

1 **How to improve threatened species management: an Australian perspective**

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21
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23
24 **Abstract**

25 Targeted threatened species management is a central component of efforts to prevent species
26 extinction. Despite the development of a range of management frameworks to improve

27 conservation outcomes over the past decade, threatened species management is still
28 commonly characterised as ad hoc. Although there are notable successes, many management
29 programs are ineffective, with relatively few species experiencing improvements in their
30 conservation status. We identify underlying factors that commonly lead to ineffective and
31 inefficient management. Drawing attention to some of the key challenges, and suggesting
32 ways forward, may lead to improved management effectiveness and better conservation
33 outcomes. We highlight six key areas where improvements are needed: 1) stakeholder
34 engagement and communication; 2) fostering strong leadership and the development of
35 achievable long-term goals; 3) knowledge of target species' biology and threats, particularly
36 focusing on filling knowledge gaps that impede management, while noting that in many cases
37 there will be a need for conservation management to proceed initially despite knowledge
38 gaps; 4) setting objectives with measurable outcomes; 5) strategic monitoring to evaluate
39 management effectiveness; and 6) greater accountability for species declines and failure to
40 recover species to ensure timely action and guard against complacency. We demonstrate the
41 importance of these six key areas by providing examples of innovative approaches leading to
42 successful species management. We also discuss overarching factors outside the realm of
43 management influence that can help or impede conservation success. Clear recognition of
44 factors that make species' management more straightforward – or more challenging – is
45 important for setting realistic management objectives, outlining strategic action, and
46 prioritising resources. We also highlight the need to more clearly demonstrate the benefit of
47 current investment, and communicate that the risk of under-investment is species extinctions.
48 Together, improvements in conservation practice, along with increased resource allocation
49 and re-evaluation of the prioritisation of competing interests that threaten species, will help
50 enhance conservation outcomes for threatened species.

51

52 **Key words**

53 Adaptive management, conservation, endangered species management, invasive species

54

55 **1. Introduction**

56 Threatened species management, based on assessments of species extinction risk, threat
57 identification, prioritisation of species for management, and implementation of targeted

58 management actions, is central to curbing biodiversity loss (Primack, 2006). Despite
59 substantial efforts, notable success has been achieved for relatively few species, and as a
60 result, few threatened species have recovered sufficiently following management
61 interventions to allow delisting (Bottrill et al., 2011; Male and Bean, 2005). In part, this
62 failure can be attributed to a severe lack of resources (Evans et al., 2016; McCarthy et al.,
63 2012). For example in Australia, McCarthy et al. (2008) found that funding for threatened
64 birds was inadequate to prevent further extinctions and facilitate recovery for most listed
65 species, but also that a relatively small increase in resourcing could substantially improve the
66 conservation status of many species. Australian environmental spending is disproportionately
67 low, with Australia one of only several developed countries featuring in the top 40
68 underfunded countries for conservation spending (Waldron et al., 2013). Further, there has
69 been a sharp reduction in funding over the past decade, with less than five cents for every
70 \$100 of government spending in 2018 directed to biodiversity conservation (ACF, 2018).
71 However, there are several other prominent reasons for the worsening conservation status of
72 many threatened species, such as a failure to address major threats (Johnson et al., 2017),
73 poor enforcement of existing legal protections (Harrison et al., 2016), increasing ignorance of
74 scientific evidence (Sutherland and Wordley, 2017), and a culture of apathy (Russell-Smith et
75 al., 2015). In combination, these issues contribute to inaction or inefficient last minute
76 attempts to rescue species on the brink of extinction (Woinarski et al., 2017).

77 While part of the blame for ongoing species declines can be attributed to funding shortfalls or
78 socio-political issues, in practice, species declines could also be halted by improving the
79 effectiveness of on-ground conservation effort (Sunderland et al., 2009; Toomey et al., 2017).
80 Although there are examples of successful recovery efforts (see Garnett et al., 2018), many
81 other projects are marred by ad hoc and inefficient planning and implementation (Ferraro and
82 Pattanayak, 2006; Pullin et al., 2004; Sutherland et al., 2004). Further, the effectiveness of
83 conservation management is often poorly evaluated, making it difficult to assess how
84 effective each action was, or what species trajectories would have been in the absence of
85 management intervention (Cresswell and Murphy, 2016). A range of decision frameworks
86 and tools have emerged from conservation planning research to address these challenges (see
87 review by Schwartz et al. (2018)), and there have been substantial advances in the practice of
88 expert elicitation (Hemming et al., 2018). While the increasing use of decision frameworks
89 and support tools over the past 20 years has contributed to enhanced outcomes, there is still
90 substantial room for improvement (Cook et al., 2010; Ferraro and Pattanayak, 2006).

91 Here we address challenges that can impede conservation management of threatened species
92 in Australia. We have taken an Australian perspective for several key reasons. These include
93 the fact that Australia supports a highly diverse and endemic range of species and
94 ecosystems, some of which have been recently lost (e.g. 35% of modern global mammal
95 extinctions have occurred in Australia (Woinarski et al., 2015)), and many more that are
96 threatened (see: Australian Government, 2018). Australia also has a large and diverse array of
97 species recovery programs, with some failures but also prominent successes, upon which to
98 learn from and improve (Garnett et al., 2018). Finally, there is a strong tradition of research
99 excellence in conservation and environmental management in Australia, thus there is scope
100 and capacity within the nation to improve conservation management standards (Harrison,
101 2006).

102 We focus on what can be done to improve threatened species management under current
103 constraints. We acknowledge the need for societal changes in human values and their
104 interaction with the environment (Abson et al., 2017), along with a substantial funding
105 increase (Johnson et al., 2017; Waldron et al., 2013). We also address other over-arching
106 factors outside the realm of management control that can impede conservation success. We
107 consider that despite there being a range of program management frameworks readily
108 available, a large implementation gap remains. We provide illustrative case studies of
109 innovative approaches leading to successful species management, noting that ‘success’ is
110 context-specific and that long-term success will often require continuation of current
111 management trajectories. The views outlined below are the result of a three day workshop of
112 conservation practitioners and researchers with long-term experience in threatened species
113 management, where we worked to collectively identify pitfalls that can lead to ineffective and
114 inefficient management. By drawing attention to some of the key challenges, and providing
115 ways forward, we hope to present a perspective that leads to improved conservation
116 effectiveness and better conservation outcomes.

117 **2. Challenges and solutions in threatened species management**

118 Once a decision to manage a threatened species has been made, the management process
119 consists of three broad stages; 1) conceptualisation and planning, 2) management
120 implementation and evaluation, and 3) program evaluation and revision (Fig. 1). These broad
121 categories reflect a standard management cycle (e.g. Schwartz et al., 2018). Below, we
122 identify common challenges that occur across each of these stages and provide examples of

123 how they have been overcome. In addition, we discuss challenges in two overarching
124 elements that profoundly impact management; stakeholder engagement and communication,
125 and leadership and personnel. Our evaluation is not exhaustive, but rather reflects personal
126 experience with issues that most commonly arise in the context of threatened species
127 management in Australia. We refer the reader to Schwartz et al. (2018) for guidance on
128 decision support tools and frameworks for conservation management. We provide a range of
129 species-specific case-studies of successful management programs overcoming many of the
130 challenges discussed in the following section (see Supporting Material Table S1 for
131 additional examples).

132 2.1. Conceptualisation and planning

133 A key set of interrelated deficiencies in threatened species management can stem from
134 management that is based on inadequate understanding of the target species' ecology or
135 threats (Fig. 1). These deficiencies result in poor problem definition, and a lack of clear and
136 realistic objectives. Although the need for robust understanding of the target species' ecology
137 and threat impacts is well established (Caughley and Gunn, 1996), in reality it is poorly
138 adhered to, and often under-valued. Attaining sufficient ecological knowledge generally
139 requires detailed field work to ascertain, among other things, the target species' distribution,
140 habitat requirements, life history parameters, population trajectories, and threat impacts
141 (Table S1; example 1). These processes need to be understood across the target species'
142 entire distribution (to make informed choices of where to prioritise management), or the
143 proportion of the species' distribution where management efforts will be implemented.
144 Because threat impacts and threat tolerance are shaped by environmental and biotic processes
145 that vary across environmental space (Scheele et al., 2017a), information obtained for one
146 population is not always transferable to other populations. It is also crucial to understand
147 interactions between multiple threats and the capacity for changes in one element of a system
148 to amplify the impacts of other threats. Many present day management practices remain
149 focused on a single threat despite growing scientific understanding of the importance of
150 considering threat interactions (Scheele et al., 2017a).

151 While there is a clear need for more ecological research, constrained budgets mean that
152 research must be strategic, with a focus on resolving uncertainty that will improve
153 management decisions. The development of a conceptual model of the target system can help
154 identify knowledge gaps and where to focus research. For example, Bode et al. (2017) used

155 expert opinion to develop an ecosystem model linking malleefowl (*Leipoa ocellata*)
156 persistence with abiotic and biotic processes in mallee ecosystems. The model helped
157 managers identify direct and indirect threats facing the species, the likely response of
158 populations when each threat interaction is managed, and the most uncertain threat
159 interactions that require further research.

160 While inadequate knowledge of a target species' ecology and threat impacts can hamper
161 decisions about management alternatives, in many cases there is a need for conservation
162 management to proceed – or at least be initiated – despite knowledge gaps. In such cases,
163 management is commonly guided by expert judgement. For example, expert judgment
164 informed a decision to undertake aerial phosphite application in 1997 to control *Phytophthora*
165 *cinnamomi* in key areas in south west Western Australia, despite uncertainty about
166 phytotoxicity. Urgent management was deemed necessary because the rapid spread of *P.*
167 *cinnamomi* was driving the local extinction of at least 11 threatened plant species.
168 Importantly, the early, incisive intervention that was based on expert judgement was
169 complimented with monitoring and evaluation of management effectiveness. Monitoring
170 revealed that populations of most species have stabilised following phosphite application
171 (Barrett and Yates, 2015), and that phytotoxic effects are minimal in these vegetation systems
172 (Rathbone and Barrett, 2018).

173 Challenges arising from ecological uncertainty are often compounded by diverse stakeholder
174 interests, trade-offs, resource limitations and ambiguity surrounding management efficacy.
175 One constructive approach to these complexities is to use formal structured decision making,
176 particularly in cases where there is substantial ecological uncertainty and a need for rapid
177 action (Gregory et al., 2012) (Table S1; example 2). Structured decision making provides a
178 framework to evaluate different alternatives in a transparent way to identify optimal solutions
179 and clearly articulated objectives and actions (Gregory et al., 2012; Runge, 2011; Schwartz et
180 al., 2018). In the absence of a formal decision-making process, ad hoc approaches may be
181 prone to bias, fail to clearly specify objectives and consider all alternatives, or how planned
182 actions will achieve stated objectives.

183 Under a structured decision making approach, it is critical during the planning stage to
184 differentiate between fundamental objectives (for example, reducing extinction risk for a
185 target species) and means objectives (such as increasing breeding success for a target species
186 by 20%) (Gregory et al., 2012). Development of fundamental objectives requires engagement

187 of all relevant stakeholders (see examples 3-5 in Table S1 for case studies where a range of
188 stakeholders were engaged in developing fundamental objectives and evaluating management
189 options). It is important that means objectives are linked with performance measures
190 throughout the life of a program to help evaluate efficacy and allow for ongoing refinement
191 (Tear et al., 2005). Canessa et al. (2016) provide a good example of objective setting in the
192 context of ex-situ conservation. They elicited 32 alternative management strategies from
193 experts on the threatened spotted tree frog (*Litoria spenceri*) and found the strategy that
194 maximised the chance of a wild population persisting for 20 years at the lowest cost.
195 However, they also explored how the optimal strategy depended on the weighting given to
196 the two objectives (i.e. maximise persistence vs minimise cost). In this case, the optimal
197 strategy was sensitive to which objective was considered more important, highlighting the
198 need to explicitly define the fundamental objective early in a management program.

199 In addition to planning for chosen management actions, contingency planning is a crucial, yet
200 often-neglected, element of threatened species management. Good risk management and
201 planning for unexpected outcomes is not always incorporated into conservation programs
202 (Lindenmayer et al., 2018). Contingency planning requires clear recognition that failure is a
203 possibility – something that managers, practitioners and researchers are not always willing, or
204 able to admit. For example, red fox (*Vulpes vulpes*) control was initially highly successful for
205 facilitating the recovery of an assemblage of small to medium-sized mammals in south-
206 western Australia, but after an initial increase in abundance, many species experienced major
207 declines. The declines were thought to be associated with increases in feral cat (*Felis catus*)
208 predation (Marlow et al., 2015), following meso-predator release of cats as a consequence of
209 fox control (Wayne et al., 2017). This case highlights two key lessons. First, high quality
210 monitoring was crucial to identifying secondary declines, and second, the need for
211 management to plan for the unexpected.

212 2.2. Management implementation and evaluation

213 In many cases, scientific research needs to be better integrated into management, particularly
214 when there is substantial ecological uncertainty about threat impacts or management
215 effectiveness (Fig. 1). Importantly, research needs to be targeted toward resolving knowledge
216 gaps that will improve management decisions (e.g. Stojanovic et al., 2018). Adaptive
217 management – a more complex extension of structured decision making – provides a
218 powerful framework to formally integrate research into management (Table S1; examples 6

219 and 7). Under an adaptive management approach, uncertainty is identified and then
220 alternative management actions are specifically designed to aid learning by resolving
221 uncertainty, while simultaneously progressing management objectives (Runge, 2011;
222 Westgate et al., 2013).

223 Despite its intuitive appeal, there are few robust examples of active adaptive management of
224 threatened species (Westgate et al., 2013) (an exception is the recently commenced
225 malleefowl program Table S1; example 6). However, less stringent adaptive management is
226 often appropriate and is more commonly applied. An example is a landscape-scale fire
227 management experiment designed to inform and facilitate the recovery of the threatened
228 Gouldian finch (*Erythrura gouldiae*) in Australia's tropical savanna (Legge et al., 2015).
229 First, research established a negative association between frequent and intense fire and finch
230 body condition indices. Second, this information was used to develop and then implement a
231 new fire management plan, to which Gouldian finches responded positively. More broadly,
232 barriers to successful adaptive management are well-documented in the literature, with poor
233 communication and a lack of collaborative relationships between managers and researchers
234 commonly cited as a key barrier that needs to be overcome to facilitate management-research
235 integration (Burbidge et al., 2011). Ensuring conservation agencies have research capacity
236 with expertise to expedite management-research relations internally, and to communicate and
237 collaborate with researchers in other institutions, will go some way to addressing this issue.

238 Once management actions have been implemented, it is essential to conduct reliable
239 monitoring of population responses within a management framework that requires follow up
240 actions as the monitoring progresses (Table S1; examples 8-10). However, a recent review of
241 threatened species monitoring in Australia found that across taxonomic groups, between 21-
242 46% of threatened vertebrate species received no monitoring at all (Legge et al., 2018).
243 Further, where monitoring does occur, it is often poorly designed, typically having low power
244 to detect changes in population abundance, or to quantify the efficacy of management actions
245 (Legge et al., 2018). Poor quality monitoring reflects under-resourcing, but also monitoring is
246 frequently inhibited by poor data management practices, with data 'stock-piled' over time
247 without analysis, and meta-data and data frequently lost – an issue that is amplified with
248 personnel changes (Lindenmayer and Likens, 2018). Data loss then exacerbates further
249 problems, such as the absence of baselines from which to measure changes and evaluate
250 management success. Finally, and perhaps most troubling, are cases where species are
251 monitored robustly, but the monitoring program lacks triggers for management interventions,

252 resulting in species being monitored to extinction, like the Christmas Island pipistrelle
253 (*Pipistrellus murrayi*) (Lindenmayer et al., 2013). Such failures highlight of the need to link
254 monitoring and management closely, and initiating management without delay.

255 2.3. Program evaluation and revision

256 Thorough, large-scale evaluations of threatened species conservation efforts in Australia are
257 lacking, a point raised repeatedly within State of the Environment reports (Cresswell and
258 Murphy, 2016) (for a species-specific example of program evaluation see Table S1; example
259 11). Reporting on resource investment commonly focuses on where and how money was
260 spent, with little quantification of whether management benefited the target species or met
261 objectives (Fig. 1). For example, measures like kilometres of fencing built, or changes in feral
262 predator bait take, are often reported. However, to properly evaluate whether management
263 has had the desired effects, we need to be able to measure whether actions like fencing or
264 predator baiting were associated with increased abundance of the target species of
265 conservation concern (i.e. the fundamental objective) (Table S1; examples 12 and 13).
266 Inadequate evaluation is related to poorly formulated objectives that lack specific, measurable
267 outcomes. As a first step, we suggest that assessment of management effectiveness is
268 incorporated into funding programs, and mandated as a condition of funding being granted
269 (requiring improved monitoring). However, there may be little political appetite for changes
270 requiring greater accountability of spending if funding bodies are currently rewarded with
271 easily met targets that can be used to demonstrate so-called conservation success. In addition,
272 the fundamental mismatch between biological and political funding timeframes remains an
273 ongoing challenge.

274 At a broader level, evaluation efforts are inhibited by lack of accountability for species
275 declines and extinctions, and the absence of independent reviews of conservation programs
276 (for a species-specific example see Table S1; example 14). The current Australian system
277 lacks a direct chain of accountability for species declines or extinctions, with Woinarski et al.
278 (2017) highlighting the need for legislation adjustments to address this shortcoming. Further,
279 under Australian legislation, the implementation of national recovery actions is not mandated,
280 which inhibits efforts to improve accountability and ensure timely actions. In contrast, the
281 U.S. Endangered Species Act, provides clear legislative responsibilities for the U.S. Fish and
282 Wildlife Service to prepare and implement recovery plans, and develop policy and guidelines
283 for recovery plan preparation (Hoekstra et al., 2002).

284 Periodic independent review can be useful to ensure transparency in decision making and can
285 help guard against complacency, where management slips into a ‘business as usual’ routine,
286 without evaluation of new evidence or approaches. Given the complexities and uncertainty
287 inherent in many threatened species management programs, there is a need for periodic re-
288 evaluation of current practises and the foundational knowledge base (Bottrill et al., 2011;
289 Walsh et al., 2013). Avoiding complacency also requires awareness of the shifting baseline
290 phenomena, whereby gradual deterioration in a species’ status or habitats occurs too slowly
291 to be registered by individuals or monitoring programs (Bilney, 2014). For example, plant
292 species with long generation times typical of many Australian threatened woody shrubs and
293 trees may show significant time delays to extinction, well beyond standard monitoring
294 periods (see: Krauss et al., 2010).

295 2.4. Stakeholder engagement and communication

296 The need to involve a wide range of decision makers and stakeholders in threatened species
297 conservation has long been recognised (Garnett et al., 2018). In the context of threatened
298 species management in Australia, improved engagement and communication is needed on
299 multiple levels; conservation practitioners and managers are often intermediaries between
300 decision makers that control resources, and stakeholders who are involved in implementing
301 management, or who are impacted by management actions (Table S1; example 15). In the
302 first case, there is a need to provide convincing and robust justification to decision makers of
303 the value and merits of investing in threatened species conservation. The justification for
304 threatened species conservation is strongest for programs that engage a wide range of
305 stakeholders to ensure all objectives are considered, provide clearly articulated benefits, and
306 describe measurable objectives that can be used to demonstrate the value of investing
307 resources. In the second case, stakeholders who are impacted by threatened species protection
308 or management need to be integrated into decision-making processes, and should be kept
309 informed of developments throughout the life-cycle of the program. The aim of this dialogue
310 is to develop mutually acceptable actions, although compromise on both sides is often needed
311 (Redpath et al., 2013). These actions will be most effective when conservation practitioners
312 and managers build strong relationships with the community of affected stakeholders, and
313 work to ensure that decision making is transparent (Mishra et al., 2017). Strong relationships
314 are needed to overcome the ‘knowing-doing’ gap, whereby we know what to do, but
315 communicating what is needed, and then doing it, is a barrier (Hulme, 2014).

316 In addition to regular and effective communication with decision makers and stakeholders,
317 communication with the broader community is required to increase understanding of
318 conservation challenges and current management approaches (Table S1; example 16)
319 (Redpath et al., 2013). Ultimately, efforts to increase resource allocation to conservation
320 programs are dependent to a large extent on increasing the value the community places on
321 biodiversity conservation. It is the job of conservation scientists and managers to
322 communicate good news stories of successful programs (Garnett et al., 2018), but also to
323 highlight the major challenges involved, and that the consequence of inaction is species
324 extinction.

325 2.5. Leadership and personnel

326 Delivery of successful species conservation programs requires strong leadership and a well-
327 functioning team (Black et al., 2011) (Table S1; example 17). Conversely, poor leadership
328 and dysfunctional teams have been identified as a reason for failure in some conservation
329 programs (Battisti, 2017). A key barrier to the success of threatened species programs is
330 indecisive and overly risk averse leadership. Indecisiveness can result from high levels of
331 uncertainty, poor individual leadership, or in response to broader drivers such as competing
332 priorities, or a lack of political will to act (Meek et al., 2015). In the cases of many threatened
333 species, there is often an urgent need for action, without which there is an imminent risk of
334 extinction (Table S1; example 18). For example, failure to enact threat reduction or
335 establishment of ex-situ populations played a role in the extinction of three Australian
336 vertebrate species between 2009 and 2014 (Woinarski et al., 2017). Conservation success is
337 influenced by myriad factors, many of which are outside the control of conservation
338 practitioners; however, ensuring good leadership and personnel is something that can often be
339 directly shaped by conservation practitioners, and hence something we need to get right
340 (Black et al., 2011).

341 A commonality we have often observed in successful programs is the important role of a
342 ‘species champion’. Species champions come from a diverse range of backgrounds, from
343 someone in government who advocates strongly for a species, to private landowners, and
344 passionate community members. Species champions can often overcome legislative and
345 funding shortfalls to achieve successful outcomes. Key traits include a robust understanding
346 of the target species’ ecology and threats, but also strong planning skills and the capacity to
347 build and organise a team – including engaging with experts where needed. Species

348 champions are also innovators, developing new approaches to successfully manage species
349 (Clark and Kellert, 1988). Most important, however, is their capacity to be optimistic,
350 including clearly articulate a positive long-term vision for the successful recovery of the
351 target species (i.e. ‘stretch goals’).

352 Negative sentiments are common in threatened species management, and it is hard to
353 overstate the value of positive visions for success (Redford et al., 2016). For example,
354 Gillespie et al. (2018) identify that the presence of a species champion was crucial for the
355 long-term success of conservation programs for several critically endangered frog species
356 from south-eastern Australia (Table 1; example 19). Of course, having a program driven by a
357 species champion can create vulnerability if that person becomes no longer involved in the
358 program. As such, there is a need to foster institutional memory through the long-term
359 retention of key players, ensure adequate succession planning, and encourage and facilitate
360 knowledge transfer between multiple players (Holling and Meffe, 1996). While long-term
361 institutional involvement is often key, programs that develop a vision broader than any one
362 institution, are often highly successful (Redford et al., 2016).

363 **3. What makes threatened species management so difficult?**

364 In the preceding section we outlined common challenges in threatened species management.
365 However, there are also over-arching factors outside the sphere of management influence that
366 can impede conservation success. Clear recognition of factors that make a species’
367 management more straightforward – or more challenging – is important for setting realistic
368 management objectives and prioritising resources. Below we outline some recurring
369 impediments to threatened species management.

370 3.1. Threatened species management conflicts with other priorities

371 Threatened species management can directly conflict with competing social and economic
372 priorities. This is especially the case when threats to species are primarily human driven, such
373 as habitat loss associated with land-use practices. An example is the conservation of
374 Leadbeater’s possum (*Gymnobelideus leadbeateri*); a critically endangered species that
375 occurs in the wet mountain ash (*Eucalyptus regnans*) forests of Victoria. Long-term research
376 has identified key threats to the survival of the species; habitat loss and degradation from
377 forestry activities and wildfire (Lindenmayer et al., 2016). In terms of promoting this species’
378 conservation, the science is clear; we need to set aside large areas of forested land for
379 conservation, thereby removing the key threat of logging (Lindenmayer et al., 2016). The

380 economic costs of ending logging (including job loss) would be more than offset by
381 economic gains to agriculture, water provisioning, tourism, and carbon storage (Keith et al.,
382 2017). However, this solution remains politically challenging due to the reaction of the
383 forestry industry to such a policy. A similar conflict is also apparent in the Australian Capital
384 Territory where government policy promotes continued urban expansion into grassland and
385 woodland ecosystems that provide critical habitat for several threatened reptiles and
386 invertebrate species (Howland et al., 2016). In both cases, known threats to highly threatened
387 species are perpetuated due to prioritisation of competing interests ahead of those species.
388 Improving conservation outcomes in such cases is highly challenging and will ultimately
389 require decision makers to accept greater responsibility for the fate of threatened species. We
390 suggest that it is crucial to explicitly recognise that current policy choices prioritise economic
391 or social interests that are key threats to species, and clearly acknowledge and communicate
392 that threatened species will be negatively impacted, and at risk of extinction if the status quo
393 is maintained. Subsequently, this may trigger a rethink of societal values and re-analysis of
394 the economic value of competing interests; allowing society to choose whether priorities
395 should be shifted to promote species conservation (Abson et al., 2017). Such rethinking is
396 particularly pertinent in light of evidence showing strong public support for threatened
397 species conservation (McCune et al., 2017).

398 3.2. Unknown threats and unknown solutions

399 In some cases, species can experience major declines resulting from an unknown threat, or if
400 effective management actions to combat a threat are not known. Enigmatic declines are
401 increasingly common in a globalised world where new threats can rapidly emerge. An
402 illustrative example is the enigmatic declines of hundreds of frog species, both in Australia
403 and globally, from the 1970s onwards. In Australia, the disappearances of several rainforest
404 frog species was first documented in 1979 (Scheele et al., 2017b). Further declines were
405 observed across eastern Australia in the 1980s and 1990s, but it was not until 1998 that a
406 previously unknown disease – chytridiomycosis – was identified and demonstrated to be the
407 cause of frog declines (Scheele et al., 2017b). Following identification of the threat, it took a
408 further decade to develop management actions, and these remain only partially effective
409 (Scheele et al., 2014). In total, it took over three decades from threat emergence and
410 documentation of initial species declines to the development of conservation actions to
411 combat chytridiomycosis. In the intervening years, seven species of frog likely went extinct
412 and a further six species declined severely and are at high risk of extinction without targeted

413 ex-situ programs (Scheele et al., 2017b). While there is no single, easy method for identifying
414 novel threats and developing effective responses, long-term investment in ecological research
415 and monitoring will build capacity to better unravel emerging causes of decline and develop
416 effective management responses.

417 3.3. Highly mobile and cryptic species

418 Coordinating and implementing conservation actions across large spatial scales covering
419 multiple land tenures and government jurisdictions is challenging. This is compounded by the
420 fact that information on the ecology, threats and effectiveness of management actions is
421 particularly lacking for nomadic and migratory species (Webb et al., 2017). An example of a
422 species with such management challenges is the regent honeyeater (*Anthochaera phrygia*).
423 This semi-nomadic species is critically endangered with an estimated population size of only
424 350-400 adults, distributed across a 600 000 km² range across parts of South Australia,
425 Victoria, New South Wales, Australian Capital Territory and Queensland. This species moves
426 across vast distances in response to flowering of nectar producing trees. Restoration plantings
427 have been identified as a key management action, but deciding where to establish planting is
428 highly problematic due to the species' transient occurrence, and the lag between planting and
429 maturity. Similar challenges are also evident for international migratory species that face
430 severe threats in parts of their range that undermine conservation actions in other regions, and
431 for which managers in Australia have limited capacity to influence (Hansen et al., 2018). In
432 addition, many other traits common to threatened species, such as irruptive population
433 dynamics (arid rodent species), highly cryptic behaviour (pygmy bluetongue, *Tiliqua*
434 *adelaidensis*) and extreme rarity (plains wanderer, *Pedionomus torquatus*; night parrot,
435 *Pezoporus occidentalis*), can make management challenging (Dickman et al., 2018).

436 3.4. Lack of critical reflection on management practices

437 For management of threatened species to succeed, it is critical not only that proper evaluation
438 is undertaken to understand which actions work and which fail, but also to reflect on the
439 process by which decisions are taken and how those processes can be systematically
440 improved over time. This is the essence of adaptive management, which provides a powerful
441 framework to undertake threatened species management (Runge, 2011). It is particularly
442 useful in cases where there is uncertainty surrounding the effectiveness of different
443 management approaches, and where actions are implemented repeatedly, providing
444 opportunities for learning to be integrated and management adjusted accordingly (Runge,

2011). However, the term adaptive management is at risk of becoming a panchreston – a term associated with such a wide range of definitions that it becomes almost meaningless. A lack of clear consensus of what is adaptive management, especially amongst practitioners, is highly problematic (Westgate et al., 2013). The label of ‘adaptive management’ is applied liberally to cover very simple ad hoc trial and error management programs (with no/limited formal monitoring), right through to complex programs that adhere to the core principles of adaptive management, like conceptual model development, thorough monitoring and program evaluation and refinement. In practice, the best point of this continuum to apply to any conservation problem is context-specific; sometimes ad hoc trial and error is exactly the right approach to take. However, since adaptive management conveys the sense of ‘best-practice’, programs so-labelled are sometimes perceived to be immune from scrutiny and without need for improvement. Failure to recognise the need to continually improve management hinders progress on species conservation.

4. Key lessons from threatened species management in Australia

Based on several decades of our collective experience addressing a diverse range of management, policy, and research challenges relating to threatened species, we have observed several lessons broadly applicable to threatened species management:

1. We need to learn from failure. This requires a cultural shift from hiding and downplaying failures, to openly acknowledging failure and most importantly, ensuring that we learn from failures to avoid repeating the same mistakes (Redford and Taber, 2000). To enable failures to be reported and evaluated, programs need to realistically evaluate failure risk in the planning stage.

2. In complex situations, there is a need to slow down and take stock of current knowledge, identify uncertainty and develop a structured approach to move forward. Too often, with a perceived urgency for action, complex problems are glossed over, which can later resurface, sometimes to create insurmountable problems (Lindenmayer and Likens, 2018). The development of a conceptual model can help identify key areas of uncertainty. At the same time, it is crucial to ensure that management does not stall due to uncertainty.

3. More rigorous evaluation of management efficacy is critical, along with greater information of threatened species trajectories. This can be achieved through long-term population abundance or occurrence monitoring, or detailed evaluation of target species’

476 demography, with subsequent projections of population abundance. Without improved
477 monitoring of management efficacy and species' population trajectories, progress on refining
478 and improving management actions will be unacceptably slow.

479 4. The formation of successful species recovery teams requires a diversity of people with
480 complementary skillsets (Clark and Westrum, 1989), and bringing in people with different
481 skills during each stage of the program. For example, specialist facilitators with experience in
482 structured decision making can help with the problem definition stage of planning, while
483 statisticians might play a role designing monitoring so that it has sufficient power to detect
484 management effectiveness. Threatened species recovery is a multifaceted process, and
485 unbalanced teams may fail to deliver successful conservation outcomes.

486 5. When recovery plans are deemed necessary, it is crucial that they are funded and
487 implemented, with clear accountability for actions outlined and enforced, and thorough
488 evaluation of management effectiveness. Evaluations of recovery plans and associated data
489 should be compiled in a central depository for public access.

490 **5. Conclusion**

491 Threatened species conservation is a cornerstone of efforts to curb global biodiversity loss. A
492 universal challenge in threatened species management remains limited resources (Johnson et
493 al., 2017). Efforts to increase funding require managers and scientists to clearly demonstrate
494 the benefit of current investment, and better communicate that the risk of under-investment is
495 species extinctions. In parallel, there is opportunity for improvement in management
496 practices. We highlight the importance of: 1) inclusive stakeholder engagement and
497 communication; 2) fostering strong leadership and the development of ambitious long-term
498 goals; 3) knowledge of target species' ecology and threats, particularly focusing on filling
499 knowledge gaps that impede development of effective management; 4) setting objectives
500 with measurable outcomes; 5) strategic monitoring and action evaluation; and 6) greater
501 accountability for species declines to ensure timely action and guard against complacency.
502 Together, good conservation practice, along with increased resource allocation and re-
503 evaluation of the prioritisation of competing interests that threaten species, will help ensure
504 enhanced conservation outcomes for threatened species.

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510

511 **Appendix A:** Supporting Material Table S1. Case-studies of threatened species management
512 in Australia demonstrating key principles described in the main text.

513

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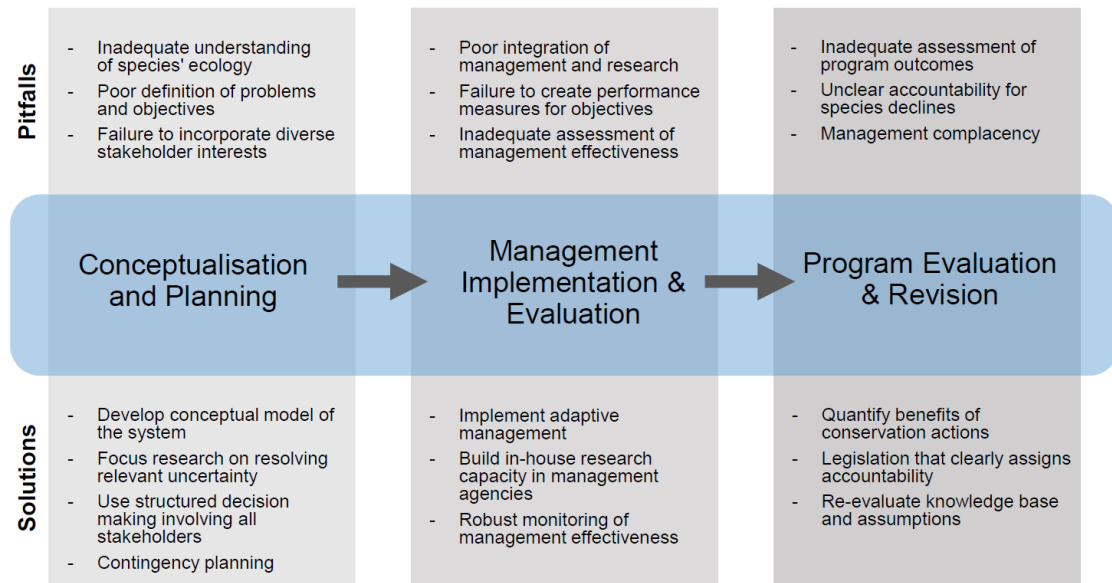
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712

713 Figure 1. Common pitfalls and potential solutions for improving threatened species
 714 management.

715

716 **Appendix A. Supporting Material**

717

718 **Title:** How to improve threatened species management: an Australian perspective

719

720 **Authors:** Scheele, B.C., Legge, S., Armstrong, D.P., Copley, P., Robinson, N., Southwell, D.,
721 Westgate, M.J. & Lindenmayer, D.B.

722

723 **Table S1.** Case-studies of threatened species management in Australia demonstrating key principles
724 described in the main text. For each species, the Environment Protection and Biodiversity
725 Conservation Act 1999 species status is provided.

1. Conceptualisation and planning

Example 1: Importance of thorough ecological knowledge for managing inter-dependencies between threatened species

The conservation of a threatened species may be dependent on the management and conservation of another threatened species. For example, the recently listed, critically endangered plant-louse (*Trioza barrettae*) is entirely dependent on a single host plant species, the critically endangered *Banksia brownii*, which is under severe threat from the emerging pathogen *Phytophthora cinnamomi*. Addressing rapid decline and co-extinction of both species has involved translocations of *B. brownii* to *Phytophthora* free areas, followed by translocations of the plant-louse onto the translocated host (Moir et al., 2016). Consideration of all aspects of a species biology, including dependants, is crucial for effective threatened species management.

Example 2: Using structured decision making to target research and learning

Deciding on a course of action for threatened species is difficult when the fundamental objective and effect of management alternatives is uncertain. Bode et al. (2017) ran a series of structured decision-making workshops with experts in malleefowl (*Leipoa ocellata*, listed as vulnerable) ecology and mallee ecosystems to identify management alternatives for malleefowl, as well as the fundamental objective of a management program. Experts helped develop an ecosystem model for the species that quantified the uncertainty of proposed management actions. This identified knowledge gaps, the need for further learning, and formed the basis an adaptive management project.

Example 3: Identifying fundamental objectives and optimal management actions

Clear specification of the fundamental objective is crucial to successful management because it determines the choice of management action. Canessa et al (2016) developed a framework to determine whether to adopt ex-situ management for threatened species. They applied their framework to the critically endangered spotted tree frog (*Litoria spenceri*) in Australia and found the management strategy that maximised the chance of a wild population surviving for 20 years at the lowest cost. The optimal strategy depended on the weightings placed on the objectives (maximise persistence or minimise cost) by managers.

Example 4: Integrating threatened plant conservation into fire management

Managers often have to juggle multiple objectives, and assimilate them into broader management goals. Auld and Scott (2013) provide a case-study where the ecological requirements of the endangered shrub, *Grevillea caleyi*, were incorporated into broader fire planning protocols. The integrated fire management plan considered associated management actions such as weed control aimed at managing small ridgetop populations adjacent to urban areas, while ensuring threatened species management objectives were addressed.

Example 5: Resolving competing objectives between multiple threatened species

Threatened species can themselves be a threatening process to other threatened species, potentially creating ethical dilemmas of how to prioritise management. For example, browsing by rabbits (*Oryctolagus cuniculus*) and the endangered Quokka (*Setonix brachyurus*) was shown to contribute to the rapid and recent decline in numbers of critically endangered plants; *Andersonia axilliflora*, *Darwinia collina*, *Latrobea colophona*, *Leucopogon gnaphalioides*. These species are also threatened by *Phytophthora cinnamomi* and frequent fire. Rathbone and Barrett (2017) demonstrated that potentially conflicting objectives could be managed by installing wire enclosures around threatened plants to eliminate browsing effects.

2. Management implementation and evaluation

Example 6: Implementing adaptive management to resolve uncertainty around management effectiveness

Adaptive management can help learn which management action is best for a species while simultaneously achieving management objectives. The development of the adaptive management program for the vulnerable malleefowl (*Leipoa ocellata*) demonstrates that by integrating knowledge from existing databases, and engaging with all stakeholders, greater understanding of complex ecological problems can be realised and solutions developed to address uncertainty (Benshemesh et al., 2018). This process involved developing conceptual models of how threatened species, threatening processes and management interact. Different management actions were considered and their effect on the system was modelled. This led to clear management actions to test in an adaptive management framework.

Example 7: The importance of monitoring in adaptive management

West et al. (2017) conducted a trial reintroduction of 16 captive warru (*Petrogale lateralis*) to test whether it was feasible to establish reintroduced populations. Monitoring the survival of individuals in reintroduced populations was crucial to tracking management success and facilitating further iterations of the adaptive management cycle. Importantly, they identified a period of high mortality in the three months immediately post-release and recommended intensive monitoring during this period for future releases.

Example 8: Genetic monitoring and evaluation of plant translocations

It is important to assess the genetic diversity of reintroduced populations. Kraus et al. (2002) assessed the genetic diversity of translocated populations of the endangered Corrigin grevillea (*Grevillea scapigera*). They demonstrated a failure to maintain genetic fidelity of propagules resulting in significantly less genetic diversity in the translocated population than was possible from original seed collections. This discovery was subsequently addressed in later translocations.

Example 9: Genetic monitoring and evaluation of animal translocations

Ottewell et al. (2014) evaluated the genetic diversity of golden bandicoots (*Isodon auratus*) that were translocated from a large island source population to two other island sites and a mainland fenced enclosure. Their assessment indicated that the population currently has adequate diversity due to a large founder population and high reproductive rates. However, ongoing augmentation will be required to prevent genetic erosion in the long-term. Timely evaluation can enable early intervention before it is too late, or becomes more resource intensive.

Example 10: The value of monitoring for learning from failure

A trial release of the endangered captive-bred woma pythons (*Aspidites ramsayi*), into the exotic-predator-free Arid Recovery Reserve in northern South Australia ended within four months, with all of the reintroduced womas unexpectedly killed by mulga snakes (*Pseudechis australis*) - confirmed or implied in all cases (Read et al., 2011). Lessons learned included the need for conditioning of captive-bred snakes for wild release and the role of the mulga snake in structuring Australian arid-zone snake assemblages.

3. Program evaluation and revision

Example 11: Critical evaluation of current management actions to identify shortcomings

The critically endangered orange-bellied parrot is on the verge of extinction in the wild, with only three wild-bred females returning to the breeding area in 2016-17 (supplemented by release of captive-bred birds). Stojanovic et al. (2017) critically evaluated existing recovery actions for this species and identified 10 new or varied actions for urgent implementation aimed at preventing extinction of the species. These focused primarily on improving quality and availability of wild foods and more intensively managing the wild population, especially during nesting.

Example 12: Identifying key drivers of success

Moseby et al. (2011) assessed the effectiveness of 10 reintroduction attempts in and around the Arid Recovery Reserve in northern South Australia between 1998 and 2008. Five locally-extinct mammal species and one reptile species were reintroduced into a fenced Reserve where cats (*Felis catus*), red foxes (*Vulpes vulpes*) and rabbits (*Oryctolagus cuniculus*) were excluded. Reintroductions of the greater stick-nest rat (*Leporillus conditor*, vulnerable), burrowing bettong (*Bettongia lesueur*, vulnerable), greater bilby (*Macrotis lagotis*, vulnerable) and western barred bandicoot (*Perameles bougainville*, endangered) were all considered successful because of population establishment, continued survival after eight years, increased distribution across the Reserve, and population persistence during a drought event. The trial reintroductions of the numbat (*Myrmecobius fasciatus*, vulnerable) and woma python (*Aspidites ramsayi*, endangered) into the Reserve were unsuccessful due to predation by native avian and reptilian predators respectively. The reintroduction of the greater bilby and burrowing bettong to outside of the Reserve was also unsuccessful. Assessment of the program has enabled Arid Recovery to prioritise efforts, secured ongoing funding through demonstrated effectiveness, and prompted a rethink of how to address ineffective management strategies.

Example 13: Analysing long-term monitoring data to assess effectiveness of management actions

Walsh et al. (2012) analysed long-term monitoring data to evaluate the effectiveness of red fox (*Vulpes vulpes*) baiting as a management strategy for the vulnerable malleefowl (*Leipoa ocellata*). Unexpectedly, fox baiting was found to have little-to-no effect on malleefowl persistence, despite it being the preferred management strategy for this species. This example demonstrates the need to evaluate management effectiveness and the value of monitoring data for assessing progress towards management objectives.

Example 14: Identifying accountability for species trajectories

The south-eastern Australian red-tailed black-cockatoo (*Calyptorhynchus banksii graptogyne*, endangered) recovery plan highlights threats to the cockatoo's food supplies and nesting habitats and identifies strategies for minimising the scale and risk of each threat (Department of Environment and Water Resources, 2007). The strategies identified also indicate where accountabilities lie to ensure that protective measures are put in place. These strategies include fire management planning to minimise crown scorch to stringybark trees thereby limiting losses of seed crops which the cockatoos depend upon. The strategies also include improvements to local planning controls over vegetation clearance applications to ensure protection of cockatoo nest trees and important feeding habitat.

4. Stakeholder engagement and communication

Example 15: Importance of involving all stakeholders

The critically endangered Lord Howe island stick insect (*Dryococelus australis*) conservation program provides an example of involving all stakeholders to ensure good outcomes (Carlile et al., 2009). Early and ongoing engagement with the local community meant that a proposed ship rat (*Rattus rattus*) eradication program was well-supported and implemented. Involvement with experts from Melbourne Zoo further enabled the development of appropriate husbandry procedures for the survival of captive bred individuals.

Example 16: Indigenous landowner engagement and decision making

An innovative conservation program for the vulnerable warru (*Petrogale lateralis*) on Anangu Pitjantjatjara Yankunytjatjara Lands has focused on improving in-situ survival and recruitment of warru (Read et al., 2018). Management has been led by Indigenous Warru Rangers in partnership with researchers and state government agencies. Management has focused on targeted removal of feral cats (*Felis catus*) and red foxes (*Vulpes vulpes*), management of invasive buffel grass (*Cenchrus ciliaris*), and establishing a captive breeding program. On-ground management occurs entirely on Indigenous lands, and Indigenous stakeholders are heavily involved in planning, management and strategic decision-making.

5. Leadership and personnel

Example 17: Building strong collaborations in with partners

The critically endangered spiny daisy (*Acanthocladium dockeri*) in South Australia has a small, but strong, recovery team that has achieved consistent and effective progress on implementation of its recovery plan (Clarke et al., 2013). The team consists of a mix of landholders, local industry and local and State Government representatives. The plan has had a sound research base from the time of the species rediscovery and has strong buy in from landholders and local industry.

Example 18: The need to commence management despite an initial lack of knowledge

Aerial application of phosphite to protect highly susceptible threatened plants from *Phytophthora cinnamomi* has been implemented since 1997, despite initial concerns about phytotoxicity and cumulative impacts over time, with the rapid decline and local extinction of a number of plant species now halted and stabilised (Barrett and Yates, 2015). The early and successful application of phosphite has had major conservation benefits and highlights the value of decisive leadership in urgent situations.

Example 19: The need for recovery teams to incorporate a broad range of skillsets

The recovery team for the critically endangered southern and northern corroboree frogs (*Pseudophryne corroboree* and *P. pengilleyi*) consists of a diverse range of government practitioners, field ecologists, evolutionary biologists, disease biologists and zoo practitioners (McFadden et al., 2013). The diversity of team members has been crucial for the development of innovative solutions to achieve successful captive breeding of the species and to develop and trial new reintroduction techniques to re-establish wild populations. A range of skillsets has been particularly important in responding to a novel, emerging threat (chytrid fungus) that is highly challenging to manage.

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