

Corrigendum to: Drone surveys cause less disturbance than ground-based surveys in endangered spectacled flying-foxes (*Pteropus conspicillatus*)

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This article corrects *Australian Mammalogy* 47, AM25010
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The author advises of a couple of errors in [Table 2](#) of the published paper which is regretted. The start time in the bottom two rows of the table were incorrectly listed as 12:17 am and 12:31 am. These should instead read 12:17 pm and 12:31 pm. The corrected [Table 2](#) is provided below.

Table 2. Drone flight parameters and observed spectacled flying-fox (SFF; *Pteropus conspicillatus*) behavioural responses to drone and ground surveys at roosts in El Arish and Tolga Scrub, north-eastern Queensland, in September 2024.

Date	Site	Start time	Flight duration (min)	Drone model	SFF response (drone)	SFF response (ground)
2/9/2024	El Arish	10:30 am	2	M3T	Resting	Alert, alarmed, escape
2/9/2024	El Arish	10:52 am	9	M350	Resting	
6/9/2024	El Arish	9:48 am	25	M350	Resting	Alert, alarmed
18/9/2024	El Arish	7:36 am	10	M3T	Resting	Alert, alarmed, escape
18/9/2024	El Arish	7:49 am	12	M350	Resting	
18/9/2024	El Arish	8:18 am	4	M3T	Resting	
19/9/2024	Tolga Scrub	8:33 am	5	M3T	Resting	Alert
19/9/2024	Tolga Scrub	8:41 am	6	M350	Resting	
19/9/2024	Tolga Scrub	12:17 pm	10	M350	Vigilant	Alert, alarmed
19/9/2024	Tolga Scrub	12:31 pm	5	M3T	Vigilant	

Each ground survey was conducted once per set of drone flights to minimise colony stress. Behavioural response categories are defined in [Table 1](#). M3T and M350 refer to the DJI Mavic Enterprise 3T and DJI Matrice 350 RTK drones respectively.

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Drone surveys cause less disturbance than ground-based surveys in endangered spectacled flying-foxes (*Pteropus conspicillatus*)

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ABSTRACT

Robust population estimates are critical for detecting biodiversity declines. Thermal drones offer a promising alternative to invasive, imprecise ground-based techniques for monitoring endangered spectacled flying-foxes (*Pteropus conspicillatus*). This study evaluated spectacled flying-fox behavioural responses to drones to address concerns that they will disturb roosting colonies. At two studied roosts, drones elicited minimal disturbance, whereas ground-based surveys triggered alarm and escape responses, particularly among unhabituated flying-foxes. These findings highlight thermal drones as a non-invasive tool for monitoring spectacled flying-foxes. Further research is needed to evaluate their accuracy and precision compared with ground counts.

Keywords: animal behaviour, Chiroptera, conservation, Old World fruit bats, Pteropodidae, RPAS, thermal infrared, UAV, wildlife monitoring.

Introduction

Robust population estimates are critical for detecting biodiversity declines and evaluating conservation interventions (Lindenmayer *et al.* 2012). Monitoring techniques must avoid altering natural behaviours because stress may negatively affect reproductive success (Carey 2009; Edwards *et al.* 2019). For highly mobile, colonial species such as flying-foxes and waterbirds, ground-based breeding colony censuses can induce widespread disturbance, roost abandonment, and potential miscounts (Borrelle and Fletcher 2017). Minimising disturbance while maximising detectability is critical to effective population monitoring (Lindenmayer *et al.* 2020).

Drones have emerged as a promising tool for monitoring colonial-nesting fauna. Compared with ground counts, they offer greater area coverage, access to remote sites, and reduced observer bias (Lyons *et al.* 2019; Lachman *et al.* 2020; Hayes *et al.* 2021; Attard *et al.* 2024). Drone-mounted thermal cameras (thermal drones) further enhance detection for camouflaged or partially obscured animals by distinguishing their heat signatures from background environments (Witt *et al.* 2020; Virtue *et al.* 2023). Although many species do not react to drones (Arona *et al.* 2018; Geldart *et al.* 2022; Norris and Larson 2025), some taxa exhibit strong disturbance responses (Weimerskirch *et al.* 2018; Giles *et al.* 2021; Aubin *et al.* 2023; Demmer *et al.* 2024). Assessing target species' responses to drone- and ground-based surveys is crucial for selecting a suitable monitoring approach.

Flying-foxes (Pteropodidae) are well-suited to thermal drone monitoring because their heat signatures are readily detected while roosting in forest canopies (McCarthy *et al.* 2021; Seegobin *et al.* 2024). Thermal drones have been successfully used to count grey-headed flying-foxes (*Pteropus poliocephalus*), providing more accurate and precise colony estimates than do ground counts by human observers (McCarthy *et al.* 2021, 2022). Currently, 38 of 54 assessed *Pteropus* spp. are threatened and six are extinct (Kingston *et al.* 2023; IUCN 2025). As long-distance pollinators and seed dispersers (Fujita and Tuttle 1991; McConkey and Drake 2006), flying-foxes require robust population assessments to detect declines that could negatively affect forest biodiversity. Yet, established ground-based census methods, such as fly-out or walk-through counts, are hindered by

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roost inaccessibility, human-induced disturbance, and observer bias, limiting their ability to detect shifting population trends (Westcott and McKeown 2004; Westcott *et al.* 2012). Thermal drones could enhance statistical power to detect trends by enabling objective, whole-roost surveys and reducing disturbance-induced movement that could skew counts (McCarthy *et al.* 2022).

Endangered spectacled flying-foxes (*Pteropus conspicillatus*), endemic to tropical north-eastern Queensland (Roberts *et al.* 2020), have declined by approximately 75% over 14 years as a result of deforestation, cyclones, and an extreme heat event that killed nearly a third of the population (Westcott *et al.* 2018; Lopes *et al.* 2024). Timely detection of ongoing trends in the diminished population requires more precise local abundance estimates to improve monitoring power (Westcott *et al.* 2012). Flying-fox intolerance to humans often prevents ground counters from entering roosts, necessitating extrapolation at larger roosts (Westcott *et al.* 2011, 2012). Given these constraints, thermal drones are being trialled as an alternative for improving count accuracy and precision (E. B. B. Norris, unpubl. data). This study compares spectacled flying-fox behavioural responses to

drone- and ground-based surveys, evaluating disturbance levels and establishing the minimum flight height to prevent disturbance.

Methods

The study formed part of a pilot study testing thermal drones for monitoring spectacled flying-foxes. The research was approved by James Cook University Animal Research Authority No. A2969.

Behavioural assessments occurred at two spectacled flying-fox roosts in north-eastern Queensland, Australia, during September 2024 (Fig. 1). The El Arish roost (−17.801560, 146.006416) is an open eucalypt forest and the Tolga Scrub roost (−17.230005, 145.479608) is a complex notophyll vine forest. Roosts were selected on the basis of accessibility, occupancy, and unrestricted airspace for drone flights.

Two drone models were tested, namely, a DJI Matrice 350 RTK (M350) with a DJI Zenmuse H30T payload (7.39 kg), and a DJI Mavic 3T Enterprise (M3T) with a built-in thermal camera (0.92 kg; Supplementary Table S1) (DJI Technology



Fig. 1. Maps of (a, b) the two study sites at El Arish and Tolga Scrub in north-eastern Queensland, Australia, and (c, d) aerial images showing drone launch sites adjacent to spectacled flying-fox (*Pteropus conspicillatus*) roost trees at (c) El Arish and (d) Tolga Scrub.

Co., Shenzhen, China). Six drone flights were conducted at El Arish over 3 days and four at Tolga Scrub in 1 day, all between sunrise and midday in partly cloudy conditions.

To determine the minimum disturbance-free flight height, the M350 was flown to 50 m above canopy height (ACH), then gradually lowered to 5 m ACH (Supplementary Video S1). The conservative initial flight height, which exceeded the 23 m flight height used for grey-headed flying-foxes (McCarthy *et al.* 2022), was chosen in case spectacled flying-foxes reacted differently to the drone, as has been observed among congeneric waterbird species (Marchowski 2021). No reaction was observed to the drone flying >7 m ACH; however, a minimum flight altitude of 15 m ACH was implemented to improve orthomosaic processing. Subsequent automated flights were conducted at this height with speeds of 2–3 m s⁻¹, a nadir-oriented camera, and following parallel transects with 90% image overlap.

To compare disturbance responses, drone flights preceded a single ground-based survey. The smaller M3T drone, which produces less noise and was expected to cause less disturbance, was deployed first on each survey occasion, to assess flying-fox tolerance before using the M350. Ground surveys were conducted last, as flying-foxes may abandon roosts when

approached by humans (Westcott *et al.* 2011). During all surveys, disturbance behaviours were classified using an ethogram (Table 1) based on personal observations and established drone-response behaviours in primates (Rahman *et al.* 2021). Alarm calls were distinguished from social vocalisations, and wing flapping as an alarm response was distinguished from thermoregulatory wing fanning.

Drones were launched ~20 m from roosts to minimise pre-flight disturbance (Fig. 1c, d) and flown individually over the forest edge where flying-foxes beneath the drone were visible to ground-based observers. Reactions were observed by a ground observer by using binoculars and the drone pilot monitoring real-time thermal video (Table 2). Flights were to be terminated immediately if disturbance was observed.

For ground surveys, one observer recorded flying-fox responses as they approached the roost from ~20 m away and slowly entered the understorey. A second observer recorded responses from a fixed position 20 m away by using binoculars (Table 2). The approaching observer retreated if more than 20 flying-foxes initiated flight, following established disturbance thresholds for grey-headed flying-foxes (McCarthy *et al.* 2022).

Results and discussion

Spectacled flying-foxes reacted minimally to drone surveys, with no alarm or escape responses being observed (Table 2). Despite its greater size and noise output, the M350 drone did not elicit stronger responses than did the M3T. When the M350 descended to 7 m ACH, some individuals briefly looked up, indicating increased alertness (Table 1), before resuming their activity (Supplementary Video S1). Hence, a minimum flight height of 7 m ACH was initially considered adequate to avoid disturbance. However, lower altitudes

Table 1. Ethogram of spectacled flying-fox (*Pteropus conspicillatus*) behavioural responses to drone and ground observer presence.

Behaviour	Description
Resting	Inactive, sleeping, grooming, playing, or mating
Vigilant	Lateral head movements and eyes open
Alert	Visually tracking disturbance source
Alarmed	Alarm calling, flapping wings, or moving short distances between branches
Escape	Moving away from disturbance source

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reduced the camera's field of view, increasing the number of images required for orthomosaic processing and impeding image alignment. To balance these factors, a minimum flight height of 15 m ACH was established to maintain sufficient image quality and enable orthomosaic processing.

Disturbance responses to drones varied with time of day. During early morning, most individuals remained asleep and unresponsive to drone presence. Social activity increased after ~9 am and, by midday, individuals were more vigilant towards the drones (Table 2). Although afternoon vigilance responses were mild (Table 1), early morning drone surveys are preferable not only to minimise disturbance but also to take advantage of improved thermal contrast and detectability in cooler ambient temperatures with indirect sunlight (Burke *et al.* 2019).

Spectacled flying-foxes showed strong disturbance responses to on-ground human observers. At El Arish, individuals alarm-called, flapped their wings, or climbed higher when approached, with entry into the understorey triggering flight (Table 2; Supplementary Video S2). At Tolga Scrub, responses were more subdued, with few individuals initiating flight (Table 2). This difference is likely to reflect human habituation, because Tolga Scrub is occupied year-round and borders a frequently used sportsground (Fig. 1) (Parsons *et al.* 2011). In contrast, the El Arish roost is occupied periodically (E. B. B. Norris, pers. obs.), and no human activity was observed during surveys, despite its proximity to a sportsground (Fig. 1). Drone habituation was unlikely, because neither site had prior drone exposure. Although some individuals may have encountered drones elsewhere, the rarity of past drone surveys suggests that the observed responses reflect natural behaviour, supporting the broader applicability of these findings.

Reproductive stage may influence behavioural responses to drones and ground-based human observers. During the mating season (January to May), polygynous males exhibit heightened defensive behaviours, potentially increasing energetic costs as males defend harems from perceived threats (Fox 2006; Welbergen 2006). Meanwhile, females may limit flight responses during gestation and parturition to conserve energy and protect young. The surveys described in this study were conducted in September, during gestation but before parturition and copulation. At this time, heightened male defensive behaviours were not expected, but gravid females may have limited their flight responses to conserve energy. Whereas further research is needed to assess seasonal variation in behavioural responses, subsequent whole-roost drone surveys during parturition (November) and early mating (January), conducted since this study, have also not elicited obvious disturbance (E. B. B. Norris, pers. obs.).

Spectacled flying-foxes are vulnerable to raptor predation (Koel 2023), but show minimal response to overhead raptors while roosting (R. Hopkinson, pers. comm.). This lack of reaction, as with drones, may be an anti-predator strategy, because initiating flight could increase predation risk

(Welbergen 2006). Instead, flying-foxes may rely on concealment to avoid detection. Although no visible distress was observed, and individuals displayed natural behaviours (e.g. grooming, socialising) during drone flights, future research incorporating physiological stress metrics (e.g. heart rate, glucocorticoids) could better assess potential disturbance effects of drone exposure (Reeder *et al.* 2006; Geldart *et al.* 2022).

The present findings support thermal drones as a minimally invasive tool for censusing spectacled flying-foxes. Compared with ground surveys, drones reduce disturbance-induced movement, enabling whole-roost surveys and potentially reducing miscounts (Vallecillo *et al.* 2021). However, dense vegetation and higher ambient temperatures in tropical environments may affect detection rates, making it essential to assess whether drone-based methods yield similarly robust results, as those reported for grey-headed flying-foxes in temperate open forests (McCarthy *et al.* 2022). Ongoing research will evaluate these trade-offs, comparing the accuracy and precision of thermal drone and ground-based counts for spectacled flying-foxes.

Supplementary material

Supplementary material is available online.

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Data availability. This research note is based on incidental observations. All relevant data have been included in the paper and supplementary material. Additional raw observation records, images, and metadata can be made available upon reasonable request to the corresponding author.

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