The impact of urbanisation on the mammals of Melbourne – do atlas records tell the whole story or just some of the chapters?

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ABSTRACT

The impacts of urbanisation on the biodiversity of native plants and animals are typically deleterious and potentially profound. These consequences are likely to increase as the size of the human population and geographic extent of many urban areas continue to expand. Unfortunately, the absence of detailed "before development" data makes it difficult to accurately assess changes in species diversity or abundance over time. In this study, atlas data are used to investigate the impacts of urbanisation of the greater Melbourne area on the composition of the mammal community. The mammal community of Melbourne at the time of European settlement in 1856 was diverse, with 50 species recorded. A broad measure of change in distribution found that 16 species were recorded in fewer local government areas in the last 20 years than in the preceding years to 1856; the majority were small ground-dwelling mammals. The converse was true for the microchiropteran bats, with 14 species being recorded in more local government areas after 1980, probably a reflection of improved survey techniques. There was little to no relationship at the landscape scale between the presence of a species or species group and the amount of remnant vegetation or public open space within a 700 m radius of the survey point. This is probably because species that rely on tracts of native vegetation are unable to persist in the urban mosaic of greater Melbourne, while more generalist species are able to cope with the radical changes associated with urbanisation. This study has highlighted the need for surveys of mammal communities that are stratified across the urban landscape to document the conservation status of species and provide the foundation for future state of the environment reporting.

Key words: urbanisation, Melbourne, mammal, species decline, conservation status, atlas data, state of the environment reporting

Introduction

In 1975, approximately one-third of the world's human population lived in urban areas (World Resources Institute 1996). By 2025, this proportion is expected to reach two-thirds, as the number, size and extent of human settlements continue to increase (World Resources Institute 1996). This trend is also apparent in Australia, with Melbourne, the capital city of the State of Victoria, expected to increase its current human population of 3.5 million inhabitants (73% of the population of Victoria) (Department of Infrastructure 2002), to 4 million by 2021 (State of Victoria 2000). The impacts of this urbanisation on biodiversity are potentially profound as natural habitats are replaced with human-dominated landscapes. However, the detailed information on the distribution and abundance of many species of plants and animals required to demonstrate change in conservation status is often lacking. This information is an important pre-requisite to sustaining native biota in the current urban system as well as in the creation of new, expanded or intensified urban centres.

The absence of long-term or before-and-after data sets may be overcome if records of plant or animal sightings have been collated and stored in herbaria, museums or atlas databases (e.g. McCarthy 1998; Pergams and Nyberg 2001; Telfer *et al.* 2002). These databases contain variable amounts of data, but usually at least include the species, when it was seen or collected, and location. The major limitations in utilising such databases to infer change in conservation status are that the abundance of a species may not have been recorded and that survey effort is unlikely to have been constant over time or among species. Furthermore, the absence of a species from a point in the landscape may not reflect a true absence, but could rather be explained by a false negative observation or lack of survey effort at that point. Nevertheless, variation in the recording rate over time may provide sufficient information to infer indicative trends in the range and abundance of species or species groups, thus allowing potential at-risk species to be identified.

The development and urbanisation of parts of Australia has been relatively rapid since the initial settlement by Europeans in 1788. Approximately one-third of all mammal extinctions worldwide since the year 1600 have occurred in Australia (Maxwell *et al.* 1996). This has been largely attributed to a combination of factors that include the introduction of non-indigenous predators (e.g. feral cat *Felis catus*, red fox *Vulpes vulpes*) and herbivores (e.g. rabbits *Orytolagus cuniculus*), altered fire regimes and habitat clearing (Recher and Lim 1990). Greater Melbourne,

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located in southeastern Australia, was established by Europeans in 1835 (Harvey 1982) and presently contains approximately 3.5 million human inhabitants (Department of Infrastructure 2002) spread over approximately 4000 km^2. The impact of this urbanisation on each species of mammal is not clear, as an overall review of their status within the Melbourne area has not been attempted since Seebeck (1977). In this study, I utilised a database of mammal sightings (Atlas of Victorian Wildlife, AVW) to assess the impacts of urbanisation on mammals in the Melbourne area. The specific questions were:

1) What is the extent of records of mammals within Greater Melbourne contained within the database?
2) Can broad changes in the distribution of species or species groups be identified?
3) Is there any relationship between the present-day composition of the mammal community and broad patterns in the extent of remnant vegetation and public open space adjacent to each animal record?

Methods

Study Area

The study area for this research (hereafter referred to as Greater Melbourne) extends in a radius of approximately 40–60 km from the centre of Melbourne, as defined by Leary and McDonnell (2001). Greater Melbourne covers approximately 3930 km^2 and encompasses 31 Local Government Areas (LGA) (Fig. 1). A proportion of some LGAs on the perimeter of the Study Area were excluded as they were predominantly rural (Leary and McDonnell 2001). A subset of the Greater Melbourne Study Area was used to examine relationships between various aspects of the composition of the mammal community and landscape habitat variables. This subset area (Fig. 1) was defined by the availability of remnant vegetation and public open space geospatial databases and included 19 LGAs that covered 113 km^2.

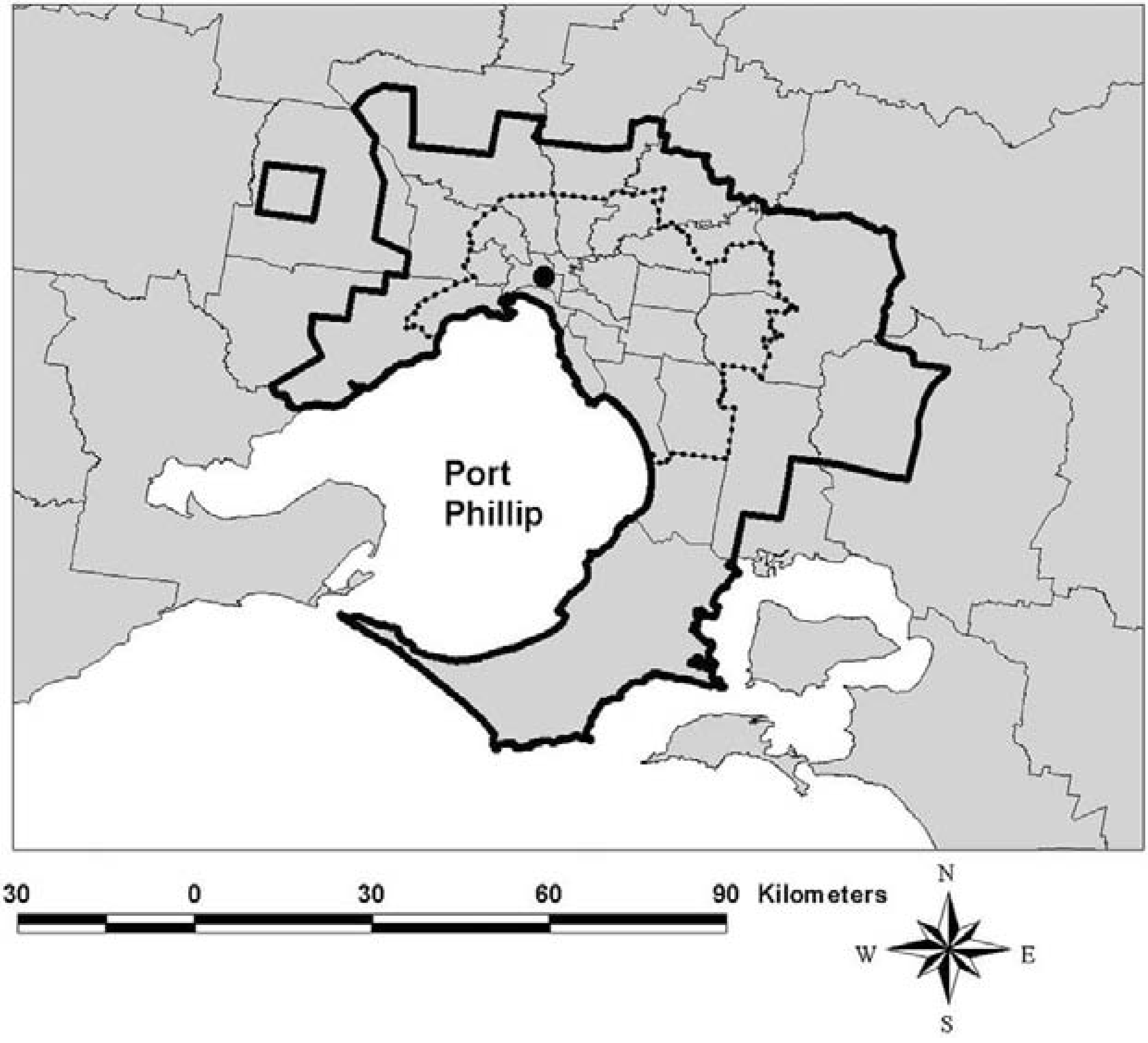

Figure 1. Location of the Study Areas around the central business district of Melbourne (solid black dot), southeastern Australia. The boundary of Local Government Areas is delineated by thin solid line. The Greater Melbourne Study Area is denoted by a thick solid line, with subset area denoted by dotted line.

Mammal records

Records of mammals within Greater Melbourne were extracted from the AVW (Department of Natural Resources and Environment) in October 2001. The AVW is co-ordinated by the State Government of Victoria and is a database of animal sightings within Victoria. Sightings are submitted by people with varying levels of expertise, ranging from qualified biologists to members of the general public. Records may be collected during formal fauna surveys or by incidental sightings. Consequently, the amount of data attached to each record varies, but must include species, date and location for it to be accepted. The location of each sighting is recorded in the database at the highest possible resolution, down to an accuracy of 100 m. Records where the species or date was missing or tentative (e.g. identified only to genus level) were deleted from the data set before analysis. Other records were deleted if they were of marine species, duplicate records, or if the location was obviously incorrect (e.g. terrestrial species occurring in marine environments).

Analyses

Each species of indigenous mammal within the AVW was placed *a priori* into one of seven functional groups based on body size, diet and ecological niche. The groups were defined as follows: 1) arboreal species are those defined as having a primarily arboreal lifestyle; 2) macropods are large, relatively mobile terrestrial species belonging to the family macropodidae; 3) small ground-dwelling mammals weigh less than 5500 g and spend a large proportion of their time on the ground; 4) microchiroptera are the insectivorous bats; 5) megachiroptera are flying-foxes; 6) aquatic species are closely associated with water courses; and 7) the wombat did not fit in any other category (Table 1) . All records were assigned to a year of observation and imported into ARCVIEW. The number of records and year of first and most recent record were calculated for each species. Atlas databases contain many potential biases that may limit the types of analysis that can be undertaken. For example, survey effort may vary spatially and temporally due to such variables as improved survey techniques, observer expertise or level of interest. To compensate for such variation, I assessed broad changes in the distribution of a species by comparing the number of LGAs each species was recorded in the years prior to 1980 (i.e. 1850–1979) to the number of LGAs post 1980 (1980–October 2001). This conservative approach increases the likelihood that interpreted declines are real.

Records from the AVW were assigned to the nearest 1-minute latitude and 1-minute longitude grid (hereafter referred to as grid cells) for analysis of the relationships between landscape variables and composition of the mammal community. Using ARCVIEW, the amount of remnant vegetation (VEG) and public open space (OS) within 700 m of the mid-point of each grid cell were calculated. A radius of 700 m was used because it provided a buffer of greater than 350 m between adjacent polygons. For this analysis, the composition of the present-day mammal community was based on post-1980 records to increase the likelihood that species distributions were current. To compensate for variation in survey effort among grid cells, mammal data were converted to a presence or absence value. Logistic regression (Hosmer and Lemeshow 1989) modelling was used to estimate the probability of occurrence of each species group at a grid cell as a function of the amount of remnant vegetation and public open space. Logistic regression analysis was undertaken in SPSS (Version 11) and both variables (VEG and OS) were entered into the model together.

Results

Number of species and records

A total of 12151 records of 65 species of mammal (50 indigenous, 15 introduced) was recorded in the AVW within Greater Melbourne from 1850–October 2001. Of these records, 9071 (75%) were of indigenous species. The number of records per species (Table 1) varied from 1 (Eastern Broad-nosed Bat *Scotorepens balstoni*) to 1646 records (Common Ringtail Possum *Pseudocheirus peregrinus*). The most widespread species was the Common Brushtail Possum *Trichosurus vulpecula*, which was recorded in all 31 LGAs. The White-footed Dunnart *Sminthopsis leucopus*, Tasmanian Bettong *Bettongia gaimardi*, Eastern Broad-nosed Bat, Leadbeater's Possum *Gymnobelideus leadbeateri*, and the Mormopterus sp. *Mormopterus planiceps* were the most restricted, with each occurring in a single LGA (Table 1).

The reporting rate (based on date of observation) varied considerably over time (Fig. 2), from zero in many of the years prior to 1940 to a maximum of 1457 in 1988, with the majority (67.7%) being collected between 1980 and 2001. The number of records for Greater Melbourne since 1988 has declined to approximately 200–300 per year (Fig. 2).

Changes in the composition of the mammal community

Sixteen species of indigenous mammals were recorded in fewer LGAs from 1980 – 2001 than during the time period 1850–1979 (Fig. 3). The three species that experienced the greatest range reduction were the Eastern Quoll *Dasyurus viverrinus*, Southern Brown Bandicoot *Isoodon obesulus* and Echidna *Tachyglossus aculeatus*, being recorded in 8, 7 and 6 fewer LGAs, respectively, in the 20 years after 1980 than in the years prior to 1980. Four species (Bush Rat *Rattus fuscipes*, Dusky Antechinus *Antechinus swainsonii*, White-footed Dunnart and Common Bent-wing Bat *Miniopterus schreibersii*) were recorded in the same number of LGAs before and after 1980. The remaining 30 species were recorded in more LGAs since 1980 than before, with the Water Rat *Hydromys chrysogaster*, Grey-headed Flying-fox *Pteropus poliocephalus*, Southern Forest Bat *Vespadelus regulus*, White-striped Freetail Bat *Tadarida australis* and Little Forest Bat *Vespadelus vulturnus* being recorded in an additional 11 – 19 LGAs (Fig. 3).

The proportion of species with changed distributions was not distributed equally across the functional groups. For example, 14 out of 16 species of microchiroptera were recorded in more LGAs since 1980, with the remaining two species recorded in either the same number of LGAs or one fewer. Conversely, 8 of 17 species of small ground-dwelling mammals were recorded in fewer LGAs since 1980, with three species experiencing no change, and

Table 1. The species of indigenous mammals recorded from the Greater Melbourne area, 1850 – 2001, in the Atlas of Victorian Wildlife. Functional group is based on body size, diet and ecological niche (refer text for definition). Status refers to the official threat of extinction within Victoria assigned by NRE (2000). Ext refers to extinct in Victoria; C. End critically endangered; End endangered; Vul vulnerable; LR lower risk – near threatened; and DD data deficient. LGA is Local Government Area.

Functional group	Species		Status	Number of LGAs	Total number of records
Arboreal	Common Ringtail Possum	*Pseudocheirus peregrinus*		29	1646
	Common Brushtail Possum	*Trichosurus vulpecula*		31	1288
	Mountain Brushtail Possum	*Trichosurus caninus*		4	34
	Sugar Glider	*Petaurus breviceps*		17	443
	Yellow-bellied Glider	*Petaurus australis*		4	45
	Eastern Pygmy-possum	*Cercartetus nanus*		7	12
	Feathertail Glider	*Acrobates pygmaeus*		13	96
	Greater Glider	*Petauroides volans*		3	44
	Koala	*Phascolarctos cinereus*		20	390
	Leadbeater's Possum	*Gymnobelideus leadbeateri*	End	1	6
Macropod	Black Wallaby	*Wallabia bicolor*		17	399
	Eastern Grey Kangaroo	*Macropus giganteus*		19	279
Small ground-dwelling mammals	Broad-toothed Rat	*Mastocomys fuscus*	LR	4	29
	Agile Antechinus	*Antechinus agilis*		11	488
	Brush-tailed Phascogale	*Phascogale tapoatafa*	Vul	3	53
	Bush Rat	*Rattus fuscipes*		10	380
	Common Dunnart	*Sminthopsis murina*	DD	3	12
	Dusky Antechinus	*Antechinus swainsonii*		5	175
	Eastern Barred Bandicoot	*Perameles gunnii*	C. End	4	9
	Eastern Quoll	*Dasyurus viverrinus*	Ext	8	21
	Echidna	*Tachyglossus aculeatus*		26	382
	Fat-tailed Dunnart	*Sminthopsis crassicaudata*	DD	6	30
	Long-nosed Bandicoot	*Perameles nasuta*		11	57
	New Holland Mouse	*Pseudomys novaehollandiae*	C. End	3	29
	Southern Brown Bandicoot	*Isoodon obesulus*		14	143
	Spot-tailed Quoll	*Dasyurus maculatus*	End	6	9
	Swamp Rat	*Rattus lutreolus*		9	285
	Tasmanian Bettong	*Bettongia gaimardi*	Ext	1	2
	White-footed Dunnart	*Sminthopsis leucopus*		1	30
Microchiroptera	Chocolate Wattled Bat	*Chalinolobus morio*		16	95
	Gould's Wattled Bat	*Chalinolobus gouldii*		25	370
	Common Bent-wing Bat	*Miniopterus schreibersii*		7	23
	Eastern Broad-nosed Bat	*Scotorepens orion*		4	8
	Inland Broad-nosed Bat	*Scotorepens balstoni*		1	1
	Eastern False Pipistrelle	*Falsistrellus tasmaniensis*		3	6
	Gould's Long-eared Bat	*Nyctophilus gouldi*		5	5
	Lesser Long-eared Bat	*Nyctophilus geoffroyi*		22	272
	Large Forest Bat	*Vespadelus darlingtoni*		18	125
	Southern Forest Bat	*Vespadelus regulus*		16	52
	Little Forest Bat	*Vespadelus vulturnus*		21	243
	Large-footed Myotis	*Myotis macropus*		3	4
	Mormopterus sp. (eastern form)	*Mormopterus sp.*		4	6
	Mormopterus sp. (long penis)	*Mormopterus planiceps*		1	1
	White-striped Freetail Bat	*Tadarida australis*		26	161
	Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*	Vul	6	7
Megachiroptera	Grey-headed Flying-fox	*Pteropus poliocephalus*	Vul	23	157
	Little Red Flying-fox	*Pteropus scapulatus*		2	2
Wombat	Common Wombat	*Vombatus ursinus*		15	179
Aquatic	Platypus	*Ornithorhynchus anatinus*		23	391
	Water Rat	*Hydromys chrysogaster*		27	147

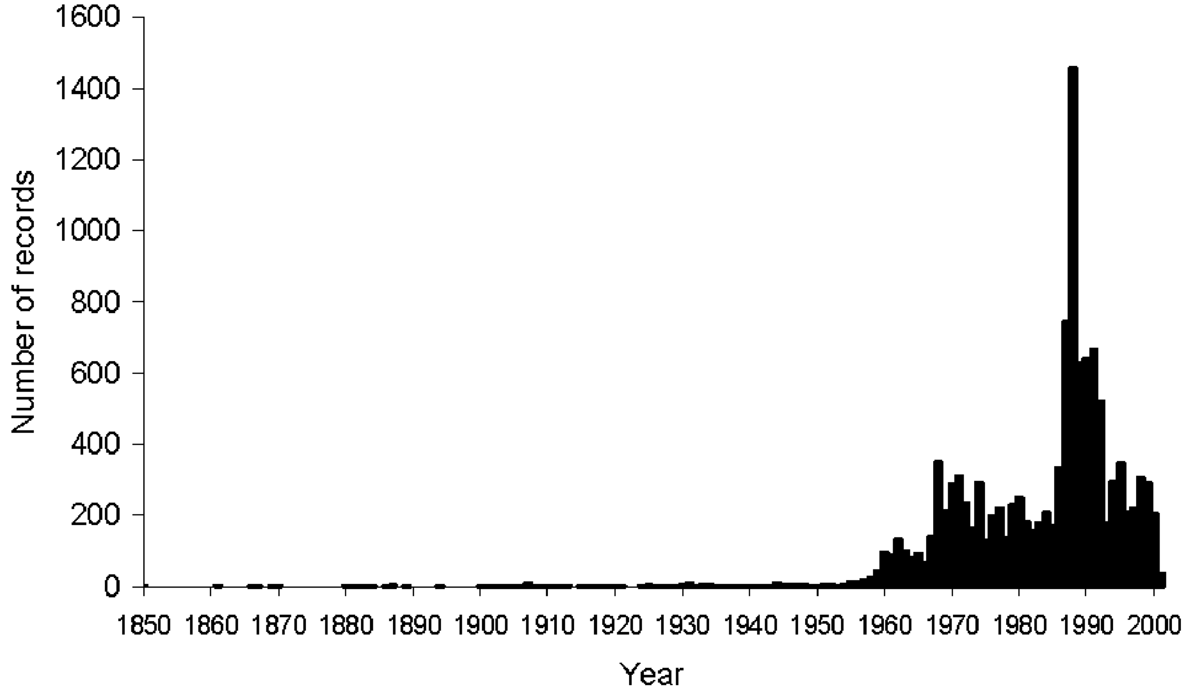

Figure 2. The temporal distribution of records of indigenous and introduced mammals in Melbourne Study Area (total records = 12,151)

six being detected in more LGAs. However, the greatest increase in the number of LGAs in which a species of small ground-dwelling mammal was recorded after 1980 was just two for three species (Broad-toothed Rat *Mastocomys fuscus*, Agile Antechinus *Antechinus agilis*, and Common Dunnart *Sminthopsis murina*). Arboreal marsupials were generally recorded in more LGAs after 1980 (7 out of 10 species recorded in 1–2 more LGAs). The two species closely associated with water bodies appear to have responded very differently, with the Platypus *Ornithorhynchus anatinus* being recorded in one less LGA and Water Rat recorded in 13 more LGAs. Of the two macropods, the Black Wallaby *Wallabia bicolor* was recorded in two more LGAs while the Eastern Grey Kangaroo *Macropus giganteus* was recorded in one fewer LGA. The Wombat *Vombatus ursinus* was recorded in one LGA fewer in the years after 1980.

Influence of remnant vegetation and public open space on the presence of indigenous mammals.

Indigenous mammals were recorded at 237 of the 421 grid cells within the 113 km^2 of the subset Study Area. There was an average of 3.42 ha (range 0–91 ha) of remnant vegetation and 24.50 ha (range 0–153 ha) of public open space within 700 m radius of each grid cell. The amount of public open space and remnant vegetation had little to no relationship with the probability of occurrence of most groups of species (Table 2, Fig. 4). For example, public open space was the only significant variable in the model predicting the occurrence of macropods (n = 21, Wald statistic 5.393, sig. of Wald 0.020) (Fig 4a, b), microchiroptera (n = 77, Wald statistic = 3.968, sig. of Wald 0.046) (Fig. 4c, d) and small ground-dwelling

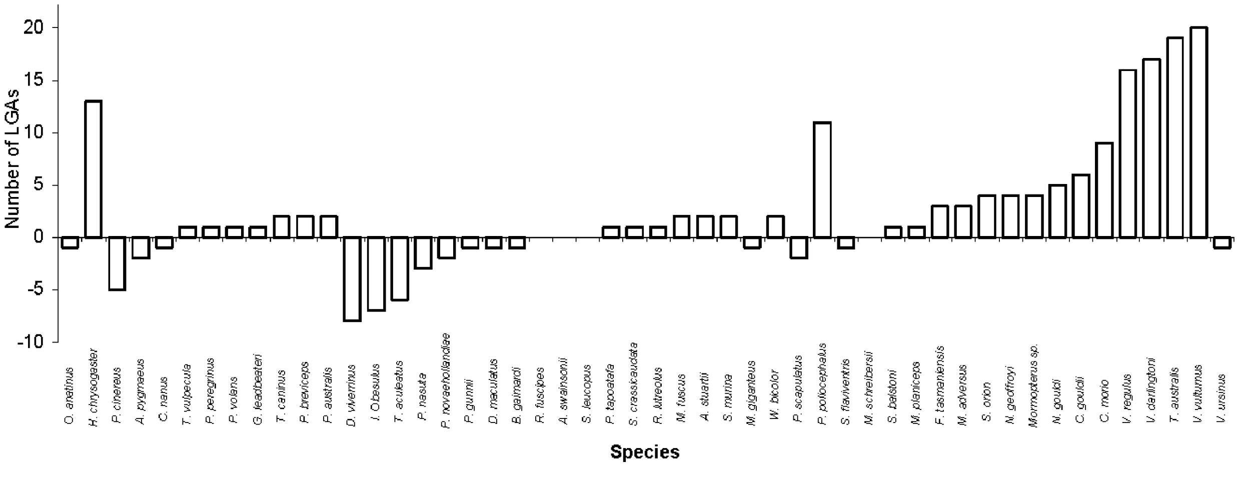

Figure 3. Change in the number of LGAs in Melbourne in which indigenous mammals were observed from 1850 – 1980 and 1980 – 2001. Species with columns above or below the x-axis were recorded in more or less LGAs since 1980, respectively. Species are ordered into functional groups (see Table 1).

Table 2. Relationship between the presence of a species group and the amount of remnant vegetation and public open space. Species group is explained in Table 1, with the number of grid cells in which the species group was recorded in parentheses.

Species group		Estimate	s.e.	Significance
Macropods (21)	Constant	-3.458	0.321	
	Remnant vegetation	0.004	0.021	0.845
	Open space	0.016	0.007	0.020
Microchiroptera (77)	Constant	-1.824	0.175	
	Remnant vegetation	0.020	0.013	0.117
	Open space	0.009	0.005	0.046
Introduced species (174)	Constant	-0.618	0.137	
	Remnant vegetation	0.022	0.014	0.122
	Open space	0.008	0.004	0.059
Large possum (196)	Constant	-0.149	.131	
	Remnant vegetation	0.009	0.012	0.487
	Open space	-0.001	0.004	0.851
Arboreal marsupials (200)	Constant	-0.131	0.131	
	Remnant vegetation	0.007	0.012	0.590
	Open space	0.001	0.004	0.931
Indigenous species (237)	Constant	0.193	0.132	
	Remnant vegetation	0.009	0.013	0.514
	Open space	0.001	0.004	0.747
Small ground-dwelling species (37)	Constant	-2.727	0.241	
	Remnant vegetation	0.007	0.017	0.681
	Open space	0.012	0.006	0.029
Aquatic species (46)	Constant	-2.295	0.213	
	Remnant vegetation	-0.007	0.020	0.736
	Open space	0.008	0.006	0.144
Flying-foxes (43)	Constant	-2.240	0.217	
	Remnant vegetation	0.000	0.019	0.987
	Open space	0.003	0.006	0.681

mammals (n = 37 grid cells, Wald statistic 4.78, sig. of Wald 0.029) (Fig 4e, f). The large confidence intervals associated with the logistic regression models indicate a high level of uncertainty associated with some of the predictions. For example, Fig. 4a shows that we can be 95% confident that the probability of occurrence of macropods lies between 0.05 and 0.65 when there is 140 ha of public open space within a 700 m radius of the centre of the grid cell.

Discussion

The mammal fauna of Greater Melbourne and the impact of urbanisation

Melbourne is located at the junction of four major biogeographic regions – Gippsland Plain, Victorian Volcanic Plain, Eastern Highlands and Midlands (Conn 1993). Consequently, the mammal fauna of Greater Melbourne is relatively diverse with 50 of the 91 species recorded for Victoria (Menkhorst 1995) because it contains species representative of these different habitat types. The mega- and microchiroptera are especially well represented in the Melbourne area, with records in Greater Melbourne for 18 of the 22 species known for Victoria.

Urbanisation can impact upon fauna in various ways, such as through the direct loss and fragmentation of natural habitat, the creation of new habitats, altered levels of nutrients and chemicals in the air, soil and water, invasion by weeds and feral predators, competition with introduced or overabundant indigenous species, altered fire regimes, and altered microclimate. Species may respond to urbanisation in three broad ways by: 1) decreasing their range or abundance; 2) increasing range or abundance; or 3) maintaining a relatively stable range or abundance. When the different responses of indigenous species of mammals are combined with the suite of introduced species, the composition of the mammal fauna of Greater Melbourne is greatly different to that which probably occurred prior to European settlement. Information on the composition of the mammal community of Greater Melbourne prior to European settlement is scarce and what is available can be found in the reports and diaries of early explorers. For example, Flinders saw 'the kangaroo in the woods' (Flannery 2000) and Brown reported seeing a dingo and 'dung of the kangaroo' (Vallance *et al.* 2001).

The group of mammals that appear to have undergone the greatest reduction in range and abundance in

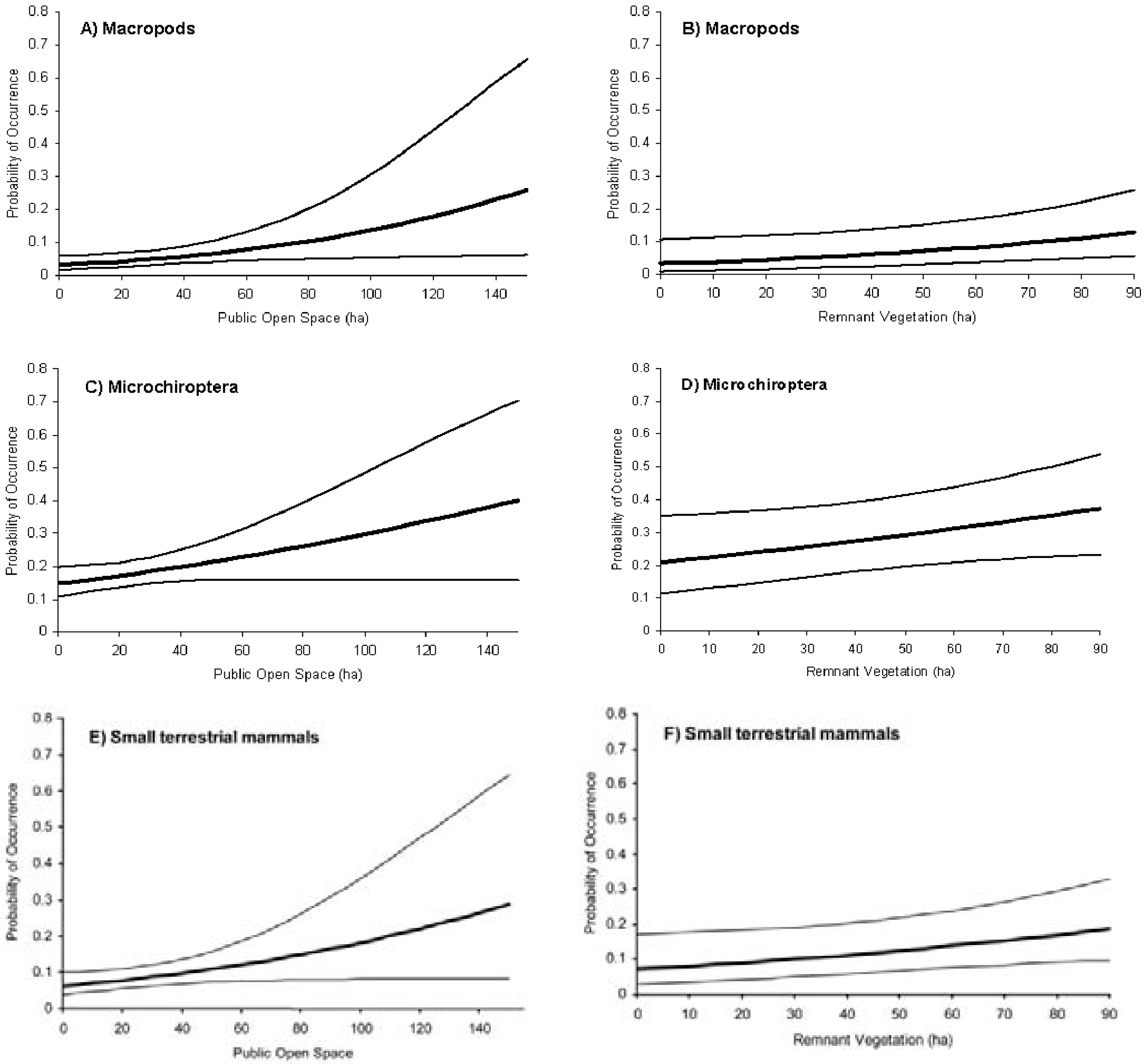

Figure 4. Logistic regression model of the occurrence of species of macropod (*logit(p)* = -3.458 + 0.004 VEG + 0.016 OS); microchiropteran species (*logit(p)* = -1.824 + 0.020 VEG + 0.009 OS); and small ground-dwelling mammals (*logit(p)* = -2.727 + 0.007 VEG + 0.012 OS) as a function of the amount of remnant vegetation (VEG) and public open space (OS) within a 700 m radius of each grid cell. a), c), e) Effect of public open space, with remnant vegetation set at its mean (3.42 ha); b), d), f) Effect of remnant vegetation, with public open space set at its mean (24.5 ha).

Melbourne since European settlement are the small ground-dwelling mammals. Eight out of 17 species of small ground-dwelling mammal were recorded in fewer LGAs since 1980, with the Eastern Quoll, Southern Brown Bandicoot and Echidna experiencing the greatest reduction in the number of LGAs in which they were recorded (Fig. 3). This is not a new observation, as many authors have concluded that in Australia, small-sized mammals are more prone to higher rates of decline and extinction than other mammalian taxa (Lunney and Leary 1988; Burbidge and McKenzie 1989; Recher and Lim 1990; Short and Smith 1994; Smith and Quinn 1996). The susceptibility of the Southern Brown Bandicoot to local extinction in Greater Melbourne was recognised in 1966 when Dixon (1966) predicted that 'rapid industrial expansion beyond Melbourne…means that *Isoodon* will be eliminated from most outlying suburbs' (Dixon 1966 pg. 63). Thus, it is not surprising that Southern Brown Bandicoots have been recorded in seven fewer LGAs since 1980. The conservation prospects for many other species of small mammal are not promising because more than half of the species recorded in Greater Melbourne are considered to be under some level of official threat (Table 1).

A number of species are widespread across the Greater Melbourne area, indicating a level of resilience to changes due to urbanisation. The most widespread species in the Melbourne area (recorded in all 31 LGAs) was the Common Brushtail Possum, a common resident in many parks, gardens and residential areas where trees occur. The adaptability of the Common Brushtail Possum in the urban context (Statham and Statham

1997) suggests that at present, populations within Greater Melbourne are secure. Another widespread species whose range appears to have remained relatively constant pre and post 1980 is the Platypus. Recent survey work has shown that this species occurs in many streams and rivers (Serena *et al.* 1998) in close proximity to the central business district of Melbourne.

The third response describes those species whose range appears to have expanded since European settlement. While many species in this study (60%) were observed in more LGAs after 1980 than before, only six (four species of microchiroptera, Water Rat and Grey-headed Flying-fox) were recorded in 10 or more LGAs. The most likely explanation for the increase in the number of records of microchiropteran species is the introduction and increasing availability of more accurate survey techniques (e.g. harp traps and ultrasonic call detectors) since the 1970s (Fenton 1970; Tidemann and Woodside, 1978). The Water Rat is a relatively cryptic species, and it is unclear if the apparent range expansion in the last 20 years is due to greater survey effort, increased reporting due to a greater level of public awareness and hence likelihood to report sightings, or in fact a real range expansion. Consequently, the only species most likely to have experienced a major range expansion in Greater Melbourne in the past 20 years is the Grey-headed Flying-fox. Colonies of Grey-headed Flying-foxes are common in many urban centres along the eastern coast of Australia (e.g. Sydney, Parry-Jones and Augee 2001) and, since the mid-1980s, a permanently-occupied camp has been established in Melbourne (Menkhorst and Dixon 1985). Numbers have increased from a few stragglers in most years in the 1960s and 1970s (Seebeck 1977, pg 167) to a peak population in 2003 of approximately 30,000 individuals during summer and autumn (Royal Botanic Gardens Melbourne, unpub. data). In addition to changes in the status of indigenous species, a suite of 15 non-indigenous species has been introduced, with many becoming widespread and abundant across Melbourne (e.g. European Fox, Marks and Bloomfield 1999).

The lack of a significant relationship between the amount of remnant vegetation and mammal distribution is probably because the species reliant on large or unmodified tracts of native vegetation declined prior to 1980, effectively preventing the development of robust habitat models. Future urban and suburban developments that do not retain sufficiently large tracts of high-quality native vegetation will likely experience a similar reduction in diversity of species reliant on native vegetation. In contrast, widespread and common species, such as the Common Brushtail Possum, are able to persist by utilising resources distributed across the modified urban landscape.

The future for urban planning

The apparent decline of many species of mammal across Greater Melbourne has occurred despite observations made over 25 years ago that very few species of mammal 'are capable of continued co-existence with urban and suburban development' (Seebeck 1977, pg. 170). The point that Seebeck (1977) did not make was that it relates to urban and suburban development in its current form. Future developments that genuinely incorporate strategies to conserve biodiversity are likely to see a greater compliment of species persisting. A general framework for the restoration of urban landscapes has been proposed and specific recommendations for the conservation of birds in urban areas has been developed (Marzluff and Ewing 2001). A similar strategy needs to be developed to maintain viable populations of mammals in urbanised landscapes of Australia. At a minimum, the strategy would include maintaining and enhancing the size, connectivity and quality of tracts of native vegetation as well as the control of introduced predators.

Limitations of the AVW dataset

The study reported here was based solely on information contained within the AVW. There is, undoubtedly, a wealth of information about the historical and present-day occurrence of many species of wildlife in sources other than the AVW. Historical reconstructions of species declines have been pieced together from various sources, including letters and field notes from early explorers or collectors, newspaper reports, published and oral local histories and unlikely data sources, such as shipping manifests (*e.g.* Lunney and Leary 1988; Lunney *et al.* 1997; Ling 1999; Short and Calaby 2001). Combined with field surveys and collation of historical material, the current status of specific 'at-risk' species can be more accurately determined. For example, research of this kind by Wilson (1996) showed that the New Holland Mouse had disappeared from at least three, and possibly six localities in Greater Melbourne in the past 10–16 years. The Southern Brown Bandicoot may be a suitable species for this type of research because it is relatively conspicuous and, as it was relatively common until 20–30 years ago, some older people may still remember where it once occurred.

The data contained within the AVW contain biases that need to be considered before accepting apparent trends in conservation status. For example, the annual recording rate of mammals within the AVW varied considerably between 1850 and 2001, with a major peak in the late 1980s, before returning to rates similar to the early 1980s (Fig. 2). The peak in reporting rate during the late 1980s–early 1990s coincides to a period of detailed fauna surveys conducted in the outer suburbs of Melbourne by the Arthur Rylah Institute for Environmental Research. This variation in recording effort may confound analysis of trends in the distribution and abundance of species. Nevertheless, approximately two-thirds of the records contained in the AVW originate after 1980, thus increasing the likelihood that any documented range contractions post 1980 are real, and not a sampling artifact.

It is impossible to be certain that the lack of a record of a species in the AVW represents an actual absence on the ground. This is particularly true when the Atlas is made up of data collected from a range of sources. Other atlas databases (e.g. the Atlas of Australian Birds, co-ordinated by Birds Australia) attempt to avoid this limitation by ensuring surveys are conducted systematically across the landscape (e.g. every 1º grid cell across mainland Australia) and that survey methods are consistent among observers. Another method would be to conduct carefully designed before and after studies over long time periods to more confidently quantify the rate and direction of change. While it may be too late to document the before-situation in many urban areas, the ongoing and rapid development of many coastal towns and villages in eastern and southwestern Australia provide an excellent opportunity for such studies. These coastal areas are under pressure from urban and residential development, as 25% of Australia's increase in human population between 1991–1996 occurred within 3 km of the coast (Newton *et al.* 2001). However, more important than just documenting change is to understand the driving processes and these developments offer the opportunity to experimentally design residential and urban developments that have least environmental impact. The design of new and existing urban areas to accommodate the conservation of natural assets is considered a high priority around the world (e.g. Nakamura and Short 2001).

Some records in the AVW included the number of individuals seen, but abundance was not consistently reported. Therefore, a positive record in the AVW only reliably indicates the presence of the species at that location. In addition, it is unknown if a sighting represents a vagrant individual or an individual that forms part of a resident, viable population. Targeted, species-specific studies are required to elucidate population size, reproductive success, dispersal and rates of mortality. An important element of this research is that attention must be given to understanding the underlying causes of the patterns observed. For example, the rate of predation in urban bushland remnants may be relatively easy to document. However, to design future urban landscapes that conserve viable populations of indigenous mammals, it is essential to understand the interplay between the rate of predation and the size, shape and location of the remnant within the urban context. An outcome of this investigation of data contained within the AVW is that the results may be used to select potential "at-risk" species for detailed study.

The use of 1-minute latitude and longitude grid cells may limit the geospatial analyses that can be undertaken. While many records within the AVW are recorded at a greater spatial resolution (*i.e.* to an AMG grid reference accurate to 100m x 100m), the only consistent locality data was the 1 minute grid cell. Consequently, the true location of the animal could be many hundreds of meters from the actual grid cell, thus reducing the power of the analysis of landscape and habitat variables around that grid cell. This may also partially explain the absence of many significant relationships between the presence of a species or species group and the amount of remnant vegetation or public open space around the record.

Conclusion

The transformation of a landscape of natural vegetation into a 4000 km^2 urbanised mosaic has resulted in a demonstrated decline of approximately one-third of the species of mammal known to occur in Greater Melbourne. There is insufficient historical data for a large group of species, primarily the microchiropteran bats, to confidently demonstrate a change in their range or distribution. The species whose ranges have remained stable or increased are typically generalists that are capable of utilising the new or altered resources available in the urban landscape. The AVW contains sufficient information in a readily accessible form to piece together the decline of many species of mammal due to the urbanisation of Melbourne.

However, the AVW is unable to tell the whole story for all species because of a range of potential biases inherent with databases of this kind. Biases include lack of survey effort in some areas, variability in survey effort over time, and a trend to report only rare or interesting species. While expert opinion may fill in the knowledge gaps and account for some biases for certain species, this information is largely unpublished and inaccessible. Targeted field-surveys must be undertaken before local populations of 'at-risk' species disappear and should include undocumented and anecdotal sources of information from older members of the community while such information is still available. Furthermore, if the AVW is to remain a valuable tool for documenting change in the status of species in Greater Melbourne, a renewed interest in submitting animal records to the database is required. More urgent, however, is a need to set up long-term ecological research sites that can document change in existing and new developments. At present, there are no registered long-term ecological studies being conducted in any Australian urban centre, despite their recognised value and importance in understanding ecosystem functioning (Hahs 2001). Atlas databases that contain variable information from a range of sources are useful for some analyses when other data are lacking, but action now will ensure that future research can quantitatively answer questions about the impacts of urbanisation on biodiversity in a scientifically valid and meaningful way.

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