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Trends in monitoring of Australia's threatened birds (1990–2020): much improved but still inadequate

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ABSTRACT
Monitoring is vital to conservation, enabling conservation scientists to detect population declines, identify threats and measure the effectiveness of interventions. However, not all threatened taxa are monitored, monitoring quality is variable, and the various components of monitoring are likely to differ in their rates of improvement over time. We assessed the presence of monitoring and monitoring quality, using a range of metrics, for all Australia's threatened bird taxa from 1990 to 2020 (four assessments spanning 30 years). We used our assessments to understand decadal trends in the number of taxa monitored; monitoring quality; and the groups that conduct monitoring. The monitoring of Australia's threatened birds has increased substantially since 1990, from 19% of taxa to 75% in 2020. Monitoring quality has also improved, with 24.1% of taxa assessed overall as 'Good' or 'Very Good' in 2020 (up from 4.8% in 1990). However, by 2020, most monitoring programmes still scored poorly for Data availability/reporting, Management linkage, Demographic data and Training/succession planning. In 2020, private individuals and governments accounted for 59% of monitoring contributions, with the greatest number of taxa monitored by private individuals (79 of 166 taxa assessed). Despite improvements in monitoring since 1990, only a minority of taxa had high-quality monitoring in the most recent assessment period. Monitoring is a powerful tool in conservation, justifying investment in improving how it is conducted. We draw on our results and examples of high-quality monitoring programmes to develop a set of priority actions to improve monitoring of Australia's threatened birds.

KEY POLICY HIGHLIGHTS

- Although monitoring of Australia's threatened birds has improved greatly over the last 30 years, most-threatened bird taxa still have inadequate monitoring and systemic changes are required to improve monitoring quality on the scale required.
- We recommend priority actions to improve monitoring including funding reforms, targeted improvements of poor performing monitoring components and actions to boost some of the current strengths in monitoring programmes.
- Private individuals conduct monitoring for more taxa than any other group, so boosting the quality of their monitoring is especially important.

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Introduction

Biodiversity is declining world-wide. In the face of the looming extinction crisis, it is imperative to know where, when, how, and which species are suffering the most so we can prioritise the allocation of conservation efforts to save them. Monitoring enables us to track changes over time, and is routinely employed to document recovery from natural events such as fire (Rowley *et al.* 2020), or to understand the outcomes of translocations or other conservation investments (Bubac *et al.* 2019; Jahn *et al.* 2022). A monitoring strategy is an essential activity in species conservation – if implemented successfully, it can detect changes in populations, providing an opportunity to mitigate stressors in time to stop a population becoming extirpated. Ideally, it is used to assess the net benefits

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of different kinds of conservation interventions in an adaptive management framework (Walsh *et al.* 2023). Furthermore, monitoring can be used to initiate policy changes (Bayraktarov *et al.* 2021). Inadequate monitoring impedes our capacity to identify population declines and their causes. Without this kind of information, it is difficult to identify research priorities, evaluate management effectiveness, inform management/policy decisions, and adhere to international policy agreements such as the Convention on Biological Diversity (Tulloch *et al.* 2016; Legge *et al.* 2018).

Failure to monitor, or to achieve the desired objectives of monitoring, can be due to many factors. Monitoring is not uniformly adopted, is generally poorly funded, and often lacks clearly articulated goals and long-term perspectives (Magurran *et al.* 2010; Lindenmayer *et al.* 2012). For example, a global meta-analysis found very few monitoring programmes of sufficient length to enable detailed analysis of environmental change (Dornelas *et al.* 2018), while Valdez *et al.* (2023) showed that existing monitoring data remain too incomplete to form a reliable picture of biodiversity trends. Monitoring of insufficient frequency can fail to detect population changes until it is too late to act, with such failings having contributed to the extinction of the Bramble Cay Melomys *Melomys rubicola* (Waller *et al.* 2017) and the recent extirpation of one of three populations of the Abrolhos Painted Button-quail *Turnix varius scintillans* on North Island in the Houtman Abrolhos (Carter *et al.* 2023).

When evaluating monitoring, it is important to consider monitoring *adequacy*, rather than simply the incidence of monitoring. This includes understanding the characteristics of 'adequate/effective' monitoring programmes compared to 'inadequate/ineffective' monitoring programmes. Many authors have explored what constitutes a good monitoring programme (e.g. Field *et al.* 2004, 2007; Nichols and Williams 2006; Lindenmayer and Likens 2009; Tulloch *et al.* 2011; Lindenmayer *et al.* 2020; Prowse *et al.* 2021), while others have highlighted perverse outcomes associated with inadequate monitoring (e.g. Lindenmayer *et al.* 2018; Kelling *et al.* 2019). Several elements are essential to effective monitoring: that it is fit-for-purpose; at an appropriate scale; implemented using appropriate methods; of sufficient frequency, longevity and design quality; and correctly coordinated (Woinarski 2018). When evaluating a monitoring programme, it is necessary to consider not only what the data look like, but any secondary objectives. For example, a - common second objective of volunteer or 'citizen scientist' monitoring programmes is to educate or engage the public (Tulloch *et al.* 2013).

Given the clear and comprehensive definitions of effective monitoring, one might wonder why all monitoring programmes aren't perfectly designed and implemented. The prevalence of poor quality monitoring is related to the limited resources available, constrained access to technical input, and trade-offs between monitoring and other priorities. Planning and undertaking a monitoring programme requires multiple decisions about how resources can be spent to achieve what is usually more than one objective, with each objective likely having different data requirements and costs (McDonald-Madden *et al.* 2010; Tulloch *et al.* 2013). As a result, most monitoring programmes are not as effective as they could be.

Government conservation departments are increasingly under-resourced and unable to undertake routine monitoring at the scale and with the frequency required (Boutin *et al.* 2009; Lindenmayer *et al.* 2012). Other stakeholders, particularly non-government conservation organisations, indigenous land managers, and a range of research institutions have consequently become significant parties involved in biodiversity monitoring. Involvement by a broader range of groups can enhance public awareness and foster policy change. However, it is not clear how the relative prominence of monitoring by these groups has changed over time. Likewise, decadal changes in the amount and quality of monitoring overall are not well understood.

By understanding decadal trends in the amount and quality of monitoring, it is possible to identify and rectify consistently weak components, both at a broad (structural) level and a programme level. Given the conservation importance of undertaking monitoring and the rapid rate of change in many threats and species' status, major monitoring programmes should be regularly reviewed to ensure that they meet criteria for best practice (Woinarski 2018). Monitoring programmes also should incorporate new technologies such as automated acoustic recorders and wildlife cameras (Stephenson 2020) and consider the inherent challenges in integrating the growing number of citizen science datasets (Johnston *et al.* 2023). A quintessential and often overlooked requirement of successful monitoring is the use of an adaptive framework. Adaptive monitoring should regularly assess monitoring quality, incorporate any necessary changes due to new techniques or the integration of new monitoring partners and evolve as research questions change (Lindenmayer and Likens 2009). From a conservation perspective, the most effective and desirable form of monitoring is 'active adaptive monitoring' (i.e. 'learning while doing') where the monitoring is fully integrated into a broader adaptive management programme (McCarthy and Possingham 2007; Walsh *et al.* 2012).

Garnett and Geyle (2018) examined the adequacy of monitoring for Australian threatened bird taxa, finding that 29% of threatened birds had no monitoring in place, and that there was a bias towards monitoring more threatened taxa with large populations in accessible places. Here, we build on that work, using more rigorous criteria to determine monitoring quality for each threatened taxon at four reporting periods spanning 30 years (1990, 2000, 2010 and 2020). Specifically, we used our assessments to understand decadal trends in (1) the number of taxa monitored (2) monitoring quality and (3) the groups that conduct monitoring.

Methods

Bird taxa assessed

In this study, we assessed the monitoring of threatened Australian bird species and sub-species. We restricted this study to threatened taxa because we were interested in changes over time in the monitoring of this group, which has different monitoring, funding and conservation management context to non-threatened species. We note that there is potential for monitoring quality to influence threatened status (i.e. declining taxa require some monitoring to indicate decline and justify listing). This avenue of enquiry deserves greater attention but is outside the scope of this study.

We considered a taxon as threatened if it was assessed as Threatened or Near Threatened (hereafter referred to as threatened) by any one of the International Union for the Conservation of Nature (IUCN) Red List, Endangered Species Protection Act 1992, Australian and New Zealand Environment and Conservation Council (ANZECC) 1990 or the Environment Protection and Biodiversity Conservation (EPBC) Act 2000. We conducted this assessment of threatened status four times – once for each decadal reporting period (1990, 2000, 2010 and 2020). We excluded taxa that were assessed as being threatened in only one of the four reporting periods. We did this because we were interested in trends over time in monitoring adequacy of threatened species. Although this approach had potential to bias results, excluded taxa consisted of only three taxa that were excluded because they were downlisted (in all three cases, taxa were assessed as threatened in 1990 but were subsequently downlisted). A further 62 taxa were assessed as being threatened for the first time in 2020 and thus were excluded (Table 1). Because we excluded many taxa from the 2020 reporting period, this study is best viewed as a study of decadal trends in monitoring, rather than an assessment of the current state of monitoring for Australia's threatened birds.

To ensure consistency, we assessed monitoring adequacy for all remaining taxa across all time periods. Of the 166 taxa considered, five were threatened in two time periods, 22 were threatened in three time periods, and 139 were threatened in all four time periods (Table 1). This approach only had a negligible effect on the number of taxa assessed as 'taxa with monitoring' per reporting period and therefore was unlikely to bias results (Table 1).

Assessments of monitoring per taxon

For each taxon, we assessed whether there had been any monitoring, and if so, determined the quality of monitoring. For the 2020 reporting period, assessments of monitoring quality were made as part of the Action Plan for Australian Birds 2020 (Garnett and Baker 2021). Assessments for the remaining three reporting periods were made by applying the same criteria as in the 2020 report, using the documentation available for the Action Plan from the relevant period (Garnett 1992; Garnett and Crowley 2000; Garnett *et al.* 2011).

For each taxon, monitoring adequacy was assessed against 10 criteria or 'metrics' (Supplementary Material I), of which the first nine were derived from Woinarski (2018). An additional criterion 'Training and Succession Planning' was included because to be sustained, monitoring must be continued by multiple practitioners operating in a consistent manner, with as little inter-observer variability as possible. This requires training of people in monitoring techniques and a considered succession strategy to ensure all the processes involved in monitoring are perpetuated, although still allowing for

Table 1. Percentage of threatened bird taxa in Australia with any monitoring per reporting period, considering only those taxa that were assessed as threatened in that reporting period, rather than all 166 taxa assessed across all reporting periods.

	1990	2000	2010	2020
Count of taxa threatened at reporting period (Out of 166 included in this study)	146	160	159	157
Count of taxa monitored at reporting period	29	74	103	114
Percentage of taxa threatened at reporting period that were monitored	20	46	65	73
Percentage of all 166 taxa that were monitored (For comparison)	19	45	65	75

innovation as superior monitoring techniques become available (Lindenmayer and Likens 2010).

Each metric had six levels of adequacy, from zero for taxa with no monitoring up to five for best practice for the metric concerned (Supplementary Material I). Taxon monitoring scores were calculated by summing scores for the 10 measures and converting to a percentage of maximum possible to obtain a score out of 100. Scores below 50 were considered 'Very Poor', 50–59 'Poor', 60–69 'Medium', 70–79 'Good' and scores ≥ 80 'Very Good'. The bands used were based on those used by Woinarski (2018) and Garnett and Baker (2021). Here, and in those foundational studies, a broad band was allocated to the 'Very Poor' category because data obtained from monitoring programmes with scores below 50 can rarely be used to assess trends with any confidence. The 'Very Good' category was also broad relative to the poor-good categories because the highest standards are usually required for several of the criteria for the cumulative score to exceed 80. When presenting results related to monitoring quality, we merged the 'no monitoring' and 'Very Poor' categories so that five levels of monitoring quality are presented.

For each decadal reporting period and each taxon, those responsible for undertaking the monitoring, if it occurred at all, were categorised as government (employees or contractors), academic researchers, private company employees, private individuals, non-government organisations or indigenous rangers (except where the monitoring was being undertaken outside Australia for which no categorisation was attempted). All groups that contributed substantially to monitoring for a given taxon were listed under that taxon, that is, groups were not mutually exclusive.

Presentation of results

We used summary statistics in this study, rather than frequentist tests of significance. We consider this approach appropriate because the data effectively represents a census of monitoring adequacy in Australian threatened bird taxa, rather than a sample of a population with error distributions.

We present trends in monitoring adequacy over time for all species combined, and for five broad taxonomic groups of Australian threatened birds, as has been undertaken in other studies (Szabo *et al.* 2012; Garnett and Geyle 2018). The groups are seabirds; shorebirds; parrots; passerines; others.

Results

Trends in the number of taxa with any monitoring

We found consistent and substantial improvements in the number of threatened bird taxa monitored over the four reporting periods in this study (Figure 1). Of the 166 taxa assessed, 19% were monitored in 1990, compared to 75% in 2020. Considering only those taxa threatened at each reporting period (rather than comparing all 166 taxa across all reporting periods) made almost no difference to results (Table 1).

In 1990, four of the five broad taxonomic groups assessed had similar and very low rates of monitoring (14–25%) with the remaining group, shorebirds, monitored at a higher rate (43%; Figure 1). By 2020, however, four of the five groups had similar and very high rates of monitoring (79–90%), with the remaining group, seabirds, monitored at a lower rate (51%).

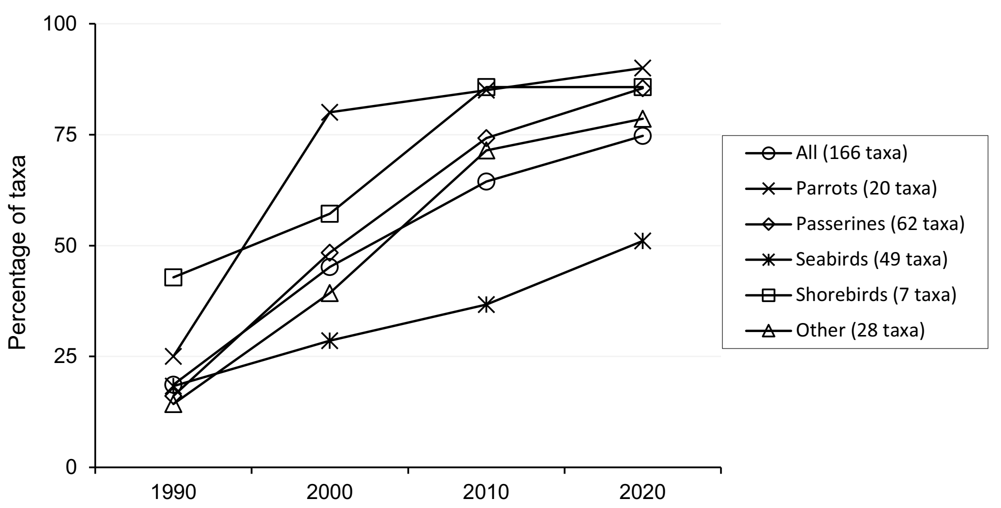


Figure 1. Decadal trends in the percentage of threatened bird taxa with any monitoring. Results are presented for 'all' taxa and for five broad taxonomic groups. The number of taxa assessed in each group is listed in parentheses in the legend.

Trends in the quality of monitoring

We found substantial and consistent improvements over the decades assessed in the overall quality of monitoring (Figure 2, centre panel). The percentage of taxa with 'Good' or 'Very Good' monitoring increased from 4.8 (eight taxa) in 1990 to 24.1 (40 taxa) in 2020. However, despite these improvements, by 2020 just over half of the taxa assessed (51.9%; 86 taxa) still had 'Poor' to 'Very Poor' monitoring.

We also found substantial variation among the 10 monitoring components, in terms of the degree of improvement over the decades assessed (Figure 2). The components of monitoring with the greatest level of improvement over the decades assessed were Fit-for-purpose, Coverage, Frequency, Longevity, Design quality and Coordination (Figure 2, panels 1–6). However, despite greater increases in these components, 'Fit-for-purpose' was the only component to have greater than 50% of taxa assessed as 'Good' or 'Very Good' (89 taxa). The poorest performing components of monitoring were Data availability/reporting, Management linkage, Demographic parameters and Training/succession planning (Figure 2, panels 7–10). Although these components have improved since 1990, the scale of improvements was much less, and fewer than a quarter of the taxa were assessed as 'Good' or 'Very Good' in 2020.

The pattern of improvement over decades varied between monitoring components. For example, the number of monitoring programmes classed as 'Good' in the Fit-for-purpose and Design quality components increased substantially since 1990, whilst the number of programmes scoring 'Very Good' for these components showed a relatively subdued increase. By contrast, Frequency and Coordination showed the greatest increase in the 'Very Good' class.

In 1990, overall monitoring scores of 'Good' or 'Very Good' were rare for all broad taxonomic groups (Figure 3). Whilst there was improvement in overall monitoring quality over the decades assessed for all taxonomic groups, the scale of improvement was not consistent across groups. Parrots, passerines and shorebirds, showed the greatest improvements. While seabirds showed the least improvement (Figure 3).

Trends in who conducts monitoring

For all decades assessed, most monitoring was conducted by governments and private individuals (88% in 1990; 86% in 2000; 81% in 2010; 69% in 2020; Figure 4). The rate of increase in taxa monitored since 1990 was greater for private individuals than for governments. As a result,

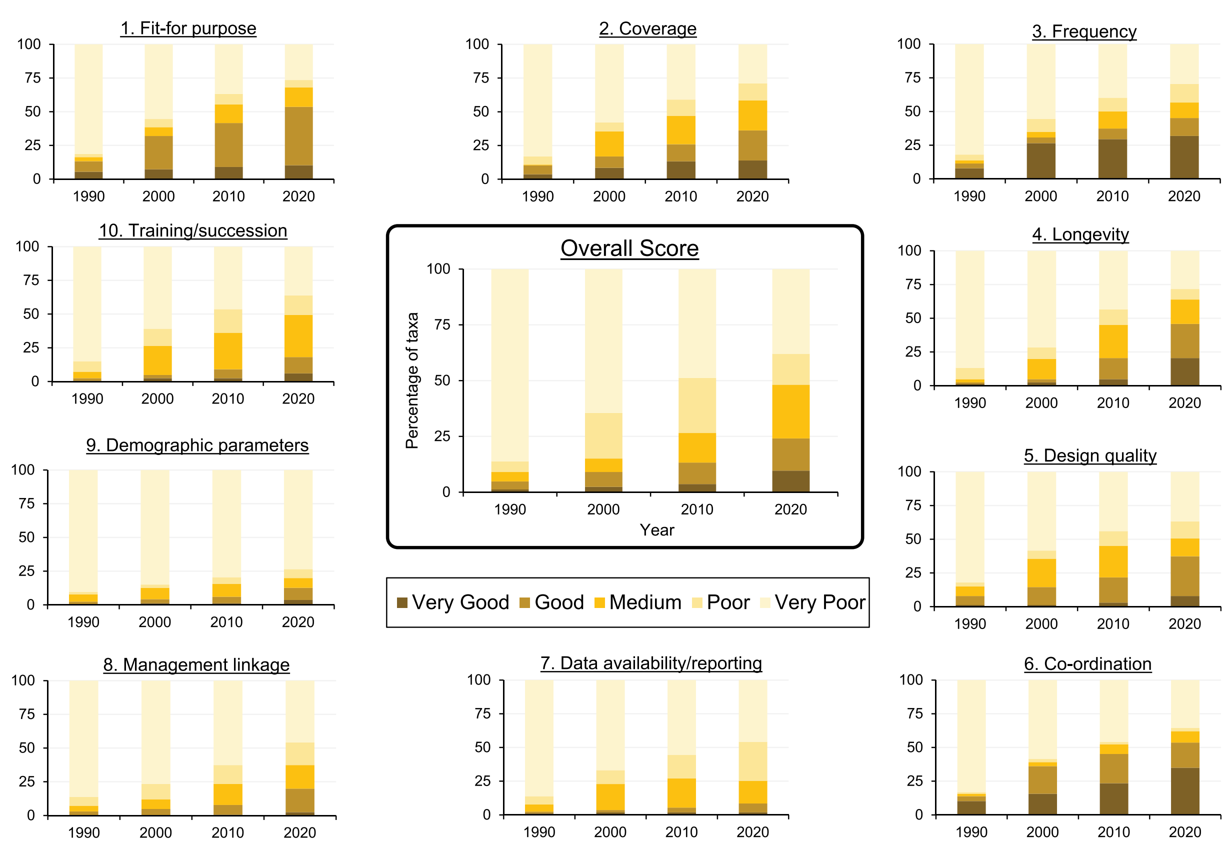


Figure 2. Decadal trends in the adequacy of monitoring for Australia's threatened bird taxa. The overall score (centre) is comprised of 10 components of monitoring assessed independently for each taxon (numbered 1–10).

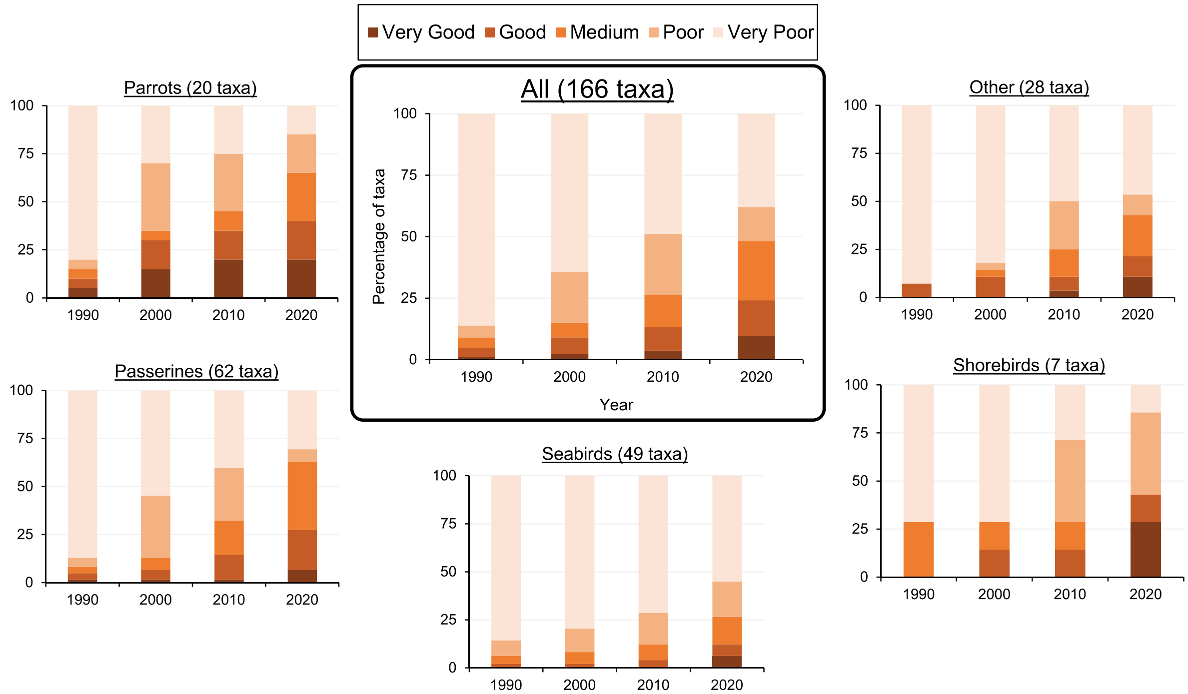


Figure 3. Decadal trends in the adequacy of monitoring for Australia's threatened bird taxa. Results are presented for 'all' taxa and separately for five broad taxonomic groups. The number of taxa assessed in each group is listed in parentheses.

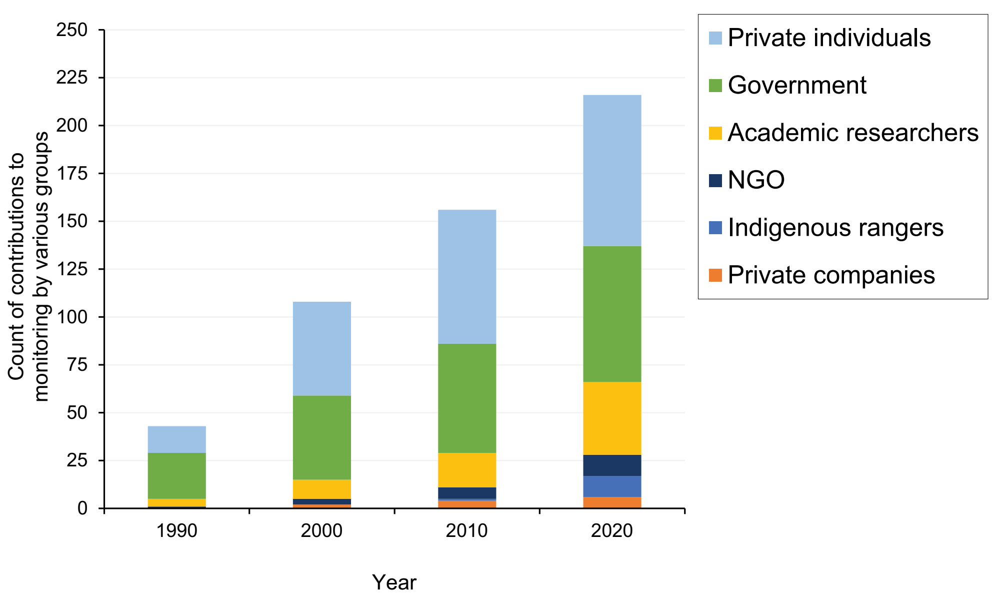


Figure 4. Decadal trends in who conducts monitoring for Australia's threatened bird taxa. Note: multiple groups sometimes contributed to the monitoring of a single taxon. As a result, the total count of contributions to monitoring is greater than the total number of taxa monitored for any given decadal reporting period.

by 2020 private individuals conducted monitoring for more of the taxa assessed than any other group (79 taxa compared to 71 taxa monitored by government; Figure 4). Academic researchers showed a large proportional increase in taxa monitored over decades, and by 2020 they monitored 38 of the taxa assessed (Figure 4). Indigenous rangers and NGOs also had large proportional increases over the decades assessed. For example, indigenous rangers monitored 11 of the taxa assessed by 2020, up from one taxon in 2010 (Figure 4).

Discussion

Our results showed that both the number of taxa with any monitoring and the quality of monitoring of Australia's threatened birds have improved since 1990. However, these improvements were somewhat limited in scale, and uneven across the monitoring components and broad taxonomic groups assessed. We also found that since 1990, private individuals have overtaken government as the most prolific of any group conducting monitoring. Below, we reflect on these results to understand the strengths and weaknesses in the monitoring of Australia's threatened birds and patterns in who undertakes monitoring. We present a set of priority actions to improve monitoring, informed by our results. Our priority actions relate to both the broad-level (structural) and the programme-level.

Strengths of monitoring programmes

Increases in monitoring quality were greater for some components of monitoring than others. Effective coordination has repeatedly emerged as a key determinant of monitoring success, especially for programmes reliant on citizen scientists for data collection (Tulloch *et al.* 2013). For threatened Australian birds, coordination quality has increased since 1990, and monitoring programmes have become more fit-for-purpose, driven by improved linkages between monitoring efforts and overarching scientific objectives. However, the pattern of improvement over decades was not the same for these two components: improvements in Fit-for-purpose centred on an increase in the number of programmes scoring 'Good', whereas for Coordination, improvements centred on an increase in the number of programmes scoring 'Very Good'. This may indicate that the barriers to optimal monitoring are not uniform between components, and achieving the best monitoring possible may remain elusive for some components despite concerted improvements to monitoring programmes.

Several other strengths relate to volunteer-driven monitoring programmes, that had greater coverage, frequency and longevity than government-led programmes. Similar patterns have been noted in Canada, where government-led monitoring programmes centred on birds were found to lack consistency in method, frequency and spatial coverage, limiting inference about the broader biodiversity patterns they were intended to indicate (Boutin *et al.* 2009).

We can learn from specific, high-quality monitoring, even in those components that did not generally improve over time for the 166 taxa assessed. In Box 1, we highlight five programmes that scored 'Very Good' overall and overcame specific challenges to effective monitoring that are common to many taxa. To some extent, these examples can act as a guide for other monitoring programmes by highlighting the ways some key challenges can be overcome.

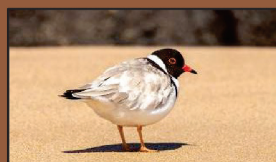
Weaknesses of monitoring programmes

Despite increases in the number and quality of monitoring programmes, monitoring remains absent or inadequate for many of Australia's threatened bird taxa. Poor monitoring can have serious consequences for protecting and recovering threatened species. Insufficient monitoring coverage (e.g. Red Goshawk *Erythrotriorchis radiatus* monitoring) may mean that population declines in particular parts of a species' ranges are missed, threats are missed or misidentified, local extinctions occur, and the area of occupancy of the species is reduced, potentially leading to increased extinction risk. Insufficient monitoring frequency and longevity (e.g. Southern Fairy Prion *Pachyptila turtur subantarctica* monitoring) may lead to missed population fluctuations in response to disturbances, preventing the accurate prediction of those species' trajectories into the future under increasing disturbances, and potentially leading to overestimates of their security (Woinarski 2018). 'Demographic parameters' scored poorly in most monitoring programmes, despite these data being critical for modelling population rates of change and turnover. In many cases, this information is needed to inform local-scale management decisions (Robinson *et al.* 2014; Zipkin and Saunders 2018). A lack of adequate population demographic data can lead to overlooked demographic biases in populations, such as low recruitment in long-lived species (e.g. Pink Cockatoo *Cacatua leadbeateri*, Kangaroo Island Glossy Black Cockatoo *Calyptorhynchus lathami halmaturinus*, Carnaby's Black Cockatoo *Zanda latirostris*), and failure to recognise limitations to population recovery until it is too late. When monitoring programmes are poorly linked to management, as found by our analysis, uninformed land and sea management decisions will be made, or, no conservation management may be undertaken at all, and the species could go extinct (Martin *et al.* 2012) – as has probably already occurred for some island populations of the Abrolhos Painted Button Quail *Turnix varius scintillans* (Carter *et al.* 2023). Active adaptive management with monitoring embedded in the management is the optimal approach (Walsh *et al.* 2012) but was adopted for very few of the taxa assessed.

Resolving these issues is urgent: without adequate spatially explicit biodiversity data, good management and policy decisions that enable the protection of species and ecosystems may be unachievable (Walsh *et al.* 2015). Achieving effective conservation relies on

Box 1 – Overcoming key monitoring challenges

Many taxa share challenges to effective monitoring. Below we present case studies to illustrate how some challenges were overcome for some taxa. The case studies shown capture themes observed in many of Australia's threatened bird taxa. For example, the high quality monitoring of the Eastern Hooded Plover *Thinornis cucullatus cucullatus* is due to the successful collaboration of an NGO and volunteers/community groups. For extremely rare taxa, like the Helmeted Honeyeater *Lichenostomus melanops cassidix* and Orange-bellied Parrot *Neophema chrysogaster*, collaborations remain vital, but with a greater focus on links between conservation organisations with complementary specialist skills. Long-term sustainability through training and succession planning is generally rare in monitoring programs. However, the Carnaby's Black Cockatoo *Zanda latirostris* and Malleefowl *Leipoa ocellata* have achieved this.



Challenge: Widespread taxon (multiple states)

Strengths: Long-term, frequent monitoring that collects meaningful and relevant data across the taxon's range

Lessons: Partnership between Birdlife Australia (NGO for logistics/funding/training) and volunteers/community groups providing field hours

- NGOs effective facilitators when working across borders
- Volunteers valuable when covering large areas

Challenge: Very rare taxa with detailed and accurate data required

Strengths: Data detail/quality and direct links to management

Lessons: Committed long-term funding. Collaboration between organisations with different skills. Monitoring built into broader conservation strategy – done by the same people

- Integrate monitoring into broader program for strong links
- With enough funding demographic data is achievable

Challenge: Maintaining programs through training and succession planning

Strengths: Long-term viability through internal training that facilitates effective succession

Lessons: Explicit focus on training and succession required for long-term viability, whether this is by individuals or NGOs.

-Committed individuals can maintain programs long-term by prioritising volunteer training (even in the absence of secure long-term funding)

Box 1. Eastern Hooded Plover – Imogen Warren, Helmeted Honeyeater – Nick Bradsworth (Zoos Victoria), Orange-bellied Parrot – Chris Tzaros (Birds, Bush and Beyond), Carnaby's Black Cockatoo – Georgina Steytler, Malleefowl – Simon Verdon.

decision makers knowing with accuracy and in a timely manner where species occur, how their populations are changing, and which interventions are working (Costello *et al.* 2013). Our analysis indicates that three quarters of threatened bird species have poor to very poor data reporting and availability processes. Sharing species occurrence information publicly or privately presents a challenge because it requires balancing potentially difficult and uncertain trade-offs – data become available for conservation organisations to learn where and how to manage the species, but, at the same time, there is increased risk of humans accessing habitats, wildlife poaching, and habitat disturbance or loss that affect species' ability to persist (Tulloch *et al.* 2018). There are many protocols and procedures now available for sensitive data to be shared in a way that allows for the data to be used for conservation whilst also protecting locations that may be sensitive to human exploitation (Tulloch *et al.* 2018). For example, the Restricted Access Species Data Project covers geospatial species-related data that requires some level of restriction and includes a subset of threatened species locations, biosecurity threats to the nation's agriculture or data from consultants or private landholders. This project is a collaboration between multiple levels of government and non-government organisations. Those collecting sensitive information on threatened species should be urged to share these data in appropriate publicly accessible repositories such as this.

It is important to note that although many monitoring programmes for threatened birds are inadequate, they are still collecting useful data. Many simply require an increase in one component, either coverage, or frequency, to make them suitable for informing management and conservation decisions. Although many advocate for monitoring species richness as an indicator of biodiversity health rather than individual species themselves (Hillebrand *et al.* 2018), biodiversity monitoring programmes need to go beyond analyses of trends in richness in favour of more meaningful assessments of biodiversity change. This is because temporal trends in species richness have been shown to be insufficient to capture key changes in biodiversity in changing environments (Hillebrand *et al.* 2018), and particularly important for threatened species that, because of unique demographic or resource use characteristics, are often subject to cumulative impacts that exceed the stressors on other common species.

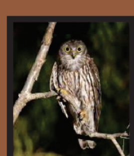
Who conducts monitoring

An important finding from our study is the rise and prevalence of private individuals collecting data on threatened bird species – by 2020 they were the most prolific group conducting monitoring. Rather than a cohesive unit, 'private individuals' is an umbrella term, covering multiple groups conducting monitoring. In Box 2, we present a break-down of the types of contributions made by private individuals. Private individuals present great opportunities for monitoring effectiveness, but also come with their own set of risks and potential data pitfalls. The private individuals contributing to large citizen science datasets like eBird and Birdata (BirdLife Australia 2023; Cornell Lab 2023), monitoring of specific sites and birds by community groups, and monitoring coordinated by NGOs, are often referred to as 'citizen scientists'. Citizen scientists invest massive amounts of time and effort in monitoring biodiversity, with estimates of public funding required if volunteers no longer participated in biodiversity monitoring in the order of millions of dollars per programme (Levrel *et al.* 2010; Tulloch *et al.* 2013).

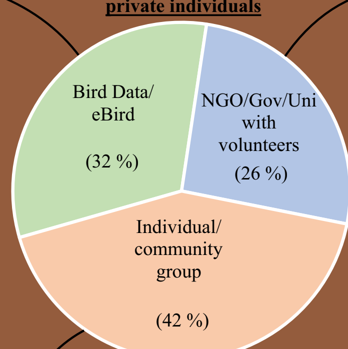
Although voluntary monitoring programmes often collect massive amounts of data, they frequently suffer from data gaps and biases (Boakes *et al.* 2010; Tulloch and Szabo 2012), and problems associated with maintaining volunteer interest and objectivity (Booth *et al.* 2011). The data compiled from volunteer monitoring programmes often exhibit strong spatial and temporal biases in survey effort (Boakes *et al.* 2010; Tulloch and Szabo 2012), stemming from volunteer motivations to monitor in some places and times more than others

Box 2 – Monitoring by private individuals

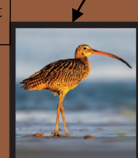
In 2020, private individuals monitored 48 percent of all threatened bird taxa in Australia, making this the most prolific group conducting monitoring. 'Private individuals' may refer to contributions to digital open access data (Bird Data, eBird), motivated individuals/community groups designing and running programs or volunteers contributing to surveys led by other organisations (see Pie-chart below). Here, we provide examples of monitoring programs led or supported by private individuals. The fact that private individuals conduct more monitoring than any other group illustrates the power of community engagement and community led conservation science. However, the relative prominence of private individuals in monitoring also indicates the inadequacy of monitoring by government organisations.



Southern Barking Owl
Ninox connivens connivens
Researchers collated publically available presence records collected over decades, mostly by private individuals. Data was used as a kind of post-hoc monitoring strategy, in the absence of alternative monitoring. Results showed drastic decline in south-west Western Australia.
- Davis *et al.* 2022



Mallee Emu-wren
Stipiturus mallee
Researchers worked with volunteers to collect thousands of hours of field data across the species range. Volunteers were vital to achieving the required level of survey intensity. Data were used to estimate population size and inform wild-to-wild translocations
- Verdon and Clarke 2022



Far Eastern Curlew
Numenius madagascariensis
Long-term data collected by the Australian Wader Study Group identified a significant decline in the Far Eastern Curlew. This is an example of a successful complex monitoring program, community-led but in collaboration with other parties
- Hansen *et al.* 2018

Box 2. Barking Owl – John Harrison, Mallee Emu-wren – Tom Hunt, Far Eastern Curlew – G. Barry Baker.

(Tulloch *et al.* 2013; August *et al.* 2020). This can create problems for researchers and decision-makers who then use biased data to answer questions that the data were not originally collected to inform. For example, a recent study evaluating whether protected areas have been effective at preventing declines in threatened birds discovered that more monitoring occurred inside protected areas, few protected areas had paired monitoring programmes inside and outside protected areas to compare population trends with a baseline, and more than 90% of Australia's protected areas did not have any threatened bird monitoring programme, making it challenging to infer any causal effects of protected area implementation and management on changes in bird trends (Barnes *et al.* 2015; Bayraktarov *et al.* 2021). Other problems associated with volunteer-collected datasets include observer error and heterogeneity in the ability of observers to detect species (Kery *et al.* 2006; Etterson *et al.* 2009).

To improve the current quality and quantity of bird monitoring by private individuals, evidence-based, science-informed monitoring plans can be developed, prioritising where, how, and who to monitor (e.g. Callaghan *et al.* 2021; Stojanovic *et al.* 2021). In this space, BirdLife Australia are currently developing a network of strategically located fixed terrestrial sites using 20-minute/2-hectare counts for long-term monitoring of birds. When implemented, this strategy will capitalise on the field-time donated by private individuals whilst reducing the biases often present in such datasets. Of course, some level of bias in datasets collected by private individuals is to be expected and new analytical methods have been developed in recent years to deal with issues such as sampling bias and uneven detection (e.g. Callaghan *et al.* 2019, 2021; Johnston *et al.* 2020).

For monitoring by private individuals to be effective, end data users (e.g. conservation planners and managers) need to build long-lasting effective partnerships with the private individuals conducting monitoring (Salerno *et al.* 2021). Government agencies at all levels also play an important role in supporting volunteer efforts via a range of mechanisms including facilitating and supporting formal and informal governance arrangements and providing funding and platforms for data storage and sharing. There is increasing evidence that more robust governance results in more positive outcomes from community conservation initiatives (Salerno *et al.* 2021). For example, regular reporting of results highlighting links to management outcomes is important for maintaining engagement of private individuals. It is therefore concerning that data availability/reporting and management linkage scored poorly for most bird taxa in this study.

Another important result from our study is the large proportional increase in bird monitoring by indigenous rangers. Indigenous ranger programmes have expanded substantially in Australia over the past two decades, and ranger teams (as well as other indigenous groups) are now implementing conservation management over large areas covering a variety of tenures (Leiper *et al.* 2018). Inclusion of indigenous people in national conservation agendas is promoting more holistic socio-ecological systems thinking (Ens *et al.* 2015). Collaborative approaches that intertwine indigenous values, knowledge and expertise, with western scientific approaches, are increasingly being used to inform monitoring in diverse taxa and ecosystems (e.g. Lilleyman *et al.* 2022; Southwell *et al.* 2022).

Priority actions to improve the state of monitoring of Australia's threatened birds

We used our results to identify priority actions to improve the monitoring of Australia's threatened birds (Table 2). These actions address both broad-level (structural) change and programme-level change.

Four priority actions relate to the way monitoring programmes are funded. Funding arrangements are often acknowledged as a key limiting factor for effective monitoring programmes (Lindenmayer *et al.* 2011). Our funding-related priority actions aim to broaden funding periods for monitoring programmes to increase longevity, frequency, and coordination whilst reducing bureaucratic burden (Action 1); reduce competition for funds between monitoring programmes and programmes relating to on-ground actions (Action 2); provide dedicated funds for seabird monitoring (Action 3); and develop a continental-scale monitoring programme for all taxa, to improve monitoring of non-threatened taxa (Action 4). We also advocate for increased coordination between scientists and community groups conducting monitoring, noting that private individuals and indigenous groups have the greatest capacity to improve monitoring quality. Finally, we emphasise the need for succession planning, noting that for many threatened taxa, the length of time needed to effect lasting change to population trajectories is greater than both government election cycles and periods of activity from motivated private individuals. Investing in succession planning is central to building the necessary infrastructure for long-term monitoring programmes and needs to be prioritised to maximise monitoring effectiveness.

Table 2. Priority actions to improve the monitoring of Australia's threatened birds (not in order of importance).

Action	Goal	Relevant Agencies	Reasoning
1. Broaden funding periods to create long-term funded monitoring programmes (Broad level)	Improve longevity, frequency, coordination and training/ succession planning of monitoring programmes	Funders – Government and non-government	Many monitoring programmes are funded through one-off grants or funding agreements that cover one survey period, resulting in poor longevity, frequency, coordination and training/ succession planning (Figure 2). Long-term funding (e.g. 10-yr minimum), would allow for multiple survey periods, creating greater capacity to detect population trends in the target taxa. Such a system would also allow greater investment in internal upskilling and would facilitate more effective engagement with other parties such as community groups plus greater capacity to improve on poor performing monitoring components such as Demographic parameters.
2. Create funding opportunities exclusively for monitoring (Broad level)	Increase number of taxa monitored and monitoring quality	Funders – Government and non-government	Funding is often a limiting factor for monitoring programmes. Monitoring programmes are often not competitive against grant applications with on-ground recovery actions. One way to improve monitoring adequacy compared to its current state (Figure 2, centre panel), is to create funding opportunities specifically for monitoring (this applies to both grant opportunities and internal funding). With dedicated funding, programmes would have greater capacity to improve poor performing components such as Demographic parameters.
3. Develop and fund specific seabird monitoring programmes (Broad level)	Improve rate and quality of monitoring for the poorest performing taxonomic group	Funders – Government and non-government	Seabirds had substantially lower rates and quality of monitoring compared to the other broad taxonomic groups assessed (Figure 3, bottom panel). Therefore, great gains could be made by developing a targeted monitoring programme for this group. There may be further efficiencies in such a programme as multiple species co-occur and have similar life-histories, meaning a single programme could capture multiple taxa. In addition, monitoring at breeding islands has potential to improve the component 'Demographic parameters', an important and poor performing monitoring component.
4. Develop and fund a continental-scale general bird monitoring programme (i.e. non-threatened species) (Broad level)	Improve monitoring adequacy for non-threatened taxa.	Funders – Government and non-government	Although threatened birds were the focus of this study, we can only know a bird is declining and qualifies as threatened when there is sufficient monitoring data available. Therefore it is important to improve monitoring adequacy for non-threatened species. This could be achieved by a fit-for-purpose, spatially broad and well designed monitoring programme with dedicated long-term funding. Some attempts for such a network are currently underway (e.g. a strategic network of monitoring sites being developed by BirdLife Australia). However, with a dedicated fund, such a programme could be broadened in terms of the spatial extent, the taxa covered and the types of data collected.
5. Mandate minimum monitoring requirements for threatened taxa in any funding agreement (with monitoring quality standards for all components, but a focus on poor performing components such as Demographic parameters) (Broad level)	Increase number of taxa monitored and monitoring quality, especially in poor performing components	Federal government	Despite improvements in monitoring since 1990, more than half of the taxa assessed still have no monitoring or 'Poor' to 'Very Poor' monitoring (Figures 1 and 2, centre panels). To achieve the required scale of improvements in the coming decades, we need strong monitoring standards for Australia's threatened bird taxa and funds for their implementation. This would also provide a pathway to improving those components that have shown the least improvement in the last 30 years (e.g. Demographic parameters).
6. Develop and administer open-access repository of data and reports for all of Australia's threatened birds (Broad level)	Improve data availability/reporting	Either Federal government or NGO-led	A central and secure repository, administered over the long-term would greatly increase availability of data and reporting. Our results indicated that improvements are needed for this monitoring component (Figure 2, bottom-centre panel). The Threatened Species Index is on its way to achieving this but lacks a repository for reporting materials and secure long-term funding. The Restricted Access Species Data Project covers geospatial species-related data that requires some level of restriction and includes a subset of threatened species locations.
7. Develop the data infrastructure to record and track all aspects of monitoring (Broad level)	Improve monitoring quality across all components	Research agencies or NGOs	Standardised approaches to capturing the locations and numbers of birds are becoming increasingly available with the potential to automate some reporting. No equivalent is available for some of the other aspects of monitoring that need to be recorded to understand the reasons behind trends such as breeding success, survival, habitat quality etc.
8. Monitor the monitoring (Broad level)	Improve monitoring standards across all taxa	Either Federal government or NGO led	Tracking trends in monitoring quality across large groups of taxa makes it possible to identify aspects of monitoring that require reinforcement and can also demonstrate a return on investment for agencies and individuals supporting monitoring.

(*Continued*)

Table 2. (Continued).

Action	Goal	Relevant Agencies	Reasoning
9. Strengthen links between scientists and private individuals/ community groups/indigenous groups that conduct monitoring (Broad level and programme level)	Improve monitoring design quality, demographic parameters and coordination for programmes led by private individuals and indigenous groups	Government and non-government funders; NGOs with experience in facilitating partnerships between scientists, private individuals and indigenous groups	Private individuals conduct monitoring for more taxa than any other group, and indigenous groups are increasingly involved in monitoring (Figure 4). Therefore, investing in improving the quality of monitoring conducted by private individuals and indigenous groups has the greatest potential to improve monitoring quality overall. Given that such monitoring is often done in the absence of sufficient long-term funding, fostering closer links between scientists, private individuals and indigenous groups is an effective way to get more out of monitoring.
10. Develop succession plans for current monitoring programmes (Broad level and programme level)	Improve training/succession planning and longevity	programme coordinators; Government; NGOs with experience working with private individuals	Very few programmes have 'Good' or 'Very Good' training/succession planning (Figure 2). At a programme level, invest in developing a succession plan, especially for programmes that rely heavily on a few motivated individuals. At a Broad level, government agencies and NGOs can develop support programmes to facilitate this process.
11. Incorporate monitoring into broader management teams or build greater links between managers and those conducting monitoring. (Programme level)	Improve management links	programme coordinators, land management agencies	In the 2020 assessment, only four taxa had 'Very Good' management linkages (Figure 2, bottom-left panel). For monitoring to contribute to species conservation it needs to influence management. One way this has occurred for some taxa is via monitoring built into the broader conservation programme. However, other frameworks may also be effective. Programmes conducted outside of management agencies, but with strong links to those agencies can also foster effective conservation. This may be more appropriate for migratory species or species occurring across multiple states.

Study approach and associated limitations

The system used for assessing monitoring quality involved transforming qualitative/descriptive classes into a numbered scale (Guttman 1944). This transformation inevitably comes with potential biases, and it is possible that the use of different qualitative classes and/or a different scale would have altered the outcomes. Whilst the transformation used represents a limitation of this study, this method is broadly applied in the fields of social sciences and public health research (Boateng *et al.* 2018), with similar approaches becoming more common in the field of conservation and ecology research (e.g. opinion analysis using quantitative surveys; Drijfhout *et al.* 2020). Potential biases can be limited by using classes that are relevant to the study goals, measurable and clearly distinguishable from one another, which we have done (Morgado *et al.* 2017).

Binning the aggregated scores for each taxa on a scale from 'Very Poor' to 'Very Good' introduced a second potentially confounding effect. Never-the-less we did this because although the bounds of such bins are ultimately arbitrary, we considered the binning both useful for summarising results, and relevant to the study goals. For example, a review of all taxa with overall monitoring quality scores of 'Very Poor' (the monitoring quality bin with the broadest range: 0–50%) showed that the programmes for these taxa were consistently unable to deliver the core goals of monitoring programmes such as reliably identifying population trends or threats. An alternative approach included using the continuous scores for each taxa and presenting the means and standard errors. While this approach would have removed the subjectivity related to binning monitoring quality scores, we deemed the presentation of means less relevant to our study goals than presenting data related to the number of taxa in each monitoring quality bin. Using bins allowed us to ask questions such as 'How many taxa had "Good" to "Very Good" monitoring and did this change over the decades assessed?' rather than 'Did the mean monitoring quality score change over the decades assessed?'

Conclusion

Since 1990, both the amount and quality of monitoring for Australia's threatened bird taxa have improved substantially. However, despite this result, monitoring quality remained inadequate in 2020, with roughly half the taxa assessed scoring 'Poor' or 'Very Poor' overall. Given the important role of monitoring in effective conservation, further improvements are required and investments that help achieve this are justified. Our priority actions in Table 2 provide practical ways to improve the monitoring of Australia's threatened bird taxa, with a focus on improving shortcomings common to many programmes and providing greater support to aspects that are already functioning well.

The prominence of private individuals in monitoring was somewhat unexpected. This result presents both opportunities and risks for the monitoring and conservation of Australia's threatened birds. This group can contribute to many monitoring programmes at large-scales and are especially important given that limited access to funding hinders effective monitoring of many taxa. Creating systems that support and boost the contributions of private individuals is an important pathway to improved monitoring. A pathway that requires greater investment in the years ahead.

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Data availability statement

All data is included in Supplementary Material: https://doi.org/10.1080/01584197.2023.227512.

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