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The microchiropteran bat fauna of Singapore

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The historical mammalian literature and recent surveys document a total of 24 microchiropteran species for the small equatorial island nation of Singapore. Intensive surveys carried out in the 1990s and subsequent records indicate that, of these 24 taxa, 15 are still present, another eight species, including all three hipposiderids, have become locally extinct and one other is indeterminate. Almost half (6) of the surviving species have very low abundances. Three new records of bat species in Singapore, namely *Nycteris tragata, Rhinolophus lepidus* and *Murina suilla* are assumed to have been present in the past but not detected in earlier surveys. *Nycteris tragata* and *M. suilla* are categorized as locally endangered. The vespertilionid, *Myotis oreias*, recorded previously only in Singapore, was not found in this survey and may be globally extinct.

Key words: bats, diversity, Microchiroptera, Singapore, South-East Asia

INTRODUCTION

The island nation of Singapore is located at the southern tip of Peninsular Malaysia from which it is separated by the narrow Johore Straits. Technically this equatorial island falls within the area of maximum bat species richness (or density) for the Old World (Findley, 1993) that is prescribed by the extraordinary diversity of the Malay Peninsula and Borneo (Kingston *et al*., 2003; Simmons, In press). However, changes in land-use following the founding of modern Singapore in 1819 are among the most dramatic in South-East Asia; more than 90% of the native mixed dipterocarp and wetland forest has been cleared, urbanization encompasses more than 50% of the island, and less than 5% of the total land area remains as primary or secondary forest (Corlett, 1992). Singapore thus presents an intriguing locality for the study of bat diversity and conservation, but, prior to the 1990s, bats had yet to be surveyed systematically. The historical data up to that time consisted of accumulated scattered records of individual naturalists over the preceding 175 years, the majority of whom were collecting prior to the advent of survey techniques (mist nets, harp traps and acoustic monitoring) that greatly improve the detection of species. Inventories provided by Corbet and Hill (1992) and Hutson *et al.* (2001) both list just four microchiropteran

taxa as having been recorded for Singapore, although a more comprehensive historical inventory, summarized by Yang *et al*. (1990), lists 20 species of Microchiroptera (excluding a doubtful record of *Nyctalus noctula*) with an additional species, *Rhinolophus stheno*, recorded by Harrison (1966). Of these 21 species, 17 were considered by Yang *et al*. (1990) to have an indeterminate status. Only seven species had been recorded in the 20 years preceding 1990; five species were last recorded between 1910 and 1935; three last seen in the nineteenth century; and the rest noted as having no recent record (Yang *et al*., 1990). Two species, *Hipposideros ridleyi* and *Myotis oreias*, had not been recorded in Singapore subsequent to their initial single records (respectively Robinson and Kloss, 1911; Flower, 1900). In the Singapore Red Data Book (Ng and Wee, 1994) both species are considered endangered. *Hipposideros ridleyi* is recorded for Peninsular Malaysia and Borneo (Francis *et al*., 1999) but in a recent IUCN status survey (Hutson *et al*., 2001) it is categorized as vulnerable and declining. *Myotis oreias* is currently known only from Flower's (1900) record (Simmons, In press) but a re-description of the holotype (Francis and Hill, 1998) notes that the type locality of Singapore is questionable. The IUCN status for *M. oreias* is categorised as 'data deficient endemic' (Hutson *et al*., 2001). Despite the paucity of bat records from Singapore, five species or subspecies of Microchiroptera [*Myotis oreias* (Temminck, 1840); *Rhinolophus luctus morio* Gray, 1842; *Hipposideros ridleyi* Robinson and Kloss, 1911; *Megaderma spasma medium* Andersen, 1918; and *Rhinolophus sedulus edax* Andersen, 1918] have Singapore as their type locality. This no doubt reflects the fact that the island was the first port of call for many naturalists and explorers of the region in the 19th and earlier part of the 20th centuries.

This paper reports on extensive surveys carried out in the early 1990s, plus subsequent records and surveys, that re-examine bat diversity in modern, highly urbanized Singapore, a city state with one of the highest human population densities in the world (Tan, 2002). The use of survey techniques that were not available to previous naturalists (harp traps, acoustic monitoring) may be expected both to increase the number of species recorded for the island, and to provide an accurate assessment of the current conservation status of bat species in Singapore.

Materials and Methods

Bats were trapped in a variety of habitat types throughout mainland Singapore and its offshore islands (Fig. 1). Free-flying bats were captured with mist nets or harp traps, or a combination of both, in primary forest, secondary forest, parkland, mangrove, urban and rural environments, or over water bodies. Detailed records of net/trap nights were not kept but the survey was an intensive one, conducted over a two-year period (June 1992 to December 1994). Mist nets (30–50 denier, 4 bank and lengths of 6–12 m) were generally deployed near ground level but sometimes set higher up (but not canopy level) using a pulley system (Kunz and Kurta, 1988). They were positioned across known flight paths, alongside forest paths, at foraging sites, over water bodies or outside roosts. The harp trap was a two-bank design based on the Tuttle trap (Tuttle, 1974; Tidemann and Woodside, 1978). Foliage-roosting bats were sometimes caught with hoop nets, and a custom designed roost exit trap (Pottie, 1996) was used successfully for chimney roosting bats.

Straits Times (a Singapore national daily newspaper) and Nature Society (Singapore) Newsletter articles solicited information on roost sites additional to those known to the biological community. A two-year bat box programme deploying 270 boxes throughout mainland Singapore was another method used to census roosting bats. The boxes, based on a design from Stebbings and Walsh (1988), were sited at six locations representing primary forest, secondary forest, park land, near open water, mangrove and low-density residential. Precise locations and details of deployment are given in Pottie (1996). Boxes were inspected at 6–8 week intervals over the two-year period.

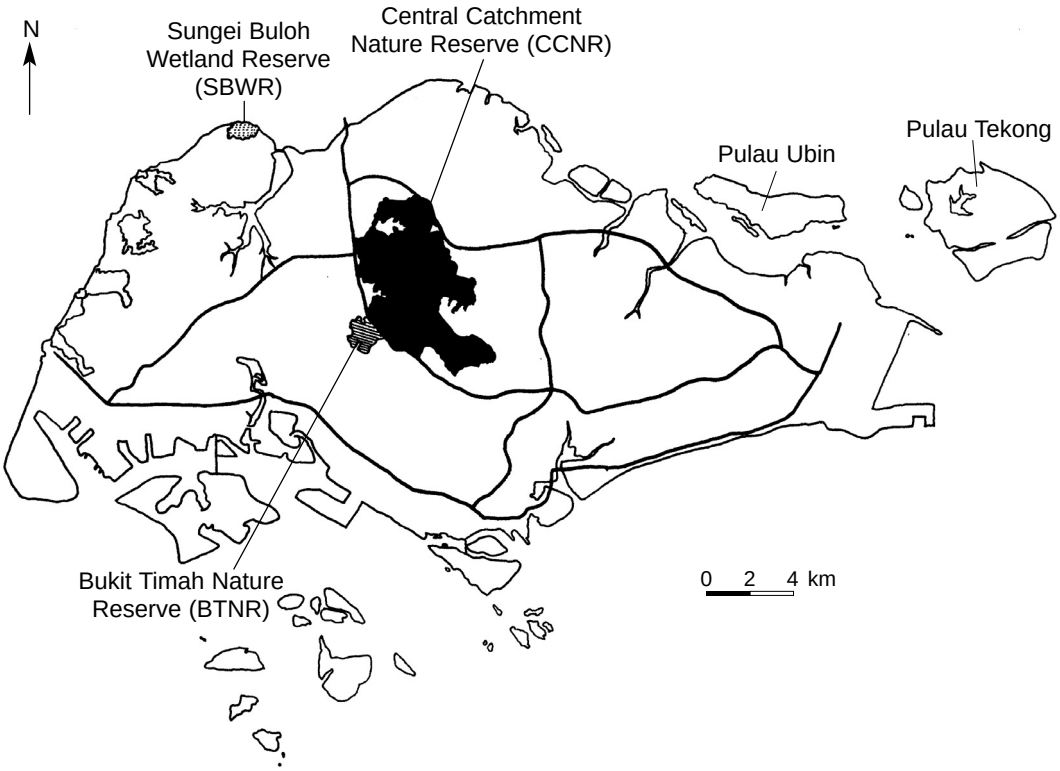

FIG. 1. Map of mainland Singapore, its Southern and Northeastern Islands and the location of the Nature Reserves. The percentage of land designated as Nature Reserves amounts to 4.8% of the current total land area of 697 km^2

In view of the anticipated precarious conservation status for many species, individuals were generally released after capture. Bat species were identified using external characteristics following Medway (1983) and Lekagul and McNeely (1988), primary literature sources and the field guide of Payne and Francis (1985). All individuals were weighed (using Avinet spring scales to 0.5 g) and measured (lengths of forearm, head and body, tail and pinna) with dial calipers to 0.1 mm. The sex of each bat was recorded and juveniles distinguished from adults by the presence of cartilaginous epiphyseal plates in the finger bones (Anthony, 1988). Outstretched wings were photographed through a glass top table with a grid overlay, using a 35 mm camera with a 100 mm lens. Wing span and wing area were derived from the digitized images and aspect ratio and wing loading calculated following Norberg and Rayner (1987). Some individuals were held captive temporarily, for validation of echolocation calls, but only those few individuals that died in captivity were retained and these were deposited as specimens with the Zoological Reference Collection of the Raffles Museum.

Echolocation call design was characterized for 11 species using a D980 Pettersson ultrasound detector. Time expanded calls (10×) were recorded on a Sony DAT TCD-D3 tape recorder and subsequently analysed on a 386 computer using the Pettersson LP900v2 software to display frequency-time-energy structure and to derive the following parameters: maximum frequency, minimum, peak, call duration and pulse repetition rate. Bats were recorded free-flying in a large aviary or on release. Cyalume light-tags (< 0.1 g) were initially used to keep track of released bats but this was discontinued as ambient light levels at night in Singapore enabled untagged bats to be tracked visually while being acoustically recorded following release. Sound analyses were restricted to the search phase of calls with the best signal to noise ratio. Habitat distribution, diversity and abundance of foraging Microchiroptera was assessed using a programme of acoustic transects in eight habitat types: primary forest, secondary forest, mangrove, rural, suburban (parks and low rise housing), urban (high rise housing and industrial sites), city, and water bodies. Two 1 km transects from each category

were selected and each was walked on 10 nights from 19:00 to 21:00 hrs and one night from 00:00 to 01:00 hrs with the D980 detector channels set to frequency division and time expansion modes. The weather was always clear or slightly cloudy and survey nights were selected without regard to the phase of the moon. Calls were recorded in time expansion mode and analysed later in the laboratory. Acoustic identification of free-flying bats can be difficult, particularly in diverse systems where species overlap in call parameters (Jones *et al*., 2000; Parsons and Jones, 2000) but, given the limited diversity of the Singapore bat fauna, it proved possible to visually match spectra of most free-flying bats to the calls of identified captive bats recorded while flying in an aviary or after release.

Survey of Species

During the present survey, 11 species of microchiropteran bats were physically captured and identified (Table 1). Echolocation recordings indicated the presence of an additional species, *Rhinolophus luctus* (Fig. 2E and Table 2) and a thirteenth, *Cheiromeles torquatus* (a highly distinctive large bat), has been sighted in flight (Table 1). Acoustic records also indicate the presence of an unidentified FM bat (Fig. 2C). Two additional microchiropteran species have been captured since the survey ended, namely *Tylonycteris pachypus pachypus* (Teo and Rajathurai, 1997) and *Murina suilla* (R. Teo, unpubl. data for 2002, pers. comm.). The Straits Times and the Nature Society Newsletter requests for information revealed five roosts of *Scotophilus kuhlii* (a common bat in Singapore), with a further 35 responses reporting roosts of the fruit bat *Cynopterus brachyotis. Scotophilus kuhlii* was the only species to utilize the bat boxes.

Including the identified acoustic record, but not the unidentified one, the confirmed microchiropteran species count is 15 (Table 1). Another eight species, recorded in the historical inventory, were not found in the 1992–1994 surveys, or subsequently, and are considered to be locally extinct, while one other, *Pipistrellus stenopterus*, is considered indeterminate. This species, last confirmed for Singapore nearly 50 years ago (Hendrickson, 1957), owes its indeterminate status to an unpublished, unconfirmable record (no specimen) in the mid 1980s.

Table 1. The current known status of Microchiroptera in Singapore based on surveys and records over the period 1992–2004. The categories Common (C), Uncommon (U), Rare (R) and Endangered (En) are designated as > 500; 100–499; 10–99; < 10 individuals respectively. Ex denotes local extinction and I indeterminate. Nomenclature follows Simmons (In press)

Species	Recorded this survey (*)	Present status
Emballonuridae		
Emballonura monticola	*	En
Saccolaimus saccolaimus	*	C
Taphozous melanopogon	*	R
Nycteridae		
Nycteris tragata	*	En
Megadermatidae		
Megaderma spasma	*	En
Rhinolophidae		
Rhinolophus lepidus	*	C
R. luctus[1]	*	En
R. sedulus		Ex
R. stheno		Ex
R. trifoliatus	*	R
Hipposideridae		
Hipposideros bicolor		Ex
H. cervinus		Ex
H. ridleyi		Ex
Vespertilionidae		
Murina suilla[2]		En
Myotis adversus	*	C
M. muricola	*	C
M. oreias		Ex
Pipistrellus javanicus		Ex
P. stenopterus		I
Scotophilus kuhlii	*	C
Tylonycteris pachypus		En
T. robustula	*	U
Molossidae		
Cheiromeles torquatus	*	En
Chaerephon plicatus		Ex

[1] — *Rhinolophus luctus*, recorded only during acoustic surveys and only occasionally, could not be readily counted and is here designated as endangered

[2] — Unpublished data (R. Teo, pers. comm.)

TABLE 2. Characteristics of search phase calls ($\bar{x}$ ± SE) for Singapore Microchiroptera. The data, except for *N. tragata*, are based on field recordings of released bats

Species	Number of		Frequency (kHz)		Frequency with most energy (kHz)	Search call duration (ms)
	Bats	Calls	Maximum	Minimum		
Emballonura monticola	4	40	49.3 ± 0.81	46.0 ± 1.53	49.1 ± 0.29	6.80 ± 0.02
Saccolaimus saccolaimus	23	198	23.5 ± 1.32	21.8 ± 1.42	22.6 ± 0.42	12.20 ± 0.08
Taphozous melanopogon	6	60	28.7 ± 1.24	25.2 ± 0.82	27.9 ± 0.56	10.43 ± 0.06
Nycteris tragata	2	30	98.8 ± 0.27	70.0 ± 0.22	83.8 ± 0.31	0.51 ± 0.01
Rhinolophus lepidus	24	240	–	–	97.8 ± 0.07	28.30 ± 1.36
R. luctus	2	28	–	–	42.6 ± 0.01	69.90 ± 1.71
R. trifoliatus	4	40	–	–	53.1 ± 0.03	44.50 ± 2.15
Myotis adversus	26	243	82.5 ± 0.71	30.4 ± 0.36	46.2 ± 0.31	4.68 ± 0.10
M. muricola	18	180	79.9 ± 1.02	53.7 ± 0.48	57.2 ± 0.01	4.98 ± 0.07
Tylonycteris robustula	12	120	105.7 ± 1.89	43.2	52.3 ± 0.22	3.65 ± 0.04
Scotophilus kuhlii	27	270	84.9 ± 2.25	36.6 ± 0.46	43.3 ± 0.16	4.01 ± 0.03
Unknown	4	56	98.5 ± 2.03	25.4 ± 0.79	38.9 ± 0.26	3.56 ± 0.03

houses (1–27 per roost). The largest roost however (300+) was found in an unoccupied basement close to Orchard Road (central urban). The acoustic transect surveys show that this fast-flying species forages above all habitat types (Table 4) throughout Singapore, a finding confirmed by subsequent surveys (Teo and Rajathurai, 1997). *Saccolaimus saccolaimus* is categorised as common in Singapore (Table 1).

Taphozous melanopogon Temminck, 1841

Only 26 individuals have been recorded, all of whom were mixed with *S. saccolaimus* in the large basement roost noted above. It was never found in the chimney roosts favoured by *S. saccolaimus* and we thus consider *T. melanopogon* to be rare. During the transect surveys *T. melanopogon* was recorded over fewer habitat types than *S. saccolaimus* (Table 4) but this may reflect the relative rarity of *T. melanopogon* (just 22 passes compared with 791 for *S. saccolaimus*). Both species use multi-harmonic, shallow-declining FM search calls (Fig. 2A) but those of *T. melanopogon* can be distinguished on the basis of higher maximum and minimum frequencies (Table 2). Both *S. saccolaimus* and *T. melanopogon* were characterised by high wing loadings and high aspect ratios (Table 3) characteristic of fast flying aerial hawking species.

Nycteridae

Nycteris tragata (Andersen, 1912)

This is a new mammal record for Singapore. One male and one female of this species were discovered in 1993 roosting in a dry culvert in Sime Forest (primary forest) in the Central Catchment Nature Reserve (CCNR). The female died in captivity and is deposited as a specimen in the Zoological Reference Collection (catalogue no. ZRC 4.7906). The male was released at the point of capture. Standard dimensional data for the forearm, head and body, tail and pinna were, respectively, 52.7, 72.7, 78.4 and 32.8 mm for the female, and 50.3, 68.9, 69.9 and 31.2 mm for the male. The wing morphometric data (Table 3) indicate a low aspect ratio and low wing loading which are characteristic of this species and considered to be adaptations for slow, highly manoeuvrable flight during which the bat listens for prey on the ground with its large, high-drag ears. A low wing loading also enables

TABLE 3. Wing morphometry and body mass ($\bar{x}$ ± SE) for Singapore Microchiroptera

Species	*n*	Body mass (g)	Wing span (cm)	Wing area (cm^2)	Aspect ratio	Wing loading (Nm^{-2})
Emballonura monticola	5	5.57 ± 0.27	26.34 ± 0.24	94.27 ± 1.72	7.3 ± 0.09	5.7 ± 0.30
Saccolaimus saccolaimus	28	46.40 ± 2.08	46.10 ± 0.51	248.00 ± 4.78	8.6 ± 0.13	18.4 ± 0.90
Taphozous melanopogon	6	26.50 ± 1.34	38.29 ± 0.24	180.14 ± 3.65	8.2 ± 0.15	14.4 ± 0.45
Nycteris tragata	2	16.50 ± 0.53	31.30 ± 0.01	210.06 ± 1.00	4.7 ± 0.49	7.7 ± 0.60
Rhinolophus lepidus	27	6.48 ± 0.09	22.60 ± 0.23	103.28 ± 3.13	5.0 ± 0.10	6.2 ± 0.09
R. trifoliatus	3	12.33 ± 0.10	29.41 ± 0.01	191.61 ± 0.02	4.5 ± 0.15	6.3 ± 0.08
Myotis adversus	32	9.02 ± 0.11	26.90 ± 0.28	122.16 ± 2.53	5.7 ± 0.10	7.3 ± 0.09
M. muricola	21	4.90 ± 0.22	24.40 ± 0.13	83.14 ± 1.83	7.5 ± 0.14	6.1 ± 0.26
Scotophilus kuhlii	35	19.89 ± 0.20	28.48 ± 0.29	118.29 ± 3.28	7.0 ± 0.15	16.8 ± 0.40
Tylonycteris robustula	13	6.50 ± 0.19	18.01 ± 0.11	52.54 ± 1.23	7.2 ± 0.14	12.2 ± 0.29

the bat to take off from the ground with large prey items. This species was not recorded during the acoustic transects, but this may reflect the low-intensity search phase calls in this species which comprise very brief, steep multiharmonic FM sweeps (Fig. 2D and Table 2). *Nycteris tragata* was formerly regarded as a subspecies of *N. javanica* (Medway, 1983; Payne *et al*., 1985; Lekagul and McNeely, 1988) but it is now considered a distinct species (Van Cakenberghe and de Vree, 1993; Simmons, In press). The morphological characteristics of the Singapore specimens concur with those of *N. tragata* and the discovery of this species in Singapore fits in with its known geographic range of Myanmar, Peninsular Malaysia, Thailand and Borneo (Lekagul and McNeely, 1988; Simmons, In press).

Megadermatidae

Megaderma spasma (Linnaeus, 1758)

Regarded as common 75–80 years ago (Chasen, 1925) this bat is no longer known in mainland Singapore but has been recorded on the northern islands just offshore. Four individuals (2 ♂♂ and 2 ♀♀) were discovered roosting in a culvert, on Pulau Tekong, a forested island used exclusively

TABLE 4. Distribution of acoustic activity of Microchiroptera across eight habitat types in Singapore. Values for each species represent percentages (rounded to whole numbers) of total activity (bat passes) detected in each habitat. The numbers in parentheses indicate the species activity as a percentage of all bat activity for that habitat

Species	Mangrove	Primary forest	Secondary forest	Rural	Suburban	Urban	City	Water
Saccolaimus saccolaimus	12 (47)	7 (29)	11 (35)	16 (32)	15 (28)	14 (45)	10 (63)	15 (28)
Taphozous melanopogon	0 (0)	0 (0)	23 (2)	0 (0)	27 (1)	0 (0)	50 (9)	0 (0)
Rhinolophus lepidus	0 (0)	65 (29)	35 (13)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
R. luctus	0 (0)	100 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
R. trifoliatus	0 (0)	100 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Myotis adversus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2)	0 (0)	97 (44)
M. muricola	2 (2)	14 (15)	17 (15)	27 (14)	32 (16)	4 (3)	0 (0)	3 (2)
Scotophilus kuhlii	13 (51)	4 (16)	8 (28)	23 (46)	21 (41)	16 (50)	4 (28)	11 (22)
Tylonycteris robustula	0 (0)	4 (2)	12 (5)	27 (7)	44 (11)	0 (0)	0 (0)	13 (3)
Unknown sp.	0 (0)	0 (0)	18 (1)	35 (1)	47 (2)	0 (0)	0 (0)	0 (0)
Total species per habitat	3	7	7	5	6	4	3	4
Total passes per habitat	208	194	239	406	419	255	121	406

for military training. On nearby Pulau Ubin a roost of three was found at the eastern end of the island in October 2004 (R. Teo, pers. comm.). The echolocation calls of this locally endangered species were not recorded.

Rhinolophidae

Rhinolophus lepidus Blyth, 1844

This bat is a new mammal record for Singapore. It was initially designated (Pottie, 1996) as *R. refulgens*, a name now considered to be synonymous with *R. lepidus* (Simmons, In press). Dimensional data (n = 27) for the mean lengths of forearm, head and body, tail and pinna were 39.9 ± 0.18, 42.8 ± 0.41, 19.9 ± 0.15 and 15.8 ± 0.14 mm, respectively. Recorded roosting and flying at many locations within the CCNR-BTNR region (primary and secondary forest) during this survey and subsequently (Teo and Rajathurai, 1997; unpubl. 2002 observations of fourth author). It is restricted to the central forested catchments, both primary and secondary (Table 4), and adjacent rural fringes. A population of at least 350 has been recorded at Bukit Timah (Teo and Rajathurai, 1997). After three previously sealed caves at BTNR were unbricked and the entrances fitted with horizontal grills in 1994, a pair of *R. lepidus* was found roosting in one of the caves. This species, now designated as common, is either a recent immigrant or it has been overlooked by early collectors. Echolocation call structure is typical of *Rhinolophus* species and is dominated by a pure tone (constant frequency or CF) of 97.8 kHz with an initial frequency modulated (FM) upsweep and a terminal FM downsweep (see Fig. 2E and Table 2). Morphometric data (Table 3) demonstrate a low wing loading and short, low aspect ratio wings suitable for slow, manoeuvrable flight in a cluttered environment.

Rhinolophus luctus Temminck, 1835

Identified in Singapore only from its 42.6 kHz CF echolocation calls (Fig. 2E and Table 2), which matched validated calls of this species in Malaysia. Calls were recorded in primary forest only (Table 4), except for one record in a suburban area, amongst foliage, at Changi. Roosts of this species were not found.

Rhinolophus trifoliatus Temminck, 1834

Three solitary individuals were found, on separate occasions, roosting beneath under-story foliage of primary forest. Other individuals were detected in flight or perch-hunting along tracks or in clearings in the CCNR forest. The FM-CF-FM echolocation calls have a CF frequency of 53.1 kHz (Fig. 2E and Table 2). The island-wide acoustic surveys detected this species in primary forest only (Table 4), although there is a single recent (2001) unpublished record of a female roosting in secondary forest (R. Teo, pers. comm.) The small number of records puts this bat in the locally endangered category. *Rhinolophus trifoliatus* has low aspect ratio wings with a low wing loading (Table 3) characteristic of slow manoeuvrable flight.

Vespertilionidae

Myotis adversus (Horsfield, 1824)

Formerly considered rare in Singapore (Harrison, 1966), this species is in fact common. In one case the roof-space of a gazebo extending over MacRitchie Reservoir (within CCNR) housed 14–24 individuals. The most frequent roost sites were the weep holes of storm drains. During transect surveys (Table 4) and other ad hoc surveys, detector recordings of the FM calls (Fig.

2B and Table 2) and visual observations established that this bat almost always foraged over water. The low wing loading and medium aspect ratio (Table 3) are characteristic of the slow, manoeuvrable flight of this bat.

Myotis muricola muricola
(Gray, 1846)

Found island-wide, roosting singly or in groups of up to 10 individuals in the central furled leaves of banana plants, or sometimes singly under open leaves. Categorised as common. Foraging occurred in all habitats except city and over water (Table 4). This species was frequently seen (and detected acoustically) flying around lights to catch insects. The search-phase echolocation call structure is quite distinct from that of other vespertilionids found in Singapore and consists of a steep down-sweep from 80 kHz to a relatively prolonged, high energy CF component at 57 kHz (Fig. 2B and Table 2). The wing morphology for the present sample of this species (n = 21) indicates a low wing loading and a moderately high aspect ratio (Table 3).

Scotophilus kuhlii castaneus
Gray, 1838

This is the most common microchiropteran species in Singapore. Seen and acoustically recorded (Fig. 2B and Table 2) foraging in or above all habitats, particularly urban/suburban parkland and rural areas (Table 4). Over 20 roof-space roost sites were surveyed and colonies of up to 400 individuals were found, although smaller groups were more common. This was the only species to occupy bat boxes during the two-year period of the bat box programme. *Scotophilus kuhlii* has a high wing loading and a moderately high aspect ratio (Table 3) characteristic of fast, open air flight.

Tylonycteris robustula robustula
Thomas, 1915

Recorded roosting in bamboo stands in five areas (Botanic Gardens, MacRitchie Park, Bishan, Chinese Gardens and Sungei Mandai), but with less than 100 records, this species is considered uncommon. During the acoustic surveys it was found foraging in a wide range of habitats, particularly suburban, but was absent from built-up urban/city environments and mangroves (Table 4). This bat has been recorded subsequently (1999–2001) at Pulau Ubin (Robert Teo, pers. comm.). Its echolocation calls consist of a steep FM sweep to a shallow CF component (Fig. 2B and Table 2). The morphometric data for the population sample of this small bat indicates a relatively high wing loading and a high aspect ratio (Table 3) for this species.

Tylonycteris pachypus pachypus
(Temminck, 1840)

This species which, like its congener, is similarly adapted to roost in bamboo internodes, was historically last recorded in Singapore by Chasen (1925). It was not found during this survey but in 1997 a single bat, mist-netted just below the summit at Bukit Timah Hill (Teo and Rajathurai, 1997), represents a rediscovery of this species in Singapore and a category change from locally extinct to endangered.

Molossidae

Cheiromeles torquatus torquatus
Horsfield, 1824

This bat, the largest of all the aerial hawking Microchiroptera (Macdonald, 1995), has a long wing-span and is highly distinctive in flight. It was identified (visually) on only one occasion with at least five

of these fast flying bats hawking aerial insects above the secondary forest canopy of the CCNR. No roost sites were found. Prior to this series of surveys the last record was in 1979 (Anon, 1988).

Discussion

Just 11 of the 21 Microchiroptera species records in the historical inventory for Singapore (Harrison, 1966; Yang *et al*., 1990) are currently identified from captures or, in one case, sightings. Field echolocation recordings indicate the presence of two more species (Table 2). One of these, also in the historical inventory and identified as *R. luctus*, brings the survivor tally to 12 species but the other acoustic record was not identified. Surprisingly, there are three additional species that are new mammal records for Singapore, namely *N. tragata*, *R. lepidus* and *M. suilla*.

Seven species, namely: *R. sedulus*, *R. stheno*, *H. bicolor*, *H. cervinus*, *H. ridleyi*, *P. javanicus* and *C. plicatus* are considered locally extinct. Another species, *P. stenopterus*, is indeterminate (possibly extinct) and one other, *M. oreias*, known only from the Singaporean holotype, may be totally extinct unless other records in the region emerge. More than half (62%) of the locally extinct bats (Table 1, Ex) belong to the families Rhinolophidae and Hipposideridae. Hipposiderids have completely disappeared. Extinction patterns for both Microchiroptera and Megachiroptera are considered in a separate publication (D. J. W. Lane, T. Kingston, and B. P. Y.-H. Lee, unpubl. data) but the possible causes of a decline to endangered status and local extinction of microbats in Singapore all hinge on the dramatic change in land use patterns and the increase in human population density (currently > 6000/km^2 — Tan, 2002) that this small island state has undergone.

The confirmed species count for Singapore Microchiroptera is 15. Several species, namely *E. monticola*, *M. spasma*, *N. tragata*, *R. trifoliatus*, *R. luctus*, *T. pachypus*, *M. suilla* and *C. torquatus* have very low abundances and are considered highly endangered (Table 1). Despite the welcome addition of three new confirmed microchiropteran records, the low population numbers for many of these aerial insectivores indicate that a continued decline in microchiropteran diversity in Singapore is probable.

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