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How to cite:

Martin, Thomas E.; Monkhouse, Joseph; O'Connell, Darren P.; Analuddin, Kangkuso; Karya, Adi; Priston, Nancy E. C.; Palmer, Charlotte A.; Harrison, Barnabas; Baddams, Jack; Mustari, Abdul H.; Wheeler, Philip M. and Tosh, David G. (2019). Distribution and status of threatened and endemic marsupials on the offshore islands of south-east Sulawesi, Indonesia. *Australian Mammalogy*, 41(1) pp. 76–81.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:
<http://dx.doi.org/doi:10.1071/AM17052>

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

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

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

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

Running head: Distribution of marsupials in South-east Sulawesi

Introduction

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

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

Materials and methods

Study area

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

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

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

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

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

Survey work

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

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

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

Results

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

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

Bear Cuscus – *Ailurops ursinus*

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

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

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

Small Sulawesi Cuscus – *Strigocuscus celebensis*

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

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

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

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

Peleng Cuscus – *Strigocuscus pelengensis*

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

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

Discussion

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

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

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

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

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

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

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

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

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

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.

330 **Conflicts of interest**

332 The authors declare no conflicts of interest

334 **References**

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Figure Captions

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

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

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