

1 **Distribution and status of threatened and endemic marsupials on the**
2 **offshore islands of southeast Sulawesi, Indonesia.**

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8 Definitive version available at <http://www.publish.csiro.au/AM/AM17052>

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32 **Abstract.** We highlight hitherto unreported populations of two globally threatened
33 Phalangeridae species on southeast Sulawesi's offshore islands – Bear Cuscus *Ailurops*
34 *ursinus* and Small Sulawesi Cuscus *Strigocuscus celebensis* – and observations of a third
35 range-restricted species – Peleng Cuscus *Strigocuscus pelengensis*. Our data are based on
36 records made during 11 years of seasonal surveys on Buton, and short-term expeditions
37 to Kabaena and Manui. Our observations of *S. celebensis* on Buton, where it occurs in
38 three protected areas, represent an important range extension for this species, as do our
39 observations of *A. ursinus* on Kabaena, where it is also widespread. We also report the
40 unexpected presence of *S. pelengensis* on Manui. Buton in particular appears to be an
41 important stronghold for both *A. ursinus* and *S. celebensis*, given that forest ecosystems
42 here remain extensive and relatively intact. Both these species may also display a
43 previously unreported adaptability to disturbed forest and even some non-forest habitats
44 within our study area. Hunting pressures, a proven threat to these species in northern
45 Sulawesi, may also be lesser here.

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47 **Additional keywords:** cuscus, Indonesia, marsupial, Phalangeridae, population

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49 **Running head:** Distribution of marsupials in South-east Sulawesi

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63 **Introduction**

64 The biodiversity hotspot of Wallacea, Indonesia, is notable for its high rate of endemism,
65 particularly in mammals, and its mix of fauna of both Asian and Australasian origin
66 (Whitten *et al.* 2002; Myers 2003). Sulawesi, the largest landmass in Wallacea, represents
67 the westernmost extent of marsupial species in Asia (Whitten *et al.* 2002), where five
68 members of the Phalangeridae Family occur (Helgen and Jackson 2015). Four species are
69 endemic to Sulawesi and its satellite islands (including the Sula Islands). The remaining
70 species, the Ornate Cuscus *Phalanger ornatus*, is found in both far-northern Sulawesi and
71 the Moluccas (Helgen and Jackson 2015). These endemic Sulawesi Cuscuses represent an
72 important global conservation priority, with one species (Talaud Bear Cuscus *Ailurops*
73 *melanotis*) being considered Critically Endangered and a top 25 ‘EDGE’ species (Flannery
74 and Helgen 2016; Zoological Society of London 2017); two species (Bear Cuscus *Ailurops*
75 *ursinus* and Small Sulawesi Cuscus *Strigocuscus celebensis*) being considered Vulnerable
76 (Helgen *et al.* 2008; Salas *et al.* 2008); and the final species (Peleng Cuscus *Strigocuscus*
77 *pelengensis*) being considered Least Concern, but of very restricted geographic range
78 (Leary *et al.* 2016a).

79 The Sulawesi Phalangeridae remain poorly-studied (Helgen and Jackson 2015). Little is
80 known about their ecology, the threats they face, and even their distribution within
81 Sulawesi (although see Dwyahreni *et al.* 1999; Farida and Dahruddin 2008). Here, we
82 report observations of three endemic Cuscus species on southeast Sulawesi’s offshore
83 islands, made during the course of 13 years of seasonal fieldwork. We highlight the
84 existence of previously unreported populations of Cuscus on these islands, discuss the
85 apparent status of these populations, and provide a summary of ecological observations
86 that will improve existing knowledge of these poorly-known marsupials.

87

88 **Materials and methods**

89 **Study area**

90 Fieldwork was focussed towards three islands off the coast of Sulawesi’s southeastern
91 peninsula (Fig. 1): Buton, Kabaena and Manui. We also briefly visited the islands of Muna
92 and Wowoni.

93 Buton, located off the mainland's southeastern peninsula, is the largest (c. 560,000 ha)
94 of Sulawesi's satellite islands. It is mostly covered by rugged hills, with a few isolated
95 peaks reaching up to 1100 m. The island retains much of its original natural vegetation
96 cover, with 77% of its surface occupied by forest (Martin *et al.* 2015), and has been
97 highlighted as an area of high conservation value (Cannon *et al.* 2007). Most of these
98 forested areas lie within formal protected areas, particularly the 65,000 ha Lambusango
99 Forest Reserve and the 810 ha Kakenauwe Forest Reserve in the south of the island, and
100 the 98,600 ha Buton Utara Forest Reserve in the north.

101 Kabaena, lying west of Buton, is the third-largest (c. 87,300 ha) of southeast Sulawesi's
102 offshore islands. It is more mountainous than its neighbouring islands, consisting of a
103 single central massif, Gunung Sambapolulu, which reaches 1560 m (Keim 2009). Forest
104 cover here is patchy - most lowland areas have been cleared for agricultural land - with
105 pockets of rainforest remaining in parts of the mountainous interior, along with more
106 extensive patches of savannah and open woodland (Gillespie *et al.* 2005). None of these
107 remaining forest patches are formally protected.

108 Manui is a small (c. 9000 ha), low-lying island (maximum altitude 170 m) that is also the
109 most biogeographically isolated of southeast Sulawesi's major satellites, located
110 approximately 50 km east of the mainland. It remains very poorly studied. It is covered
111 mostly in dry monsoon forest (a very different climax vegetation compared to the seasonal
112 rainforest found on the rest of southeast Sulawesi's offshore islands), farmland (primarily
113 cassava and coconut) and patches of rough scrub. No protected areas exist on the island.

114 Muna, the second-largest of southeast Sulawesi's offshore islands (c. 289,000 ha) lies
115 between Buton and Kabaena. It is largely comprised of a low-lying (mostly <100 m)
116 limestone plateau, reaching a maximum elevation of 400 m (Milsom *et al.* 1999). This
117 relatively flat, easily accessible terrain has led to Muna being almost entirely deforested
118 and mostly covered with plantations, arable farmland and scrubland, with only very small
119 pockets of forest remaining (Gillespie *et al.* 2005). Wowoni (c. 65,000 ha) lies north of
120 Buton. Substantial tracts of forest persist throughout much of the island's interior (Farida
121 and Dahruddin 2008) which are predicted to have high conservation value (Cannon *et al.*
122 2007), although its ecology remains largely unexplored.

123

124 **Survey work**

125 These islands were visited as part of seasonal biodiversity surveys run by Operation
126 Wallacea (www.opwall.com). These have run annually between June and August from
127 1996-2017, with at least one author participating each year between 2004 and 2017 (except
128 in 2015). Most fieldwork has focussed on Buton, which was visited annually for eight
129 weeks between 2004 and 2014. Kabaena was visited in June-July 2016 for four weeks,
130 Manui was visited in August 2017 for one week, and Muna and Wowoni were visited in
131 July 2017 for one week and two weeks respectively. Fieldwork on Buton, Kabaena and
132 Manui encompassed a range of forest and non-forest habitat, while on Muna and Wowoni
133 only farmland and scrub habitats were visited.

134 No specific survey methodologies were employed to formally assess Cuscus populations
135 on these islands; attempts to do so failed, largely due to the difficulty of detecting these
136 species using standardized methodologies. *A. ursinus* was frequently observed in the forest
137 and was technically a recordable species in systematic mammal transect surveys, in
138 practice however these did not produce robust information on the species' occurrence, with
139 encounters from these surveys averaging <1 observation per season. Fieldwork on
140 Kabaena, Muna, Wowoni, and Manui was focussed specifically towards an evolutionary
141 study of island birds. Therefore, Cuscus observations on all islands are the result of
142 opportunistic encounters, pooled from all authors, rather than from formal targeted surveys.
143 To provide supporting independently verified evidence for our observations, we archived
144 a research-grade (i.e. independently verified by at least two other users) image of each
145 Cuscus species on each island they were observed on inaturalist (inaturalist.org).

146 Previously existing knowledge of species' distribution was gathered from range maps
147 produced by the IUCN (Helgen *et al.* 2008; Salas *et al.* 2008; Leary *et al.* 2016a), and
148 Helgen and Jackson (2015), and information provided in Flannery (1995), Suyanto *et al.*
149 (2002) and Whitten *et al.* (2002).

150

151 **Results**

152 In total, we recorded three Cuscus species on three of southeast Sulawesi's offshore islands.
153 We discuss these observations in the species accounts below. Links to our verified records

154 can be found in Supplementary Table S1. A selection of images is provided in
155 Supplementary Fig. S2.

156

157 **Bear Cuscus** – *Ailurops ursinus*

158 *A. ursinus* was observed on two islands, Buton and Kabaena (Supplementary Fig. S2a). It
159 appears to be widespread and fairly common on Buton, having been observed in three
160 protected areas: Lambusango Forest Reserve, Kakenauwe Nature Reserve, and Buton
161 Utara Nature Reserve. It has also been recorded in multiple habitats, including primary and
162 secondary forest, scrub, and farmland. This includes one observation in July 2014 of an
163 individual found in an extensive area of degraded coastal scrub (5°31'18.9"S
164 122°33'55.2"E), with no connectivity to closed-canopy forest ecosystems. It is difficult to
165 detect within the forest interior, normally being located high in the canopy. However, it is
166 often quite conspicuous in forest-edge ecosystems, where high densities have been
167 recorded. A 2.4 km roadside survey detected a maximum of 15 individuals (6.25
168 individuals per km walked) in a single count; this was immediately after an intense
169 rainstorm.

170 The species was recorded at all three research locations visited on Kabaena; Sikeli at 10
171 m (5°15'48.2"S 121°47'45.2"E), Enano at 132 m (5°15'47.4"S 121°58'08.6"E), and
172 Tangkeno at 650 m (5°16'43.6"S 121°55'24.5"E), suggesting it to be widespread on the
173 island. Observations at Enano and Tangkeno were made in secondary forest, while at Sikeli
174 a single observation of an adult carrying a juvenile was made within an area of highly-
175 degraded coastal farmland, with no connectivity to surrounding forest patches.

176 In contrast to the findings of Dwyahreni *et al.* (1999), who frequently observed *A.*
177 *ursinus* in groups, the great majority of our *A. ursinus* sightings on both Buton and Kabaena
178 were of single individuals or a parent with a juvenile. Sightings of two adults together were
179 uncommon, and groups of more than three individuals were observed very rarely.

180

181 **Small Sulawesi Cuscus** – *Strigocuscus celebensis*

182 *S. celebensis* was only observed on Buton (Supplementary Fig. S2b-d). It is a cryptic
183 species given its nocturnal activity cycle (Whitten *et al.* 2002), and is difficult to survey
184 systematically. Nevertheless, it was encountered opportunistically relatively frequently,

185 typically being observed two or three times each field season. Most observations of this
186 species were at night, with occasional observations during the day of individuals disturbed
187 by survey work. These diurnal observations include two incidences of the species being
188 accidentally disturbed within, and subsequently emerging from, hollow dead trees. The
189 first of these encounters involved a single individual observed within a mixed coffee and
190 cashew plantation (5°11'53.7"S 122°50'56.7"E) in July 2005, and the second involved an
191 adult and juvenile observed in closed canopy forest (5°11'48.2"S 122°53'02.1"E) in July
192 2007. These records suggest the species utilizes these tree hollows as sleeping sites during
193 the day, as has been reported for other nocturnal Cuscus species (e.g. Flannery 1995; Salas
194 2002).

195 Observations were made throughout much of the island's forested area, including within
196 three protected areas; Lambusango Forest Reserve, Kakenauwe Nature Reserve, and Buton
197 Utara Nature Reserve. Our observations of *S. celebensis* have most frequently been made
198 in closed canopy forest habitats, although the species has occasionally been encountered in
199 edge forest, farmland, and within gardens near the city of Ereke (4°48'57.9"S
200 123°10'24.0"E) with no direct connectivity to large tracts of closed canopy forest.

201 A further notable observation regarding *S. celebensis* records from Buton relates to the
202 variability in the colouration of individuals. Helgen and Jackson (2015) describe the
203 species as being a uniform grey-brown colour dorsally, with a white underbelly, while
204 Flannery (1995) describes it as being drab brown. On Buton we have observed individuals
205 with dark grey, grey-brown and sandy-brown dorsal fur (Supplementary Fig. S2b-d), as
206 well as some individuals possessing a black forehead stripe (Supplementary Fig. S2b) and
207 others where this is absent (Supplementary Fig. S2c-d), suggesting the species pelage is
208 more variable than currently described.

209

210 **Peleng Cuscus** – *Strigocuscus pelengensis*

211 We recorded *S. pelengensis* on Manui (Supplementary Fig. S2e-f), where two separate
212 individuals were observed on 07 August 2017 within an extremely rocky, inaccessible area
213 of dry forest growing over a field of large coral boulders (3°35'43.0"S 123°03'09.9"E). The
214 first individual was initially seen in a low bush growing between these boulders; when
215 disturbed, it crawled into a deep coral hole and disappeared from view. The second

216 individual was observed in a tall tree. These individuals were readily distinguished from *S.*
217 *celebensis* by their noticeably larger and more heavily-built bodies, their orange-brown
218 dorsal colouration and yellowish belly fur, and their wider tail-base (Flannery 1995; Helgen
219 and Jackson 2015). They also lacked the distinctive dorsal stripe of the larger-bodied *P.*
220 *ornatus* (Flannery 1995; Helgen and Jackson 2015).

221

222 **Discussion**

223 The results of our surveys on southeast Sulawesi's offshore islands identify important
224 range extensions for all three Cuscus species detected – specifically, *A. ursinus* on
225 Kabaena, *S. celebensis* on Buton, and *S. pelengensis* on Manui. None of our consulted
226 sources indicate these species to be previously recorded on these islands.

227 While our records of *A. ursinus* on Kabaena are new, it has previously been recorded on
228 Buton (Whitten *et al.* 2002; Salas *et al.* 2008; Helgen and Jackson 2015). We did not record
229 the species on either Muna or Wowoni, although this might not be surprising given our
230 very short fieldwork periods on these islands. It is possible the species persists on both
231 these islands, considering its presence on more biogeographically isolated Buton and
232 Kabaena, and as it has also successfully colonized the Banggai and Togian Islands in
233 eastern and northern Sulawesi respectively (Flannery 1995; Salas *et al.* 2008; Helgen and
234 Jackson 2015). On Muna it is considered to be a formerly-occurring species that may have
235 been extirpated due to habitat loss (Salas *et al.* 2008). This may or may not be the case.
236 Small forest fragments remain on Muna which support large-bodied mammals such as
237 Booted macaque *Macaca ochreata* and Sulawesi wild pig *Sus celebensis*. These may be
238 sufficient to sustain a persistent population of *A. ursinus*, given the species appears to have
239 some tolerance of non-forest habitats on neighbouring islands (see below). It seems likely
240 the species also occurs on Wowoni, given its relative proximity to the mainland, the large
241 tracts of forest ecosystems remaining here, and because other Cuscus species have been
242 demonstrated to occur (Farida and Dahrudin 2008).

243 The fact that *S. celebensis* has not been previously reported on Buton is somewhat
244 surprising, given the island has one of the most extensive areas of suitable habitat for the
245 species anywhere in southeast Sulawesi. Our records of the species' presence in three
246 reserves found on the island also partially address a knowledge gap identified by Helgen

247 *et al.* (2008) regarding protected areas known to support this species. Although we did not
248 record *S. celebensis* elsewhere, Farida and Dahrudin (2008) detected the species on
249 Wowoni, an important extension to the species' known range which has yet to be
250 incorporated into distribution maps.

251 Our records of *S. pelengensis* on Manui were unexpected, given that the species is
252 currently only recorded from the Banggai and Sula islands, some 210km to the north
253 (Suyanto *et al.* 2002; Helgen and Jackson 2015; Leary *et al.* 2016a). It is unclear whether
254 these individuals represent an established population and whether they are from a natural
255 colonisation or anthropogenic introduction. In support of these being an established, natural
256 colonisation, the closely-related *S. celebensis* has colonised remote islands in North
257 Sulawesi, apparently naturally, albeit from mainland populations (Helgen and Jackson
258 2015), and in the Sula islands *S. pelengensis* is recorded from open dry forest, secondary
259 habitats, farmland and scrub, matching the habitats which dominate Manui (Flannery 1995;
260 Helgen and Jackson 2015).

261 Not only do southeast Sulawesi's offshore islands support populations of endemic
262 Cuscuses, but they may also represent particularly important conservation areas for these
263 species. Buton in particular still supports nearly 350,000 ha of lowland tropical forest, 65%
264 of which lies within official protected areas and much of which is considered to have high
265 conservation value (Cannon *et al.* 2007; Martin *et al.* 2015). Therefore, on Buton at least,
266 large tracts of suitable habitat remain for both *A. ursinus* and *S. celebensis* – an important
267 refuge given rapid habitat loss elsewhere in their range (Helgen *et al.* 2008; Salas *et al.*
268 2008; Helgen and Jackson 2015).

269 Additionally, our observations also indicate that all three Cuscus species recorded are
270 capable of utilizing, at least to a certain degree, degraded forest, scrub, farmland and garden
271 habitats, in some cases where these non-forest habitats have little or no connectivity to
272 closed canopy forest ecosystems. Such utilization has been found for other Sulawesi
273 endemics (Martin and Blackburn 2010; Gillespie *et al.* 2015), and has been previously
274 described in *S. pelengensis* (Helgen and Jackson 2015) as well as in other Cuscus species
275 in New Guinea (e.g. Leary *et al.* 2016b). However, these patterns have not been previously
276 reported in *A. ursinus* and *S. celebensis*, with both Salas *et al.* (2008) and Helgen and
277 Jackson (2015) stating that these species do not readily use disturbed habitats. Our results

278 raise the possibility that these species may be more adaptable to habitat modification than
279 previously thought, although how optimal these habitats are for these Cuscus species, and
280 the extent to which they are used, remains unclear.

281 The other important threat to these species – hunting for food (Helgen *et al.* 2008; Salas
282 *et al.* 2008; Helgen and Jackson 2015) – may be a lesser concern in southeast Sulawesi
283 compared to elsewhere. Mackinnon (1979), O'Brien and Kinnaird (1996), Riley (2002)
284 and Lee *et al.* (2005) all report that both *A. ursinus* and *S. celebensis* are heavily hunted for
285 food in predominately Christian northern Sulawesi. On southeast Sulawesi's offshore
286 islands, however, where populations are predominately Muslim, hunting pressures may be
287 lower, as consuming Cuscus meat is considered a religious taboo (Lee *et al.* 2005). The
288 minority non-Muslim communities also do not appear to eat Cuscus meat on Buton, despite
289 not being explicitly constrained by religious beliefs (Priston 2005). Support for the
290 suggestion that hunting pressure is lower is indirectly provided by the fact that, in the
291 course of our cumulative 13 field seasons in the region, we have never observed Cuscus
292 being actively hunted, or sold in a market, as a source of food on any of our study islands.
293 Community interview data presented in previous research (Priston 2005; Hardwick *et al.*
294 2017) also indicates that, unlike pigs and macaques, farmers on Buton do not consider
295 Cuscuses to be significant crop raiders, and they are not persecuted. Care should, however,
296 be taken when interpreting the results of these interviews, given that participants may have
297 provided responses they believe to be appropriate when discussing conservation issues,
298 rather than reporting the truth (Hardwick *et al.* 2017). Nevertheless, people on Buton have
299 frequently told us in conversation that they have hunted or otherwise persecuted several
300 threatened and protected species on the island, including the Lowland anoa *Bubalus*
301 *depressicornis*, Maleo *Macrocephalon maleo* and Booted Macaque *Macaca ochreata*
302 (Priston 2005; D. Tosh and P. Wheeler pers. obs.) but never any Cuscus species. Rare
303 second-hand accounts exist of *A. ursinus* being captured and kept as pets on Buton and
304 Kabaena (although none of the authors have personally observed this). It is perhaps
305 possible that a hypothetical lower hunting pressure on Cuscus in our study area may also
306 help explain their presence in a range of non-forest habitats here; a finding which has not
307 been reported elsewhere. It could be that in northern Sulawesi (where most previous field
308 data for these species has been sourced), Cuscus are principally found in forest habitats as

309 hunting has extirpated them from other, more open habitats where they are more
310 conspicuous and easily harvested, not because they are intrinsically ecologically dependent
311 on these forest habitats. However, although we have never observed evidence of hunting,
312 we cannot be sure this never occurs without completing targeted surveys, as conducted by
313 Lee *et al.* (2005). All Cuscus species in South-east Sulawesi breed slowly, typically raising
314 a single offspring at a time which take several years to reach maturity (Helgen and Jackson
315 2015). Thus, even a low or moderate level of hunting pressure that remained undetected
316 during our fieldwork might still exert a substantial influence on their demography.

317 In summary, our findings suggest that the islands of southeast Sulawesi are likely to
318 represent important strongholds for at least two of the region's endemic Cuscuses,
319 supporting large areas of habitat and potentially experiencing lesser hunting pressures than
320 reported elsewhere in these species' ranges.

321

322 **Acknowledgements**

323 This project was supported by Operation Wallacea. We thank the Indonesian Institute of
324 Sciences (LIPI) and Kementerian Riset dan Teknologi Republik Indonesia (RISTEK) for
325 providing a series of permits for 2004-2014 fieldwork on Buton, and permits
326 174/SIP/FRP/E5/Dit.KI/V/2016 and 160/SIP/FRP/E5/Fit.KIVII/2017 for all other islands.
327 We also thank David Kelly, Nicola Marples Vivien Cumming, and two anonymous
328 reviewers for their constructive and helpful comments.

329

330 **Conflicts of interest**

331

332 The authors declare no conflicts of interest

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440 **Figure Captions**

441
442 **Fig. 1.** Map showing **A)** the location of southeast Sulawesi (inset) within the Indonesian
443 archipelago (total shaded area), and **B)** the locations of the offshore islands of Kabaena,
444 Muna, Buton, Wowoni and Manui in relation to mainland southeast Sulawesi.
445

446 **Supplementary Table S1** – Summary of links to verified records (attached as a separate
447 excel file).
448

449 **Supplementary Fig. S2.** Images showing **A)** Bear Cuscus (*Ailurops ursinus*) seen on
450 Kabaena Island, southeast Sulawesi, **B, C & D)** Small Sulawesi Cuscus (*Strigocuscus*
451 *celebensis*) seen on Buton Island, southeast Sulawesi, showing, respectively, dark grey,
452 grey-brown, and sandy-brown dorsal fur, **E & F)** Two different Peleng Cuscus
453 (*Strigocuscus pelengensis*) individuals seen on Manui Island, southeast Sulawesi. Photo
454 credits in order of lettering: Darren O’Connell, Jack Baddams, Philip Wheeler, Joseph
455 Monkhouse, Joseph Monkhouse, Joseph Monkhouse.