Aligning citizen science with best practice: Threatened species conservation in Australia

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Abstract
Well-designed citizen science projects can improve the capacity of the scientific community to detect and understand declines in threatened species, and with the emergence of frameworks to guide good design, there is an opportunity to test whether projects are aligned with best practice. We assessed the current landscape of citizen science projects for threatened species conservation via a content analysis of the online communique of citizen science projects across Australia. Only 2% of projects stated clear research questions, although approximately 86% had implied project objectives aimed at threatened species conservation. Most projects were focused on field-based monitoring activities with half using structured ecological survey methods. Most reviewed projects (65%) shared data with open access biodiversity databases and the vast majority use at least one social media platform to communicate with potential and existing participants (up to 81%). Approximately 50% present citizen-sourced data summaries or publications on their websites. Our study shows there is a very strong foundation for public participation in threatened species conservation activities in Australia, yet there is scope to further integrate the principles of citizen science best practice. Improved integration of these principles will likely yield better outcomes for threatened species as well as for the citizen scientists themselves.
1 | INTRODUCTION

Citizen science is an increasingly widespread form of scientific inquiry, in which members of the public collaborate with professional scientists (Bonney, Phillips, Ballard, & Enck, 2016; Miller-Rushing, Primack, & Bonney, 2012; Pocock, Tweddle, Savage, Robinson, & Roy, 2017). However, in combination with its rapid growth since the 1990s and attempts to clearly articulate expectations of citizen science, there are various ways of defining “citizen science” (see Bonney, Cooper, et al., 2009; Haklay, 2013; Jordan, Ballard, & Phillips, 2012; McKinley et al., 2017; Wiggins & Crowston, 2011). There is also skepticism among some data end-users about the rigor of citizen science projects, and the quality of the resulting data, where critics often point to the absence of standardized methods in the design and implementation of many citizen science activities (Chatzigeorgiou et al., 2016; Dearing, 2010; Show, 2015).

The pervasiveness or implications of these shortcomings have rarely been empirically tested, and are often presented without acknowledging that many similar issues affect structured science (Dickinson, Zuckerberg, & Bonter, 2010). In principle, many of the perceived flaws associated with citizen science data can be managed at the project planning, data review or data analysis stage (Davies, Stevens, Meekan, Struve, & Rowcliffe, 2012; Galloway, Tudor, & Haegen, 2006; Gilfedder et al., 2018; Lukyanenko, Parsons, & Wiersma, 2016), and recognition by analysts of the proper application of such data. There is a growing body of research demonstrating the robust utility of citizen science data for achieving a range of objectives, including: informing conservation questions about where to carry out management, improving knowledge gain, and achieving social-ecological benefits such as education and public awareness (Frigerio et al., 2018; McKinley et al., 2017; Tulloch, Possingham, Joseph, Szabo, & Martin, 2013; Zapponi et al., 2017).

Although citizen science can be characterized in a number of ways, relating to the various modes of public involvement (Bonney, Ballard, et al., 2009; Miller-Rushing et al., 2012; Shirk et al., 2012), here, we speak largely to the most prevalent model: contributory participation via data collection and processing. Data collected by the public can substantially improve our understanding of a species’ conservation status, ecology, and threatening processes, especially at large spatial and temporal scales, where data deficits in professionalized projects are common (Conrad & Hilchey, 2011; Devictor, Whittaker, & Beltrame, 2010; McKinley et al., 2017; Sullivan et al., 2009; Theobald et al., 2015; van der Velde et al., 2017). For example, monitoring by numerous citizen scientists over a number of decades revealed enormous declines in migratory shorebirds of the East Asian Austral-asian Flyway, leading directly to a suite of conservation interventions (Hansen et al., 2018). Likewise, a nationwide citizen science study along the Australian coast yielded important information about the nature and extent of plastic debris pollution (van der Velde et al., 2017). This was followed by a nationwide push by the general public to reduce the consumption and availability of single-use plastic items, illustrating a link between raising awareness through evidence gathering and catalyzing a shift in behavior at a large scale.

Nonetheless, data quality is an important consideration in all forms of science. In response to the recent meteoric growth in citizen science, several best practice frameworks have emerged to guide project design and implementation so they deliver maximum data quality (Bonney, Cooper, et al., 2009; Cooper, Dickinson, Phillips, & Bonney, 2007; Pocock et al., 2017). However, we are not aware of any evaluations of the extent to which citizen science projects conform to these best practice principles. In this study, we provide such a test, using Australian citizen science projects focused on threatened species conservation as a case study.

Some best practice frameworks have been developed by organizations that have had high profile successes in the field of public participation in science (e.g., Cornell Lab of Ornithology, Royal Society for the Protection of Birds). While terminology may vary, there are several commonalities among the recommended key principles of the frameworks (Figure 1). These principles are also most applicable to the contributory model, often employed in citizen science for biodiversity (Shirk et al., 2012). First, a citizen science project should set a clear objective, scientific or otherwise, which is sometimes done by stating a research question that citizen-collected data might answer. Second, project coordinators need to identify the target pool of participants they want to recruit for the project. Identifying participants may come before or after the selection of the methodological approach or survey protocol (Tulloch et al., 2013). This may depend on the objectives of the project (e.g., if engagement of a particular audience is an explicit aim, then participant identification would naturally occur prior to selecting the methodological approach). Third, offering training resources is recommended to ensure the participants understand the project objectives and their role in it, as well as any survey or management protocols. Fourth, effective communication mechanisms are needed so that project coordinators can recruit participants and share the results of the project as well
as highlight remaining gaps in understanding of the target species or system. These feedback mechanisms also provide a forum for participants to share their experiences with project coordinators and fellow citizen scientists (van der Wal, Sharma, Mellish, Robinson, & Siddharthan, 2016).

There is little evidence of evaluation of integrating the aforementioned principles among citizen science projects, despite several papers providing frameworks for assessing citizen science outcomes (Bonney et al., 2016; Brossard, Lewenstein, & Bonney, 2005; Davies et al., 2012; Jordan et al., 2012). Outcome evaluation is challenging, however, assessing the integration of key project design and implementation principles can give some indication of the likelihood of achieving desirable outcomes. This is especially important for citizen science projects focusing on threatened species, where action is required urgently and efficiently.

Effective threatened species recovery often requires a thorough understanding of species’ biology and ecology, as well as accurate and up-to-date information on geographic distributions and threatening processes (Boitani et al., 2011). Despite this, agencies charged with threatened species recovery often lack the capacity to undertake intensive background and baseline research for all threatened species in their remit (Gallo-Cajiao et al., 2018; Waldron et al., 2013). In response to this shortfall, conservation professionals may recruit citizen scientists to assist with data collection, or in some cases lead monitoring efforts or direct conservation actions for species recovery.

Australia has an active volunteering community, with 31% of Australian adults contributing more than 743 million hours to various community causes in 2014 (ABS, 2017). This large population of volunteers makes Australia an ideal case study to examine the application of best practice design frameworks in citizen science for threatened species conservation. Such an assessment can also inform about trends at a relatively large scale and in an area of global biodiversity significance and threat. Australia currently has the fourth-highest level of animal species extinction (IUCN Red List, 2018) and the highest rate of modern mammalian extinctions globally, with 29 species declared extinct since European settlement (Woinarski, Burbidge, & Harrison, 2015). The top three threats to Australia’s biodiversity are habitat loss due primarily to agriculture, introduced species, and ecosystem degradation caused by inappropriate fire regimes (Evans et al., 2011; Kearney, Adams, Fuller, Possingham, & Watson, 2018).

Here we outline the current landscape of citizen science relevant to threatened species conservation in Australia, and determine the extent to which projects are being designed and implemented according to best practice. We (a) present an in-depth summary of citizen science projects that are focused on Australian threatened species and (b) critically review the extent to which the four principles identified in the best practice frameworks for citizen science are being integrated into these projects. Finally, we identify practical opportunities to enhance implementation of best practice in citizen science projects that aim to conserve threatened species.

2 METHODS

To build an initial list of citizen science projects relevant to threatened species conservation in Australia, we queried the Australian Citizen Science Project Finder between May and October 2017. This database is administered by the Atlas of Living Australia (ALA) in collaboration with the Australian Citizen Science Association and became active in 2017 (https://biocollect.ala.org.au/acsa). During this time period, we also supplemented this list with additional projects previously known to us or of which we became aware via word-of-mouth. Additionally, we invited the public to suggest projects to us through via social media channels (i.e., Facebook and e-newsletters). Acquiring projects through these diverse means provided us with a large sample of citizen science projects (n = 133) related to threatened species.
species recovery actions, research and monitoring via either in-field, desk-top, or lab-based activities. As a constantly evolving and expanding field of inquiry, it is possible further projects have come online since this data collection period. We are therefore presenting a snapshot in time of the citizen science landscape for threatened species in Australia.

We included projects that involved species listed as nationally threatened in Australia (Environment Protection and Biodiversity Conservation Act 1999) where (a) one or more threatened species were the sole focus of the project, (b) the project is centered on monitoring in an area inhabited by a threatened species or at a wide enough scale, using survey methods likely to detect the species, or (c) the project involved activities that addressed a threatening process in a known location of a threatened species. Application of the above criteria resulted in many projects engaged in broader ecological restoration activities being excluded from our study, where a direct link between their work and at least one threatened species could not be demonstrated.

We assessed the attributes of each citizen science project or coordinating organization by visiting websites and social media platforms (Table S1). We used an inductive approach to build a set of attributes about each project, adding attributes to the database as each project was reviewed and commonalities were observed (Elo & Kyngäs, 2008). In total we characterized 21 attributes that were either categorical or continuous variables (Tables S1 and S2) to build a picture of the practice of citizen science for threatened species in Australia, and to assess the extent to which these activities align with best practice frameworks. The attributes related to the framework principles of: (a) project objectives, (b) participant activities and methods, (c) training resources, and (d) communication and publication of data (Figure 1, Tables S1 and S2). Additional attributes allowed us to build a more holistic picture of how and where citizen science is happening for Australian threatened species (Table S1) (Lloyd et al., unpublished data).

Each project could receive more than one count for some attributes. For example, the Bittern Project includes standardized structured surveys for the threatened Australasian bittern (Botaurus poiciloptilus), as well as providing the opportunity to upload incidental sighting data. For the attribute “type of organisation,” we separated nongovernmental organizations (NGOs) into large or local, depending on the scale of their work (i.e., large = international, national or state scale; local = regional or local scale, Table S1). For the purposes of this study, community groups are considered as local NGOs. During our assessment of each project, we quantified how many projects had (a) research questions and/or explicitly stated their aims/objectives, (b) descriptions of the methods (i.e., citizen activity), (c) descriptions of how project coordinators communicated with potential and existing participants (i.e., recruitment and feedback channels).

3 | RESULTS

We identified 133 citizen science and public participation projects relevant to threatened species recovery, coordinated by 93 separate organizations. The oldest citizen science project reviewed was the Underwater Research Group Dive Club of New South Wales, which started in 1955 (i.e., running for 65 years and still going), followed by two continuing wader monitoring projects (45-years and 40-years old) and a national bird survey project (Birds in Backyards, 39-years old). Most projects commenced after 2000 (n = 108), with four of the 133 projects no longer running as they were designed to be short term (1- to 2-year projects; Table S2).

NGOs coordinated the majority (67%) of projects. Forty-seven projects were coordinated by 21 large NGOs; operating at a national level (e.g., Australian Koala Foundation, Australian Museum, BirdLife Australia), international level (e.g., Earthwatch Institute) or state level (e.g., Wildlife Queensland) (Figure 2a; Table S3). Forty-two projects were coordinated by 40 local NGOs (Figure 2a) including: landcare, conservation, and catchment management groups (e.g., Nature Conservation Margaret River Region), “friends of” groups (e.g., Friends of the Koala Inc., Friends of the Western Ground Parrot Inc.), and “save the” groups (e.g., Save the Bilby Fund, Save the Tasmanian Devil Project). Government agencies (n = 22) and research institutions (n = 10) coordinated 21 and 12% of the citizen science projects, respectively, for threatened species in Australia (Figure 2a). BirdLife Australia, Australia’s largest bird conservation NGO, coordinated the most citizen science projects for one organization, running 24 projects relevant to threatened species (Table S3). The Office for Environment and Heritage (New South Wales Government) led the state-based agencies, with nine projects (e.g., South Coast Shorebird Recovery Program and Keeping up with the Superb Parrot, including four within the National Parks and Wildlife Service; Table S3). Tasmania was the only state or territory in Australia without a government managed project or tool for the public to contribute data about threatened species they encounter (although several national-level projects could contribute to threatened species conservation in Tasmania).

Most projects focused on more than one species (n = 93, 70%; Figure 2b). This was related to the number of projects that draw on citizen science to learn more about biodiversity more generally (e.g., Spot Our Species, eBird Australia, Biodiversity Watch, DigiVol, FrogID, Threatened Bird Network, Reef Life Survey), rather than by taking a species-specific approach (e.g., Australian Painted Snipe Project, Save the Tasmanian Devil—Roadkill Project, Tweed Council Koala Count, Grey Nurse Shark Watch).
FIGURE 2  Number of projects per categorical attribute, as labeled for each subfigure (a–l) \( N = 133 \)
3.1 | Element 1: Identification and communication of project objectives

In our sample, only 2% of projects stated clear research questions (ecological, social or otherwise), but 86% communicated explicit broader aims or objectives (Figure 2c). In some cases, where objectives were not explicitly stated, we were able to infer overarching goals of the project based on the activity and methods used (i.e., statements related to the need to monitor presence of threatened species or the threats faced by the species). Increasing ecological understanding about threatened species was the stated or implied goal for 95% of the projects, with education and engagement a priority for 32%, either as a primary or secondary goal (Figure 2c). Three projects stated research questions in their online content; one independent citizen scientist-driven project (i.e., Koala Tracker), one coordinated by a local NGO (i.e., Frog Census of the South East managed by Natural

| Coordinating organization type | Large NGO (n = 47 projects) | Local NGO (n = 42 projects) | Government (n = 28 projects) | Research institution (n = 16 projects) |
|--------------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------------------|
| Project objectives             |                             |                             |                             |                                        |
| Explicit—Stated                |                             |                             |                             |                                        |
| Stated research questions      | 1                           | 2                           | 0                           | 0                                      |
| Stated aims/objectives         | 43                          | 37                          | 19                          | 15                                     |
| Implied—Inferred objectives   |                             |                             |                             |                                        |
| Increasing ecological          | 45                          | 38                          | 28                          | 15                                     |
| understanding about species    |                             |                             |                             |                                        |
| Education/engagement of        | 17                          | 14                          | 5                           | 2                                      |
| participant                    |                             |                             |                             |                                        |
| On-ground actions that aid in  | 1                           | 2                           | 0                           | 1                                      |
| threatened species recovery    |                             |                             |                             |                                        |

| Methods and participant activities | Large NGO (n = 47 projects) | Local NGO (n = 42 projects) | Government (n = 28 projects) | Research institution (n = 16 projects) |
|------------------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------------------|
| Incidental sightings/records       | 29                          | 21                          | 22                          | 11                                     |
| Structured/standardized surveys    | 25                          | 26                          | 7                           | 6                                      |
| On-ground or other activities      | 3                           | 3                           | 1                           | 1                                      |

| Training resources                |                             |                             |                             |                                        |
| Yes                                | 35                          | 21                          | 16                          | 9                                      |
| No                                 | 5                           | 14                          | 11                          | 2                                      |
| Uncertain                          | 7                           | 7                           | 1                           | 5                                      |

| Communication and data sharing    |                             |                             |                             |                                        |
| Social media                      |                             |                             |                             |                                        |
| Facebook                          | 44                          | 30                          | 19                          | 15                                     |
| Twitter                           | 42                          | 14                          | 17                          | 12                                     |
| Instagram                         | 37                          | 13                          | 13                          | 11                                     |
| Data sharing                      |                             |                             |                             |                                        |
| Publication or reporting of results on website or social media | 30                          | 20                          | 6                           | 8                                      |
Resources South East), and one by a large NGO (i.e., South-eastern Red-tailed Black-Cockatoo Count managed by BirdLife Australia) (Table 1).

Four (3%) of the reviewed projects conducted direct actions aimed at threatened species recovery (Figure 2c). Three of these, including the Australian Nuclear Science and Technology Organisation Plastics Project, BeachPatrol and Tangaroa Blue, engage citizens to remove plastics debris from coastal ecosystems. The fourth project, ToadWatch in the Northern Territory, asks citizen scientists to join events focused on removing toxic, invasive cane toads from natural environments to reduce ingestion of toads by native threatened mammals, reptiles, and amphibians.

3.2 Element 2: Selection of methods, survey protocols, and participant activities

Reporting of incidental sightings of threatened species was a frequent method (63%, Figure 2d), although structured monitoring occurred in 49% of the projects reviewed here. Structured or standardized surveys were commonly used by local NGOs (62%), but less commonly by large NGOs (53%), government agencies (31%), and research institutions (38%; Table 1). Direct action activities and other types of direct participation represented 6% of the reviewed projects.

Data collected by the public were typically shared with project coordinators using desktop methods or online forms (85%; Figure 2e). These data were generally captured in the field using a paper form or similar recording mechanism (i.e., paper form, notepad, incidental sightings submitted after species observation). Mobile device applications were used to capture and share data by 39 (29%) of the projects reviewed here and paper forms were used for 27 projects (20%) with data entry online being completed with project coordinators in the field or mailed to the project coordinators after the activity (Figure 2e).

Just over half of the projects (54%) focused on or collected data for one species only, while 37% carried out more general monitoring where or when there was a high likelihood of encountering a threatened species (Figure 2f). Nine projects drew on public participation to monitor or manage the threats affecting threatened species in Australia. Actions included actively removing a threatening process (e.g., marine plastic debris) and monitoring the causes of decline without actively removing it (e.g., Feral or in Peril, CatTracker, FeralScan). One project, called Veteran and Significant Trees of the Redlands, asked citizens to report the presence of habitat trees to the local Council as these are valuable for threatened koala population in the Redlands area.

Continuous public participation was sought for a large proportion of the projects reviewed here (70%), with relatively few projects administered seasonally (21%), annually (8%) or as once-off events (4%; Figure 2g). Most projects (n = 92, 69%) focused on threatened species in terrestrial habitats (Figure 2h), with the remainder focusing on beach (n = 36), marine (n = 31), and freshwater habitats (n = 27).

3.3 Element 3: Provision of resources for training or an invitation to participate in training

Training or provision of training resources was offered by the majority of projects, with 82 (61%) making a clearly articulated training invitation on their website or social media (Figure 2i). Of the remainder, 32 projects do not make training resources available and for 18 projects it was unclear whether training was being offered. This ambiguity stems from the fact that some projects require registration as a participant prior to receiving full access to project information and resources. Invitations for training and provision of background information were most commonly offered on project websites by large NGOs (74%), followed by government run projects (59%) and local NGOs (50%) (Table 1).

3.4 Element 4: Communication with participants and data sharing

Social media was being used to recruit participants and provide feedback to the public with Facebook being the most widely used network (n = 108), followed by Twitter (n = 86), and Instagram (n = 75; Figure 2j). Social media presence was either in the form of a page for the organization coordinating the project or a page or profile dedicated to the project itself.

Of the projects we located and reviewed, most data from most projects was contributed to Australia’s national biodiversity data repository, the ALA, with these data subsequently added to the Global Biodiversity Information Facility data repository (n = 87, 65%) (Figure 2k). Data from either of these platforms can be freely accessed and used by anyone.

Publications or reporting of data summaries on project websites were found for 50% of the reviewed projects (Figure 2l), although many of the reporting pages that shared interpretive information were not being updated regularly. Large NGOs were more likely to provide feedback to participants and the public more generally (based on citizen collected data or contributions) in the form of reports or data summaries (64%), compared to research institutions (50%), local NGOs (48%), and government agencies (21%; Table 1).
4 | DISCUSSION

Our data show that there is a rich network of citizen science projects, spanning all states and territories, relevant for the more than 1,700 threatened species in Australia. In contrast with some widely held assumptions about citizen science, we found that almost half of the identified projects were deploying structured survey methods, and almost two thirds share their data with national and international biodiversity data repositories. The projects assessed here aim to deepen our understanding of threatened species, the processes that threaten them and raise awareness of the growing biodiversity crisis among Australia's flora and fauna (Garnett, Ainsworth, & Zander, 2018; Legge et al., 2018; Woinarski et al., 2015). Our continental scale assessment has found widespread integration of several key best practice principles among the reviewed citizen science projects for threatened species. With standout best practice alignment among organizations such as: Discovery Circle, BirdLife Australia, and several projects run by National Parks Associations. These organizations tend to communicate their results with data summaries or reports on their websites, clearly offer training and learning resources to potential participants and share their data with a central database like ALA. However, while objectives are generally communicated well and are often paired with training for participants (Figure 2i), there is scope for further integrating best practice into projects aimed at threatened species. In particular, the sharing of findings in easily accessible reports and data summaries and declaring how the data is used (if at all) for the benefit of conservation (i.e., contributed to centrally managed biodiversity inventories or resulting in scientific publications).

4.1 | Honest objectives and realistic expectations

The majority of citizen science efforts for threatened species in Australia based their activities on either implied or explicit objectives aiming to improve our understanding of threatened species themselves and/or the key threatening processes (Figure 2c). However, the methods often required to achieve such conservation goals (e.g., accurate population estimates via presence and absence surveys, density estimates) can be onerous for voluntary participants to adhere to (Chase & Levine, 2018; Eveleigh, Jennett, Blandford, Brohan, & Cox, 2014). A secondary goal appeared to be education and raising awareness among participants and the public more broadly. Herein lies a common trade-off among many citizen science efforts (Chase & Levine, 2018; Frigerio et al., 2018). This conundrum can lead to a mismatch between the actual and communicated objectives of the project among all relevant stakeholders (Eveleigh et al., 2014). While these two goals need not be mutually exclusive, citizen science coordinators need to be honest with their participants about whether the recruitment incentive (i.e., increasing our scientific understanding of a species at a management level), can truly be achieved via the citizen science activities being undertaken. For example, incidental fauna and flora observations, as offered by about half of the projects reviewed here, can yield information about the distribution and seasonality of species. Dishonest or unrealistic communications pertaining to project goals risks the credibility citizen science while adding to the debate surrounding the true utility of citizen sourced data.

4.2 | Citizen science as a community of coordinators and participants

There were clear leaders in the field that diligently apply the key framework principles to their project design (Figure 1; Table 1). However, it appeared many projects for threatened species were not always closely aligned to the existing frameworks that provide a blueprint for how citizen science can and should be done effectively (Figure 2i, k, l; Table 1). This presents an opportunity for the leaders in this field to extend their knowledge to other citizen science coordinators and projects, through effective collaboration and communication. There are several organizations developed to advocate citizen science and adoption of best practices. The Australian Citizen Science Association began in 2014 and members have worked at local, state, federal, and international levels to increase capacity for citizen science projects to work cooperatively, exchange knowledge and make scientific discoveries (https://citizenscience.org.au/ and https://citizenscience.org.au/10-principles-of-citizen-science/) (Göbel, Cappadonna, Newman, Zhang, & Vohland, 2017; Storksdieck et al., 2016). By creating the project finder, and the online platform (BioCollect), the ALA has enabled local NGOs and community groups to have access to project specific webpages with guidance and infrastructure for data collection protocols, data entry and data sharing to the ALA itself. Facilitation bodies such as these have a key role to play, acting as conduits between the myriad groups and participants that currently make up the citizen science landscape in Australia and globally.

Many projects have engaged with social media to promote their activities and recruit, yet many did not share project findings or summaries of citizen collected data (Figure 2j). This is an important opportunity, as feedback improves participant satisfaction (van der Wal et al., 2016). Social media communications are also useful for raising awareness of threatened species-related issues and what the citizen science projects aim to achieve (i.e., increasing knowledge of the species and/or increased public awareness).
4.3 | Lack of awareness is the real risk, not the citizens

We acknowledge there are risks associated with involving the public in threatened species conservation actions. The risk posed by participants potentially disturbing vulnerable species or causing degradation to habitats (Steven, Pickering, & Castley, 2011), must be assessed during project design, and managed during training of participants and implementation. Likewise, revealing sites where threatened species have been observed may pose another source of risk (Lindenmayer & Scheele, 2017; Tulloch et al., 2018). For the most part, however, the risks of demonstrated negative impacts on threatened species due to a lack of ecological understanding exceed those related to the possible negative effects posed by volunteers (Tulloch et al., 2018). One can reasonably speculate that a significant proportion of people that choose to volunteer their time for a citizen science project aimed at improving the prognosis for a threatened species have the interests of that species forefront of mind. Any potential impacts that could ensue would likely be unintentional and mitigated via thorough training prior to participation. Some projects reviewed here required people to undertake a quiz that often included demonstrating that participants were aware of how to be involved without posing a risk to the subject species. Additionally, there are a growing number of projects that draw on remote or off-site involvement of citizens, in post-data processing, where the risk is all but completely removed through reduced proximity and the use of technology (e.g., the Wildlife Spotter project) (Moran et al., 2014). This is a useful method to increase attention on areas that are otherwise difficult to survey for logistical reasons, often related to geography. This remains an aspect of citizen science that would benefit from further examination. The relentless threats to the species at the center of these projects demands we involve as much of the community as possible in recovery actions, for both enhanced ecological understanding and increased awareness among the general public.

4.4 | Limitations of this study

It is possible that some citizen science projects relevant for threatened species in Australia were not included in this study. The methodological approach taken here meant that only projects with at least a moderate online presence (i.e., registering with the national database for citizen science) were intercepted and thus included in our study. If the coordinating organizations did not use keywords and tags including threatened species and/or citizen science or public participation in their digital media it also made detection using online methods difficult. We attempted to overcome this by inviting practitioners to alert us to the presence of other threatened species relevant projects (i.e., expert elicitation and a snowballing technique). This raises an interesting issue around visual representation and the likelihood of attracting a new stream of participants, if that is needed for project sustainability, where project coordinators may or may not make projects easy to find via online searches. Public participation and citizen science projects often struggle to retain commitment among volunteers (Boakes et al., 2016; Eveleigh et al., 2014). Obstacles to embracing new technologies, such as not having access to digital resources or an inability to use such tools due to a lack of skills and knowledge, including online communication platforms, will only serve to exacerbate this challenge. A further challenge is presented where a species lacks certain attributes that make it attractive enough to potential to citizen scientists to feel motivated to contribute their time to its conservation and monitoring. This aspect has been examined for birds in Australia by Garnett, Woinarski, Lindenmayer, and Latch (2018), and continues to be the focal point for a successful public awareness campaign run by BirdLife Australia; “Preventing Extinctions” (BirdLife Australia, 2019). Species face myriad threats in Australia and globally, with conservation practitioners in a race to prevent species extinctions. Citizen science can play a role in these mitigation strategies, and threatened species make ideal catalysts for engagement given the urgency attached to acting in their best interest. Our study has presented further evidence for the strong push to draw on people power as a mechanism to learn more about threatened species conservation and improve the understanding and engagement between the general public and biodiversity. However, successes may not be fully realized if projects are not designed with critical principles of best practice integrated from the outset. Transparency and honesty regarding project objectives as well as recognition of what can and cannot be achieved through citizen science needs to remain at the forefront for citizen scientists’ contribution to be of the greatest value for threatened species conservation.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS’ CONTRIBUTIONS

R.S. is responsible for conceptual design, data collection, data analysis and interpretation, and paper writing; S.T.G. is...
responsible for conceptual design, data interpretation, paper writing; G.G. is responsible for conceptual design, data interpretation, and paper writing; J.O.C. is responsible for conceptual design, data interpretation, and paper writing; J.L.O. is responsible for data collection, data analysis and interpretation, and paper writing; C.R. is responsible for conceptual design, data interpretation, paper writing; A.T. is responsible for conceptual design, data interpretation, and paper writing; R.A.F. is responsible for conceptual design, data interpretation, and paper writing.

DATA ACCESSIBILITY STATEMENT

We will deposit all primary data relating to our citizen science review in a curated repository such as Dryad or Pangaea, alongside our published paper(s) that use the data in question. These will be publicly accessible after each publication is completed. The only exception to this will be any confidential remarks made to researchers, which, if possible will be released in an anonymized form along with the rest of the data. However, if there is a chance that this process could result in an individual being identified and associated with the remark, we will be required under the conditions of our ethics approval to restrict access the data, and delete it after 5 years following production of publications arising from the data.

ETHICS STATEMENT

This project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research and complies with the regulations governing experimentation on humans and was approved by the University of Queensland Human Research Ethics Committee B (Approval Number 2017000457).

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**SUPPORTING INFORMATION**

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

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