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Lowland rainforest bat communities of Buton Island, Southeast Sulawesi, including new regional records

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Abstract. The forest habitats of Sulawesi and its attendant islands support diverse bat communities with numerous regionally endemic species. However, these communities remain poorly described, with very little data being published from the region in recent years. In this study we provide a detailed description of the Chiroptera of Buton Island, Sulawesi's largest satellite island located off the southeast coast of the mainland. Harp traps and mist nets were deployed over two eight-week research seasons between June and August in 2013 and 2014. Survey effort totalled 1,044 mist net hours and approximately 3,148 hours of harp trapping, supplemented with further opportunistic records. We sampled 178 individual bats in the course of this survey work, and identified a total of 23 species, including four species endemic to the Wallacean biodiversity hotspot and three species considered by the IUCN to be near-threatened. We present morphometric measurements for most species presented in our inventory. Our records for one species (*Cynopterus* c.f. *titthaecheilus*) in likelihood represent a major spatial range extension, this species not having been previously reported from the Sulawesi region. Our records for an additional 12 species represent minor spatial range extension within the Sulawesi Island group. Non-parametric richness estimators and species accumulation curves predict that further species may be present on Buton: any future survey work should expand the range of habitats surveyed and utilise more specialist equipment to provide the best chance of increasing the known species inventory of the Island.

Key words. bats, Chiroptera, distribution, faunistics, Sulawesi, Wallacea

INTRODUCTION

The forest habitats of Sulawesi—the largest landmass within the Wallacean biodiversity hotspot (Myers et al., 2000; Myers, 2003)—support diverse vertebrate communities displaying high levels of endemism (Whitten et al., 2002). However, they remain poorly explored by zoologists. This is especially true for bats as only a limited number of accounts regarding chiropteran diversity of specific sites have been published from Sulawesi in recent decades (Hill, 1991; Riley, 2002; Maryanto et al., 2011), alongside a regional review (Suyanto & Kartikasari, 2001), a discussion of specimen collections (Bergmans & Rozendaal, 1988), a phylogeographical study of a single species-complex (Campbell et al., 2004) and several species descriptions (Maryanto & Yani, 2003; Bates et al., 2007; Maryanto et al., 2012). Overall, the lack of published research from Sulawesi has led to a significant knowledge shortfall regarding which species occur in this biodiversity hotspot, where they occur, and their ecology. More specifically, there is a particular drought of information outside mainland Sulawesi's central mountains and its northern offshore islands, where published research has been focused. This study will attempt to partially address this research gap by presenting data based on 16 weeks of survey effort from a lowland tropical forest ecosystem on Buton Island, southeast Sulawesi. We report all species records yielded from these surveys, providing overviews of the status of each of these species on Buton. We also construct species accumulation curves and non-parametric species richness estimators to provide the first overall estimates of bat community richness in a lowland Wallacean rainforest.

MATERIAL AND METHODS

Study site. Buton island is the largest (c. 560,000 ha) of Sulawesi's offshore islands, and is located approximately 6 km (at the nearest point) off the mainland's southeastern peninsula (O'Donovan, 2001) (Fig. 1A). The topography of Buton is fairly rugged, with much of the islands' interior being dominated by low mountains, which rise to a maximum altitude of 1,000 m (Whitten et al., 2002). Geology on the island is complex; lower-lying areas are dominated by uplifted karstic limestone (Whitten et al., 2002), while the mountainous interior is a heterogenous mix of limestones, sandstones, chert, and ultramafic soils overlying ophiolitic rock (Milsom et al., 1999). The island experiences a tropical

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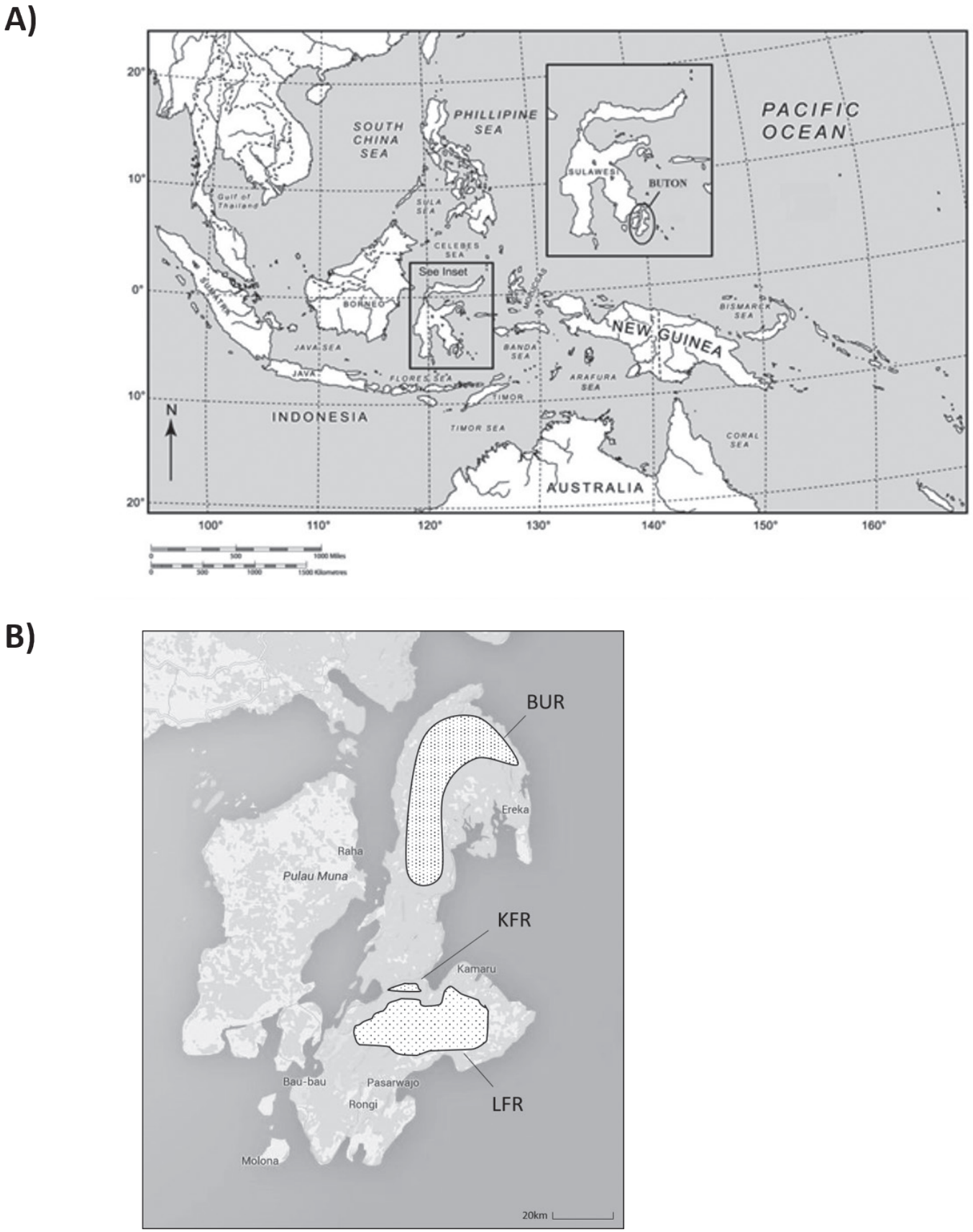

Fig. 1. Maps showing: A, The location of Buton Island within Southeast Asia and the Sulawesi region; B, a map of Buton Island, with the delimitations of the Island's principal protected areas – the Lambusango Forest Reserve (LFR), the Kakenauwe Forest Reserve (KFR) and Buton Utara Nature Reserve (BUR) shown in shaded polygons.

monsoon climate, classified as *Am* on the Köppen climate classification system (Peel et al., 2007), with a June–September dry season and a November–April wet season. Mean annual rainfall is 1,790 mm, peaking between April and June (Bau Bau Weather station, unpublished data). Temperature is fairly consistent, with monthly averages ranging between 25°C and 27°C (Whitten et al., 2002). While approximately 70% of Buton remains forested, large areas of cleared agricultural land occur around the low-lying coastal areas of the island, with principal crops including rice, maize, sweet potatoes, cassava and plantations of cashew nuts, cocoa, and coconut (Priston, 2005; Martin et al., 2012; Priston et al., 2012). Agricultural activity on the island continues to expand, facilitating a deforestation rate of approximately 0.54% per annum (Martin et al., 2015).

Fieldwork was completed within and around the peripheries of the three main protected areas on Buton Island: Lambusango Forest Reserve (LFR) (in the vicinity of 5°12′11.4″S and 122°53′14.8″E), Kakenauwe Forest Reserve (KFR) (in the vicinity of 5°10′51.4″S and 122°53′53.0″E) and Buton Utara Nature Reserve (BUR) (in the vicinity of 4°36′26.0″S and 123°05′38.0″E) (Fig. 1B). All these protected areas are managed by the Indonesian Natural Resources Conservation Agency (BKSDA) and are considered 'strict' reserves where all socio-economic activity is nominally prohibited (Singer & Purwanto, 2006). All habitats within the borders of the protected areas can be classed as lowland tropical forest, whereas habitats in the peripheral areas consist of cleared agricultural land, cultivated mainly with the principal crop types listed above.

Sampling. Bat communities on Buton Island were surveyed over two eight-week field seasons running between June and August in 2013 and 2014. This work was completed as part of the long-term, multidisciplinary biodiversity surveys run by Operation Wallacea (Operation Wallacea, 2016). Two techniques were used to sample the bat communities: mist netting and harp trapping.

Harp trapping occurred within all three protected areas but efforts were focussed in KFR and LFR. In these reserves, between three and five harp traps (each with four banks and a frame size of 2.4 m^2) (Francis, 1989) were positioned each evening along cleared transects, with a distance of 10 m between each trap, while in BUR only two traps were used each evening, these being selectively sited in locations predicted to yield high numbers of captures (e.g., next to wide river channels or on cleared paths) (Barlow, 1999). Traps were open from 1700 hours (one hour before sunset) until 2100 hours, and were checked every 30 min. Traps remained open overnight, with a final check at 0700 hours, after which the traps were closed and repositioned for the next night of trapping (Francis, 1989).

Mist netting was carried out in suitable areas, including cut transects, cleared rivers and within established forest camps, and farmland habitats on the peripheries of the protected areas (Barlow, 1999). On mist net trapping nights, two 36 mm mesh nets (measuring 20 m long and 2.6 m high) were

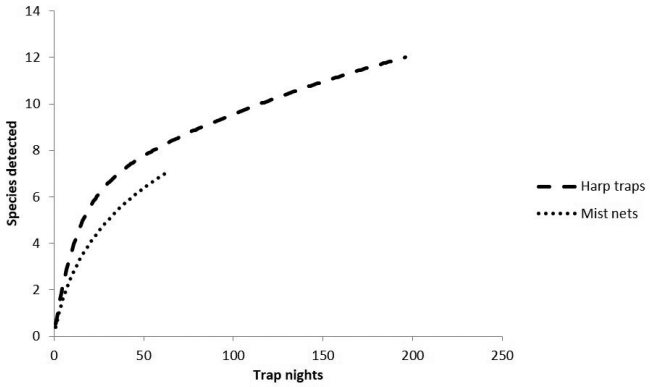

Fig. 2. Sample-based rarefaction curves displaying number of bat species detected against number of trapping nights for harp trapping and mist netting surveys on Buton Island, Southeast Sulawesi.

opened at sunset (1800 hours) and removed at 2100 hours to eliminate possible overnight captures. Mist nets were also checked every 10 min, due to the increased stress and exposure involved with this trapping methodology (Barlow, 1999). Total hours of trapping effort were calculated by multiplying the number of survey hours by the number of open traps and nets deployed in the field. Total numbers of trap nights (number of survey nights multiplied by the number of traps used) were also calculated for use in our species richness estimators (see below).

All bats caught in harp traps or mist nets were processed using the same methods. All captures were first extracted (immediately in the case of mist nets; after variable time periods in the case of harp traps) and placed within cotton holding bags. Once removed to a suitable distance from the traps, individuals were weighed using pre-calibrated Pesola spring balances: either a 30 g, 100 g, or 500 g balance was used, depending on the species of bat. Forearm measurements (mm) were taken using Moore & Wright vernier callipers, with handlers wearing protective gloves.

Forearm and weight measurements were taken as these are generally considered to be the most important morphometric variables with regards to species identification (Hill, 1991; Fukuda et al., 2009; Monadjem et al., 2010). Gender, age and reproductive status of female individuals were also determined and noted. Bats noticeably pregnant or actively lactating were given priority and processed first. We also made notes of male bats displaying noticeably large testicles or with visible presence of epididymis. Records were made on the general conditions of individuals, presence of ectoparasites and endoparasites, and any other notable features (e.g., unusual coloration or wing damage). Species were identified using a key created by the authors from previous years' experience and cross checked with existing literature from the area (Flannery, 1995; Bonaccorso, 2000; Payne & Francis, 2007) and a mammalian life history database (PanTHERIA, 2009). All taxonomy followed Wilson & Reeder (2015). Optimally voucher specimens of our captures would have been taken and deposited in a collection, although this was not possible due to the difficulties of obtaining relevant permits within Indonesian protected areas (Grajal, 1999; Sodhi & Liow, 2000). As a necessary proxy for specimen collection, high

resolution photographs were taken of all species captured to assist further with identification and provide evidence of their occurrence on Buton.

We also noted any informal, opportunistic bat records made during the course of each season. Opportunistic records include sightings of roosts while cutting new transects, investigation of fruit bat colonies alongside roads, records made while exploring local cave systems, and identification of any bats trapped unintentionally by bird mist net surveys run as part of the same project. Opportunistic sightings were only recorded where a confident identification supported by photographic evidence could be made. Photographs of species taken in the course of our fieldwork were consolidated into two photographic guides, which were deposited with the Field Museum, Chicago (Patterson et al., 2017a; Patterson et al., 2017b).

Data analysis. Analysis of our data comprised of two broad approaches: a community-level analysis of estimated bat diversity in our study site, and the production of an annotated species inventory for Buton Island. We describe each of these analytical approaches in turn.

We estimated the total diversity of the bat community on Buton island using sample-based rarefaction curves and non-parametric species richness estimators. Rarefaction curves were constructed by plotting the number of trap nights for each method against the number of species detected, using the software package EstimateS Version 9.1.0 (Colwell, 2013). We also generated ACE, Chao 2 and MMMeans nonparametic species estimators using 100 randomisation runs in EstimateS (Colwell, 2013), these being considered appropriate for extrapolating vertebrate community richness in tropical forests (Herzog et al., 2002). We then took a mean value from these three estimators (rounding to the nearest integer value) as a 'true' species richness estimate, given that the effectiveness of different estimators varies depending on dataset composition (Sodhi et al., 2005).

For our annotated species inventory, we first listed all species detected in taxonomic order (following Wilson & Reeder, 2005), and noted the conservation status of each species, following the IUCN Red List (IUCN, 2016). It was also noted whether a species was endemic to the Wallacean biodiversity hotspot as defined by Myers et al. (2003), or to Indonesia, as defined by species descriptions on the IUCN Red List (IUCN, 2016). We then assigned categorical abundance estimates for each species based on frequency of records. The following categories were used: common (>20 records); uncommon (5–19 records) and rare (<5 records). Finally, we determined whether records for each species on our inventory represented extensions to their known spatial range. Two different magnitudes of range extensions were evaluated: major range extensions for species not previously reported from anywhere in the Sulawesi Island group, and minor range extensions for species previously known to occur on Sulawesi, but not indicated as occurring on Buton Island by existing species distribution maps. We identified range extensions by comparing each species on our inventory with distribution maps provided by the IUCN (2016), range descriptions provided by Wilson & Reeder (2015), and records described in published papers from the region (Revilliod, 1911; Bergmans & Rozendaal, 1988; Hill, 1991; Suyanto & Kartikasari, 2001; Riley, 2002; Campbell et al., 2004; Maryanto et al., 2011). We also consulted distribution descriptions in an existing field guide to the Southwest Pacific and the Moluccan Islands (Flannery, 1995). While this guide focusses on a region beyond our study area, it does provide extralimital ranges for many species occurring on Sulawesi. We acknowledge that the range of resources against which we compare our records is somewhat limited — this is due to the lack of research completed across Sulawesi in recent decades (further highlighting the need for more information regarding regional species distributions).

RESULTS

A total of 178 individual bats comprising 19 species were captured during 4192 hours of trapping effort (3,148 harp-trapping hours split between 196 trap nights and 1,044 mist netting hours split between 62 trap nights) over the two seasons of fieldwork. Harp traps captured 131 individuals and 12 species, while mist nets captured 46 individuals and six species. Species detected by harp trapping and mist netting were entirely independent, with no species being detected by both methods. An additional four species were detected through informal fieldwork records, giving a total of 23 species for our species inventory. A total of 11 species were recorded from BUR, 11 species from LFR and six species from KFR (Table 1). An additional five species were recorded from open farm habitats beyond the borders of the protected forest areas. Morphometric data was recorded for 160 individuals (90.9% of the overall individuals captured) (Table 2).

Non-parametric species richness estimators (Table 3) predict an overall richness of 15 species susceptible to detection by harp traps, and 10 species which are susceptible to detection by mist nets. Given that these two species groups appear to be independent on Buton (as no species was detected by both methods), we therefore combine these values to estimate the total bat community richness of our study area as 25 species. Our inventory completeness, based on formal survey effort, is therefore estimated as 76%. Rarefaction curves (Fig. 2), corroborate these estimates, with the trajectories of the curves suggesting overall richness to be slightly higher than that sampled by our sample effort.

Three species in our inventory are considered near-threatened by the IUCN (2016). Additionally, only seven species are considered to possess stable populations, indicating that the conservation status of other species may change in the future. Four species detected on Buton are endemic to the Wallacean biodiversity hotspot — a regional endemism rate of 17.4%. A further two species are nationally endemic to Indonesia. We identified our record for one species as a major range extension, and records for a further 12 species as minor range extensions. A full summary of species detected in our study area is provided in Table 1, and morphometric

Table 1. Checklist of bat species recorded on Buton Island in 2013 and 2014. All species considered to be major range extensions (not previously reported from southeast Sulawesi) are indicated **, while all species considered to be minor range extensions (previously reported from southeast Sulawesi but not Buton Island) are indicated *. Species indicated ‡ are endemic to the Wallacean biodiversity hotspot as defined by Myers et al. (2003). Species indicated † are assessed as threatened or near threatened by the IUCN (2016). Relative abundance estimates are denoted as follows: C = common; U = uncommon; R = rare. Number of records for each species is given in parenthesis after each relative abundance estimate. Species with a relative abundance estimate marked § indicate species recorded once, at a roost. These are assigned a single record each, although the true number of individuals observed was higher. Initials in the 'Locations' column indicate whether species have been recorded in Buton Utara Reserve (BU), Lambusango Forest Reserve (LF), Kakenauwe Forest Reserve (KF), or farmland adjacent to the forest reserves (FL). Initials in the 'Method' column indicate the methods each species was detected by. M = Mist-nets; H = Harp traps; N = Hand-nets; O = Direct observation. All taxonomy follows Wilson & Reeder (2015).

Family	Species	Relative abundance	Location	Method
Pteropodidae	*Cynopterus* c.f. *brachyotis*	C (33)	BU, LF, FL	M
	Cynopterus c.f. *titthaecheilus***	R (2)	BU	M
	Dobsonia crenulata‡	R (2)§	FL	N
	*Eonycteris spelaea**	R (1)	FL	M
	*Macroglossus minimus**	U (6)	BU, FL	M
	Nyctimene cephalotes‡	R (1)	BU	M
	*Pteropus alecto**	R (1)§	LF	O
	*Rousettus amplexicaudatus**	R (3)	BU	M
	Styloctenium wallacei†‡*	R (1)	LF	M
Rhinolophidae	*Rhinolophus celebensis*	U (12)	LF, KF	H
	*Rhinolophus euryotis**	C (29)	BU, LF, KF	H
	Rhinolophus philippinensis	R (32)	BU, LF	H
Hipposideridae	*Hipposideros cervinus**	C (31)	BU, LF, KF	H
	*Hipposideros diadema**	R (1)	KF	H
	Hipposideros pelingensis†‡	R (1)	LF	H
Emballonuridae	*Emballonura monticola*	R (1)	FL	N
Vespertilionidae	*Tylonycteris robustula**	R (1)	BU	H
	Miniopterus australis	R (1)	BU	H
	Miniopterus schreibersii†*	R (3)	BU	H
	Murina florium	U (11)	LF, KF	H
	*Kerivoula hardwickii**	C (17)	LF, KF	H
	Kerivoula papillosa	C (18)	LF, KF	H
	*Phoniscus jagorii**	R (1)	LF	H

data for all species processed are provided in Table 2. Our photographic guides to the bats of Buton Island (Patterson et al., 2017a; Patterson et al., 2017b) can be freely accessed via the website of the Chicago Field Museum.

These guides provide images for all species in our inventory except for *Pteropus alecto* and *Miniopterus australis* (two species we were not able to obtain photographic records for). Additional photographic records for our single major range extension are provided in Plate 1. The species descriptions below provide more detailed information on each species in our inventory:

Cynopterus c.f. *brachyotis*

A common species in our study area, known from a total of 33 captures in BUR, LFR and open farmland habitats. The species is widespread across much of South and Southeast Asia, and has been formerly noted as occurring on Buton by Campbell et al. (2004). The taxonomy of *C. brachyotis* remains uncertain. It is classified as a single species by the taxonomic resource followed in this paper (Wilson & Reeder, 2015), although genetic analyses suggest that it is likely to be a complex of different lineages (Campbell et al., 2004). Other sources, notably the IUCN (2016), thus separate *C. brachyotis* into several different species, three of which potentially could occur in our study area (the nominate *C. brachyotis*, *C. minutus* and *C. luzoniensis*). However, without genetic analyses we are unable to determine with confidence which of these three proposed taxonomic splits the individuals captured on Buton belong to. To account for this potential uncertainty, we therefore class our records on Buton Island as *C.* c.f. *brachyotis*, rather than classify it as a specific species as recommended by Wilson & Reeder (2015). Interestingly, our results do indicate some morphological separation between *C.* c.f. *brachyotis* individuals sampled in forest and those caught in open habitats, as theorised by Campbell et al. (2004). Individuals caught in open farmland habitats (N=7) possessed, on average, a slightly longer forearm length (62.2 mm) compared with those caught in forest (N=26) (57.14 mm). This could perhaps provide some tentative evidence for open-area populations developing

Table 2. Summary of morphometric measurements taken from bats captured by harp traps and mist nets on Buton Island, southeast Sulawesi in 2013 and 2014. Weight values shown are the mean values of all individuals measured, with standard deviation values to two decimal places. Sample size is given in parenthesis. A value of N/A in a cell indicates that no individuals of the corresponding sex were caught for that species.

Species	Sex	Forearm (mm)	Weight (g)
Cynopterus c.f. *brachyotis*	Male	61.04 ± 4.12 (18)	30.83 ± 10.69 (18)
	Female	57.29 ± 4.46 (7)	27.36 ± 3.52 (7)
Cynopterus c.f. *titthaecheilus*	Male	74.45 ± 4.45 (2)	71.00 ± 1.41 (2)
	Female	N/A	N/A
Dobsonia crenulata	Male	105.25 ± 6.75 (2)	136.00 ± 14.85 (2)
	Female	118.80 (1)	105.25 (1)
Eonycteris spelaea	Male	69.00 (1)	60.00 (1)
	Female	N/A	N/A
Macroglossus minimus	Male	50.6 ± 9.63 (3)	21.17 ± 4.91 (3)
	Female	53.70 (1)	27.00 (1)
Nyctimene cephalotes	Male	N/A	N/A
	Female	70.20 (1)	40.50 (1)
Rousettus amplexicaudatus	Male	72.35 (1)	64.00 (1)
	Female	69.63 ± 3.64 (2)	44.00 ± 9.90 (2)
Rhinolophus celebensis	Male	39.55 ± 1.12 (8)	6.13 ± 2.28 (8)
	Female	40.17 ± 1.15 (3)	5.83 ± 0.76 (3)
Rhinolophus euryotis	Male	49.02 ± 3.78 (16)	10.33 ± 2.26 (16)
	Female	49.53 ± 2.31 (15)	10.42 ± 2.27 (15)
Rhinolophus philippinensis	Male	52.4 ± 3.78 (2)	10.33 ± 2.26 (2)
	Female	N/A	N/A
Hipposideros cervinus	Male	41.93 ± 9.92 (16)	6.77 ± 0.86 (16)
	Female	45.84 ± 1.58 (15)	6.54 ± 0.32 (15)
Hipposideros diadema	Male	N/A	N/A
	Female	82.60 (1)	32.50 (1)
Hipposideros pelingensis	Male	N/A	N/A
	Female	95.40 (1)	50.00 (1)
Emballonura monticola	Male	44.40 (1)	6.00 (1)
	Female	N/A	N/A
Tylonycteris robustula	Male	N/A	N/A
	Female	26.80 (1)	5.00 (1)
Miniopterus australis	Male	30.50 (1)	4.00 (1)
	Female	N/A	N/A
Miniopterus schreibersii	Male	48.00 (1)	12.00 (1)
	Female	47.78 ± 0.18 (2)	11.25 ±0.35 (2)
Murina florium	Male	33.5 ± 0.55 (4)	6.08 ± 0.72 (4)
	Female	34.13 ± 1.28 (6)	6.68 ± 0.87 (6)
Kerivoula hardwickii	Male	31.48 ± 4.44 (12)	4.06 ± 1.57 (12)
	Female	31.47 ± 1.17 (4)	3.65 ± 0.77 (4)
Kerivoula papillosa	Male	45.51 ±0.73 (4)	11.29 ± 0.91 (4)
	Female	47.81 ± 1.63 (14)	11.36 ± 0.53 (14)
Phoniscus jagorii	Male	N/A	N/A
	Female	39.50 (1)	8.00 (1)

Table 3. Non-parametric species estimates for bat communities on Buton Island, southeast Sulawesi. Abundance-based coverage estimator (ACE), Chao2, and MMMeans are non-parametric species estimators (Colwell & Coddington, 1994).

	Harp traps	Mist nets
Trapping nights	196	62
Species observed	12	7
Individuals observed	131	47
ACE	18.22	10.91
Chao2	13.99	8.48
MMMeans	12.95	9.3
Average species richness estimates	15	10

longer wing-length to adapt to less confined environments, although this cannot be considered conclusive due to our small sample size, and this requires further research.

Cynopterus c.f. *titthaecheilus*

An Indonesian endemic, this species appears to be rare in our study area. It is only known from two adult individuals captured in mist nets within BUR by GP (11 July 2014, 18 July 2014) (Plate 1). We tentatively identify this species as *C. titthaecheilus* due to our morphometric measurements of these captures being very similar to those reported from Bali (Kitchener & Foley, 1985), and also because there are no other *Cynopterus* species known to occur in the Sulawesi region or its immediate surrounds that possess an equivalent size of our captures, which had an average weight of 71 g. However, without genetic analyses we cannot be completely confident of this species identification, and thus we identify it tentatively as *Cynopterus* c.f. *titthaecheilus*. If our records can be conclusively confirmed as being *C. titthaecheilus*, this would represent a major range extension for the species. The IUCN (2016) and Wilson & Reeder (2015) describe the species as occurring only in Java, Sumatra, Bali, Lombok and Timor, and no other literature sources consulted note the species as occurring anywhere within the Sulawesi region.

Dobsonia crenulata

A Wallacean endemic which appears to be a rare species on Buton. It was recorded twice during our study period, with a single individual observed hanging from a tree in the Lambusango Forest Reserve by OC (20 June 2014), and with a large roost within an extensive cave system (where *E. monticola* was also present) in KFR being located by GP & TEM (31 July 2014). Individuals hand netted from this cave system displayed slight colour variations from vivid yellow fur to a subdued yellow-green hue. Opportunistic sightings by TEM also suggest the species to be common on the nearby Wakatobi Islands – specifically on the major island of Kaledupa and its smaller attendant island Hoga. Previously considered a subspecies of *Dobsonia viridis* (Hill, 1991; Flannery, 1995), Wilson & Reeder (2015) regard *D. crenulata* as a separate species endemic to Sulawesi and the Moluccas. It has been previously mapped as occurring on Buton (Hutson et al., 2008b).

Eonycteris spelaea

A widespread cave-dwelling species found from India to the Moluccas. It is rare in our study area, being known from two individuals captured in mist nets by GP and OC in farmland on the periphery of KFR in 2014. We believe these records represent a minor range extension to the species' known distribution. It has previously been mapped in SE Sulawesi, including the nearby island of Muna (Francis et al., 2008b), although has not been reported from Buton Island.

Macroglossus minimus

A widespread species found from Southeast Asia to Northern Australia, *M. minimus* is the smallest member of the Pteropodidae Family in our study area. It appears to be uncommon on Buton, being known from a total of six individuals. Two of these were heavily pregnant females mist-netted by GP (9 July 2014) in farmland adjacent to BUR. Two additional lactating females were also caught at the same time and location. It is also notable that a further individual captured that evening was found to be pregnant with two offspring. Our records represent a minor range extension to the species' known range. It is mapped as occurring throughout mainland Sulawesi, including the southeastern peninsular (Francis et al., 2008a), although not from Buton Island.

Nyctimene cephalotes

A Wallacean endemic found throughout Sulawesi, the southern Moluccas and parts of Nusa Tenggara. It appears to be rare on Buton, being known from a single individual mist netted by GP in BFR (2 July 2014) over a river system. It is previously mapped as occurring on Buton (Tsang, 2016).

Pteropus alecto

The largest bat recorded in our study area, it is a widespread species found from the Greater Sundas to Eastern Australia. We captured no individuals of this species in our study period, although a substantial roosting colony of at least 100 individuals was directly observed near the centre of LFR several times in July 2014. Our records represent a minor range extension for this species. It is known to occur extensively throughout mainland Sulawesi (Hutson

Plate 1. Images of *Cynopterus* c.f. *titthaecheilus*, showing a single adult male from the following angles: A, full head; B, side head; C, the full body profile. Another full body shot of a second adult male: D, is also displayed.

et al., 2008f), but has not previously been reported from Buton Island.

Rousettus amplexicaudatus

A cave-dwelling species with a widespread distribution between Southeast Asia and the Western Pacific. *Rousettus amplexicaudatus* is rare on Buton, being known from three captures in 2014. Our records represent a minor range extension for the species; it is known to occur widely across mainland Sulawesi (Csorba et al., 2008c) but has not been previously reported from Buton.

Styloctenium wallacei

A Wallacean endemic known to occur only on Sulawesi and its offshore islands. This species is classified as near threatened by the IUCN (Ruedas et al., 2010); however, declines associated with habitat loss in its limited range could lead to a future reassessment as vulnerable. It is a rare species in our study area, being known only from a single opportunistic record — an individual captured in a bird mist-net in July 2013 by TEM. This record was external to our formal bat survey protocols, and as such we did not include it in our quantitative mist net trapping dataset. We report this record as a minor range extension to the known range of *S. wallacei*, the species having been previously mapped as occurring across much of Sulawesi (Bergmans & Rozendaal, 1988; Maryanto et al., 2011; Ruedas et al., 2010) but not Buton Island.

Rhinolophus celebensis

An Indonesian endemic found on Sulawesi, Java, and several smaller islands. It is an uncommon species on Buton, being known from only 12 harp trap captures from LFR and KFR in 2013 and 2014. It has been previously mapped as occurring on Buton (Hutson et al., 2008d).

Rhinolophus euryotis

A widespread species found from Sulawesi eastwards to Papua New Guinea and a common species in our study area, being known from 32 captures from LFR, KFR, and BUR. Our records represent a minor range extension for this species. It has been previously mapped as occurring throughout mainland Sulawesi (Leary & Bonaccorso, 2008) although not on Buton Island.

Rhinolophus philippinensis

A widespread although sporadically-occurring species found in disjunctive populations between the Greater Sundas and Philippines to Australia. It is a rare species in our study area, being known from three mist-net records in LFR and BUR. The Buton population of *R. philippinensis* is comprised of three distinct size morphs, the evolutionary divergence of which has been the subject of previous research (Kingston & Rossiter, 2004). One of our captures belonged to the 'large' morph (with a forearm length of 58.0 mm and a weight of 12.5 g), with another belonging to the 'small' morph (with a forearm length of 46.8 mm and a weight of 6 g). The final individual captured during fieldwork escaped before morphometric measurements could be taken, thus we could not determine which size morph it belonged to. The species is previously known to occur on Buton, being reported as occurring here by Kingston & Rossiter (2004).

Hipposideros cervinus

A widespread species occurring from mainland Southeast Asia to the West Pacific. It is a common species on Buton, being known from 31 capture records throughout our study period, spread between LFR, KFR, and BUR. Our records represent a minor range extension for this species, which is known to occur widely across mainland Sulawesi (Csorba et al., 2008a) but has not been previously mapped on Buton.

Hipposideros diadema

A widespread species occurring from Southeast Asia to Northern Australia. It appears to be rare on Buton. A single individual was captured by NA and OC in a harp trap within KFR (14 July 2014), and two further individuals were opportunistically observed near the centre of LFR in 2014 after disturbance created during the cutting of a transect. We report our records as a minor range extension for *H. diadema*. The species has been previously mapped as occurring throughout mainland Sulawesi (Csorba et al., 2008b), but has not been noted as occurring on Buton.

Hipposideros pelingensis

Previously considered part of the *H. dinops* species complex, *H. pelingensis* is now treated a separate species endemic to Sulawesi and its offshore islands (Wilson & Reeder, 2015). It is considered near-threatened by the IUCN (Hutson et al., 2008c) due to limestone extraction and other forms of disturbance within its forest habitats. It is rare within our study area, being known from a single individual caught by NA and OC in a harp trap within LFR (2 August 2014). It has been previously mapped as occurring on Buton (Hutson et al., 2008c).

Emballonura monticola

A widespread species found from Peninsular Malaysia to Sulawesi. It appears to be a rare species in our study area. A single male was captured in a hand net by GP and TEM in an extensive cave system (where *D. crenulata* was also present) (31 July 2014). This individual was distinguished from other emballonurids occurring in the region (notably *E. alecto*) by its slightly smaller body mass and forearm length (see Table 2), and its distinctive long, worm-like penis (Flannery, 1995). It has been previously mapped as occurring on Buton Island (Bates et al., 2008a).

Tylonycteris robustula

A small-bodied species with a distinctive flattened skull and thickened dark pink pads at the base of the thumb and sole of the foot. It is a rare species on Buton, being known from a single individual caught in a mist net by GP over an open river system in BUR (9 July 2014). We report this record as a minor extension to the species' known range. It is currently reported as occurring throughout mainland Sulawesi (Bates et al., 2008b) although none of our consulted sources indicate it as occurring on Buton.

Miniopterus australis

A species with a large geographic distribution stretching from Sumatra to Eastern Australia and the West Pacific. It is a rare species in our study area, being known from a single individual captured by GP in a harp trap within BUR (18 July 2014). It has been previously mapped as occurring on Buton (Rosell-Ambal et al., 2008b).

Miniopterus schreibersii

A very wide-ranging species found from Eurasia to West Africa and Australia, the Buton populations belonging to the subspecies *M. s. oceanensis*. The species as a whole is considered near-threatened due to disturbance of its roosting habitats, especially in the European part of its range, although the conservation status of *M. s. oceanensis* remains unassessed (Hutson et al., 2008a), and its precise taxonomy unclear. It is a rare species in our study area, being known from three individuals captured in harp traps by GP within BUR (14 July 2014, 15 July 2014). Our records represent a minor extension to the known range of this species, which has been previously mapped in southeast Sulawesi (Hutson et al., 2008a) but not Buton.

Murina florium

A disjunctively distributed species that remains poorly studied within its known range between Western Wallacea and Northern Australia and the Western Pacific. An uncommon species in our study area, known for 11 harp trap captures within LFR and KFR. It has been previous reported as occurring on Buton (Hutson et al., 2008e).

Kerivoula hardwickii

A wide-ranging species found from Pakistan to Sulawesi and the Lesser Sundas. It is a common species in our study area, being known from 17 harp trap captures in LFR and KFR. We class our records as a minor range extension, the species having been previously reported from southeast Sulawesi (Rosell-Ambal et al., 2008a) but not Buton.

Kerivoula papillosa

A wide-ranging species found disjunctively throughout Southeast Asia and the Indonesian archipelago. A common species known from 18 harp trap captures in LFR and KFR. It has been previous reported as occurring on Buton (Hutson & Kingston, 2008).

Phoniscus jagorii

A widely, yet sporadically, distributed species known from mainland Southeast Asia, the Philippines, the Greater Sundas and Sulawesi. It is rare in our study area, being known from a single individual captured in a harp trap by NA and OC within LFR (04 July 2014). We conservatively identify this record as a minor species range extension. The species is known to occur in Sulawesi (Wilson & Reeder, 2015) but the only available detailed geographical information suggests it only occurs in the northern parts of the island (Kingston et al., 2008).

DISCUSSION

Results from our survey work on Buton Island make an important contribution to existing knowledge of chiropteran diversity and distributions in the Sulawesi region. Additionally, our results highlight the extent to which bat communities in Sulawesi and the wider Wallacean hotspot remain under-explored. While our overall survey effort is modest compared to other studies completed in western Indonesia (e.g., Abd Rahman et al., 2011; Struebig et al., 2012), our work still represents the largest survey yet completed in southeastern Sulawesi, and is only exceeded in scale regionally by the fruit bat-specific survey completed in Lore Lindu by Maryanto et al. (2011). The fact that 39% of all species detected in this survey represent range extensions is highly indicative of Sulawesi's neglected status, and we strongly advocate further exploration of the region. Further fieldwork would be valuable not only in other parts of Sulawesi (in particular south Sulawesi and mainland southeast Sulawesi where, with the exception of single species description (Bates et al., 2007), virtually no recent fieldwork has been conducted), but also on Buton Island, as further surveys here would in likelihood enhance the understanding of the bat community outlined in this paper.

While the trapping hours underscoring our results represent significant and valuable survey effort, the results of our non-parametric species richness estimators and sample-based rarefaction curves suggest that it is likely that an increased duration of study could further increase the number of species known to occur on Buton, given our inventory completeness (excluding opportunistic records) is estimated as 76%. Further species records may be best achieved by directing survey efforts towards habitats overlooked in this study. Our survey work placed a strong focus on lowland forest ecosystems up to an altitude of approximately 300 m asl, and mixed agricultural land immediately adjacent to these forests, along with some limited opportunistic exploration of small cave systems. Many other ecosystems exist on Buton, however, and rigorous exploration of these could increase the overall inventory of the island's bat diversity. Flannery (1995) and the IUCN (2016), for example, both indicate that there are several habitat-specialist species in mainland Sulawesi that could theoretically occur on Buton (e.g., *Rousettus bidens* and

Mops sarasinorum). Habitats particularly worthy of further exploration include areas of highland forest, especially the highest peaks found in the far north of the island which reach >1,000 m in altitude (Whitten et al., 2002), large cave systems, mangroves, and small offshore islets. One example of the latter habitat is Snake Island, a 1.5 km wide islet located off the southwestern coast of Buton which is known to support bird species not present on Buton itself (Catterall, 1997); it might thus be reasonable to suppose it may also support different bat species.

Given that the bulk of survey work completed on Buton to date has been geographically concentrated in the south-central and northern parts of the island, it is also recommended that any future survey work direct effort towards exploring southern, western, and northwestern areas. These poorly-known parts of Buton support extensive and often high quality forest habitats (Cannon et al., 2007) and preliminary surveys of other taxa suggest species can be found here that are not present elsewhere. For example, nesting sites of the Maleo (*Macrocephalon maleo*), an endangered megapode, have never been detected in LFR, KFR or the northern sections of BFR, but explorations in other parts of the Island have confirmed their presence on Buton (D. Tosh – *pers obs*).

The results reported in this paper are also somewhat influenced by detection bias inherent in our methodologies. Although we detected species from a wide variety of chiropteran families, our harp trapping protocols focussed on the capture of smaller-bodied microbats (e.g., Vespertilionidae, Rhinolophidae, Hipposideridae and Emballonuridae), and our mist-netting effort was entirely concentrated within 0 and 2.6 m off the ground in all habitats. Given that many large-bodied Pteropodidae species are generally more susceptible to capture by canopy netting and are best sampled by targeted surveys of specific areas (i.e., roosts) (Kalko & Handley, 2001; Maryanto et al., 2011), it should not be surprising if the diversity of these species is under-represented in our results. This may also apply to the relative abundances reported for Pteropodidae. For example, *Pteropus alecto, Dobsonia crenulata* and *Styloctenium wallacei* were each only encountered on a single occasion, and we report all three species as being rare: a classification that may be an artefact of our ground-based trapping effort. Some canopy-level high-flying open habitat species might have also been missed by our ground-level netting methodologies (MacSwiney et al., 2008). Employing acoustical sampling techniques may be a means of yielding new species records from these cryptic groups, as has been the case in other Southeast Asian tropical forests (Furey et al., 2009; Phommexay et al., 2011).

In summary, while further work remains to be completed on Buton, the results we present here provide rare overall diversity estimates and species-level information for a Wallacean lowland forest bat community. We also highlight the conservation importance of these forest ecosystems, especially with respect to their supporting numerous endemic and threatened species, drawing attention to the fact that, even with the data provided here, these forests and their bat communities remain very poorly explored. Given the high rate of deforestation for lowland forests on Sulawesi (Miettinen et al., 2011) further survey work in these ecosystems should be considered a high priority in order to assess their full conservation value and devise suitable management strategies, before they are irreplaceably degraded and fragmented.

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