Cities are hotspots for threatened species

Ives, Christopher; Lentini, Pia; Threlfall, Caragh; Ikin, Karen; Shanahan, Danielle; Garrard, Georgia; Bekessy, Sarah

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Spatial patterning of threatened species distributions and the pivotal role of cities for conservation.

Christopher D. Ives^{1*+}, Pia E. Lentini^{2*}, Caragh G. Threlfall³, Karen Ikin⁴, Danielle F. Shanahan⁵, Georgia E. Garrard¹, Sarah A. Bekessy¹, Richard A. Fuller⁵, Laura Mumaw¹, Laura Rayner⁴, Ross Rowe^{4,6,7}, Leonie E. Valentine⁸, Dave Kendal⁹

¹ School of Global, Urban and Social Studies, RMIT University.

² School of BioSciences, University of Melbourne

³ School of Ecosystem and Forest Sciences, University of Melbourne

⁴ Fenner School of Environment and Society, Australian National University

⁵ School of Biological Sciences, University of Queensland

⁶ Australian Government Department of the Environment

⁷ National Environmental Research Program, Landscapes and Policy Research Hub, University of Tasmania

⁸ School of Plant Biology, The University of Western Australia.

⁹ Australian Research Centre for Urban Ecology

* These authors contributed equally to this work.

⁺ Current address: Faculty of Sustainability, Leuphana University, Lüneburg Germany.

chris.ives@leuphana.de

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Corresponding author: Christopher Ives

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27 **Abstract**

28

29 Aim

30 Although urbanisation impacts many species, there is little information on the patterns of threatened
31 species occurrences in urban relative to non-urban areas. By assessing the extent of threatened
32 species distributions across all Australian cities, we aim to investigate the currently under-utilised
33 opportunity cities present to national biodiversity conservation.

34

35 Location

36 Australian mainland, Tasmania and offshore islands.

37

38 Methods

39 We assessed the distributions of Australia’s 1,643 terrestrial threatened species and the extent to
40 which they overlapped with 99 cities (of > 10,000 people), with all non-urban areas, and with
41 simulated ‘dummy’ cities which covered the same area and bioregion as the true cities but were
42 non-urban. We analysed differences between animals and plants, and examined variability within
43 these groups using species accumulation modelling. Threatened species richness of true versus
44 dummy cities was analysed using generalised linear mixed-effects models.

45

46 Results

47 Australian cities support substantially more nationally threatened animal and plant species than all
48 other non-urban areas on a unit-area basis. Thirty percent of threatened species were found to occur
49 in cities. Distribution patterns differed between plants and animals: threatened animals were
50 generally distributed across multiple cities, while more individual plant species were found in each
51 city with a greater proportion of their distributions occurring in urban areas. Individual cities tended
52 to comprise unique suites of threatened species, and especially plants. The analysis of true versus

53 dummy cities demonstrated that, even after accounting for factors such as net primary productivity
54 and distance to the coast, cities still consistently supported a greater number of threatened species.

55

56 Main conclusions

57 This research highlights that Australian cities are important for threatened species conservation, and
58 that the species assemblages of individual cities are relatively distinct. National conservation policy
59 should recognise that cities play an integral role when planning for and managing threatened
60 species.

61 **1. Introduction**

62 Threatened species can be found in cities all over the world. Twenty-two percent of the known
63 occurrences of endangered plants in the USA fall within the 40 largest cities (Schwartz *et al.*, 2002),
64 and in an analysis of 54 cities Aronson *et al.* (2014) found that nearly a third are known to contain
65 globally threatened birds. Indeed, the probability of a species being listed on the IUCN Red List
66 increases with the percentage of its range that is urbanised (McDonald *et al.*, 2008). The reasons for
67 this are becoming well understood: cities are often located in areas of high biological diversity
68 (Luck, 2007), and urbanisation is a significant and expanding land use change that leads to habitat
69 loss and fragmentation (Seto *et al.*, 2012). While the impacts of urbanisation on biodiversity are
70 undeniable, this may also make cities especially important for achieving conservation outcomes.
71 However, little is known about the relative importance of cities for conserving different kinds of
72 organisms.

73

74 Urban areas occupy < 0.5% of the Earth's total land area (Schneider *et al.*, 2009), yet some
75 threatened species are highly reliant on urban environments. For example, in the United Kingdom,
76 the song thrush *Turdus philomelos*, a declining species of national conservation concern, occurs at
77 densities more than three times higher in urban habitats than in the surrounding rural environment
78 (Mason, 2000). The endangered Nielsen Park She-oak (*Allocasuarina portuensis*) also occurs
79 exclusively within the metropolitan area of greater Sydney. Despite examples such as these, the
80 designation of protected areas remote from human disturbance remains the dominant conservation
81 paradigm worldwide (Miller & Hobbs, 2002). We have known for a long time that such wilderness
82 thinking does not reflect ecological reality (Williams, 1980; Cronon, 1995). Yet conservation
83 decision-making continues to implicitly, and sometimes explicitly, exclude urban environments
84 from conservation investment (e.g. Sanderson *et al.*, 2002; Mittermeier *et al.*, 2003), as the negative
85 pressures associated with urban development are seen to render urban habitats as 'lost causes' from

86 a biodiversity perspective (Cavin, 2013). By ignoring urban areas, important conservation
87 opportunities are potentially missed.

88

89 On the Australian continent more than 1,600 species are considered threatened with extinction
90 (Walsh *et al.*, 2013). Australian environmental policies and legislation are similar to those of other
91 jurisdictions in that they tend to prioritise existing natural environments over disturbed or human-
92 modified areas for biodiversity conservation or investment. Indeed, the second principle
93 underpinning Australia's Biodiversity Conservation Strategy is that "*biodiversity is best conserved*
94 *by protecting existing natural environments*" (Natural Resource Management Ministerial Council,
95 2010, p16). Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC
96 Act), threats to listed species of conservation concern occurring in areas of highly modified or
97 degraded habitat within city boundaries may be less likely to be deemed significant. This is because
98 decision makers need to consider, among other factors, the "*sensitivity of the environment which*
99 *will be impacted*", as well as whether the action will lead to a long-term decrease in the size of a
100 population (Department of the Environment, 2013, p5). Consequently, certain projects within cities
101 may not trigger impact assessment and approval requirements because the long-term viability of the
102 population or habitat is assessed as having already been compromised. This set of circumstances,
103 particularly in the case of small scale urban expansion, has the potential to lead to death by a
104 thousand cuts, whereby incremental habitat destruction can lead to significant landscape-scale
105 biodiversity loss (Dales, 2011; McCauley *et al.*, 2013).

106

107 The aim of this study is to assess the extent to which threatened species are reliant on conservation
108 within cities. To explore this, we use the continent of Australia, which has very high endemic
109 biodiversity (Chapman, 2009), as a case example, and investigate how the geographic distributions
110 of species of national conservation concern overlap with urban areas. Specifically we measure how
111 restricted threatened species' geographic ranges are to cities, and whether this is different for plants

112 versus animals. Finally, we explore the potential contribution that individual cities can make to
113 biodiversity conservation by examining how the composition of threatened species varies in
114 different cities across the continent.

115

116 **2. Methods**

117 *2.1 Threatened species and city data*

118 All 1,643 species (1,215 plants and 428 animals) that are considered to be of ‘national
119 environmental significance’ under Australia’s EPBC Act were included in our analyses. This
120 includes nationally-listed threatened species, native migratory species listed under international
121 conventions or agreements, and marine species that use terrestrial areas for nesting (Commonwealth
122 of Australia, 2014a). We hereafter refer to all of these species as ‘threatened species’. The listing
123 criteria and categories used under the EPBC Act are adapted from those used to list species under
124 the IUCN Red List of Threatened Species (Walsh *et al.*, 2013), with the main difference being the
125 absence of a ‘near threatened’ category from the EPBC Act making the list more conservative
126 (Commonwealth of Australia, 2014a). The majority of these species were from the flowering plant
127 class Magnoliopsida (857 species) followed by lilies (Liliopsida, 289 species), birds (181 species),
128 mammals (84 species), and reptiles (50 species).

129

130 Polygons representing the modelled distribution of each species were sourced from the Australian
131 Department of the Environment’s ‘Environment Resources Information Network’ (Commonwealth
132 of Australia, 2014b). The Australian Government uses these data to inform management and policy
133 decisions and to undertake preliminary assessments of whether proposed developments or land use
134 changes trigger targeted assessment and approval under the EPBC Act. The polygons were
135 modelled from observation records, ecological data and research information provided from a range
136 of Australian government, industry and non-government organisations, in addition to national-scale
137 environmental data. For migratory species, distributions refer only to breeding sites, sites of

138 significance, or known locations rather than the entire range of the species. The polygons are not
139 intended to be definitive maps of species occurrence, and generalisations made in the modelling
140 process preclude detailed analyses of species distributions at fine scales. However, a reasonable
141 level of spatial certainty is possible through classification of the polygons by the likelihood of
142 species occurrence. For our analyses, only polygons where species are ‘known to occur’ (restricted
143 to preferred habitat near observation records) and ‘likely to occur’ (preferred habitat within species
144 range) were used. Polygons indicating where species ‘may occur’ (areas within environmental
145 envelope or geographic region) were excluded. Polygons were projected to Geocentric Datum of
146 Australia 1994 Australian Albers, and clipped to a shapefile representing terrestrial areas (the
147 Australian mainland, Tasmania, and offshore territorial islands).

148
149 A layer representing the urban areas of Australia was derived from Australian Bureau of Statistics
150 data (Section of State Ranges classification based on Statistical Area 1 polygons; Australian Bureau
151 of Statistics, 2011a). This is a standard categorisation of land in Australia, used by government and
152 non-government agencies. According to the dataset, land was classified as of “urban character” if:
153 (i) the urban ‘Mesh Block’ (the smallest census unit) population is $\geq 45\%$ of the total population of
154 the Statistical Area 1 polygon and dwelling density ≥ 45 dwellings per sq km; or (ii) the population
155 density is ≥ 100 persons per sq km and dwelling density ≥ 50 dwellings per sq km; or (iii) the
156 population density is ≥ 200 persons per sq km (Australian Bureau of Statistics, 2011b, p19). Only
157 urban polygons with populations $> 10,000$ people were selected (hereafter referred to as ‘cities’ for
158 simplicity), thereby excluding the smallest settlements. Following our criteria, the 99 cities in
159 Australia cover $17,420 \text{ km}^2$ (0.23% of terrestrial land mass), and range in size from 10.5 km^2 for
160 Nelson Bay, New South Wales, to 2597.4 km^2 for Melbourne, Victoria (mean = 175.3 km^2 , median
161 = 50.0 km^2 , SD = 420.2 km^2). Although designated as ‘urban’ in character, the scale at which these
162 areas were classified meant that they contained a range of land covers including built and natural
163 lands.

164

165 *2.2 The importance of cities for threatened species*

166 Using ArcMap (v10.2, ESRI Redlands CA USA), we identified areas where the city polygons
167 intersected with threatened species distribution polygons. From this, we calculated the proportion of
168 each species' distribution that was urban and created a threatened species list for each city. To
169 analyse the unique contribution of each city to the total assemblage of species located in urban
170 areas, presence/absence species accumulation curves were generated using the 'specaccum'
171 function in the 'vegan' package in R (R Core Team 2014, vers 3.1.0). We also generated a pairwise
172 Jaccard dissimilarity matrix for the presence and absence of plant and animal species per city and
173 carried out a hierarchical cluster analysis (using the 'average' linkage method and the 'hclust'
174 function) to assess differences in community composition between cities. We then mapped mean
175 dissimilarity values for each of the cities to help visualise patterns of beta diversity across the
176 continent.

177

178 We converted the polygons representing threatened species to 1 km²-resolution binary rasters using
179 the 'rasterize' function in R's 'raster' package (vers 2.2-31). Raster cells were given a value of 1 if
180 the centre of the cell overlapped with the associated polygon, or 0 if there was no overlap. We
181 calculated the number of threatened species that were known or likely to occur in each cell by
182 summing the values across all of the threatened species rasters.

183

184 As a conservative comparative analysis, we repeated the processes outlined above using only those
185 polygons that represented where species were 'known' to occur. As the difference between these
186 analyses was minimal (see Appendix S1) we consequently present only the results from the
187 combined 'known' and 'likely' distributions here, as this includes the larger complement of species.

188

189 *2.3 Mixed-effects models to account for potentially confounding factors*

To account for potentially confounding environmental variables that might influence the threatened species richness of a city irrespective of urbanisation, for each of our 99 ‘true’ cities we generated a paired ‘dummy’ city of equivalent area which was randomly positioned within the same bioregion (of which there are 89 across Australia). We then calculated both total threatened species richness of each true and dummy city, and the mean richness of the raster cells that comprised them. Both total and mean threatened species richness were analysed using mixed-effects regression models in the ‘lme4’ package in R. Total threatened species richness was fitted as a generalised linear mixed-effects model against a Poisson distribution using a log link with the ‘glmer’ function, and mean threatened species richness as a linear mixed-effects model with the ‘lmer’ function. The models were fitted with five fixed predictor variables; (i) categorical city type (i.e. true v dummy), (ii) mean net primary productivity (NPP, calculated as the mean across the months of 2014 and downloaded as a 0.1 degree raster from NASA Earth Observations 2015), (iii) city area, (iv) distance from the coast (measured from the nearest city edge), and (v) latitude. Continuous variables were centred and scaled prior to the analysis. The bioregion in which the true or dummy city occurred was fitted as a random effect in both models. We also noted that protected areas made up a substantially smaller proportion of the landmass in the true cities (mean = 0.03 ± 0.17 SD) than the dummy cities (mean = 0.12 ± 0.33 SD), but because this was strongly correlated with city type it was not included in the models.

208

209 **3. Results**

210 *3.1 The distribution of threatened species in cities versus non-urban areas*

211 Of the 1,643 threatened species in our analysis, 503 (30%) had distributions that intersected with
212 cities. This proportion differed for plants and animals, with 25% of listed plants and 46% of listed
213 animals having at least part of their distributions located in cities. Species distribution size varied
214 considerably (many species had relatively small distributions and only a small number had very
215 large distributions) but distribution size was not strongly correlated with the proportion of a species’

216 distribution located in cities (Spearman's $\rho = 0.33$). The distributions of animals (mean = 4.5
217 million ha, median = 63,743 ha) tended to be much larger than those of plants (mean = 240,000 ha,
218 median = 13,463 ha). Threatened species richness was higher in coastal areas and around the edges
219 of cities (Fig. 1).

220

221 < Figure 1 >

222

223 There was substantial variation in the degree to which the distributions of threatened species
224 included cities; species that were at least partially urban were found in an average of six cities
225 (± 11.8 SD). While some species were found in many cities (e.g. the eastern great egret *Ardea*
226 *modesta* was found in 90 urban settlements), 258 threatened species (51%) occurred in one urban
227 settlement only (Fig 2a). The distributions of eight threatened species (all plants) entirely
228 overlapped with cities, while 51 (10%) of the 503 threatened species found in cities had >30% of
229 their distribution in urban areas (Fig. 2b). Patterns were quite different for threatened plants and
230 animals; plants tended to be found in fewer cities (mean = 1.95 ± 2.34 SD) than animals (mean =
231 12.57 ± 16.63 SD) and were thus more spatially restricted, but had a larger proportion of their
232 distribution in cities (plant mean = 0.16 ± 0.26 SD, animal mean = 0.04 ± 0.08 SD, Fig. 2).

233

234 < Figure 2 >

235

236 3.2 The importance of cities for threatened species

237 All 99 cities were known or likely to contain threatened animal species, and 88 cities (89%)
238 contained threatened plant species or appropriate habitat (see Appendix S2 for city-specific details).
239 Cities coincided with the distributions of substantially more threatened species than all other non-
240 urban areas on a per-unit-area basis (Fig. 3). This was true for both animals and plants, with a very
241 high proportion of non-urban cells containing no threatened plant species. The mean threatened

species richness for 1 km² city cells was 10.04 ($\pm$ 3.79 SD), and 2.72 ($\pm$ 2.88 SD) for non-urban cells.

< Figure 3 >

On average, cities contained 32 threatened species ($\pm$ 25.5 SD). Sydney contained the most threatened species (124 species), but only a few (large) cities contained a high diversity of threatened species (Fig. 4a). This was especially pronounced for plants, with only 12% of cities containing >10 threatened plant species (see Fig. 4a).

Individual cities contained distinct sets of threatened species, and contributed unique species to the total urban assemblage with no evidence of an asymptote in the threatened species accumulation curves (Figure 4b). This differentiation among cities was driven primarily by threatened plants. Hierarchical cluster analysis supported this result, demonstrating that few cities had a similar threatened species composition (Appendix S3, Fig S3.1 and S3.2). The mean Jaccard dissimilarity score between cities for animals was 26.94 ($\pm$ 3.63 SD), with Kalgoorlie-Boulder supporting the most unique animal assemblage and Port Macquarie the least (Fig. S3.3). Plant communities were even more dissimilar between cities, with a mean Jaccard dissimilarity score of 26.76 ($\pm$ 3.76 SD); Kempsey supported the most unique plant assemblage while Taree's assemblage was most similar to other cities (Fig. S3.4).

< Figure 4 >

Our comparison of true versus non-urban dummy cities reinforced the findings of our broader analysis. As noted above, total threatened species richness ranged from 2-124 for true cities (mean = 31.49, $\pm$ 25.39 SD), and for dummies this range was 1-61 (mean = 12.12, $\pm$ 11.07 SD). The mean

268 threatened species richness of cells was 0.19-18.36 for true cities (mean = 9.04, $\pm$ 3.78 SD), and
269 0.02-14.07 for dummies (mean = 7.26, $\pm$ 3.88 SD).

270

271 Regression modelling demonstrated that non-urban dummy cities had consistently lower total
272 threatened species richness (coefficient estimate -0.84, $\pm$ 0.05 SE) and mean 1 km² cell threatened
273 species richness (-1.67, $\pm$ 0.42 SE) than the true cities, even once potentially confounding factors
274 had been accounted for (Fig. 5, see Appendix S4 for all coefficient estimates). Other factors which
275 appeared to have strong effects on threatened species richness included net primary productivity,
276 which was positively associated with mean cell richness (1.15, $\pm$ 0.34 SE), and distance from the
277 coast, which had a negative effect on both mean cell richness (-1.21, $\pm$ 0.38 SE), and total richness
278 (-0.72, $\pm$ 0.09 SE, Fig. 5).

279

280 < Figure 5 >

281

282 **4. Discussion**

283 *4.1 The importance of cities for conservation*

284 This is the first study to demonstrate at a continental scale that cities contain more threatened
285 species per unit area than non-urban areas. Our analyses have shown that all Australian cities
286 harbour or are likely to harbour threatened species, and 30% of Australia's threatened species
287 occur, or are likely to occur, in cities that cover only 0.23% of the total land area. The elevated
288 importance of cities for threatened species richness remained evident even when accounting for
289 other biogeographic factors that may affect species richness such as primary productivity, distance
290 from the coast, and latitude. This extends on the findings of Schwartz *et al.* (2002), who revealed
291 that 22% of the occurrences of US endangered plant populations were located in the 40 largest
292 metropolitan areas (comprising 8.4% of the land area). We note, however, that these findings may
293 be influenced by the fact that both Australian and US cities are relatively young on a global scale,

294 and may be carrying extinction debts (Hahs *et al.*, 2009). Further, it is likely that the regions defined
295 as ‘urban’ in this study contain a more heterogeneous composition of land covers than other studies
296 in the literature. We therefore reaffirm the need for clear definitions of urbanisation to be reported
297 in urban biodiversity studies, as has been called for by other scholars (McDonnell & Hahs, 2013).

298

299 The greater richness of threatened species in cities compared with equivalent non-urban dummy
300 cities was more pronounced for total threatened species richness than for mean cell threatened
301 species richness (Fig. 5). This suggests that the assemblages of threatened species in cities vary
302 more greatly across their area than equivalent non-urban areas. Cities are known to have high levels
303 of landscape heterogeneity (Alberti, 2005), with patches of remnant habitat commonly interspersed
304 with highly disturbed areas. This landscape configuration may favour a wider variety of threatened
305 species, thus increasing beta diversity and contributing to the higher total threatened species
306 richness observed in cities. This is plausible in Australia where native ecosystems commonly
307 remain within and around cities and adjacent to other land uses (Bekessy *et al.*, 2012; Newton *et al.*,
308 2001).

309

310 4.2 Spatial patterning of species distributions

311 The composition of threatened species varies among cities (Fig. 4b, Appendix S3). This suggests
312 that the pattern identified by Aronson *et al.*, (2014), whereby city biotas reflect regional species
313 pools, extends to threatened species. This trend may be especially pronounced in Australia given
314 that the cities included in our study cover a vast spatial area with huge variation in environmental
315 conditions. Patterns were different for plants and animals. Unique sets of threatened plants were
316 found in individual cities, while threatened animals tended to be found in multiple cities (Fig. 4b).
317 These results strongly suggest that all cities ought to be considered carefully in threatened species
318 conservation and management.

319

320 We found that a small subset of threatened species were highly restricted to cities, and that this
321 pattern was more pronounced for plants than it was for animals. Individual plant species were
322 usually found within few cities, however a large proportion of their distribution was contained
323 within those cities. In contrast, few animal species had a substantial share of their distributions
324 located in cities (Fig. 2b). Most threatened plants in our dataset have relatively small distributions,
325 and would be considered local endemics that are unique to certain bioclimatic regions of Australia.
326 For example, the fringed spider-orchid *Caladenia thysanochila* is an endangered species with a
327 small distribution, found entirely within a rapidly urbanizing region of Melbourne, Victoria
328 (Department of the Environment, 2014). In contrast, some animals had very large distributions,
329 occurring in 30 or more cities (Fig. 2a). This pattern of distribution for plants likely contributes to
330 our finding of higher total threatened species richness per city than mean cell threatened species
331 richness. Our finding that some threatened plants are found exclusively in urban environments is
332 similar to that for North American floras (Schwartz *et al.*, 2002) and highlights that cities can be
333 important for the conservation of rare and unique plants.

334

335 4.3 Implications for conservation policy and practice

336 The disproportionate representation of threatened species in Australian cities identified in this study
337 suggests that practitioners should seek to identify and act upon conservation opportunities in urban
338 environments. It is important to note, though, that cities contain both threats and opportunities for
339 biodiversity conservation. The animals in our dataset included several nationally migrant and
340 nomadic species, such as the grey-headed flying-fox, *Pteropus poliocephalus* (Eby & Collins, 1999)
341 and swift parrot, *Lathamus discolor* (Swift Parrot Recovery Team, 2001), that move across large
342 areas as food resources (e.g. nectar, fruit or blossoms) become seasonally available. Often these
343 resources are found in non-remnant, human-modified habitats. Indeed, Carnaby's black cockatoo,
344 *Calyptorhynchus latirostris*, relies on an introduced pine plantation within the city of Perth for food,
345 despite the fact that this represents a comparatively small proportion of their range (Valentine *et al.*,

2014). Cities may be especially valuable to these kinds of species, as they can provide more stable resources throughout the year as a result of human planting selection and supplementary watering (Parris & Hazell, 2005; Williams *et al.*, 2006). In contrast, other species rely on remnant patches of vegetation for their survival, many of which are under threat or in a degraded condition. The fringed spider-orchid, for example, is unlikely to persist if its remaining historical habitat is developed for housing, and its occurrence may even represent an extinction debt given the amount of habitat remaining. Irrespective of whether threatened species are threatened by urbanisation or supported by urban conditions, this study highlights the need for conservation action in cities. Depending on the nature of conservation threats and opportunities, a suite of conservation tools should be employed, such as spatial planning of urban development (e.g. Bekessy *et al.*, 2012), focussed recovery planning, and active management, restoration, and improvement of habitats (Hahs *et al.*, 2009; Standish *et al.*, 2012).

358

359 *4.4 Caveats and future research opportunities*

As with any spatial data compiled from multiple sources over a period of time, our species data may contain mapping errors. The most pertinent errors are those of commission and omission as a result of incomplete and unequal sampling effort. Few systematic biodiversity surveys have been conducted in Australia, yet those that have been done have often excluded urban areas (e.g. the regional forest agreement process; Slee, 2001). On the other hand, it is possible that ad-hoc databases may have an over-representation of urban records, as survey effort will arguably be greater in more populous areas. Ultimately, despite any inaccuracies, the results presented here are noteworthy since the datasets are those used by decision makers when assessing development applications and generating species recovery plans. Nevertheless, while our conservative analysis indicated that modelling assumptions did not have a large impact on our inference relating to the distribution of threatened species in cities, future research could explore the role of possible sampling biases further.

372

373 Finally, we note that while presence of a population in a location does not indicate its fitness or
374 long-term viability in that location, it signals a potential conservation opportunity. In their
375 multidisciplinary review of 787 urban biodiversity conservation studies, Shwartz *et al.* (2014) found
376 only eight papers reported similar or improved levels of population viability of species of
377 conservation significance in urban areas compared to nearby greener environments. Yet they also
378 note that only three studies specifically set out to test this condition of viability, all of which
379 reported in the affirmative. From these results Shwartz *et al.* (2014) concluded that “the importance
380 of urban areas for general conservation is not convincingly supported by scientific research” (p. 43).
381 Nevertheless, we argue that even if threatened species experience lower levels of population
382 viability in urban environments, their overrepresentation in these areas makes cities even more
383 important for conservation management and planning, noting too that doing nothing may reduce
384 viability even further. We echo Shwartz *et al.*’s call for further research into the population
385 dynamics of significant species in cities as a way of shedding light on ecological mechanisms that
386 influence species persistence, as it can help determine which specific conservation actions are
387 required.

388

389 **5. Conclusion**

390 Using Australia as a case example, this study is the first to demonstrate at a continental scale that
391 cities contain disproportionately more threatened species than equivalent non-urban areas. Some
392 species (particularly plants) have a much greater proportion of their distribution within urban areas
393 than others, and all Australian cities are home to different suites of threatened species. These
394 findings highlight and reinforce the global importance of planning and managing urban landscapes
395 to conserve biodiversity (Secretariat of the Convention on Biological Diversity, 2012). We
396 recommend that practitioners seriously consider the contribution that urban environments could

397 make to national biodiversity conservation, and incorporate this information into species recovery
398 planning.

399

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524

525 **Biosketch**

526 The authors of this study are Australian researchers with interests in urban ecological systems and
527 biodiversity conservation. Together, a wide range of disciplines is represented including ecology,
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532 More details about EDG can be found at <http://www.edg.org.au/>

533

534 **Figure legends**

535 Figure 1. Threatened species richness across Australia, with darker colours representing greater
536 richness. Urban areas are outlined in black. Cities shown in greater detail in boxes are (a) Perth, (b)
537 Brisbane and (c) Melbourne.

538

539 Figure 2. Plots of (a) species ranked according to the number of cities in which they occur and (b)
540 the proportion of their distributions that fall in cities. Species are ordered on the x-axes by their
541 rank, with the species occurring in the most cities, or with the greatest proportion of their
542 distribution as urban, assigned the rank of 1.

543

544 Figure 3. The proportion of 1 km² cells in Australia, classified as either urban (white) or non-urban
545 (grey) which support different numbers of threatened species. Data are presented for (a) all
546 threatened species, (b) animals and (c) plants. Bars being skewed to the left of the plots indicates
547 that a greater proportion of cells support fewer threatened species. Across Australia a small number
548 of cells contained from 19 up to 32 threatened species, but the plot has been truncated at 18 along
549 the x-axis because bars were not visible when the proportion was <0.005.

550

551 Figure 4. Plots of (a) ranked and (b) cumulative richness of threatened species in cities. The lack of
552 asymptote in the species accumulation curves (b) suggests that each city contributes different
553 species to the overall pool of threatened species found in urban areas.

554

555 Figure 5. Model curves comparing cities and equivalent ‘dummy cities’ within bioregions for (a)
556 total threatened species richness, and (b, c) mean 1 km² richness of threatened species. Higher
557 richness is consistently observed for cities, even once distance from the coast and net primary
558 productivity are accounted for.

561 **Figure 2.**

562

563 **Figure 3.**

564
565

568 **Figure 5.**
569

570

571 **List of Supplementary Materials**

572

573 Appendix S1: Comparative analysis between known and known and/or likely to occur distributions

574

575 Appendix S2: List of Australian cities, with human population size and total, animal, and plant
576 threatened species richness.

577

578 Appendix S3: Analysis of differences in threatened species composition between cities including
579 hierarchical cluster analysis of (i) animals and (ii) plants, and maps of mean threatened species
580 community similarity across Australia for (iii) animals and (iv) plants.

581

582 Appendix S4: Models of (i) total city threatened species richness, and (ii) mean 1km² cell
583 threatened species richness for true cities versus dummy cities (non-urban controls).