The current status of bats in Western Australia

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ABSTRACT

Understanding of the distribution and ecology of some Western Australian bats has advanced considerably in the last ten years, while knowledge of others remains basic. The state has one species listed in the highest conservation level under state legislation (*Rhinonicteris aurantia*), and one population of this species is listed in a Threatened category under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Six other species are included on the Department of Environment and Conservation's Priority Fauna Listing based on their known distribution and representation on conservation and threatened lands (*Falsistrellus mackenziei, Hipposideros stenotis, Macroderma gigas, Mormopterus loriae cobourgiana, Nyctophilus major tor* and *Vespadelus douglasorum*). These listings reflect mainly a lack of knowledge and perceived threat. Recent unpublished research on *R. aurantia* and *M. gigas* has provided much relevant information for assessing development proposals, mainly in the Pilbara where plans for iron and gold mines coincide with their habitat. There are several unresolved taxonomic issues in the fauna, and when these are resolved, the tally for the state might increase by up to two species from a total of 37. The impact of logging, mining and other disturbances involving forest clearing in the south west is largely unknown, but the first studies have been completed recently. The status of cave occupancy of bats in south west caves was recently assessed, and only five caves have persistent bat colonies of significant size. A series of studies on aerodynamics, foraging strategy and call design has added a new dimension to the understanding of WA bats. Surveys for bats based on acoustic recordings of echolocation calls have increased considerably, and either one of two approaches based on AnaBat equipment are undertaken. Keys are mostly unavailable for identifying WA bats from their echolocation calls, but measurements of echolocation parameters from regional bat surveys and keys from other parts of Australia provide a good basis for making identifications in many cases.

Key words: conservation status, distribution, echolocation, Pilbara, taxonomy, threatened species.

Introduction

The vast expanse and diverse ecological communities of Western Australia (WA) support a total of 37 recognised species in seven families, with two species represented by two subspecies or forms within the state (Table 1). Our understanding of the WA bat fauna has grown in the past 30 – 40 years, with highlights including several new species added or resolved in the 1970's and 1980's (e.g. Kitchener 1976, 1980; Koopman 1984; Kitchener *et al.* 1986, 1987; also Parnaby 2009), studies of physiology, feeding and reproduction in the 1990's (Hosken *et al.* 1994, 1996; Hosken and O'Shea 2001), ecological studies involving field surveys, aerodynamics and echolocation in the past decade (McKenzie and Muir 2000; Bullen and McKenzie 2001, 2002a,b, 2004, 2005, 2007, 2008; McKenzie *et al.* 2002; McKenzie and Bullen 2003, 2009; see review by Bullen and McKenzie, this issue), and distributional, habitat, and taxonomic studies in the last decade involving two species listed in categories of conservation significance (Armstrong 2000, 2001, 2002, 2003, 2005, 2006a,b; Armstrong and Anstee 2000; Armstrong and Coles 2007). This review provides a timely update to the taxonomy and nomenclature of WA bats, current conservation listings, a review of threats to various species, a brief analysis of the broad patterns of bat diversity across the biogeographic regions of the state, and some observations on recent trends in approaches to surveying bats with acoustic recording equipment.

1. Taxonomy and nomenclature

Several reviews in the past decade have provided an update on the taxonomy and nomenclature of bats occurring in Western Australia (How *et al.* 2001, with updates online as per WAM 2009; Simmons 2005; Armstrong and Reardon 2006; Churchill 2008; Van Dyck and Strahan 2008). All of these sources have authority and/or have provided justifications for their designations, though the inconsistencies between them are a source of confusion. For example, the list of How *et al.* (2001) is kept current and is available for download (WAM 2009). Some nomenclature has changed since Simmons (2005) and Armstrong and Reardon (2006) (the latter requiring some corrections to the citation of species authorities), and some designations of Churchill (2008) were premature and not considered appropriate by those who were quoted as providing personal communications (Reardon 2009). The authoritative guide of Van Dyck and Strahan (2008) used the list provided by the Australasian Bat Society (Armstrong and Reardon 2006), though not completely. Rather than addressing these deficiencies by making designations like Churchill (2008), I have attempted to provide a list of the most correct and current nomenclature based on well justified designations in the published literature (Table 1).

Churchill (2008) updated the names of *Nyctophilus timoriensis* to *N. major*, and *N. bifax daedalus* to *N. daedalus*. These updates were premature, but now have support following the recent publication of the taxonomic treatments for these species (Parnaby 2009). *Nyctophilus major* is now recognised formally as two subspecies in WA – *N. m. major* and *N. m. tor* (Parnaby 2009). Despite older nomenclature being used in various conservation listings (*see next section*), the only implication for the change is the

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requirement for a simple update of nomenclature for the same listed forms.

The species-level taxonomy of the free-tailed bat genus *Mormopterus* has always been unstable (Reardon *et al.* 2008), and the correct genus-level name for *Tadarida australis* has also been the subject of contention (e.g. opinions in Reardon 1999 and Churchill 2008). Some premature and unfortunately inappropriate references by Churchill (2008) to the molossids pre-released results of taxonomic work in progress and preliminary hypotheses by T.B. Reardon *et al.*, who responded subsequently (Reardon 2009). The most current view of relationships within the Australian Molossidae is given in Reardon *et al.* (2008) and Van Dyck and Strahan (2008), which is based largely on the prior species boundary delineations of Adams *et al.* (1988), and further revisions are nearing completion. I have provided names that consider the wish of Reardon (2009) as per his statement:

> The special circumstances regarding the molossid treatment do warrant my asking that people follow the taxonomy for this family as presented in Van Dyck and Strahan (2008) until the appropriate papers are published.

The names of the taxa included previously under *Miniopterus schreibersii* were also updated in Table 1, but the correct name for Australian representatives of '*M. schreibersii*' is yet to be determined pending the results of genetic studies for South-east Asian and Australasian members of the genus (by B. Appleton and colleagues). The name *M. oceanensis* in Table 1 is provided following Appleton *et al.* (2004) and Tian *et al.* (2004), which is also followed by the IUCN (2010). Churchill (2008:222) states that "the name *orianae* actually should have precedence over *oceanensis* as it is the oldest available name (B. Appleton pers. comm.)" and uses *M. orianae* despite it not being "formally published". However, *blepotis* might also be a candidate name, which has precedence over *orianae*. It is not appropriate to make any formal designation until taxonomic studies have been completed, so to be consistent with the peer-reviewed literature and the IUCN, I have listed *M. oceanensis* in Table 1 as perhaps the best interim compromise.

One species is represented by two forms in Western Australia – *Rhinonicteris aurantia*. A formal update of the nomenclature of this species was provided by Armstrong (2006a). Work relating to taxonomy (Armstrong 2002, 2003, 2005, 2006b; Armstrong and Coles 2007) stopped short of providing a formal taxonomic assessment of the Pilbara phonic type because further genetic work was required, and evolutionary studies have yet to decipher the meaning of significant differences in mean call frequency between geographic isolates representing phonic groups (e.g. Guillén *et al.* 2000; Jones and Barlow 2004; Yoshino *et al.* 2008; Chen *et al.* 2009). A formal taxonomic designation will be made following the publication of a population genetic study with representation across the range of this species (K.N. Armstrong unpublished).

In addition to the issues mentioned above, there are several other ambiguities in the taxonomy of WA bats. Some of these might involve relationships at the species level, or involve phylogeographic structuring of geographic or morphological groups (e.g. *Chalinolobus morio, Vespadelus finlaysoni;* see comments in Kitchener *et al.* 1987 on *V. finlaysoni*). Considering all of these issues together, the number of full, well resolved species recognised in WA is not likely to increase significantly, possibly by up to two species, but changes in nomenclature are expected in several genera for a variety of reasons (Table 2). Some of the changes might stem from a revision of the relationships between Australian and more widely distributed forms overseas (e.g. *Hipposideros ater, Miniopterus oceanensis*). At least one new species is expected to be 'discovered' in the coming years, as there have been three collections of a *Vespadelus* closely resembling *V. douglasorum* in two locations in the Kimberley. The available specimens are distinct from *V. douglasorum*, differing in some external features and most characteristically the length of phalanges 1 and 2 in the third digit (McKenzie 1999; Armstrong and Kitchener 2008). We await the collection of a male so that penile morphology can help determine the status of these different forms, and genetic markers may also help to provide resolution.

2. Conservation status and bats of conservation significance

Seven WA bat species are listed currently in categories of conservation significance (Table 3). Two of these are Western Australian endemics (*Falsistrellus mackenziei*, *V. douglasorum*). The remainder have distributions that extend into other states (*H. stenotis, M. gigas, M. loriae cobourgiana*), or are represented in WA by more than one subspecies or isolated populations (*N. major, R. aurantia*). As a result of their occurrence in WA, coupled with observed or perceived threats, these species have been listed in conservation categories to ensure their continued persistence in this state. Consequently, their conservation status is listed differently under State, Commonwealth and international schemes. Updated conservation listings under the IUCN's Red List have followed the Global Mammal Assessment made in 2005 (IUCN 2010). These listings consider full species only, and take a broad view of their conservation status throughout their global distribution. Thus, IUCN listings sometimes differ from those that are based on priorities in individual Australian states. Of particular note is *R. aurantia* which is listed as 'Least Concern" by the IUCN, and in a non-Threatened category in the Northern Territory, but under Schedule 1 of the Western Australian *Wildlife Conservation (Specially Protected Fauna) Notice 2010* as "Fauna that is rare or is likely to become extinct". In addition, one of two WA populations is listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act 1999*) on the basis of differences between Pilbara and northern geographic isolates (McKenzie *et al.* 1999a; Armstrong 2002, 2005, 2006b; Armstrong and Coles 2007).

The WA Department of Environment and Conservation (DEC) maintains a Priority Fauna List, which includes species not listed under the *Wildlife Conservation (Specially Protected Fauna) Notice 2010*. Priority Fauna are given special consideration when assessing development proposals on the basis of a perceived risk of decline, which is generally a function of their estimated population size and distribution. The list is updated regularly and

Table 1. List of current correct nomenclature and authorities for bats in Western Australia. * indicates that the distribution of this species may cross the state border, but it is not included in the final tally.

***Genus species* Authority**	**Common name**
Pteropodidae	
Pteropus alecto gouldi Peters, 1867	black flying-fox
Pteropus scapulatus Peters, 1862	little red flying-fox
Macroglossus minimus nanus Matschie, 1899	northern blossom bat
Megadermatidae	
Macroderma gigas (Dobson, 1880)	ghost bat
Hipposideridae	
Hipposideros ater gilberti Johnson, 1959	western dusky leaf-nosed bat
Hipposideros stenotis Thomas, 1913	northern leaf-nosed bat
Rhinonicteris aurantia (Gray, 1845)	orange leaf-nosed bat
Rhinonicteris aurantia (Gray, 1845) Pilbara form	Pilbara leaf-nosed bat
Emballonuridae	
Taphozous georgianus Thomas, 1915	common sheath-tailed bat
Taphozous hilli Kitchener, 1980	Hill's sheath-tailed bat
**Taphozous kapalgensis* McKean and Friend, 1979	Arnhem sheath-tailed bat
Saccolaimus flaviventris (Peters, 1867)	yellow-bellied sheath-tailed bat
Molossidae	
Tadarida australis (Gray, 1838)	white-striped free-tailed bat
Chaerephon jobensis colonicus (Thomas, 1906)	northern free-tailed bat
Mormopterus beccarii astrolabiensis Meyer, 1899	Beccari's free-tailed bat
Mormopterus loriae cobourgiana Johnson, 1959	western little free-tailed bat
Mormopterus sp. (form sp. 3 in Adams *et al.* 1988)	inland free-tailed bat
Mormopterus sp. (form sp. 4 (O) in Adams *et al.* 1988)	south-western free-tailed bat
Miniopteridae	
Miniopterus oceanensis orianae Thomas, 1922	northern bent-winged bat
Vespertilionidae	
Chalinolobus gouldii (Gray, 1841)	Gould's wattled bat
Chalinolobus morio (Gray, 1841)	chocolate wattled bat
Chalinolobus nigrogriseus nigrogriseus (Gould, 1852)	hoary wattled bat
Falsistrellus mackenziei Kitchener, Caputi and Jones, 1986	western false pipistrelle
Myotis macropus (Gould, 1855)	large-footed myotis
Nyctophilus arnhemensis Johnson, 1959	northern long-eared bat
Nyctophilus daedalus Thomas, 1915	pallid long-eared bat
Nyctophilus geoffroyi geoffroyi Leach, 1821	lesser long-eared bat
Nyctophilus gouldi Tomes, 1858	Gould's long-eared bat
Nyctophilus major major Gray, 1844	western greater long-eared bat
Nyctophilus major tor Parnaby, 2009	central greater long-eared bat
Nyctophilus walkeri Thomas, 1892	pygmy long-eared bat
**Pipistrellus adamsi* Kitchener, Caputi and Jones, 1986	forest pipistrelle
Pipistrellus westralis Koopman, 1984	northern pipistrelle
Scotorepens balstoni balstoni (Thomas, 1906)	inland broad-nosed bat
Scotorepens greyii (Gray, 1843)	little broad-nosed bat
Scotorepens sanborni (Troughton, 1937)	northern broad-nosed bat
Vespadelus baverstocki (Kitchener, Jones and Caputi, 1987)	inland forest bat
Vespadelus caurinus (Thomas, 1914)	northern cave bat
Vespadelus douglasorum (Kitchener, 1976)	yellow-lipped cave bat
Vespadelus finlaysoni (Kitchener, Jones and Caputi, 1987)	Finlayson's cave bat
Vespadelus regulus (Thomas, 1906)	southern forest bat

includes several categories (Table 3). If listed species are observed on a site planned for development, the DEC will generally recommend that proponents undertake specific management activities to reduce impacts. This system ensures that species such as *M. gigas* are considered as part of a company's commitments when mining commences, and which has resulted in at least two long term monitoring programmes.

In the past decade, much attention has been given to two species – *M. gigas* and *R. aurantia*, mainly because their habitats coincide with mining resource interests, which have boomed in that time. Both species have been the subject of numerous consultative survey and monitoring projects by the author, and much new information collected as part of these has helped proponents address the issue of their presence (K.N. Armstrong unpublished

Table 2. Some of the taxonomic or nomenclatural issues in WA bats.

Taxon	Comment
Chalinolobus morio	The distribution of *morio* includes two isolated populations (one in the Pilbara, and the other in central Australia) and also includes cave- and tree-dwelling groups. The distinctness of geographic isolates and ecological types has not received attention.
Hipposideros ater gilberti	Disjunct populations in Australia have not been examined genetically, and there is a possibility that extralimital subspecies are distinct at species level, given that the type locality of *ater* is in Sri Lanka.
Hipposideros stenotis	Disjunct populations in the Kimberley and Northern Territory have not been examined rigorously; relationships within the *cyclops* group of *Hipposideros* not examined genetically.
Macroderma gigas	Distinctness of the Pilbara population is being evaluated using microsatellites and mitochondrial DNA markers by K.N. Armstrong.
Mormopterus sp. 3	Currently in revision.
Mormopterus sp. 4 (pop. O)	Currently in revision.
Mormopterus beccarii	Currently in revision.
Mormopterus loriae cobourgiana	Currently in revision.
Miniopterus schreibersii orianae	Further work is required to confirm the subspecies status following on from Cardinal and Christidis (2000), species status and correct specific epithet (*blepotis, oceanensis, orianae*) dependent on studies on representatives with extralimital distributions.
Rhinonicteris aurantia	Distinctness of Pilbara population being evaluated using microsatellites and mitochondrial DNA markers by K.N. Armstrong.
Vespadelus aff. *douglasorum*	Potential new species; no males available for comparisons of baculum and glans, all tissue available fixed in formalin and not suitable for traditional molecular analysis (McKenzie 1999; Armstrong and Kitchener 2008).
Vespadelus finlaysoni	Morphometric distinctness of a geographic group in the Carnarvon Basin / Cape Range area, relative to remaining geographically defined groups (Kitchener *et al.* 1987) has not been examined in detail.
Vespadelus regulus	Likely to be split into two species, with the boundary near Adelaide. Nomenclature of the Western Australian species will remain unchanged given the type locality is near Albany.

Table 3. Conservation status under various State, Commonwealth legislation and international schemes. Note that nomenclature varies slightly in the listings.

Species	DEC[1]	WA[2]	EPBC[3]	IUCN[4]
Orange leaf-nosed bat *Rhinonicteris aurantia* (northern form)	VU	S1	—	LC
Pilbara leaf-nosed bat *Rhinonicteris aurantia* (Pilbara form)	VU	S1	VU	LC
Ghost bat *Macroderma gigas*	P4	—	—	VU C1
Western false pipistrelle *Falsistrellus mackenziei*	P4	—	—	NT
Central greater long-eared bat *Nyctophilus major tor* (still listed as *Nyctophilus timoriensis* (central form) by DEC and *Nyctophilus timoriensis* by the IUCN 2010)	P4	—	—	DD
Northern leaf-nosed bat *Hipposideros stenotis*	P2	—	—	LC
Western little free-tailed bat *Mormopterus loriae cobourgiana* (listed as Little North-western Mastiff Bat by DEC)	P1	—	—	LC
Yellow-lipped cave bat *Vespadelus douglasorum*	P2	—	—	LC

[1] Western Australian Department of Environment and Conservation's Priority Fauna List (current as of 13 July 2010). Priority codes of relevance include: Priority 1—taxa with few, poorly known populations on threatened lands; Priority 2—taxa with few, poorly known populations on conservation lands; Priority 4—taxa in need of monitoring; Available for download at URL: http://www.dec.wa.gov.au under "Listing of species and ecological communities".
[2] Western Australian *Wildlife Conservation (Specially Protected Fauna) Notice 2010* (current as of 23 February 2010). Categories of relevance include: Schedule 1 (abbreviated to S1 in the table): Fauna that is rare or is likely to become extinct. Available for download at URL: http://www.dec.wa.gov.au under "Listing of species and ecological communities".
[3] Australian Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Threatened categories of relevance include: VU: Vulnerable.
[4] International Union for Conservation of Nature Red List status (IUCN 2010). Categories of relevance include: DD: Data Deficient; NT: Near Threatened; LC: Least Concern; VU: Vulnerable. Previous listings are available in each species profile; see http://www.iucnredlist.org for definition of subcategory VU C1.

data and manuscripts in prep.). In addition to records from consultative environmental assessments, the Pilbara Biological Survey produced 11 new records of *R. aurantia* from echolocation recordings of bats in flight (McKenzie and Bullen 2009). However, despite such efforts over several years, neither series of surveys have confirmed a new roost site, much less a colony of significant size. The majority of the known population is aggregated in relatively few disused mines in the eastern Pilbara and caves in Barlee Range Nature Reserve (Armstrong 2001; DEWHA 2010a). A conclusion of McKenzie and Bullen (2009) was that both *R. aurantia* and *M. gigas* were more common than previously thought. The new records of *R. aurantia* detected in flight obviously indicate the presence of other colonies, but these might derive from either small transitory aggregations, or stable colonies that contribute significant abundance to the known population. Resolution of whether these observations equate to a higher than previously recognised abundance, or whether they simply present a better resolved area of occupancy within the region will rely on the application of a rigorous method to determine daytime occupancy (e.g. DEWHA 2010a,b).

Knowledge of other species listed in Table 3 remains basic, since they have not been the subject of recent targeted research. Information on these species has been collected opportunistically in the past, which is summarised in compilations such as the 'Action Plan for Australian Bats' (Duncan *et al.* 1999) and the various editions of 'Mammals of Australia' (Van Dyck and Strahan 2008).

3. Distributions and patterns of diversity

Information on the distributions of WA bats is available from four main sources: 1) the most recent issues of authoritative guides such as 'Mammals of Australia' (Van Dyck and Strahan 2008) and 'Australian Bats' (Churchill 2008); 2) the NatureMap online resource maintained by the Department of Conservation and Environment (DEC) and the Western Australian Museum (WAM), which provides plotted locations of specimens held in the WAM and records contained in species databases held by the DEC (DEC 2007–); 3) a tabulated summary of a database from Burbidge *et al.* (2007) that associated each mammal species in Australia with regions defined under the Interim Biogeographic Regionalisation of Australia (IBRA) (DEWHA 2010c); and 4) a digital Geographic Information Systems (GIS) coverage that includes polygons representing the distribution of the world's mammals, as compiled and edited by experts during the IUCN Global Mammal Assessment held in Adelaide in August 2005 (IUCN 2010). The information in each of these differs slightly, as demonstrated below, so it is important that information relating to species occurrence is determined from more than one source.

The landscapes across Western Australia are diverse, ranging from mesic in the south, to xeric in the interior, to arid-tropical and monsoonal in the north. Consequently, the composition and diversity of chiropteran assemblages varies widely across the state according to the availability of roosts with suitable microclimates and structure, the productivity of the landscape, the diversity of regional habitats, the influence of coastal habitats and Australia's biogeographical history involving the invasion of tropical elements and their subsequent adaptation, diversification and penetration of the continent. A brief summary of the pattern of bat diversity is provided based on a simple overlay analysis of the distribution of each species with the major habitats represented in WA.

Western Australia can be divided into 26 biogeographic regions according to the IBRA version 6.1, which is based on vegetation communities and land systems (DEWHA 2010c). The species richness of the assemblage in each region was determined by firstly overlaying in ArcView 3.2 a digital coverage of the IBRA 6.1 (those parts within the WA state boundary only) with a coverage that included the distribution of the world's bats (IUCN 2010), and then checking the tallies for each region against a summary derived from Burbidge *et al.* (2007) (Table 4; Figure 1). A 'heat map' was produced based on data from the digital GIS overlay only, with the intention of illustrating broad patterns of bat richness based on regional landscape-scale habitats (Figure 2). Correction was not made for the areas of overlap between *Mormopterus* species 3 and 4 (included as one range '*Mormopterus planiceps*') in Figure 2, but it was corrected for in Table 4 and Figure 1. There are three main patterns. Relatively low bat diversity (maximum of 10 species in the Jarrah Forest bioregion) is apparent from the southern portion of the State, and a similar pattern is apparent throughout much of the interior. The Pilbara, Gascoyne, Carnarvon Basin and Great Sandy Desert bioregions have moderate richness of between 10 and 18 species, with the greatest diversity in this area along the Pilbara coast. The Kimberley has the highest richness of bats, with a minimum of 17 species along its southern edge, and up to 24 species in the coastal and high rainfall areas of the north-west of the region.

The patterns correspond reasonably well with previously defined Zoogeographic subregions or biomes of Australia (e.g. Heatwole 1987; Olsen *et al.* 2001), as well as the general relationship amongst IBRA bioregions based on similarities in their mammalian species composition (Burbidge *et al.* 2007). The Kimberley region contains the Timorian elements that occupy tropical and subtropical savannas, grasslands and shrublands, and which have been influenced by invasions of elements from the tropical northern areas of New Guinea and beyond. The richness of this region is enhanced by species that are found predominantly or exclusively in mangal and other coastal habitats in the north-western areas receiving the highest rainfall. The arid Eyrean region with its deserts and xeric shrublands contains arid-adapted species that roost in trees or the relatively uncommon caves in the low rocky areas. The Pilbara region is represented by a relatively high richness for this biome, because of tropical relicts such as *M. gigas* and *R. aurantia*, and the influence of coastal habitats that have had past connections to the northern biome. The more mesic South-western subregion (semi-arid Eyrean in Burbidge *et al.* 2007) that provides Mediterranean forests, woodlands and scrub has a relatively low diversity compared to Pilbara and Kimberley regions, but higher diversity than some parts

Table 4. Summary of the occurrence of each of the 37 species of bat in the IBRA bioregions with confirmed records, with an additional two species that have distributions with boundaries near the edge of the Western Australian – Northern Territory borders. Full names of IBRA codes in Figure 1. 'Count' refers to the number of regions a species occurs in, thus giving an indication of how widespread it is. Explanation of symbols at bottom of table.

Species	AW	CAR	CK	COO	CR	DL	ESP	GAS	GD	GS	GSD	GVD	HAM	JF	LSD	MAL	MUR	NK	NUL	OVP	PIL	SWA	TAN	VB	WAR	YAL	**Count**
Pteropodidae																											
Macroglossus minimus			✧			●												●						○			3
Pteropus alecto		●	●			●		●			✧							●		●	●			●			8
Pteropus scapulatus		●	●			●		●		✧	●							●		●	●		○	●		✧	10
Megadermatidae																											
Macroderma gigas			●		EX	●		SD	EX		EX				EX		EX	●		●	●			●			7
Hipposideridae																											
Hipposideros ater			●			●												●		●				●			5
Hipposideros stenotis			✧			✧												●		✧				●			2
Rhinonicteris aurantia		✧	●			●		●			✧							●		●	●			●			7
Emballonuridae																											
Saccolaimus flaviventris		●	●		✧	●		●	✧		●	✧			●		✧	●		●	●		●	●			11
Taphozous georgianus		●	●			●		●			✧				●		✧	●		●	●			●			9
Taphozous hilli		✧			●			●	●		●	✧			✧		●				●		●			●	8
Taphozous kapalgensis																				✧				✧			0
Molossidae																											
Chaerephon jobensis		●	●			●		●			✧				✧		✧	●		●	●		✧	●			8
Mormopterus beccarii		●	●		✧	●		●	●		●				●		✧	●		●	●		✧	●			11
Mormopterus loriae		●				●															●						3
Mormopterus sp. 3	●			●	●				✧	○	○	●		○		✧	●		✧							✧	8
Mormopterus sp. 4	●			●			✧			✧				●		●						●			●		6
Tadarida australis	●	●	✧	●	●	✧	●	●	●	●	●	●	●	●	●	●	●		●	✧	●	●	●		●	●	21
Miniopteridae																											
Miniopterus oceanensis			●			●												●		●				●			5

Table 4. (Con't) Summary of the occurrence of each of the 37 species of bat in the IBRA bioregions with confirmed records, with an additional two species that have distributions with boundaries near the edge of the Western Australian – Northern Territory borders. Full names of IBRA codes in Figure 1. 'Count' refers to the number of regions a species occurs in, thus giving an indication of how widespread it is. Explanation of symbols at bottom of table.

Species	AW	CAR	CK	COO	CR	DL	ESP	GAS	GD	GS	GSD	GVD	HAM	JF	LSD	MAL	MUR	NK	NUL	OVP	PIL	SWA	TAN	VB	WAR	YAL	Count
Vespertilionidae																											
Chalinolobus gouldii	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	26
Chalinolobus morio	●			●			●			●		●	●	●		●	✧		●		●	●			●	✧	12
Chalinolobus nigrogriseus			●			●					✧							●		●				●			5
Falsistrellus mackenziei														●								●			●		3
Myotis macropus			✧			✧												●		●				●			3
Nyctophilus arnhemensis		●	●			●												●		●	●			●			7
Nyctophilus daedalus		✧	●			●		●										●		●	●			●			7
Nyctophilus geoffroyi	●	●	✧	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	25
Nyctophilus gouldi														●								●			●		3
Nyctophilus major	●			●			✧			✧			●	●		●	✧		●			●			●	✧	8
Nyctophilus walkeri																		●		○				●			3
Pipistrellus adamsi																								✧			0
Pipistrellus westralis			✧			●												●						●			3
Scotorepens balstoni	●	✧		●	●			●	●	●	●	●			✧	●	●		✧	✧	✧		✧			●	11
Scotorepens greyii		●	●			●		✧			✧				●			●		●	●		●	●			9
Scotorepens sanborni			✧			●								✧				●				✧		●			3
Vespadelus baverstocki	✧			●								●					●									✧	3
Vespadelus caurinus			●			●												●		●			○	●			6
Vespadelus douglasorum			●			●												●		●							4
Vespadelus finlaysoni		●			●	●		●	●	●	●	●			●		●			✧	●		✧			●	12
Vespadelus regulus	●			●			●						●	●		●			●			●			●		9
Total Richness by region	9	13	17	10	7	23	5	15	7	7	10	8	6	10	8	8	8	24	6	20	18	9	8	23	9	6	

●: records based on extent of occurrence from Burbidge *et al.* (2007) that were classified as "persists in >50% of its former range within the bioregion", and which are also included in the coverage of the distribution of the world's bats (IUCN 2010); ○: records from the database of Burbidge et al. (2007) but which are not included in the coverage by the IUCN (2010); ✧: records derived from the IUCN (2010) coverage but not Burbidge et al. (2007); EX: extinct in that bioregion, with no reasonable doubt that the last individual has died (Burbidge et al. 2007); SD: severe decline, extant within the bioregion but has declined by >90% of former range within the region (Burbidge et al. 2007).

of the arid interior. The lack of caves and relatively cool temperatures could exclude some species that require rocky subterranean roosting habitats and ambient temperatures that are physiologically favourable. Further comments and reviews are given in Merrick *et al.* (2006) and Burbidge *et al.* (2007).

The different limits on bat species distribution from each of the four sources considered in this review highlight that more than one should be consulted for information. The database of Burbidge *et al.* (2007) is updated from the first version produced for the National Land and Water Resources Biodiversity Audit (see McKenzie and Burbidge 2002 for comments on mammals) based on information compiled during the 2005 Australasian workshop of the IUCN's Global Mammal Assessment, but it is clear from Table 4 that there are many differences between this and the data coverage provided by the IUCN (2010). For some species such as *Pipistrellus adamsi* and *Taphozous kapalgensis*, occurrence in Western Australia is based on unpublished records at the margins of their distributions that are thought to just extend over the state boundary. These two species have not been included in the final tally for the state. Likewise, *Mormopterus eleryi* (previously *Mormopterus* sp. 6; see Reardon *et al.* 2008) is not included in the state tally, since the record placed by Burbidge *et al.* (2007) in the Great Sandy Desert bioregion is from a location within the Northern Territory. The exclusion of other species from particular bioregions highlights the difference between compiled museum and other observation records, and the broad distributions that are given in authoritative guides. The latter are derived from peer-reviewed compilations from the authors of species accounts, but it is recognised that the maps are a "crude indication of where a species may be found" (Van Dyck and Strahan 2008). However, an exclusive reliance on museum records is not advisable in most cases because collection data has biases based on the variable nature of specimen collection throughout a species true range, and also issues involving delays in the updating of specimen

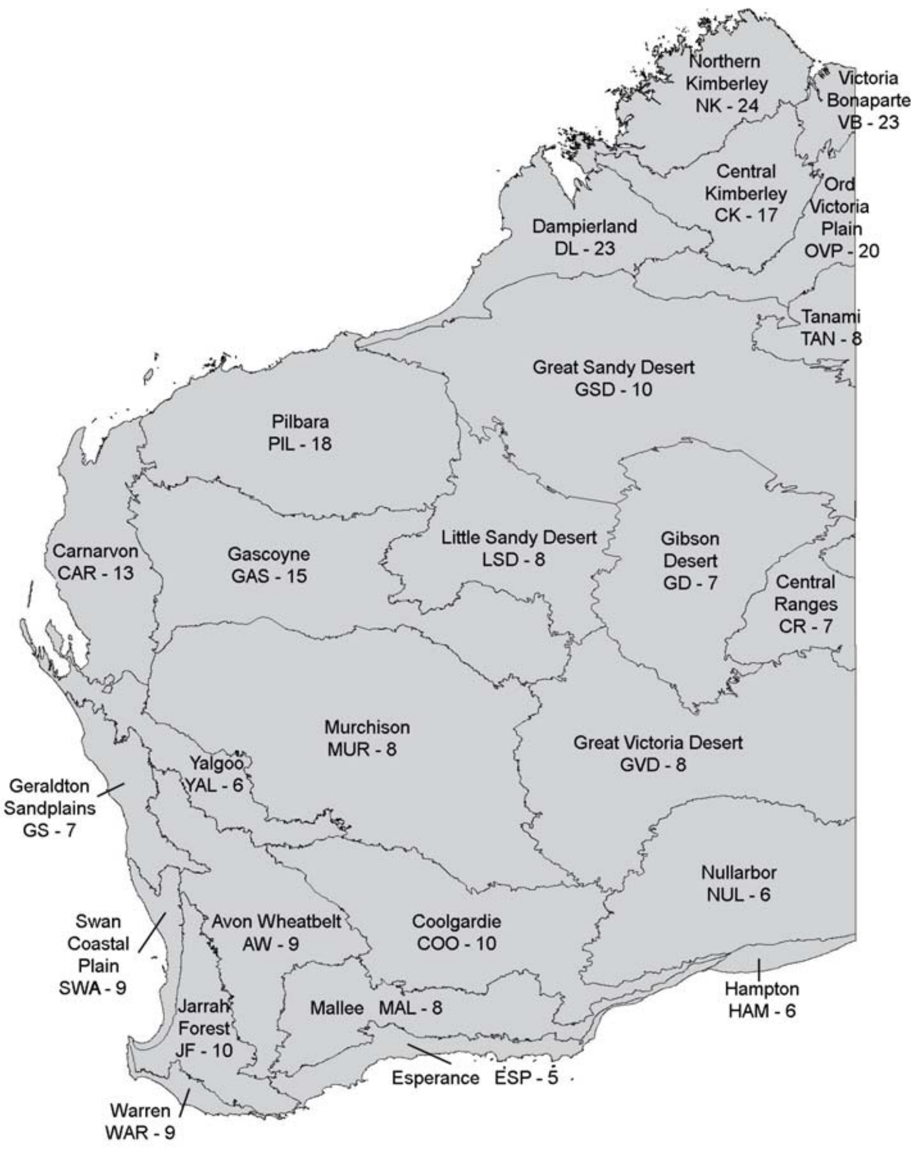

Figure 1. Summary of bat richness by IBRA region in Western Australia, with records derived from the database of Burbidge *et al.* (2007).

nomenclature, which might require extensive checking of specimens in addition to database modification. Distributions of mammals are subject to continual revision as further information becomes available from a variety of sources, or as changes occur in their habitats.

4. Recent trends in acoustic surveys for bats

Surveys for bats are conducted increasingly as part of environmental impact assessments in Western Australia. In part, this has occurred because of the convenience of using electronic bat detectors, and the improvements in their hardware and software technology that have been made in the past decade. In the past five years, acoustic surveys have been conducted through two main approaches: 1) using all components of the AnaBat system as supplied by the manufacturers (Titley Scientific), with identification facilitated by Zero Crossings Analysis (ZCA) of the frequency divided square wave output (hereafter termed 'AnaBat–ZCA'); and 2) by making a continuous recording of the output of an Anabat II detector via an external recording device (MiniDisc, digital recorder), with identifications made following analysis of the same frequency divided square wave signal by fast-Fourier Transformation ('AnaBat–FFT'). The latter approach was first described in a paper that reported a method for differentiating *Nyctophilus* species (Bullen and McKenzie 2002a), and further details followed in McKenzie and Bullen (2003), which presented a way of differentiating species pairs that had been difficult previously (see McKenzie and Muir 2000). A recent publication from the Pilbara Biological Survey used this method exclusively (McKenzie and Bullen 2009).

There is currently disagreement about whether the AnaBat–FFT approach brings important advantages over the more widely used AnaBat–ZCA approach, though an explicit empirical comparison, to determine if one can aid in the identification of a greater number of species than the other, has not been published. Given that not all mining proponents and environmental consultants will have a detailed technical understanding of either approach, it should be highlighted that both rely on the same microphone and frequency divided square wave signal, and the same measurements derived using FFT are also available in AnalookW software that provides output from ZCA (i.e. the frequency at which there is a peak

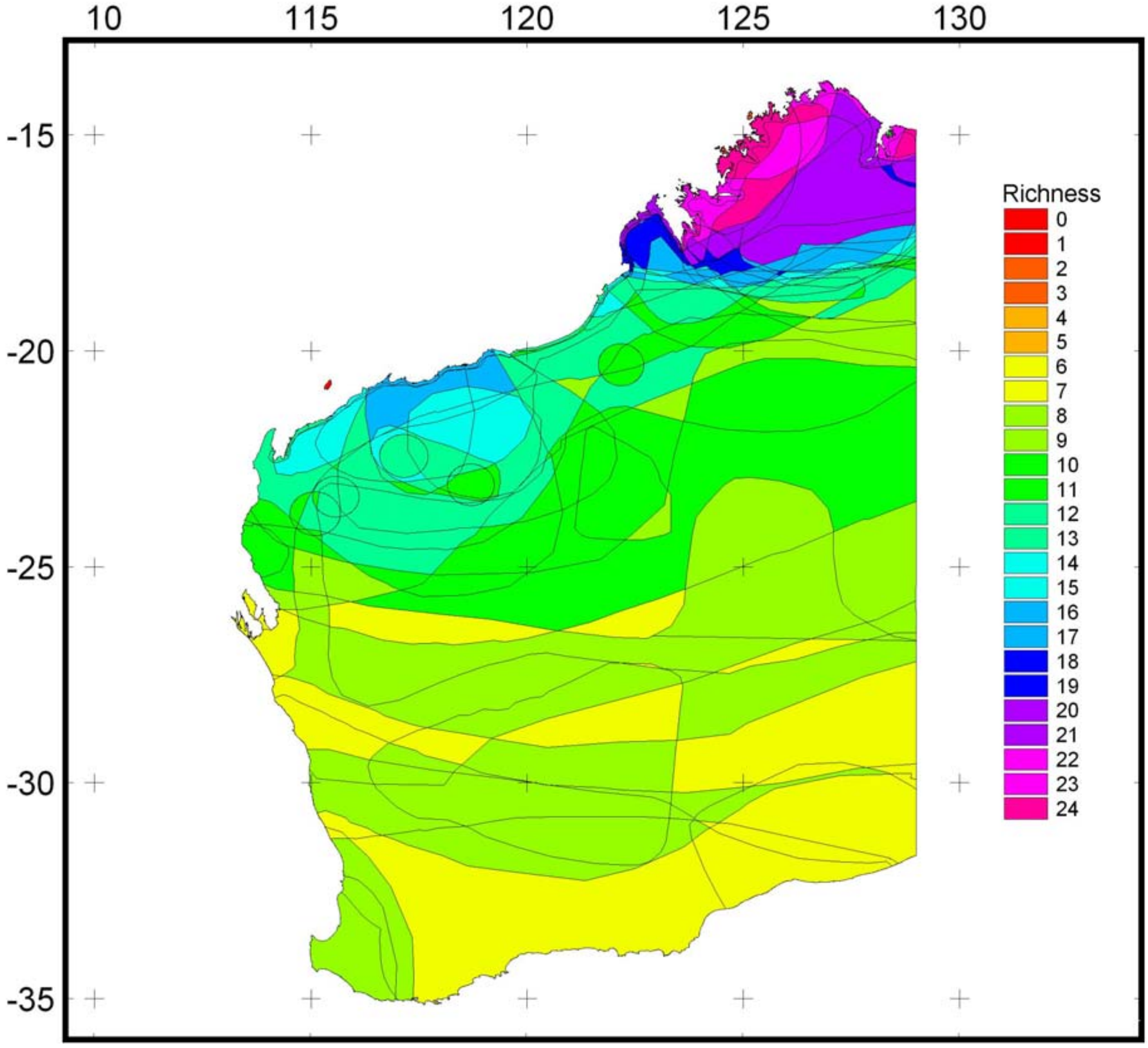

Figure 2. Representation of bat species richness across Western Australia, as derived from IUCN (2010).

number of cycles (F_{pz}), plus an equivalent derivation of Q-factor; Corben 2007). However, the AnaBat–FFT approach relies on Anabat II hardware, which is no longer manufactured, and there are several significant practical advantages of using the AnaBat–ZCA approach, most notably in terms of the efficiency of data storage and data analysis time (K.N. Armstrong pers. obs.). Both approaches have been mentioned in Western Australian guidelines for conducting terrestrial vertebrate fauna surveys for environmental impact assessments (DEC 2010 in press), though neither is recommended over the other. In the context of surveying for Threatened listed species, a recommended approach for surveying Pilbara *R. aurantia* was provided using the AnaBat–ZCA approach and other field techniques in the 'Survey guidelines for Australia's threatened bats' (DEWHA 2010b).

5. Summary of threats by region

Threats to bat species in Western Australia may be summarised according to region, since they are based on the predominant land uses within each.

Kimberley

The Kimberley region is relatively remote, though humans have an influence over large expanses through pastoralism and altered burning regimes (in addition to the uncontrolled wildfires started by lightning strikes) (EPA 2006), though these are not mentioned as direct threats to bats listed in categories of conservation significance (except as a general threat to *M. gigas*; McKenzie *et al.* 1999b). The potential for declines and extinction is not regarded as high in this region as elsewhere, but mining activity is increasing, and coincides with the occurrence of species of conservation significance in some cases (e.g. *H. stenotis, M. gigas* and *R. aurantia* on Koolan Island; McKenzie *et al.* 1995). These species are also sensitive to disturbances within their roosts (Duncan *et al.* 1999).

Pilbara

The Pilbara is Australia's largest and most active large-scale mining province, and the likelihood of the occurrence of *M. gigas* and *R. aurantia* within proposed mining infrastructure footprints is a regular issue. In addition, these two species occupy most of the largest disused (or seldom used) underground gold and copper mines and bulk sampling iron ore adits. Their presence is an issue for plans to open cut the site of historical workings because the largest regional aggregations are found in them (Hall *et al.* 1997; Armstrong and Anstee 2000; Armstrong 2001). The old mines are subject to disturbance from human entry, nearby exploration or evaluation drilling, nearby blasting from mining, flooding and collapse (McKenzie *et al.* 1999a; Armstrong 2001). The abundance of *M. gigas* might be affected significantly by entanglement in barbed wire fences (Armstrong and Anstee 2000), but in the last decade some mining companies have restricted the use of barbed wire to avoid local mortality from entanglements. The greatest impediment to the successful management of the Pilbara populations of *M. gigas* and *R. aurantia* is the lack of a comprehensive over-arching regional management plan because there appears to be no formal consideration of the possible effects from activities causing disturbance contemporaneously at several sites. None of the mines in the eastern Pilbara that contain most of the known population are subject to any formal monitoring or management, and it would therefore be prudent of the government land manager to consider a formal regional plan for protection of these species as a priority.

In addition to the issue involving cave roosting bats, *M. l. cobourgiana* is listed as a Priority species because its preferred habitat is the thin strip of mangal along the Pilbara and a small part of the Kimberley coast, some of which has been subject to clearance for port facilities in the past. The apparent absence of this species from most of the Kimberley coast (despite much survey effort) is mysterious and the possibility that future surveys will detect it is not only enticing, but would determine whether this species was as vulnerable as is considered currently.

Murchison and Goldfields

Most species in these regions are common, although *N. m. tor* is listed as a Priority species by the DEC. The low amplitude of its echolocation calls, as well as their similarity to calls produced by *N. geoffroyi*, may reduce its apparent representation in nightly echolocation recordings. This highlights the need to include trapping in addition to echolocation recordings in field surveys. Relatively few records of this subspecies exist, and too little of its ecology is known to be able to identify threats, though clearing of mallee and grazing may have led to a reduction in populations (McKenzie *et al.* 1999c). Some colonies of common species have formed local aggregations of significant size in disused adits (*Taphozous hilli* and *Vespadelus finlaysoni*), and may be subject to human disturbance or destruction from mining.

South-west

Forest habitat destruction and modification in this region derives from a range of land uses such as bauxite, coal and mineral sands mining, forestry, agriculture and viticulture, and urban development, as well as burning practices for management purposes. Forests are managed in the Department of Conservation and Environment's regions of Swan, South West and Warren through the 'Forest Management Plan 2004–2013' (Conservation Commission of Western Australia 2004), which gives figures for the area of land designated as national parks, nature reserves and conservation parks (1,264,100 ha), and state forests (including those planted with exotics) and timber reserves (1,216,400 ha). Knowledge of the effect of different land uses has not been studied in any detail, but a postgraduate study on the effects of logging is nearing completion (Webala *et al.* in press; Webala *et al.* submitted), and another on the effects of bauxite mining and the success of post-mining rehabilitation has just commenced. Windfarm proposals have also increased in recent years, although the data to conduct risk assessments on these is limited. The first commercial windfarm was established in 1993 at Ten Mile Lagoon near Esperance, and four others have been commissioned since that time (Albany, commissioned in October 2001; Nine Mile Beach near Esperance, commissioned in mid-2003; Emu Downs near Cervantes, commissioned in

October 2006; and Walkaway near Geraldton), with more beginning construction (e.g. Collgar near Merredin commenced construction in June 2010). Cave visitation and inappropriate gating are issues in some caves in the south-west (e.g. Quininup Lake Cave and others north of Perth, also Yanchep National Park; Armstrong *et al.* 2005; Susac 2007). The protection of cave fauna and habitats is advocated by groups such as the Speleologists Research Group of WA (SRGWA), and the WA Speleologists Group (WASG). Armstrong *et al.* (2005) highlighted that the occurrence of bat colonies in caves (*Chalinolobus morio* and/or *Vespadelus regulus*) was relatively low – only five caves in the entire south-west region (excluding the Nullarbor Plain) – and there is evidence of historical declines (mainly prior to the 1950's). While no cave-roosting bat species in this region is listed in a category of conservation significance, the occurrence of bats in south-west caves is uncommon and an ecological novelty. There is a need for a more formal and comprehensive plan for managing these south-west cave colonies.

6. Other knowledge gaps

One conspicuous absence from the literature on WA bats is a key to echolocation calls, but there have been regional surveys that have produced tabulated summaries of some pulse characteristics (Fullard *et al.* 1991; McKenzie and Muir 2000; McKenzie and Bullen 2009). These, together with keys that describe the bats of other regions in Australia (Milne 2002; Pennay *et al.* 2004) allow identification of most WA species. The unpublished work by P.W. Webala and C. Corben has also characterised the bats of south-western Australia.

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