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

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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  $\geq 45$  dwellings per sq km; or (ii) the population  
155 density is  $\geq 100$  persons per sq km and dwelling density  $\geq 50$  dwellings per sq km; or (iii) the  
156 population density is  $\geq 200$  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  $10.5 \text{ km}^2$  for  
160 Nelson Bay, New South Wales, to  $2597.4 \text{ km}^2$  for Melbourne, Victoria (mean =  $175.3 \text{ km}^2$ , median  
161 =  $50.0 \text{ km}^2$ , SD =  $420.2 \text{ km}^2$ ). 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 km<sup>2</sup>-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 =  $0.03 \pm 0.17$  SD) than the dummy cities (mean =  $0.12 \pm 0.33$  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 ( $\pm 11.8$  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 =  $1.95 \pm 2.34$  SD) than animals (mean =  
231  $12.57 \pm 16.63$  SD) and were thus more spatially restricted, but had a larger proportion of their  
232 distribution in cities (plant mean =  $0.16 \pm 0.26$  SD, animal mean =  $0.04 \pm 0.08$  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 km<sup>2</sup> 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 km<sup>2</sup> 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,  
528 social science and environmental policy. This article is an output from a workshop funded by the  
529 Australian Research Council Centre of Excellence for Environmental Decisions. Many of the  
530 authors are affiliated with the Environmental Decisions Group (EDG): a network of conservation  
531 researchers working on the science of effective decision making to better conserve biodiversity.  
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

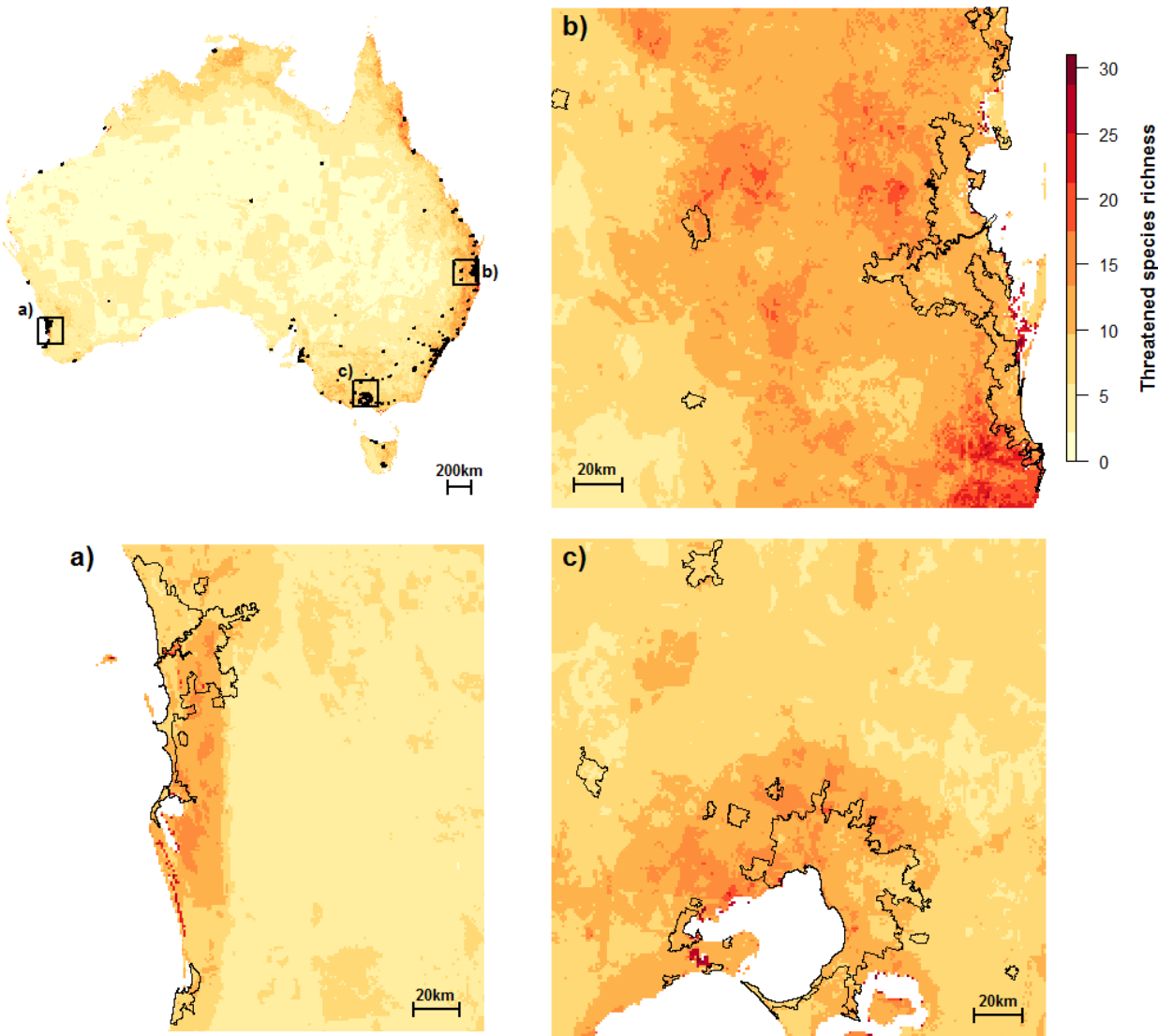
544 Figure 3. The proportion of 1 km<sup>2</sup> cells in Australia, classified as either urban (white) or non-urban  
545 (grey) which support different numbers of threatened species. Data are presented for (a) all  
546 threatened species, (b) animals and (c) plants. Bars being skewed to the left of 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

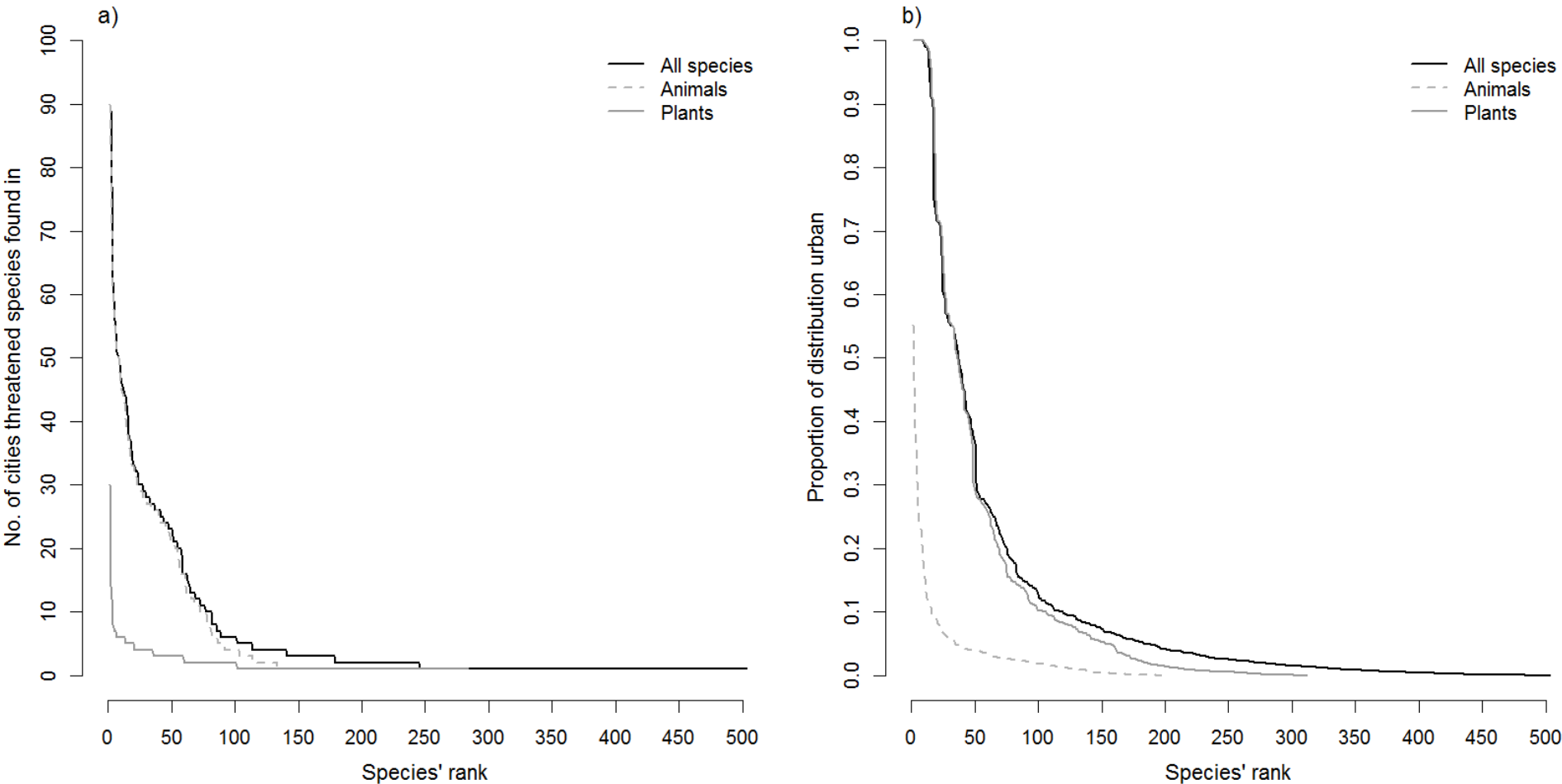
551 Figure 4. Plots of (a) ranked and (b) cumulative richness of threatened species in cities. The lack of  
552 asymptote in the species accumulation curves (b) suggests that each city contributes different  
553 species to the overall pool of threatened species found in urban areas.

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 km<sup>2</sup> 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.

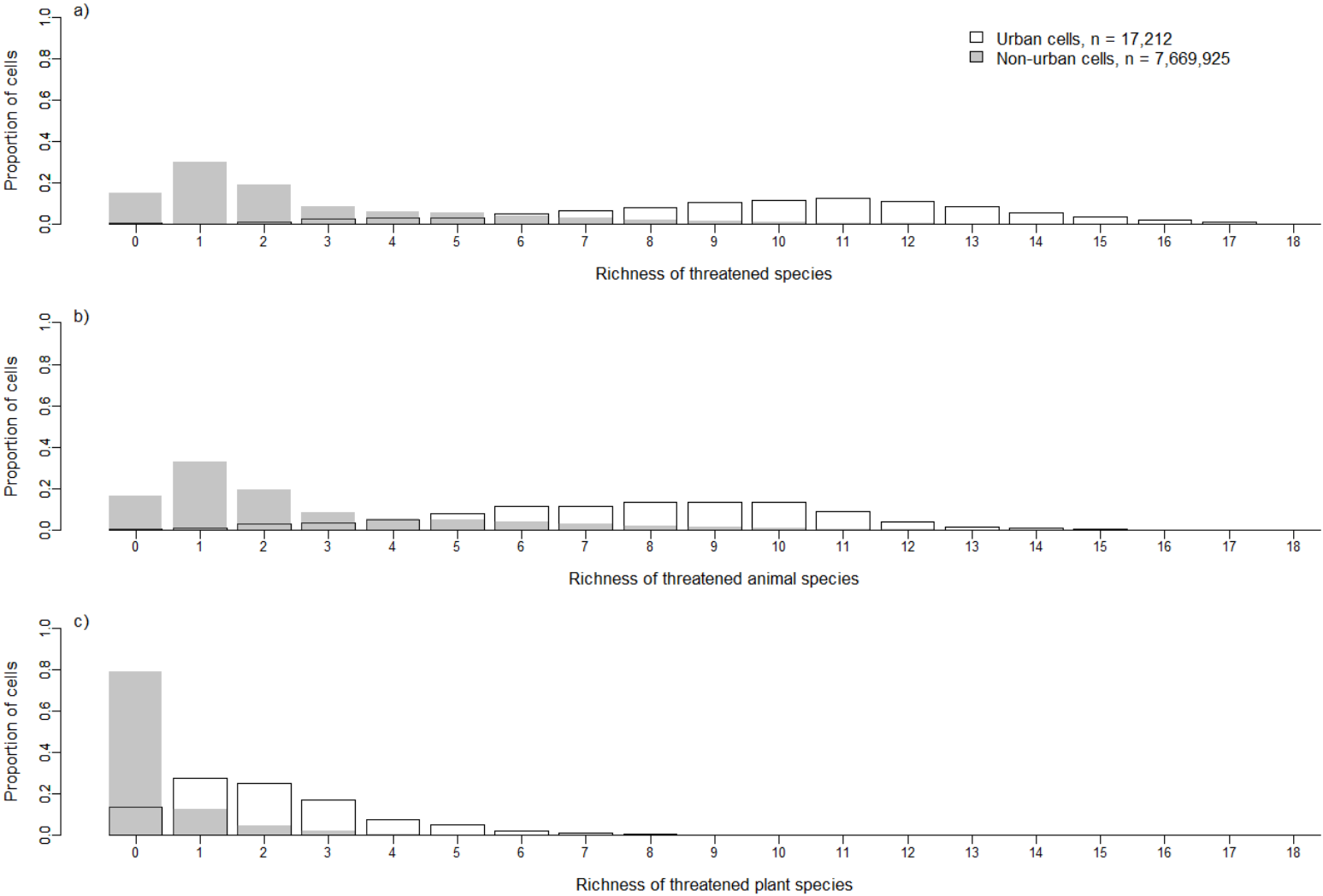


561 **Figure 2.**

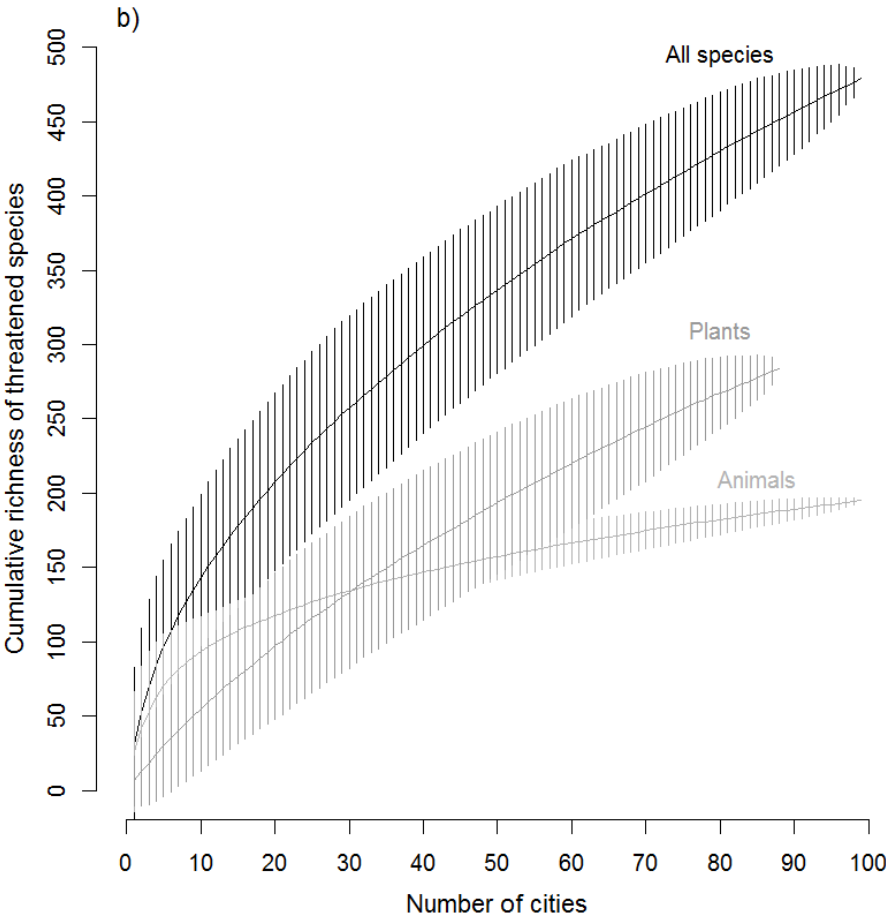
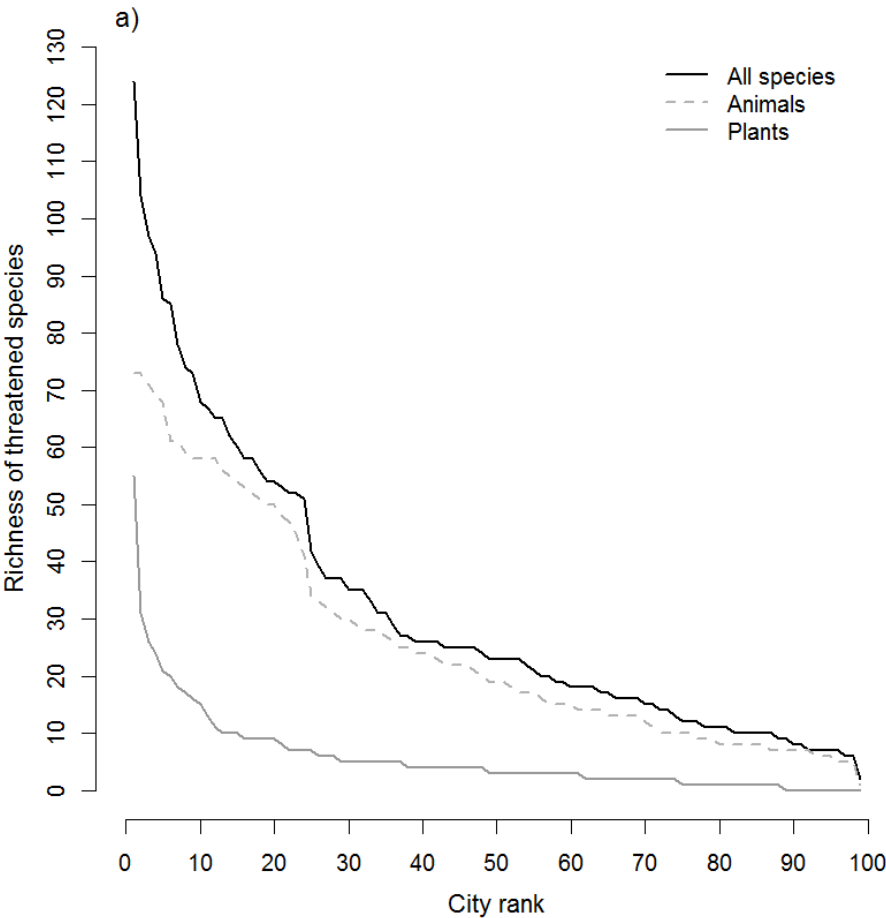


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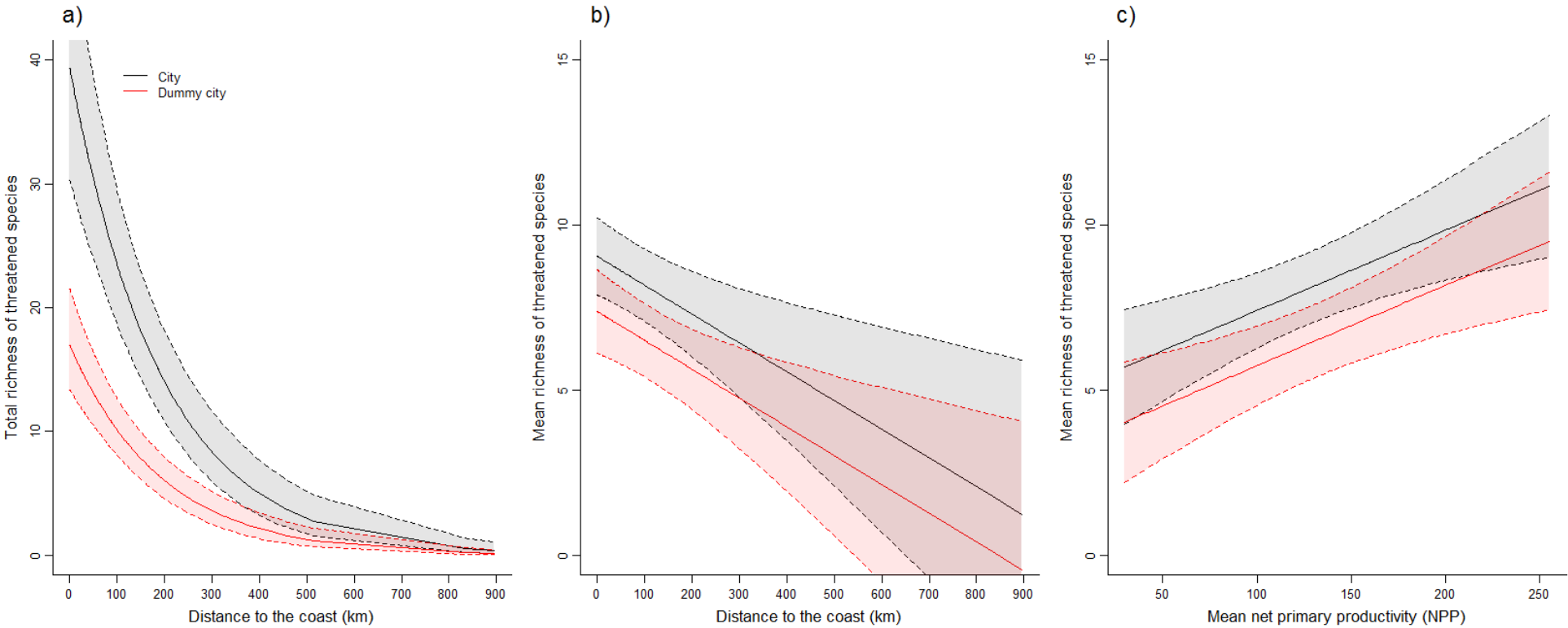
563 **Figure 3.**



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 1km<sup>2</sup> cell  
583 threatened species richness for true cities versus dummy cities (non-urban controls).