How to ensure threatened species monitoring leads to threatened species conservation

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Summary

Monitoring is essential for effective conservation and management of threatened species and ecological communities. However, more often than not, threatened species monitoring is poorly implemented, meaning that conservation decisions are not informed by the best available knowledge. We outline challenges and provide best-practice guidelines for threatened species monitoring, informed by the diverse perspectives of 26 conservation managers and scientists from a range of organisations with expertise across Australian species and ecosystems. Our collective expertise synthesised five key principles that aim to enhance the design, implementation and outcomes of threatened species monitoring. These principles are: 1) Integrate monitoring with management; 2) Design fit-for-purpose monitoring programs; 3) Engage people and organisations; 4) Ensure good data management; and 5) Communicate the value of monitoring. We describe how to incorporate these principles into existing frameworks to improve current and future monitoring programs. Effective monitoring is essential to inform appropriate management and enable better conservation outcomes for our most vulnerable species and ecological communities.

Key words: adaptive management; conservation management; knowledge transfer; management cycle; monitoring and evaluation; threatened species, populations & communities; translating science

Introduction

The world is losing species at an alarming rate (Butchart et al. 2010, Waldron et al. 2017), far higher than background rates through geological time (Ceballos et al. 2017). Australia, especially, is experiencing ongoing species declines and extinctions (Cresswell and Murphy 2017, Waldron et al. 2017). Many extinctions may have been avoided if adequate knowledge of declines existed, and if this knowledge triggered actions to halt declining species trajectories (Martin et al. 2012, Lindenmayer et al. 2013, Woinarski et al. 2016). In this regard, the application of effective monitoring is central to informing management and preventing species extinctions (Martin et al. 2007). Monitoring is the process of collecting and analysing repeated observations or measurements to identify changes and evaluate progress of management towards stated aims. In the context of threatened species conservation, monitoring is essential to detect trends in abundance and distribution through time, measure the impacts of threatening processes, and evaluate the effectiveness of management responses (Legge et al. 2018). It is also important for informing legislative protection and securing investment in management, and is a powerful communication tool that allows for meaningful engagement with a broad range of stakeholders. Despite these imperatives, the current contribution of monitoring to the conservation and management of threatened biodiversity in Australia is severely deficient (Legge et al. 2018).

Threatened species monitoring and management in Australia is not of a standard and comprehensiveness commensurate with the nation's wealth, scientific capacity and stable governance structure (McDonald et al. 2015, Waldron et al. 2017, Legge et al. 2018). A recent assessment of Australia's threatened species and ecological communities has revealed inadequacies in the quantity and quality of monitoring, with a lack of monitoring for many threatened species and communities (Legge et al. 2018). An estimated 24 – 46% of threatened vertebrate species receive no monitoring at all, and a high proportion of monitoring programs that do exist are poorly designed with not enough statistical power to detect changes in population trends. More worryingly, Legge et al. (2018) also identified poor coordination between monitoring programs, inadequate data management and reporting, and limited integration between monitoring and management. These issues are not unique to Australia, with inadequacies in monitoring being documented globally (Legg and Nagy 2006, Lindenmayer and Likens 2010).

Resource constraints are often cited as a fundamental reason for not being able to monitor effectively (Lindenmayer et al. 2012, Environment and Communications References Committee 2013). Consequently, there have been calls to prioritise monitoring and management choices and

increase efficiency (Joseph et al. 2009). Yet, overall we need more resources, not simply better allocation. Indeed, the Australian Government falls short on delivering adequate resources for biodiversity by both national (Cresswell and Murphy 2017) and international standards (Waldron et al. 2013). This is despite threatened biodiversity facing increasing pressures, and despite the inclusion of an explicit target to develop a national monitoring program in Australia's Biodiversity Conservation Strategy (2010–30) (Natural Resource Management Ministerial Council 2010). We note that, at present, monitoring is not mandatory even for critically endangered species. We advocate that adequately resourced monitoring programs be developed for priority threatened species, in line with nations such as United States of America, where biennial monitoring of threatened species population trend is mandated via funded recovery plans (U.S. Endangered Species Act of 1973). Further improvements in monitoring can be made through enhancing existing capacity such as through greater engagement, effective partnerships, and increased coordination and integration of programs.

Other reasons for inadequate monitoring, however, are more concerning than resource limitations. These include a growing disregard for science (Lindenmayer et al. 2015, Sutherland and Wordley 2017), de-valuing of evidence-based management (Russell-Smith et al. 2015), competing interests that undervalue biodiversity or erode ecological integrity (Ritchie et al. 2013), wilful obstruction towards receiving bad news (Woinarski et al. 2016), and hesitation to act on information (Martin et al. 2012). Such attitudes and behaviours are attributed to limited understanding of the value of threatened species monitoring by scientists, governments, industry and the broader public, along with a culture of pessimism that considers extinction inevitable (Garnett and Lindenmayer 2011). Under-appreciation of biodiversity values and defeatism, however, can be transformed into empowerment to act, by promoting both intrinsic and extrinsic biodiversity values (Keith et al. 2017), inspiring hope (Garnett and Lindenmayer 2011, Balmford 2012, Garnett et al. 2018), and demonstrating how effective monitoring can inform decision-making and management to enhance threatened species conservation (Lindenmayer et al. 2013).

Biodiversity monitoring is challenging; there are many variables, interacting factors and ecological surprises that can confound our understanding of species, ecosystems and processes (Lindenmayer and Likens 2018). Threatened species monitoring is, however, even more challenging than monitoring non-threatened taxa. Attributes such as rarity, low or variable detectability, and narrow habitat niches present challenges with design and logistics (Martin et al. 2007, Crates et al. 2017). There are restrictions in the use of experimental methods due to ethical issues of working with threatened species and a greater requirement to avoid negative consequences (e.g. the use of

biotelemetry tools, Cooke 2008). The fragile existence of threatened species further demands that monitoring has adequate precision and sensitivity to detect subtle changes in populations to inform important decisions and future management without delay (Martin et al. 2007, Martin et al. 2012).

Although the overall state of threatened species monitoring in Australia is inadequate (Legge et al. 2018), this is not universally the case. For example, shorebird monitoring in Australia is a successful long-term collaboration between citizen scientists, governments and researchers that has yielded large-scale robust information on shorebird demographics, habitats and threatening processes to enable effective, coordinated recovery efforts (Hansen et al. 2018). Much can be learnt from evaluating good monitoring programs (e.g. Bayraktarov et al. 2018), and using existing frameworks that have been developed to guide monitoring. Here, we collate personal experience in what makes monitoring difficult, learn lessons from good examples and synthesise the academic literature to draw out key principles that lead to better monitoring.

Essential principles for making the monitoring of threatened biodiversity count

Our principles are the product of a two-day workshop in 2016 on threatened species monitoring in Australia, involving 26 practitioners from government, non-government organisations, environmental consulting companies and academic institutions. Participants had expertise in monitoring that encompassed threatened flora and fauna across all major Australian biomes; they shared their knowledge and experience in threatened species monitoring via pre-workshop surveys (Robinson et al. 2018), individual presentations and targeted group discussion. The workshop culminated in focused discussion on how to improve threatened species monitoring. Within small groups, ideas and insights were shared then, as a collective, these were collated and distilled into five essential principles for monitoring; these being: 1) Integrate monitoring with management; 2) Design a fit-for-purpose monitoring program; 3) Engage people and organisations; 4) Ensure good data management; and 5) Communicate the value of monitoring. These principles complement existing guidelines for developing monitoring programs (e.g. Reynolds et al. 2016), and monitoring-management frameworks (e.g. Williams 2011, Schwartz et al. 2012). Central to all these frameworks is a holistic and cyclical view of improving monitoring and management through learning, evaluating and applying new knowledge. We outline how our principles fit with such frameworks with the specific aim of improving conservation actions for threatened species (Fig. 1). Our principles, although designed to address monitoring of threatened species, are equally applicable to the monitoring of threatened ecological communities.

Principle 1. Integrate monitoring with management

126 Threatened species monitoring is often poorly integrated with management, even for species with
127 dedicated monitoring programs (Legge et al. 2018). Failing to explicitly link the two limits the
128 potential to positively influence conservation outcomes and document the effectiveness of actions
129 (Martin et al. 2012). A threatened species monitoring program should complement a recovery plan
130 (or analogous process) with clearly articulated management responsibilities and accountabilities.
131 These monitoring and management plans should be publicly available (e.g. online reports, published
132 management plans) to ensure transparency in process and accountability for actions, and be
133 regularly reviewed and updated.

134 Many monitoring-management frameworks have been devised to help plan, design and implement
135 an integrated monitoring-management plan (e.g. Schwartz et al. 2012, Reynolds et al. 2016). These
136 frameworks vary, but all begin by defining and scoping the problem (or problems) affecting a species
137 (Fig. 1). These initial steps focus on developing compatible conservation monitoring and
138 management aims and outlining existing and potential management actions and strategies.
139 Collaboration and integration at this early stage facilitates greater uptake and implementation of
140 new knowledge by managers later in the management cycle (Nichols and Williams 2006). An
141 understanding of the management context further helps to identify priority areas for monitoring
142 based on management needs and knowledge gaps (Nichols and Williams 2006). Clarifying
143 relationships between threats, actions and species persistence helps to prioritise management
144 actions and refine what monitoring is required to improve our understanding and management.
145 Sometimes limited knowledge of these relationships can stall decisions on how to act. In such
146 situations, Value of Information, in combination with expert elicitation, can help quantify the
147 benefits of resolving uncertainty through monitoring and refine what data are required (Runge et al.
148 2011). For example, Bode et al (2017) used expert elicitation along with ecosystem modelling to
149 illustrate the links between threats to Malleefowl (*Leipoa ocellata*) and effective management
150 action; this process has subsequently helped guide management and monitoring needs. In other
151 cases, critical management decisions may need to be made in the absence of certainty or monitoring
152 data. However, monitoring the outcomes of such management decisions is essential (Radford et al.
153 2018).

154 Integration with management is also important during the monitoring design phase. To encourage
155 management accountability and action, the monitoring design should outline decision triggers
156 (Lindenmayer et al. 2013) and identify who is responsible for management intervention. Decision
157 triggers indicate critical stages along a species' population trajectory, or a level of impact from
158 threatening process, where an action is required (Lindenmayer et al. 2013, Addison et al. 2016, Cook

et al. 2016). Often, immediate and decisive action is necessary to avert negative outcomes or prevent extinction (Martin et al 2012). For example, decisive action by the Orange-bellied Parrot (*Neophema chrysogaster*) recovery team in response to critically low numbers of wild individuals triggered a captive breeding program that averted extinction of the wild population (Martin et al 2012). Conversely, indecision and opaque accountability meant that the Christmas Island Pipistrelle (*Pipistrellus murrayi*) was monitored to extinction (Martin et al 2012). Decision triggers should be identified early to minimise indecision, and enforce action and accountability in a timely fashion (Martin et al. 2012), yet such triggers are rarely defined during the design phase of monitoring programs.

The next two phases of the monitoring-management cycle focus on evaluating monitoring data (i.e. learning) and improving future management decisions (Fig. 1). Evaluation and reporting ensures that monitoring results inform management and other stakeholders, enabling responsive action (e.g. via decision triggers) and adjustments to ongoing monitoring and management action. Evaluation should occur at multiple levels. At the species or population level, analysing monitoring data can quantify trends in distribution and abundance, which can inform future projections of species or population trends, and be used to review listing status under threatened species legislation. For example, ongoing monitoring of Woylies (*Bettongia penicillata*) tracked initial population increases followed by subsequent unexpected declines which prompted a re-listing of the species (Groom 2010). At the program level, evaluation reveals the effectiveness of management actions, suitability of methodological approach, efficiency of resource allocation, and explains how well the program is meeting conservation objectives. For example, review of a long-running vertebrate monitoring program in Northern Australia revealed that statistical power to detect further declines in occupancy was low. This prompted a re-design of the program and changes to the location, timing and frequency of monitoring (Einoder et al. 2018). Evaluation, and subsequent program improvement, ensures effective and efficient threatened species monitoring and management.

Principle 2: Design a fit-for-purpose program

Threatened species monitoring can rarely be a by-product of generic biodiversity monitoring (i.e. 'surveillance' monitoring). It needs to be targeted, question-driven and scientifically robust, to be able to detect and quantify causes of decline and evaluate management effectiveness (Lindenmayer and Likens 2018). The design of a threatened species monitoring program (i.e. where, when, what and how to survey) must address the monitoring objectives and questions, be tailored to suit the specific attributes of the target species and have adequate statistical rigour with respect to the

monitoring objective (Lindenmayer and Likens 2018). Failure to consider these design issues could result in a costly data collection exercise that is unable to detect causes and effects, and ultimately a waste of resources that could otherwise be spent on management (Legg and Nagy 2006).

The design of a monitoring program for threatened species is usually more challenging than for non-threatened taxa. Species rarity can invoke particular sampling and detection challenges. For example, the Regent Honeyeater (*Anthochaera Phrygia*) is rare and highly mobile (Crates et al. 2017), making it difficult to know where to locate monitoring sites to confidently detect population changes given low and variable occupancy over time. Monitoring design should be informed by the type and quantity of data required, what analyses are to be conducted, the variability in the dynamics of the species or system (e.g. spatial coverage, irruptive species), and the probability of detection (Block et al. 2001, Martin et al. 2007). Power analysis is required to ensure that sufficient effort is allocated towards monitoring to detect variation in populations should a change occur (e.g. Einoder et al. 2018). At the most basic design level, sampling methods must be able to adequately represent the abundance of target species or life history stages (e.g. new recruits, Lintermans 2016). Monitoring-program design should also consider the level of skill or training needed, timing and duration of data collection, and opportunities for new technologies. Design and methodology need to also consider cost-effectiveness, ethics, longevity and feasibility of the monitoring program.

To meet rigorous design criteria, threatened species monitoring programs can be at risk of becoming extremely expensive and / or logistically unfeasible. Innovative approaches could be investigated that enable more cost-effective and or data-specific methods. For example, advancements in drone technology can facilitate greater precision in data capture (Hodgson et al. 2016) and eDNA has proven to be an effective tool in monitoring some endangered species or threats (Thomsen et al. 2012); both techniques promise benefits in cost effectiveness. Similarly, citizen science projects such as the web-based Wildlife Spotter (DigiVol 2018) have increased data processing capacity of camera trap images with high accuracy of species identification (Koleck 2018).

Principle 3. Engage people and organisations

Successful engagement ensures that a monitoring program is valued, integrated in decision making, and has financial and popular support from institutions, partner agencies and across the broader community (Dickman 2013). Effectively engaging with people and organisations means that all relevant stakeholders are involved or consulted appropriately throughout the monitoring process (Burbidge et al. 2011, Ens et al. 2012, Ives and Kendal 2014). Engagement can promote knowledge

exchange, develop common or compatible goals, raise awareness, generate political support and create change.

Identifying stakeholders and the significance of their role to the success of the monitoring is important at the outset (Fig. 1). Similar to managers of threatened species, there may be stakeholders whose involvement or activities may significantly affect the monitoring and / or the threatened species or ecosystems of interest. These may include users of the threatened species or their habitat (e.g. recreational users and extractors / harvesters of water, minerals, timber, flowers, food, etc.) and adjacent land users whose activities may impact the threatened species (e.g. source of invasive species such as introduced predators). Such stakeholders may be better identified as integrated partners in the monitoring program, because if they 'own it' they are more likely to be part of the solutions and remedial actions if they are required. Other stakeholders whose roles may be more supportive than integral, remain important but may be better engaged differently (e.g. consultation or participation as assistants more so than partners). In the case of the Lord Howe Island Stick Insect (*Dryococelus australis*), early engagement with the local community meant that the recovery of the species was supported from the outset. Soon after its rediscovery, it was listed and a recovery plan that involved the community was produced (Carlile et al. 2009). Recovery of the species has subsequently inspired an ambitious Black Rat (*Rattus rattus*) eradication program that was possible only with strong community support (Carlile et al. 2009). Without some level of consensus between stakeholders on issues of management and recovery approach, monitoring efforts may be hampered.

During the design and implementation stages, people with expertise or those closely involved with or conducting the monitoring should be consulted (Fig. 1). Researchers and statisticians are particularly valuable in the design stage to draw out key monitoring questions, highlight limitations in monitoring approaches, and give advice on appropriate methods, data requirements, and data analysis (Lindenmayer et al. 2012). Conversely, field staff and land managers can provide valuable insights to what is happening on the ground, and outline constraints to implementation (Burbidge et al. 2011). Engagement across jurisdictional boundaries (regions, states) facilitates coordinated 'big picture' management and monitoring approaches and multijurisdictional recovery teams play a key role (Lintermans 2013). Regular interaction with those implementing the monitoring (e.g. via training and project updates) ensures problems are quickly resolved, maintains consistent application of methods and data collection, improves morale, and, in the case of volunteers, can lead to greater commitment to the project (Koleck 2018).

Inadequate acknowledgement and involvement of stakeholders throughout the monitoring process can, conversely, undermine the capacity of the program to properly address monitoring objectives, and exclude potential supporters. In the case of the nationally vulnerable Baudin's Cockatoo (*Calyptorhynchus baudinii*), limited representation and ad hoc engagement with the fruit growing and timber industries effectively ignored links between these industries and the primary threats (e.g. illegal shooting, insufficient tree hollows) (Holmes et al. 2017). Consideration of additional stakeholder values, beyond that of monitoring threatened species, may further require development of compatible goals, or the design of multi-objective programs. For example, monitoring programs on Indigenous lands should be developed in partnership with Indigenous communities and aim to integrate values and objectives from both Indigenous and non-Indigenous perspectives (Ens et al. 2012). Indigenous groups often place importance on integration of environmental outcomes with cultural, social and economic outcomes, and aim to bring together Indigenous knowledge (in culturally-appropriate ways) with western science, which influences both the design and execution of monitoring and management programs (Bohensky et al. 2013, Ens et al. 2015). In North America, the incorporation of Indigenous ecological knowledge is often required in threatened species recovery planning, adding value and improving knowledge outcomes (Polfus et al. 2014). In cross-cultural collaborations, ample time should be provided to understand perspectives, develop trust and build relationships, define the governance structure, and establish intellectual property agreements (Ens et al. 2012, Bohensky et al. 2013). Investing time and energy to develop good stakeholder relationships and develop compatible objectives early in the process can provide long-term benefits such as financial support (Bush Heritage Australia 2017), community advocacy (Ainsworth et al. 2016) and institutional commitment to projects (Burbidge et al. 2011).

Principle 4. Ensure good data management

Data management is an essential component of developing and maintaining effective monitoring programs. Good data management will identify data needs, maintain data integrity, and enable early detection of species trends allowing managers to act quickly (e.g. Groom 2010). However, data management is often neglected and its value apparent only when it fails (Caughlan and Oakley 2001). For example, if data analysis requirements are poorly estimated during program design, there may be a failure to make reliable inferences about threatened species (Houston and Hiederer 2009). Similarly, budget blow-outs resulting from a lack of accounting for the cost of data management (Caughlan and Oakley 2001), or data loss resulting from insufficient data security (Whitlock 2011) highlight the need for good data management practices. Data management should be considered throughout the life of a monitoring program and be properly costed at the start of the project. Data

management plans assist by outlining how data will be organised, stored, processed and analysed. Such plans further detail responsibilities for who maintains the database, and who can use the data (Vos et al. 2000).

An example of a well maintained database for a single species is the National Malleefowl Monitoring Database (Benshemesh et al. 2018). This central data repository was custom designed to enable consistent data collection, accessibility to users, stakeholders and contributors, and facilitate regular reporting. Data are collected and loaded onto the database by volunteers and screened by experts before being analysed; this process streamlines data collation whilst ensuring data quality. Not all monitoring programs, however, are as well coordinated or their data as accessible. Monitoring data from small scale or short term projects are largely unavailable, or difficult to access. A national review of conservation activities for threatened freshwater fish reported that >80% of on-ground actions had associated monitoring, but there were no national databases to store and curate such datasets (Lintermans 2013), making learning from previous monitoring approaches problematic. Emerging web-based technologies are, however, opening up possibilities for online data storage and synthesis, allowing for better integration and access of disparate databases, and powerful tools for processing and modelling (Vitolo et al. 2015).

During initial problem framing, it is important to consider what data are required and already available (Fig. 1). Australia's Long Term Ecological Research Network (LTERN 2018), until recently, maintained a large database of species observation records that was available for broader use. Unfortunately, its recent decommission now jeopardises the future of associated monitoring and reporting (Lindenmayer 2017). Other data requirements may be met by collaborating with related monitoring projects to integrate and share data. The development of Australia's first threatened species index relies on collating data from multiple sources (Bayraktarov et al. 2018). Data sharing arrangements can minimise unnecessary monitoring, reduce costs, and value-add to existing data. However, the sensitive nature of threatened species data and the concern for abuse of knowledge (e.g. poaching, interference of habitat) will require that certain data restrictions be considered to protect sensitive species location data (Lindenmayer and Scheele 2017).

Principle 5. Communicate the value of monitoring

Multiple values are inherent in threatened species monitoring, including tracking changes in populations, evaluating management performance and effectiveness, and contributing to improved biodiversity conservation. Extrinsic values, such as empowering local communities (Ens et al. 2012), creating social connections between diverse people and groups (Holmes et al. 2017), and

highlighting health, economic and societal benefits (Keith et al. 2017), may not be the primary reason to monitor but can be important for other parts of society and contribute to conservation initiatives (Ives and Kendal 2014). These diverse values are often lost in the overwhelming tide of negative stories about the future of threatened species and ongoing extinctions. Continuous reminders of dire situations can lead to a sense of hopelessness and inevitability, and a lack of motivation to work towards solutions; this only serves to reinforce undesirable outcomes (Garnett and Lindenmayer 2011). Instead, messages need to be framed around solutions to the threatened species crisis, and examples of how monitoring has improved conservation trajectories. These messages need to be communicated broadly and creatively to inspire participation and support of threatened species monitoring (Fig. 1).

The telling of success stories is an important tool in inspiring activism and engagement, and promoting the value of monitoring. Several authors have done this eloquently, compiling a list of conservation success stories to inspire optimism (Balmford 2012, Garnett et al. 2018). Support, especially in the form of funding, can be further encouraged by spruiking novel and unusual elements of a species' biology, and innovative monitoring methods or management approaches. For example, the Lord Howe Island Stick Insect has achieved widespread fame and support, a rare feat for an insect, due to a creative campaign capitalising on quirky aspects of the species biology (large size), the charm of its rediscovery (an adventurous tale of rock climbing on an isolated sea spire), and the diverse use of media and educational tools (e.g. books, film, school programs) (Carlile et al. 2009). Similarly, the Difficult Birds Research Group (DBRG 2018) have used original messaging (e.g. cartoons) to communicate their innovative management approaches and successfully attract crowd funding for several threatened bird species.

Conservation success stories and messages of hope may, however, not appeal to all members of society due to different underlying values. In such circumstances, messaging that speaks to different values can be more useful. For example, the old growth forests of Mountain Ash (*Eucalyptus regnans*) in the Central Victorian highlands are home to a range of species, including the critically endangered Leadbeater's Possum (*Gymnobelideus leadbeateri*), and vulnerable Greater Glider (*Petauroides volans*). The forest ecosystem is also listed as critically endangered by the IUCN (Burns et al. 2015). Despite clear and longstanding promotion of these conservation values, one of the main threatening processes (clear-fell timber harvesting) continues (Burns et al. 2015). This has prompted researchers and advocates to diversify their messaging. Environmental accounting is being used to put an economic value on the range of natural values of these forests (e.g. water provisioning, carbon sequestration, cultural and recreational services) (Keith et al. 2017). This message draws in

other elements of society, such as those interested in employment, health benefits and economic growth. Communicating the value of monitoring through creative messaging can foster broad(er) support among stakeholders, secure funding and facilitate uptake and integration of monitoring into management (Ives and Kendal 2014, Lindenmayer and Likens 2018).

The value of threatened species monitoring can be further communicated through education and engaging conservation champions to teach people of all ages about the value of threatened species and the role of monitoring. Mulligan's Flat, a conservation reserve in the Australian Capital Territory, has successfully motivated people to be interested in the conservation of several threatened species, through visits to schools and community events, showcasing animals such as the Eastern Bettong (*Bettongia gaimardi*). Conservation champions can influence and strengthen values, and drive species recovery. Local champions, in particular, can lend credibility to conservation initiatives, and mobilise action, exemplified by the conservation trajectories of two almost morphologically identical, equally threatened birds (Ainsworth et al. 2016). In the first instance, local advocacy led to strong emotional attachment to the Capricorn Chat (*Epthianura crocea macgregori*), resulting in increased awareness, government funding and effective conservation actions. In contrast, the Alligator River Chat (*Epthianura crocea tunneyi*) had no local support; it subsequently received no dedicated funding, was infrequently monitored, and no recovery program was implemented. Social values are influential in determining conservation effort, thus it is important to understand what motivates people in order to effectively engage and promote positive action.

Conclusion

Effective threatened species monitoring can make an important contribution to improved conservation outcomes. We outline five principles designed to improve threatened species monitoring. They serve as a reminder of key elements to consider when planning, designing, implementing and reviewing monitoring programs. First, monitoring must be integrated with management with clear objectives, transparency and accountability. Second, a fit-for-purpose monitoring design is required to address specific monitoring questions. Third, inclusive, respectful engagement with a broad range of stakeholders is necessary for shaping monitoring objectives and securing the future of the program. Fourth, data management needs to be comprehensive and considered early in the design phase. Lastly, the value of monitoring must be enthusiastically and creatively communicated to ensure that its contribution to threatened species conservation, and broader societal values, is understood and supported. Implementation of these principles will not prevent species extinctions. However, when conservation actions and decisions are underpinned by

good processes and knowledge, declines due to inaccurate or irrelevant data, inefficient or ineffective management actions, poor knowledge transfer and communication, and lack of support or awareness can be avoided. As practitioners in this space, we need to promote the value of monitoring and increase its efficacy to enable informed management and enhanced conservation of our threatened biodiversity.

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References

Addison, P. F. E., Cook, C. N., and de Bie, K. (2016). Conservation practitioners' perspectives on decision triggers for evidence-based management. Journal of Applied Ecology **53**:1351-1357.

Ainsworth, G. B., Aslin, H. J., Weston, M. A., and Garnett, S. T. (2016). Do social values influence levels of conservation effort in threatened species? The case of two Australian chats. Oryx **50**:636-645.

Balmford, A. (2012). Wild hope: on the front lines of conservation success. University of Chicago Press, Chicago.

Bayraktarov, E., Ehmke, G., Tulloch, A., Driessen, J., O'Connor, J., Barnes, M., Woinarski, J., Garnett, S., McRae, L., Lindenmayer, D. B., Avery-Gomm, S., Morgain, R., Nguyen, H., Watmuff, J., MacGregor, N., Byrne, M., Hardie, M., Joseph, L., Mokany, A., Bennison, K., Brazill-Boast, J., Carter, O., Chauvenet, A., Guru, S., Hill, B., Hodgon, J., Holewa, H., Kark, S., Kitchin, M., Kutt, A., La Salle, J., Latch, P., Legge, S., McDonald-Madden, E., Moorrees, A., Nicholls, M., Robinson, J., Rogers, D., Turak, E., Vardon, M., and Possingham, H. (2018). A Threatened Species Index for Australia: Interim Report Part 1 – Birds. National Environmental Science Program's Threatened Species Recovery Hub.

Benshemesh, J., Southwell, D. M., Lahoz-Monfort, J. J., Hauser, C. E., Rumpff, L., Bode, M., Burnard, T., and Wintle, B. A. (2018). The national malleefowl monitoring effort: citizen scientists, databases and adaptive management. Pages 389-398 *in* Legge, S., Lindenmayer, D. B., Robinson, N. M., Scheele, B. C., Southwell, D. M., and Wintle, B. A., editors. Monitoring threatened species and ecological communities. CSIRO publishing, Melbourne.

Block, W. M., Franklin, A. B., Ward, J. P., Ganey, J. L., and White, G. C. (2001). Design and Implementation of Monitoring Studies to Evaluate the Success of Ecological Restoration on Wildlife. Restoration Ecology **9**:293-303.

Bode, M., Baker, C. M., Benshemesh, J., Burnard, T., Rumpff, L., Hauser, C. E., Lahoz-Monfort, J. J., and Wintle, B. A. (2017). Revealing beliefs: using ensemble ecosystem modelling to extrapolate expert beliefs to novel ecological scenarios. Methods in Ecology and Evolution **8**:1012-1021.

Bohensky, E. L., Butler, J. R. A., and Davies, J. (2013). Integrating Indigenous Ecological Knowledge and Science in Natural Resource Management: Perspectives from Australia. Ecology and Society **18**:20.

Burbidge, A. H., Maron, M., Clarke, M. F., Baker, J., Oliver, D. L., and Ford, G. (2011). Linking science and practice in ecological research and management: How can we do it better? Ecological Management & Restoration **12**:54-60.

Burns, E. L., Lindenmayer, D. B., Stein, J., Blanchard, W., McBurney, L., Blair, D., and Banks, S. C. (2015). Ecosystem assessment of mountain ash forest in the Central Highlands of Victoria, south-eastern Australia. Austral Ecology **40**:386-399.

Bush Heritage Australia. (2017). Annual Report 2016-2017. Bush Heritage Australia, Melbourne.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Morcillo, M. H., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vié, J.-C., and Watson, R. (2010). Global Biodiversity: Indicators of Recent Declines. Science **328**:1164-1168.

Carlile, N., Priddel, D., and Honan, P. (2009). The recovery programme for the Lord Howe Island Phasmid (*Dryococelus australis*) following its rediscovery. Ecological Management & Restoration **10**:S124-S128.

Caughlan, L., and Oakley, K. L. (2001). Cost considerations for long-term ecological monitoring. Ecological Indicators **1**:123-134.

Ceballos, G., Ehrlich, P. R., and Dirzo, R. (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences **114**:E6089-E6096.

448 Cook, C. N., de Bie, K., Keith, D. A., and Addison, P. F. E. (2016). Decision triggers are a critical part of
449 evidence-based conservation. Biological Conservation **195**:46-51.
450 Cooke, S. J. (2008). Biotelemetry and biologging in endangered species research and animal
451 conservation: relevance to regional, national, and IUCN Red List threat assessments.
452 Endangered Species Research **4**:165-185.
453 Crates, R., Terauds, A., Rayner, L., Stojanovic, D., Heinsohn, R., Ingwersen, D., and Webb, M. (2017).
454 An occupancy approach to monitoring regent honeyeaters. The Journal of Wildlife
455 Management **81**:669-677.
456 Cresswell, I., and Murphy, H. (2017). Australia state of the environment 2016: biodiversity,
457 independent report to the Australian Government Minister for the Environment and Energy.
458 Australian Government Department of the Environment and Energy, Canberra.
459 Dickman, C. R. (2013). Human community ecology: making connections for conservation. Pacific
460 Conservation Biology **19**:312-319.
461 Difficult Bird Research Group. (2018). https://www.difficultbirds.com/about-us. Australian National
462 University.
463 DigiVol. (2018). https://volunteer.ala.org.au/wildlife-spotter. Australian Museum.
464 Einoder, L. D., Southwell, D. M., Gillespie, G. R., Fisher, A., Lahoz-Monfort, J. J., and Wintle, B. A.
465 (2018). Optimising broad-scale monitoring for trend detection: review and re-design of a
466 long-term program in northern Australia. Pages 271-280 *in* Legge, S., Lindenmayer, D. B.,
467 Robinson, N. M., Scheele, B. C., Southwell, D. M., and Wintle, B. A., editors. Monitoring
468 threatened species and ecological communities. CSIRO Publishing, Melbourne.
469 Ens, E. J., Finlayson, M., Preuss, K., Jackson, S., and Holcombe, S. (2012). Australian approaches for
470 managing 'country' using Indigenous and non-Indigenous knowledge. Ecological
471 Management & Restoration **13**:100-107.
472 Ens, E. J., Pert, P., Clarke, P. A., Budden, M., Clubb, L., Doran, B., Douras, C., Gaikwad, J., Gott, B.,
473 Leonard, S., Locke, J., Packer, J., Turpin, G., and Wason, S. (2015). Indigenous biocultural
474 knowledge in ecosystem science and management: Review and insight from Australia.
475 Biological Conservation **181**:133-149.
476 Environment and Communications References Committee. (2013). Effectiveness of threatened
477 species and ecological communities' protection in Australia. Commonwealth of Australia,
478 Canberra.
479 Garnett, S. T., and Lindenmayer, D. B. (2011). Conservation science must engender hope to succeed.
480 Trends in Ecology & Evolution **26**:59-60.

481 Garnett, S. T., Woinarski, J., Lindenmayer, D. B., and Latch, P. (2018). Recovering Australian
482 threatened species : a book of hope. CSIRO Publishing, Melbourne.
483 Groom, C. (2010). Justification for continued conservation efforts following the delisting of a
484 threatened species: a case study of the woylie, Bettongia penicillata ogilbyi
485 (Marsupialia:Potoroidae). Wildlife Research **37**:183-193.
486 Hansen, B. D., Clemens, R. S., Gallo-Cajiao, E., Jackson, M. V., Kingsford, R. T., Maguire, G. S., Maurer,
487 G., Milton, D., Rogers, D. I., Weller, D. R., Weston, M. A., Woehler, E. J., and Fuller, R. N.
488 (2018). Shorebird monitoring in Australia: a successful long-term collaboration among citizen
489 scientists, governments and researchers. Pages 151-166 *in* Legge, S., Lindenmayer, D. B.,
490 Robinson, N. M., Scheele, B. C., Southwell, D. M., and Wintle, B. A., editors. Monitoring
491 threatened species and ecological communities. CSIRO Publishing, Melbourne.
492 Hodgson, J. C., Baylis, S. M., Mott, R., Herrod, A., and Clarke, R. H. (2016). Precision wildlife
493 monitoring using unmanned aerial vehicles. Scientific Reports **6**:22574.
494 Holmes, T. Q., Head, B. W., Possingham, H., and Garnett, S. T. (2017). Strengths and vulnerabilities of
495 Australian networks for conservation of threatened birds. Oryx **51**:673-683.
496 Houston, T. D., and Hiederer, R. (2009). Applying quality assurance procedures to environmental
497 monitoring data: a case study. Journal of environmental monitoring **11**:774-781.
498 Ives, C. D., and Kendal, D. (2014). The role of social values in the management of ecological systems.
499 Journal of Environmental Management **144**:67-72.
500 Joseph, L. N., Maloney, R. F., and Possingham, H. P. (2009). Optimal Allocation of Resources among
501 Threatened Species: a Project Prioritization Protocol. Conservation Biology **23**:328-338.
502 Keith, H., Vardon, M., Stein, J. A., Stein, J. L., and Lindenmayer, D. (2017). Ecosystem accounts define
503 explicit and spatial trade-offs for managing natural resources. Nature ecology & evolution
504 **1**:1683-1692.
505 Koleck, J. (2018). Community involvement in monitoring threatened species: a WWF perspective.
506 Pages 347-360 *in* Legge, S., Lindenmayer, D. B., Robinson, N. M., Scheele, B. C., Southwell, D.
507 M., and Wintle, B. A., editors. Monitoring threatened species and ecological communities.
508 CSIRO Publishing, Melbourne.
509 Legg, C. J., and Nagy, L. (2006). Why most conservation monitoring is, but need not be, a waste of
510 time. Journal of Environmental Management **78**:194-199.
511 Legge, S., Lindenmayer, D. B., Robinson, N. M., Scheele, B. C., Southwell, D. M., and Wintle, B. A.,
512 editors. (2018). Monitoring threatened species and ecological communities. CSIRO
513 Publishing, Melbourne.
514 Lindenmayer, D. (2017). Save Australia's ecological research. Science **357**:557-557.

Lindenmayer, D., and Scheele, B. (2017). Do not publish. Science **356**:800-801.

Lindenmayer, D. B., Blair, D., McBurney, L., and Banks, S. C. (2015). Ignoring the science in failing to conserve a faunal icon – major political, policy and management problems in preventing the extinction of Leadbeater's possum. Pacific Conservation Biology **21**:257-265.

Lindenmayer, D. B., Gibbons, P., Bourke, M. A. X., Burgman, M., Dickman, C. R., Ferrier, S., Fitzsimons, J., Freudenberger, D., Garnett, S. T., Groves, C., Hobbs, R. J., Kingsford, R. T., Krebs, C., Legge, S., Lowe, A. J., McLean, R. O. B., Montambault, J., Possingham, H., Radford, J. I. M., Robinson, D., Smallbone, L., Thomas, D., Varcoe, T., Vardon, M., Wardle, G., Woinarski, J., and Zerger, A. (2012). Improving biodiversity monitoring. Austral Ecology **37**:285-294.

Lindenmayer, D. B., and Likens, G. E. (2010). The science and application of ecological monitoring. Biological Conservation **143**:1317-1328.

Lindenmayer, D. B., and Likens, G. E. (2018). Effective ecological monitoring. CSIRO publishing, Collingwood, Vic.

Lindenmayer, D. B., Piggott, M. P., and Wintle, B. A. (2013). Counting the books while the library burns: why conservation monitoring programs need a plan for action. Frontiers in Ecology and the Environment **11**:549-555.

Lintermans, M. (2013). A review of on-ground recovery actions for threatened freshwater fish in Australia. Marine and Freshwater Research **64**:775-791.

Lintermans, M. (2016). Finding the needle in the haystack: comparing sampling methods for detecting an endangered freshwater fish. Marine and Freshwater Research **67**:1740-1749.

Long Term Ecological Research Network. (2018). http://www.ltern.org.au Terrestrial Ecosystem Research Network, University of Queensland.

Martin, J., Kitchens, W. M., and Hines, J. E. (2007). Importance of Well-Designed Monitoring Programs for the Conservation of Endangered Species: Case Study of the Snail Kite. Conservation Biology **21**:472-481.

Martin, T. G., Nally, S., Burbidge, A. A., Arnall, S., Garnett, S. T., Hayward, M. W., Lumsden, L. F., Menkhorst, P., McDonald-Madden, E., and Possingham, H. P. (2012). Acting fast helps avoid extinction. Conservation Letters **5**:274-280.

McDonald, J. A., Carwardine, J., Joseph, L. N., Klein, C. J., Rout, T. M., Watson, J. E. M., Garnett, S. T., McCarthy, M. A., and Possingham, H. P. (2015). Improving policy efficiency and effectiveness to save more species: A case study of the megadiverse country Australia. Biological Conservation **182**:102-108.

548 Natural Resource Management Ministerial Council. (2010). Australia's Biodiversity Conservation
549 Strategy 2010-2030. Australian Government, Department of Sustainability, Environment,
550 Water, Population and Communities, Canberra.
551 Nichols, J. D., and Williams, B. K. (2006). Monitoring for conservation. Trends in Ecology & Evolution
552 **21**:668-673.
553 Polfus, J. L., Heinemeyer, K., Hebblewhite, M., and Taku River Tlingit First, N. (2014). Comparing
554 traditional ecological knowledge and western science woodland caribou habitat models. The
555 Journal of Wildlife Management **78**:112-121.
556 Radford, J., Q., Wager, R., and Kerezsy, A. (2018). Recovery of the red-finned blue-eye: informing
557 action in the absence of controls and replication. Pages 377-387 *in* Legge, S., Lindenmayer,
558 D. B., Robinson, N. M., Scheele, B. C., Southwell, D. M., and Wintle, B. A., editors. Monitoring
559 threatened species and ecological communities. CSIRO Publishing, Melbourne.
560 Reynolds, J. H., Knutson, M. G., Newman, K. B., Silverman, E. D., and Thompson, W. L. (2016). A road
561 map for designing and implementing a biological monitoring program. Environmental
562 Monitoring and Assessment **188**:399.
563 Ritchie, E. G., Bradshaw, C. J. A., Dickman, C. R., Hobbs, R., Johnson, C. N., Johnston, E. L., Laurance,
564 W. F., Lindenmayer, D., McCarthy, M. A., Nimmo, D. G., Possingham, H. H., Pressey, R. L.,
565 Watson, D. M., and Woinarski, J. (2013). Continental-Scale Governance and the Hastening of
566 Loss of Australia's Biodiversity. Conservation Biology **27**:1133-1135.
567 Robinson, N. M., Morgain, R., Legge, S., Scheele, B. C., Lindenmayer, D. B., Southwell, D. M.,
568 Bennison, K., Benshemesh, J., Bickerton, D., Brooks, L., Carter, O., Dickman, C. R., Ehmke, G.,
569 Kanowski, J., Koleck, J., Lintermans, M., Marsh, H., Oliver, D., Paltridge, R., Radford, J.,
570 Skroblin, A., Wayne, A. F., and Woinarski, J. C. Z. (2018). Organisational perspectives on
571 threatened species monitoring. Pages 415-427 *in* Legge, S., Lindenmayer, D. B., Robinson, N.
572 M., Scheele, B. C., Southwell, D. M., and Wintle, B. A., editors. Monitoring threatened
573 species and ecological communities. CSIRO Publishing, Melbourne.
574 Runge, M. C., Converse, S. J., and Lyons, J. E. (2011). Which uncertainty? Using expert elicitation and
575 expected value of information to design an adaptive program. Biological Conservation
576 **144**:1214-1223.
577 Russell-Smith, J., Lindenmayer, D., Kubiszewski, I., Green, P., Costanza, R., and Campbell, A. (2015).
578 Moving beyond evidence-free environmental policy. Frontiers in Ecology and the
579 Environment **13**:441-448.

Schwartz, M. W., Deiner, K., Forrester, T., Grof-Tisza, P., Muir, M. J., Santos, M. J., Souza, L. E., Wilkerson, M. L., and Zylberberg, M. (2012). Perspectives on the Open Standards for the Practice of Conservation. Biological Conservation **155**:169-177.

Sutherland, W. J., and Wordley, C. F. R. (2017). Evidence complacency hampers conservation. Nature ecology & evolution **1**:1215-1216.

Thomsen, P. F., Kielgast, J. O. S., Iversen, L. L., Wiuf, C., Rasmussen, M., Gilbert, M. T. P., Orlando, L., and Willerslev, E. (2012). Monitoring endangered freshwater biodiversity using environmental DNA. Molecular Ecology **21**:2565-2573.

Vitolo, C., Elkhatib, Y., Reusser, D., Macleod, C. J. A., and Buytaert, W. (2015). Web technologies for environmental Big Data. Environmental Modelling & Software **63**:185-198.

Vos, P., Meelis, E., and Ter Keurs, W. J. (2000). A Framework for the Design of Ecological Monitoring Programs as a Tool for Environmental and Nature Management. Environmental Monitoring and Assessment **61**:317-344.

Waldron, A., Miller, D. C., Redding, D., Mooers, A., Kuhn, T. S., Nibbelink, N., Roberts, J. T., Tobias, J. A., and Gittleman, J. L. (2017). Reductions in global biodiversity loss predicted from conservation spending. Nature **551**:364–367.

Waldron, A., Mooers, A. O., Miller, D. C., Nibbelink, N., Redding, D., Kuhn, T. S., Roberts, J. T., and Gittleman, J. L. (2013). Targeting global conservation funding to limit immediate biodiversity declines. Proceedings of the National Academy of Sciences **110**:12144-12148.

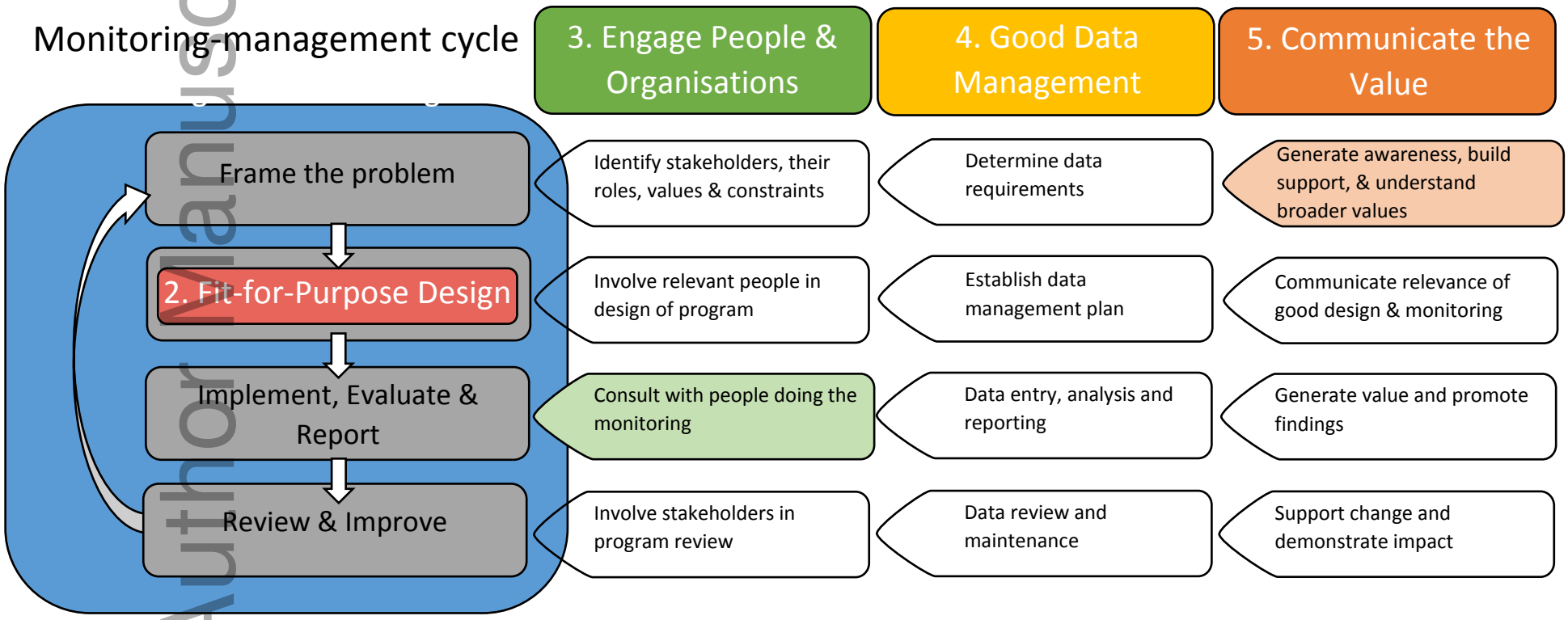
Whitlock, M. C. (2011). Data archiving in ecology and evolution: best practices. Trends in Ecology & Evolution **26**:61-65.

Williams, B. K. (2011). Adaptive management of natural resources—framework and issues. Journal of Environmental Management **92**:1346-1353.

Woinarski, J. C. Z., Garnett, S. T., Legge, S. M., and Lindenmayer, D. B. (2016). The contribution of policy, law, management, research, and advocacy failings to the recent extinctions of three Australian vertebrate species. Conservation Biology **31**:13-23.

Figure legends

Fig. 1. The five essential monitoring principles (numbered) and how they fit within a four stage monitoring-management cycle (grey boxes).



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