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Introduction

Bat research in Australasia – in memory of Les Hall, part 2

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This is the second part of the Special Issue of the *Australian Journal of Zoology* in honour of Dr Leslie Hall.

Les published more than 200 scientific papers and four books on bats. He lectured human and veterinary anatomy and conservation biology at the University of Queensland for over 26 years, contributed as a scientific adviser to Bat Conservation International, served as a long-standing member on the IUCN Chiropteran Specialist Group, and was an Honorary Life Member of the Australasian Bat Society. The Cape York free-tailed bat (*Ozimops halli*) was named after him, and in 2017 he received further recognition as a Member of the Order of Australia, one of Australia's highest honours for outstanding service and exceptional achievement.

When Les suddenly passed away in February 2019 he joined a dear friend and other respected bat scientist – Greg Richards – with whom he co-wrote the seminal book 'Flying foxes: fruit and blossom bats of Australia' (Hall and Richards 2000). Sadly, Greg had died only months earlier in August 2018. To add insult to injury, in May 2019, the bat community lost another true-blue legend – Jack Pettigrew – of 'flying-primate hypothesis' infamy (Pettigrew 1986) and eclectic coauthor on several of Les' bat papers (e.g. Hall and Pettigrew 1995). Les, Greg and Jack were larger-than-life figures, and with their sudden demise within the span of less than one year, the field of bat biology was decidedly left less colourful than it was. All three have proud legacies as trailblazers and guiding lights in bat research, with enduring impacts on the scientific understanding, management and conservation of bats in Australasia.

In this second part of the Special Issue on Australasian bats, there are five papers on flying-foxes, focussing on attributes of roosting habitat, costs and outcomes of dispersals, and sensitivity to extreme heat events. In addition, it contains seven papers on Australasia's smaller, echolocating species, focussing on a wide variety of topics, ranging from roosting behaviours and requirements to taxonomic differences in the neurobiological basis for echolocation used for foraging.

Timmiss *et al*. (2020) examined the attributes of roosting and foraging habitat of Australia's four mainland flying-fox (*Pteropus* spp) species. Their findings show that flying-fox roosts ('camps') overwhelmingly occurred within human-modified landscapes across eastern Australia, and highlight a serious lack of protection of roosting and foraging habitat for these ecologically important species. Macdonald *et al*. (2020) looked in more detail at the local and landscape-scale camp-site characteristics of the little red flying-fox (*P. scapulatus*) and whether roosting habitat was limited for the species. They found that increased vegetation greenness and decreased distance to water were the two most important landscape-level characteristics associated with *P. scapulatus* camps. However, suitable roosting habitat was not limited so that camp-site selection is likely to be a function of factors other than the bioclimatic characteristics considered in their analysis. Despite the work by Timmiss *et al*. (2020) and Macdonald *et al*. (2020), a comprehensive understanding of the criteria that flying-foxes use to select sites for roosting remains elusive, however, limiting the capacity for land managers to develop alternative sites for camps subject to human–wildlife conflict and associated camp dispersals.

Roberts *et al*. (2020) reviewed the information on the costs and outcomes of 48 flying-fox camp dispersals in Australia to help improve the evidence base for camp management decisions. They found that only 23% of dispersal attempts were successful in resolving conflict for local communities. In the majority of cases, replacement camps formed nearby, often proliferating and exacerbating impacts throughout the broader community. Dispersals typically required repeat actions over months or years, and while costs were poorly documented, no dispersal attempt costing less than AU $250 000 proved successful. They concluded that camp dispersal should be considered a high-risk, high-cost tool for mitigating human versus flying-fox conflict, and recommended that in-situ management strategies should be developed, research on the impacts of camp management actions on flying-foxes should be conducted, and information on management options should be made available to stakeholders.

Bell *et al*. (2020) optimised a method for the analysis of flying-fox diets, based on metabarcoding of environmental DNA (eDNA) from pollen and other plant material in faeces. Using this technique, they generated a list of forage plants for little red flying-fox (*P. scapulatus*), black flying-fox (*P. alecto*) and spectacled flying-fox (*P. conspicillatus*) based on faecal samples from several camps across Queensland. Species and genera from the family Myrtaceae were the predominant diet components identified in this study, consistent with previous work. With increasingly more plant genomes becoming publicly available, this new, incisive technique for assessing flying-fox diets holds great promise for furthering the knowledge of the roles of flying-foxes in forest ecosystems, as well as the understanding of foraging behaviours associated with flying-fox urbanisation and human versus flying-fox conflict.

Ratnayake *et al*. (2020) examined the fur properties of museum specimens of Australia's four mainland flying-fox species to help explain species and demographic differences in mass mortality from extreme heat events – an emerging threat for flying-foxes particularly in the context of climate change. Their findings indicated substantial variation in the fur traits that affect thermal responses among and within the species, with *P. alecto* individuals, and adult females and juveniles, having fur thermal properties that are expected to compromise their survival during extreme heat events, consistent with previously observed mortality biases. Differences in fur properties among and within the species likely play a role in flying-fox sensitivities to heat stress, and it is important to incorporate this in biophysical models predicting how the species will cope with extreme heat events under future climate change scenarios.

Moving to the smaller, echolocating species, Lumsden *et al*. (2020) studied roosting behaviour and the tree-hollow requirements of the lesser long-eared bat (*Nyctophilus geoffroyi*) and Gould's wattled bat (*Chalinolobus gouldii*) in south-eastern Australia. Their radio-tracking showed that relatively large numbers of hollow-bearing trees in close proximity are required, providing a variety of hollow types, even for these widespread, generalist species. Cawthen *et al*. (2020) examined the importance of the type, amount and spatial arrangement of mature forest in timber production forests for roosting habitat for the chocolate wattled bat (*Chalinolobus morio*), the Tasmanian long-eared bat (*Nyctophilus sherrini*) and the lesser long-eared bat (*Nyctophilus geoffroyi*) during the maternity season. Their radio-tracking showed the importance of retaining mature forest at multiple spatial scales. These findings provide insight into the type, amount and spatial arrangement of mature forest used by different bat species in a timber production landscape. Both of these studies highlight the importance of old trees with hollows and offer important advice on how they can be better protected by forest managers in the future.

Gonsalves *et al*. (2020) assessed the long-term effects of grating on bats by documenting trends in emergence activity and bat abundance at grated and ungrated derelict mines and quantified behavioural responses of bats in autumn and winter. Their study showed that bat-friendly grates appear to be an effective management option for the eastern horseshoe bat (*Rhinolophus megaphyllus*), but alternatives need to be trialled for other, less maneuverable species. Further studies of this kind are needed to improve the management of derelict mines, given they are a safety hazard to humans but are commonly used by bats across many areas of Australasia.

Mills (2020) studied long-term summer and autumn activity patterns of the eastern bent-wing bat (*Miniopterus orianae oceanensis*) at an important maternity site in southern New South Wales. The emergence data from thermal infrared video revealed a seasonal pattern in the roost's population size corresponding with the timings of (1) spring immigration of adults, (2) peak emergence activity of adults, (3) juvenile independence, (4) peak emergence activity of adults and juveniles, and (5) autumn emigration of all individuals. Understanding the timings of such intraseasonal changes in the local population of this species has important implications for management, including for wind farm construction and impact assessments of turbine strike. These kinds of long-term studies are much needed to improve our understanding of Australasia's bats.

Armstrong *et al*. (2020*a*) investigated the detection and identification of sheath-tailed bats, focussing on the threatened bare-rumped sheath-tailed bat (*Saccolaimus saccolaimus*) in northern Australia. Using a combination of trapping and acoustic recordings, they present new empirical data and critical analysis to assist with acoustic detection and identification of *S. saccolaimus*, and assess the presence of the species within potentially high-value habitat on Cape York Peninsula. Their paper showed that *S. saccolaimus* can be acoustically distinguished from other species except from *S. mixtus*, and *S. saccolaimus* was not captured nor detected within their focal study area. They argue that even well resourced, intensive surveys targeting *S. saccolaimus* might find it very difficult to provide an unambiguous identification if the abundance or activity of other species with similar call types is high; and hence, that previous conclusions around the distribution and habitat use of this threatened species should be treated with caution.

Armstrong *et al*. (2020*b*) describe the outcomes of the first acoustics-based citizen-science survey of insectivorous bat species across the Murray–Darling Basin of South Australia. This intensive survey effort more than doubled the number of bat occurrence records for the area in two years, and presented evidence of a species-rich assemblage of bats still existing throughout the area. Having basic occurrence information has been useful to inform government land management policy, predict the impact of development proposals on bat populations, and update conservation assessments for a range of microbat species, and participation in the citizen science project has led to positive behaviours for improving bat habitat on private land. Given the cryptic nature of small insect-eating bats, engaging the community is crucial to add support for better protection of bats and their habitat, which is often otherwise overlooked.

Finally, Pavey (2020) examined whether neurobiological differences between Horseshoe (Rhinolophidae) and Old World leaf-nosed (Hipposideridae) bats have produced ecological divergence between the families by testing predictions of differences in prey capture behaviour, foraging habitat and diet. However, the findings showed that the two families occupy similar foraging habitat and exploit the same prey base, despite differences in echolocation and audition, indicating that the two families use different echolocation means to achieve the same ecological ends. This paper provides a detailed summary of the complexities of the bats' sensory systems, and it is the intricate ability to echolocate their prey and surroundings that has fascinated scientists for so long, and continues to do so.

The richness and diversity presented in the two-part Special Issue is a worthy tribute to Les and signals that the field of bat biology is alive and well, and indeed thriving, in Australasia today. Much of this can be attributed to the inspiration provided by Les and his peers (alias good friends), Greg and Jack. The future bodes well for bat research in the region!

Conflicts of interest

The authors declare no conflicts of interest.

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