearwaters	Near threatened				
Providence Petrel	Petrels and Shearwaters	Vulnerable				
Pycroft's Petrel	Petrels and Shearwaters	Extinct				
Soft-plumaged Petrel	Petrels and Shearwaters	Critically Endangered	Vulnerable			
Sooty Shearwater	Petrels and Shearwaters	Near threatened				
South Georgian Diving-Petrel	Petrels and Shearwaters	Vulnerable				
Southern Common Diving-Petrel	Petrels and Shearwaters	Vulnerable				
Southern Fairy Prion	Petrels and Shearwaters	Endangered	Vulnerable			
Southern Fulmar Prion	Petrels and Shearwaters	Vulnerable				
Southern White-necked Petrel	Petrels and Shearwaters	Endangered				
Subantarctic Wilson's Storm-Petrel	Petrels and Shearwaters	Vulnerable				
Tasman Little Shearwater	Petrels and Shearwaters	Vulnerable				
Tasman White-bellied Storm-Petrel	Petrels and Shearwaters	Vulnerable	Vulnerable			
Western Kermadec Petrel	Petrels and Shearwaters	Endangered	Vulnerable			
Westland Petrel	Petrels and Shearwaters	Vulnerable				
* White-chinned Petrel	Petrels and Shearwaters	Vulnerable				
* White-headed Petrel	Petrels and Shearwaters	Endangered				
Abbott's Booby	Tropicbirds Frigatebirds Gannets Boobies	Endangered	Endangered			
Christmas Island Frigatebird	Tropicbirds Frigatebirds Gannets Boobies	Critically Endangered	Endangered			
Christmas Island White-tailed Tropicbird	Tropicbirds Frigatebirds Gannets Boobies	Endangered	Endangered			
Tasman Booby	Tropicbirds Frigatebirds Gannets Boobies	Near threatened				

2.4 Functional Bird Subgroups (Bird Habitats)

2.4.1 Dry sclerophyll woodland/forest

Threatened bird species in dry sclerophyll woodland/forest included 2,477 time series (21.0% of all records used for analyses) from 11 taxa (representing 4.7% of all Australian threatened/Near Threatened birds) from 8 data sources with a time-series length of 14.1 ± 5.7 years (mean ± SD) and a number of sample years per time series of 10.4 ± 5.0 (mean ± SD) – see Table 6 for a summary on all taxa included in this index. Due to data availability, the year 1999 was chosen as a baseline for this index (Figure 9c). The trend shows a decrease of 48.0% relative to the 1999 baseline, with an overall slope of -0.002 (2.0% decrease in index value per year). The index value in 2015 is 0.520 with 95% confidence intervals between 0.350 and 0.845 indicating that the decrease between 1999 and 2015 is between 35.0% and 84.5%. The index is representative of most south-eastern woodland habitats, but has low representativeness for Western Australian woodland excepting that close to Perth (Figure 9b).

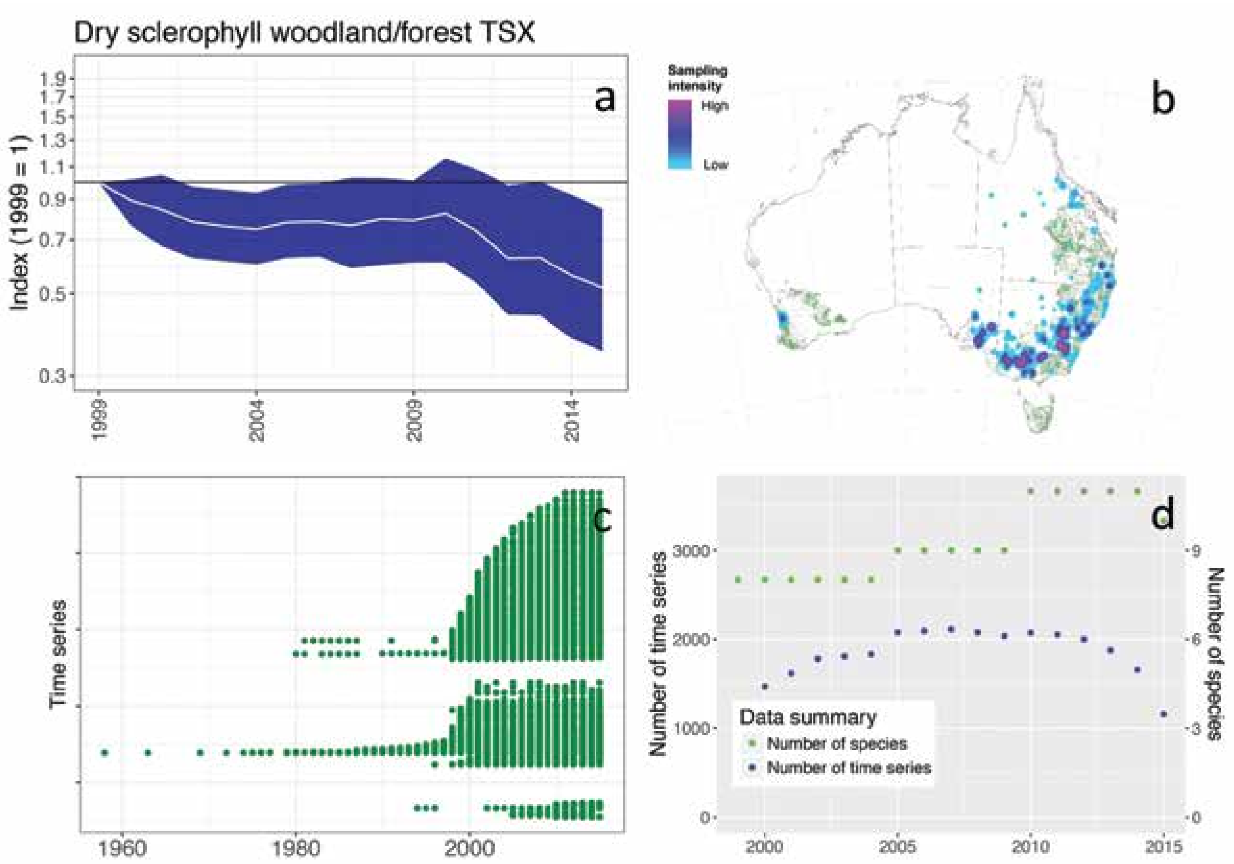


Figure 9: A Threatened Species Index (TSX) for dry sclerophyll woodland/forest habitat birds. Panels indicate a) a TSX for dry sclerophyll woodland/forest habitat birds with a base year set at 1999 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index (dry sclerophyll woodland/forest habitat is indicated in green), c) number of species population time series for sites surveyed repeatedly through time and d) a summary of the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 6: Summary table of data used to calculate the TSX dry sclerophyll woodland/forest habitat birds. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 14.1 ± 5.7
Number of samples (years) per time series (mean ± SD): 10.4 ± 5.0
Number of data sources in Index: 8
Number of taxa in Index: 11

Taxon name	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in Index						
Baudin's Black-Cockatoo	Endangered	Vulnerable	1	28	7.1	2.8
Carnaby's Black-Cockatoo	Endangered	Endangered	1	111	7.2	2.0
Painted Honeyeater	Vulnerable	Vulnerable	2	94	13.8	26.0
Regent Honeyeater	Critically Endangered	Critically Endangered	1	15	16.8	0.7
South-eastern Black-chinned Honeyeater	Near threatened		2	370	13.9	7.9
South-eastern Brown Treecreeper	Near threatened		2	692	13.1	17.8
South-eastern Hooded Robin	Near threatened		1	419	13.4	21.0
Southern Barking Owl	Near threatened		2	424	20.8	30.0
Southern Squatter Pigeon	Least concern	Vulnerable	1	29	12.1	29.6
Superb Parrot	Least concern	Vulnerable	1	185	12.9	19.9
Swift Parrot	Critically Endangered	Critically Endangered	1	110	8.9	80.8
Taxa not in Index						
Forest Red-tailed Black-Cockatoo	Vulnerable	Vulnerable	0	0	0	
Forty-spotted Pardalote	Endangered	Endangered	0	0	0	
Mt Lofty Ranges Spotted Quail-thrush	Critically Endangered (Possibly Extinct)	Critically Endangered	0	0	0	
South Australian Bassian Thrush	Vulnerable	Vulnerable	0	0	0	
South-eastern Glossy Black-Cockatoo	Near threatened		0	0	0	
South-eastern Red-tailed Black-Cockatoo	Endangered	Endangered	0	0	0	

2.4.2 Tropical savanna woodland

A TSX for seven tropical savanna woodland habitat birds included 98 time series (0.8% of all records used for analyses) from five data sources with a time-series length of 15.1 ± 4.1 years (mean ± SD) and a number of sample years per time series of 8.3 ± 3.5 (mean ± SD) - see Table 7 for a summary on all taxa included in this index. Due to data availability, the year 1999 was chosen as a baseline for this index (Figure 10a). The trend shows an increase of 6.8% (Figure 10a) relative to the 1999 baseline, with an overall slope of -0.034 (3.4% decrease in index value per year). The index value in 2015 is 1.068 with 95% confidence intervals between 0.338 and 3.129 indicating a large uncertainty on whether tropical savanna woodland birds are on an increasing or decreasing trajectory. The index has good representativeness across north-western savanna woodland habitats in Northern Territory and Western Australia, but has low representativeness for Queensland savanna woodland excepting isolated pockets near inhabited areas on the east coast (Figure 10b). The relative stability for tropical savanna woodland habitat birds after 2007 is consistent with the few studies on trends within this habitat (Woinarski et al. 2012).

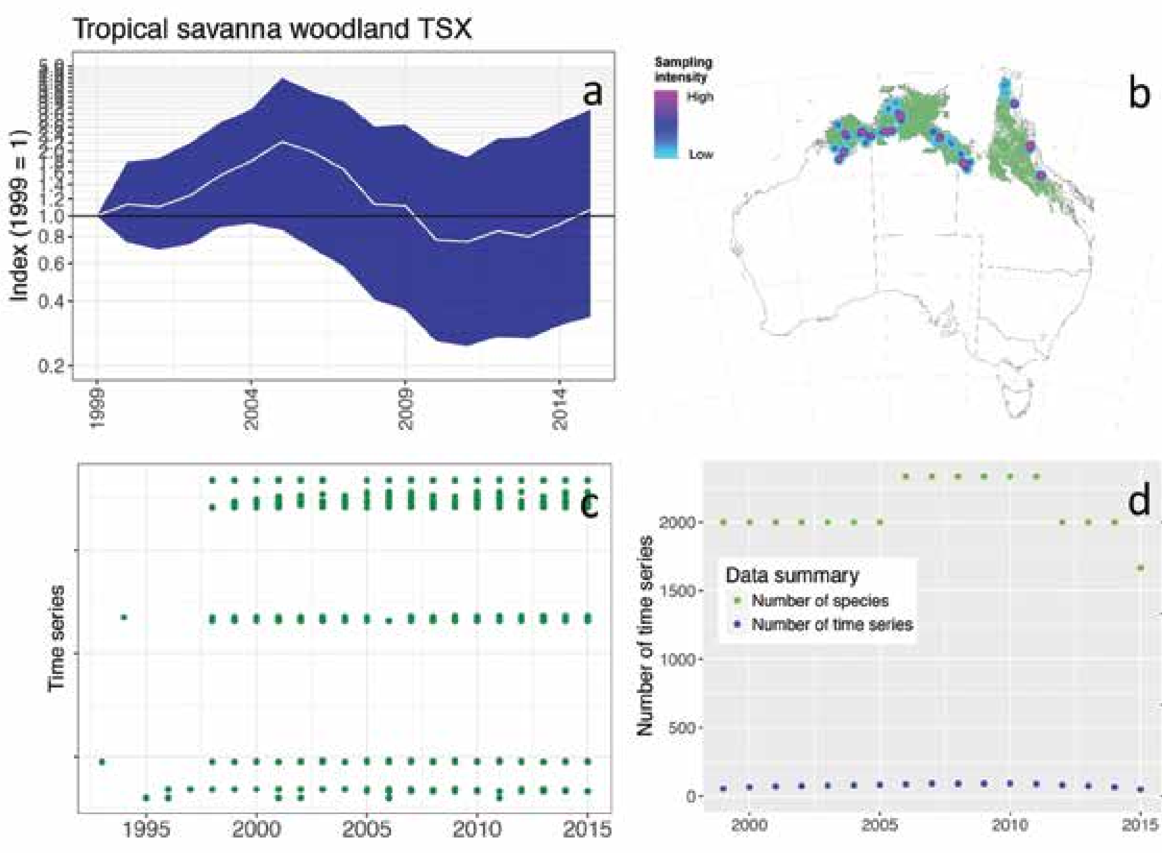


Figure 10: A Threatened Species Index (TSX) for tropical savanna woodland habitat birds. Panels indicate a) a TSX for tropical savanna woodland habitat birds with a base year set at 1999 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index (tropical savanna woodland habitat in green), c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 7: Summary table of data used to calculate the TSX for tropical savanna woodland habitat birds. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material

Time-series length (mean ± SD): 15.1 ± 4.1
Number of samples (years) per time series (mean ± SD): 8.3 ± 3.5
Number of data sources in Index: 5
Number of taxa in Index: 7

Taxon name	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in index						
Eastern Partridge Pigeon	Vulnerable	Vulnerable	1	4	20.5	4.3
Eastern Purple-crowned Fairy-wren	Near threatened		1	13	15.8	21.4
Fawn-breasted Bowerbird	Near threatened		1	5	16.2	10.7
Gouldian Finch	Near threatened	Endangered	2	44	15.5	9.2
Northern Masked Owl	Vulnerable	Vulnerable	1	4	17.8	17.3
Southern Black-throated Finch	Vulnerable	Endangered	1	6	8.7	0.4
Western Purple-crowned Fairy-wren	Endangered	Endangered	2	22	13.9	4.8
Taxa not in index			**0**	**0**	**0**	**0**
Golden-shouldered Parrot	Endangered	Endangered	0	0	0	0
Buff-breasted Button-quail	Endangered	Endangered	0	0	0	0
Stokes Range White-quilled Rock-Pigeon	Near threatened		0	0	0	0
Western Partridge Pigeon	Vulnerable	Vulnerable	0	0	0	0
White-bellied Crimson Finch	Near threatened	Vulnerable	0	0	0	0

2.4.3. Island Endemics – Highlighting the Need for Data

A TSX for island endemic birds included 486 time series (4.1% of all records used for analyses) on six taxa (representing 2.5% of all Australian threatened/Near Threatened birds) from two data sources with a time-series length of 11.1 ± 0.8 years (mean ± SD) and a number of sample years per time series of 5.7 ± 1.4 (mean ± SD). This index has relatively poor representation for this groups as a whole, thus is a good example where more efforts need to be invested in the collation of existing data. Data were only available for five Christmas Island species and the Kangaroo Island Glossy Black-Cockatoo - see Table 8 for a summary on all taxa included in this index. Due to data availability, the year 2005 was chosen as a baseline for this index (Figure 11c). The trend shows a decrease of 2.5% (Figure 11a) relative to the 2005 baseline, with an overall slope of 0.045 (4.5% increase in index value per year). The index value in 2015 is 0.975 with 95% confidence intervals between 0.459 and 1.787 indicating a general increase, although with substantial uncertainty of its magnitude.

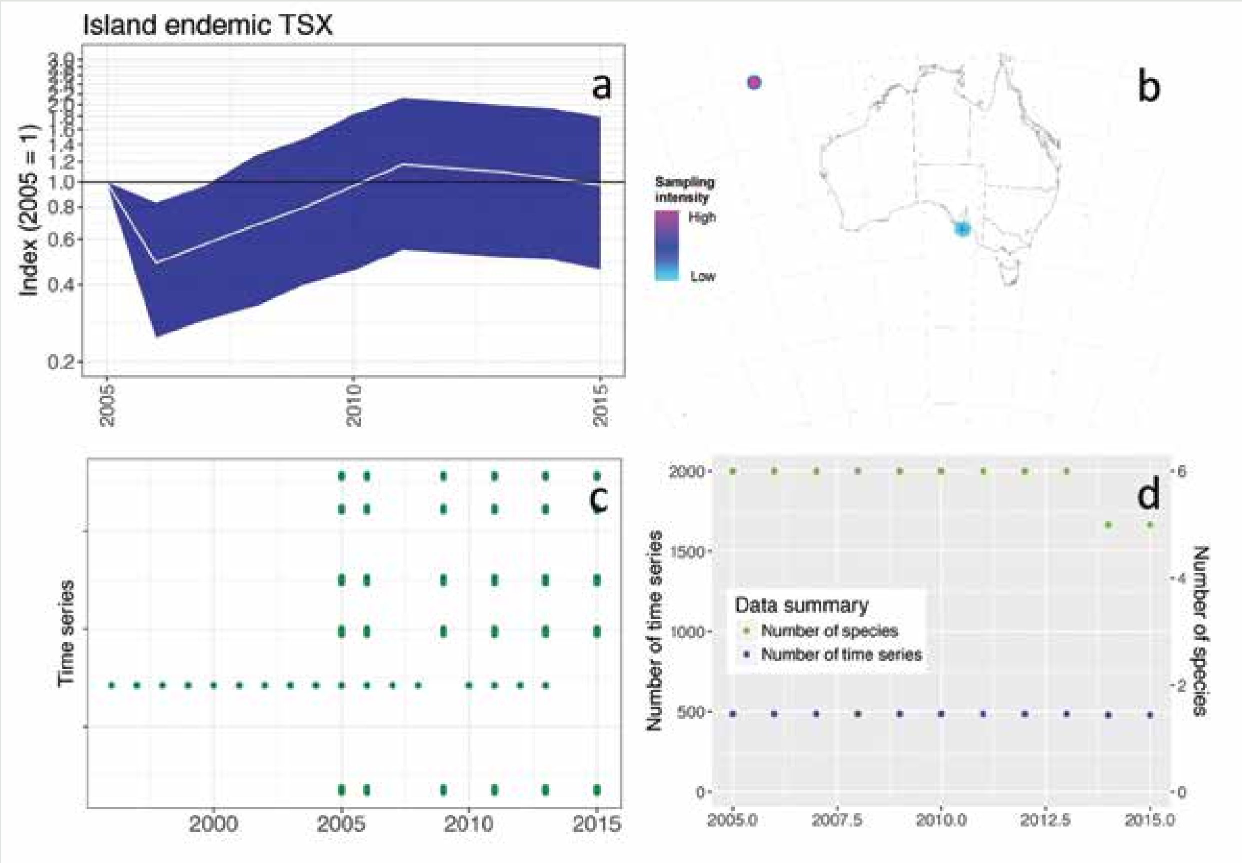


Figure 11: A Threatened Species Index (TSX) for Island endemic birds. Panels indicate a) a TSX for Island endemic birds with a base year set at 2005 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time-series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 8: Summary table of data used to calculate the TSX for Island endemic birds. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 11.1 ± 0.8
Number of samples (years) per time series (mean ± SD): 5.7 ± 1.4
Number of data sources in Index: 2
Number of taxa in Index: 6

Taxon name	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in index						
Christmas Island Goshawk	Endangered	Endangered	1	26	11.0	42.7
Christmas Island Grey-capped Emerald-Dove	Near threatened	Endangered	1	109	11.0	
Christmas Island Imperial-Pigeon	Near threatened		1	115	11.0	42.7
Christmas Island Thrush	Near threatened	Endangered	1	114	11.0	42.7
Christmas Island White-eye	Near threatened		1	115	11.0	42.7
Kangaroo Island Glossy Black-Cockatoo	Endangered	Endangered	1	6	18.0	18.3
Taxa not in index						
Barrow Island White-winged Fairy-wren	Vulnerable	Vulnerable	0	0	0	0
Christmas Island Glossy Swiftlet	Near threatened		0	0	0	0
Christmas Island Hawk-Owl	Vulnerable	Vulnerable	0	0	0	0
Dirk Hartog Rufous Fieldwren	Vulnerable		0	0	0	0
Dirk Hartog Southern Emu-wren	Vulnerable		0	0	0	0
Dirk Hartog White-winged Fairy-wren	Vulnerable	Vulnerable	0	0	0	0
Dorre Rufous Fieldwren	Vulnerable		0	0	0	0
Glossy Swiftlet	Near threatened		0	0	0	0
Grey-capped Emerald-Dove	Near threatened		0	0	0	0
Houtman Abrolhos Painted Button-quail	Endangered	Vulnerable	0	0	0	0
Island Thrush	Near threatened		0	0	0	0
Kangaroo Island Western Whipbird	Near threatened		0	0	0	0
King Island Black Currawong	Endangered	Vulnerable	0	0	0	0
King Island Brown Thornbill	Critically Endangered	Endangered	0	0	0	0
King Island Green Rosella	Vulnerable	Vulnerable	0	0	0	0
King Island Scrubtit	Critically Endangered	Critically Endangered	0	0	0	0
King Island Yellow Wattlebird	Near threatened		0	0	0	0
Lord Howe Golden Whistler	Near threatened		0	0	0	0
Lord Howe Pied Currawong	Endangered	Vulnerable	0	0	0	0
Lord Howe Silvereye	Near threatened		0	0	0	0
Norfolk Island Boobook	Critically Endangered	Endangered	0	0	0	0
Norfolk Island Gerygone	Near threatened		0	0	0	0
Norfolk Island Golden Whistler	Near threatened	Vulnerable	0	0	0	0
Norfolk Island Green Parrot	Critically Endangered	Endangered	0	0	0	0
Norfolk Island Grey Fantail	Near threatened		0	0	0	0
Norfolk Island Sacred Kingfisher	Near threatened		0	0	0	0
Norfolk Island Scarlet Robin	Endangered	Vulnerable	0	0	0	0
Red-fronted Parakeet	Critically Endangered		0	0	0	0
Shark Bay Variegated Fairy-wren	Vulnerable		0	0	0	0
Slender-billed White-eye	Near threatened		0	0	0	0
Tasman Boobook	Critically Endangered		0	0	0	0
Tiwi Horsfield's Bushlark	Vulnerable	Vulnerable	0	0	0	0
Tiwi Masked Owl	Endangered	Endangered	0	0	0	0
Tiwi Hooded Robin	Critically Endangered (Possibly Extinct)	Endangered	0	0	0	0

2.5 State and Territory Threatened Species Indices for Birds

The jurisdictional subdivision of taxa was based on the spatial location of monitoring data provided for a taxon. Note that taxa with monitoring data from one jurisdiction may also occur in other jurisdictions. It should also be noted that this report does not present all mechanics and capability of the Threatened Species Index – only a small subset of all possible index interrogations are presented here.

2.5.1 Australian Capital Territory and New South Wales

Bird taxa monitored in New South Wales (NSW; 1,881 time series, 16.0% of all records used for analyses) and the Australian Capital Territory (ACT; 127 time series corresponding to 1.1% of all records used for analyses) were grouped together due to the small number of time series for ACT and contiguous habitat. This resulted in a data subset for ACT and NSW Near Threatened and threatened birds with 2008 time series (17.1% of the database used for analyses) for 31 taxa (representing 13.1% of all Australian threatened/Near Threatened birds) from 15 data sources with a time-series length of 15.2 $\pm$ 6.4 (mean $\pm$ SD) and a number of sample years per time series of 11.0 $\pm$ 5.3 (mean $\pm$ SD) - see Table 9 for a summary of all taxa included in this index (Figure 12a). The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. The trend shows a decrease of 39.6% compared to the baseline in 1980 (Figure 12a) with an overall slope of -0.007 (0.7% decrease in index value per year). This decrease is 14.4% more than the overall TSX for Australia (section 2.2). The index value in 2015 is 0.604 with 95% confidence intervals between 0.291 and 1.302 indicating that the real trend may have decreased by up to 70.9% or increased by up to 30.2% between 1980 and 2015. The index has very good spatial representativeness across habitats in eastern NSW, but has low representativeness of inland arid NSW habitats (Figure 12b). Note that the uncertainty in this index may decrease after processing and incorporating data from the BioNet state repository in NSW received late 2017.

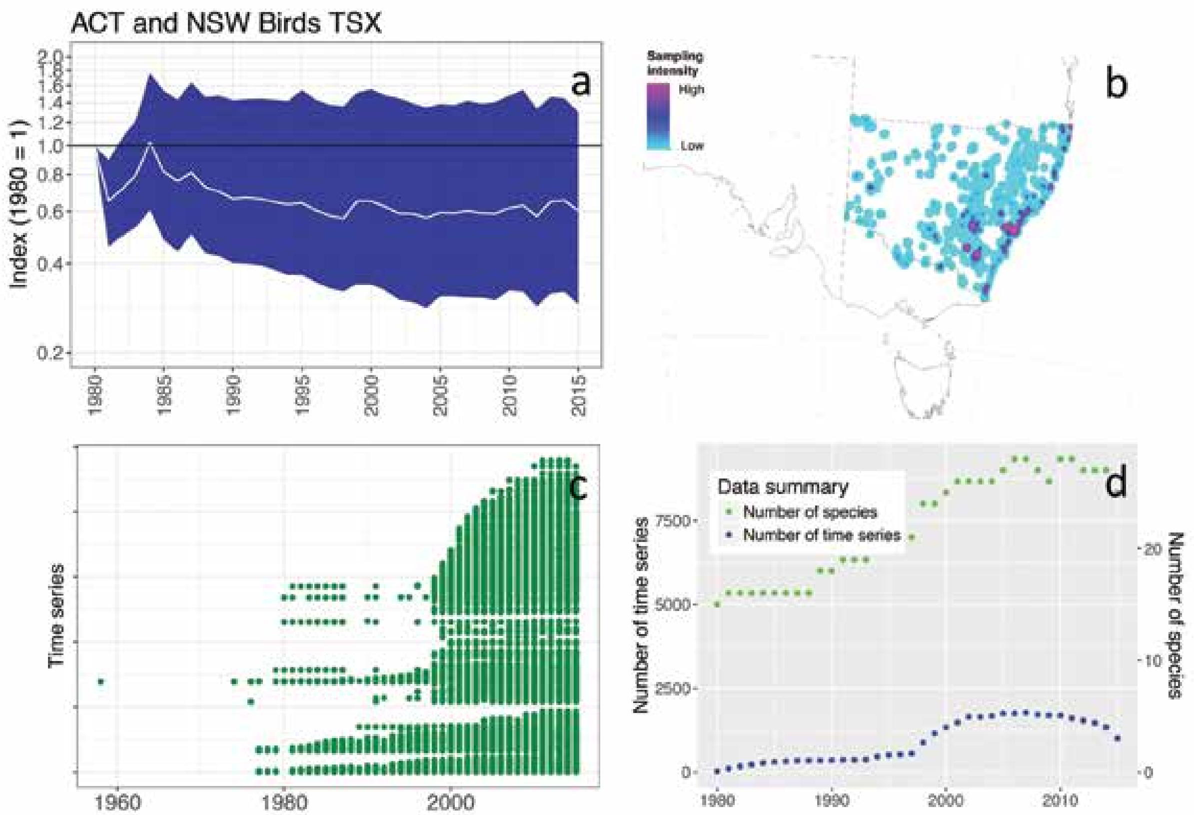


Figure 12: A Threatened Species index (TSX) for all threatened and Near Threatened birds monitored in the Australian Capital Territory (ACT) and New South Wales (NSW). Panels indicate a) a TSX for birds monitored in ACT/NSW with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 9: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in the Australian Capital Territory and New South Wales. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 15.2 ± 6.4
Number of samples (years) per time series (mean ± SD): 11.0 ± 5.3
Number of data sources in Index: 15
Number of taxa in Index: 31

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index							
Australian Gould's Petrel	Marine	Petrels and Shearwaters	Vulnerable	Endangered	1	2	14.0
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	41	25.9
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	83	23.6
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	102	22.7
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	49	26.9
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	28	26.5
Grey Plover	Shoreline (migratory)		Near threatened		2	33	25.7
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	44	27.3
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	57	26.2
Red-necked Stint	Shoreline (migratory)		Near threatened		2	80	25.2
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	59	26.1
Eastern Major Mitchell's Cockatoo	Terrestrial		Near threatened		1	52	13.8
Eastern Regent Parrot	Terrestrial		Endangered	Vulnerable	2	1	17.0
Flame Robin	Terrestrial		Near threatened		4	129	13.9
Grey Falcon	Terrestrial		Vulnerable		2	17	21.0
Northern Eastern Bristlebird	Terrestrial		Critically Endangered		1	26	11.2
Painted Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	2	42	14.3
Regent Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	15	16.8
South-eastern Black-chinned Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	124	15.5
South-eastern Brown Treecreeper	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	333	14.2
South-eastern Hooded Robin	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		1	104	13.5
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	155	21.3
Superb Parrot	Terrestrial	Dry sclerophyll woodland/forest	Least concern	Vulnerable	1	161	12.7
Swift Parrot	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	42	9.1
Southern Eastern Bristlebird	Terrestrial	Heathland	Endangered		2	15	16.0
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	4	10.5
Albert's Lyrebird	Terrestrial	Rainforest	Near threatened		1	12	6.0
Northern Rufous Scrub-bird	Terrestrial	Rainforest	Endangered		2	15	7.0
Southern Rufous Scrub-bird	Terrestrial	Rainforest	Endangered		1	20	6.4
Australasian Bittern	Wetland		Endangered	Endangered	2	36	14.4
Australasian Bittern	Wetland		Endangered	Endangered	2	36	14.4

2.5.2 Northern Territory

Bird taxa monitored in the Northern Territory (NT) resulted in an index based on 211 time series (1.8% of all records used for analyses) for 17 taxa (representing 7.2% of all Australian threatened/Near Threatened birds) from four data sources with a time-series length of 22.2 ± 8.6 years (mean ± SD) and 12.4 ± 5.9 (mean ± SD) sample years per time series (Figure 13c) - see Table 10 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions except for NT where no data were available before 1982; thus here the 1982 was selected as a reference year. The trend shows an increase of 113.3% compared to the baseline set in 1982 (Figure 13a) with an overall slope of 0.026 (2.6% increase in index value per year). This increase contrasts with decreases indicated by the overall TSX for Australia (section 2.2). The index value in 2015 is 2.133 with 95% confidence intervals between 0.696 (decreasing) and 5.485 (increasing) indicating high variance in trends across NT taxa. Sampling intensity is restricted to isolated pockets of habitat across NT, resulting in relatively low spatial representativeness across the entire territory (Figure 13b).

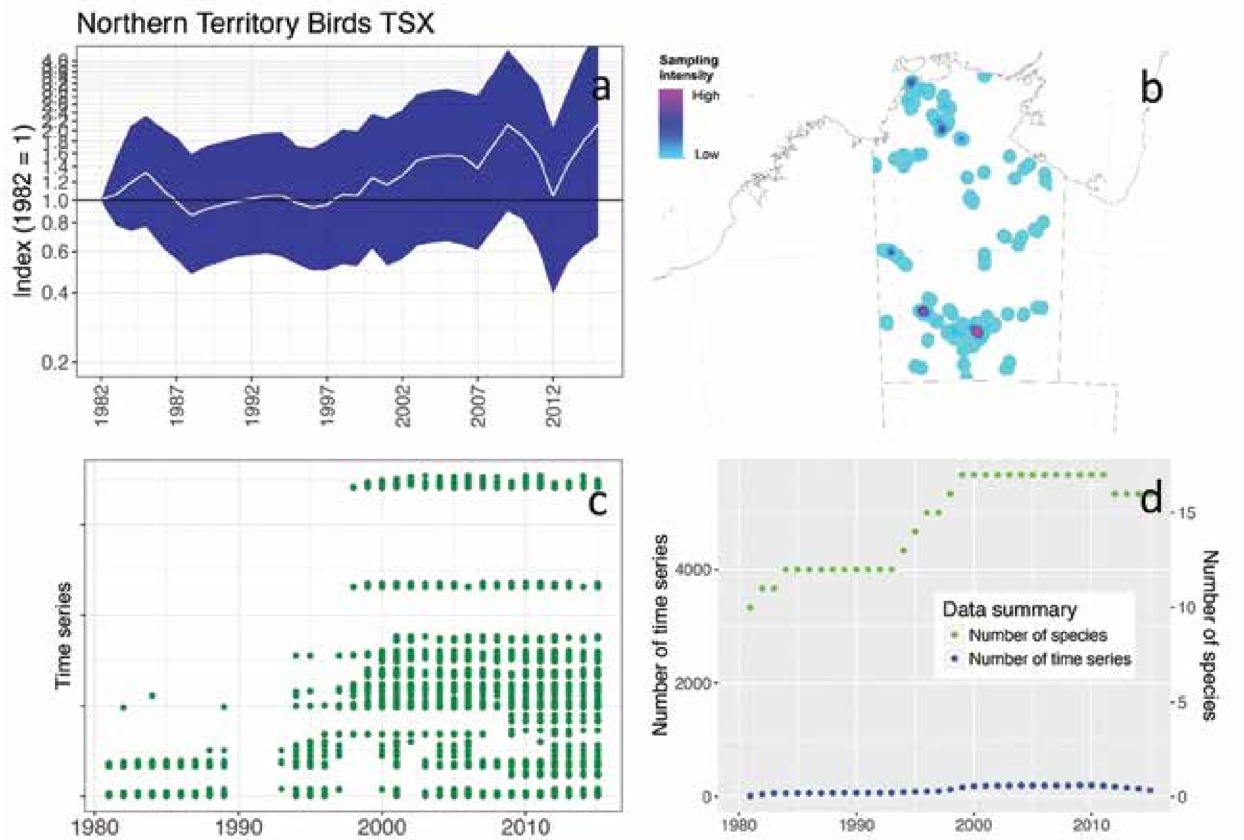


Figure 13: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in the Northern Territory (NT). Panels indicate a) a TSX for birds monitored in NT with a base year set at 1982 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 10: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in the Northern Territory. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 22.2 ± 8.6
Number of samples (years) per time series (mean ± SD): 12.4 ± 5.9
Number of data sources in Index: 4
Number of taxa in Index: 17

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index							
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	7	29.43
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	7	28.29
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	8	30.00
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	8	29.38
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	8	29.38
Grey Plover	Shoreline (migratory)		Near threatened		2	8	29.38
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	8	30.00
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	7	30.29
Red-necked Stint	Shoreline (migratory)		Near threatened		2	9	29.22
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	8	30.00
Grey Falcon	Terrestrial		Vulnerable		2	65	18.37
Red Goshawk	Terrestrial		Near threatened	Vulnerable	2	18	21.56
Princess Parrot	Terrestrial	Arid Woodland/ shrubland	Near threatened	Vulnerable	2	6	18.17
Eastern Partridge Pigeon	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	1	4	20.50
Eastern Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	Near threatened		1	5	13.60
Gouldian Finch	Terrestrial	Tropical savanna woodland	Near threatened	Endangered	2	28	15.00
Western Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	Endangered	Endangered	2	7	16.71

2.5.3 Queensland

Bird taxa monitored in Queensland (QLD) resulted in an index based on 4,416 time series (37.0% of all records used for analyses) for 30 taxa (representing 12.7% of all Australian threatened/Near Threatened birds) from 11 data sources with a time-series length of 17.5 $\pm$ 6.6 (mean $\pm$ SD) and 12.4 $\pm$ 6.1 (mean $\pm$ SD) sample years per time series (Figure 14c) - see Table 11 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. The trend shows a decrease of 11.7% (Figure 14a) compared to the baseline in 1980 with an overall slope of -0.008 (0.8% decrease in index value per year). Between 1980 and 1995 Queensland shows an inverse trend to the decreases indicated by the overall Australian TSX (section 2.2). The Index value in 2015 is 0.883 with 95% confidence intervals between 0.392 and 1.650. Spatial representativeness of the index across east coast and far inland arid habitats of QLD is very high, and the index has low representativeness across central QLD Mulga, Mitchell Grass Down habitats, and the Gulf of Carpentaria due to low sampling intensity there (Figure 14b).

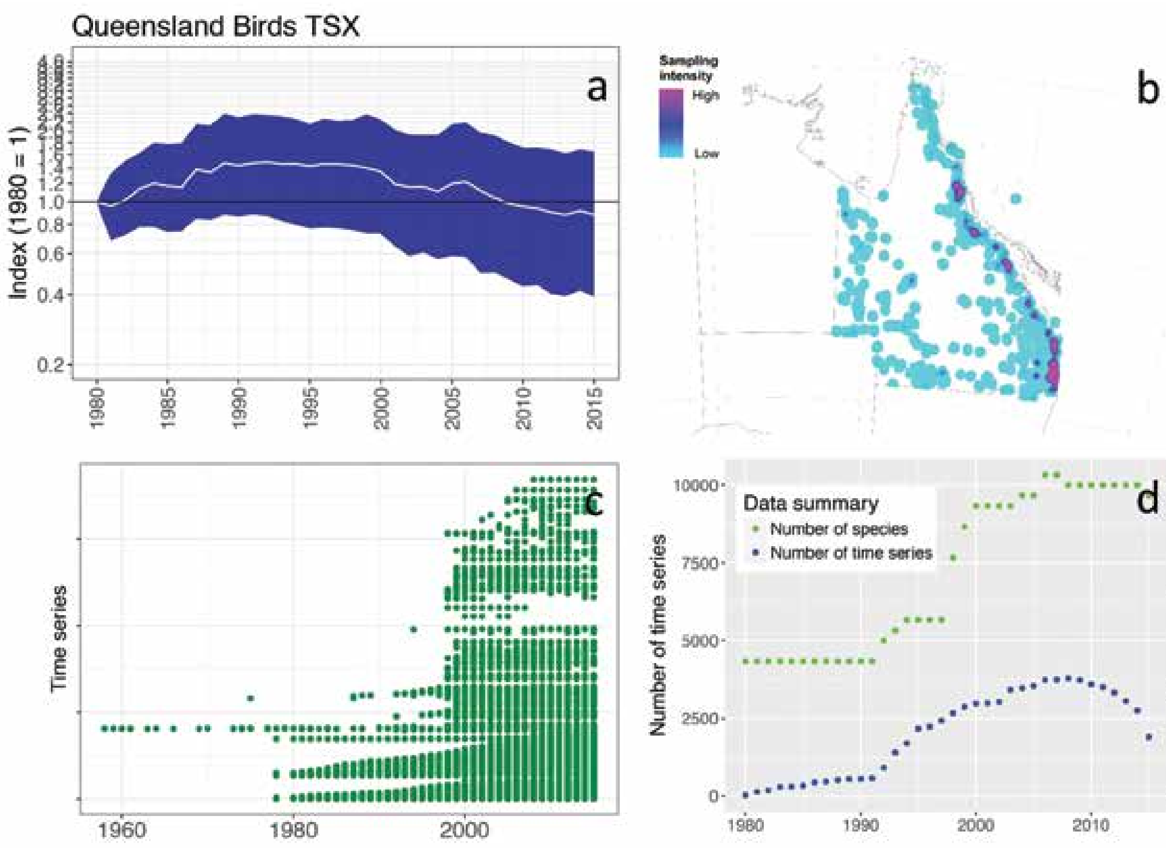


Figure 14: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in Queensland (QLD). Panels indicate a) a TSX for birds monitored in QLD with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 11: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in Queensland. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 17.5 ± 6.6
Number of samples (years) per time series (mean ± SD): 12.4 ± 6.1
Number of data sources in Index: 11
Number of taxa in Index: 30

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index							
Indian Ocean Red-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Near threatened		3	2	13.0
Asian Dowitcher	Shoreline (migratory)		Near threatened		2	25	22.2
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	264	18.2
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	446	17.3
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	597	16.9
Great Knot	Shoreline (migratory)		Vulnerable	Critically Endangered	2	463	17.9
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	337	17.6
Grey Plover	Shoreline (migratory)		Near threatened		2	246	18.1
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	414	17.2
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	283	18.7
Red-necked Stint	Shoreline (migratory)		Near threatened		2	514	17.1
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	375	17.7
Capricorn Yellow Chat	Terrestrial		Endangered	Critically Endangered	1	12	9.8
Eastern Major Mitchell's Cockatoo	Terrestrial		Near threatened		1	28	14.7
Grey Falcon	Terrestrial		Vulnerable		2	76	17.5
Letter-winged Kite	Terrestrial		Near threatened		2	9	15.9
Northern Eastern Bristlebird	Terrestrial		Critically Endangered		1	2	7.5
Red Goshawk	Terrestrial		Near threatened	Vulnerable	2	22	26.4
Painted Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	2	15	14.8
South-eastern Black-chinned Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	31	14.4
South-eastern Brown Treecreeper	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	15	13.3
South-eastern Hooded Robin	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		1	4	13.5
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	166	19.2
Southern Squatter Pigeon	Terrestrial	Dry sclerophyll woodland/forest	Least concern	Vulnerable	1	29	12.1
Northern Rufous Scrub-bird	Terrestrial	Rainforest	Endangered		2	9	11.0
Eastern Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	Near threatened		1	8	17.3
Fawn-breasted Bowerbird	Terrestrial	Tropical savanna woodland	Near threatened		1	5	16.2
Gouldian Finch	Terrestrial	Tropical savanna woodland	Near threatened	Endangered	2	3	15.0
Northern Masked Owl	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	1	3	19.0
Southern Black-throated Finch	Terrestrial	Tropical savanna woodland	Vulnerable	Endangered	1	6	8.7
Australasian Bittern	Wetland		Endangered	Endangered	2	7	12.3

2.5.4 South Australia

Bird taxa monitored in South Australia (SA) resulted in an index based on 953 time series (8.1% of all records used for analyses) for 28 taxa (representing 11.9% of all Australian threatened/Near Threatened birds) from seven data sources with a time-series length of 21.5 ± 10.7 years (mean ± SD) and 11.5 ± 5.9 (mean ± SD) sample years per time series (Figure 15c) - see Table 12 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. The trend shows a decrease of 72.5% relative to the baseline (Figure 15a) with an overall slope of -0.022 (2.2% decrease in index value per year). This decrease is 47.3% greater than the overall TSX for Australia (section 2.2). The index value in 2015 is 0.275 with 95% confidence intervals between 0.152 and 0.482 indicating a decrease of between 84.8% and 51.8% for threatened and Near Threatened birds in SA between 1980 and 2015. The index is mostly representative of southern and coastal habitats particularly those in the Eyre and Yorke Peninsulas and around Adelaide and the Mount Lofty Ranges, and has low representativeness of the northern SA arid zone excepting the north-east corner of the State near the north of Lake Eyre (Figure 15b).

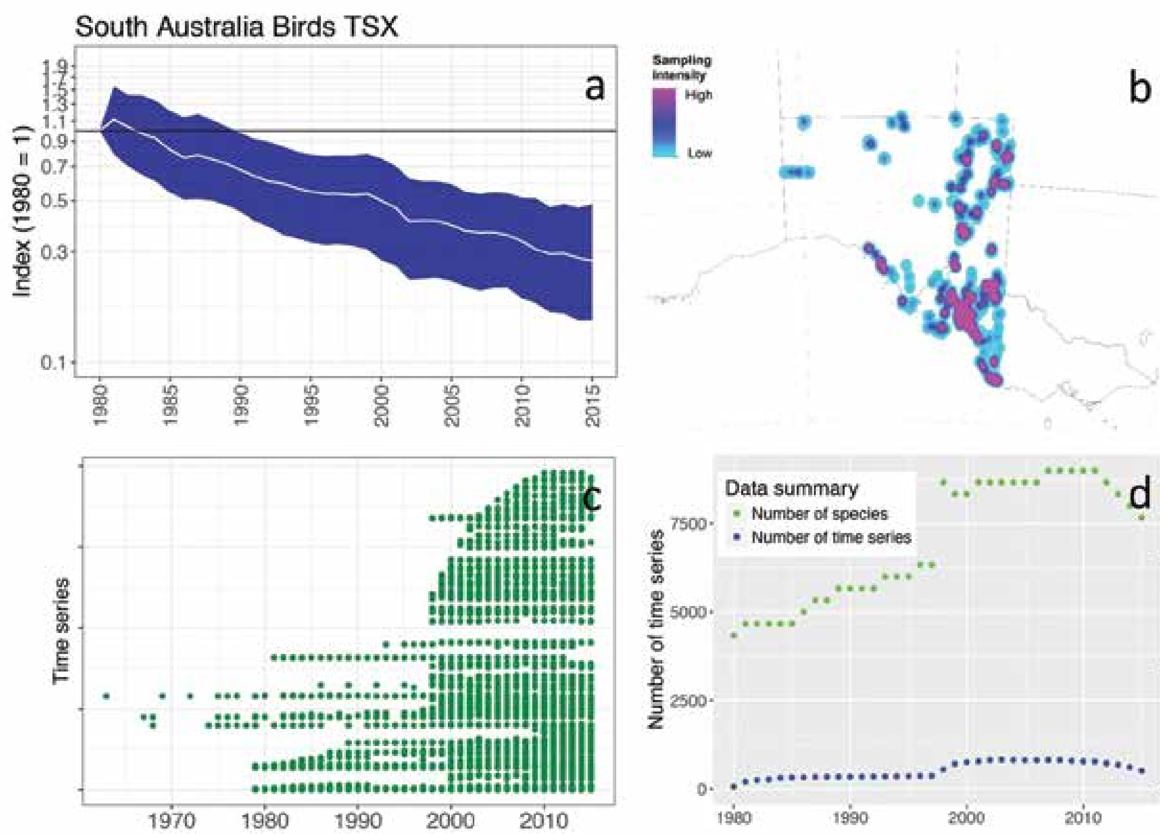


Figure 15: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in South Australia (SA). Panels indicate a) a TSX for birds monitored in SA with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 12: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in South Australia. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 21.5 ± 10.7
Number of samples (years) per time series (mean ± SD): 11.5 ± 5.9
Number of data sources in Index: 7
Number of taxa in Index: 28

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time series length
Taxa in Index							
Australian Fairy Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Vulnerable	Vulnerable	2	41	9.5
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	12	30.8
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	69	28.4
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	39	28.3
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	37	28.2
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	15	34.1
Grey Plover	Shoreline (migratory)		Near threatened		2	47	28.4
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	24	32.0
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	39	27.8
Red-necked Stint	Shoreline (migratory)		Near threatened		2	83	26.6
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	54	29.4
Eastern Major Mitchell's Cockatoo	Terrestrial		Near threatened		1	28	16.6
Eastern Regent Parrot	Terrestrial		Endangered	Vulnerable	2	40	13.2
Flame Robin	Terrestrial		Near threatened		4	7	13.3
Fleurieu Peninsula Southern Emu-wren	Terrestrial		Endangered	Endangered	1	1	6.0
Grey Falcon	Terrestrial		Vulnerable		2	50	21.1
Letter-winged Kite	Terrestrial		Near threatened		2	26	22.9
Orange-bellied Parrot	Terrestrial		Critically Endangered	Critically Endangered	1	1	30.0
Princess Parrot	Terrestrial	Arid Woodland/ shrubland	Near threatened	Vulnerable	2	7	16.6
Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	26	14.8
South-eastern Hooded Robin	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		1	161	14.6
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	16	24.3
Mount Lofty Ranges Chestnut-rumped Heathwren	Terrestrial	Heathland	Endangered	Endangered	1	1	32.0
Kangaroo Island Glossy Black-Cockatoo	Terrestrial	Island endemic	Endangered	Endangered	1	6	18.0
Black-eared Miner	Terrestrial	Mallee woodland	Endangered	Endangered	2	70	16.8
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	28	17.1
Australasian Bittern	Wetland		Endangered	Endangered	2	20	12.8
Blue-billed Duck	Wetland		Near threatened		3	5	7.4

2.5.5 Tasmania

Bird taxa monitored in Tasmania (TAS) resulted in an index based on 478 time series (4.1% of all records used for analyses) for 21 taxa (representing 8.9% of all Australian threatened/Near Threatened birds) from six data sources with a time-series length of 21.7 ± 9.5 years (mean ± SD) and 15.2 ± 9.2 (mean ± SD) sample years per time series (Figure 16c) - see Table 13 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. Little data were available for threatened terrestrial birds in Tasmania. Only two terrestrial species were available. These two terrestrial taxa for which data were available, i.e. Tasmanian Wedge-tailed Eagle and Flame Robin (sourced from Birdata) are widespread and confound the sampling intensity in Figure 14b to appear larger. The Tasmanian TSX is largely representative of migratory shoreline and marine species constituting 19 of the 21 taxa in total. The trend shows a decrease of 27.7% relative to the baseline 1980 (Figure 16a) with an overall slope of -0.008 (0.8% decrease in index value per year). This decrease is of the same magnitude (2.5% more) like the overall TSX for Australia (section 2.2). The index value in 2015 is 0.723 with 95% confidence intervals between 0.406 and 1.238. The high variance in the trends of TAS birds results in uncertainty in whether overall TAS birds were on an increasing or decreasing trajectory between 1980 and 2015. The index is mostly representative of southern and central habitats, and has low representativeness of the northern TAS habitats (Figure 16b). Further data on threatened and Near Threatened taxa are needed to improve the representativeness of the Tasmanian TSX.

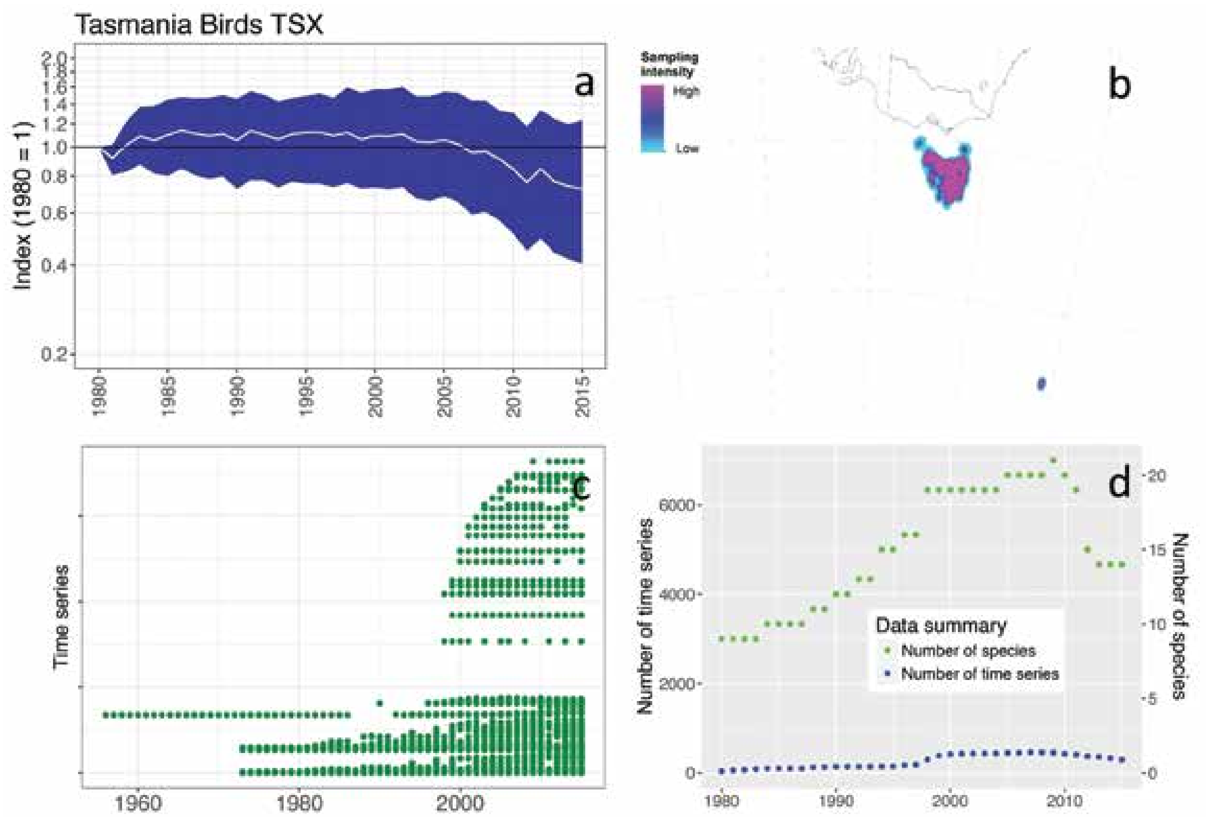


Figure 16: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in Tasmania (TAS). Panels indicate a) a TSX for birds monitored in TAS with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year. Note that the inland sampling intensity in b) is mainly due to the widespread terrestrial taxa Tasmanian Wedge-tailed Eagle and Flame Robin.

Table 13: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in Tasmania. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 21.7 ± 9.5
Number of samples (years) per time series (mean ± SD): 15.2 ± 9.2
Number of data sources in Index: 6
Number of taxa in Index: 21

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time series length
Taxa in Index							
Black-browed Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Vulnerable	2	1	18.0
Grey-headed Albatross	Marine	Albatrosses and Giant-Petrels	Critically Endangered	Endangered	1	1	18.0
Light-mantled Sooty Albatross	Marine	Albatrosses and Giant-Petrels	Near threatened		1	7	7.0
Northern Giant-Petrel	Marine	Albatrosses and Giant-Petrels	Least concern	Vulnerable	1	17	14.0
Shy Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	2	3	12.3
Southern Giant-Petrel	Marine	Albatrosses and Giant-Petrels	Least concern	Endangered	1	1	17.0
Wandering Albatross	Marine	Albatrosses and Giant-Petrels	Critically Endangered	Vulnerable	1	1	55.0
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	1	43.0
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	26	30.0
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	29	30.9
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	7	23.7
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	2	18.5
Grey Plover	Shoreline (migratory)		Near threatened		2	11	29.7
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	15	32.0
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	19	31.6
Red-necked Stint	Shoreline (migratory)		Near threatened		2	40	28.9
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	26	26.3
Flame Robin	Terrestrial		Near threatened		4	60	14.2
Tasmanian Wedge-tailed Eagle	Terrestrial		Vulnerable	Endangered	1	207	18.6
Australasian Bittern	Wetland		Endangered	Endangered	2	3	18.3
Blue-billed Duck	Wetland		Near threatened		3	1	8.0

2.5.6 Victoria

Bird taxa monitored in Victoria (VIC) resulted in an index based on 2,158 time series (18.3% of all records used for analyses) on 31 taxa (representing 13.1% of all Australian threatened/Near Threatened birds) from 14 data sources with a time-series length of 18.6 ± 10.9 years (mean ± SD) and 12.9 ± 9.5 (mean ± SD) sample years per time series (Figure 17c) - see Table 14 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. The trend shows a decrease of 36.0% relative to the baseline in 1980 (Figure 17a) with an overall slope of -0.010 (1.0% decrease in index value per year). This decrease is 10.8% greater than the overall TSX for Australia (section 2.2). The index value in 2015 is 0.640 with 95% confidence intervals between 0.398 and 0.994 indicating a decrease of between 60.2% and 0.6% for threatened and Near Threatened birds in VIC between 1980 and 2015. The index is representative of most VIC habitats excepting the Victorian Alps, Highlands and East Gippsland Uplands (Figure 17b).

Image: Regent honeyeater. Photo: Derek Keats Wikimedia Commons CC BY 2.0

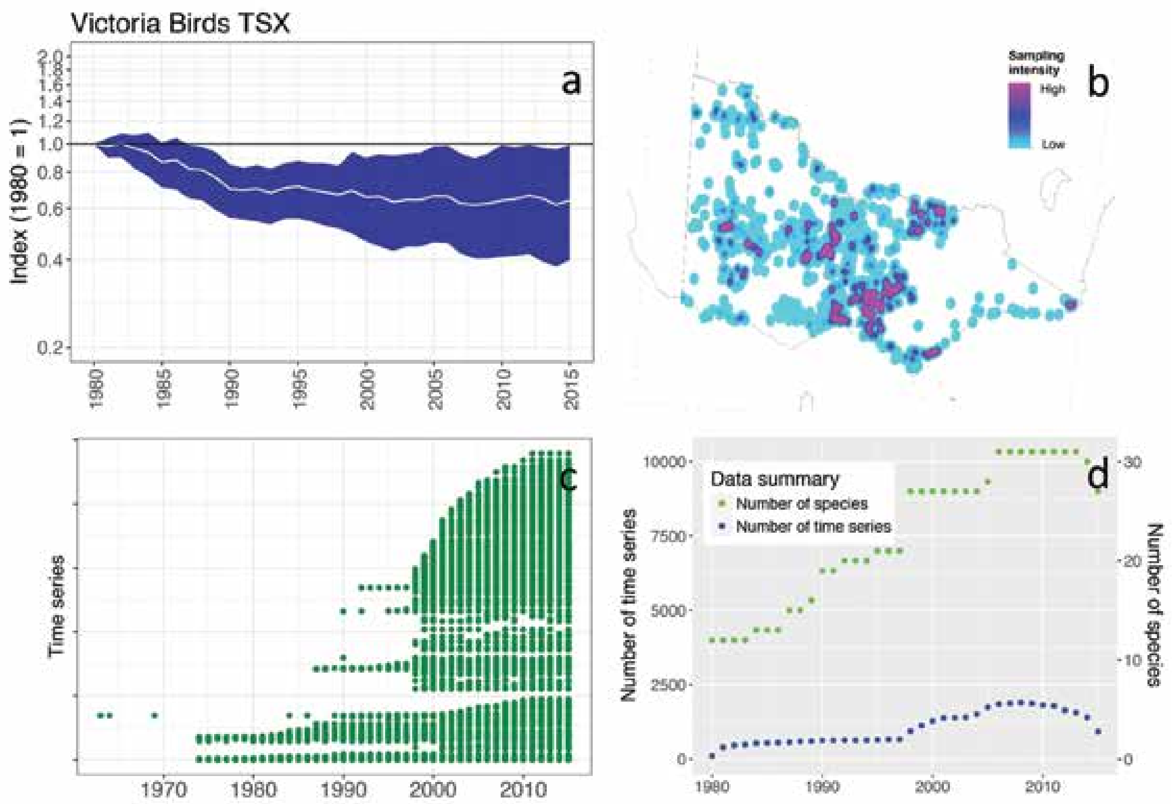


Figure 17: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in Victoria (VIC). Panels indicate a) a TSX for birds monitored in VIC with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 14: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in Victoria. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 18.6 ± 10.9
Number of samples (years) per time series (mean ± SD): 12.9 ± 9.5
Number of data sources in Index: 14
Number of taxa in Index: 31

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index							
Australian Fairy Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Vulnerable	Vulnerable	2	1	41.00
Black-tailed Godwit	Shoreline (migratory)		Near Threatened		2	29	30.76
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	132	29.80
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	82	31.10
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	38	30.26
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	19	32.58
Grey Plover	Shoreline (migratory)		Near Threatened		2	40	32.78
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	36	34.14
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	53	33.25
Red-necked Stint	Shoreline (migratory)		Near Threatened		2	173	28.15
Ruddy Turnstone	Shoreline (migratory)		Near Threatened		2	50	31.96
Eastern Hooded Plover	Shoreline (resident)		Vulnerable	Vulnerable	1	32	28.44
Eastern Major Mitchell's Cockatoo	Terrestrial		Near Threatened		1	18	13.61
Eastern Regent Parrot	Terrestrial		Endangered	Vulnerable	2	21	13.81
Flame Robin	Terrestrial		Near Threatened		4	412	12.88
Helmeted Honeyeater	Terrestrial		Critically Endangered	Critically Endangered	1	1	27.00
Orange-bellied Parrot	Terrestrial		Critically Endangered	Critically Endangered	1	6	24.50
Painted Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	2	32	13.16
South-eastern Black-chinned Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Near Threatened		2	189	12.59
South-eastern Brown Treecreeper	Terrestrial	Dry sclerophyll woodland/forest	Near Threatened		2	322	11.94
South-eastern Hooded Robin	Terrestrial	Dry sclerophyll woodland/forest	Near Threatened		1	139	12.20
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	Near Threatened		2	69	23.26
Superb Parrot	Terrestrial	Dry sclerophyll woodland/forest	Least Concern	Vulnerable	1	3	16.33
Swift Parrot	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	67	8.81
Southern Eastern Bristlebird	Terrestrial	Heathland	Endangered		2	11	15.45
Black-eared Miner	Terrestrial	Mallee woodland	Endangered	Endangered	2	9	10.00
Mallee Emu-wren	Terrestrial	Mallee woodland	Endangered	Endangered	1	25	10.00
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	46	20.20
Red-lored Whistler	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	1	40	9.98
Australasian Bittern	Wetland		Endangered	Endangered	2	22	15.41
Blue-billed Duck	Wetland		Near Threatened		3	41	10.15

2.5.7 Western Australia

Bird taxa monitored in Western Australia (WA) resulted in an index based on 1,066 time series (9.1% of all records used for analyses) on 25 taxa (representing 10.6% of all Australian threatened/Near Threatened birds) from eight data sources with a time-series length of 17.0 ± 10.0 years (mean ± SD) and 10.2 ± 5.6 (mean ± SD) sample years per time series (Figure 18c) - see Table 15 for a summary of all taxa included in this index. The baseline for all state and territory indices was set to 1.0 in 1980 to allow for comparison between regions. The trend shows an increase of 20.9% relative to the baseline in 1980 (Figure 18a) with an overall slope of 0.001 (0.1% increase in index value per year). The index value in 2015 is 1.209 with 95% confidence intervals between 0.454 and 3.005 indicating high variance in trends across WA taxa between 1980 and 2015. The index is mostly representative of WA habitats near coastal urban centres and has low representativeness of inland arid and semi-arid habitats and coastal habitats far from urban areas (Figure 18b).

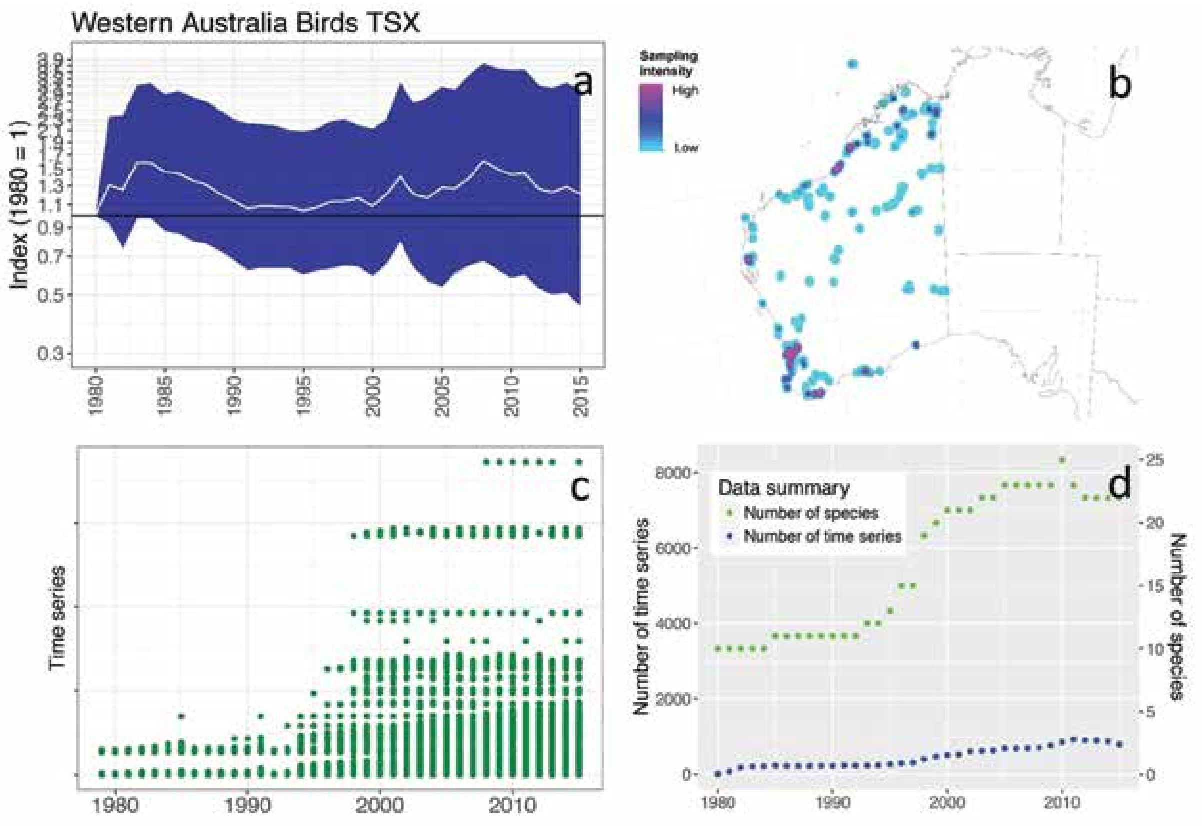


Figure 18: A Threatened Species Index (TSX) for all threatened and Near Threatened birds monitored in Western Australia (WA). Panels indicate a) a TSX for birds monitored in WA with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 15: Summary table of data used to calculate the TSX for threatened and Near Threatened birds monitored in Western Australia. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time series length (mean ± SD): 17.0 ± 10.0
Number of samples (years) per time series (mean ± SD): 10.2 ± 5.6
Number of data sources in Index: 8
Number of taxa in Index: 25

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length
Taxa in Index							
Indian Ocean Red-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Near threatened		3	3	10.3
Indian Ocean White-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Endangered		1	3	9.7
Asian Dowitcher	Shoreline (migratory)		Near threatened		2	22	15.1
Black-tailed Godwit	Shoreline (migratory)		Near threatened		2	50	18.6
Curlew Sandpiper	Shoreline (migratory)		Critically endangered	Critically Endangered	2	101	20.5
Eastern Curlew	Shoreline (migratory)		Critically endangered	Critically Endangered	2	59	17.9
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	75	18.8
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	71	18.1
Grey Plover	Shoreline (migratory)		Near threatened		2	90	19.6
Lesser Sand Plover	Shoreline (migratory)		Endangered	Endangered	2	49	18.9
Red Knot	Shoreline (migratory)		Endangered	Endangered	2	63	20.1
Red-necked Stint	Shoreline (migratory)		Near threatened		2	149	19.0
Ruddy Turnstone	Shoreline (migratory)		Near threatened		2	61	18.4
Grey Falcon	Terrestrial		Vulnerable		2	42	17.2
Red Goshawk	Terrestrial		Near threatened	Vulnerable	2	7	19.0
Princess Parrot	Terrestrial	Arid Woodland/ shrubland	Near threatened	Vulnerable	2	14	13.6
Baudin's Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Vulnerable	1	28	7.1
Carnaby's Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Endangered	1	111	7.2
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	Near threatened		2	15	19.3
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	12	14.3
Gouldian Finch	Terrestrial	Tropical savanna woodland	Near threatened	Endangered	2	13	16.8
Northern Masked Owl	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	1	1	14.0
Western Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	Endangered	Endangered	2	15	12.5
Australasian Bittern	Wetland		Endangered	Endangered	2	2	11.5
Blue-billed Duck	Wetland		Near threatened		3	10	8.0

2.6 Conservation Status

2.6.1 Near Threatened Taxa

The subset of bird taxa listed as Near Threatened on the list of BirdLife Australia/Threatened Species Committee resulted in an index based on 5,673 time series (48.2% of all records used for analyses) on 20 taxa (out of 54 in total) from 15 data sources with a time-series length of 17.4 ± 8.5 years (mean ± SD) and 11.6 ± 6.7 (mean ± SD) sample years per time series (Figure 19c) - see Table 16 for a summary of all taxa included in this index. The baseline was set to 1.0 in 1980 due to data availability and to allow for comparison between indices. The trend shows a decrease of 28.4% (Figure 19a) relative to the baseline in 1980 with an overall slope of -0.001 (0.1% decrease in index value per year). The index therefore shows a similar decrease (3.2% more) than the overall Australian TSX (section 2.2). The index value in 2015 is 0.716 with 95% confidence intervals between 0.270 and 1.472 indicating a decrease of between 73.0% and an increase of 47.2% for Near Threatened birds in Australia between 1980 and 2015 suggesting a high variability within the data available. Since 2000, the index appears relatively stable throughout time. The index has good representativeness of Near Threatened birds in south-eastern regions of Australia but low representativeness of birds in inland NT, WA and SA (Figure 19b).

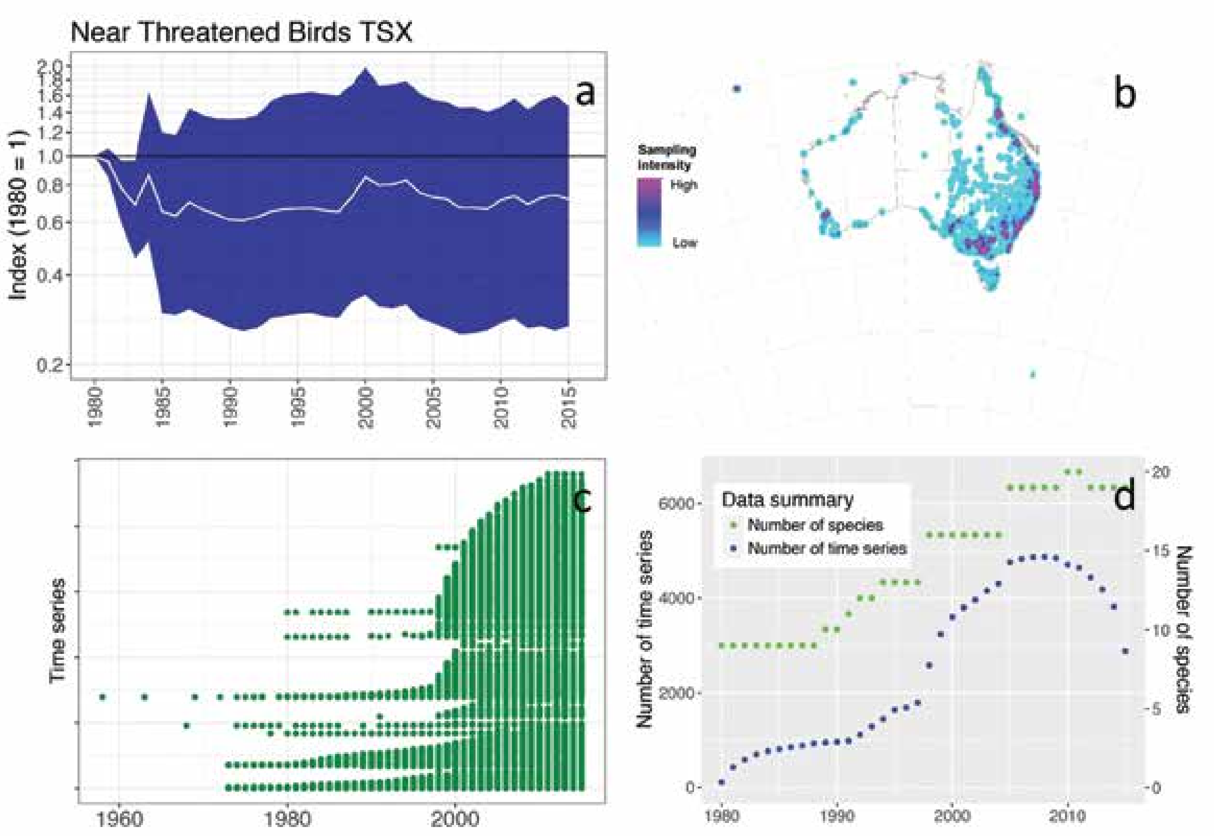


Figure 19: A Threatened Species Index (TSX) for Near Threatened birds. Panels indicate a) a TSX for Near Threatened birds (listed on BirdLife Australia/Threatened Species Committee list from 2016) with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Photo of Light-mantled Sooty Albatross kindly provided by G. Ehmke, BirdLife Australia.

Table 16: Summary table of data used to calculate the TSX for Near Threatened birds as per BirdLife Australia/Threatened Species Committee list from 2016. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 17.4 ± 8.5
Number of samples (years) per time series (mean ± SD): 11.6 ± 6.7
Number of data sources in Index: 15
Number of taxa in Index: 20

Taxon name	Functional group	Functional sub-group	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in index						
Light-mantled Sooty Albatross	Marine	Albatrosses and Giant-Petrels	1	7	7.0	
Indian Ocean Red-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	3	5	11.4	
Asian Dowitcher	Shoreline (migratory)		2	47	18.9	14.5
Black-tailed Godwit	Shoreline (migratory)		2	404	20.5	13.0
Grey Plover	Shoreline (migratory)		2	475	21.7	15.6
Red-necked Stint	Shoreline (migratory)		2	1048	21.1	13.9
Ruddy Turnstone	Shoreline (migratory)		2	633	21.2	14.3
Eastern Major Mitchell's Cockatoo	Terrestrial		1	126	14.6	26.7
Flame Robin	Terrestrial		4	671	13.1	24.1
Letter-winged Kite	Terrestrial		2	35	21.1	76.7
South-eastern Black-chinned Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	2	370	13.9	7.9
South-eastern Brown Treecreeper	Terrestrial	Dry sclerophyll woodland/forest	2	692	13.1	17.8
South-eastern Hooded Robin	Terrestrial	Dry sclerophyll woodland/forest	1	419	13.4	21.0
Southern Barking Owl	Terrestrial	Dry sclerophyll woodland/forest	2	424	20.8	30.0
Christmas Island Imperial-Pigeon	Terrestrial	Island endemic	1	115	11.0	42.7
Christmas Island White-eye	Terrestrial	Island endemic	1	115	11.0	42.7
Albert's Lyrebird	Terrestrial	Rainforest	1	12	6.0	0.2
Eastern Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	1	13	15.8	21.4
Fawn-breasted Bowerbird	Terrestrial	Tropical savanna woodland	1	5	16.2	10.7
Blue-billed Duck	Wetland		3	57	9.5	11.8
Taxa not in index						
Southern Buller's Albatross	Marine	Albatrosses and Giant-Petrels	0	0	0	
Macaroni Penguin	Marine	Penguins	0	0	0	
Royal Penguin	Marine	Penguins	0	0	0	
Subantarctic Gentoo Penguin	Marine	Penguins	0	0	0	
Flesh-footed Shearwater	Marine	Petrels and Shearwaters	0	0	0	
Mottled Petrel	Marine	Petrels and Shearwaters	0	0	0	
New Caledonian Tahiti Petrel	Marine	Petrels and Shearwaters	0	0	0	
Pacific Tahiti Petrel	Marine	Petrels and Shearwaters	0	0	0	
Sooty Shearwater	Marine	Petrels and Shearwaters	0	0	0	
Tasman Booby	Marine	Tropicbirds Frigatebirds Gannets Boobies	0	0	0	
Eastern Grey Plover	Shoreline (migratory)		0	0	0	
Eastern Siberian Black-tailed Godwit	Shoreline (migratory)		0	0	0	
Eastern Siberian Whimbrel	Shoreline (migratory)		0	0	0	
Palaearctic Ruddy Turnstone	Shoreline (migratory)		0	0	0	
Chestnut-breasted Whiteface	Terrestrial		0	0	0	
Papuan Barking Owl	Terrestrial		0	0	0	
Papuan Brown Goshawk	Terrestrial		0	0	0	
Singing Starling	Terrestrial		0	0	0	
South-eastern Glossy Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	0	0	0	
Black Grasswren	Terrestrial	Grassland	0	0	0	
Cape York Star Finch	Terrestrial	Grassland	0	0	0	
Lake Frome Thick-billed Grasswren	Terrestrial	Grassland	0	0	0	
Mainland Ground Parrot	Terrestrial	Heathland	0	0	0	
Christmas Island Glossy Swiftlet	Terrestrial	Island endemic	0	0	0	
Kangaroo Island Western Whipbird	Terrestrial	Island endemic	0	0	0	
King Island Yellow Wattlebird	Terrestrial	Island endemic	0	0	0	
Lord Howe Golden Whistler	Terrestrial	Island endemic	0	0	0	
Lord Howe Silvereye	Terrestrial	Island endemic	0	0	0	
Norfolk Island Gerygone	Terrestrial	Island endemic	0	0	0	
Norfolk Island Grey Fantail	Terrestrial	Island endemic	0	0	0	
Norfolk Island Sacred Kingfisher	Terrestrial	Island endemic	0	0	0	
Slender-billed White-eye	Terrestrial	Island endemic	0	0	0	
Cape York Eclectus Parrot	Terrestrial	Rainforest	0	0	0	
Stokes Range White-quilled Rock-Pigeon	Terrestrial	Tropical savanna woodland	0	0	0	

2.6.2 Vulnerable Taxa

The subset of bird taxa listed as Vulnerable on the list of BirdLife Australia/Threatened Species Committee and/or EPBC Act resulted in an index based on 1,344 time series (11.4% of all records used for analyses) on 15 taxa (out of 67 in total) from 14 data sources with a time-series length of 17.4 $\pm$ 7.8 (mean $\pm$ SD) and 11.7 $\pm$ 6.0 (mean $\pm$ SD) sample years per time series (Figure 20c) - see Table 17 for a summary of all taxa included in this index. The baseline was set to 1.0 in 1980 due to data availability and to allow for comparison between other indices. The trend shows a decrease of 48.9% (Figure 20a) relative to the baseline in 1980 with an overall slope of -0.011 (1.1% decrease in index value per year). The index therefore shows a greater decrease of 23.7% than the overall Australian TSX (section 2.2). The index value in 2015 is 0.511 with 95% confidence intervals between 0.246 and 1.022 indicating a decrease of between 75.4% and an increase of 2.2% for Vulnerable birds between 1980 and 2015. The index has broad but patchy representativeness of Vulnerable birds across many coastal and inland habitats (Figure 20b).

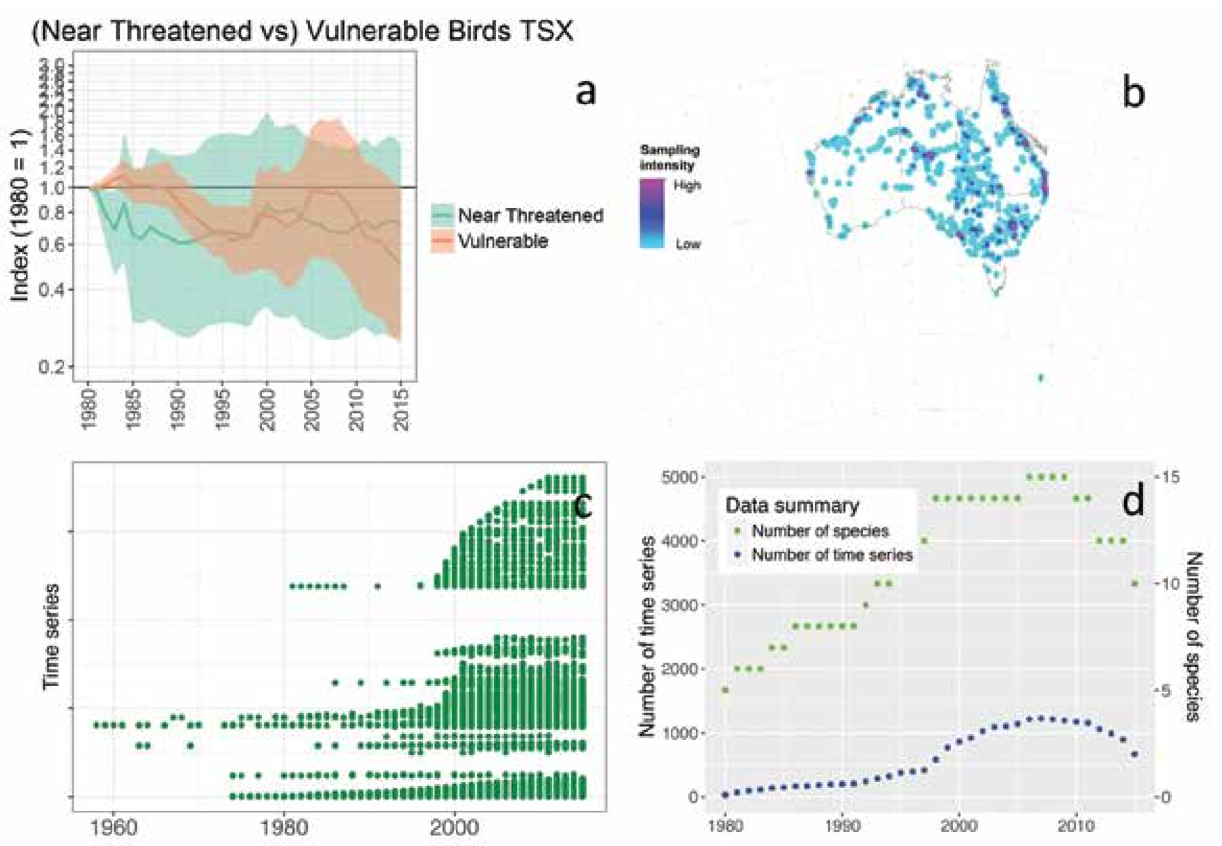


Figure 20: A Threatened Species Index (TSX) for Vulnerable birds. Panels indicate a) a TSX for Vulnerable birds (listed on BirdLife Australia/Threatened Species Committee list from 2016 or and/or EPBC Act from 2017) with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), displayed in orange versus the trend for Near Threatened birds (in green), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 17: Summary table of data used to calculate the TSX for Vulnerable birds as per BirdLife Australia/Threatened Species Committee (2016) and/or EPBC Act (2017). Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 17.4 ± 7.8
Number of samples (years) per time series (mean ± SD): 11.7 ± 6.0
Number of data sources in Index: 14
Number of taxa in Index: 15

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in index								
Northern Giant-Petrel	Marine	Albatrosses and Giant-Petrels	Least concern	Vulnerable	1	17	14.0	
Shy Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	2	3	12.3	
Australian Fairy Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Vulnerable	Vulnerable	2	42	10.3	7.7
Greater Sand Plover	Shoreline (migratory)		Vulnerable	Vulnerable	2	480	19.5	13.1
Eastern Hooded Plover	Shoreline (resident)		Vulnerable	Vulnerable	1	32	28.4	8.9
Grey Falcon	Terrestrial		Vulnerable		2	250	18.6	56.3
Red Goshawk	Terrestrial		Near threatened	Vulnerable	2	47	23.4	22.1
Princess Parrot	Terrestrial	Arid Woodland/ shrubland	Near threatened	Vulnerable	2	27	15.4	8.9
Painted Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	2	94	13.8	26.0
Southern Squatter Pigeon	Terrestrial	Dry sclerophyll woodland/forest	Least concern	Vulnerable	1	29	12.1	29.6
Superb Parrot	Terrestrial	Dry sclerophyll woodland/forest	Least concern	Vulnerable	1	185	12.9	19.9
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	90	18.0	6.6
Red-lored Whistler	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	1	40	10.0	4.7
Eastern Partridge Pigeon	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	1	4	20.5	4.3
Northern Masked Owl	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	1	4	17.8	17.3
Taxa not in index								
Heard Island Black-faced Sheathbill	Marine		Vulnerable		0	0	0	
Heard Island Imperial Shag	Marine		Near threatened	Vulnerable	0	0	0	
Macquarie Island Imperial Shag	Marine		Vulnerable	Vulnerable	0	0	0	
Campbell Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	0	0	0	
Northern Buller's Albatross	Marine	Albatrosses and Giant-Petrels	Near threatened	Vulnerable	0	0	0	
Salvin's Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	0	0	0	
Southern Royal Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	0	0	0	
White-capped Albatross	Marine	Albatrosses and Giant-Petrels	Vulnerable	Vulnerable	0	0	0	
Eastern Rockhopper Penguin	Marine	Penguins	Vulnerable		0	0	0	
Black Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Buller's Shearwater	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Herald Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Matsudaira's Storm-Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
New Caledonian Gould's Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Providence Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
South Georgian Diving-Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Southern Common Diving-Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Southern Fulmar Prion	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Subantarctic Wilson's Storm-Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Tasman Little Shearwater	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Tasman White-bellied Storm-Petrel	Marine	Petrels and Shearwaters	Vulnerable	Vulnerable	0	0	0	
Westland Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
White-chinned Petrel	Marine	Petrels and Shearwaters	Vulnerable		0	0	0	
Mongolian Greater Sand Plover	Shoreline (migratory)		Vulnerable		0	0	0	
Mongolian Lesser Sand Plover	Shoreline (migratory)		Vulnerable		0	0	0	
Terek Sandpiper	Shoreline (migratory)		Vulnerable		0	0	0	
Western Alaskan Bar-tailed Godwit	Shoreline (migratory)		Vulnerable	Vulnerable	0	0	0	
Samphire Thornbill	Terrestrial		Vulnerable	Vulnerable	0	0	0	
Forest Red-tailed Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	0	0	0	
South Australian Bassian Thrush	Terrestrial	Dry sclerophyll woodland/forest	Vulnerable	Vulnerable	0	0	0	
Eyre Peninsula Western Grasswren	Terrestrial	Grassland	Vulnerable	Vulnerable	0	0	0	
Flinders Ranges Short-tailed Grasswren	Terrestrial	Grassland	Vulnerable	Vulnerable	0	0	0	
Flinders Ranges Thick-billed Grasswren	Terrestrial	Grassland	Vulnerable		0	0	0	
White-throated Grasswren	Terrestrial	Grassland	Vulnerable	Vulnerable	0	0	0	
Flinders Ranges Chestnut-rumped Heathwren	Terrestrial	Heathland	Vulnerable		0	0	0	
Barrow Island White-winged Fairy-wren	Terrestrial	Island endemic	Vulnerable	Vulnerable	0	0	0	
Christmas Island Hawk-Owl	Terrestrial	Island endemic	Vulnerable	Vulnerable	0	0	0	
Dirk Hartog Rufous Fieldwren	Terrestrial	Island endemic	Vulnerable		0	0	0	
Dirk Hartog Southern Emu-wren	Terrestrial	Island endemic	Vulnerable		0	0	0	
Dirk Hartog White-winged Fairy-wren	Terrestrial	Island endemic	Vulnerable	Vulnerable	0	0	0	
Dorre Rufous Fieldwren	Terrestrial	Island endemic	Vulnerable		0	0	0	
King Island Green Rosella	Terrestrial	Island endemic	Vulnerable	Vulnerable	0	0	0	
Norfolk Island Golden Whistler	Terrestrial	Island endemic	Near threatened	Vulnerable	0	0	0	
Shark Bay Variegated Fairy-wren	Terrestrial	Island endemic	Vulnerable		0	0	0	
Tiwi Horsfield's Bushlark	Terrestrial	Island endemic	Vulnerable	Vulnerable	0	0	0	
Mallee Western Whipbird	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	0	0	0	
Australian Palm Cockatoo	Terrestrial	Rainforest	Vulnerable	Vulnerable	0	0	0	
Black-breasted Button-quail	Terrestrial	Rainforest	Near threatened	Vulnerable	0	0	0	
Western Partridge Pigeon	Terrestrial	Tropical savanna woodland	Vulnerable	Vulnerable	0	0	0	
White-bellied Crimson Finch	Terrestrial	Tropical savanna woodland	Near threatened	Vulnerable	0	0	0	
Recherche Cape Barren Goose	Wetland		Vulnerable	Vulnerable	0	0	0	
Tasmanian Lewin's Rail	Wetland		Vulnerable		0	0	0	

2.6.3 Endangered Taxa

The subset of bird taxa listed as Endangered on the list of BirdLife Australia/Threatened Species Committee and/or EPBC Act resulted in an index based on 2,123 time series (18.0% of all records used for analyses) on 24 taxa from 14 data sources with a time-series length of 17.4 ± 8.8 years (mean ± SD) and 11.9 ± 7.4 (mean ± SD) sample years per time series (Figure 21c) - see Table 18 for a summary of all taxa included in this index. The baseline was set to 1.0 in 1980 due to data availability and to allow for comparison between other indices. The trend shows an increase of 55.7% (Figure 21a) relative to the baseline in 1980 with an overall slope of 0.022 (2.2% increase in index value per year). The index therefore shows an opposite trend compared with the decrease indicated in the overall Australian TSX (section 2.2). The index value in 2015 is 1.557 with 95% confidence intervals between 0.812 and 2.714 indicating a large uncertainty around the trend for endangered Australian bird taxa between 1980 and 2015. The trend appears relatively stable since 2005 throughout time. The index is mostly representative of Endangered birds inhabiting coastal and peri-urban habitats and has low representativeness of birds in many inland habitats (Figure 21b).

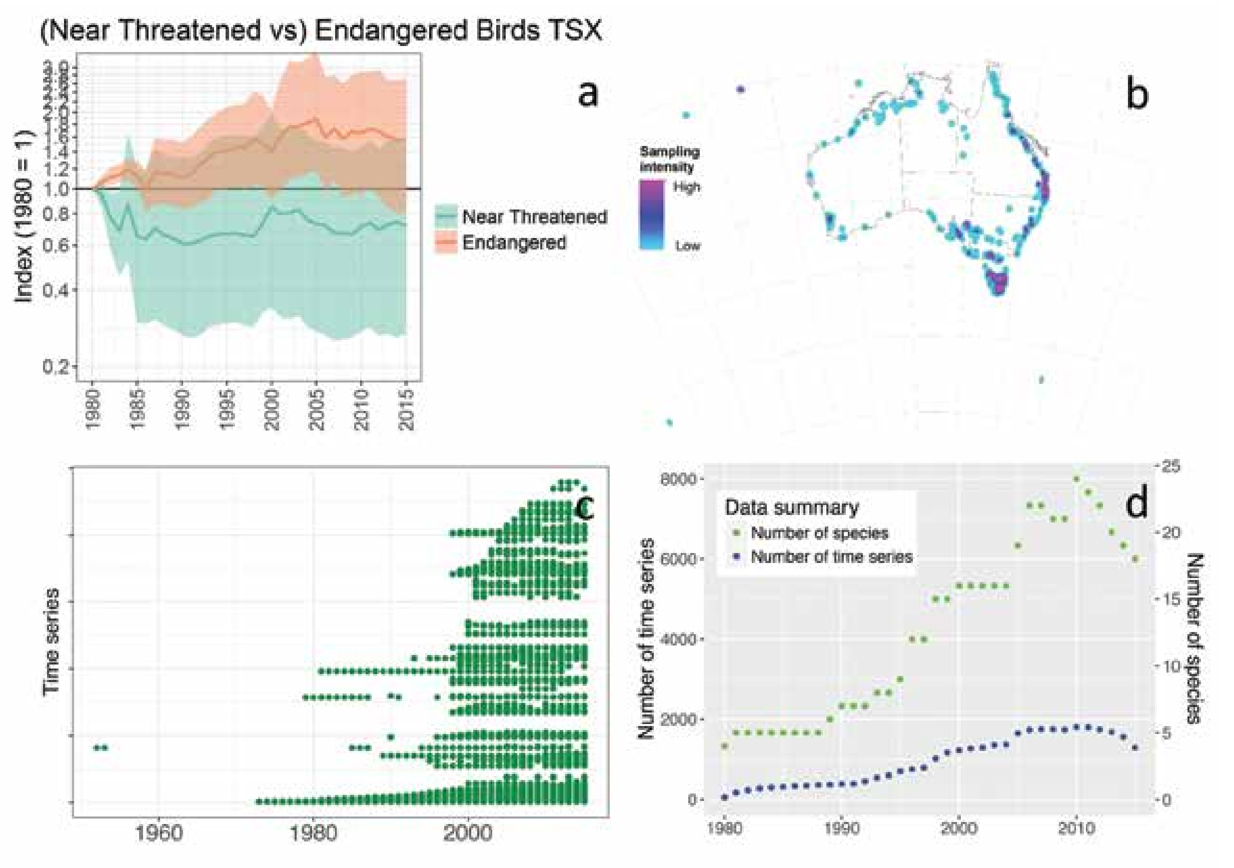


Figure 21: A Threatened Species Index (TSX) for Endangered birds. Panels indicate a) a TSX for Endangered birds (listed on BirdLife Australia/Threatened Species Committee list from 2016 or and/or EPBC Act from 2017) with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), displayed in orange versus the trend for Near Threatened birds (in green), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year. Note that the high sampling intensity for Tasmania is mainly represented by one terrestrial taxon: Tasmanian Wedge-tailed Eagle.

Table 18: Summary table of data used to calculate the TSX for Endangered birds as per BirdLife Australia/Threatened Species Committee (2016) and/or EPBC Act (2017). Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 17.4 ± 8.8
Number of samples (years) per time series (mean ± SD): 11.9 ± 7.4
Number of data sources in Index: 22
Number of taxa in Index: 24

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in Index								
Black-browed Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Vulnerable	2	2	33.5	
Southern Giant-Petrel	Marine	Albatrosses and Giant-Petrels	Least concern	Endangered	1	1	17.0	
Australian Gould's Petrel	Marine	Petrels and Shearwaters	Vulnerable	Endangered	1	2	14.0	
Indian Ocean White-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Endangered		1	3	9.7	
Eastern Regent Parrot	Terrestrial		Endangered	Vulnerable	2	62	13.5	24.3
Fleurieu Peninsula Southern Emu-wren	Terrestrial		Endangered	Endangered	1	1	6.0	9.5
Tasmanian Wedge-tailed Eagle	Terrestrial		Vulnerable	Endangered	1	207	18.6	57.8
Baudin's Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Vulnerable	1	28	7.1	2.8
Carnaby's Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Endangered	1	111	7.2	2.0
Mount Lofty Ranges Chestnut-rumped Heathwren	Terrestrial	Heathland	Endangered	Endangered	1	1	32.0	11.2
Southern Eastern Bristlebird	Terrestrial	Heathland	Endangered		2	26	15.8	10.2
Christmas Island Goshawk	Terrestrial	Island endemic	Endangered	Endangered	1	26	11.0	42.7
Christmas Island Grey-capped Emerald-Dove	Terrestrial	Island endemic	Near threatened	Endangered	1	109	11.0	
Christmas Island Thrush	Terrestrial	Island endemic	Near threatened	Endangered	1	115	11.0	42.7
Kangaroo Island Glossy Black-Cockatoo	Terrestrial	Island endemic	Endangered	Endangered	1	6	18.0	18.3
Black-eared Miner	Terrestrial	Mallee woodland	Endangered	Endangered	2	79	16.1	55.4
Mallee Emu-wren	Terrestrial	Mallee woodland	Endangered	Endangered	1	25	10.0	8.5
Northern Rufous Scrub-bird	Terrestrial	Rainforest	Endangered		2	24	8.5	1.5
Southern Rufous Scrub-bird	Terrestrial	Rainforest	Endangered		1	20	6.4	0.6
Gouldian Finch	Terrestrial	Tropical savanna woodland	Near threatened	Endangered	2	44	15.5	9.2
Southern Black-throated Finch	Terrestrial	Tropical savanna woodland	Vulnerable	Endangered	1	6	8.7	0.4
Western Purple-crowned Fairy-wren	Terrestrial	Tropical savanna woodland	Endangered	Endangered	2	22	13.9	4.8
Australasian Bittern	Wetland		Endangered	Endangered	2	91	14.1	21.4
Cocos Keeling Buff-banded Rail	Wetland		Vulnerable	Endangered	1	1	18.0	
Taxa not in Index								
Amsterdam Albatross	Marine	Albatrosses and Giant-Petrels	Vagrant	Endangered	0	0	0	
Chatham Albatross	Marine	Albatrosses and Giant-Petrels	Vagrant	Endangered	0	0	0	
Gibson's Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Vulnerable	0	0	0	
Indian Yellow-nosed Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Vulnerable	0	0	0	
Northern Royal Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Endangered	0	0	0	
Sooty Albatross	Marine	Albatrosses and Giant-Petrels	Endangered	Vulnerable	0	0	0	
Tristan Albatross	Marine	Albatrosses and Giant-Petrels	Vagrant	Endangered	0	0	0	
Houtman Abrolhos Lesser Noddy	Marine	Gulls Terns Noddies Skuas Jaegers	Endangered	Vulnerable	0	0	0	
Indian Ocean Antarctic Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Endangered	Vulnerable	0	0	0	
New Caledonian Fairy Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Endangered		0	0	0	
New Zealand Antarctic Tern	Marine	Gulls Terns Noddies Skuas Jaegers	Endangered	Endangered	0	0	0	
Antarctic Prion	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Grey Petrel	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Grey-backed Storm-Petrel	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Hutton's Shearwater	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Southern Fairy Prion	Marine	Petrels and Shearwaters	Endangered	Vulnerable	0	0	0	
Southern White-necked Petrel	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Western Kermadec Petrel	Marine	Petrels and Shearwaters	Endangered	Vulnerable	0	0	0	
White-headed Petrel	Marine	Petrels and Shearwaters	Endangered		0	0	0	
Abbott's Booby	Marine	Tropicbirds Frigatebirds Gannets Boobies	Endangered	Endangered	0	0	0	
Christmas Island White-tailed Tropicbird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Endangered	Endangered	0	0	0	
Kamchatkan Lesser Sand Plover	Shoreline (migratory)		Endangered		0	0	0	
New Siberian Islands Red Knot	Shoreline (migratory)		Endangered		0	0	0	
North-eastern Siberian Red Knot	Shoreline (migratory)		Endangered		0	0	0	
Alligator Rivers Yellow Chat	Terrestrial		Endangered	Endangered	0	0	0	
Eyre Peninsula Southern Emu-wren	Terrestrial		Endangered	Vulnerable	0	0	0	
Night Parrot	Terrestrial		Endangered	Endangered	0	0	0	
Noisy Scrub-bird	Terrestrial		Endangered	Vulnerable	0	0	0	
Tasmanian Azure Kingfisher	Terrestrial		Vulnerable	Endangered	0	0	0	
Tasmanian Masked Owl	Terrestrial		Endangered	Vulnerable	0	0	0	
Forty-spotted Pardalote	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Endangered	0	0	0	
South-eastern Red-tailed Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Endangered	0	0	0	
Bulloo Grey Grasswren	Terrestrial	Grassland	Endangered	Endangered	0	0	0	
Carpentarian Grasswren	Terrestrial	Grassland	Vulnerable	Endangered	0	0	0	
Gawler Ranges Short-tailed Grasswren	Terrestrial	Grassland	Vulnerable	Endangered	0	0	0	
Western Bristlebird	Terrestrial	Heathland	Endangered	Vulnerable	0	0	0	
Western Heath Western Whipbird	Terrestrial	Heathland	Endangered	Endangered	0	0	0	
Houtman Abrolhos Painted Button-quail	Terrestrial	Island endemic	Endangered	Vulnerable	0	0	0	
King Island Black Currawong	Terrestrial	Island endemic	Endangered	Vulnerable	0	0	0	
Lord Howe Pied Currawong	Terrestrial	Island endemic	Endangered	Vulnerable	0	0	0	
Norfolk Island Scarlet Robin	Terrestrial	Island endemic	Endangered	Vulnerable	0	0	0	
Tiwi Masked Owl	Terrestrial	Island endemic	Endangered	Endangered	0	0	0	
Australian Southern Cassowary	Terrestrial	Rainforest	Vulnerable	Endangered	0	0	0	
Coxen's Fig-Parrot	Terrestrial	Rainforest	Endangered	Endangered	0	0	0	
Buff-breasted Button-quail	Terrestrial	Tropical savanna woodland	Endangered	Endangered	0	0	0	
Golden-shouldered Parrot	Terrestrial	Tropical savanna woodland	Endangered	Endangered	0	0	0	
Australian Painted-snipe	Wetland		Endangered	Endangered	0	0	0	
Lord Howe Woodhen	Wetland		Endangered	Endangered	0	0	0	

2.6.4 Critically Endangered Taxa

The subset of bird taxa listed as Critically Endangered on the list of BirdLife Australia/Threatened Species Committee and/or EPBC Act resulted in an index based on 2,632 time series (22.4% of all records used for analyses) on 11 taxa (out of 26 in total) from nine data sources with a time-series length of 19.9 ± 9.6 years (mean ± SD) and 12.9 ± 7.7 (mean ± SD) sample years per time series (Figure 22c) - see Table 19 for summary of all taxa included in this index. The baseline was set to 1.0 in 1980 due to data availability and to allow for comparison between other indices. The trend shows a decrease of 53.1% (Figure 22a) relative to the baseline in 1980 with an overall slope of -0.019 (1.9% decrease in index value per year). The index trend shows a decrease that is double (53.1%) that of the overall Australian TSX (section 2.2). The most severe decrease in the index coincides with an increase in data informing the index (Figure 22d). The index value in 2015 is 0.469 with 95% confidence intervals between 0.269 and 0.902 indicating a decrease of between 73.1% and 9.8% for Critically Endangered birds between 1980 and 2015. The index is mostly representative of Critically Endangered birds inhabiting coastal and peri-urban habitats and has low representativeness of birds in many inland habitats (Figure 22b).

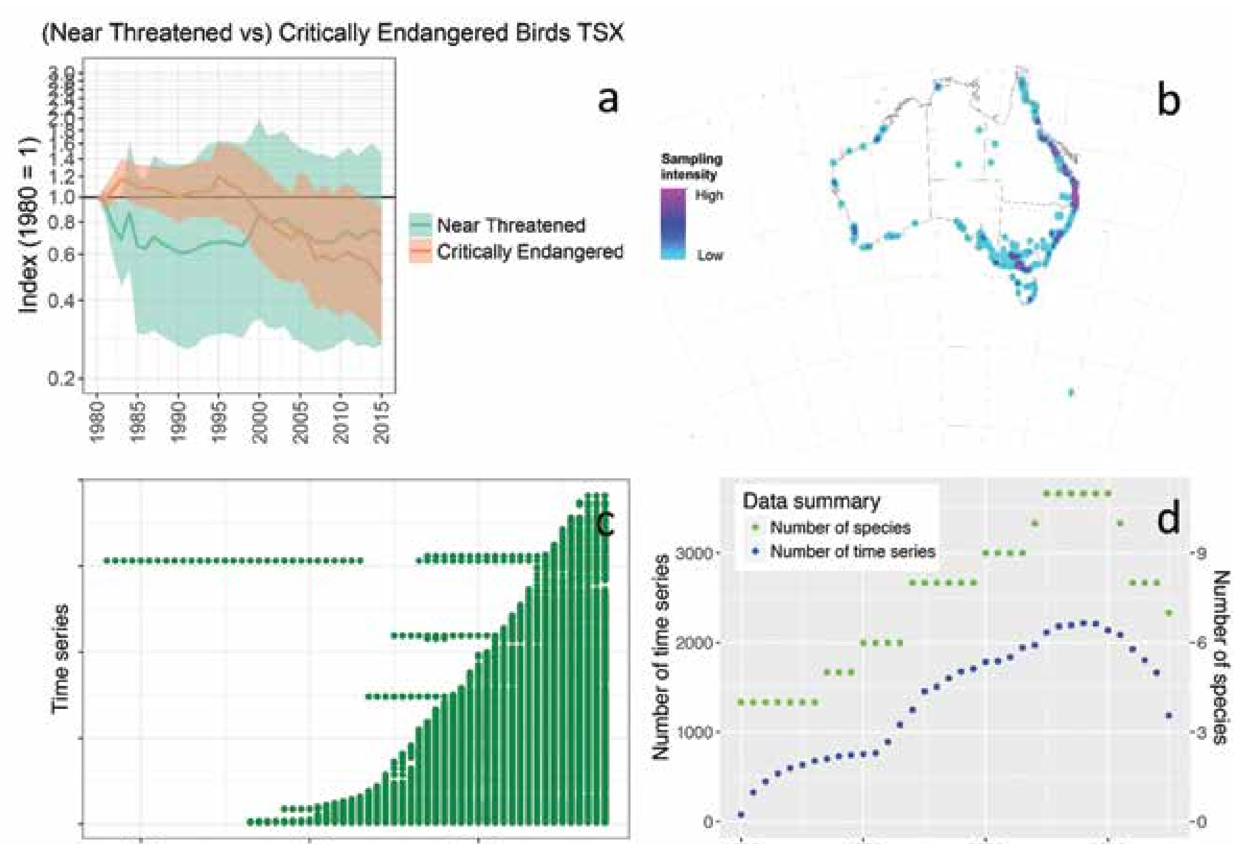


Figure 22: A Threatened Species Index (TSX) for Critically Endangered birds. Panels indicate a) a TSX for Critically Endangered birds (listed on BirdLife Australia/Threatened Species Committee list from 2016 or and/or EPBC Act from 2017) with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), displayed in orange versus the trend for Near Threatened birds (in green), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 19: Summary table of data used to calculate the TSX for Critically Endangered birds as per BirdLife Australia/ Threatened Species Committee (2016) and/or EPBC Act (2017). Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 19.9 ± 9.6
Number of samples (years) per time series (mean ± SD): 12.9 ± 7.7
Number of data sources in Index: 9
Number of taxa in Index: 11

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in index								
Grey-headed Albatross	Marine	Albatrosses and Giant-Petrels	Critically Endangered	Endangered	1	1	18.0	
Wandering Albatross	Marine	Albatrosses and Giant-Petrels	Critically Endangered	Vulnerable	1	1	55.0	
Curlew Sandpiper	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	864	21.5	12.4
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	916	19.9	11.8
Great Knot	Shoreline (migratory)		Endangered	Critically Endangered	2	677	20.1	12.4
Capricorn Yellow Chat	Terrestrial		Endangered	Critically Endangered	1	12	9.8	98.2
Helmeted Honeyeater	Terrestrial		Critically Endangered	Critically Endangered	1	1	27.0	
Northern Eastern Bristlebird	Terrestrial		Critically Endangered		1	28	11.0	10.5
Orange-bellied Parrot	Terrestrial		Critically Endangered	Critically Endangered	1	7	25.3	2.0
Regent Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	15	16.8	0.7
Swift Parrot	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	110	8.9	80.8
Taxa not in index								
Blue Petrel	Marine	Petrels and Shearwaters	Critically Endangered	Vulnerable	0	0	0	
Soft-plumaged Petrel	Marine	Petrels and Shearwaters	Critically Endangered	Vulnerable	0	0	0	
Christmas Island Frigatebird	Marine	Tropicbirds Frigatebirds Gannets Boobies	Critically Endangered	Endangered	0	0	0	
Northern Siberian Bar-tailed Godwit	Shoreline (migratory)		Endangered	Critically Endangered	0	0	0	
Grey Range Thick-billed Grasswren	Terrestrial	Grassland	Critically Endangered	Critically Endangered	0	0	0	
Plains-wanderer	Terrestrial	Grassland	Endangered	Critically Endangered	0	0	0	
Western Ground Parrot	Terrestrial	Heathland	Critically Endangered	Critically Endangered	0	0	0	
King Island Brown Thornbill	Terrestrial	Island endemic	Critically Endangered	Endangered	0	0	0	
King Island Scrubtit	Terrestrial	Island endemic	Critically Endangered	Critically Endangered	0	0	0	
Norfolk Island Boobook	Terrestrial	Island endemic	Critically Endangered	Endangered	0	0	0	
Norfolk Island Green Parrot	Terrestrial	Island endemic	Critically Endangered	Endangered	0	0	0	
Southern Star Finch	Terrestrial		Critically Endangered (Possibly Extinct)	Endangered	0	0	0	
Mt Lofty Ranges Spotted Quail-thrush	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered (Possibly Extinct)	Critically Endangered	0	0	0	
Tiwi Hooded Robin	Terrestrial	Island endemic	Critically Endangered (Possibly Extinct)	Endangered	0	0	0	
White-chested White-eye	Terrestrial		Critically Endangered (Possibly Extinct)	Extinct	0	0	0	

2.7 National Priority Species (Birds)

Data suitable for index calculation were available for 12 taxa of the 20 national priority birds targeted by the National Threatened Species Strategy. Suitable monitoring data with more than four years of sample are presently not available for the following taxa because 1) they do not exist, 2) a custodian could not be identified or 3) data were not shared by the custodian:

- Night Parrot
- Golden-shouldered Parrot
- Norfolk Island Boobook
- Norfolk Island Green Parrot
- Southern Cassowary
- Plains-wanderer
- Western Ground Parrot
- South-eastern Red-tailed Black-Cockatoo

Monitoring data for Mallee Emu-wren and Regent Honeyeater were included in the calculation, however the spread of data indicate that data may not be spatially representative of most populations for these two species.

A preliminary TSX was calculated for 12 bird taxa and 1,341 time series (11.4 % of all records used for analyses) from 14 data sources. The mean time-series length was 18.2 ± 9.3 years (mean ± SD) and the number of sample years per time series was 12.2 ± 7.3 (mean ± SD) - see Table 20 for a summary of all taxa included in this index. The baseline for 12 of the 20 national priority birds for which data were available was set to 1.0 in 1980 due availability of data and to allow for comparisons with other indices calculated. The trend shows a decrease of 40.1% relative to the baseline in 1980 (Figure 23) with an overall slope of -0.018 (1.8% decrease in index value per year). This index trend shows a decrease of 14.9% more than the overall Australian TSX (section 2.2). The index value in 2015 is 0.599 with 95% confidence intervals between 0.363 and 1.059 and large cumulative uncertainty after 2005.

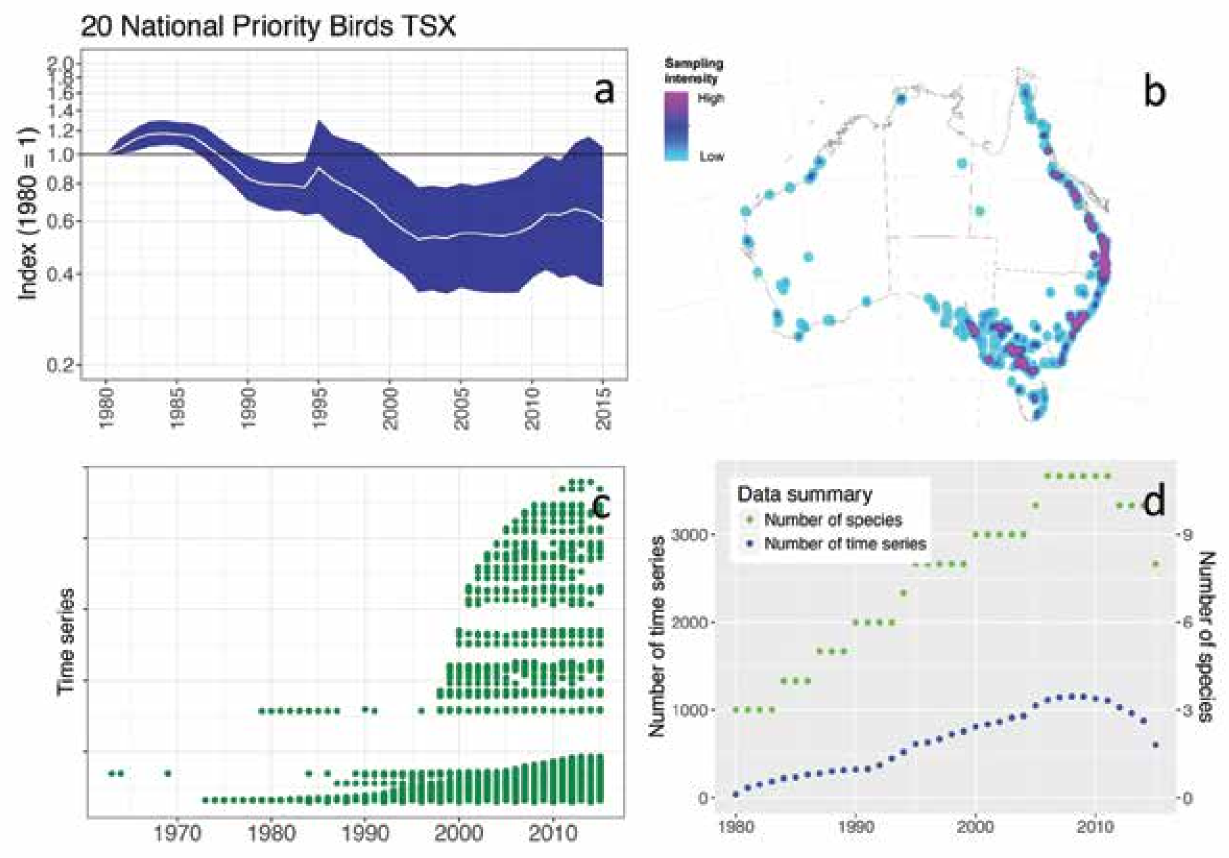


Figure 23: A Threatened Species Index (TSX) for the 20 priority birds of the National Threatened Species Strategy. Panels indicate a) a TSX for 12 taxa of the 20 priority birds with a base year set at 1980 and log-transformed vertical axis (the multi-species trend is shown in white and the 95% cumulative confidence intervals around the index value are in blue), b) spatial representation of sampling intensity of data included in the index, c) number of species population time series for sites surveyed repeatedly through time and d) a summary on the number of species (in green) and number of time series (in blue) used to calculate the index for each year.

Table 20: Summary table of data used to calculate the TSX for 12 of the 20 Priority Birds of the National Threatened Species Strategy. Scientific names for all taxa are given within the 'Index Summary Tables' folder of the electronic supplementary material.

Time-series length (mean ± SD): 18.2 ± 9.3
Number of samples (years) per time series (mean ± SD): 12.2 ± 7.3
Number of data sources in Index: 14
Number of taxa in Index: 12

Taxon name	Functional group	Functional sub-group	BirdLife Australia status	EPBC status	# data sources	# time series	Mean time-series length	Spatial representativenes
Taxa in Index								
Eastern Curlew	Shoreline (migratory)		Critically Endangered	Critically Endangered	2	916	19.9	12.2
Eastern Hooded Plover	Shoreline (resident)		Vulnerable	Vulnerable	1	32	28.4	8.9
Capricorn Yellow Chat	Terrestrial		Endangered	Critically Endangered	1	1	27.0	98.2
Helmeted Honeyeater	Terrestrial		Critically Endangered	Critically Endangered	1	28	11.0	
Northern Eastern Bristlebird	Terrestrial		Critically Endangered		1	7	25.3	10.5
Orange-bellied Parrot	Terrestrial		Critically Endangered	Critically Endangered	1	15	16.8	2.0
Regent Honeyeater	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	110	8.9	0.7
Swift Parrot	Terrestrial	Dry sclerophyll woodland/forest	Critically Endangered	Critically Endangered	1	26	15.8	80.8
Southern Eastern Bristlebird	Terrestrial	Heathland	Endangered		2	25	10.0	10.2
Mallee Emu-wren	Terrestrial	Mallee woodland	Endangered	Endangered	1	90	18.0	8.5
Malleefowl	Terrestrial	Mallee woodland	Vulnerable	Vulnerable	2	91	14.1	6.8
Australasian Bittern	Wetland		Endangered	Endangered	1	24	15.7	24.2
Taxa not in Index								
Night Parrot	Terrestrial		Endangered	Endangered	0	0	0	
Golden-shouldered Parrot	Terrestrial	Tropical savanna woodland	Endangered	Endangered	0	0	0	
Norfolk Island Boobook	Terrestrial	Island endemic	Critically Endangered	Endangered	0	0	0	
Norfolk Island Green Parrot	Terrestrial	Island endemic	Critically Endangered	Endangered	0	0	0	
Southern Cassowary	Terrestrial	Rainforest	Vulnerable		0	0	0	
Plains-wanderer	Terrestrial	Grassland	Endangered	Critically Endangered	0	0	0	
Western Ground Parrot	Terrestrial	Heathland	Critically Endangered	Critically Endangered	0	0	0	
South-eastern Red-tailed Black-Cockatoo	Terrestrial	Dry sclerophyll woodland/forest	Endangered	Endangered	0	0	0	

2.8 Synthesis of Findings

A primary finding of the project to date is that there is much monitoring sufficient for presentation of regular trend indices being conducted on threatened and Near Threatened birds in Australia. Much of the data arising from such monitoring programs are readily shared and suitable for integration into a national Threatened Species Index. The resulting index (and its subsidiary components) provides trend patterns that are objective, repeatable, and broadly consistent with the limited available previous documentations of trends in some threatened Australian bird groups. Although this is to be tested more thoroughly.

A major outcome of this project is in its identification of gaps. Not all existing monitoring programs and data currently meet the standards required for integration; some species are not monitored at all, and some groups that undertake monitoring have not (yet) contributed to this collation. These are well-recognised deficiencies. However, the current project should serve to indicate the type of monitoring that would be most useful for incorporation in national population trend reporting, and should help set priorities for the establishment of new monitoring programs for currently poorly-sampled species. The presentation and dissemination of these results should also serve to encourage the participation of other groups holding data that have not yet been contributed. This exercise serves to show what is possible, and we would expect that in future years far more data should be available, covering a larger number of threatened and Near Threatened species, and with increasing spatial representativeness.

Variation around the mean trend is to be expected. The overall Threatened Birds Index contains a diverse mix of species representing life histories ranging from small, sedentary passerines confined to highly specific habitats in deserts to the largest seabirds on earth from the sub-Antarctic. Due to many differences in the threats faced by these species as well as their responses to these threats and their management, there is a high degree of variance in the trends of populations across Australia. This results in substantial uncertainty around the mean index estimate. Furthermore, some included species are being managed intensively and showing some signs of recovery, whereas others are not. Contrasting trends for species' populations over time increase the variation in index estimates and should not be viewed as an inherently bad thing. In fact, if we are to be successful in conservation goals, uncertainty may well increase with time as the proportion of declining species reduces and more species populations recover.

For some species groups, there is great consistency in trends. The index for migratory shoreline birds matches expectations and previous work (Szabo et al. 2012, Clemens et al. 2016, Studds et al. 2017) which have documented consistent declines across many species in this group. Uncertainty for this index in particular is low indicating a very high level of consistency in species data within this group. Likewise, the index corroborates and extends previous reporting of relative stability among birds in tropical savannas (Woinarski et al. 2012).

Other indices present a less clear picture. The marine index features a very high level of uncertainty (Figure 8). The high variation may result from the relatively low number of time series and large increase in the number of species monitored over time, or indicate real variation in how marine bird populations are responding to conservation actions. Extensive conservation measures have been enacted for many seabirds over the years and some species are known to be on the increase (e.g. the Australian Gould's Petrel), while others such as the Australian Fairy Tern are under ongoing pressure and are in decline (Garnett et al. 2011).

Interpretation of indices should not be regarded as straightforward, and requires careful examination of diagnostics and thorough exploration of the data characteristics that form the base of a composite index. Some Indices are not representative of a region or species group. The Island endemic species index, for example, features significant data for Christmas and Kangaroo Island endemics, however these species represent only six of the 40 threatened and Near Threatened Australian island endemic terrestrial birds from two specific locations. Thus, this index should be taken as a signal that there is a need to increase the data for Island endemics, before they are used to make inferences about the overall trends in this group of species over time. If data on the numerous threatened endemic birds of islands from Norfolk, Lord Howe and King Island in particular become available, the islands-endemic component of the index will become much more representative.

Indices for some functional groups of conservation interest are presented here, however many more combinations of sub-indices are possible and could be calculated. For instance, grouping based on prevailing threats (e.g. fire sensitivity), or of the intensity of responsive management (e.g. whether a species has an implemented recovery plan or not) are possible and may be of significant interest. The scientific workflow developed for the index allows for seamless sub-setting of data spatially, by species characteristics and/or by other attributes of interest assuming sufficient data are available.

2.9 How can/should the index be used?

The index can be an enduring tool for tracking change in all threatened species over time and space, so long as collaborating agencies and other stakeholders continue to contribute monitoring data. By making the aggregated datasets and code freely available to the public, the index can be readily interrogated and tested. The data collected through this project are collated in the first ever Australia-wide monitoring database representing all available time series of Near Threatened and threatened bird species.

The index can be used to report on the Australian Government's progress towards meeting international conservation targets (such as the Aichi Target 12). Because the index can be aggregated for species or by regions, it can report on progress towards managing declines due to threats in particular regions (using an aggregated regional index over time) and due to threats that only act on a group of certain species such as migratory shorebirds (using species-group-level indices). Having flexibility to change the baseline year allows examination of trends in time periods of most interest to the user/audience for informing a particular question (Figure 1). Furthermore, it will assist in prioritising management responses (e.g. to groups or regions where the highest biodiversity declines have occurred), and provide a broad background picture of change in an overall region or assemblage against which to compare more specific data on multi-species populations being managed. This information could then be used in reporting of return on management investment at a broad level. For example, we might compare changes in trends within an area undergoing enhanced management of threats to changes in trends within a nearby area that has had little investment in threat management.

Once the index has been tested and validated with multiple taxonomic groups (birds, plants, mammals), we envisage an online visualisation tool that is linked directly to aggregated datasets and is based on freely available code. This would allow anyone (government departments, NGOs, the public) to be able to access and interrogate the aggregated data to answer specific questions about species composite trends in their region or species of interest.

The index should ultimately form the basis for broad community discussion of the state of our threatened biodiversity, and be widely recognised as an authoritative metric for our performance in mitigating threats and preserving our biological heritage.

The index estimates do not constitute taxon (species or subspecies) specific trend estimates and cannot be used in conservation assessments or to directly assess management effectiveness.

2.10 Pathway for Inclusion of Further Taxonomic Groups

Trends for birds may not be representative of threatened species generally. A Threatened Species Index will be more meaningful in summarising the State of Australia's biodiversity when comparable information can be incorporated from time-series data for other taxonomic groups.

Although other taxa do not have some of the factors that assisted with the creation of the Threatened Species Index for birds (e.g. a high-capacity national bird conservation and research organisation), they share many of the same characteristics of birds that will enable time series to be identified and collated, including: a wide variety of monitoring efforts and duration for threatened mammals, including a long history of targeted monitoring of iconic and high-profile threatened mammals (e.g. koala, critical weight range mammals); high detectability for many threatened mammals and non-ephemeral plants; extensive partnerships between researchers, government and non-government organisations (e.g. Bush Heritage Australia, Australian wildlife Conservancy) committed to long-term stewardship, monitoring and management of threatened plants and mammals.

Elements that are easily transferrable from the Threatened Bird Index to an index for any other taxonomic group include:

- *Ongoing relationships with data custodians:* We have established a good collaborative network with major threatened species data custodians; this will simplify the process of data negotiation, data sharing agreements and data processing for taxonomic groups additional to birds
- *Collaboration with NESP TSR Hub projects involving new data custodians:* We have already identified many data custodians of threatened species data through collaboration with other NESP TSR Hub projects:
    - Project: 2.2 Tackling threats to endangered hollow-nesting birds
    - Project: 2.4 Developing a Red Hot List for Australia's most imperilled plants
    - Project: 3.2 Improving threatened species monitoring
    - Project: 3.3 Practical adaptive management to improve threatened species conservation programs

    - Project: 3.2.5 Arid Zone Monitoring (project has collated datasets on threatened mammals from arid zones which can be used for the mammal index)
    - Project: 4.2 Saving species on Australian islands (project has collated datasets on threatened island species)
    - Project: 5.1.1 Strategic Planning for the Far Eastern Curlew
    - Project: 6.5 Citizen Science for threatened species conservation and building community support

- *Existing database infrastructure for entering and collating data on new taxa:* By exploring all possible database structuring with birds, we have designed a database that can be re-used to collate time-series data and metadata for any taxon from any taxonomic group.

- *Rigorous data assessment framework:* We have developed a rigorous data suitability assessment framework, an automated scientific workflow that includes all data processing, analysis and reporting steps required. These will be applicable to data for any taxonomic group. Data required to assess suitability for each new taxon are also available, e.g. spatial representativeness can be assessed using the publicly available Species of National Environmental Significance gridded spatial layers published by the Department of the Environment and Energy.

2.11 Conclusions

This interim report provides a strong proof-of-concept that a collaborative and reliable Threatened Species Index for Australian birds is feasible, and can be interrogated to provide reporting at a range of scales and for a range of purposes.

With the Threatened Species Index for birds, we have demonstrated that:

- A collaborative network among agencies and groups that collect monitoring data on threatened species can lead to the development of a coordinated index.

- Data on annual time series from monitoring of threatened species' populations from reliable sources exist and - after vetting and processing – can be used to produce an index representing >30% of all threatened and Near Threatened birds.

- A robust and credible Threatened Species Index can be produced and further refined.

- The Threatened Species Index can provide reliable and robust measures of changes in the abundance of subsets of Australia's threatened species (e.g. by state or territory, broad ecosystem type, threatening process, conservation status etc.).

- There is substantial interest from many stakeholders including all levels of government, non-government organisations and academia in the further development of indices for other taxonomic groups (e.g. plants, mammals, and freshwater species) and a continuation of the index as a legacy product beyond the life of the hub.

- The Threatened Species Index can provide a platform for a national 'conversation' about threatened and Near Threatened species, and thereby increase community awareness and appreciation of our threatened biodiversity, and create a mandate for investment in its protection.

- The Threatened Species Index may improve the quality and extent of threatened biodiversity monitoring in Australia by providing impetus in the form of a highly visible national index.

We have identified that our ongoing relationships with data custodians, the collaboration with other NESP TSR Hub projects and new data custodians that we have already approached, the rigorous data assessment framework, and the automated workflow system streamlining the processing of large data volumes will enable us to develop robust and credible Threatened Species Indices for further taxonomic groups.

We conclude with four major needs to adopt the Threatened Species Index as a national headline indicator:

1. The Threatened Species Index is feasible as a reporting tool toward the 5-years target of improving the trajectories of 20 priority birds, 20 mammals and 30 plants, however, monitoring data at fixed sites repeated over time are needed;
2. Support to continue repeated monitoring at long-term fixed-sites is needed;
3. Supporting the process of data archiving and the role of data curators in the long term are equally important;
4. Data sharing is essential; we believe that custodians who refused to share their data with the Threatened Species Index project will change their mind once they start trusting the TSX process and outcomes.

A. Supplementary Material

A1 Frequently Asked Questions

A1.1 What are the data provider agreements and what do they entail?

Ongoing data sharing agreements for this project only were signed with each of the institutions supporting the project with data where data were not already open access. Licensing ensures that all data can be implemented in the index through a process of aggregation of individual site trends for every single species. In particular, signed agreements for the provision of data include a detailed policy relating to locational precision for sensitive species. Agreements also regulate how raw data are to be de-identified and converted into data aggregated to IBRA subregions for analyses which will be made publicly available, and define the long-term hosts for both levels of data resolution. Data custodians were offered the option of providing their raw data on an open-access basis or for use by third parties, but very few elected to do so.

A1.2 What are raw data? (Legal Terms)

Raw data are a set of numerical measures of abundance or presences/absences linked to the full resolution geographical coordinates for a threatened or Near Threatened species at a specific time point with a specified monitoring method. Raw data are provided by third parties and are to be handled confidentially. A small number of principal researchers of the Threatened Species Index project dealing with raw data quality control and pre-processing are provided with direct access to these data unless otherwise specified in the data sharing agreement.

A1.3 What are aggregated data? (Legal Terms)

Aggregated data consist of many numerical point data that have undergone quality control, pre-processing, and have been grouped into representative units suitable for analysis. For example, data from the same monitoring method and for the same species that can be aggregated into a spatio-temporal time series for a certain area with predefined (e.g. based on proximity of points to each other) or natural (e.g. islands) boundaries. Aggregated data are de-identified from the original raw data. Spatial coordinates for aggregated time-series data are given as latitude and longitude of the centroids of IBRA subregions in which the observations of species within one time series were recorded. Aggregated time-series data on species populations are the first level of research output of this project. Aggregated data are made publicly available in the long term, in all cases adhering to sensitive species policies described in the data sharing agreement signed or specified by the data provider.

A1.4 What is the difference between raw and aggregated data?

Raw data consist of field survey data provided by many custodians. This is mostly one species counted at a point in time and at a certain location. Typically data that have been consistently collected with the same methods over time are most useful for the index, but other types of monitoring also allow trends to be calculated. For this reason, initially all types of monitoring and survey data need to be collected for threatened species. We treat these data confidentially because they often contain sensitive information. We sign data provider agreements that regulate how these data are to be handled and account for additional stakeholder-specific requirements.

Aggregated data are the raw data which have been combined to derive regional population measures. For the Threatened Species Index, our spatial aggregation unit is an IBRA subregion and our temporal aggregation unit is one year. Aggregated data consist of the population measures (e.g., the annual population abundance of a species in a given IBRA subregion) that have been vetted and processed and where we have applied empirical criteria to assess suitability of data for trends calculation. The aggregated data will be published open access but exact species locations will be de-identified to the IBRA subregion scale i.e. all time series will have spatial information located on the centroids of the IBRA subregion in which that observations were recorded.

A1.5 Who can access raw data?

Raw data are accessed only by the Threatened Species Index Analysts. Raw data will not be made available beyond the project due to strict data-sharing protocols. Instead, aggregated data will be available on a cloud server which will be accessible to the general public.

The necessity of collating a wide array of threatened species data from multiple data custodians entailed the development of strict data-sharing protocols, without which few custodians would have agreed to share their data. Data-sharing agreements for this project were thus strictly limited to the purposes of developing and coordinating a Threatened Species Index. Custodians were offered the option of electing to share their raw data as open access, which none took up. Some data custodians agreed to share data provided with third parties e.g. The Atlas of Living Australia or other collaborating NESP TSR Hub projects. Otherwise, raw data for this project were not collected or intended for other purposes.

A1.6 Who can access aggregated data?

Everyone can access and download aggregated data displaying yearly counts of populations of species at sites with a spatial information to the IBRA subregion scale. In the first instance, these data will be accessible through a web page hosted by BirdLife Australia.

A1.7 What data can be used for other research projects?

All aggregated time-series data will be made available to other research projects and to the general public. These data are therefore available to other research projects.

A1.8 What are research outputs?

Research outputs are outputs after feeding aggregated data into methods for analysis - e.g. to calculate population indices. The graphical representation of research outputs e.g. Threatened Bird Index will be made publicly available in the long term, along with tools to allow all users to interrogate the index.

A1.9 Can data provider agreements be broadened to include third parties?

Our initial intention was to broaden the data provider agreement to include access to raw data by third parties where possible. For instance, during the data sharing agreement process we discussed with custodians the possibility of making data received available for public display (e.g., within the Atlas of Living Australia) or of the data being shared with other projects within the TSR Hub. Only a handful of data custodians agreed for their data to be passed on to ALA and many limited their agreement in a provision to the Threatened Species Index Project only. In rare cases, the data custodians requested that their data be destroyed upon completion of the research activities of the Threatened Species Index Project due to sensitivities around species locations, private properties or due to other unspecified reasons.

A1.10 What does the index mean?

The Living Planet Index method (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017) is calculated as a geometric mean of trends for each species within a Generalised Additive Modelling (GAM) framework. The index value is the average change in multi-species population abundance from one year to the next. It shows the rate of change and not the absolute change in population sizes. For any given year in the population time series, the index values represent the overall trend in that year compared to the baseline year set to 1.0 in 1970 - in case of calculating the Living Planet Index. The baseline year for the Threatened Species Index will be subject to data availability and quality but is more likely to be set to 1.0 in 1990. The confidence intervals illustrate 95% confidence in the index value in any given year relative to the baseline year.

A1.11 How can the index be interrogated?

The index can be interrogated by means of selecting the options within an open access web-visualisation tool. Possible selections for interrogation are:

- Region:
    - Australia
    - Australian Capital Territory and New South Wales
    - Northern Territory
    - Queensland
    - South Australia
    - Tasmania
    - Victoria
    - Western Australia
- Species groups:
    - Birds (option available at this stage)
    - Plants (envisioned for the future)
    - Mammals (envisioned for the future)
    - Freshwater species (envisioned for the future)
- Functional Bird Groups:
    - Marine
    - Terrestrial
    - Wetland
    - Shoreline (migratory)
    - Shoreline (resident)

Image: Helmeted Honeyeater.
Photo: Dylan Sanusi-Goh Wikimedia Commons CC BY 4.0

- Functional Bird Subgroups:

  Marine
    - Albatrosses and Giant-Petrels
    - Gulls Terns Noddies Skuas Jaegers
    - Penguins
    - Petrels and Shearwaters
    - Tropicbirds Frigatebirds Gannets Boobies

  Terrestrial
    - Arid Woodland/ shrubland
    - Dry sclerophyll woodland/forest
    - Grassland
    - Heathland
    - Island endemic
    - Mallee woodland
    - Parrots, Lorikeets, Rosellas, Cockatoos, Corellas
    - Rainforest
    - Tropical savanna woodland

  Wetlands
    - Gulls Terns Noddies Skuas Jaegers

Image: Plains Wanderer. Photo: Patrick_K59 Wikimedia Commons CC BY 2.0

- Other possible groupings
  - Guild (e.g. Nectarivore, Granivores, etc.)
  - Migratory/resident status of birds inhabiting the shoreline
  - Threat type (e.g. fire, habitat loss, etc.)
  - Conservation status (Near Threatened, Vulnerable, Endangered, Critically Endangered)
  - Management status (e.g. species with/without recovery plans, etc.)
  - Groups of national environmental significance (e.g. priority species of the National Threatened Species Strategy)

Sub-indices are only possible for groupings of taxa that have sufficient data (see section A2.6 in the supplementary material on the suitability criteria for the inclusion/exclusion of data) which will not always be the case either because of lack of monitoring or because there are not many taxa of a group within a region (e.g. Penguins in the Northern Territory).

A1.12 Why do the confidence intervals around the index value get larger with time?

The confidence intervals around the index value indicate the area in which the index is true with a 95% confidence. Cumulative uncertainty is inherent in aggregate indices including the Living Planet Index method which calculates trends of global vertebrate biodiversity (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017). Since the index value is a measure of relative change throughout time relative to a baseline year, the uncertainty in the index is cumulative i.e. the confidence intervals demonstrate the uncertainty in the index values inherited from the baseline and propagated through the time series. The uncertainty in the index value is subject to 1) the year set as a baseline and 2) the species data available at any given point through time. Whether the confidence intervals around the index values become larger or smaller as new data are added over time depends on the variation within the new data added as well as how much the trends in the new data vary from the existing data. For example, confidence intervals are likely to widen if over time trends among species become more discordant. In contrast, if all species in an analysis group start responding comparably to a threat factor or a management intervention, then trends across all species will become more concordant and confidence intervals should narrow; and if the included monitoring programs become better and better at detecting these trends over time then there is likely to be less erratic noise. Provided that the variation within the added data is small, the index should become more robust after each iteration and the addition of new data.

A1.13 How can the index be produced every year for the future to come?

Continuation of the index into the future will be reliant on ongoing contributions of data custodians, and some ongoing resourcing for analysis and reporting. Since the index is dynamic, the addition of new data each year into the future will not only improve the accuracy of current trends but also the historical trends. A subsidiary benefit of the index is that it collates and increases the fitness for purpose of data from unpublished sources which may be lost to research and the general public otherwise.

A1.14 What are the most time- and effort consuming elements when creating an index?

- Negotiating data provision (has to be done only once for the ongoing project)
- Negotiating conditions under which data are provided (signing data sharing agreements; has to be done only once for the ongoing project)
- Data reformatting before ingestion into the database

A1.15 What elements from the Threatened Species Index for birds can be utilised to minimise time to produce an index for plants, mammals, and freshwater species?

- Basic structure of the data sharing agreements
- Existing collaborative network with major data custodians
- The process of data ingestion has been automated through a data import web interface
- MySQL database structure can be used for other taxonomic groups
- Spatial and temporal processing of raw data into aggregated data
- Data suitability criteria can be applied for data on other taxonomic groups under minor modifications
- Some data sharing agreements allow the provision of other taxonomic groups other than birds
- Web-visualisation tool for interrogation can be used to include other taxonomic groups

A1.16 How could the index be used as an enduring tool into the future?

The index can be an enduring tool for tracking change in all threatened species over time and space. By making the aggregated datasets and code freely available to the public, the index can be readily updated by those with more monitoring data on trends of species.

The data collected through this project will be the first ever Australia-wide monitoring database for all available time series of all threatened species. The Atlas of Living Australia have agreed to host the aggregated datasets for index calculation. The Terrestrial Ecosystem Research Network (TERN) are a natural host for raw data because they have sensitive data policies already in place to ensure data security, and because they drove the development of an automated scientific workflow which automates raw data ingestion into the raw database, data vetting and suitability assessment, aggregation to spatial and temporal units, index calculation and visualisation. The hub intends to provide annual updates of the Threatened Species index for Birds and other indices developed throughout the life of this NESP project.

Because other organisations will be involved with different taxonomic groups, we cannot yet guarantee the future of the index beyond the life of the hub. One of our priorities in coming years is to work on this legacy, which we will include as a milestone in future research plans: 'Report proposing a strategy on institutionalising the birds, plants and mammals index, engaging with potential funders' by September 2020. By making the aggregated dataset, the code for the workflow as well as the web-visualisation tool for interrogation of the index freely available to the public, we anticipate that the value of the index should be widely accepted, and such applicability should ensure that the index endures into the future.

A1.17 How can the index be used for reporting on the state of threatened species?

The index can be used to report on the Australian Government's progress towards meeting international conservation targets (such as the Aichi Target 12 or the Sustainable Development Goal 15.5). Because it can be aggregated to species or to region, it can report on progress towards managing declines due to threats in particular regions (using an aggregated regional index over time) and due to threats that only act on a group of certain species such as migratory shorebirds (using species-group-level indices i.e. by selecting Functional Bird Groups). Furthermore, it will assist in the prioritisation of management responses (e.g. to groups or regions where the highest biodiversity declines have occurred), and reporting of return on management investment (e.g. in changes of trends associated with enhanced management).

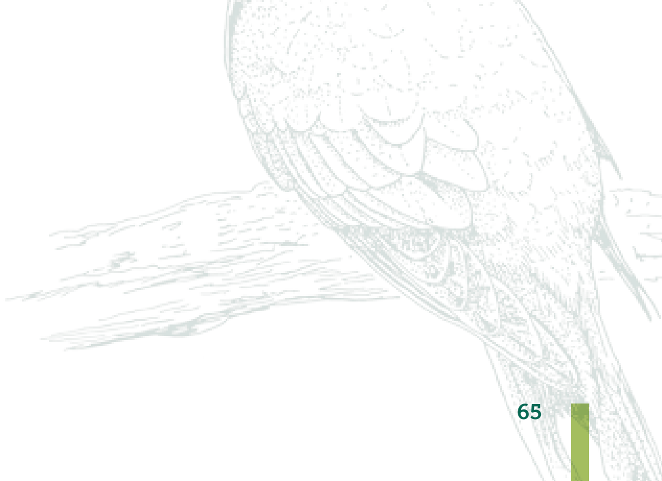
Once the index has been tested and validated, an online visualisation tool that is linked directly to aggregated datasets and is based on freely available code can be used for interrogation. This would allow anyone (Government Departments, NGOs, the public) to be able to access and interrogate the data to answer particular questions about trends in their region or species of interest.

A1.18 How can the index be improved?

The major scope for ongoing refinement of the index and improvement of its comprehensiveness and capability to answer policy and management questions is through the development and incorporation of more (and more appropriate) monitoring programs, especially for species (or regions) that are poorly represented currently. The project to date has helped to identify some of these major gaps.

Further improvement of the index can be achieved through a thorough assessment of data suitability for trends in consultation with the data custodians for each trend produced in an expert elicitation survey.

When published publicly, the index would benefit from receiving feedback from the public about how reliable the data are for a particular sub-index. This could be provided by a confidence scoring approach or other mechanisms, and is an important area of future research.



A2. The Methods

A2.1 Data Collation

Data requests were sent to >130 data custodians from academia, species recovery groups, state agencies, non-government organisations, and citizen science groups. Data were received from 69 different data sources and a total of 27 ongoing data provider agreements, data deeds, and/or data licences were negotiated and signed by the data custodian, BirdLife Australia (Paul Sullivan, CEO), and the University of Queensland (Ian Harris, Director Research Partnerships Office) on behalf of the Threatened Species Recovery Hub. Initial data requests consisted of 1) a data request email, 2) a complete list of 236 bird taxa for which data were sought, 3) a copy of the approved research project plan, 3) and a copy of the data provider agreement used in this project (see these documents in the 'Data request' folder in the electronic supplementary material).

Data provider agreements were signed with each of the institutions supporting the project with data where data were not already open access. Licensing ensures that all data can be implemented in the index through a process of aggregation of individual site trends for every single species. Signed agreements for the provision of data include a detailed policy relating to locational precision for sensitive species. Agreements regulate how raw data are to be de-identified and converted into data with spatial information provided to the scale of IBRA subregions used for analyses which will be made publicly available, and define the long-term hosts for both levels of data (raw and aggregated) resolution. Data custodians were offered the option of providing their raw data on an open-access basis or for use by third parties, but very few elected to do so.

The collection and collation of these amounts of data required 17 months (August 2016 to December 2017) of liaising with data custodians, data sharing negotiation, collection and processing by three full-time staff including in-kind support of UQ's Research Partnerships Office estimated at one day per fortnight. All major custodians were contacted at least twice by email and/or communication was followed up by phone calls.

Two workshops were held to enable data collection:

1. A one-day workshop to develop collaborative and legal arrangements across a wide set of stakeholders that undertake monitoring on threatened species in Australia was carried out in April 2016. Participants at this workshop were representatives from the Australian Government (Parks Australia), at least one representative from each state and territory agency, the Atlas of Living Australia (ALA), the Terrestrial Ecosystem Research Network (TERN), the Australian Wildlife Conservancy (AWC), the Bush Heritage Australia, BirdLife Australia, the University of Queensland (UQ), Charles Darwin University (CDU), and Australian National University (ANU). This first one-day workshop aimed to engage with the Department of the Environment and Energy (DoEE), state agencies and conservation NGOs, to define what end-users and partners wanted from a Threatened Species Index, to ensure that the right tools were created for end-users and decide on a strategy to achieve this. Within this workshop, we sought input from stakeholders about their specific needs for reporting on trends in threatened species. The output of this workshop was the facilitation of data transfer, provision of information on data quality, the establishment of an efficient platform for data sharing and management, an initial discussion on the methods towards indices reporting on Australia's threatened species. This workshop helped us to identify the major custodians for threatened species data and create a collaborative data provider agreement together with BirdLife Australia, the ALA and collaborating TSR Hub projects regulating the access, handling and de-identification of raw bird population data received for this project. This one-day workshop was carried out in April 2016.
2. A second half-day virtual workshop focusing entirely on data management was carried out in June 2016. The workshop aimed to engage with ALA, TERN, BirdLife Australia and UQ's Research Partnerships Office to discuss options around data sharing, data-basing, metadata, curation, analysis, accessibility, and display of large and disparate datasets. The output of this workshop was to develop and optimise a data sharing agreement which can deal with data on sensitive species. The workshop was followed by several phone meetings allocated to smaller groups to address tasks related to data management.

Workshops enabling data collation were followed by four two-week visits of UQ staff to BirdLife Australia in Melbourne and vice versa.

A2.2 Scientific Workflow

In collaboration with the Terrestrial Research Ecosystem Network (Siddeswara Guru), UQ's Research Computing Centre (Hoang Nguyen) and Planticle Apps + Development (James Watmuff), a scientific workflow was developed using the Kepler platform (Altintas et al. 2004, Ludaescher et al. 2006, Michener et al. 2007) on Collaborative Environment for ecosystem Science Research and Analysis (CoESRA). CoESRA is a workflow-based web-enabled cloud platform that allows researchers to perform complex analyses using scientific workflow and then make them available for others to use and re-run with minimal effort. Kepler scientific workflows were previously developed to automate the process of applying conservation planning software Marxan (Guru et al. 2015) or to carry out a complete IUCN Red List of Ecosystems Assessment (Guru et al. 2016). The scientific workflow streamlines the pre-processing steps required to format, vet, and aggregate raw data into a consistent format as well as to carry out index diagnostics for quality control and can be applied to any taxonomic group for which a Threatened Species Index is calculated under minor adjustments. The scientific workflow is supported by an external funding of $30,000, along with the National Collaborative Research Infrastructure Service (NCRIS) Research Data Service - Terrestrial Data Systems.

This scientific workflow developed for the Threatened Species Index has been developed entirely by open-source software and automates the processes of:

1. Ingestion of datasets into raw database (online)
2. Data quality & suitability check
3. Data processing (temporal & spatial aggregation)
4. Collation of data into aggregated database
5. Index calculation running diagnostics
6. Producing graphs for subsets of data,
7. Web visualisation tool for interrogation

The end result of the scientific workflow is a dynamic graph on the Threatened Species Index calculated for a subset of data depending on the values used for interrogation e.g. for which species group to calculate an index or for which area to calculate it.

The data processing steps of the workflow are summarised in the scientific workflow outline diagram accessible from the 'Scientific workflow outline' folder in the electronic supplementary material.

A2.3 Standardisation of Data

Data received from individual custodians or data repositories were highly variable in terms of the reporting units, data format and availability of metadata information. The disparate formats reflect the urgency for introducing data standards and maintain effective data curation throughout Australia. Although each data request provided a structured format suitable for loading data into the projects database (see 'Data import templates' in the electronic supplementary material), data custodians rarely used these templates to transfer their data. Most data obtained did not adhere to any specific data standards or included only minimum Darwin Core information on scientific name, event date, decimal longitude and latitude, and individual count without any metadata necessary for trend analyses such as survey methodology/ effort, site identifiers, spatial coordinate system, units of measurement or taxonomic system. A description of the data fields, often abbreviated, was largely missing. Only few repositories had sufficiently developed data dictionaries to increase the fitness for purpose of their data. Where metadata were not immediately available, efforts were made by the Threatened Species Index analysts to establish the necessary information by consultation with the data custodian or looking up information in related scientific publications or data repository web resources where attributed. Data duplication, where primary data were archived by more than one repositories, was avoided by removing records with identical primary source information where provided. The time required for data handling by one data analyst varied enormously and ranged from one day to several weeks per data source requiring a substantial amount of manual processing and reformatting of data.

To ensure data and metadata were handled appropriately, data templates were developed and used to import all data. Templates were kept as simple "flat tables" to maximise ease of use for the widest range of potential contributors while allowing for the full range of highly variable data types to be catered for – e.g. differing coordinate systems, units of measurement, temporal information (e.g. full date to year only), site identifiers and covariates (see 'Data import templates' in the electronic supplementary material).

A2.4 Data Ingestion

Data were imported through a web-based data ingestion application. The data ingestion application has mechanisms for data quality control, data validation as well as rules ensuring that basic metadata, through required fields of a data import template, are included and data integrity is maintained after importing each single data file (see 'Data import templates' folder in the electronic supplementary material). Figure 24 shows the successful import of a data file into the database and Figure 25 shows an example that has triggered the quality control mechanisms of the web-based data ingestion application:

Figure 24: Screenshot shows an example where a data file was successfully ingested through the web-based data ingestion application into the database.

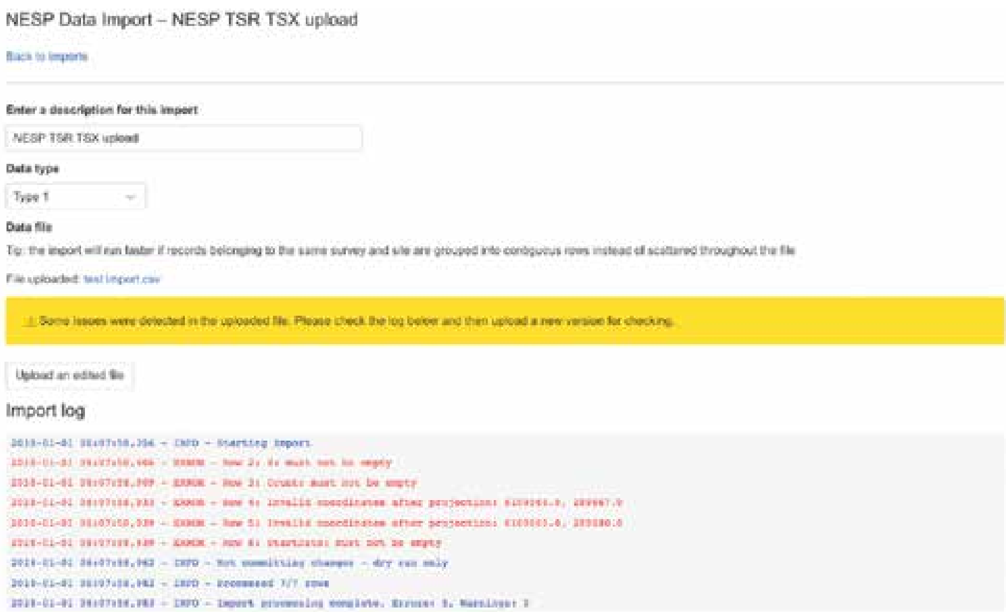
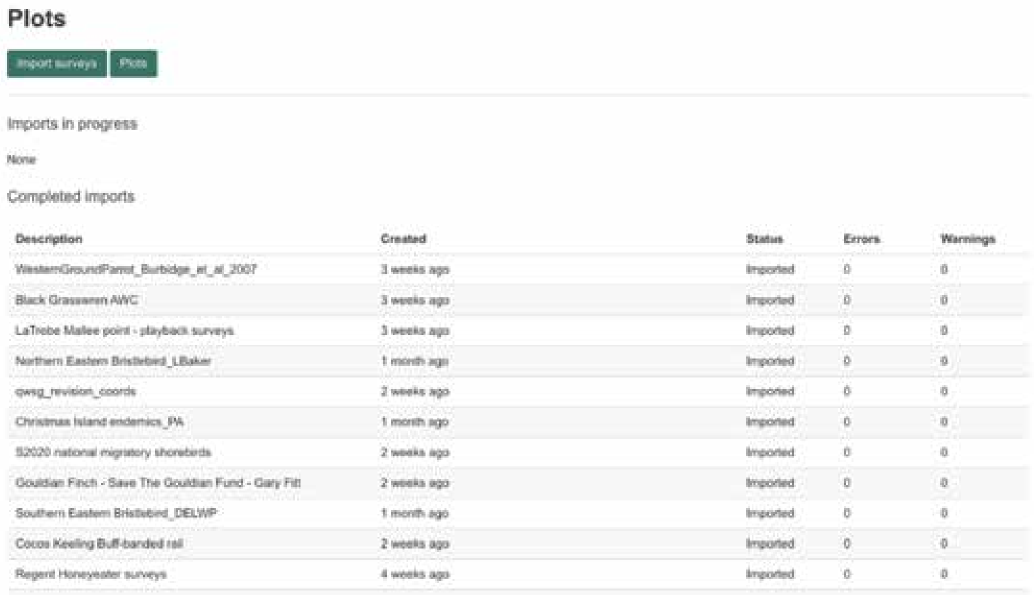


Figure 25: Screenshot shows an example where the data quality control mechanisms of the data ingestion application were triggered by ingesting a data file with lacking or erroneous information.

Datasets from 69 sources were entered through the web-based data ingestion application. The application has the feature to visualise a summary of the history of entered data files comprising an effective tool for analysts to overlook the process of shared data administration and to keep track of the data entry progress (Figure 26). The web-application is currently under development, thus a password-protected private resource. It is envisioned to make this resource available to public access once a user management system is developed in which data custodians will be able to log-in and update their data for periodic index recalculation. Administrators will review updates before they are committed to the main database and scientific workflow to ensure data integrity is maintained.


Plots

Import surveys | Plots

Imports in progress

None

Completed imports

Description	Created	Status	Errors	Warnings
WesternGroundParrot_Burbidge_et_al_2007	3 weeks ago	Imported	0	0
Black Grasswren AWC	3 weeks ago	Imported	0	0
LaTrobe Mallee point - playback surveys	3 weeks ago	Imported	0	0
Northern Eastern Bristlebird_LBaker	1 month ago	Imported	0	0
qwsg_revision_coords	2 weeks ago	Imported	0	0
Christmas Island endemics_PA	1 month ago	Imported	0	0
S2020 national migratory shorebirds	2 weeks ago	Imported	0	0
Gouldian Finch - Save The Gouldian Fund - Gary Fitt	2 weeks ago	Imported	0	0
Southern Eastern Bristlebird_DELWP	1 month ago	Imported	0	0
Cocos Keeling Buff-banded rail	2 weeks ago	Imported	0	0
Regent Honeyeater surveys	4 weeks ago	Imported	0	0

Figure 26: Screenshot shows a summary of the history of entered data files entered via the web-based data ingestion application.

The data import, processing and visualisation code is published at https://github.com/nesp-tsr3-1/tsx under the MIT License, which is a simple permissive license with conditions only requiring preservation of copyright and license notices.

A2.5 Database

A relational database was developed using the standard open-source database system MySQL. The database employs an extensive system of indices, foreign keys, and spatial objects (e.g. point and polygons) which are transferrable to any species taxonomic group under minor adjustments. This spatio-temporal raw database constitutes the basis for data processing and aggregation (see 'Database schema' in the electronic supplementary material for copies of the database design schema and codes).

A2.5.1 Data Types

The spatio-temporal database handles two main types of raw data imported via the web-based data ingestion application:

Type 1 Data

Type 1 data feature monitoring data for single species or groups of species (e.g. migratory shorebirds). For the Threatened Species Index for birds, Type 1 data comprised 87.0% of all raw data sources used for analyses (i.e. 60 sources out of 69 were Type 1 data). In comparison to Type 2 data (see Type 2 data definition below), Type 1 data required relatively little processing after data were formatted and imported.

Type 1 data need to satisfy the following requirements:

- All taxa are defined to ultrataxon level
- Survey methods are clearly defined and attributed to each data point
- The unit of measurement is defined and attributed to each data point
- The temporal definition is at least to a year

- Information on pre-defined (fixed) sites is provided with accurate spatial definitions and consistent survey methods/ effort used within sites
- Non-detections of taxa (i.e. absence or 0 counts) are recorded
- Spatial coordinates are available for all data points

After data collection, a total of 104,658 surveys representing 72 taxa were entered as Type 1 data into the raw spatio-temporal database. After data ingestion, all Type 1 data were aggregated to the temporal unit of one year.

Type 2 Data

Type 2 data are often referred to as "big data". This data generally contain data from large multi-species datasets provided predominantly by state & territory repositories, non-government organisations and a few research institutions. There were fewer Type 2 data sources (13.0% i.e. 9 out of 69 sources in total), however those included a high number of records. In some cases, Type 2 data included records on any bird taxon irrespective of conservation status. These were limited to Near Threatened and threatened taxa at a later state of the data processing workflow. Including information on all taxa was necessary since most threatened and Near Threatened birds in Australia are subspecies, but very few large data repositories store subspecies classifications, thus data for the parent species are needed.

Type 2 data need to satisfy the following requirements which are less stringent than for Type 1 data:

- Taxon is defined at least to species level
- Survey methods are defined and attributed to each data point
- Unit of measurement is defined and attributed to each data point
- Consistent measure/methods are used through time
- The temporal definition is at least to a year
- Recorded non-detections of taxa are not required, i.e. presence-only data are allowed
- Spatial coordinates are available for all data points

After data collection, a total of 16,245,126 records from 1,131,754 surveys representing 988 species (including non-threatened taxa) were entered as Type 2 data into the raw spatio-temporal database. After data ingestion, Type 2 data undergo several data processing steps which have been automated within the scientific workflow (see Type 2 Data Processing section).

A2.5.2 Type 2 Data Processing

Type 2 data required extensive vetting, taxonomic reclassification and spatial processing. This processing was implemented using Python software and MySQL routines. The routines were developed for efficiency and integrity given the large number of data points involved. Spatial layers of species and subspecies ranges (including zones of bird hybridisation and co-occurrence) and survey sites were used. (Spatial layers of species and subspecies ranges were provided by Glenn Ehmke, BirdLife Australia, unpublished).

Ultrataxon definition and range filtering

Because Type 2 data are usually not classified to the subspecies level, data for threatened subspecies which have non-threatened conspecifics must be processed to exclude non-threatened subspecies before indices are calculated. Thus, it was necessary to classify primary Type 2 data using spatial range layers of ultrataxa (provided by Glenn Ehmke, BirdLife Australia, unpublished). Subspecies classifications were populated through intersection of species data points with spatial range layers of ultrataxa.

Pseudo-absence allocation

Because absence data or non-detections (i.e. zero counts of taxa) are not specifically recorded in Type 2 data, absence information must be inferred. However, it is important when developing statistical models to limit absence data points to spatial areas in which the focal species can occur in order to avoid spurious results. This is particularly critical for species with a restricted range which would otherwise be overflown by irrelevant absence data from outside the species' geographic range.

Alpha hulls were used to define spatial areas in which each species frequently occurs. Alpha hulls are a relatively prescriptive, or "tight" estimate of geographic range which corresponds closely to patterns of bird survey effort making them ideal for use in data constraining procedures for trend analyses. Using the Environmental Resources Information Network (ERIN) Species Range Mapping Tool developed by Simon Bennett (ERIN Species Team, Department of the Environment), alpha hulls were calculated from species occurrence data. These alpha hulls were then used to define absence data.

Ultrataxon definition and pseudo-absence of Type 2 data allocation yielded 81,030,127 records representing 1248 bird ultrataxa (including non-threatened taxa).

A2.5.3 Data Aggregation

From raw Type 1 and Type 2 data, 1,996,264 records from 502,419 surveys of 100 threatened/Near Threatened bird taxa were aggregated into 122,686 time series. A time series was a grouping of unique combinations of:

- Data source (SourceID)
- Unit of measurement (UnitID)
- Search type – i.e. method/effort (SearchTypeID)
- Site (SiteID)
- Species (TaxonID)

This ensured that only consistent data (i.e. standardised) were aggregated into time series for the purposes of statistical comparison. It should be noted that the attribution of search type description relied on what data custodians specified as distinct categories. Efforts were made to validate search type description categories and sub-divide them where possible (e.g. sub-divide by survey area or duration), however information was not always available to do this, thus survey effort may vary significantly within some search types in some cases.

Time-series population values were calculated based on the unit of measurement type, i.e. counts (as a continuous variable) or occupancy (as a binary variable) and species/monitoring characteristics. Average counts (arithmetic mean) were used in aggregation for most count variables, however maximum counts were used in some instances where average values were not considered appropriate, e.g. for seabird breeding colony monitoring. Because the Living Planet Index cannot utilise occupancy data, presence/absence data were transformed into reporting rates (# presences/# absences) per site. These were temporally aggregated per month (upon availability of data on smaller sampling periods than one year) in a first step and per year as a continuous yearly variable in a second step.

A2.5.4 Units of Measurement

The units of measurement were either abundance or presence/absence of individuals monitored with a consistent monitoring methods at the same site over time:

- Proxy: breeding pairs
- Proxy: burrow estimate based on transect density
- Proxy: count of pre-fledging chicks
- Proxy: nests
- Proxy: nests with eggs
- Proxy: recorded calls
- Sample: abundance (counts)
- Sample: count of seen individuals after playback
- Sample: density (counts/fixed areas)
- Sample: Occupancy (# presences/# absences)

A2.5.5 Search Type Description

Search type description is synonymous with monitoring method applied to record the units of measurement of individuals monitored with a consistent monitoring method at the same site over time. The following monitoring methods were identified among the data collected:

- 2ha 20 minute search
- 500m Area search
- 5km Area search
- Shorebird count area survey
- Breeding territory monitoring
- Incidental search
- Fixed route search
- Bird list
- Waterhole counts
- Aerial survey
- Roost counts
- Collected specimen
- VBA Wetland count
- Estimation of annual breeding pairs by aerial photography and ground surveys
- Colony count
- Counting of birds seen after playback
- Slow walk (2-4km/h), listening to bird calls
- Annual flock count as flock flies to roosting area
- Direct observation at nest
- Search through feeding habitat patch
- 4ha 20 minute search
- 10 minute point count
- 2ha non-20 minute search
- Automated call recordering
- LaTrobe Mallee call playback/spot counts
- OBP winter count
- Slow walk (2-4km/h) - listening to bird calls
- 3ha 5 minute point count
- 200m transect point interval counts
- 100m time-controlled point interval counts
- 200x50m 30 min bird surveys
- Wildnet - Eungella Honeyeater Project surveys
- Weekly bird list within 5km
- Wildnet - coastal bird monitoring systematic surveys
- Wildnet - Wet Tropics 20 min counts
- VBA - Timed bird census
- VBA - wetland count
- VBA - Owl census
- VBA - Spotlighting
- Helmeted Honeyeater survey
- VBA - bird count
- VBA - Plains-wanderer survey
- VBA - Bird transect
- VBA - Point spot count - 30 mins
- VBA - playback
- Biological Survey of South Australia
- BDBSA - South Olary Plains
- BDBSA - Bird transects in quadrats 2 hrs min

- BDBSA - Waterbird counts within 1km
- BDBSA - Monthly paddock drives
- BDBSA - conventional area-search and transect survey methods
- BDBSA - MLR Chestnut-rumped Heathwren survey
- Call playback surveys
- BDBSA Scoping the Shoreline - 1lm transect
- 5 hectare 30 minute bird counts
- BDBSA - Murray River Wetland Counts
- BDBSA - residential survey
- BDBSA - KI Penguin census
- BDBSA MLR bird trends 2001-02 - 100m wide and at least one kilometre long transect
- Swift parrot search
- LaTrobe Mallee point - playback surveys
- Presence of males giving territorial song
- Calls heard from posts at 400m grids during dawn or dusk and in unburnt and burnt areas of the park.
- Motion sensing camera trap
- Aerial survey

Abbreviations:

- BDBSA: Biological Databases South Australia
- OBP: Orange-bellied Parrot
- VBA: Victorian Biodiversity Atlas

A2.5.6 Functional Bird Groups and Subgroups

Functional bird group:

A grouping of bird taxa based on the environment they predominantly inhabit: Terrestrial, Marine or Shoreline (migratory or resident)

Functional bird subgroup:

Groupings of terrestrial bird taxa by their predominant association with major habitat types (as determined by aggregations of National Vegetation Information System types) and marine taxa according to taxonomic family

A2.6 Suitability

After collecting and collating existing species monitoring datasets from individual researchers, threatened species managers, recovery teams, non-government organisations, citizen-science groups, as well as large data repositories, each dataset was assessed against criteria to identify whether the data satisfy the fundamental needs of trend analyses. This process ensured that the indices produced are not biased by time series with low or inconsistent sampling within or across years and space.

We developed a set of guidelines for vetting (rules for including/excluding data) and assessing suitability (based on standardisation of monitoring effort) of data for trend analyses (Table 21). We propose these methods as a best practice framework when dealing with data for single or multi-species trend analyses involving multiple sources and disparate formats.

The following rules were used to exclude datasets from Threatened Species Index analyses:

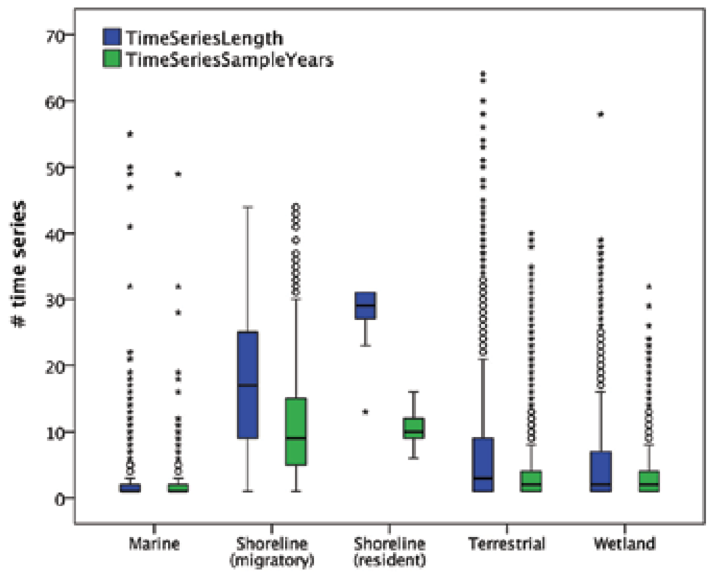
1. Delete all time-series rows with zero-only values
2. Delete all records with time series with less than 5 years of sample, i.e. with a minimum number of years between the initial and final year of a time series in which a sample was recorded 'Time-series Sample Years'
3. Delete all records with time-series Standardisation of Method Effort with a score smaller than 2
4. Delete all records with time-series Consistency of Monitoring with a score smaller than 2

Table 21: Criteria for assessing data suitability for trend analyses.

Assessment criteria	Description	Scale of assessment	Levels
Time-series Length	Time period between first year of repeated measure at one site and the last year	to the site-level (i.e. time-series level) and with an annual resolution	>1 years
Time-series Sample Years	Number of years with a value in a time series	to the site-level (i.e. time-series level) and with an annual resolution	>1 years
Time-series Completeness	Proportion of time-series range (start to finish) with containing values	to the site-level (i.e. time-series level) and annual resolution	0 to 1 (least to most suitable)
Time-series Sampling Evenness	Variance in the length of gaps in the time series	to the site-level (i.e. time-series level) and with an annual resolution	≥0 (the smaller the number the more suitable)
No Absences Recorded	0 = absences of species were recorded (non-detections) 1 = absences of species were observed in the field but not recorded	to the data source level	1 or 0
Standardisation of Method Effort	6 = Pre-defined sites plots surveyed repeatedly through time using a single standardised method and effort across the whole monitoring program 5 = Pre-defined sites/plots surveyed repeatedly through time with methods and effort standardised within site units, but not across program - i.e. different sites surveyed have different survey effort/methods 4 = Pre-defined sites/plots surveyed repeatedly through time with varying methods and effort 3 = Data collection using standardised methods and effort but surveys not site-based (i.e. surveys spatially ad-hoc). Post-hoc site grouping possible - e.g. a lot of fixed area/ time searches conducted within a region but not at pre-defined sites. 2 = Data collection using standardised methods and effort but surveys not site-based (i.e. surveys spatially ad-hoc). Post-hoc site grouping not possible. 1 = Unstandardised methods/effort, surveys not site-based.	to the data source level by enquiring with the data custodian and examining data	1 to 6 (least to most suitable)
Objective of Monitoring	4 = Monitoring for targeted conservation management 3 = Monitoring for general conservation management – 'surveillance' monitoring. 2 = Baseline monitoring 1 = Monitoring for community engagement	to the data source level	1 to 4 (least to most suitable)
Spatial Representativeness	Proportion of the available sample data on a taxon to the total known area of occurrence of this taxon	to the data source level per taxon	0 to 1 (least to most suitable)
Spatial Accuracy	Accuracy of spatial information for monitored taxon Caveat: blank cells indicate that no spatial accuracy was provided by the data custodian i.e. spatial accuracy is unknown	to the site-level (i.e. time-series level)	a number in meters
Consistency of Monitoring	4 = Balanced; all (>90%) sites surveyed in each year sampled 3 = Imbalanced because new sites are added to existing ones monitored consistency through time 2 = Imbalanced because new sites are surveyed with time, but monitoring of older sites is not maintained. Imbalanced survey design may result in spurious trends 1 = Highly imbalanced because different sites are surveyed in different sampling periods and sites are not surveyed consistently through time (highly biased).	to the data source level by visual inspection	1 to 4 (least to most suitable)

A2.6.1 Overview of Time-series length and Time-series Sample Years

The average time-series length for threatened/Near Threatened birds was highly variable, but generally low (harmonic mean = 1.9 years, median = 3), as was the average of time-series sample years (harmonic mean = 1.8 years,



median = 2). There was substantial variation in these parameters across functional groups (Figure 27).

Figure 27: Overview of time-series length and time-series sample years for functional bird groups from data without excluding records based on suitability. Plot is made based on aggregated database consisting of 11,772 non-zero time series. Boxplots show the median value (lines) the interquartile range (or 50% data volume-boxes), 1.5x the interquartile range (whiskers), outliers (dots) and extreme outliers (asterisks).

After application of suitability criteria and quality control, data from 43 sources, 104,658 surveys, 72 species resulting in 11,772 time-series records or rows in the database are used for index calculation (Figure 28).

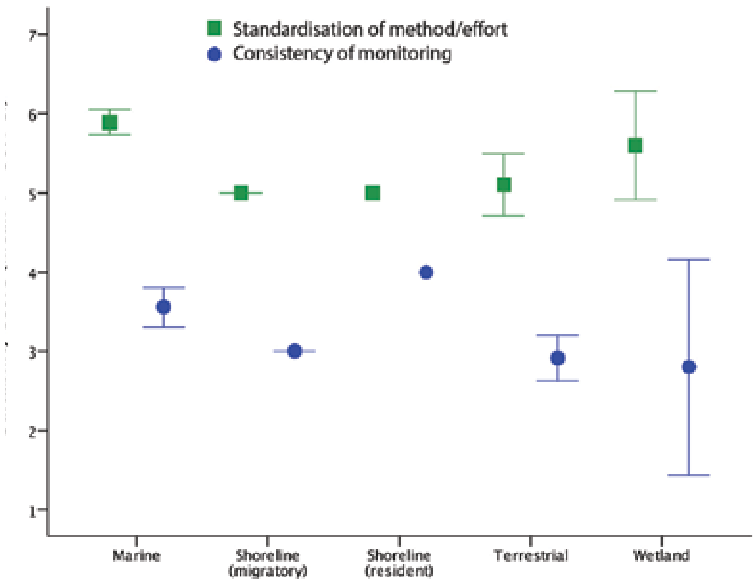


Figure 28: Overview of suitability-assessed datasets based on Standardisation of Method/Effort and Consistency of monitoring. Plot is made based on 154 datasets assessed.

A2.7 The Living Planet Index method – how does it work?

The Living Planet Index method (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017) is calculated as a geometric mean of trends for each species within a Generalised Additive Modelling (GAM) framework. The index value is the average change in multi-species population abundance from one year to the next. It shows the rate of change and not the absolute change in population sizes. For any given year in the population time series, the index values represent the overall trend in that year relative to the baseline year set to 1.0 in 1970 - in case of calculating the Living Planet Index. The baseline year for the Threatened Species Index for birds was set to 1980 due to data availability. The confidence intervals illustrate 95% confidence in the index value in any given year relative to the baseline year.

A2.7.1 What is a population time series?

A population time series is a sequence of population samples at two or more time points that uses the same method of collection at the same location i.e. repeated monitoring at fixed sites. At a minimum, a time series requires a spatial information about the location, a description of the monitoring method (e.g. standardised bird monitoring over an area of two hectares and a time of 20 minutes), and the units of measurement (e.g. numbers of individuals, number of calls recorded, occupancy measured as presence/absence)

A2.7.1 How is the index created?

For the calculation of the Living Planet Index with Australian data, we use the *rlpi* package for the software *R (R Core Team 2017)*. The package is currently under active development by the Indicators and Assessments Unit of the Zoological Society of London but can be accessed and downloaded via the software development platform *GitHub*: https://github.com/Zoological-Society-of-London/rlpi

The *rlpi* package in *R* calculates indices using the Living Planet Index methodology which has been developed within three generations (Loh et al. 2005, Collen et al. 2009, McRae et al. 2017), with the latest one using weighting of the index based on species diversity to control for taxonomic bias towards taxa for which much data are available vs taxa from ecosystems for which less data are available (e.g. tropics,(Collen et al. 2008)).

To calculate indices using the geometric mean (Santini et al. 2017), first all species' population trends from time series are aggregated to the species level for the region of interest, and then across higher taxonomic or geographical groupings. For example, multiple time series on one taxon within an Australian state will be combined first to generate individual species indices for that species and state, then these are combined to the broader taxonomic group such as birds or functional groups of birds before finally resulting in an index of a taxonomic group for that state.

The *rlpi* package works with source data in *comma separated (csv)* format where each row is a time series of a species monitored at the one site with a monitoring method and units of measurement and yearly aggregated count of measurement units. Each row or time series is composed of *popid, species name, year,* and *popvalue*. The *popid* represents the unique identifier of each time series in the dataset for LPI. The *species name* can be either the common name, binomial scientific name or trinomial scientific name if data to the subspecies level are available. The *species* name cannot have spaces between each string of letters. The *year* is the respective year for which a count value is available. The *popvalue* represents the count value of taxon in the unit provided and under a monitoring method and a site. These four values of each time series can be stored in one file consisting of multiple groups of time series (e.g. a file for shorebirds time-series populations). An *'infile'* communicates with the *LPIMain* function of the *rlpi* package where these files are stored and how they are to be combined before an index can be calculated.

The Threatened Species index for birds calculated in 2017 ends at 2015 because of technical constraints within the *rlpi* package. This is currently under development by the Zoological Society of London.

A2.7.3 Selecting the Method

Two methods i.e. models are used to generate trend values for the index. The first one applies a 'generalised additive modelling' (GAM) technique (Fewster et al. 2000, Buckland et al. 2005, Wood 2006). The second one analyses time series with the 'chain link method' (Loh et al. 2005, Collen et al. 2009).

Time series with a time-series length of n < 6 years of data and those longer time series where the GAM was a poor fit are analysed with the chain method (Collen et al. 2009, McRae et al. 2017) as per LPI default. The *rlpi* package includes a model test to evaluate the model fit of the GAM to the data and select the 'chain method' where the GAM fit was poor. All time series for which the model tests were successful are analysed using GAMs after Collen et al. 2009 and by applying the *mgcv* package in the software *R* (Wood 2003, 2004, 2006, 2011, 2016). In cases where there is a justification to use a GAM for shorter time series than 6 years, this can be changed manually in the model selection of the package. For example, (Barnes et al. 2016) have used a chain method for time series with a length of n < 5 years of data.

A2.7.4 The Chain Method

For each successive pair of years with data, the logarithm of the ratio of the species population time-series measure is calculated as (Collen et al. 2009):

$$d_t = log\left(\frac{N_t}{N_{t-1}}\right) = log\left(N_t * \frac{1}{N_{t-1}}\right)$$

where N is the species population time-series value i.e. count value with a unit and recorded under a specific monitoring method, and t is the year.

One percent (1%) of the mean species population time-series value (1% of the arithmetic average from all count values in one time series) is added to the count values in all years for time series that contain at least one zero value (zero counts indicating non-detections of species). This avoids the occurrence of the value '0' as N in any given year (Collen et al. 2009) which would conflict the logarithm function. **Missing values i.e. NULL values are imputed** by means of a log-linear interpolation:

$$N_i = N_p\left(\frac{N_s}{N_p}\right)^{\left[\frac{(i-p)}{s-p}\right]}$$

where

i

is the year for which the value is interpolated,

p

is the preceding year with a measured count value, and

s

is the subsequent year with a measured count value.

A2.7.5 Aggregating Time Series

For species with more than one population time series, the mean value of

d_t

as the rate of change in the species population over time, was calculated across all time series available for that species. Thus, species-specific values for d_t were combined in each time point using the (arithmetic) mean of **the imputed values** (i.e. time series contain no gaps at this stage) by:

$$\bar{d}_t = \frac{1}{n_t}\sum_{i=1}^{n_t} d_{it}$$

This done by applying a uniform weighting for each time series, i.e. assuming all time series are equally valid and that no time series should weight more than others. Because d_t represents the logged ratio of the count values N_t to N_{t1}, calculating the arithmetic average of all d_t values results in a geometric average of the ratio of the counts in year t compared to the counts in the previous year.

A2.7.6 Calculating Index Values

The index value

I

is calculated in year

t

by

$$I_t = I_{t-1}\, 10^{\bar{d}_t}$$

The index value for the first year, I_0, is set to 1.0 in the LPI method. This year represents the reference year for all further calculation in respect to which the rate of change is being calculated. The default reference year of the LPI method where the index value is set to 1.0 is 1970. We have changed this reference year to 1980 because this year represents the onset of time-series data in our database. For the reference year where the index value equals 1.0, there is no uncertainty in the index. As species trends, I, are added and the relative change between the species trends at any given year and the previous year are calculated, bootstrapping is used to calculate the confidence intervals where we can be 95% confident about the index value.

A2.7.7 What is a GAM?

A generalised additive model (GAM) (Hastie and Tibshirani 1987, 1990) is a nonparametric extension of a generalised linear model (GLM). The linear predictor in a GAM involves a sum of smoothing functions of covariates. That is, the linear predictor now predicts some known monotonic smoothing function of the expected value of the response. The response may follow any exponential family distribution, or simply have a known mean variance relationship, permitting the use of a quasi-likelihood approach.

GAMs are often used when there is no a *priori* justification for choosing a particular response function (e.g. linear, quadratic, etc.). In the case of the Threatened Species Index, the GAMs allow the change in relative abundance to follow any smoothing curve in addition to the standard linear forms. Thus, the GAMs allow the change in relative abundance to follow more closely expected fluctuations in response to environmental change.

GAMs fit a smoothing function, by taking each predictor variable in the model and separate it into different sections which are limited by 'knots'. Polynomial functions are then fitted to each section separately, with the constraint that there are no sharp twists or curves at the knots. These twists or curves at the knots are omitted by making sure that the second derivatives of the polynomial functions are equal at the knots.

Within the LPI method, splines are used as the smoothing functions (Wood 2006). A spline is a curve constructed from sections of polynomial functions joined together so that the curve is continuous up to the second derivative. The points at which the sections are joined are known as the knots of the spline. Each section has different coefficients, but at the knots it will match its neighbouring sections in value and the values of the first and second derivative.

The number of parameters required for a GAM fitting is more than what would be necessary for a simpler parametric fit to the same data. However, through computational shortcuts, the mean of the degrees of freedom of the model is usually lower than what you might expect from a line with so much 'wiggliness'.

The **principal statistical objective of GAM modelling is to minimise the residual deviance** (i.e. increase the goodness of fit) **while maximise parsimony** (i.e. obtain the lowest possible degrees of freedom).

Since the model fit of a GAM is based on deviance and likelihood, fitted models are directly comparable with GLMs which also use likelihood techniques or classical tests based on model deviance (Chi-squared or F tests, depending on the error structure). The goodness of fit of these models can be evaluate by means of the Akaike information criterion (AIC) which estimates the quality of the model with the best fit where the AIC score is lowest. In addition, all summary (*fitted, summary, coef,* etc.), error *(resid)* and *link* (including Poisson and binomial *link* functions) structures attributed from the GLMs or linear modelling frameworks are also available for the GAMs.

A2.7.8 How is the GAM calculated?

A generalised additive model (GAM) is fitted on observed values with

$$log_{10}(N_t)$$

as the dependent variable and year (*t*) as the independent variable. According to Wood 2006, a conservative smoothing parameter k would be the length of the population time series divided by 2. In Collen et al 2009, this smoothing parameter was observed to perform optimally, thus the default in the LPI method is set to:

$$k = \frac{time - series\ length}{2}$$

However, the LPI model allows for manual adjustment for an optimal smoothing parameter k for each time series by setting the function in the *rlpi* package:

$$MODEL\_SELECTION\_FLAG = 1$$

This selection will find the optimal smoothing parameter for each time series. This is done by comparing the estimated degrees of freedom when the smoothing parameter was successively incremented by 1. The optimal smoothing parameter will be this with the lowest number of estimated degrees of freedom.

The following selection will apply the default of half the time-series length as smoothing parameter k:

$$MODEL\_SELECTION\_FLAG = 0$$

The fitted GAM values are then used to calculate predicted values for all years (including those with no real (but imputed) count data. With these predicted count values, the mean value of the rate of change, d_t, is calculated and aggregated as described above in section A2.7.4.

A2.7.9 What is the second derivative?

The second derivative of abundance of species is the 'rate of change' of the 'rate of change'. It is well illustrated by (Fewster et al. 2000). For velocity as a common example, the first derivative or the 'rate of change' of distance travelled is velocity, while the second derivative or the 'rate of change of rate of change' is acceleration:

$$\boldsymbol{a} = \frac{d\boldsymbol{v}}{dt} = \frac{d^2\boldsymbol{x}}{dt^2}$$

With a as acceleration, v as velocity and x as distance. The second term represents the second derivative expression. The second derivative can be conceptualised as the slope of a tangent at any given point in a polynomial expression.

A2.7.10 What is bootstrapping?

Bootstrapping is used to generate confidence intervals around the index values by resampling species trends.
To calculate a bootstrap replicate, for each interval

$$t–1$$

to

$$t$$

, a sample of

$$n_t$$

species-specific values of

$$d_t$$

is selected at random with replacement from the

$$n_t$$

observed values (i.e. from the full dataset). This is carried out at each time interval for a given index, e.g. for an index on all threatened birds in Queensland. Then time series are aggregated as

$$\bar{d}t$$

and the index calculated as

$$I_t$$

as described above. The LPI default is set to the calculation of 10,000 bootstraps. Thereof, the bounds of the central 9,500 values of

$$I$$

represent the 95% confidence interval of the aggregate index.

A2.7.11 Inflection Points

Points of change in the index value can be identified by points at which the second derivative significantly differs from 0 (Fewster et al. 2000). These points are called inflection points and describe locations in the overall index where an increasing or decreasing trend for threatened species changes significantly.

A2.8 Research Collaborators of the Threatened Species Index Project

Name	Organisation/	Contribution
Hugh Possingham	UQ/TNC	Project Leader
Ayesha Tulloch	UQ/USYD	Project Co-Leader
Elisa Bayraktarov	UQ	Project PostDoc. Analysis and interpretation of datasets; liaising with stakeholders; writing manuscripts/reports; communication
James O'Connor	BirdLife	Provision of key datasets and close involvement in creating composite bird biodiversity metrics. Host of raw data (birds) for NESP projects. Key contact and representative in BirdLife Australia.
Glenn Ehmke	BirdLife/UQ	Support in data quality control, vetting, pre-processing, database management and hosting; development of scientific workflow
Joris Driessen	BirdLife/UQ	Support in data quality control, vetting, pre-processing, database management
John Woinarski	CDU	Project contributor
Stephen Garnett	CDU	Project contributor
Siddeswara Guru	UQ/TERN	Project contributor; establishing scientific workflow
Hoang Ahn Nguyen	UQ/RCC	Project contributor; establishing scientific workflow
James Watmuff	Planticle Apps + Development	Project contributor; software and web-app developer; establishing scientific workflow; front end; web visualisation tool development
Louise McRae	ZSL	Support in analysis, interpretation of trends and code development. Key contact for the Living Planet Index methodology.
Megan Barnes	UQ Honorary, University of Hawaii	Support in analysis and interpretation of trends
PhD Student: Stephanie Avery-Gomm	UQ	Collation of seabird data; statistical analyses; index calculation; writing manuscripts
Sarah Legge	UQ	Project contributor; focus on index for mammals
David Lindenmayer	ANU	Project contributor; provision of data
Liana Joseph	AWC	Project contributor; provision of data
Eve McDonald-Madden	UQ	Project contributor
John La Salle	ALA	Engaged for hosting aggregated database and visualisation of index; data curation.
Miles Nicholls	ALA	Engaged for hosting aggregated database and visualisation of index; data curation. Key contact in ALA.
Peter Brenton	ALA	Engaged for hosting aggregated database and visualisation of index; data curation.
Hamish Holewa	ALA	Chief Operating Officer
James Robinson	ALA	Business Development & Commercial Manager
Salit Kark	UQ	Interest in applicability of index for island species; provision of data on island species
Alienor Chauvenet	UQ	Support in analysis and interpretation of trends
Michael Vardon	ANU	Interest in applicability of index for environmental accounting
James Brazill-Boast	NSW OEH	NSW are developing a standardised index across all threatened species, particularly as a means of establishing a baseline prior to the implementation of the new Biodiversity Conservation Act, against which to evaluate success. Key contact and representative for NSW.
Eren Turak	NSW OEH	Developing an environmental monitoring assessment framework; contact for freshwater species; key contact and representative for NSW.
Margaret Byrne	WA DBCA	Provision of data (particularly on plants in WA); key contact and representative for WA; particularly interested whether the index can be used to report on management effectiveness
Colin Yates	WA DBCA	Key contact for the prototype development of a plant index initially based on WA data.
Daniel Rogers	SA DEWNR	Facilitation of data provision; key contact and representative for SA
Adrian Moorrees	Vic DELWP	Facilitation of data provision; policy and reporting for threatened species; key contact and representative for Vic.
Mel Hardie	Vic DELWP	Key contact for biodiversity data in the Victorian Biodiversity Atlas; interested in the implementation of data standards to make state repository data more useful for comparative trend analyses such as the index
Peter Latch	DoEE: Terrestrial Threatened Species Section	Key contact and representative in the Department of the Environment and Energy

Name	Organisation/	Contribution
Judy West	DoEE: Parks Australia	Parks Australia data and plant expertise; key contact and representative in Parks Australia.
Kerrie Bennison	DoEE: Parks Australia	Science Team Parks Australia; provision of data; key contact and representative in Parks Australia.
Nicholas MacGregor	DoEE: Parks Australia	Overview of all monitoring programs for threatened species on the Parks estate, along with maintenance and analyses and interpretation of their data; key contact in Parks Australia.
Brydie Hill	NT DENR	Provision of data; key contact and representative for NT.
John Hodgon	QLD EHP	Facilitation of data provision; key contact and representative for QLD.
Margaret Kitchin	ACT Gov	Facilitation of data provision; key contact and representative for ACT.
Oberon Carter	Tas DPIPWE	Facilitation of data provision; key contact and representative for Tasmania.
Alex Kutt	BHA	Key contact and representative for Bush Heritage Australia

A2.9 End-users we have engaged with/providing substantial support

A2.9.1 Departmental stakeholders with extensive involvement since the commencement of the project

Which Group?	Engaged via and when?	Why interested in index?
DoEE: Terrestrial Threatened Species Section	Peter Latch (since beginning of the project 2016)	Interested in index for future species recovery planning; has good ideas about visualisation of the index as a 'species dashboard'
DoEE: Parks Australia	Judy West, Kerrie Bennison and Nicholas McGregor (since start of project in 2016)	Interested in getting all threatened species data in one place; particularly interested in an index for plants

A2.9.2 Other departmental stakeholders, including those interested in adopting the index

Which Group?	Engaged via and when?	Why interested in index?
DoEE: Environmental Information Policy and Reporting, State of the Environment Reporting (SoE) Group	Emma Hyland (since start of project in 2016); Naomi Dwyer (since Sept 2017)	Interested in incorporating index as a measure to track change in threatened species for SoE reports
DoEE: Essential Environmental Measures Group	Jarrod Green (since Sept 2017; invited members of project 3.1 to be part of the Shorebird Essential Environmental Measures Group)	Use index to track change in species and use available data
DoEE: National Biodiversity Strategy	Sarah Bloustein (since Sept 2017)	Interested to use index and data to report on international targets e.g. to the Convention of Biological Diversity (CBD)
DoEE: Environmental Accounts & Science	Sarah-Jane Hindmarch, Michael Vardon (since Sept 2017)	Interested in using the index and available data to integrate in environmental accounts
DoEE: Species Information and Policy Section	Jason Ferris (since Sept 2017)	Interested in index to improve SoE reporting and do a better job than the Red List Index to report towards CBD

A2.9.3 State/territory and other stakeholders interested in adopting the index and/or integrating aggregated data

Which Group?	Engaged via and when?	Why interested in Index?
Wentworth Group of Concerned Scientists	Peter Cosier and Celine Steinfeld (since August 2017)	Interested in integrating available data into environmental accounts work
The Atlas of Living Australia	John La Salle, Miles Nicholls, Rebecca Pirzl, Peter Brenton, Hamish Holewa, James Robinson (since start of project 2016)	Interested in hosting aggregated data for index calculation
QLD: Department of Environment and Heritage Protection; Threatened Species Unit	David Shevill; John Hodgon; Samantha Ryan; Dave Harper; Jane McDonald; Sarah Parker-Webb; Rebecca Richardson (since Aug 2017); Previously we have engaged with Allan Williams (director of the Threatened Species Unit) and his team	Interest in index to report on state of threatened species in QLD
NSW: Office of Environment & Heritage; Saving Our Species Program	Linda Bell; Alana Burley (since Oct 2017); James Brazill-Boast (since start of project in 2016)	Interested in index and data for NSW and how it can help to assign threatened species in six management streams within the Saving our Species program
NSW: State of the Environment Reporting Group	Rick Noble; Gaston Rozenbilds (since Oct 2017)	Interested in index to improve SoE reporting in NSW
NSW: Environmental Accounts and Economics	Mladen Kovac; Nicholas Conner; Rogelio Canizales Perez (since Oct 2017)	Interested in index and available data to be incorporated in work on environmental accounts
NSW: Monitoring evaluation and reporting group	Jo White; Tim Cooney; Joanne Wilson (since Oct 2017)	Interested in index to improve reporting for species in NSW
Vic: State of the Environment Reporting Group	Simon Kennedy (since Jun 2017)	Interested in index to improve SoE reporting for Victoria
Vic: Victorian Biodiversity Atlas; Department of Environment, Land, Water & Planning; Victoria	Mel Hardy (since Sept 2016)	Interested to use data standards for index and integrate these into Victorian Biodiversity Atlas (VBA) infrastructure in order to produce regular indices from VBA data
SA: State of the Environment Reporting Group	Jennie Fluin (since Sept 2017); Dan Rogers (since start of project in 2016)	Interested in index to improve SoE reporting for South Australia

Image: Orange Bellied Parrot. Photo: JJ Harrison Wikimedia commons CC BY-SA 3.0

A2.10 Institutions who have supported the Threatened Species Index with data

Custodian	# datasets
Alderman et al (2011)	1
Australian Antarctic Division	3
Australian National University	1
Australian Wildlife Conservancy	3
Barry Baker	1
BirdLife Australia	13
BirdLife Tasmania	1
Black-throated Finch Recovery Team	1
Central Queensland University	1
Charles Darwin University	1
David Baker-Gabb	1
Lacey et al (2015)	1
LaTrobe University	1
Long Term Ecological Research Network (LTERN)	3
Melbourne Water	1
Monash University	1
New South Wales government	5
Northern Territory government	3
Parks Australia	3
Priddel et al (2006)	1
Queensland government	4
Queensland Wader Studies Group	1
Roger Jaensch	1
Rohan Clarke	1
Save the Gouldian Fund	1
Schulz et al (2006)	1
South Australian Government	3
Surman et al (2016)	1
Thomson et al (2015)	1
Victorian government	5
Victorian Malleefowl Recovery Team	1
Victorian Wader Studies Group	1
Western Australian government	3

Data extracted from the following references:

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A2.11 Subscribed organisations to the *Friends of the Index* email list

- Arid Recovery (not-for-profit organisation)
- Australian Antarctic Division
- Australian National University:
    - Fenner School of Environment and Society
    - Difficult Bird Group
- Australian Network for Plant Conservation (not-for-profit organisation)
- Australian Wildlife Conservancy (not-for-profit organisation)
- Biome5 - Environmental Services (consultancy)
- BirdLife Australia (non-government organisation)
- Brisbane City Council
- Commonwealth Scientific and Industrial Research Organisation:
    - Australian National Herbarium
    - National Research Collection Australia
    - The Atlas of Living Australia
- Conservation & Biodiversity Operations, Conservation and Sustainability Services, Department of Environment and Science (DES, Queensland)
- Deakin University
- Department of Environment, Water and Natural Resources (DEWNR, South Australia):
    - State of the Environment Reporting Group
- Department of National Parks, Sport and Racing (NPSR, Queensland)
- Department of the Environment and Energy:
    - Biodiversity Conservation Division
    - Threatened Species Commissioner's Office
    - Science Partnerships Section
    - Essential Environmental Measures for Australia
    - State of the Environment Section
    - Environmental Accounts and Science Branch
    - Environmental Information Policy and Reporting (ERIN):

      - Landscape Analysis, Biodiversity Trends
    - Species Information and Policy Section
    - Protected Species and Communities Branch
    - Parks Australia
- Department of Environment and Science (DES, Queensland):
    - Threatened Species Program
- Department of Environment, Land, Water & Planning (DELWP, Victoria):
    - Biodiversity Division
    - State of the Environment Reporting Group
- Department of Primary Industries, Parks, Water and Environment (DPIPWE, Tasmania):
    - Threatened Species Policy & Conservation Advice
- Editorial of Decision Point, Science for Saving Species (science communication)
- Environment and Planning Directorate (Australian Capital Territory)
- La Trobe University
- Office of Commissioner for Sustainability and the Environment (Australian Capital Territory)
- Office of Environment and Heritage (OEH, New South Wales):

    - Regional Operations North Branch
    - Regional Operations
    - Economics Team
    - Monitoring Evaluation and Reporting Data & Information
    - Threatened Species Conservation
    - Conservation Programs Branch
    - Monitoring Evaluation and Reporting Data & Information
    - State of the Environment Reporting Group
- Parks Victoria:
    - Threatened Species Program
    - Science and Management Effectiveness at Parks Victoria
- Queensland Herbarium - Department of Science, Information, Technology, Innovation and the Arts (DSITIA, Queensland)
- Scientell (science communication)
- The Glossy Black Conservancy
- The University of Queensland:
    - Centre for Biodiversity and Conservation Science
    - School of Biological Sciences
    - Research Partnerships Office
- Trust for Nature (not-for-profit organisation)
- University of Melbourne
- University of New South Wales
- Wentworth Group of Concerned Scientists
- World Wildlife Fund Australia (WWF, non-government organisation):
    - Species Conservation and Indigenous Partnerships
    - Protected Areas and Conservation Sciences
- Zoological Society of London:
    - Indicators and Assessments Unit
    - Living Planet Index Team

A2.12 Estimate of In-kind Support

In-kind cost of $791,000 over two years were estimated by:

- Allocating 60% in-kind from the University of Queensland (UQ) of the salary of staff employed on the project at UQ (i.e. Elisa Bayraktarov, Glenn Ehmke, Joris Driessen, Megan Barnes) for the time of being employed
- Estimating in-kind cost of $3,000 per dataset for correspondence and low level of data manipulation for 69 datasets used for index calculation
- Taking into account the in-kind time as FTE by research partners as on research plan version 3 (0.01 FTE was assumed for external research partners for which the FTE are not known) relating to salary estimates for the following salary levels:
    - PhD
    - PostDoc/Research Assistant
    - Prof/Chief Scientist
    - Prof/Director/Executive Role in Department
    - Senior Manager
    - Senior PostDoc/Manager
- Taking into account 0.01 FTE for legal advice (one manager, one lawyer, and Ian Harris, Director of UQ's Research Partnerships Office, signatory on behalf of the NESP TSR Hub) and data sharing negotiation with raw data host (Paul Sullivan, CEO BirdLife Australia) and 27 single data custodians.

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http://www.nespthreatenedspecies.edu.au/

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