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2 Estimating the benefit of well-managed protected areas for threatened species conservation

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23 **Title:**

24 Estimating the benefit of well-managed protected areas for threatened species conservation

25 **Abstract**

26 Protected areas (PAs) are central to global efforts to prevent species extinctions, with many countries investing
27 heavily in their establishment. Yet, the designation of PAs alone can only abate certain threats to biodiversity.
28 Targeted management within PAs is often required to achieve fully effective conservation within their
29 boundary. It remains unclear what combination of PA designation and management is needed to remove the
30 suite of processes that imperil species. Here, using Australia as a case study, we use a dataset on the pressures
31 facing threatened species to determine the role of PAs and management in conserving imperilled species. We
32 found that PAs that are not resourced for threat management could remove one or more threats to 1185 (76%)
33 species and all threats very few (n=51, 3%) species. In contrast, a PA network that is adequately resourced to
34 manage threatening processes within their boundary would remove one or more threats to almost all species
35 (n=1551; ~100%) and all threats to almost half (n=740, 48%). However, 815 (52%) species face one or more
36 threats that require coordinated conservation actions that PAs alone could not remove. This research shows that
37 investing in the continued expansion of Australia's PA network without providing adequate funding for threat
38 management within and beyond the existing PA network will benefit very few threatened species. These
39 findings highlight that as the international community expands the global PA network in accordance with the
40 2020 Strategic Plan for Biodiversity, a much greater emphasis on the effectiveness of threat management is
41 needed.

42 **Keywords:**

43 Threats; threat management; protected area management; protected area effectiveness, Aichi Targets, EPBC
44 Act; Australia.

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50 **Introduction**

51 Nationally designated protected area (PA) networks are now central to biodiversity conservation strategies
52 globally (Coetzee et al. 2014; Watson et al. 2016) as they are considered the most effective way to overcome the
53 threats that are causing the current biodiversity crisis (Rands et al. 2010). While recent research has found that
54 PAs generally support greater species richness and abundance than comparable areas that are not protected
55 (Barnes et al. 2016; Gray et al. 2016), and they are mostly effective at mitigating vegetation clearing by human
56 activity (Naughton-Treves et al. 2005; Joppa et al. 2008), there is also evidence that under current levels of
57 funding, many PAs are unable to abate the many other processes that cause species decline (Craigie et al. 2010;
58 Joppa & Pfaff 2011). Despite pronounced PA expansion over recent decades and ambitious global targets for
59 future growth under the 2020 Strategic Plan for Biodiversity (CBD 2011; UNEP-WCMC & IUCN 2016),
60 surprisingly little is known about the extent to which they can abate the full range of threatening processes that
61 imperil species (Watson et al. 2014).

62 Given the central—and sometimes sole—focus on the establishment of PAs to fulfil international conservation
63 targets (Joppa & Pfaff 2011; Lopoukhine & de Souza Dias 2012; Dudley et al. 2014), it is important to
64 understand the extent to which PAs can mitigate threatening processes. For example, Australia’s National
65 Reserve System is the country’s most important investment in biodiversity conservation (Commonwealth of
66 Australia 2013b) and in 2014, the Environment Minister announced to the World’s Park Congress that Australia
67 had achieved its international commitments because it reached the areal component of the goal of 17% of land
68 within PAs as outlined in Aichi Target 11 of the Strategic Plan for Biodiversity (Secretariat of the CBD 2010;
69 Hunt 2014). Many other nations are making progress towards their own PA coverage targets. For example, both
70 South Africa and Canada are planning a significant increase to their PA networks to make their contribution to
71 the global 17% target by 2020 (Government of South Africa 2010; Government of Canada 2016).

72 As national and global PA networks are dramatically expanded to halt biodiversity decline (Venter et al. 2014;
73 Watson et al. 2014; Barr et al. 2016), it is vital to understand their effectiveness at conserving biodiversity.
74 Given Australia is one of the first nations to have claimed to have met the 17% terrestrial area target, it is a
75 useful case study in which to assess the extent that PAs can abate those processes that threaten species. Despite
76 having a large PA network, the country has a poor history of recent extinctions (Woinarski et al. 2016), and with
77 over 1700 species currently listed as threatened with extinction nationally (Commonwealth of Australia 2015),
78 further extinctions are likely (Woinarski et al. 2015). Furthermore, most Australian species face multiple threats

79 (Evans et al. 2011) that require a variety of actions to mitigate. These range from PA designation and targeted
80 threat management across protected and non-protected areas, to stronger legislation and better land-management
81 practices (Lindenmayer 2015, Woinarski et al. 2015, Woinarski et al. 2016).

82 Quantifying the variety of actions needed to mitigate the impacts of threats on imperilled species is vital in
83 understanding the response required to conserve threatened species. Where legal support for PAs are strong,
84 their designation alone will be effective at mitigating a number of threats, particularly those that cause habitat
85 loss (e.g. agriculture, urbanization). Nevertheless, many threats operate irrespective of land tenure and as such,
86 management is required to mitigate their impacts. Where threats can be dealt with at a local or point-basis,
87 targeted management within a PA will effectively mitigate these (e.g. invasive species; fire); whereas some
88 threats are pervasive across the landscape and therefore require a systematic management approach both inside
89 and outside of PAs (e.g. invasive diseases and pathogens). In Australia for example, threats such as
90 inappropriate fire regimes and invasive species are contributing to the severe decline of numerous mammal
91 species in one of Australia's premiere protected areas (and a UNESCO Natural World Heritage site), Kakadu
92 National Park (Woinarski et al. 2011). To adequately conserve these threatened species, PA managers must be
93 resourced to undertake intensive management of these threats. In evaluating the role of PAs in threatened
94 species conservation, it is vital to recognize that in many circumstances PA designation must be complemented
95 with management to effectively conserve species.

96 Here we provide the first holistic assessment of the extent to which a continental PA network mitigates the
97 range of threats to species at risk of extinction. In doing this we aim to understand how effective PAs are at
98 removing the processes that threaten species with extinction. Using a recently compiled national database on the
99 threats to Australian species, we summarize the range of management actions required to mitigate these threats.
100 Using this summary we quantify the role that PAs play in separating threatened species from the processes that
101 threaten their persistence.

102 **Methods**

103 *Australian threatened species data*

104 Species that have been classified as threatened by the Australian Department of the Environment and Energy's
105 Threatened Species Scientific Committee and Minister are listed under the Environment Protection and
106 Biodiversity Conservation (EPBC) Act 1999 (Commonwealth of Australia 2017b). We undertook this study in
107 early 2017, at which time there were 1749 Australian species listed as threatened under the EPBC Act. We

108 followed previous studies (Carwardine et al. 2008; Evans et al. 2011) and included all terrestrial and freshwater
109 vertebrate, invertebrate and plant species, as well as marine species that rely on land or freshwater for a part of
110 their life-cycle. We only considered threats to marine species that originate and require management on land.
111 Excluded from the analysis were extinct species, species that face uncertain threats and exclusively marine
112 species. In total, 1555 Australian threatened species were considered in this analysis.

113 *Threatening process data*

114 Information on Australian threatened species and the threats reported as impacting them are available through
115 the Species Profiles and Threats (SPRAT) Database (Commonwealth of Australia 2015). The SPRAT database
116 provides threat data on species protected under the EPBC Act and has been used in a number of studies that
117 assess threatening processes on Australian species (Evans et al. 2011; Walsh et al. 2013). For this study we used
118 information from the SPRAT database that was current as of late 2015.

119 The information on threats is compiled using a range of sources including listing advice, recovery and action
120 plans, published literature and expert knowledge (Commonwealth of Australia 2015). It is likely that this
121 information is not exhaustive and the listed threats are likely to be those that are obvious and tangible to
122 endangered species' managers, meaning subtle threats may be overlooked and not reported. The SPRAT
123 database follows the standardised Threats Classification Scheme outlined by Salafsky et al. (2008). These threat
124 classifications are the same as those used by the International Union for Conservation of Nature (IUCN) for the
125 Red List of Species process and allows comparison across regions and taxonomic groups (IUCN 2016). This
126 threat classification scheme contains 11 direct threats types and one type for new and emerging threats ('Other
127 options'; Salafsky et al. 2008). The classification scheme is based on a three-level hierarchy, with each level
128 increasing in detail and specificity. The first level (major threat) being the broadest, the second level (sub-threat)
129 being more defined and the third level (specific threat) being at a much finer scale. Each major threat has
130 between three and six sub-threat classifications. Table 1 provides a full description and specific details for each
131 major threat classification.

132 *Threat management*

133 We used government threat abatement plans and peer-reviewed literature to identify potential management
134 actions to mitigate each threat. While there is potentially a number of ways to remove each threat and local
135 context influences what is the most appropriate action, we identify what would generally be the conservation
136 action or combination of actions used to mitigate each threat. For clarity we followed the standardised lexicon

137 provided by Salafsky et al. (2008) for conservation actions. Table 1 contains a summary of the threat and
138 conservation action required and Supplementary Table S1 contains the reasoning for the choice of each action.

139 *Assessing the effectiveness of the PA network to manage threats*

140 There is no dataset available that provides information on how each individual PA mitigates the threats
141 occurring within it. We therefore classified each threat relative to how effective the PA network could be in
142 overcoming it. We followed the standardised conservation actions as defined by Salafsky et al. (2008).
143 Conservation actions are interventions that need to be undertaken to reduce the extinction risk of a species
144 (Salafsky et al. 2008). Using these conservation actions, we defined three distinct threat management scenarios
145 for PAs.

146 The first, which we label ‘unmanaged’, considers PAs as a legally designated land-use, which can overcome
147 threats causing vegetation clearance and habitat loss but where on-ground threat management such as invasive
148 species control and fire management does not occur (Table 1). This scenario captures a situation where PA
149 managers are inadequately resourced to undertake on-ground threat management, as is likely to be the case in
150 some PAs across Australia (Taylor et al., 2011a; Craigie et al. 2015). It should be noted that in some countries,
151 PAs are ineffective at achieving their primary goal due to poor legislative support (Watson et al. 2014). PAs
152 designated but never implemented – commonly referred to as ‘paper parks’ – are unlikely to be able to abate the
153 threats we discuss here.

154 The second scenario, which we label ‘well-managed’, considers a PA as not only a legally designated land use,
155 and hence able to stop habitat loss, but one where there is adequate funding and resources provided to undertake
156 effective management of threats within its boundary. Here, management is a broad term that refers to on-ground
157 activities that mitigate the processes that threaten species within the PA boundary. Management actions range
158 from invasive species control and fire management, to enforcement and habitat restoration (Table 1 provides full
159 details).

160 Additionally, a number of threats to Australian species are unable to be adequately mitigated by PAs, no matter
161 how well resourced and managed (Gaston et al. 2008). Instead these threats require a coordinated response
162 across protected and non-protected areas, which we label as ‘landscape management’ (Table 1). An example of
163 threats that require a landscape management approach are the invasive diseases and pathogens listed as key
164 threatening processes under the EPBC Act (Commonwealth of Australia 2017a). These diseases impact 161
165 Australian threatened species and are thought to have caused or contributed to at least four extinctions of

166 Australian species (Commonwealth of Australia 2005, 2006, 2014). The threat abatement plans for these
167 diseases emphasise a number of management actions to be coordinated nationally. These are minimising the
168 spread of the disease by controlling dispersal through quarantine actions and controlling the movement of
169 infected species, mitigating the impact on species at infected sites through identified means, and the
170 establishment of a captive breeding program for species at high risk of extinction (Commonwealth of Australia
171 2005, 2006, 2014). While effectively managed PAs play a vital role in mitigating the impact of threats such as
172 this, a coordinated threat management approach across the broader landscape is needed to ensure effective
173 conservation.

174 It must be noted that there are local factors that require interpretation to determine the most appropriate
175 management action. These factors influence both the impact of threats and the effectiveness of the management
176 action required to deal with it. For example, the impact of salinity can vary widely in its scale and severity.
177 Where its impact is localised, a PA with restoration efforts can effectively mitigate this. Whereas when salinity
178 impacts an entire landscape, as is occurring in Australia's Murray-Darling Basin, a landscape management
179 approach is required (Murray-Darling Basin Authority 2015). Similarly, to adequately mitigate the impact of a
180 number of invasive species, multiple levels of management may be required. For example, to abate the
181 immediate impact of an invasive plant species, on-ground control (e.g. spraying, physical removal) is first
182 needed (IPAC 2016) but then should be complemented with local (and potentially national) policies aimed at
183 minimising its spread and establishment in new areas (IPAC 2016). Additionally, the size of a PA has a
184 significant impact on its effectiveness at mitigating threats. For example, the conservation of large, intact
185 landscapes are the best response to the impacts of climate change (Watson et al. 2009; Gross et al. 2015). As
186 such, small PAs which comprise a high proportion of Australia's PA network (Commonwealth of Australia
187 2013a), are unlikely to be able to mitigate the impacts of such threats. Here, we determined the typical actions
188 used to mitigate each threat. Supplementary Table S1 provides a full reasoning for the choice of the
189 conservation action required to mitigate each threat to Australian species.

190 ***Level of threat abatement***

191 To estimate the role of PAs in threatened species conservation in Australia, we quantify the level of threat
192 abatement provided by each management scenario. We do this by calculating the proportion of threats removed
193 by each scenario to Australian threatened species, and the number of species which have one or more and all
194 threats abated by each management scenario. While these calculations are theoretical, by comparing the

195 effectiveness of the two PA management scenarios we approximate the role that well-managed and unmanaged
196 PAs play in threatened species conservation in Australia.

197 **Results**

198 *The threats impacting Australian species*

199 Australian threatened species face 11 major threat classes, with invasive and other problematic species
200 impacting the greatest proportion of species (n = 1274, 82%; Fig. 1). Two other major threats, natural system
201 modifications and agriculture, impact over half of Australia's threatened species (n = 1136, 73% and n = 874,
202 56%, respectively; Fig. 1). The sub-threats of invasive non-native species (within the major threat class invasive
203 and other problematic species; 80%) and fire and fire suppression (within the major threat class natural system
204 modifications; 65%) threaten the greatest number of Australian threatened species.

205 *The number of threats reported as impacting Australian species*

206 Each Australian threatened species is impacted by between 1 and 10 major threats (Fig. 2a) and 1 and 54
207 specific threats (Fig. 2b). On average, each species faces 7.6 specific threats (± 5.8 SD). Only 95 species (6%)
208 face a single specific threat, while 1025 species (66%) face 5 or more specific threats (Fig. 2b).

209 *The number of threats mitigated by each management scenario*

210 Under our unmanaged PA management scenario, where PAs are not resourced for on-ground threat
211 management, the Australian PA network can remove 26% of all threats to Australian threatened species (Table
212 2). We found that while the PA network could mitigate one or more threats to 1185 (76%) species, it could only
213 remove all threats to 51 (3%) species (Table 2). In contrast, the well-managed scenario, where PAs are
214 adequately resourced for on-ground threat management, Australia's PA network can remove 86% of threats to
215 all threatened species. Similar to the unmanaged scenario, we found that although the well-managed scenario
216 can remove one or more threats to almost all threatened species (n = 1551; $\sim 100\%$), it can only remove all
217 threats to 740 (48%) Australian threatened species (Table 2). Of great concern is that 815 species face threats
218 that require coordinated landscape-scale management to adequately mitigate (Table 2). PAs alone, no matter
219 how well managed, cannot remove all threats to these species.

220 The disparity between scenarios can be explained by the variety of threats to Australia species and the number
221 of threats each species faces. Unmanaged PAs can only effectively mitigate threats causing habitat loss,
222 particularly Agriculture, Urbanization and Transport corridors (Table 1). As the vast majority of Australian

223 species face multiple threats, of which many require on-ground management to abate, unmanaged PAs cannot
224 remove the majority of threats to Australian species. In contrast, well-managed PAs can abate the two greatest
225 threats to Australian species – Invasive and other problematic species and Natural system modifications as well
226 as threats causing habitat loss (Table 1). Hence, well-resourced PAs can remove all threats to many more
227 species than unmanaged PAs. Although this accounts for the conservation of around half of Australia’s
228 threatened species, the other half require well-managed PAs complemented with threat management in non-
229 protected lands. Threats from invasive diseases and pathogens, air and waterborne agricultural pollutants and
230 altered flow regimes from dams require a combination of management across the entire landscape. As such, for
231 all threats to be removed to all species and ensure the effective conservation of species in Australia, well-
232 resourced PAs must be complemented with effective landscape-scale threat management.

233 **Discussion**

234 Using the actions required to mitigate threats to species, we evaluated the potential effectiveness of PAs, the
235 predominant action taken to protect biodiversity globally, at conserving threatened species. Using Australia as a
236 case study, we found that even in the best-case scenario where PAs are well-resourced and effectively managed,
237 only 48% of threatened species will have all threats removed by the nation’s PA network. These results based on
238 the well-managed PA scenario are likely to be an over-estimate of the effectiveness of the current PA network,
239 as the few studies that have discussed the adequacy of funding for management of PAs in Australia have shown
240 that there are significant shortfalls across much of continent (Taylor et al., 2011a; Craigie et al., 2015). Taylor et
241 al (2011a), for example made the case for an estimated seven-fold increase in investment needed to fill the
242 current management and protection gap in Australia’s PA network. Where PAs are inadequately funded to
243 undertake on-ground threat management, very few species (n=51, 3%) will have all threats removed.

244 Similarly, this analysis overestimates the benefit to threatened species conservation provided by Australia’s
245 current PA network. With the majority of Australian threatened species inadequately represented in PAs and
246 10% of species having no coverage (Watson et al. 2011), PAs provide little to no benefit to these species. This
247 highlights the importance of a landscape scale approach to threat management as many threatened species occur
248 outside PAs, and half (n= 815, 52%) of Australia’s threatened species face threats requiring concerted efforts
249 across protected and non-protected areas. This emphasizes the need to not only fund establishment of new PAs
250 but also to adequately fund the management within and outside of the current PA network.

251 These findings have significant implications for biodiversity conservation globally. As the international
252 community undertakes concerted efforts to halt biodiversity decline (Juffe-Bignoli et al. 2014), too narrow of a
253 focus on PA network expansion will likely lead to an insufficient response. The threat of invasive species,
254 pollution and fire impact thousands of species globally (Maxwell et al. 2016; Rodrigues et al. 2014) and in many
255 countries, invasive species impact a significant proportion of species (e.g. the United States; Wilcove et al.
256 1998). Therefore, we expect our findings to be similar in many other nations. While PAs play a crucial role in
257 solving the biodiversity crisis, we have shown here that this investment will only bear fruit if it is complemented
258 by effective threatened species management.

259 The PA management scenarios defined in this analysis are the two extremes of a spectrum. In Australia, few
260 PAs are likely receiving no threat management actions within their boundary, just as few are likely to be
261 adequately and effectively managed for all threats within their boundaries. Where Australia's current PA
262 network is on this management spectrum is difficult to determine; however, based on reported funding for PA
263 management, it is likely to be highly variable across Australia (Taylor et al. 2011a). Taylor et al. (2011a) report
264 that in 2008/09, the average funding for PA management across Australia was \$9.56/ha. While New South
265 Wales has reported that impacts to threatened species in PAs is stable or improving for the majority, it is
266 believed that in 6.6% of PAs, impacts are increasing (N.S.W. Government 2007). Considering the national
267 average for PA management funding is less than one third of New South Wales (Taylor et al., 2011a), it is likely
268 that many of Australia's PAs are inadequately resourced for effectively managing for all threats within their
269 boundaries.

270 Our analysis emphasizes the importance of all threats being removed from threatened species. While it is
271 unlikely that every threat must be removed to prevent species' extinction, recent Australian extinctions highlight
272 that a more holistic approach to threat management in Australia is needed. Insufficient management of just a
273 few threats resulted in these preventable extinctions (Woinarski et al. 2016). Well-funded, strategically planned
274 and coordinated threat management across protected and non-protected areas in Australia is needed to conserve
275 its unique biodiversity. Currently, available funding for threatened species protection and recovery in Australia
276 is inadequate (Taylor et al. 2011a, Waldron et al. 2013). Additionally, the allocation of the limited available
277 resources is currently biased (Walsh et al. 2013) and often ineffectively spent (Bottrill et al. 2011; Taylor et al.
278 2011b). While it is unlikely the suggested seven-fold increase in funding (Taylor et al. 2011a) for Australia's PA
279 network will occur soon, efficiency can be addressed with a strategic planning process for threatened species
280 management (Watson et al. 2010). Systematic and strategic investment of available funding through

281 management action-specific planning protocols has proven effective and efficient (Bottrill et al. 2008; Joseph et
282 al. 2009). These protocols incorporate cost, benefit and likelihood of success to ensure effective and efficient
283 threatened species outcomes. While such protocols have been used in some states across Australia (Tasmanian
284 Government 2010; N.S.W. Government 2013), a national approach is required given threatened species and the
285 threats they face are unaffected by state borders. As such, a national approach is key to successful threatened
286 species conservation in Australia.

287 As the global PA network continues to dramatically expand in an attempt to halt biodiversity decline, it is vital
288 to understand its effectiveness at achieving this goal. Using Australia as a case study, we were able to provide
289 the first continental evaluation on how effective a network of PAs is at removing the suite of threats that imperil
290 species. We discovered that a PA network well-resourced for on-ground threat management within its
291 boundaries could abate all known threats to half of Australia's threatened species. While PAs will play a role in
292 reducing threats to the other half of Australia's threatened species, they are unable to mitigate all of the
293 processes that impact these species. A coordinated approach across protected and non-protected areas is
294 therefore required to adequately conserve these species.

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297 Profile and Threats Database. Thank you to J. Woinarski for helpful comments on previous versions of this
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299 **Author Contributions**

300 Conception and design of study: S.K., V.A., R.F., H.P., J.W.; analysis and interpretation of data: S.K.; drafting
301 the manuscript: S.K., J.W.; revising the manuscript: S.K., V.A., R.F., H.P., J.W.

302 **Supplementary Material**

303 A table with the threat classifications faced by Australian threatened species, the typical conservation actions
304 taken to mitigate these and reasoning for the choice of this action, is available in Supplementary Table S1.

305 **Biographical sketches**

306 Stephen Kearney is interested in understanding the pressures to threatened species and how to efficiently
307 mitigate these.

308 Vanessa Adams is focussed on the human dimensions of conservation and systematic environmental decision-
309 making.

310 Richard Fuller is interested in understanding how people have affected the natural world around them, and how
311 some of their destructive effects can best be reversed.

312 Hugh Possingham is interested in decision-making for conservation, including spatial planning, optimal
313 monitoring, value of information, population management, prioritization of conservation actions, structured
314 decision-making, bird ecology and dynamic systems control.

315 James Watson is a conservation biogeographer interested in identifying conservation solutions in a time of rapid
316 anthropogenic change.

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330 **References**

- 331 Barnes MD, Craigie ID, Harrison LB et al (2016) Wildlife population trends in protected areas predicted by
332 national socio-economic metrics and body size. *Nature Communications* 7:12747
- 333 Barr LM, Watson JEM, Possingham HP, Iwamura T, Fuller RA (2016) Progress in improving the protection of
334 species and habitats in Australia. *Biological Conservation* 200:184-191
- 335 Bottrill MC, Joseph LN, Carwardine J et al. (2008) Is conservation triage just smart decision making? *Trends in*
336 *Ecology & Evolution* 23:649-654
- 337 Bottrill MC, Walsh JC, Watson JEM, Joseph LN, Ortega-Argueta A, Possingham HP, (2011) Does recovery
338 planning improve the status of threatened species? *Biological Conservation* 144:1595-1601
- 339 Carwardine J, Wilson KA, Watts M, Etter A, Klein CJ, Possingham HP, (2008) Avoiding Costly Conservation
340 Mistakes: The Importance of Defining Actions and Costs in Spatial Priority Setting. *PLoS One* 3
341 (7):e2586.
- 342 Coetzee BWT, Gaston KJ, Chown SL (2014) Local Scale Comparisons of Biodiversity as a Test for Global
343 Protected Area Ecological Performance: A Meta-Analysis. *PLoS One* 9(8):e105824.
- 344 Commonwealth of Australia (2005) Threat Abatement Plan for Beak and Feather Disease affecting endangered
345 psittacine species. Department of the Environment and Heritage, Canberra, Australia.
346 [https://www.environment.gov.au/system/files/resources/5764cda0-5e94-48c7-8841-](https://www.environment.gov.au/system/files/resources/5764cda0-5e94-48c7-8841-49b09ff7398c/files/beak-feather-tap.pdf)
347 [49b09ff7398c/files/beak-feather-tap.pdf](https://www.environment.gov.au/system/files/resources/5764cda0-5e94-48c7-8841-49b09ff7398c/files/beak-feather-tap.pdf). Accessed 6 June 2017
- 348 Commonwealth of Australia (2006) Threat Abatement Plan: Infection of Amphibians with Chytrid Fungus
349 Resulting in Chytridiomycosis. Department of the Environment and Heritage, Canberra, Australia.
350 [https://www.environment.gov.au/system/files/resources/8d01e983-3619-4d83-9b5a-](https://www.environment.gov.au/system/files/resources/8d01e983-3619-4d83-9b5a-6f9fb4d34e3b/files/chytrid-background.pdf)
351 [6f9fb4d34e3b/files/chytrid-background.pdf](https://www.environment.gov.au/system/files/resources/8d01e983-3619-4d83-9b5a-6f9fb4d34e3b/files/chytrid-background.pdf). Accessed 6 June 2017
- 352 Commonwealth of Australia (2013a) The National Reserve System - Protected Area Information. Department of
353 the Environment, Australian Government, Canberra, Australia.
354 <http://www.environment.gov.au/land/nrs/science/capad>. Accessed 6 June 2017

355 Commonwealth of Australia (2013b) The National Reserve System - Protecting biodiversity. Department of
356 Environment, Australian Government, Canberra, Australia.
357 <https://www.environment.gov.au/land/nrs/about-nrs/protecting-biodiversity>. Accessed 6 June 2017

358 Commonwealth of Australia (2014) Threat abatement plan for disease in natural ecosystems caused by
359 *Phytophthora cinnamomi*. Department of the Environment, Australian Government, Canberra,
360 Australia. [http://www.environment.gov.au/system/files/resources/bad95d05-3741-4db3-8946-
361 975155559efb/files/threat-abatement-plan-disease-natural-ecosystems-caused-phytophthora-
362 cinnamomi.pdf](http://www.environment.gov.au/system/files/resources/bad95d05-3741-4db3-8946-975155559efb/files/threat-abatement-plan-disease-natural-ecosystems-caused-phytophthora-cinnamomi.pdf). Accessed 6 June 2017

363 Commonwealth of Australia (2015) Species Profile and Threats Database. Department of the Environment,
364 Australian Government, Canberra, Australia. [http://www.environment.gov.au/cgi-
365 bin/sprat/public/sprat.pl](http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl). Accessed 6 June 2017

366 Commonwealth of Australia (2017a) EPBC Listed Key Threatening Processes, Department of the Environment
367 and Energy, Canberra, Australia. [http://www.environment.gov.au/cgi-
368 bin/sprat/public/publicgetkeythreats.pl](http://www.environment.gov.au/cgi-bin/sprat/public/publicgetkeythreats.pl). Accessed 6 June 2017

369 Commonwealth of Australia (2017b) Nominating a species, ecological community or key threatening process
370 under the EPBC Act. Department of Environment and Energy, Australian Government, Canberra,
371 Australia. <https://www.environment.gov.au/biodiversity/threatened/nominations>. Accessed 6 June 2017

372 Craigie ID, Baillie JEM, Balmford A, Carbone C, Collen B, Green RE, Hutton JM (2010) Large mammal
373 population declines in Africa's protected areas. *Biological Conservation* 143:2221-2228

374 Craigie ID, Grech A, Pressey RL, Adams VM, Hockings M, Taylor M, Barnes M (2015) Terrestrial protected
375 areas of Australia, in: Stow A, Maclean N, Holwell GI (Eds.), *Austral Ark: The State of Wildlife in
376 Australia and New Zealand*. pp. 560-581

377 Dudley N, Groves C, Redford KH, Stolton S (2014) Where now for protected areas? Setting the stage for the
378 2014 World Parks Congress. *Oryx* 48:496-503

379 Evans MC, Watson JEM, Fuller RA, Venter O, Bennett SC, Marsack PR, Possingham HP (2011) The Spatial
380 Distribution of Threats to Species in Australia. *BioScience* 61:281-289

381 Gaston KJ, Jackson SE, Cantu-Salazar L, Cruz-Pinon G (2008) The Ecological Performance of Protected Areas.
382 Annual Review of Ecology Evolution and Systematics 39:93-113

383 Government of Canada (2016) 2020 Biodiversity goals & targets for Canada, Minister of Environment and
384 Climate Change, Canada. Available from [http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-](http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-A4ADB021E9EA/3499%20-%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-%20%20Final%20Web_ENG.pdf)
385 [A4ADB021E9EA/3499%20-](http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-A4ADB021E9EA/3499%20-%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-%20%20Final%20Web_ENG.pdf)
386 [%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-](http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-A4ADB021E9EA/3499%20-%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-%20%20Final%20Web_ENG.pdf)
387 [%20%20Final%20Web_ENG.pdf](http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-A4ADB021E9EA/3499%20-%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-%20%20Final%20Web_ENG.pdf). Accessed 6 June 2017

388 Government of South Africa (2010) National Protected Area Expansion Strategy for South Africa, Pretoria,
389 South Africa. https://www.environment.gov.za/sites/default/files/docs/npaes_resource_document.pdf.
390 Accessed 6 April 2017

391 Gray CL, Hill SLL, Newbold T, Hudson LN, Borger L, Contu S, Hoskins AJ, Ferrier S, Purvis A, Scharlemann
392 JPW (2016) Local biodiversity is higher inside than outside terrestrial protected areas worldwide.
393 Nature Communications 7:12306

394 Gross J, Watson JEM, Woodley S, Welling L, Harmon D (2015) Responding to Climate Change: Guidance for
395 protected area managers and planners. Best Practice Protected Area Guidelines Series, Gland,
396 Switzerland, IUCN.

397 Hunt G (2014) IUCN World Parks Congress Opening Ceremony 2014, Greg Hunt MP, Federal Member for
398 Flinders, Minister for the Environment.
399 [http://www.greghunt.com.au/Parliament/Speeches/tabid/87/ID/3086/IUCN-World-Parks-Congress-](http://www.greghunt.com.au/Parliament/Speeches/tabid/87/ID/3086/IUCN-World-Parks-Congress-Opening-Ceremony-2014.aspx)
400 [Opening-Ceremony-2014.aspx](http://www.greghunt.com.au/Parliament/Speeches/tabid/87/ID/3086/IUCN-World-Parks-Congress-Opening-Ceremony-2014.aspx). Accessed 6 June 2017

401 IPAC (Invasive Plants and Animals Committee) (2016), Australian Weeds Strategy 2017 to 2027, Australian
402 Government Department of Agriculture and Water Resources, Canberra.

403 IUCN (2016) Classification Schemes. IUCN, Gland, Switzerland. [http://www.iucnredlist.org/technical-](http://www.iucnredlist.org/technical-documents/classification-schemes)
404 [documents/classification-schemes](http://www.iucnredlist.org/technical-documents/classification-schemes). Accessed 6 June 2017

405 Joppa LN, Pfaff A (2011) Global protected area impacts. Proceedings of The Royal Society B 278:1633-1638.

406 Joppa LN, Loarie SR, Pimm SL (2008) On the Protection of "Protected Areas". Proceedings of the National
407 Academy of Sciences of the United States of America 105:6673-6678

408 Joseph LN, Maloney RF, Possingham HP (2009) Optimal Allocation of Resources among Threatened Species: a
409 Project Prioritization Protocol. *Conservation Biology* 23:328-338

410 Juffe-Bignoli D, Burgess ND, Bingham H, Belle EMS, de Lima MG, Deguignet M, Bertzky B, Milam AN,
411 Martinez-Lopez J, Lewis E (2014) Protected planet report 2014. Cambridge, UK: UNEP-WCMC.

412 Lindenmayer DB (2015) Continental-level biodiversity collapse. *Proceedings of the National Academy of*
413 *Sciences of the United States of America* 112:4514-4515

414 Lopoukhine N, Dias BFDS (2012) Editorial: What does Target 11 really mean? *Parks* 18, 1:5-8.

415 Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* 405:243-253

416 Maxwell SL, Fuller RA, Brooks TM, Watson JE (2016). Biodiversity: The ravages of guns, nets and bulldozers.
417 *Nature* 536:143-145.

418 Murray-Darling Basin Authority (2015) Basin Salinity Management 2030. Murray-Darling Basin Ministerial
419 Council. Accessed from
420 https://www.mdba.gov.au/sites/default/files/pubs/Basin_Salinity_Management_BSM2030_0.pdf.
421 Accessed 6 June 2017

422 N.S.W. Government (2007) State of the Parks 2007. Parks Victoria, Melbourne.
423 http://parkweb.vic.gov.au/__data/assets/pdf_file/0018/311922/sop2007-part1.pdf. Accessed 6 June
424 2017

425 N.S.W. Government (2013) Saving our Species - Technical report. Office of Environment and Heritage.
426 <http://www.environment.nsw.gov.au/resources/threatenedspecies/SavingOurSpecies/130699sostech.pdf>
427 Accessed 6 June 2017

428 Naughton-Treves L, Holland MB, Brandon K (2005) The role of protected areas in conserving biodiversity and
429 sustaining local livelihoods. *Annual Review of Environment and Resources* 30:219-252

430 Rands MR, Adams WM, Bennun L et al (2010) Biodiversity conservation: challenges beyond 2010. *Science*
431 329:1298-1303

432 Rodrigues AS, Brooks TM, Butchart SH, Chanson J, Cox N, Hoffmann M, Stuart SN (2014) Spatially explicit
433 trends in the global conservation status of vertebrates. *PLoS One*, 9:e113934.

434 Salafsky N, Salzer D, Stattersfield AJ et al (2008) A standard lexicon for biodiversity conservation: Unified
435 classifications of threats and actions. *Conservation Biology* 22:897-911.

436 Secretariat of the CBD (2010) Conference of the Parties 10 Decision X/2, Strategic Plan for Biodiversity, 2011–
437 2020, pp. 1-13. <https://www.cbd.int/decision/cop/?id=12268>. Accessed 6 June 2017

438 Tasmanian Government (2010) Prioritisation of Threatened Flora and Fauna Recovery Actions for the
439 Tasmanian NRM Regions. Department of Primary Industries, Parks, Water and Environment, Hobart,
440 Tasmania.
441 [http://dpiwwe.tas.gov.au/Documents/Tasmanian%20Threatened%20Species%20Prioritisation%20June](http://dpiwwe.tas.gov.au/Documents/Tasmanian%20Threatened%20Species%20Prioritisation%20June%202010.pdf)
442 [%202010.pdf](http://dpiwwe.tas.gov.au/Documents/Tasmanian%20Threatened%20Species%20Prioritisation%20June%202010.pdf). Accessed 6 June 2017

443 Taylor M, Sattler P, Fitzsimons J, Curnow C, Beaver D, Gibson L, Llewellyn G (2011a) Building nature's
444 safety net 2011: The state of protected areas for Australia's ecosystems and wildlife. WWF-Australia,
445 Sydney.

446 Taylor M, Sattler PS, Evans M, Fuller RA, Watson JEM, Possingham, HP (2011b) What works for threatened
447 species recovery? An empirical evaluation for Australia. *Biodiversity and Conservation* 20:767-777

448 UNEP-WCMC and IUCN, 2016. Protected Planet Report 2016. UNEP-WCMC and IUCN: Cambridge UK and
449 Gland, Switzerland

450 Venter O, Fuller RA, Segan DB et al (2014) Targeting Global Protected Area Expansion for Imperiled
451 Biodiversity. *Plos Biology* 12, 6:e1001891.

452 Waldron A, Mooers AO, Miller DC, Nibbelink N, Redding D, Kuhn TS, Roberts JT, Gittleman JL (2013)
453 Targeting global conservation funding to limit immediate biodiversity declines. *Proceedings of the*
454 *National Academy of Sciences of the United States of America* 110:12144-12148

455 Walsh JC, Watson JEM, Bottrill MC, Joseph LN, Possingham HP (2013) Trends and biases in the listing and
456 recovery planning for threatened species: an Australian case study. *Oryx* 47:134-143

457 Watson JEM, Bottrill MC, Walsh JC, Joseph LN, Possingham HP (2010) Evaluating threatened species
458 recovery planning in Australia. Prepared on Behalf of the Department of the Environment, Water,
459 Heritage and the Arts by the Spatial Ecology Laboratory, University of Queensland, Brisbane, 158pp.

460 Watson JEM, Darling ES, Venter O, Maron M, Walston J, Possingham HP, Dudley N, Hockings M, Barnes M,
461 Brooks TM (2016). Bolder science needed now for protected areas. *Conservation Biology*, 30:243-248.

462 Watson JEM, Dudley N, Segan DB, Hockings M (2014) The performance and potential of protected areas.
463 *Nature* 515:67-73.

464 Watson JEM, Evans MC, Carwardine J, Fuller RA, Joseph LN, Segan DB, Taylor MF, Fensham RJ,
465 Possingham HP (2011) The capacity of Australia's protected-area system to represent threatened
466 species. *Conservation Biology* 25:324-332

467 Watson JEM, Fuller RA, Watson AWT, Mackey BG, Wilson KA, Grantham HS, Turner M, Klein CJ,
468 Carwardine J, Joseph LN, Possingham HP (2009) Wilderness and future conservation priorities in
469 Australia. *Diversity and Distributions* 15:1028-36.

470 Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E (1998) Quantifying threats to imperiled species in the
471 United States, *Bioscience* 48:607-615.

472 Woinarski JC, Burbidge AA, Harrison PL (2015) Ongoing unraveling of a continental fauna: decline and
473 extinction of Australian mammals since European settlement. *Proceedings of the National Academy of*
474 *Sciences of the United States of America* 112:4531-4540

475 Woinarski JC, Garnett ST, Legge SM, Lindenmayer DB (2016) The contribution of policy, law, management,
476 research, and advocacy failings to the recent extinctions of three Australian vertebrate species.
477 *Conservation Biology* 31:13-23

478 Woinarski JCZ, Legge S, Fitzsimons JA et al (2011) The disappearing mammal fauna of northern Australia:
479 context, cause, and response. *Conservation Letters* 4:192-201.

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486 **Figure captions**

487 **Figure 1:** The number of Australian threatened species facing each of Salafsky et al.'s (2008) major threat
488 classifications (1a) and the relative impact of each major threat classification on Australian threatened species
489 (1b). The relative impact is defined as the cumulative number specific threats within a major threat that impacts
490 a species. It takes into account that species may face more than one specific threat under each major threat. For
491 example, a species may be threatened by an invasive plant species and an invasive animal species and as such is
492 impacted twice by the major threat classification invasive and problematic species. Threat information is
493 compiled using a range of sources including listing advice, recovery and action plans, published literature and
494 expert knowledge (Commonwealth of Australia 2015). It is likely that this information is not exhaustive and the
495 listed threats are likely to be those that are obvious and tangible to species' managers, meaning subtle threats
496 may be overlooked and not reported.

497 **Figure 2:** The number of Australian threatened species that face one or more major threat classifications (2a)
498 and the number of threatened species facing one or more specific threats (2b). Species facing more than 30
499 specific threats (n=9, 0.006%) were excluded from graph 2b to enable better graphic presentation. Threat
500 information is compiled using a range of sources including listing advice, recovery and action plans, published
501 literature and expert knowledge (Commonwealth of Australia 2015). It is likely that this information is not
502 exhaustive and the listed threats are likely to be those that are obvious and tangible to species' managers,
503 meaning subtle threats may be overlooked and not reported.

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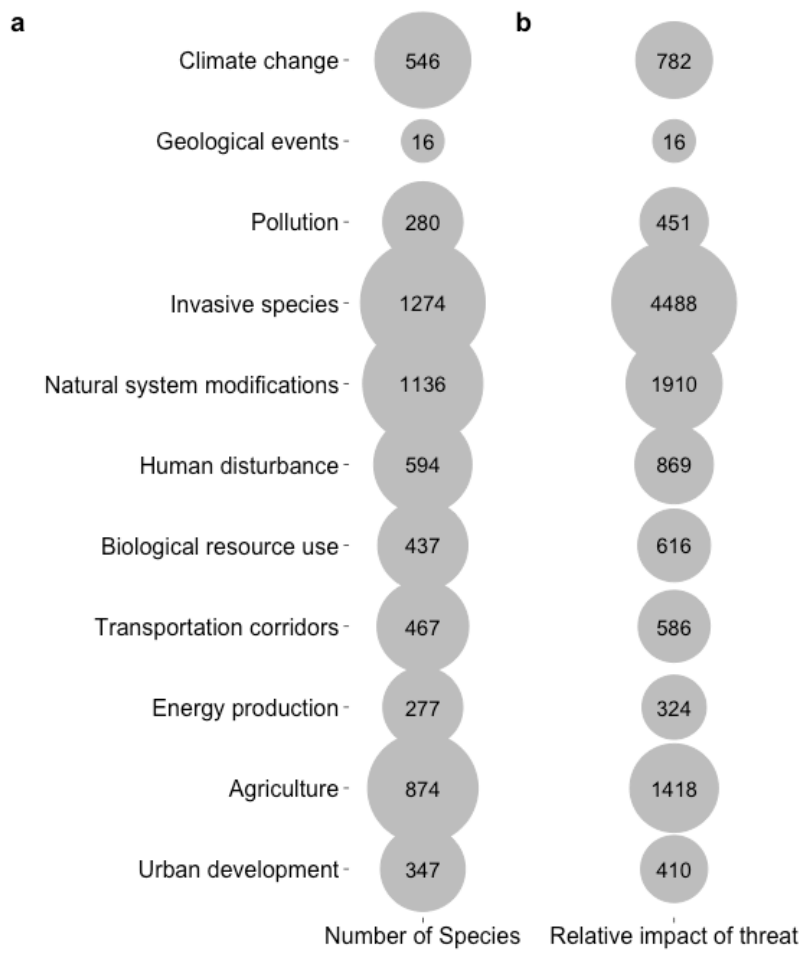
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513 **Figures**

514 **Fig. 1**



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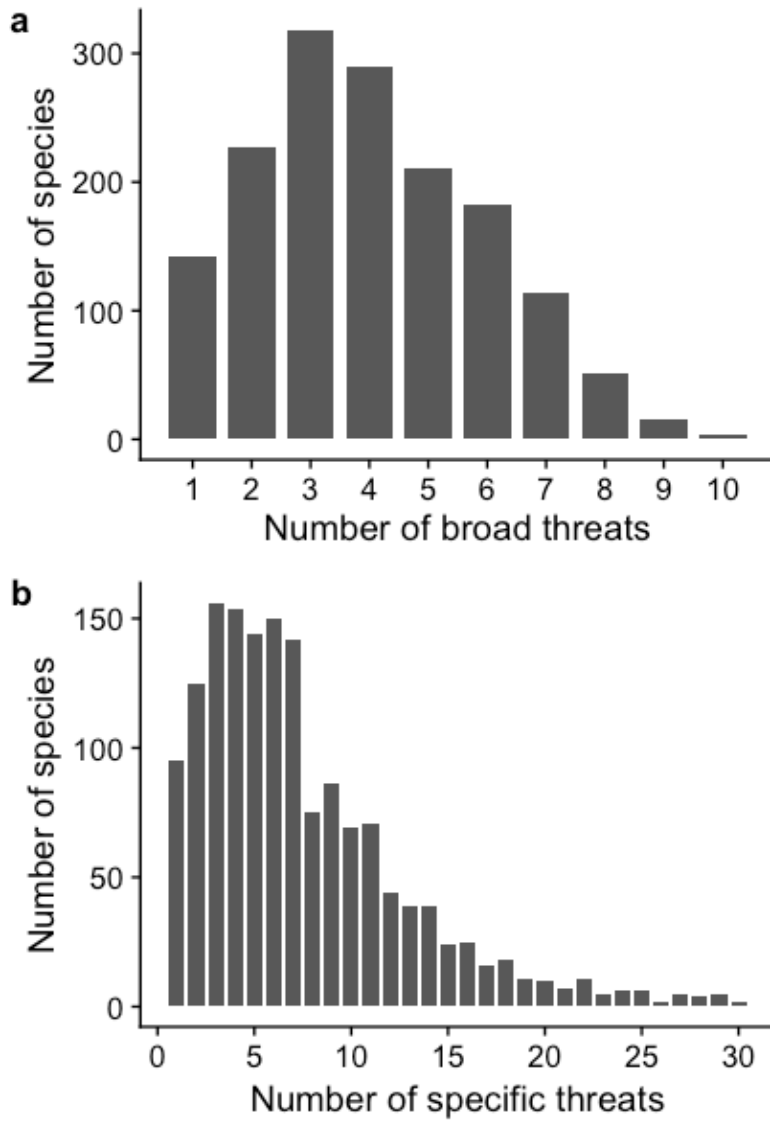
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533 **Tables**

534 **Table 1:** A description of the threat classifications, the typical conservation actions taken to mitigate these and
 535 our assessment of corresponding protected area management scenario. Threat classification, description and
 536 conservation actions taken from Salafsky et al. (2008).

537 **Table 1**

Major threat classification	Description	Sub-threats	Key conservation actions	Threat management scenario
Residential and commercial development	Threats from human settlements or other non-agricultural land uses with a substantial footprint	Commercial and industrial areas, housing and urban areas, Residential and commercial development, tourism and recreation areas	Site/area protection	Unmanaged
Agriculture and aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture (includes the impacts of any fencing around farmed areas)	Agriculture, aquaculture, livestock farming/grazing, timber plantations	Site/area protection	Unmanaged
Energy production and mining	Threats from production of non-biological resources	Oil and gas drilling, mining, quarrying and renewable energy	Site/area protection	Unmanaged
Transportation and service corridors	Threats from long narrow transport corridors and the vehicles that use them including associated wildlife mortality	Roads and railroads, shipping lanes, transportation and service corridors, utility and service lines	Site/area protection	Unmanaged
Biological resource use	Threats from consumptive use of "wild" biological resources including both deliberate and unintentional harvesting effects; also persecution or control of specific species	Fishing/ harvesting/ collecting/ gathering terrestrial, marine and aquatic species	Site/area protection & Site/area management & Compliance and enforcement	Well-managed
		Commercial logging	Site/area protection	Unmanaged
Human intrusion and disturbance	Threats from human activities that alter, destroy and disturb habitats and	Human intrusion and disturbance, recreational	Site/area protection &	Well-managed

	species associated with non-consumptive uses of biological resources	activities, work and other activities, military exercises	Site/area management	
Natural system modifications	Threats from actions that convert or degrade habitat in service of “managing” natural or semi-natural systems, often to improve human welfare	Dams and water management	Policies & Regulations	Landscape management
		Fire and fire suppression, other ecosystem modification	Site/area protection & Site/area management	Well-managed
Invasive and other problematic species, genes and diseases	Threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance	Invasive non-native species, problematic native species	Site/area protection & Invasive/problematic species control	Well-managed
		Invasive diseases, pathogens and parasites	Invasive/problematic species control	Landscape management
Pollution	Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources	Garbage and solid waste	Site/area management & Compliance and enforcement	Well-managed
		Agricultural and forestry pollutants, excess energy, urban sewage and waste water; industry/military pollution	Legislation & Policies and regulations	Landscape management
Geological events	Threats from catastrophic geological events	Landslides	Habitat & natural process restoration	Well-managed
Climate change and severe weather	Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat	Climate change, severe weather, droughts, storms and flooding, temperature extremes, habitat shifting/alteration	Habitat & natural process restoration & Species re-introduction	Well-managed

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541 **Table 2:** The total number (and percentage of total) of threats to all Australian species, the number of species
 542 with one or more threats, and all threats removed by the two protected areas (PA) management scenarios. The
 543 unmanaged scenario represents a network of protected areas that receives no funding for on-ground threat
 544 management, whereas the well-managed scenario represents a protected area network that is well-funded and all
 545 necessary on-ground threat management occurs. Landscape-scale management is required to mitigate threats
 546 that either originate outside of protected areas or require coordinated management across all land-tenures.

547 **Table 2**

	‘Unmanaged’ PA scenario	‘Well- managed’ PA scenario	Landscape management	All management types combined
The total number of threats removed to all Australian threatened species	3056 (26%)	10 220 (86%)	1651 (14%)	11 871 (100%)
The number of Australian threatened species with one or more threats removed	1185 (76%)	1551 (~100%)	815 (52%)	1555 (100%)
The number of Australian threatened species with all threats removed	51 (3%)	740 (48%)	4 (<1%)	1555 (100%)

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