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Automated monitoring of the occurrence and flight behaviours of White-throated Needletails *Hirundapus caudacutus caudacutus* at an operational wind farm in Tasmania

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Abstract. The White-throated Needletail *Hirundapus caudacutus caudacutus* is listed as Vulnerable under the Australian *Environment Protection and Biodiversity Conservation Act 1999*, and interaction with onshore wind farms has been suggested as a threatening process for this taxon in Australia. Despite these concerns, there is an absence of data to assess the actual levels of risk and to design appropriate mitigation measures. We present a proof of concept for the use of the IdentiFlight System to automate the collection of data on occurrence and flight attributes of White-throated Needletails from an operational wind farm in Tasmania. Despite having not been recorded in pre-construction bird surveys using human surveyors, the automated detection system recorded 2982 tracks of White-throated Needletails passing through the site in the period 2020–2025, with 86% of the records occurring in February and March. Birds were recorded on a total of 377 days; there were single records on 144 (38%) days and ≥5 records on 105 (28%) days. When multiple records were recorded on the same day, the median time between the first and last detection was 4 minutes. There was a strong diurnal pattern, with peaks in occurrence 3–4 hours after dawn and 3–4 hours before dusk. Of the 2982 birds recorded, 53% had at least one height recorded within the rotor-swept area. These results clearly demonstrate the potential to utilise data collected by the IdentiFlight System to gain new insights into the interactions of White-throated Needletails with wind farms that can be used to inform risk assessments and mitigation approaches for this and other under-studied avifauna species.

Introduction

The Eastern White-throated Needletail *Hirundapus caudacutus caudacutus* is one of two recognised subspecies of White-throated Needletail (Chantler & Kirwan 2020). It has a breeding range that includes areas of eastern Russia, northern Mongolia, China and the northern islands of Japan, and is a long-distance migrant to eastern Australia in its non-breeding season. The other subspecies, the Himalayan White-throated Needletail *H. c. nudipes,* is a short-distance migrant in comparison that breeds in the Himalayan foothills and is thought to winter in south-eastern Asia (Chantler & Kirwan 2020). The Eastern subspecies (hereafter referred to as White-throated Needletail) is a large member of the swift family (Apodidae); it is ~20 cm in length and weighs 115–120 g, is considered the world's fastest bird in level flight, and feeds exclusively on airborne insects (Burwell & Pavey 1992).

In Australia, the White-throated Needletail is protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) and is listed as Vulnerable, based on a reported decline in average flock sizes of the visiting population that is assumed to be because of loss of nesting habitat in the Northern Hemisphere (Tarburton 2014, 2021). Tarburton & Garnett (2021) suggested interactions with wind turbines as an emerging threat to the species in Australia. Reid *et al.* (2025) also highlighted this species as at high risk from interactions with onshore wind farms in Australia. The distribution and movement of White-throated Needletails in Australia is typically in response to changes in atmospheric conditions, the likely factors driving the large-scale distribution of airborne insects. The influence of aerial rather than terrestrial conditions means that the presence, and residence time, of White-throated Needletails at a particular location is difficult to predict.

Little is known about the global population size or the proportion of that population that winters in Australia and there is little published information on foraging behaviours, including the flight height and range of flight speeds of the species (although see Tarburton 2009; Daly & Leach 2025). These data gaps limit the capacity to properly assess the risk of collisions with wind turbines and develop appropriate mitigation techniques. Given the unpredictable nature of this species' occurrence at site-specific scales (Tarburton 2021; Yamaguchi *et al.* 2021), mitigation based on the siting of wind farms is generally not practicable and so other approaches need to be explored to accurately assess risk and develop appropriate mitigation strategies.

Study site

This study was conducted at an operational wind farm located in Tasmania that comprises 48 wind turbines, each with blade length of 71 m and a hub height of 100 m. The wind farm has a total generating capacity of 148 MW and was constructed over a 2-year period in 2018–2019. As part of a technology trial to reduce impacts to the endangered Tasmanian Wedge-tailed Eagle *Aquila audax fleayi* (Environment Protection Authority 2009) the IdentiFlight Bird Detection and Collision Avoidance System (hereafter referred to as the IdentiFlight System) was installed at the site. This was the first deployment of the technology outside the United States of America, where it had been developed to mitigate impacts to the Golden Eagle *Aquila chrysaetos* and Bald Eagle *Haliaeetus leucocephalus* from operating wind turbines (Duerr *et al.* 2023).

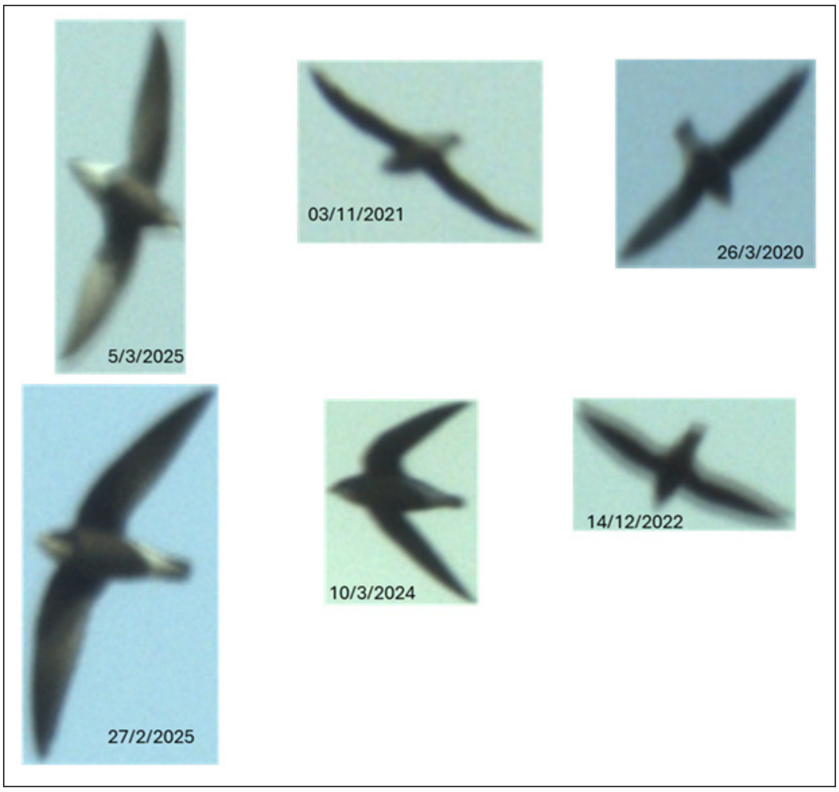

Figure 1. Images (and dates, day/month/year) of White-throated Needletails taken by the IdentiFlight System at a wind farm in Tasmania.

The IdentiFlight System uses a camera system that has a combination of a stationary camera with a wide field of view, to detect moving birds, and a high-resolution stereo camera that records the three-dimensional flight paths of each bird detected. The IdentiFlight System was installed during the 2018 and 2019 construction phase of the wind farm and includes 16 IdentiFlight stations (15 of height 7 m and one of height 10 m). Each station observes the airspace surrounding it and can detect moving eagle-sized objects within a hemisphere of diameter ~1 km. Images and positions (radial distance and height) are recorded at *c*. 1-second intervals for each detected object. A convolutional neural network (CNN, a type of neural network that is frequently used for image analysis and recognition processes) is used to identify targets. Typically, CNNs require a large number of classified images for training data, from which the feature-based attributes such as body length, wingspan, wing posture and colour composition, are used to 'classify' target species from a larger set of images (Duerr *et al.* 2023).

CNNs have been developed to identify, classify, and track Tasmanian Wedge-tailed Eagles based on a library of >500,000 images collected on the site. For each bird detected, an image is captured along with distance and size every second or until the system determines that the bird being tracked is not an eagle (usually within 7 seconds), at which point the system stops tracking that individual. During the process of classifying bird images to train the CNN, other bird species were identified, including White-throated Needletails (Figure 1). The images and associated data collected for all birds detected by the IdentiFlight System are retained, and over time a large dataset of other bird movements captured opportunistically has been generated. As demonstrated by Linder *et al.* (2022) from an installation of IdentiFlight System in Sweden, this can provide an extensive database of images and associated data on a range of bird species.

The aim of this paper is to evaluate the potential for the use of the IdentiFlight System to collect data on the White-throated Needletail that could be used to address knowledge gaps for the species, including its pattern of occurrence and flight behaviours.

Methods

Bird utilisation surveys

Pre-construction bird utilisation surveys were conducted in 2009 and 2010 in accordance with Tasmanian and Australian Government guidelines for survey frequency and field methodologies (Environment Protection Authority 2009). One of the aims of these surveys was to collect behavioural data for key species frequenting the site, with a particular emphasis on threatened and migratory species. Two years of monitoring were undertaken, covering seasonal periods in both the pre- and post-construction phases, targeting behavioural data required to be collected for any key species frequenting the site.

All occurrence records of White-throated Needletails in Tasmania were downloaded from BirdLife Australia's Birdata database (BirdLife Australia 2025) to provide a baseline for occurrence of the species in Tasmania.

IdentiFlight System images

In order to automate the image searching of the large database of images collected by the IdentiFlight System, the computational expertise developed in producing the CNN for Tasmanian Wedge-tailed Eagles was leveraged to produce a preliminary White-throated Needletail CNN. A subset of ~15% of the total number of images obtained by the IdentiFlight System was randomly selected for annotation of species classification by qualified ornithologists. This annotated data was then used to develop the preliminary CNN for the White-throated Needletail. As this is the only species of swift that regularly occurs in Tasmania, the CNN was initially developed using an artificial 'perfect' swift shape to which species-specific biometrics such as body size and wingspan as well as relative body dimensions/ shape and colour composition were added. Although the performance criteria for the preliminary CNN are not as high as for the identification of eagles (where this information is used to implement real-time curtailment), it still achieved 96% classification accuracy using the test images annotated as White-throated Needletails.

The preliminary CNN was then used to search the remaining 85+% of system data collected in 2020–2025. An initial filter using estimated wingspan of <0.8 m was applied to isolate 'non-eagle' images that could possibly contain White-throated Needletails. All images were then classified by the CNN. Tracks where the network's prediction was White-throated Needletail, with a minimum confidence of 89% for at least half of the images along a track, were included in a new dataset as potential White-throated Needletails. This new dataset was then reviewed by qualified ornithologists to verify whether the machine classifications of White-throated Needletails were correct.

All images and associated data collected for an individual bird being tracked were assigned a unique identity, and for the purposes of this analysis it was assumed that each detection/track represented a distinct individual bird. This assumption was based on there being a positive relationship with the number of birds present and the number of detections, but we recognise that does not provide a means of estimating the actual number of birds in the area as some birds may be detected more than once, whereas other birds at the site may not be detected.

To examine the pattern of diurnal activity relative to dawn and dusk over a period when the day length was changing, we used the double anchoring approach described by Vazquez *et al.* (2019). The local time of dawn and dusk was estimated for each day with the suncalc R package (Thieurmel & Elmarhraoui 2023; used to estimate the proportional progress through the day from dawn to dusk for the start of each track).

Given a recorded local time of activity (T_c), the local times of dawn (*Da*) and dusk (*Du*) on the day of that activity and the mean times of dawn (*mDa*) and dusk (*mDu*) over the first 100 days of the year, the corrected (double anchored) time for each event (T_d), is given by:

$$T_d = mDa + (mDu - mDa)\frac{T_c - Da}{Du - Da}$$

On days with multiple records, all records with a time separation of <10 minutes were considered to be part of the same 'visit' event. The visit duration was calculated as the time from earliest start time and latest end time for all individual track records within the same visit event.

Post-construction mortality monitoring

Each turbine had a designated Carcass Monitoring Zone (CMZ) comprising an inner fall zone out to a 60-m radius from the base of the tower, and an outer fall zone from 60 m to 120 m. Commencing in August 2020, the CMZs of 24 randomly selected turbines were searched each month, with the remaining 24 turbines searched in the following month such that every turbine CMZ was searched over a 2-month period. For the monthly surveys, both humans and detection dogs were used, with humans walking 6-m transects out to 60 m then 12-m transects out to 120 m, and dogs allowed to free-roam within the defined CMZ, covering the full area. Both dogs and humans were GPS-tracked for the duration of searches. Within 3 days of each set of monthly searches, replicate searches were undertaken in the inner fall zone at each of the recently surveyed turbines.

When a carcass was detected, the GPS location was recorded along with the species' identification, photographs, details of whether the detection involved a whole carcass (i.e. likely to be a recent mortality), a scavenged carcass or a collection of feathers. A description of the ground-cover vegetation at the detection location was also recorded. In the absence of species-specific detection probability data, we have used the uncorrected carcass detection data as a measure of the relative number and timing of detections of dead White-throated Needletails within the wind farm, recognising that this will likely underestimate the actual number of fatalities.

Results

In pre-construction bird surveys the most frequently recorded species were the endemic Black Currawong *Strepera fuliginosa*, the Forest Raven *Corvus tasmanicus* and the introduced Common Starling *Sturnus vulgaris*. There were no records of White-throated Needletails during the pre-construction surveys and the species is not referred to in any of the conditions for migratory or threatened species that were imposed by either the Commonwealth or State regulators in issuing their respective approvals.

In total, 2982 White-throated Needletails were recorded passing through the site and the pattern of seasonal occurrence very closely matched the overall pattern of reporting for all of Tasmania (BirdLife Australia 2025; Figure 2). February and March were the only months in which Needletails were recorded in every year during the period 2020–2025; these 2 months accounted for 86% of all records; the mean number of days when birds were present was 19 days and 24 days, respectively, for those 2 months (Table 1). There was significant inter-annual variation in the numbers of White-throated Needletails detected (X^2_5 = 360.74, P <0.001).

White-throated Needletails were recorded on a total of 377 days over the period 2020–2025; there was a single record on 144 (38%) days and there were ≥5 records on 105 (28%) days (Figure 3). There was a strong diurnal pattern in occurrence, with peaks 3–4 hours after dawn and 3–4 hours before dusk, with the lowest numbers occurring in the hours near to dawn and dusk (Figure 4).

Table 1. Monthly total count of White-throated Needletails recorded (*n*) and the number of days (*d*) on which they were recorded by IdentiFlight at a wind farm in Tasmania (January 2020–May 2025). The months with zero records are not included in the table.

Year	*January*		*February*		*March*		*April*		*October*		*November*		*December*		*Total*
	n	*d*	*n*	*d*	*n*	*d*	*n*	*d*	*n*	*d*	*n*	*d*	*n*	*d*	*n*
2020	3	3	100	21	409	27	80	7					7	6	599
2021	17	6	85	18	170	26	1	1			2	1	2	2	277
2022	5	3	31	13	301	20	4	3					9	7	350
2023	16	9	110	20	197	23	15	6			5	1	29	17	372
2024	99	15	79	22	270	23	171	4	1	1	4	4	8	5	632
2025	44	12	302	23	403	26	3	2							752
Total	**184**	**48**	**707**	**117**	**1750**	**145**	**274**	**23**	**1**	**1**	**11**	**6**	**55**	**37**	**2982**

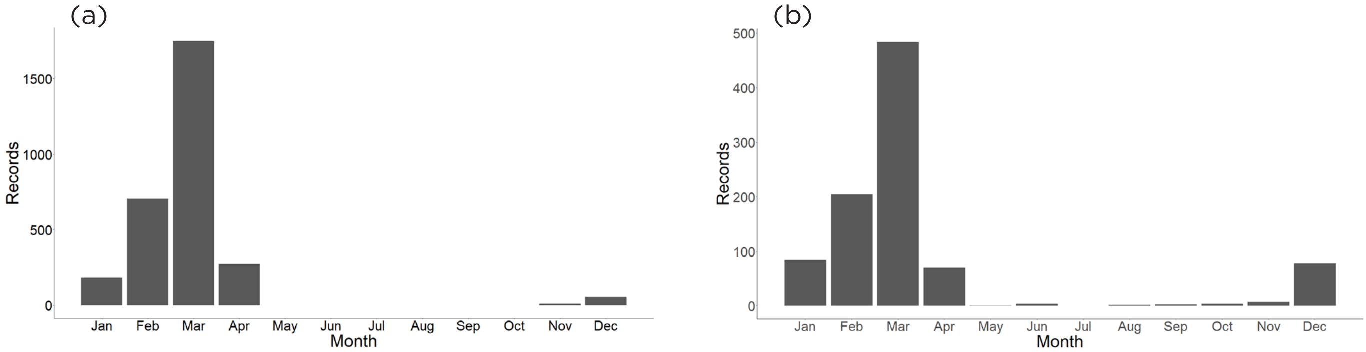

Figure 2. (a) Seasonal distribution of all records of White-throated Needletails recorded by IdentiFlight at a wind farm in Tasmania (2020–2025), (b) all records from BirdLife Australia's Birdata database for Tasmania (BirdLife Australia 2025).

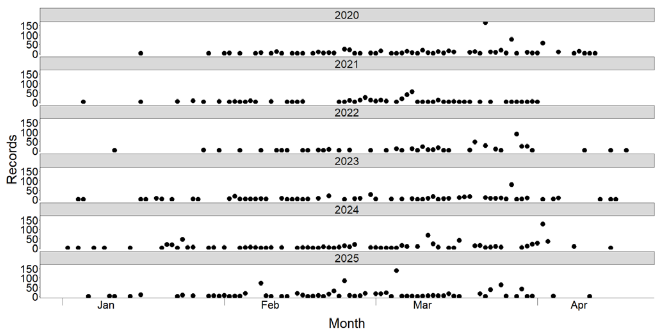

Figure 3. Daily number of records of White-throated Needletails recorded by the IdentiFlight System at a wind farm in Tasmania during the period January–March in 2020–2025.

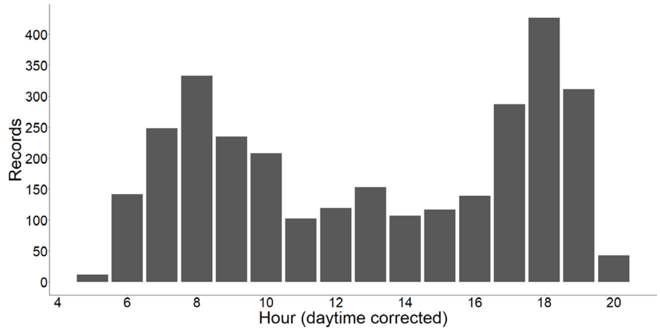

Figure 4. Total number of records of White-throated Needletails recorded by IdentiFlight System at a wind farm in Tasmania by hour of day (corrected for day length; see methods for details).

There were 351 'visits' involving multiple records separated by <10 minutes and the distribution of visit duration was highly skewed, with a median visit duration of 3.7 minutes (Figure 5). There were 77 (22%) visits of total duration >10 minutes. There was a positive relationship between the number of birds recorded and the overall visit duration (R^2 = 0.71, $F_{(1, 349)}$ = 869, P <0.001).

The median distance at which Needletails were first detected was 284 m, with a maximum first-detection distance of 576 m (Figure 6). Overall, 6352 (38%) of the 19,791 recorded heights were within the rotor-swept area (i.e. between 31 and 171 m above ground level), 10,138 (60%) were above it, and <1% were below it (Figure 7). Of the 2982 individual tracks, 1569 (53%) had at least one height record within the rotor-swept area.

In total, 13 White-throated Needletail carcasses were detected in routine surveys. These were found in 2021 (*n* = 1), 2024 (*n* = 10) and 2025 (*n* = 2), suggesting no apparent relationship between the total number of records and the number of mortalities detected in a given year (Table 1). All carcass detections were in March or April, with the exception of two carcasses detected in May and June 2024 (Figure 8).

Discussion

The data gathered using the IdentiFlight System provide an unprecedented level of information on the patterns of occurrence of White-throated Needletails at a wind farm

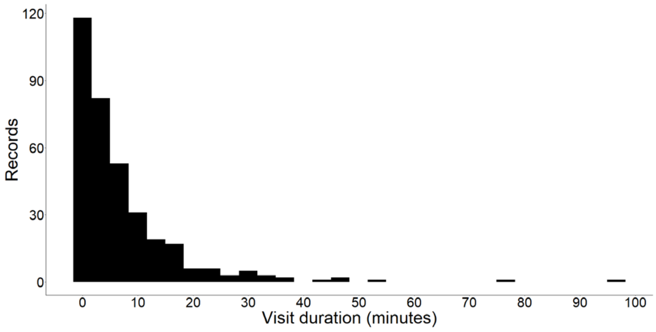

Figure 5. Visit duration involving multiple White-throated Needletails recorded on the same day by IdentiFlight System at a wind farm in Tasmania.

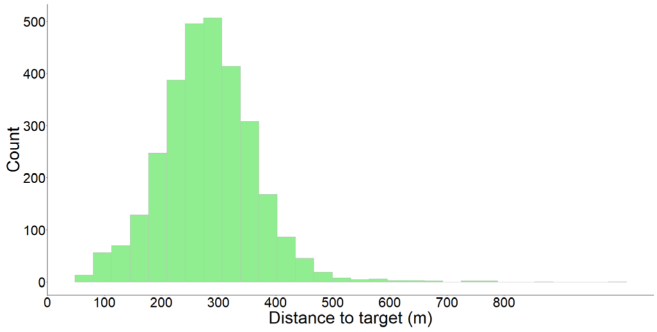

Figure 6. Radial distance (m) to the first detection on each individual track of White-throated Needletails recorded by IdentiFlight System at a wind farm in Tasmania.

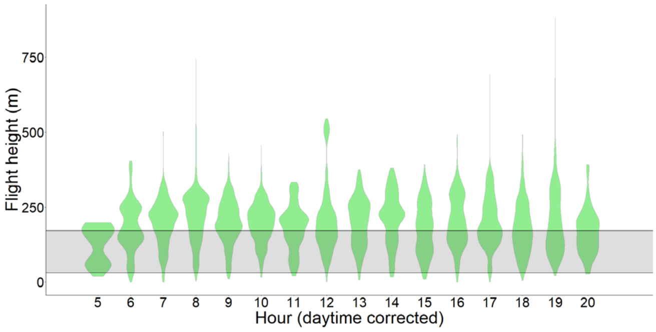

Figure 7. Flight height (green violin plot, and rotor-swept area in grey band) of White-throated Needletails recorded by IdentiFlight System at a wind farm in Tasmania, by hour of day (corrected for changes in day length).

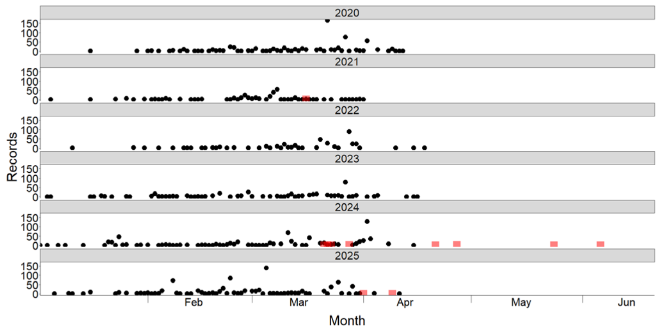

Figure 8. Daily number of records (black spots) and carcass detections (red squares) of White-throated Needletails at a wind farm in Tasmania during the period 2020–2025.

in Tasmania. Although not previously recorded during 2 years of human monitoring, conducted during the pre-construction phase of the wind farm, Needletails were detected by IdentiFlight System on the site every year of the study period (2020–2025). The seasonal pattern of occurrence was in close alignment with data from BirdLife Australia's database of bird surveys in Tasmania (BirdLife Australia 2025).

Many records were of a single bird on 1 day; when there were multiple records, these tended to involve birds being present for a relatively short period of time. This suggests that on days where there are larger numbers of birds, they occur in flocks that pass through the area of the wind farm relatively rapidly. This pattern of occurrence has substantial implications for the design of mitigation approaches as it involves 'rare events' that are difficult to predict and likely to be challenging to react to in real time. It also has important implications for extrapolation of data for use in collision-risk models that measure the movement of birds through a wind farm, based on a mean and variance, and may not be well suited to the highly skewed data on occurrence and visit duration that characterise the results presented here.

There were no records of Needletails in the pre-construction bird surveys so this species was not included in any species-specific permit conditions for the site of the wind farm. This absence is understandable given the highly seasonal nature, occurrence less than daily, and short duration of visits of Needletails. This does, however, underline the importance of using all available data sources to maximise information available for the assessment of risk from wind farms. The general bird utilisation surveys will provide an overview of the most frequently occurring species at a particular site, but where particular species of concern are detected, this may trigger species-specific survey requirements. This was the case at the study site where the presence of the Tasmanian Wedge-tailed Eagle, a frequently recorded resident species, triggered a suite of specific surveys.

The detection of irregular or highly seasonal, cryptic or rare species is likely to be commensurately lower in general bird utilisation surveys. However, many species protected as Matters of National Environmental Significance under the EPBC Act fall into those categories, and so there may be a mismatch in expectations/outcomes when relying on data from general bird utilisation surveys to determine presence and/or behaviour of significant bird species using a site. This also underlines the importance of using a holistic, risk-based approach to determining which species may be impacted by a wind farm, rather than relying solely on observational survey data. Furthermore, the temporal coverage of detections and the collection of high-accuracy ancillary data on flight height obtained with the IdentiFlight System would be impractical, if not impossible, to achieve using conventional survey techniques.

Future work

The primary aim of the IdentiFlight System installation at this wind farm in Tasmania was to detect Tasmanian Wedge-tailed Eagles and implement curtailment when required; this means that as soon as a target is classified as a non-eagle no further data are collected by that IdentiFlight System unit. This restricts the current data on White-throated Needletails to a track length of *c*. 10 seconds and limits the ability to measure flight direction, speed and other aspects of behaviour.

The seasonal patterns of occurrence aligned well with expectations given the available data, but there were more records of single birds being detected on separate days than anticipated, given the well-documented aggregations of Needletails associated with storms/cold fronts. Investigating the influence of weather on the occurrence and numbers of Needletails may require a two-stage approach to distinguish days with single records and those days with multiple birds present.

Awareness of the capability to collect unprecedented amounts of data on a range of bird species has motivated the development of IdentiFlight System software that continues to track 'non-eagles' until that bird leaves the detection zone, or an eagle is detected and the tracking is reprioritised. The diversification of use of IdentiFlight, combined with the development of a specific CNN classifier for White-throated Needletails that can be deployed within the IdentiFlight System, should allow this species to be tracked for longer and for the data to be available in real time. The longer-track data will provide the potential to examine meso-/micro-scale avoidance behaviour, for example by examining changes in the direction of the flight path within the wind farm.

Caveats and cautions

Although the data collected provide an unprecedented level of information, it is important to recognise that those are 'repurposed' from the original design of the data-collection process; it is therefore important to be mindful of the limitations when interpreting the findings.

The IdentiFlight System at the study site is currently configured to detect Tasmanian Wedge-tailed Eagles and to trigger curtailment. It is therefore focused on birds flying in or near the rotor-swept area. This camera has a vertical field of view of 65°, which means that at the median distance that Needletails were detected (284 m) the maximum height above which a bird would not be detected would be 234 m; birds at greater heights would not be detected. This means that the mean flight heights estimated are potentially biased towards lower flight heights and so the apparent proportion of flights at collision-risk height is potentially overestimated. Nevertheless, it is apparent that the majority of Needletails detected were flying above 170 m above ground level, i.e. above collision-risk height. Clearly, the combination of field of view and detection distance creates a sampling selectivity focused on a specific height range, which should be considered when interpreting both occurrence and flight height data. For example, the decrease in the occurrence of records in the middle of the day could simply reflect that birds fly higher in the warmest part of the day, making them less available for detection, given that a Needletail would have a shorter detection range than an eagle, being a significantly smaller species.

The time lag in the discovery of carcasses is an inevitable outcome of the monitoring program design/requirements that means it is not feasible to link mortalities to particular occurrence events with the current data. The carcasses discovered in late June 2024 were found >2 months after the latest record and appeared to be post-scavenged carcasses that might well have been moved by avian scavengers (Hull & Muir 2010). Notwithstanding these caveats, the frequency of occurrence at collision-risk height and apparently low incidence of collisions suggest a high rate of avoidance by Needletails when passing through the wind farm.

These results clearly 'prove the concept' of using data collected by the IdentiFlight System to gain new insights into the interactions of White-throated Needletails with wind farms. These data and insights can be used to parameterise risk assessments and to determine the need for, and subsequent design of, mitigation approaches for this, and other under-studied avifauna species of conservation concern. Improvements in the CNN to identify non-eagle species in real time, including the ability to have the White-throated Needletail as a primary species that is tracked for longer, combined with the deployment of the CNN within IdentiFlight System deployed in other regions of Australia has the potential to revolutionise our understanding of the risks posed to this species.

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