Crudine Ridge Wind Farm Bird and Bat Adaptive Management Plan Implementation Report – Year Two

Squadron Energy

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Abbreviations

Abbreviation	Description
BBAMP	Bird and Bat Adaptive Management Plan
BC Act	*Biodiversity Conservation Act 2016*
BCS	NSW Biodiversity, Conservation and Science Directorate
BUS	Bird utilisation Surveys
CRWF	Crudine Ridge Wind Farm
ELA	Eco Logical Australia Pty Ltd
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
DPE	NSW Department of Planning and Environment
IUCN	International Union for Conservation of Nature
LGA	Local Government Area
MW	Megawatt
NPW Act	NSW *National Parks and Wildlife Act 1974*
NSW	New South Wales
RSA	Rotor swept area
SSD	State Significant Development

1. Introduction

Eco Logical Australia (ELA) was engaged by Squadron Energy (formerly CWP Renewables) for the initial two year implementation of the Bird and Bat Adaptive Management Plan (BBAMP) for the Crudine Ridge Wind Farm (CRWF) project. This report details the results of Year Two of operational phase monitoring, that was undertaken from June 2022 to May 2023, along with a summary of results obtained across the full initial two year implementation of the BBAMP.

1.1 Background

CRWF is located 45 kilometres south of Mudgee and 45 kilometres north of Bathurst in the central tablelands of New South Wales.

In May 2016, the NSW Department of Planning and Environment (DPE) issued approval for the CRWF project, approving up to 77 turbines. The Commonwealth Minister for the Department of Climate Change, Energy, the Environment and Water issued approval of up to 37 turbines on 4 April 2017, selected from 57 approved turbine locations, under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The overall aim of the BBAMP is to provide a program for monitoring the impacts on birds and bats from CRWF and a strategy for managing and mitigating any significant bird and bat impacts arising from the operation of CRWF. Specific BBAMP objectives are outlined below (Section 1.3, CRWF BBAMP 2017).

- To provide baseline data on bird and bat populations that could potentially be affected by the CRWF, particularly identified at-risk species and groups.
- To implement a monitoring program capable of detecting any significant changes to the population of 'at-risk' birds and bats that can reasonably be attributed to the operation of the project.
- To directly record impacts on birds and bats through a robust carcass search sampling protocol and prompt carcass removal.
- To document an agreed decision-making framework that outlines the specific actions to be taken and possible mitigation measures implemented to understand and reduce any impacts on bird and bat populations, or in the event that an impact trigger is detected.
- To detail specific monitoring for 'at-risk' bird and bat groups.
- Minimising raptor activity in the area through controlling pests and minimising availability of raptor perches.
- Using best practice methods for bat deterrence; including managing potential lighting impacts.
- To detail specific and potential mitigation measures and related implementation strategies to mitigate any detected significant impacts on birds and bats.
- To identify matters to be addressed in periodic internal reports on the outcomes of monitoring, the application of the decision-making framework, mitigation measures adopted and their result/s.

1.2 Purpose of this monitoring report

Squadron Energy developed a BBAMP (CRWF BBAMP 2017) to satisfy the requirements of Condition 22, Schedule 3 of the NSW SSD6697 Conditions of Consent. The BBAMP was also prepared to satisfy Condition 1 (a) of the Commonwealth Approval EPBC Ref: 2011/6206. Implementation of the approved BBAMP is required in accordance with Condition 22, Schedule 3 of the NSW SSD6697 and Condition 9 of Commonwealth Approval EPBC Ref: 2011/6206.

This Year Two implementation report outlines the second year of operational phase monitoring undertaken from June 2022 to May 2023, in accordance with the methodology outline in the CRWF BBAMP 2017, with specific focus on; monitoring results, statistical analysis to provide overall mortality estimates for the CRWF, any impact triggers or unacceptable impacts identified and recommendations for ongoing monitoring, where required.

Table 1 below outlines the specific statutory requirements of the BBAMP which underlie the operational phase monitoring program and the associated methodology and performance measures applicable to the monitoring undertaken during the initial two year period of the BBAMP implementation.

Table 1: Statutory requirements of the BBAMP and their relevant methods of assessment and performance measures

Statutory Requirements	Performance Measures	Assessment Methodology	How Condition is fulfilled
NSW SSD6697 Conditions of Consent, Schedule 3			
Condition 22(b): develop a Bird and Bat Adaptive Management Plan (BBAMP) that includes: • Baseline data on bird and bat populations in the locality that could potentially be affected by the development, particularly 'at risk' species and threatened species; • A detailed description of the measures that would be implemented on site for minimising bird and bat strike during operation of the development.	Baseline bird and bat surveys completed; Bird Utilisation Surveys (BUS) (operational phase) undertaken in Year One as detailed in the BBAMP; Detail mitigation measures in approved BBAMP.	Completion of baseline surveys as per the methodology specified in Section 2.1.1 of the CRWF BBAMP	Completion of baseline surveys. Completion of operational phase surveys.
Condition 22(c): include a detailed program to monitor and report on: • the effectiveness of these measures and plans; and • bird and bat strike annually, or as	Operational phase mortality surveys undertaken monthly at a minimum of 18 turbines for at least two years, with a review after the first year to determine if a change in the methodology is required	Carcass monitoring	Recording and notification of relevant triggers as detailed below. Threatened species: A bird or bat species (or recognisable parts thereof) listed as threatened (not migratory) under the Commonwealth *Environment Protection Biodiversity Conservation Act 1999* or NSW *Threatened Species Conservation Act 1995* (now BC Act),

Statutory Requirements	Performance Measures	Assessment Methodology	How Condition is fulfilled
otherwise directed by the Secretary.	(Table 12, CRWF BBAMP 2017).		is found dead or injured within 150 m of a wind turbine during any mortality search or incidentally by wind farm personnel (Section 6.1.1, CRWF BBAMP 2017). Non-threatened species: A total of four or more bird or bat carcasses or parts thereof, of the same non-threatened species are recorded at the same turbine over two successive monitoring events (excluding ravens, magpies, sulphur-crested cockatoos, corellas, and introduced species) (Section 6.2.1, CRWF BBAMP 2017).
	Scavenger and detector efficiency trials undertaken in Year One (Table 12, CRWF BBAMP 2017).	Scavenger and detector efficiency (observer) trials	Scavenger and observer trials successfully undertaken
Commonwealth Approval – EPBC Ref: 2011/6206			
Condition 1(a): implement the above NSW Conditions of Approval, where Management Plans: means the Biodiversity Management Plan, Biodiversity Offsets Management Plan, and Bird and Bat Adaptive Management Plan.	As above	As above	As above

The scope for the works undertaken by Eco Logical Australia to implement the BBAMP during Year Two include:

- Bird and bat carcass monitoring
- Surveys of *Aquila audax* (Wedge-tailed Eagle) and other raptor species.

2. Methods

2.1 Carcass monitoring

A robust carcass monitoring program was implemented to determine the actual impact of the wind farm on birds and bats through estimating the annual number of birds and bats that collide fatally with turbines. Monthly carcass monitoring was undertaken during Year Two from June 2022 to May 2023. Monthly carcass monitoring was undertaken as per the methods prescribed in Section 4.4.2 of CRWF BBAMP 2017 and detailed below.

A total of 19 turbines were selected for monitoring based on a 'stratified random' sampling design. This design ensured that the selected turbines are representative of the full spatial extent of the site (including approximately half of the turbines for both the Pyramul and Sallys Flat turbine clusters), the surrounding broad vegetation types and landscape position (Table 2). The same 19 turbines were monitored consistently during both Year One and Year Two of the initial operational monitoring period.

Table 2: Selected turbines for carcass monitoring

Pyramul turbine cluster		Sallys Flat turbine cluster
A2	A24	A87
A4	A29	A94
A6	A32	A103
A7	A34	A104
A13	A38	A105
A17	A44	
A20	A52	

All 19 turbines were searched out to 100 m once per month within two designated zones (Figure 1):

- Inner zone: a circle with a 60 m radius from the turbine, targets the detection of carcasses of bats and small to large birds. Search transects within this zone are spaced every six metres to ensure an effective detection rate of smaller birds.
- Outer zone: comprises the zone between the 60 m and 100 m radius circles. The outer zone ensures adequate detection of carcasses of medium and large birds, which can fall further away from the turbines. Search transects within this zone are spaced at 12 m.

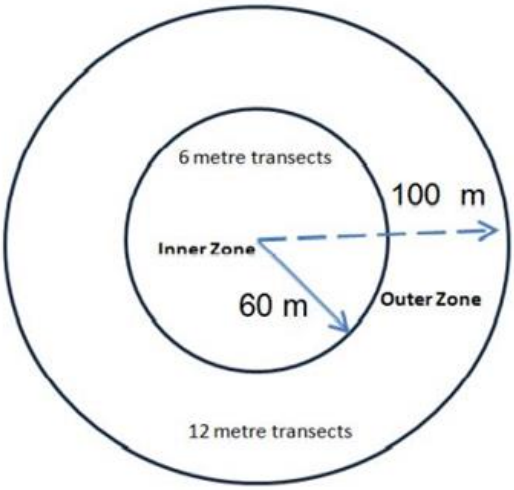

Figure 1: Inner and outer carcass search zones underneath the turbines. Source: CRWF BBAMP 2017

A follow-up 'pulse search' was then undertaken to 60 m within the inner zone. This pulse search was also undertaken each month and was completed within several days of the first search. Its aim was to detect additional mortality of birds and bats and resulted in each of the 19 selected turbines to be surveyed twice per month. Whilst the same 19 turbines were surveyed each month, the order in which they were surveyed was randomised from month to month, to provide an estimate of overall mortality across the extent of the site that was less impacted by patterns arising from spatial and temporal auto-correlation.

For each carcass detected, the following variables were recorded in the carcass search data sheet:

- GPS position, distance in metres and compass bearing of the carcass from the wind turbine tower.
- Substrate and vegetation under the carcass, particularly if it was found on a track or hard-stand area without vegetation as this may assist in quantifying the number of carcasses not found in areas where ground cover makes carcasses less visible.
- Species, age, number, sex (if possible), signs of injury and estimated date of strike
- Weather (including recent extreme weather events, if any), visibility, maintenance to the turbine and any other factors that may affect carcass discovery; and
- If the species is not able to be immediately identified, photographs will be provided to identified experienced ecologists within 2 business days of the find for identification and the ecologist must reply within 5 business days.

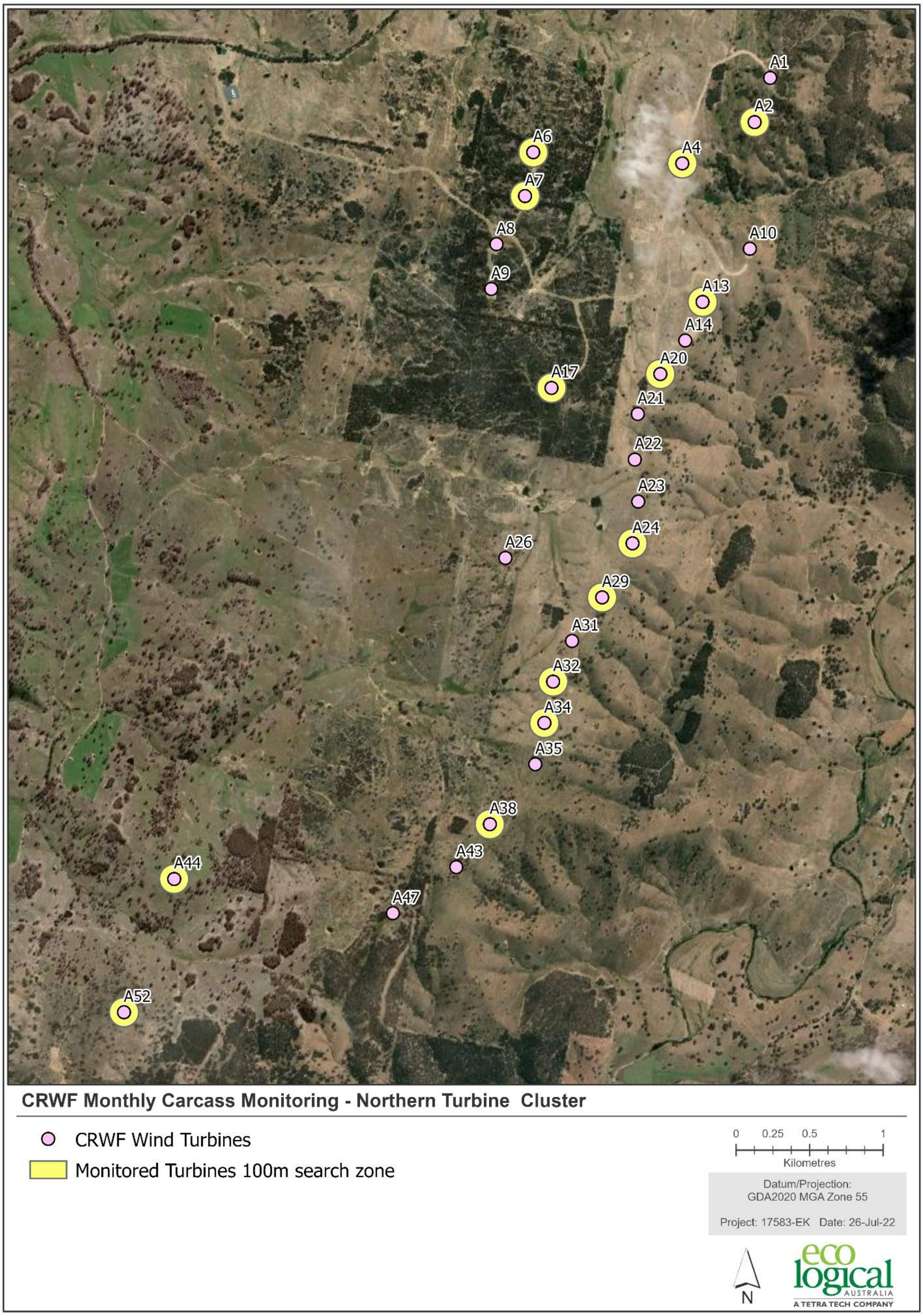

Figure 2: Northern portion (Pyramul cluster) of carcass monitoring turbines

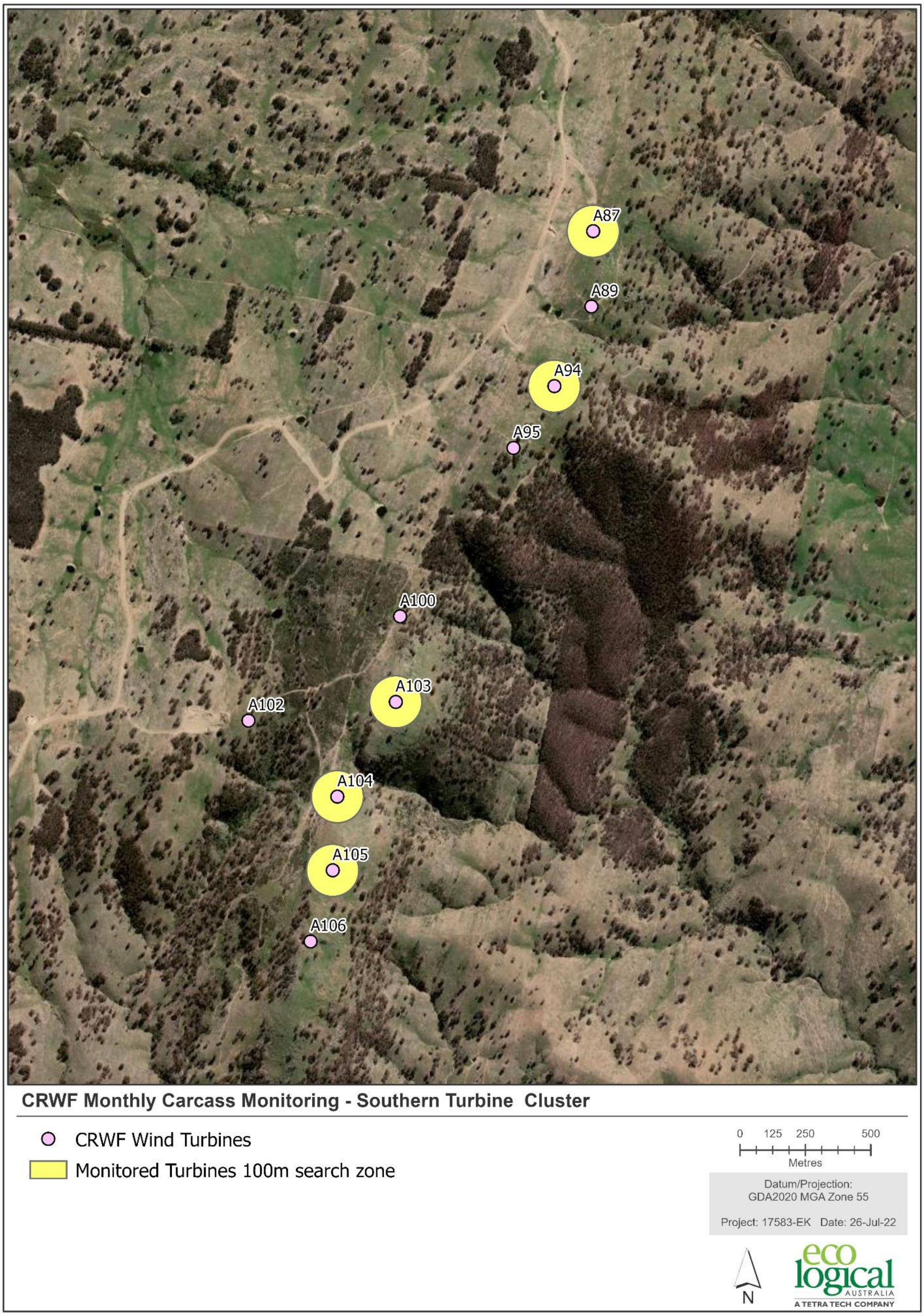

Figure 3: Southern portion (Sallys Flat cluster) of carcass monitoring turbines

2.2 Wedge-tailed Eagle and other raptors

Monitoring of raptor activity was undertaken throughout Year Two of operational monitoring. The flight path of all observed raptors was recorded using the digital geo-referenced software program ESRI ArcCollector, with the following covariate data also collected:

- Species
- Quantity
- Flight height (below Rotor Swept Area (RSA), within RSA, above RSA)
- Notes e.g. behaviour, harassment from other species.

3. Results

3.1 Carcass monitoring

A total of 23 bird and 15 bat carcasses were recorded during Year Two of the CRWF BBAMP implementation monitoring, inclusive of both formal and incidental monitoring. Bird carcasses comprised a total of seven bird species, whilst bat carcasses comprised a total of six microchiropteran species. One unidentified bird and two unidentified microbat carcasses were also recorded (Table 4).

The two most common bird species recorded were *Cracticus tibicen* (Australian Magpie) and Wedge-tailed Eagle, with seven carcasses of each species recorded. The two most common bat species recorded were *Austronomus australis* (White-striped Freetail Bat) and *Vespadelus vulturnus* (Little Forest Bat), with four carcasses of each species recorded. Wedge-tailed Eagle and White-striped Freetail Bat were the only two species recorded during both formal and incidental monitoring, with all other species recorded during formal monitoring only.

No impact triggers were identified for non-threatened species, as the required four or more carcass threshold for a species at a single turbine, over two successive monitoring events was not exceeded. No listed threatened species were recorded, therefore the threatened species impact trigger was also not exceeded. Detailed carcass monitoring results are presented in Appendix A, with a summary of all carcasses recorded during Year One and Year Two of monitoring presented in Appendix B.

Table 3: Bird and bat carcasses recorded from Year Two of carcass monitoring

Common Name	Scientific Name	Quantity	Turbine location(s)
Birds			
Australian Magpie	*Cracticus tibicen*	7	A20, A24, A32, A103, A105
Australian Wood Duck	*Chenonetta jubata*	3	A20, A24, A29
Collared Sparrowhawk	*Accipiter cirrocephalus*	2	A6, A38
Crested Pigeon	*Ocyphaps lophotes*	1	A44
Eastern Rosella	*Platycercus eximius*	1	A44
Magpie-lark	*Grallina cyanoleuca*	1	A7
Unknown bird	Aves (class)	1	A20
Wedge-tailed Eagle	*Aquila audax*	7	A20, A24, A35, A38, A43, A44
Bats – Microchiroptera			
Gould's Wattled Bat	*Chalinolobus gouldii*	2	A2, A6
Little Broad-nosed Bat	*Scotorepens greyii*	1	A52
Little Forest Bat	*Vespadelus vulturnus*	4	A2, A4, A52
Southern Forest Bat	*Vespadelus regulus*	1	A103
Southern Free-tailed Bat	*Mormopterus planiceps*	1	A52
Unknown microbat	Microchiroptera (suborder)	2	A4, A105
White-striped Freetail Bat	*Austronomus australis*	4	A17, A38, A44

Across Year Two of carcass monitoring, the number of both bird and bat carcasses recorded peaked during summer 2022/23 (Figure 4). The overall quantities of bird carcasses recorded was broadly consistent across the spring (eight bird carcasses) and summer (nine bird carcasses) period, as well as both autumn and winter (three carcasses respectively) (Figure 4). Spring followed by summer, also recorded the highest numbers of bird carcasses in Year One (ELA 2022), which coincides with the predominant bird breeding and sub-adult dispersal periods in south-eastern Australia (Menkhorst et al 2019), including for the two species with the highest recorded carcass numbers, Australian Magpie and Wedge-tailed Eagle (Table 3).

Bat carcasses were considerably higher during summer (11 bat carcasses), compared to all other seasons in Year Two, with only one (spring) and two (autumn and winter) bat carcasses recorded during these seasons (Figure 4). The increase in bat carcasses recorded during summer is likely driven by overall increased microbat activity in south-eastern Australia during the summer period, with this period coinciding with both Little Forest Bat and White-striped Freetail Bat (the two bat species most commonly recorded through carcass monitoring – Table 3) breeding and migratory events (Churchill 2008). These results were also broadly consistent with Year One, during which summer recorded the equal highest (along with autumn) number of bat carcasses (ELA 2022).

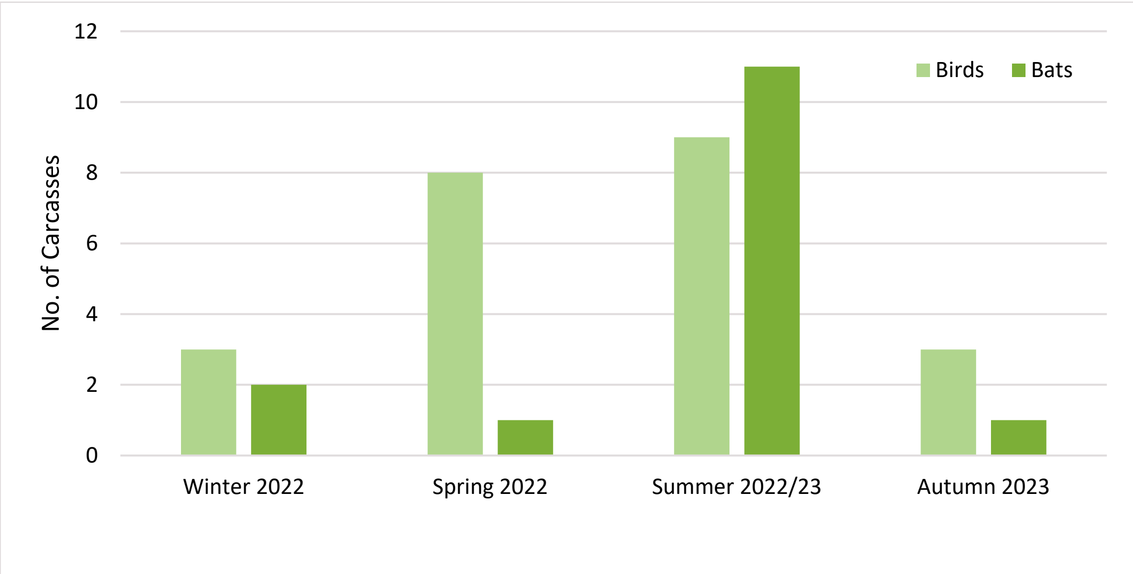

Figure 4: Bird and bat carcass seasonality from Year Two of carcass monitoring (both formal and incidental)

3.2 Wedge-tailed Eagle and other raptors

The flight paths of nine raptor species were recorded across the first two years of CRWF operational monitoring (Table 4). This includes one threatened raptor *Lophoictinia isura* (Square-tailed Kite) which is listed as vulnerable under the NSW BC Act and which was recorded opportunistically on one occasion.

The Wedge-tailed Eagle was by far the most common and abundant raptor recorded, with a total of 52 flights recorded and tracked. This species has been recorded across the full extent of CRWF, however, both individuals and adult pairs are most frequently recorded in the far northern (near turbines A1 to A10) and far southern (near turbines A102 to A106) sections of the CRWF site (Figures 5 - 6). The remaining raptor species were only recorded between one and two occasions during Year One and Year

Two monitoring (Table 4), with the exception of *Falco cenchroides* (Nankeen Kestrel), which was recorded 13 times across the full extent of the CRWF site (Figures 6 – 7).

Wedge-tailed Eagle, *Accipiter cirrocephalus* (Collared Sparrowhawk) and Nankeen Kestrel were each recorded during both Year One and Year Two monitoring, as well as during pre-approval surveys (Squadron Energy 2017). *Milvus migrans* (Black Kite), was recorded for the first time during Year Two monitoring, whilst a total of five raptor species recorded during Year One, were not subsequently recorded in Year Two (Table 4).

Wedge-tailed Eagle flight heights were predominantly undertaken within the RSA (34 of 52 flights), whilst all other raptor species recorded variable flight heights, both below and within the RSA (Table 4).

Table 4: Observed raptor flights during Year One and Year Two monitoring

Common Name	Scientific Name	Year One	Year Two	No. of individuals	No. of flights	Below RSA	Within RSA	Above RSA
Black Kite	*Milvus migrans*	No	Yes	1	1	0	1	0
Black-shouldered Kite	*Elanus axillaris*	Yes	No	1	1	0	1	0
Brown Falcon	*Falco berigora*	Yes	No	1	1	1	0	0
Brown Goshawk	*Accipiter fasciatus*	Yes	No	1	1	1	0	0
Collared Sparrowhawk	*Accipiter cirrocephalus*	Yes	Yes	2	2	1	1	0
Nankeen Kestrel	*Falco cenchroides*	Yes	Yes	13	13	9	4	0
Square-tailed Kite (V)	*Lophoictinia isura*	Yes	No	1	1	0	1	0
Wedge-tailed Eagle	*Aquila audax*	Yes	Yes	47	52	7	34	11
Whistling Kite	*Haliastur sphenurus*	Yes	No	1	1	0	1	0

V= Vulnerable to extinction, NSW BC Act

Searches were undertaken for Wedge-tailed Eagle and other raptor nests during spring 2022, within a 2 km buffer of the CRWF. No nests were recorded, as was also the case during pre-approval surveys. The non-raptor migratory and listed threatened bird species *Hirundapus caudacutus* (White-throated Needletail) was not recorded at any time across the first two years of CRWF operational monitoring.

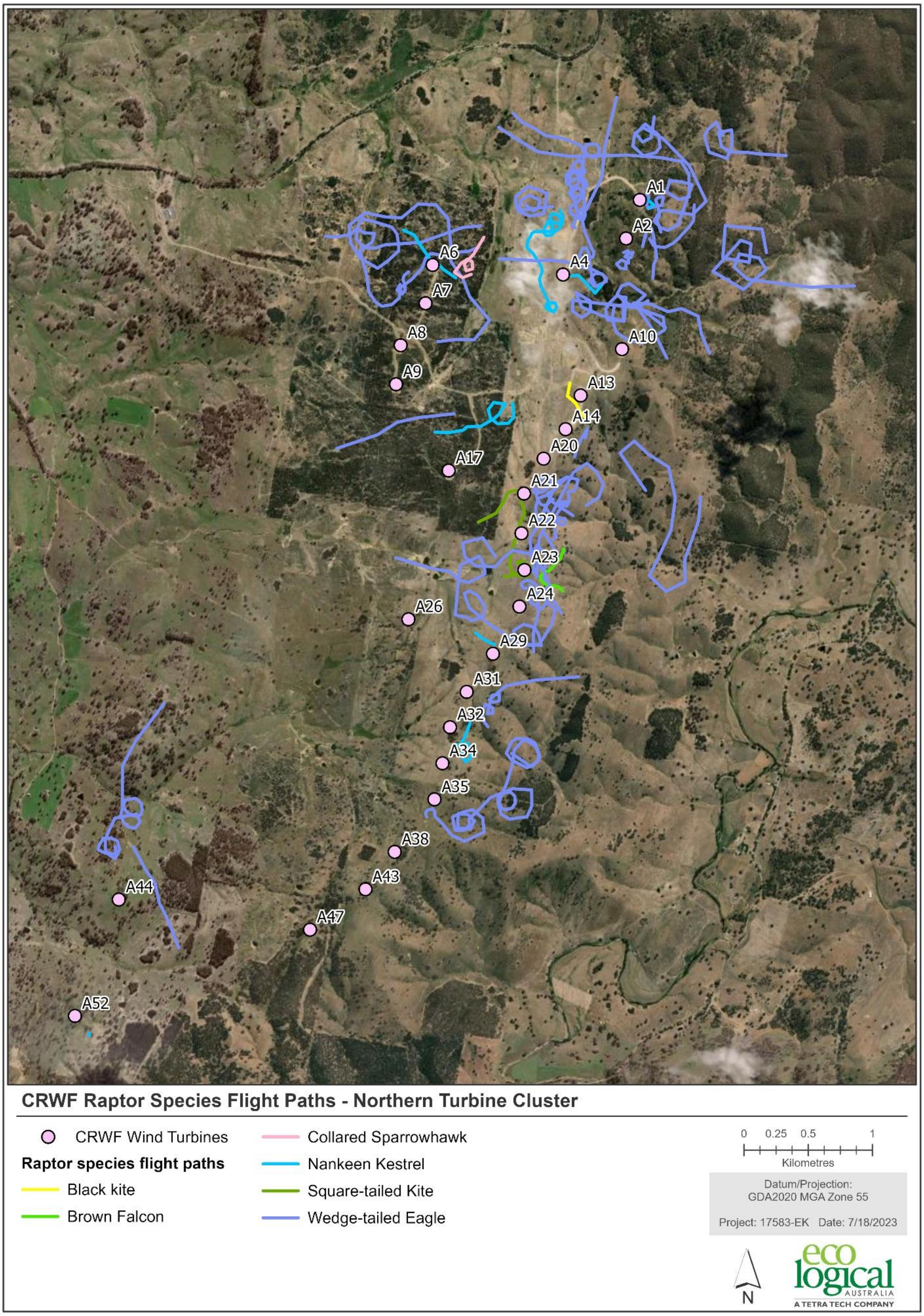

Figure 5: Raptor flight paths adjacent to northern (Pyramul cluster) portion of turbines

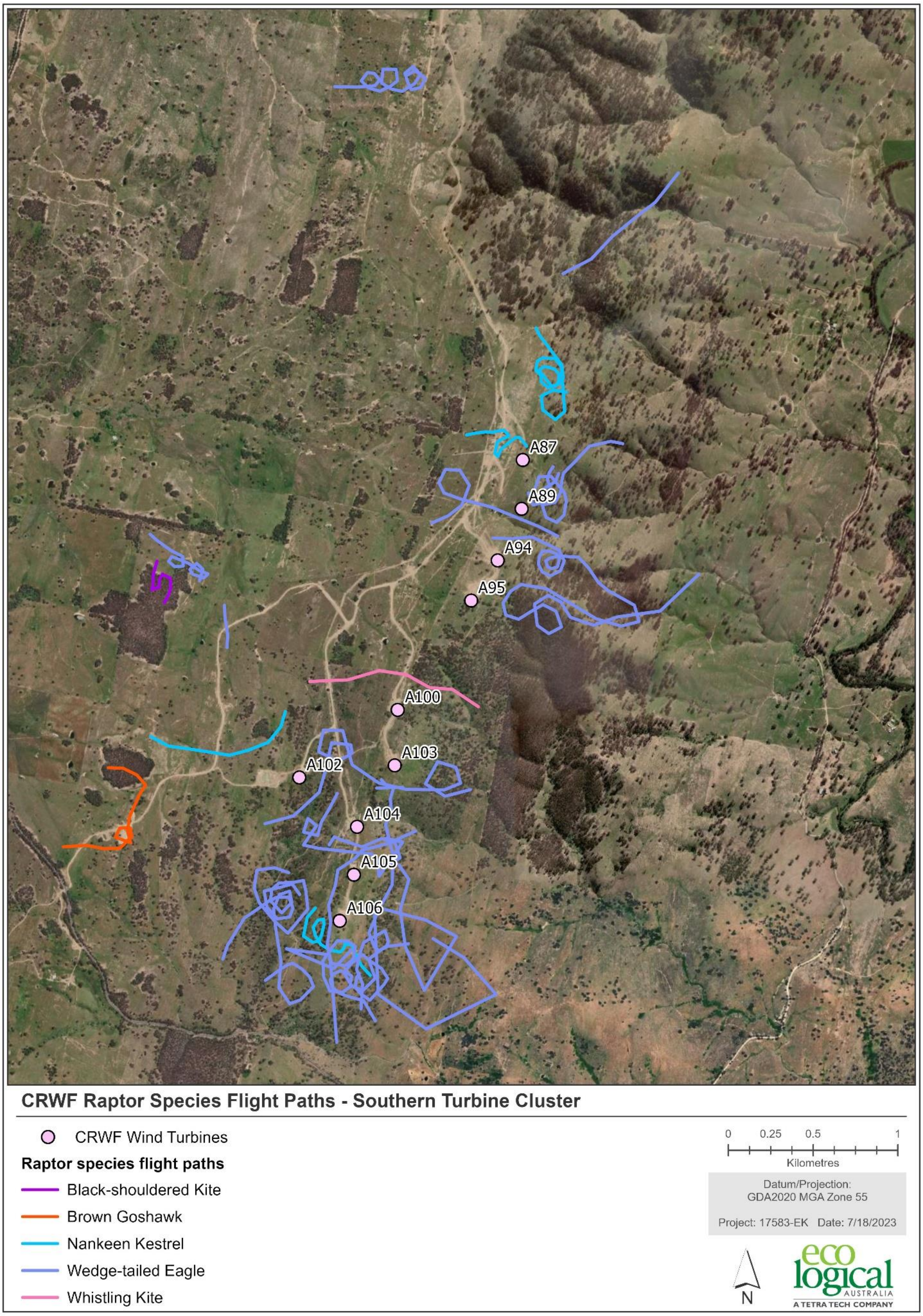

Figure 6: Raptor flight paths adjacent to southern (Sallys Flat cluster) portion of turbines

Across Year One and Year Two monitoring, Wedge-tailed Eagle observations were highest during autumn 2022 (19 flights) and summer 2022/23 (21 flights), with both of these periods also recording the highest number of Wedge-tailed Eagle carcasses, with four carcasses recorded during each season (Figure 7). Flight activity and carcass mortality was also positively correlated for all other raptor species, with spring 2021 recorded the highest number of flights (seven) and carcasses (four) (Figure 7). Outside of these peak seasonal periods, both the activity and number of Wedge-tailed Eagle carcasses remained relatively consistent, with flights ranging from two in winter 2022 to 11 in summer 2021/22 and carcasses ranging from zero (winter 2021, spring 2021 and spring 2022) to two (autumn 2023). Activity and carcass numbers of all other raptor species was also relatively consistent outside of the peak of spring 2021, with flights ranging from zero (winter 2022, spring 2022 and autumn 2023) to five (winter 2021) and either zero or one carcass being recorded during all other seasons (Figure 7).

During the peak seasons (autumn 2022 and summer 2022/23) of Wedge-tailed Eagle activity, both adult and sub-adult birds were recorded undertaking flights. During this period, 41% of flights were undertaken by adult birds and 35% were undertaken by sub-adult birds, with the remaining 24% of flights undertaken by birds unable to be definitively aged. Contrastingly, all Wedge-tailed Eagle fatalities recorded during both Year One and Year Two of the monitoring program were sub-adult birds, including during autumn 2022 and summer 2022/23 when eight of the twelve (12) total Wedge-tailed Eagle carcasses were recorded.

Analysis of all recorded sub-adult Wedge-tailed Eagle flight heights across Year One and Year Two monitoring shows that 86% of flights were undertaken predominantly within the RSA, compared to just 55% of flights for adult birds. Additionally, three adult Wedge-tailed Eagle pairs have been consistently recorded across the CRWF site throughout the course of the monitoring program (pairs in the vicinity of turbine A1 to A10, turbine A21 to A24 and turbine A102 to A106), with a pair being recorded as early as the first month of monitoring (June 2021) through to as recent as the second last month of monitoring in late-April 2023. Given the occurrence of these resident pairs within the CRWF site and the quantity of sub-adult birds recorded, it is likely that many of the sub-adult Wedge-tailed Eagles recorded are non-resident and therefore relatively unfamiliar with the site.

A group of 38 sub-adult birds in September 2021 and a smaller but still notable group of nine sub-adult birds in February 2023, were recorded flying in congregation within 10 km of the CRWF site. The September 2021 observation did not coincide with an increase in mortality (indeed the first Wedge-tailed Eagle mortality was not recorded until January 2022), however, four fatalities were recorded from late-January to mid-February 2023, broadly coinciding with the February 2023 sighting. These large groups of sub-adult Wedge-tailed Eagles, which are typically highly mobile (Debus 2019), demonstrate that on occasion, large quantities of sub-adult birds may be moving through the CRWF site. Collectively, these results and observations suggest a heightened risk to sub-adult birds compared to adult birds.

All Wedge-tailed Eagle carcasses were recorded along the main ridge of the Pyramul turbine cluster (northern section – see Figure 5). Interestingly however, no carcasses were recorded at the turbines with the highest concentration of flight activity being in the far northern (near turbines A1 to A10) and far southern (near turbines A102 to A106) sections of the CRWF site (Figures 5 - 6), with these locations also home to two of the three adult Wedge-tailed Eagle pairs recorded on site.

The peak period of other raptor species flight activity and carcass records (spring 2021) coincided with a regional mouse plague which resulted in increased raptor presence in the region, in particular Nankeen Kestrel, which is a species known to predate on small mammals including mice (Debus 2019). During this period, Nankeen Kestrel accounted for four of the seven recorded flights and two of the four recorded carcasses during spring 2021.

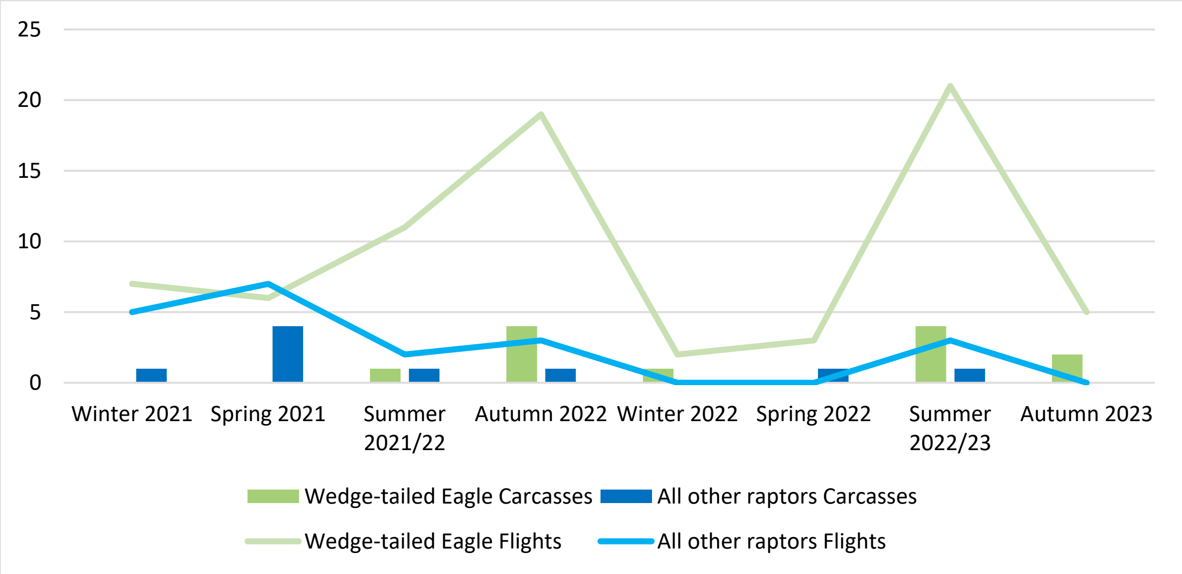

Figure 7: Wedge-tailed Eagle and all other raptor species flights and mortality during Year One and Year Two monitoring

4. Discussion

The CRWF BBAMP outlines the monitoring requirements and performance criteria to be achieved with regards to the management of bird and bat species. The following section provides a summary of progress against each monitoring requirement and/or performance criteria relevant to Year Two implementation of the BBAMP.

4.1 Bird and bat mortality estimates

Carcass monitoring data along with data from scavenger and observer (searcher) efficiency trials undertaken during the two year initial operational monitoring program (see ELA 2022) have been utilised to provide estimates of total bird and bat mortality across the CRWF. Symbolix were commissioned by Squadron Energy to undertake this analysis, with Appendix C providing the full Symbolix report which details the analysis undertaken, whilst the sections below present a summary of the mortality estimation methodology and results.

4.1.1 Searcher efficiency trials

Symbolix undertook analysis of the searcher efficiency trials undertaken in Year One of monitoring (see ELA 2022) in order to calculate overall detectability proportions of bird and bat carcasses for the CRWF. Bird, bird proxy (domestic rats), bat and bat proxy (domestic mice) carcasses were utilised across searcher efficiency trials, however, as bird proxies had much lower detection than birds (56% compared with 92% detection), they do not appear to be a suitable proxy and as such, were removed from the detectability model. Bat and bat proxies had similar detectability and were therefore combined for use in the model. As such, separate detection efficiencies were calculated for birds and bats / bat proxies, with results presented in Table 5 below.

Overall detectability for birds was calculated to be 92%, with a lower and upper 95% confidence interval of 78% and 98%, whilst for bats, the overall detectability was 60%, with a lower and upper 95% confidence interval of 39% and 79%.

Table 5: Detection efficiencies for birds and bats

Variable	Birds	Bats / Bat proxies
Number of carcasses placed	36	25
Number of carcasses found	33	15
Mean detectability proportion	0.92	0.60
Detectability lower bound (95% confidence interval	0.78	0.39
Detectability upper bound (95% confidence interval	0.98	0.79

4.1.2 Scavenger efficiency trials

Symbolix also undertook analysis of the scavenger efficiency trials undertaken in Year One of monitoring (see ELA 2022) in order to calculate median time to total carcass removal (loss) by scavenger, for birds and bats. Both bird proxies and bat proxies were scavenged in notably less time than bird and bat carcasses and therefore were removed from the model as they do not appear to be suitable proxies.

The best approximating model combined both birds (excluding Wedge-tailed Eagle) and bats and as such, a combined bird / bat model and a separate Wedge-tailed Eagle model were run. As only three Wedge-tailed Eagle carcasses were available for use in trials, they were combined with an additional 37 Wedge-tailed Eagle records from Stark and Muir (2020) to provide a more robust dataset.

The median time to total loss via scavenge for birds / bats combined was calculated at 3.78 days, with a lower and upper 95% confidence window of 1.72 and 8.30 days. For Wedge-tailed Eagle, the median time to total loss was 217 days, with a lower and upper 95% confidence window of 75 and 625 days.

4.1.3 Coverage factor

Two other key components of the mortality estimations are the coverage factor and proportion of turbines searched. The coverage factor estimates the probability that a carcass falling at a searched turbine will fall within the inner (60 m radius) and outer (100 m radius) search areas. In order to calculate this, Symbolix generated carcass fall-zone distributions for each species class (bat, small – medium bird and large bird i.e. Wedge-tailed Eagle) based on the turbine sizes used at CRWF.

On average, it was calculated that 87% of bat and 59% of small – medium birds would fall within the inner 60 m radius search zone, whilst 100% of bats and 94% of small – medium birds would fall within the outer 100 m radius search zone. For Wedge-tailed Eagle, it was calculated that 48% would fall within the inner 60 m radius search zone and 83% would fall within the outer 100 m radius search zone.

The proportion of turbines searched is required as an input to calculate the overall mortality estimation, which for the CRWF carcass monitoring program, involved 19 of 37 total turbines.

4.1.4 Bird mortality estimate

A total of 41 bird carcasses were recorded during formal surveys across Year One and Year Two of the CRWF carcass monitoring program. Using this data, combined with the mortality estimate model inputs described above, the median resulting estimate of total mortality is 238 birds lost at CRWF over the two year period, with a 95% confidence interval of equal to or fewer than 339 birds lost over the same time period. Using the median estimate, this corresponds to an estimated mortality rate of 3.22 birds per turbine per year. Year One and Year Two of monitoring had similar median estimated bird mortality with 126 birds calculated for Year One and 115 birds for Year Two.

4.1.5 Wedge-tailed Eagle mortality estimate

Whilst Wedge-tailed Eagle carcasses are also included in the total bird mortality estimate above, a separate model was run for this species given its unique characteristics with reference to the model inputs described above and its heightened turbine collision risk (Stark and Muir 2020). A total of eight Wedge-tailed Eagle carcasses were recorded during formal surveys across Year One and Year Two of the CRWF carcass monitoring program. The resulting median estimate of total mortality is 17 Wedge-tailed Eagles lost at CRWF over the two year period, with a 95% confidence interval of equal to or fewer than 27 individuals lost over the same time period. Using the median estimate, this corresponds to an estimated mortality rate of 0.11 Wedge-tailed Eagles per turbine per year. Year One and Year Two of monitoring recorded the same median estimated bird mortality at nine birds per year.

Wedge-tailed Eagle mortality estimates do not apply an upper limit on the number of birds which could be on site, assuming that Wedge-tailed Eagle presence and activity is constant all year round and that there is an unlimited supply of potential carcasses to be found. Components of the monitoring results presented in Section 3.2 above are contrary to these assumptions. For example, it has been demonstrated that Wedge-tailed Eagle activity fluctuated across the two year period (see Figure 7) and the presence of three adult pairs with their associated territories, would likely limit the total number of individuals present across the CRWF site at any given time.

4.1.6 Bat mortality estimate

A total of 28 bat carcasses were recorded during formal surveys across Year One and Year Two of the CRWF carcass monitoring program. The median resulting estimate of total mortality is 176 bats lost at CRWF over the two year period, with a 95% confidence interval of equal to or fewer than 279 bats lost over the same time period. Using the median estimate, this corresponds to an estimated mortality rate of 2.38 bats per turbine per year. Year One and Year Two of monitoring had similar median estimated bat mortality with 100 bats calculated for Year One and 86 bats for Year Two.

Bat mortality estimates do not apply an upper limit on the number of bats which could be on site, assume that bat presence and activity is constant all year round and that there is an unlimited supply of potential bat carcasses to be found. As detailed in Section 3.1, however, seasonal peaks in bat presence and activity have been observed at CRWF, as evidenced by the increased bat mortality during summer (see Figure 4), coinciding with known migratory and breeding events for locally common species including Little Forest Bat and White-striped Freetail Bat (Churchill 2008). Given these discrepancies between the mortality estimate model and the monitoring data, the model may overestimate bat mortality during periods of low activity and presence (i.e. late autumn to early spring), but equally may underestimate bat mortality during periods of high activity and presence.

4.2 Progress of management objectives and completion criteria

Table 6 below details the specific management objectives and performance criteria relevant to the implementation of the BBAMP, along with a comment regarding relevant results and adherence based on Year Two monitoring. All CRWF management objectives and performance criteria are currently being achieved.

Table 6: Management objectives and performance criteria and relevant results from Year Two monitoring

Management objectives	Management activities	Performance criteria	Comments
Mortality monitoring	18 turbines to be searched each month to 100 m in accordance with the inner- and outer zone search protocol. The same turbines will be searched each month for a period of 24 months, following which the need for further surveys will be reviewed.	Operational phase mortality surveys undertaken monthly at a minimum of 18 turbines and for at least two years, with a review after the first two years to determine if a change in the methodology is required.	Year Two of monthly carcass mortality monitoring successfully completed across 19 selected turbines (Section 3.1); No threatened species or non-threatened species impact triggers initiated from Year Two results.
Annual reports	Preparation of annual reports to be submitted to relevant State departments for the first two years after the completion of yearly monitoring activities.	Annual reports to be delivered within three months of completion of yearly monitoring;	This annual report (to be provided to relevant State department) details all relevant results from Year Two implementation monitoring.

Management objectives	Management activities	Performance criteria	Comments
		Annual reports to include results of yearly monitoring, any impact triggers or unacceptable impacts identified, mitigation measures implemented, application of the decision making framework and recommendations for the following year.	
Mitigation measures to reduce risk	Carrion removal program – stock and kangaroo carcasses will be removed from within 200 m of wind turbines on a monthly basis and disposed of; Restrict lambing and grain stock feeding within 200 m of turbines; Minimise external and internal lighting; Where required - use of visual deterrents (e.g. marker balls and/or flags) on overhead powerlines where they cross waterways.	Carcasses removed and activity recorded in management log book; No increase in raptor mortality during lambing season or due to grain feeding; Mortality at turbines near light sources does not significantly exceed that at unlit turbines. No incidental records of bird mortality from powerline collision around waterways.	Dead sheep identified for removal at turbines A4, A21 and A87; No increase in raptor mortalities recorded during the 2022 lambing season (September – October 2022) and it is noted that lambing did not occur in paddocks within the CRWF operational site. All turbines are located away from major light sources; No incidental records of bird mortality have been recorded underneath powerlines around waterways.

5. Conclusion and Recommendations

5.1 General conclusions

Year Two operational phase monitoring of the CRWF BBAMP was successfully implemented from June 2022 to May 2023. The purpose of the monitoring program is to monitor the impacts from the operation of the CRWF on birds and bats through a range of methodologies, and effectively mitigate and manage any significant risks or impacts which arise.

Formal monthly carcass monitoring was undertaken across 19 selected turbines within a 60 m inner and 100 m outer search zone. A total of 20 bird carcasses and/or identifiable remains from at least seven species were recorded, with an additional three bird carcasses recorded incidentally. A total of 13 bat carcasses and/or identifiable remains from at least six microbat species were recorded, with an additional two microbat carcasses recorded incidentally. In no instances were four or more carcasses from the same non-threatened bird or bat species recorded at the same turbine during successive searches and as such, the impact trigger for non-threatened species was not exceeded in Year Two of monitoring. Additionally, no threatened species carcasses were recorded and as a result, the impact trigger for threatened species was also not exceeded.

A total of nine raptor species flight activities were monitored and tracked across the first two years of CRWF operational monitoring, with eight individual species recorded during Year One and four individual species recorded during Year Two. Raptor flight activity was positively correlated with increased raptor mortality for both Wedge-tailed Eagle and all other raptor species combined (see Figure 7) across the two year operational monitoring period.

5.2 Bird and bat mortality estimate conclusions

Overall mortality estimates for birds, bats and Wedge-tailed Eagles were calculated by Symbolix using data inputs from Year One and Year Two of the CRWF operational monitoring period. The median mortality estimate for birds lost on site over the two year monitoring period was 238 birds, which corresponds to a mortality rate of 3.22 birds per turbine per year. Whilst Wedge-tailed Eagle is included in this total bird mortality estimate, due to the unique characteristics of the species, a mortality estimation was also calculated separately for the species which is discussed further below.

The median estimate of 238 birds is a considerable increase from the 41 birds recorded during formal carcass monitoring and is largely driven by high scavenger efficiency for birds (excluding Wedge-tailed Eagle) and the extrapolation required given the potential for birds to fall outside of the 60 m inner (41% of birds) and 100 m outer (6%) search zone, combined with the relative proportion of turbines searched (19 of 37 turbines). Of the 12 identifiable bird species recorded during both formal and informal surveys (Appendix B), all are locally common, none are threatened species listed under State or Commonwealth legislation and all are listed as Least Concern under the International Union for Conservation of Nature (IUCN) Red List of threatened species (IUCN 2022). Additionally, with the exception of Square-tailed Kite, no threatened bird species recorded during the two year monitoring period including Bird Utilisation Surveys (BUS) (ELA 2022) or pre-approval baseline surveys (ELA 2012) were recorded flying within the RSA. Combined with the monitoring data collected to date, it is therefore unlikely that any bird species has been significantly impacted by the operation of the CRWF. Given this, no bird species (with the exception of Wedge-tailed Eagle – see below) detailed in the CRWF BBAMP Risk Assessment (Squadron Energy 2017) requires an updated risk rating as per Table 6 of the BBAMP.

The median mortality estimate for Wedge-tailed Eagles lost on site over the two year monitoring period was 17 birds, which corresponds to a mortality rate of 0.11 Wedge-tailed Eagles per turbine per year. This median estimate is slightly more than double the eight Wedge-tailed Eagle carcasses recorded during formal carcass monitoring and is largely driven by the extrapolation required given the relatively high potential for this species to fall outside of the 60 m inner (52% of carcasses) and 100 m outer (17% of carcasses) search zone, combined with the relative proportion of turbines searched (19 of 37 turbines). It is noted however, that incidental monitoring frequently took place across all 37 turbines on at least a monthly basis and often times, covered areas outside of the outer search zone, for example, along the Pyramul cluster of turbines which are positioned along a single ridgeline and access road (see Figure 2).

The capacity for incidental monitoring to detect Wedge-tailed Eagle mortality at CRWF is demonstrated through the species high mean detectability (92%) and median time to total loss via scavenge (217 days) and evidenced by the relatively high proportion of carcasses recorded via incidental monitoring (four) compared with formal monitoring (eight), being 33.33%. Contrastingly, the proportion of all other bird species carcasses recorded via incidental monitoring (three) compared with formal monitoring (33) was 8.33%, whilst for bats the proportion was 12.50% (four of 32 total bat carcasses). Given this, it is likely that the total quantity of Wedge-tailed Eagles impacted during the first two years of CRWF operations sits between the 12 birds recorded during carcass monitoring and the 17 birds calculated as the median mortality estimate, and may indeed be closer to the former than the latter.

As detailed above in Section 3.2, all 12 recorded Wedge-tailed Eagle carcasses to date have been sub-adult birds, with sub-adult birds also recorded flying at higher proportions within the RSA. It is apparent that these young birds, many of which are unlikely to be resident across the CRWF, are at heightened risk of turbine strike. Adult Wedge-tailed Eagle pairs which form the basis of the local population, have been recorded consistently across the CRWF site since the commencement of the two year monitoring period and to date appear unimpacted by operations. The species is locally and regionally common throughout its widespread range and is considered to be increasing in population size (BirdLife International 2023), although atlas reporting rates declined both nationally and in New South Wales in the two decades to 2000 (Debus 2019). The generation length for Wedge-tailed Eagle is 18.1 years (BirdLife International 2023) and in south-eastern Australia, breeding success varies from 0.6 to 0.11 young per pair per year (Debus 2019). Whilst adult pairs have persisted onsite, continued mortality of younger birds may have longer term impacts to the local population if individuals birds are not able to disperse from or re-populate the local area readily and as such, continued monitoring of Wedge-tailed Eagles at CRWF is recommended (see Section 5.3 below).

Wedge-tailed Eagle was assessed as 'Moderate' risk in the CRWF BBAMP Risk Assessment (Squadron Energy 2017), given it was considered 'Almost Certain' that a risk event of 'Moderate' consequence could occur in any year. With a total of 12 mortalities recorded within the initial two year monitoring period and potentially more given the results of mortality estimation modelling detailed above, the likelihood of a risk event occuring meets the definition of the 'Certain' category given that, *it is very probable that the risk event could occur in any year (>95%)*. As such, the overall risk rating for Wedge-tailed Eagle requires updating from 'Moderate' to 'High'.

The median mortality estimate for bats lost on site over the two year monitoring period was 176 bats, which corresponds to a mortality rate of 2.38 bats per turbine per year. This median estimate is a considerable increase from the 28 bats recorded during formal carcass monitoring and is largely driven by the relatively high scavenger efficiency (3.78 days to total loss), low mean detectability (60%) and the extrapolation required given the relative proportion of turbines searched (19 of 37 turbines). Of the seven identifiable microbat species and one flying-fox species recorded during both formal and informal surveys (Appendix B), all are locally common (when present), none are threatened species listed under State or Commonwealth legislation and all are listed as Least Concern under the IUCN Red List of threatened species (IUCN 2022). However, a total of six threatened species listed under State and/or Commonwealth legislation were recorded or potentially recorded during pre-approval baseline surveys (ELA 2012), including one threatened species, *Saccolaimus flaviventris* (Yellow-bellied Sheathtail-bat), with two individuals recorded during operational carcass monitoring at the nearby Bodangora Wind Farm (Nature Advisory 2021).

Consistent with many other Australian operational wind farms, the majority of bat mortalities were of White-striped Freetail Bat (Stark and Muir 2020), with the second highest number of mortalities being Little Forest Bat, a species with commonly recorded mortalities, however, in much fewer numbers compared with White-striped Freetail Bat (Stark and Muir 2020; Nature Advisory 2021). Both species are locally and regionally common and are amongst the most reliably recorded microbat species in central west NSW (ELA unpublished data). However, given the species relatively low reproduction rate (typically one young per adult female per year – Churchill 2008) and uncertainty as to their local populations sizes, continued monitoring at CRWF is recommended (see Section 5.3 below).

White-striped Freetail Bat was assessed as 'Low' risk in the CRWF BBAMP Risk Assessment (Squadron Energy 2017), whilst Little Forest Bat was assessed as 'Negligible' risk. With a total of 13 and nine recorded mortalities respectfully for these two species within the initial two year monitoring period and a high likelihood of there being additional mortalities given the results of mortality estimation modelling detailed above, the likelihood of a risk event for both species meets the definition of the 'Certain' category given that, *it is very probable that the risk event could occur in any year (>95%)*. Whilst this update does not change the risk rating of White-striped Freetail Bat, the risk rating of Little Forest Bat requires updating to 'Low'.

5.3 Ongoing monitoring recommendations

Ongoing monitoring focused on Wedge-tailed Eagle and other raptor species, along with bats (both microbats and flying-foxes) is proposed for CRWF. A revised seasonal carcass monitoring program to be undertaken during the middle month of each season (i.e. January, April, July, October) is proposed to cover the full annual life cycle of the target species groups and provide ongoing seasonal-based data for analysis and comparison. The proposed monitoring program will involve a single survey of the 60 m inner search zone of all 37 turbines once per season. Surveying each turbine to 60 m rather than a subset of turbines to 100 m is considered a favourable approach given over 85% of all carcasses recorded during the two year initial operational monitoring period were recorded within 60 m of the turbine (see Appendix A and ELA 2022). For Wedge-tailed Eagle, the species with the largest potential fall zone (Symbolix 2023), the maximum distance a carcass was recorded from a turbine was 75 m, which given the size of the species, would still be visible in most instances whilst surveying a 60 m radius search zone. During surveys, flight paths of all raptor species (along with White-throated Needletail, if present) would continue to be tracked in real time using spatial mapping software such as ESRI Field Maps. It is proposed to continue with this revised monitoring program for a two year period, commencing from the date of its approval and formal adoption. The program would then be reviewed as part of annual monitoring at the completion of this two year period.

The continuation of incidental monitoring carried out by CRWF operational staff will also ensure all encountered bird and bat carcasses, along with relevant management issues such as carrion presence and disposal, are reported and managed on a daily basis.

5.4 General recommendations

Given the successful implementation of Year Two of the CRWF BBAMP monitoring program, Squadron Energy are considered compliant with the relevant approval conditions with regards to bird and bats, as detailed in the BBAMP.

Upon agreement of the revised ongoing monitoring program, it is recommended that the CRWF BBAMP be updated to reflect these changes, along with updated risk assessments for the relevant species detailed above in Section 5.2.

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Appendix A Carcass monitoring data

Table 7: Monthly carcass monitoring data – Year Two of operational phase monitoring

Date	Common Name	Species Group	Turbine Number	Distance from Turbine (m)	Bearing from Turbine (degrees)	Groundcover beneath carcass	Monitoring methodology
2/06/2022	Gould's Wattled Bat	Bat	A6	3	15	Hardstand (e.g. pad/road)	Formal
11/07/2022	Unknown Microbat	Bat	A4	2	180	Hardstand (e.g. pad/road)	Formal
11/07/2022	Australian Magpie	Bird	A24	50	90	Native grass and herbs	Formal
5/08/2022	Wedge-tailed Eagle	Bird	A24	44	330	Bare soil / rock	Formal
5/08/2022	Australian Magpie	Bird	A20	130	310	Hardstand (e.g. pad/road)	Formal
8/09/2022	Australian Wood Duck	Bird	A24	80	340	Exotic grass and herbs	Formal
6/10/2022	Australian Wood Duck	Bird	A20	53	163	Hardstand (e.g. pad/road)	Formal
6/10/2022	Australian Magpie	Bird	A32	52	25	Exotic grass and herbs	Formal
3/11/2022	Magpie-lark	Bird	A7	52	170	Woodland	Formal
3/11/2022	Australian Wood Duck	Bird	A29	8	260	Hardstand (e.g. pad/road)	Formal
4/11/2022	Australian Magpie	Bird	A105	23	15	Hardstand (e.g. pad/road)	Formal
4/11/2022	Australian Magpie	Bird	A103	20	17	Hardstand (e.g. pad/road)	Formal
7/11/2022	White-striped Freetail Bat	Bat	A44	27	180	Exotic grass and herbs	Formal
7/11/2022	Collared Sparrowhawk	Bird	A6	4	170	Hardstand (e.g. pad/road)	Formal
19/12/2022	Australian Magpie	Bird	A24	70	184	Native grass and herbs	Formal
17/01/2023	Unknown Microbat	Bat	A105	20	294	Hardstand (e.g. pad/road)	Formal
25/01/2023	Wedge-tailed Eagle	Bird	A35	35	345	Hardstand (e.g. pad/road)	Incidental
30/01/2023	Wedge-tailed Eagle	Bird	A38	13	260	Hardstand (e.g. pad/road)	Incidental
30/01/2023	White-striped Freetail Bat	Bat	A38	10	N/A	Hardstand (e.g. pad/road)	Incidental

Date	Common Name	Species Group	Turbine Number	Distance from Turbine (m)	Bearing from Turbine (degrees)	Groundcover beneath carcass	Monitoring methodology
2/02/2023	White-striped Freetail Bat	Bat	A17	20	N/A	Hardstand (e.g. pad/road)	Incidental
13/02/2023	Little Forest Bat	Bat	A2	52	30	Hardstand (e.g. pad/road)	Formal
13/02/2023	Wedge-tailed Eagle	Bird	A20	66	284	Native grass and herbs	Formal
13/02/2023	Australian Magpie	Bird	A24	37	170	Native grass and herbs	Formal
14/02/2023	Collared Sparrowhawk	Bird	A38	15	190	Native grass and herbs	Formal
14/02/2023	Eastern Rosella	Bird	A44	77	345	Native grass and herbs	Formal
14/02/2023	Crested Pigeon	Bird	A44	90	135	Native grass and herbs	Formal
14/02/2023	Little Broad-nosed Bat	Bat	A52	10	270	Hardstand (e.g. pad/road)	Formal
14/02/2023	Little Forest Bat	Bat	A52	8	170	Hardstand (e.g. pad/road)	Formal
14/02/2023	Little Forest Bat	Bat	A52	25	200	Hardstand (e.g. pad/road)	Formal
14/02/2023	Southern Free-tailed Bat	Bat	A52	25	200	Hardstand (e.g. pad/road)	Formal
14/02/2023	Southern Forest Bat	Bat	A103	15	55	Hardstand (e.g. pad/road)	Formal
17/02/2023	Wedge-tailed Eagle	Bird	A43	25	0	Hardstand (e.g. pad/road)	Incidental
17/02/2023	White-striped Freetail Bat	Bat	A38	12	10	Hardstand (e.g. pad/road)	Formal
17/02/2023	Gould's Wattled Bat	Bat	A2	25	70	Hardstand (e.g. pad/road)	Formal
28/03/2023	Wedge-tailed Eagle	Bird	A38	63	293	Native grass and herbs	Formal
12/05/2023	Wedge-tailed Eagle	Bird	A44	75	90	Native grass and herbs	Formal
12/05/2023	Unknown Bird	Bird	A20	45	315	Hardstand (e.g. pad/road)	Formal
15/05/2023	Little Forest Bat	Bat	A4	28	195	Hardstand (e.g. pad/road)	Formal

Appendix B Bird and bat carcass summary data

Table 8: Bird and bat carcass totals recorded during formal and informal monitoring across both Year One and Year Two

Common Name	Scientific Name	Year One	Year Two	Total
Birds				
Australian Magpie	*Cracticus tibicen*	9	7	16
Australian Raven	*Corvus coronoides*	1	-	1
Australian Wood Duck	*Chenonetta jubata*	1	3	4
Brown Falcon	*Falco berigora*	2	-	2
Collared Sparrowhawk	*Accipiter cirrocephalus*	-	2	2
Crested Pigeon	*Ocyphaps lophotes*	-	1	1
Eastern Rosella	*Platycercus eximius*	-	1	1
Galah	*Eolophus roseicapilla*	1	-	1
Magpie-lark	*Grallina cyanoleuca*	-	1	1
Nankeen Kestrel	*Falco cenchroides*	5	-	5
Pacific Black Duck	*Anas superciliosa*	1	-	1
Unknown bird	Aves (class)	-	1	1
Wedge-tailed Eagle	*Aquila audax*	5	7	12
Bats – Microchiroptera				
Gould's Wattled Bat	*Chalinolobus gouldii*	-	2	2
Large Forest Bat	*Vespadelus darlingtoni*	1	-	1
Little Broad-nosed Bat	*Scotorepens greyii*	-	1	1
Little Forest Bat	*Vespadelus vulturnus*	5	4	9
Southern Forest Bat	*Vespadelus regulus*	-	1	1
Southern Free-tailed Bat	*Mormopterus planiceps*	1	1	2
Unknown microbat	Microchiroptera (suborder)	3	2	5
White-striped Freetail Bat	*Austronomus australis*	9	4	13
Bats – Megachiroptera				
Little Red Flying-fox	*Pteropus scapulatus*	1	-	1

Appendix C CWRF mortality estimate statistical analysis (Symbolix 2023)

Crudine Ridge Wind Farm Mortality Estimate - Year 1 to 2

Prepared for Squadron Energy, 21 July 2023, Ver. 1.0

This report outlines an analysis of the mortality data collected at Crudine Ridge Wind Farm (CRWF) from 2021-06-01 to 2023-05-15 for Squadron Energy. The analysis is broken into the three related components below:

- Searcher efficiency / detectability – estimated from trials in August 2021 and April 2022
- Scavenger loss rates – consisting of trials in August 2021 and April 2022
- Mortality estimates - based on monthly surveys at 19 turbines, from 2021-06-01 to 2023-05-15

Mortality estimates have been provided for the following:

- Bats - Cumulative, Year 1 and Year 2
- Birds - Cumulative, Year 1 and Year 2
- Wedge-tailed Eagles only - Cumulative, Year 1 and Year 2

1 Available data

Survey data was collected and provided by Eco Logical Australia (ELA). A brief summary of the data is provided below, and the ultimate focus of this report is a discussion of the potential mortality.

Turbine parameter data (rotor diameter and height) was provided by Squadron Energy.

Species archetype data was taken from CL Hull and Muir (2010)

1.1 Data cleaning

Data was used as provided by ELA, with no additional cleaning required.

2 Methodology overview

Mortality through collision is an ongoing environmental management issue for wind facilities. Different sites present different risk levels; consequently different sites have different monitoring requirements. In order to estimate the mortality loss at a given site (in a way that is comparable with other facilities) we must account for differences in survey effort, searcher and scavenger efficiency. We used a Monte Carlo method to achieve this.

Best practice (M. M. Huso 2011) requires an estimator of the form:

$$\hat{M}_{ij} \cong \frac{C_{ij}}{\hat{g}_{ij}} \quad (1)$$

where

- $\hat{M}_{ij}$ is the estimated mortalities at turbine i during search j
- C_{ij} is the number of carcasses found
- $\hat{g}_{ij}$ is the estimate of the detection probability for that search and turbine

For a given turbine, $\hat{g}_{ij}$ is a function of

$$\hat{g}_{ij} \cong a_i r_{ij} p_{ij} \quad (2)$$

- a_i is the fraction of total carcasses within the searched area (note this is *not* the same as the fraction of area searched)
- r_{ij} is the fraction of the carcasses that arrived at turbine i but have not been lost to scavenge or decay before search j
- p_{ij} is the probability that an existing carcass will be detected by the searcher

The following sections outline how we estimate $\hat{\mathbf{a}}$, $\hat{\mathbf{r}}$ and $\hat{\mathbf{p}}$. $\mathbf{C}$ is given by the field observation data.

Our final task is to estimate $\hat{M}$ for each group of turbines and species.

One limitation of analytical methods is estimating r_{ij} when the time between surveys is not constant. In Australia, it is common for the time between searches to vary due to seasonal changes in effort or the use of a pulsed design in which the turbine is searched monthly with a return visit a few days later.

To allow for survey protocols with non-standard intervals, we developed a Monte Carlo algorithm. We have used this method for annual estimates at over a dozen wind farms in Australia to date.

Monte Carlo methods (Sawilowsky (2003), Ripley (1987)) simulate a large set of possible survey results, by simulating the actual sampling protocol and sampling from the empirical distributions for scavenge loss and searcher efficiency. In this way, we can directly sample the probability a carcass was lost before the survey, negating the need to calculate r_{ij} analytically each time.

We can then estimate how many carcasses were truly in the field, given the range of searcher and scavenger efficiencies, the survey frequency and coverage, and the true "found" details. After many simulations, we can estimate the likely range of mortalities that could have resulted in the recorded survey outcome.

This method has been benchmarked against analytical approaches (M. M. Huso (2011), Korner-Nievergelt et al. (2011)). Its outputs are equivalent but it is able to robustly model more complex survey designs (e.g. pulsed surveys, rotating survey list).

Figure 1 provides an overview of the methodology. A detailed explanation can be found in Stark and Muir (2020).

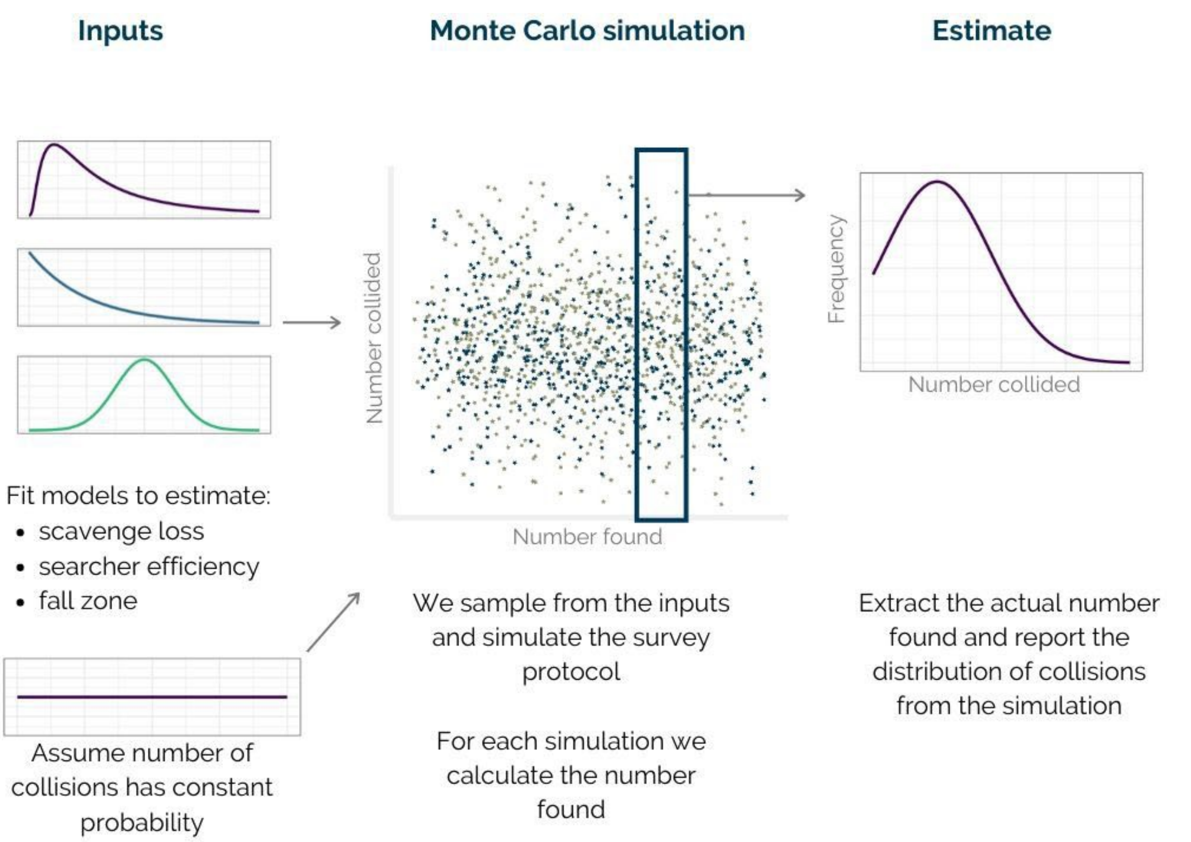

Figure 1: Overview of how the mortality estimation works.

3 Analysis and modelling

The survey program consisted of carcass searches, and adjunct scavenger and detection trials as outlined in the Bird and Bat Adaptive Management Plan (Nature Advisory (2017)) [1] provided by ELA. We summarise the methods, field data and analysis results for each below.

3.1 Carcass search data

The carcass searches provide the C term of Equation (1).

3.1.1 Survey effort

The mortality estimate was based on a dated list of turbine surveys. A total of 19 turbines were randomly selected from the 37 turbines operational onsite. Each of the selected turbines was searched by a qualified ecologist twice monthly, which included a standard survey to 100 metre radius and a pulse surveys to 60 metre radius. Each month, the pulse survey was conducted several days following the standard survey.

In no months was any turbine missed, equating to 19 standard and 19 pulse searches per month (Table 1).

[1] CRWF Bird and Bat Adaptive Management Plan.pdf

Table 1: Number of surveys per month.

Date	Standard	Pulse
2021 Jun	19	19
2021 Jul	19	19
2021 Aug	19	19
2021 Sep	19	19
2021 Oct	19	19
2021 Nov	19	19
2021 Dec	19	19
2022 Jan	19	19
2022 Feb	19	19
2022 Mar	19	19
2022 Apr	19	19
2022 May	19	19
2022 Jun	19	19
2022 Jul	19	19
2022 Aug	19	19
2022 Sep	19	19
2022 Oct	19	19
2022 Nov	19	19
2022 Dec	19	19
2023 Jan	19	19
2023 Feb	19	19
2023 Mar	19	19
2023 Apr	19	19
2023 May	19	19

3.1.2 Carcass finds

The breakdown of found carcasses per species are summarised in Table 2.

Table 2: Carcasses found during formal surveys over two years.

Species	Bat	Bird
Australian Magpie	0	15
Australian Raven	0	1
Australian Wood Duck	0	4
Brown Falcon	0	2
Collared Sparrowhawk	0	2
Crested Pigeon	0	1
Eastern Rosella	0	1
Galah	0	1
Gould's Wattled Bat	2	0
Little Broad-nosed Bat	1	0
Little Forest Bat	8	0
Little Red Flying-fox	1	0
Magpie-lark	0	1
Nankeen Kestrel	0	3
Pacific Black Duck	0	1
Southern Forest Bat	1	0
Southern Freetail Bat	2	0
Unidentified Bat	4	0
Unidentified Bird	0	1
Wedge-tailed Eagle	0	8
White-striped Freetail Bat	9	0

A number of carcasses were also found incidentally. These carcasses are not included in the data that produces the mortality estimate, we report them here for completeness (Table 3).

Table 3: Incidental finds.

Species	Number found
Australian Magpie	1
Large Forest Bat	1
Little Forest Bat	1
Nankeen Kestrel	2
Unidentified Bat	1
Wedge-tailed Eagle	4
White-striped Freetail Bat	4

3.2 Searcher efficiency

The aim of searcher efficiency trials is the quantify the effectiveness of observers, at finding carcasses. They provide the p term in Equation (2).

3.2.1 Methods

The searcher efficiency data is sourced from trials conducted through the survey period. Carcasses were laid out in accordance to the specification in 4.4.4 in Nature Advisory (2017). A qualified ecologist searched for the carcasses using the same protocol as the main mortality survey. If the carcass was found, "success" was recorded, else "failure" was recorded if the carcass was not found.

It can be difficult to source carcasses of the species being studied, so proxy species of similar size and morphology are often used. Here, House Mouse and Domestic Rat were used as proxies for bats and birds, respectively.

We estimated searcher efficiency by fitting binomial generalised linear models (GLMs). The optimal model was determined, guided by the small-sample Akaike Information Criterion (Anderson and Burnham 2004), otherwise known as the AICc.

We did not differentiate between the searcher efficiency for Wedge-tailed Eagles compare with other birds, as only three Wedge-tailed Eagle carcasses were deployed and previous meta-analyses suggests there is no significant difference in Wedge-tailed Eagle detectability to other birds (Stark and Muir (2020)). As such, for Wedge-tailed Eagle mortality estimates, we just used the best fitting detectability model for all birds.

3.2.1.1 AIC model selection The theory of AIC is deep and complex, and beyond the scope of this report. However, to summarise, AIC is a method for choosing the best approximating model of the "truth". For each model we fit to the data, we calculate the AIC. We compare the differences in AIC between models, which in turn informs us of the weight of evidence for that particular model.

AIC is not the same as significance testing. We do not aim to state anything is significant at the 5% level, instead we aim to find a good model fit for the data. Additionally, we also consider two other principles guiding model selection. They are parsimony (a simpler model is preferable to a more complex model), and application (for example, it's all well and good to find that cloud cover affects detection rates, but it's not feasible to incorporate cloud cover into a mortality estimate).

AICc is a modification of AIC, which is appropriate for smaller sample sizes.

3.2.2 Results

Searcher efficiency trials were conducted by human searchers in August 2021 and April 2022 (Table 4).

The detectability trials used both bird (36 replicates) and bat (14 replicates) carcasses (Table 5). It also used bird proxies (9 replicates) and bat proxies (11 replicates).

Table 4: Number of trials conducted on each detection survey date.

Date	Number of trials
2021-08-10	35
2022-04-04	35

Table 5: Count of species types recorded during the detection surveys.

Species	Number of records
House Mouse	11
Domestic Rat	9
Chicken	2
Eastern Rosella	1
Southern Boobook	2
Australian Wood Duck	4
Little Forest Bat	5
Striated Thornbill	1
Galah	6
Nankeen Kestrel	2
Australian Magpie	4
Little Red Flying-fox	1
Southern Freetail Bat	2
Sulphur-crested Cockatoo	2
Pied Currawong	1
White-striped Freetail Bat	5
Little Lorikeet	1
Tree Martin	1
Wedge-tailed Eagle	3
Masked Lapwing	1
Grey-headed Flying-fox	1
Musk Lorikeet	1
Rainbow Lorikeet	1
Little Corella	2
White-throated Nightjar	1

We tested two searcher efficiency models were:

- using species type (bat, bat proxy, bird, bird proxy) as a predictor; and
- the “intercept-only” model (i.e. all carcasses have the same expected searcher efficiency)

Birds had higher detectability compared to the other species type. Bat and bat proxies had similar detectability and were therefore combined. Bird proxies (Domestic Rat) had much lower detection than birds (56% compared with 92% detection) and therefore do not appear to be a good proxy for the detectability of birds. As such, we removed the bird proxies from the detectability model, and tested whether the difference between birds remained (comparing it with a bat/bat proxy agregated group).

Using this aggregated data, the top model included species type as a predictor. We therefore used separate detection efficiencies for bats and birds.

Table 6: Detection efficiencies for birds and bats.

Variable	Bats/Bat Proxies	Birds
Number found	15	33
Number placed	25	36
Mean detectability proportion	0.6	0.92
Detectability lower bound (95% confidence interval)	0.39	0.78
Detectability upper bound (95% confidence interval)	0.79	0.98

Overall detectability for bats is 60%, with a 95% confidence interval of [39%, 79%]. Overall detectability for birds is 92%, with a 95% confidence interval of [78%, 98%].

3.3 Scavenger efficiency

In order to accurately estimate mortality, we must account for carcass loss to scavengers. Scavenger trials are performed to quantify the time until a carcass is completely lost as a result of scavenger activity, which is the r term in (2).

Trials were caried out in accordance to Section 4.4.3 of Nature Advisory (2017).

3.3.1 Methods

Scavenger efficiency trials were conducted in August 2021 and April 2022 (Table 7). The trials ran over 30 days, with carcasses checked periodically by humans. As per the BBAMP, carcasses were check *"in the afternoon of deployment, twice daily for the first three days, daily for two days and then every 48 hours for the following four days and then every three days until they disappear or at the end. of 30 days"*.

Survival analysis (Kaplan and Meier (1958), Kalbfleisch and Prentice (2011)) was used to determine the distribution of time until complete loss from scavenge. Survival analysis was required to account for the fact that we do not necessarily know the exact time of scavenge loss, only an interval in which the scavenge event happened. For example, any carcass which is unscavenged at the end of the trial, has its scavenge event in the interval $[x, \infty]$ (where x is the length of the trial).

By performing survival analysis we can estimate the time until carcass loss after a given length of time, despite these unknowns.

We fit parameterised models to analyse significant factors influencing time to scavenge (i.e. carcass species type), and to find the most appropriate distribution to fit the time-to-loss curve (e.g. log-normal).

Time to carcass loss is influenced by the parameters discussed above and the distribution of the loss curve we fit to the data (M. M. P. Huso, Dalthorp, and Korner-Nievergelt 2015). The choice of loss function is important because it should capture the behaviours and relative time dependence of the various scavengers. Generally, the best distribution is the log-normal distribution (Stark and Muir 2020).

Scavenger efficiency trials only had access to three Wedge-tailed Eagle carcasses for deployment, which all remained unscavenged at the end of the trial. Previous analyses (Stark and Muir (2020)) suggest that Wedge-tailed Eagles are scavenged significantly slower than other birds. Therefore, we combined the three carcasses from the trial, with 37 Wedge-tailed Eagle records from Stark and Muir (2020). This provides a more robust estimate of the eagle time-to-scavenge distribution.

3.3.2 Results

In total, 36 bird carcasses (including three Wedge-tailed Eagles), and 14 bat carcasses, were used (Table 7). Additionally, 9 bird proxy carcasses (Rats) and 11 bat proxy carcasses (Mice) were used.

Table 7: Scavenger trial timing.

Month	Speices type	Number of trials
2021 August	Bat proxy	6
2021 August	Bird proxy	9
2021 August	Bird	15
2021 August	Bat	5
2022 April	Bat	9
2022 April	Bird	21
2022 April	Bat proxy	5

The two proxies were scavenged in notably less time than the birds and bats, and therefore do not appear to represent suitable proxies for bats or birds. As such, we removed proxies from the scavenger analysis and re-ran models with just bats and birds. The best approximating model still combined bats and birds, so this model was selected.

The log-normal distribution best described the scavenger distribution, for both models.

Figure 2 shows a survival curve fitted to the bat/bird combined cohort, and for Wedge-tailed Eagles. The survival curve (smooth solid line for fitted, step function for empirical) shows the estimated proportion of the set remaining at any given time. The shaded portions are the 95% confidence intervals on the estimate.

Under these assumptions, the median time to total loss via scavenge is 3.78 days, with a 95% confidence window of [1.72, 8.3] days for bats/birds combined (proxies removed).

All three Wedge-tailed Eagle carcasses remained at the end of the trials. As this sample size is too low to estimate a robust scavenging rate for CRWF, we aggregated these carcasses with those from Stark and Muir (2020).

The Wedge-tailed Eagle median time to total loss via scavenge is 217 days, with a with a 95% confidence window of [75, 625] days.

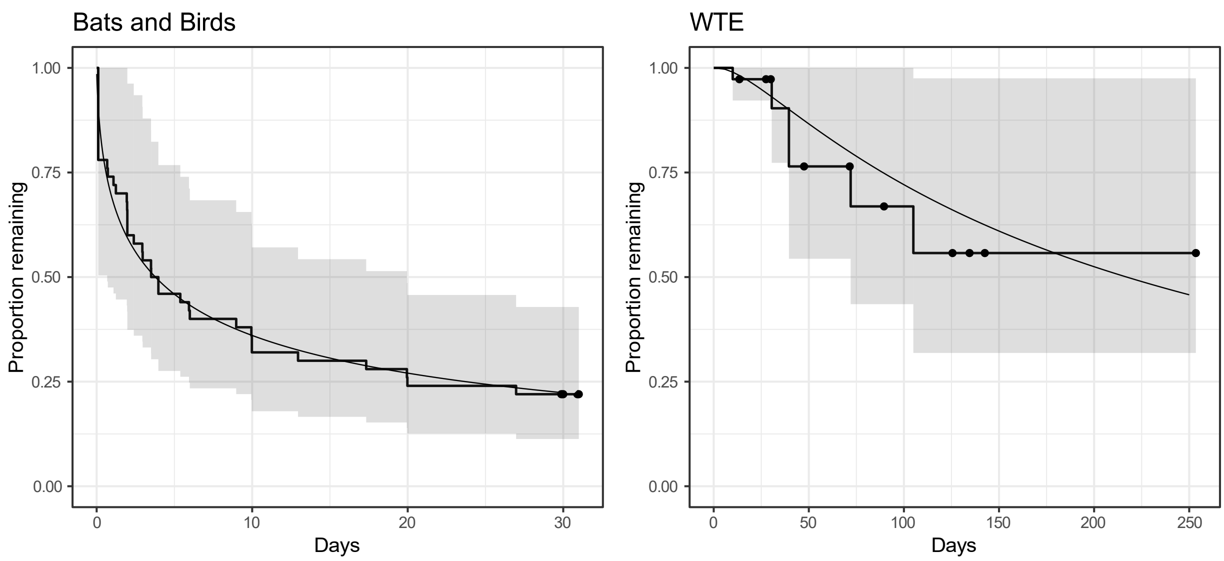

Figure 2: Empirical survival curves (the step functions), with 95% confidence interval shaded. The smooth curves presents the fitted model.

3.4 Proportion of turbines searched

In the Monte Carlo algorithm, we explicitly simulate the survey design. The proportion of turbines sampled is therefore explicitly accounted for in the simulation.

3.5 Coverage factor

The coverage factor estimates the probability that, given a carcass falls at a searched turbine, that the carcass falls within the searched area. This contributes to the a term in Equation (2)

3.5.1 Methods

We generated a carcass fall-zone distribution for each species class, given the turbine size at the wind farm. The percentage of the fall zone not covered by the survey area, provides a correction factor in the mortality estimate. Because carcasses that fall outside the searched area have a zero probability of being detected by a survey, the likelihood of landing in this region is essential to understanding the relationship between detections and actual losses.

The fall-zone estimate is the end result of the calculation detailed in CL Hull and Muir (2010). We calculated a bat, bird (small to medium) and wedge-tailed eagle (large bird) coverage factored, based on the parameters set out in CL Hull and Muir (2010).

3.5.2 Results

Table 8 displays the dimensions and RPM of the turbines at CRWF.

Table 9 shows the bird physical parameters used. These are input into the fall zone simulation.

Table 8: Turbine specifications for the wind farm.

Rotor Diameter (m)	Tower Height (m)	RPM
112	68	11

Table 9: Bird and bat archetype parameters.

Species type	Archetype	Mass (kg)	Min. area (sq m)	Max. area (sq m)
Bat	Gould's Wattled Bat	0.01	0.00	0.01
Small to medium Bird	Raven	0.68	0.04	0.10
Large Bird	Wedge-tailed Eagle	4.20	0.07	1.00

These archetypes were used as they represent a medium sized species for each species type and produce an estimate of the average fall zone, as outlined in C. Hull and Muir (2010).

Figure 3 displays the simulation results for birds and bats, given the factors specified above. We display the cumulative density function (CDF) on the y axis versus the distance from turbine (x axis). for each species type. The CDF describes the expected proportion of carcass which fall less than or equal to a certain distance from the turbine. For example, we expect about 87% of bats and 59% of small to medium birds to fall within 60m of the turbine, and 100% bats and 94% of small to medium birds fall within 100m. As Wedge-tailed Eagle carcasses can potentially fall further from the turbine we expect only about 48% of Wedge-tailed Eagles to fall within 60m of the turbine and 83% to fall within 100m.

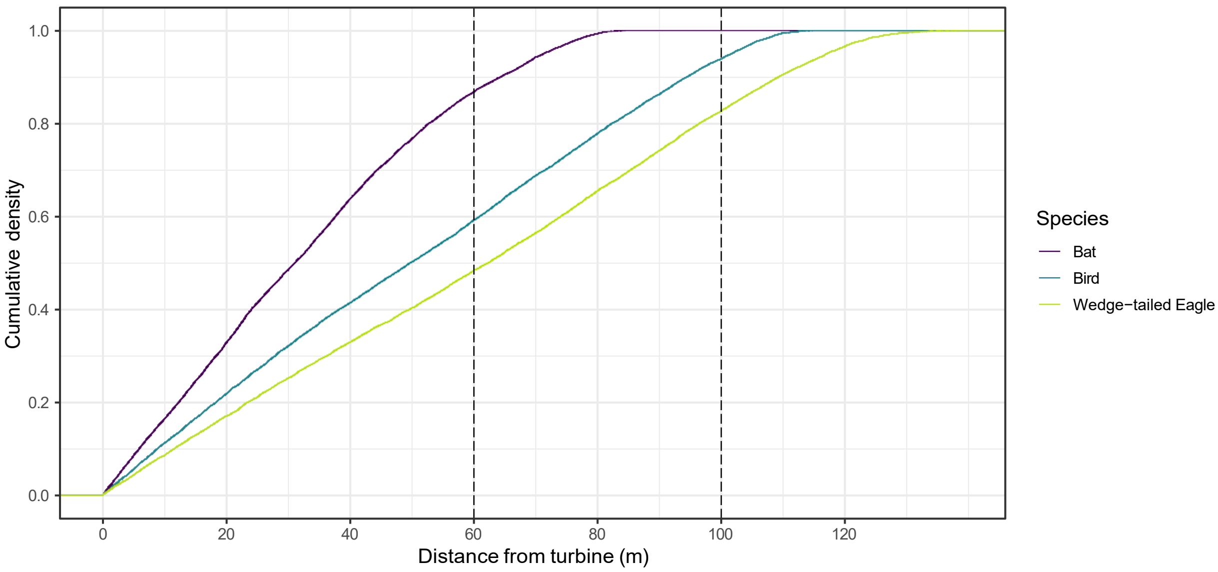

Figure 3: Cumulative distribution function of the fall zone simulation output for birds and bats. Vertical lines indicate relevant survey radii.

Once the fall zone distribution is calculated, we generate a "coverage factor" for each species type. The coverage factor represents the proportion of carcasses which fall within the searched area.

On average, we expect about 87% of bats and 59% of birds to fall within 60m of the turbine, and 100% bats and 94% of birds fall within 100m.

On average, we expect about 48% of Wedge-tailed Eagle to fall within 60m of the turbine, and 83% to fall within 100m.

4 Mortality estimate

With estimates for scavenge loss, searcher efficiency, and survey coverage, we then converted the number of bat and bird carcasses detected into an estimate of overall mortality at CRWF from 2021-05-01 to 2023-05-30. We allow for collisions to occur up to a month prior to the first survey to reduce error in the model.

The mortality estimation is done via a Monte Carlo algorithm. We used 25000 simulations for each of bats, birds and Wedge-tailed Eagle, with the survey design simulated each time. Random numbers of virtual mortalities were simulated, along with the scavenge time and searcher efficiency (based on the measured confidence intervals). The proportion of virtual carcasses that were "found" was recorded for each simulation. Finally, those trials that had the same outcome as the reported survey detections were collated, and the initial conditions (i.e. how many true losses there were) reported on.

The model assumptions are listed below:

- There were 37 turbines on site.
- 19 turbines were surveyed, and were searched out to a 100 metre radius during standard surveys and 60m during pulse surveys, in accordance with the supplied survey data.
- Search frequency for each turbine was taken from a list of actual survey dates (see Table 1 for a summary).
- Mortalities were allowed to occur up to a month before the initial survey (2021-06-01) and until the final surveyed period (2023-05-30).
- Birds, including Wedge-tailed Eagles, are on-site at all times during this period.
- Bats are on-site at all times during this period.
- Bats and birds that are struck are immediately replaced (i.e. strikes one day do not affect the chance of strikes the next).
- We have used the standard practice of assuming that all carcasses and all feather spots (regardless of size or composition) are attributable to the wind turbines.
- Finds are random and independent, and not clustered with other finds.
- There was equal chance of any turbine individually being involved in a collision / mortality.
- We took scavenge loss and search efficiency rates as outlined above.
- We assumed a log-normal scavenge shape.

4.1 Bat mortality estimate – results

During the two years of surveys a total of 28 bats were found during formal surveys. The resulting (median) estimate of total mortality is 176 bats lost on site over the two year period. Year 1 and year 2 had similar estimated mortality of bats.

Table 10 and Figure 4 display the percentiles[2] of the distributions, to show the confidence on the mortality estimate.

Table 10: Percentiles of estimated total bat losses over the two years of survey period.

0%	50% (median)	90%	95%	99%	99.9%	Model
97	176	244	279	320	335	Cumulative
50	100	146	168	204	261	Year 1 only
35	86	133	148	167	175	Year 2 only

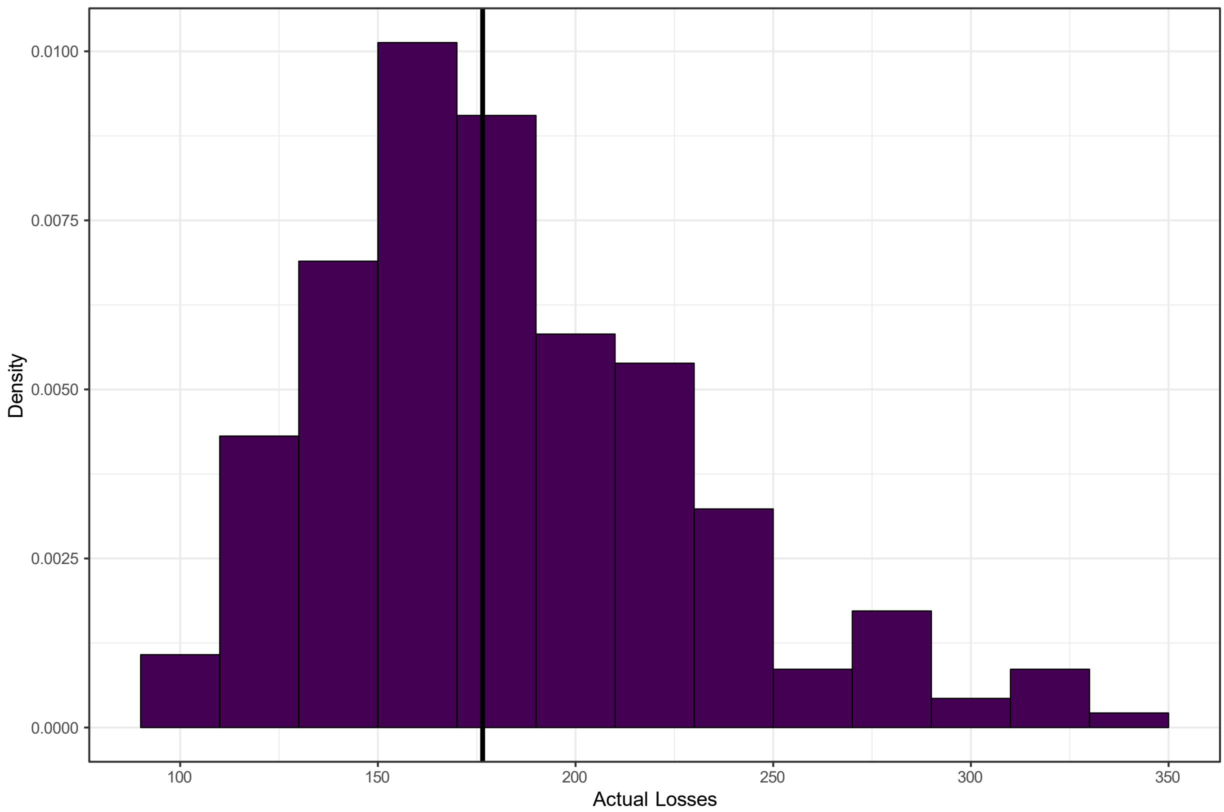

Figure 4: Histogram of the total losses distribution (bats), given 28 were detected on-site across the two years. The black solid line shows the median.

[2]The x-th percentile, is the point which x% of values are less than. So for example: the median (50th percentile) is point which half of the values are less than, and the 99th percentile is the point which 99% of the values are under.

4.2 Bird mortality estimate - results

During the two years of surveys a total of 41 birds were found during formal surveys. The resulting (median) estimate of total mortality is 238 birds lost on site over the two year period. Year 1 and year 2 had similar estimated mortality of birds.

Table 11 and Figure 5 display the percentiles of the distributions, to show the confidence on the mortality estimate.

In determining the estimate, we have used the standard practice of assuming that all carcasses and all feather spots (regardless of size or composition) are attributable to the wind turbines.

Table 11: Percentiles of estimated total bird losses over the two years of survey period.

0%	50% (median)	90%	95%	99%	99.9%	Model
120	238	311	339	381	449	Cumulative
71	126	178	201	240	254	Year 1 only
56	115	165	177	208	239	Year 2 only

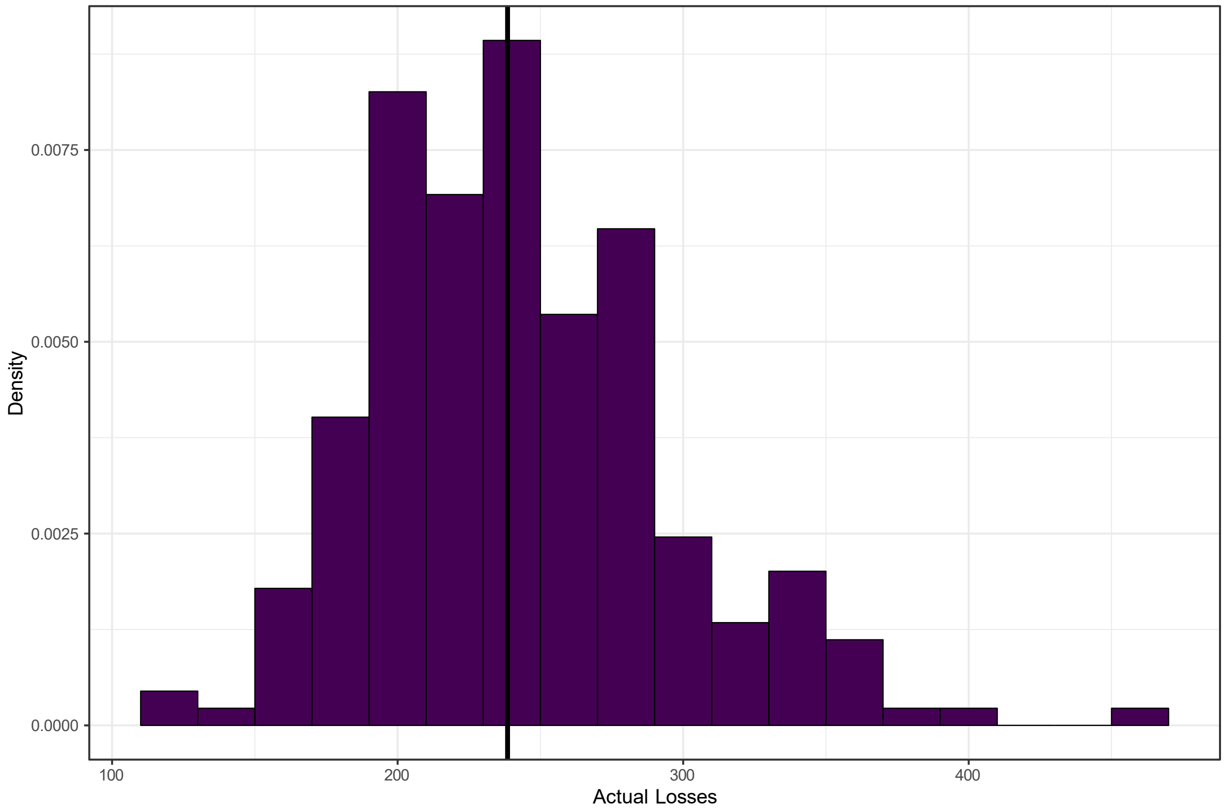

Figure 5: Histogram of the total losses distribution (birds), given 41 were detected on-site. The black solid line shows the median.

4.2.1 Wedge-tailed Eagle estimate

During the two years of surveys a total of eight Wedge-tailed were found during formal surveys. An additional four were found incidentally, which cannot be used in the formal analyses. The resulting (median) estimate of total mortality is 17 birds lost on site over the two year period. Year 1 and year 2 had similar estimated mortality of birds.

Table 12 and Figure 6 display the percentiles of the distributions, to show the confidence on the mortality estimate.

In determining the estimate, we have used the standard practice of assuming that all carcasses and all feather spots (regardless of size or composition) are attributable to the wind turbines.

Table 12: Percentiles of estimated total Wedge-tailed Eagles losses over the two years of survey period.

0%	50% (median)	90%	95%	99%	99.9%	Model
8	17	24	27	31	34	Cumulative
4	9	15	17	21	26	Year 1 only
4	9	14	15	18	23	Year 2 only

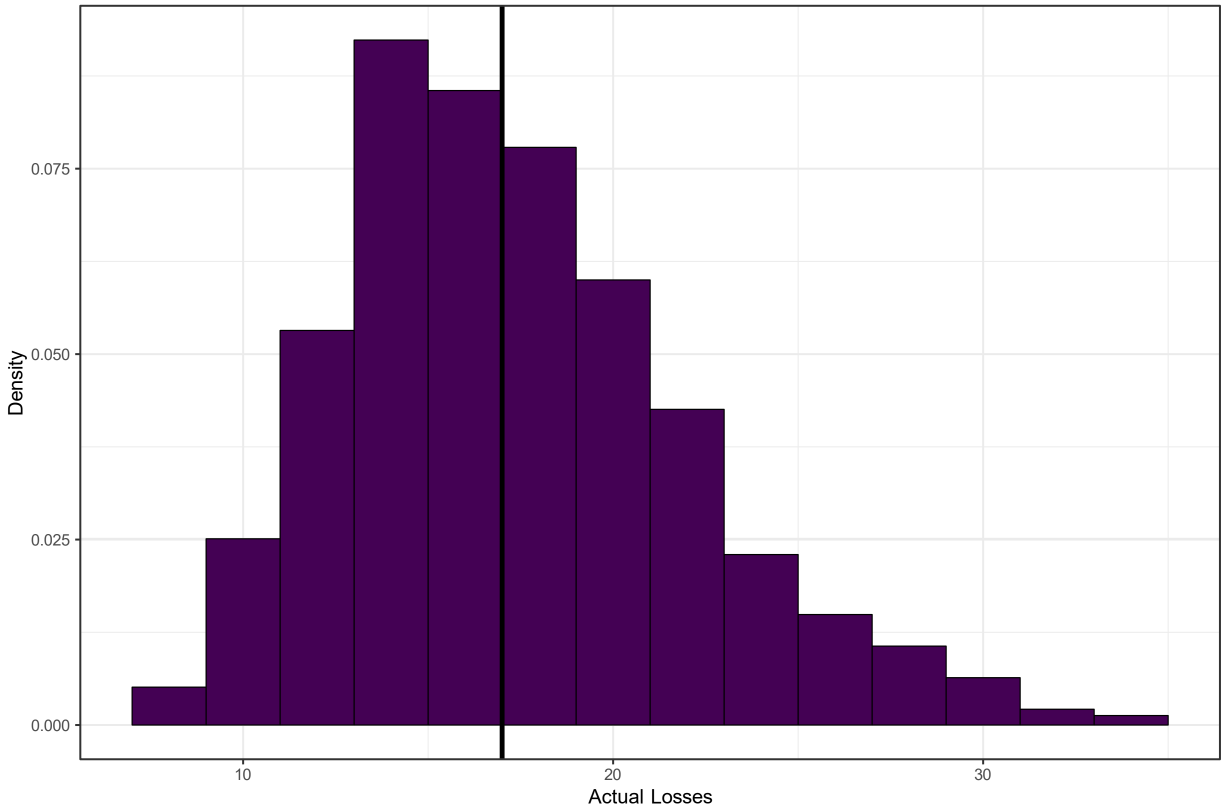

Figure 6: Histogram of the total losses distribution (Wedge-tailed Eagles), given 8 were detected on-site. The black solid line shows the median.

5 Concluding remarks

In evaluating the potential impact, it is important to remember that all mortality estimators have an inherent assumption that there is an unlimited supply of carcasses to be found. In particular, we did not apply an upper limit on the number of bats that could be onsite, and we assumed that bats were present all year round. The ecological feasibility of this assumption should be accounted for if using these results to comment on overall ecological impact.

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