# Post construction bird and bat monitoring at wind farms in Victoria

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# 1 Executive summary

Post construction data from carcass search programs in Victoria offer an opportunity to understand the collision risks that turbines pose to birds and bats. However, the data is collected on a site basis. The exact objectives and methods change depending on site-specific permit conditions, management plans, and the team of observers used.

Symbolix undertook publicly funded research to produce cumulative statistics and quantify the collision rates of different species at wind farms in Victoria. This report complements and extends recent work to draft a risk assessment framework for wind farms (Lumsden and Smales 2019), and reviewed the data limitations and initial statistics from post construction monitoring (Moloney and Smales 2019).

Our objective was to develop a combined data set from multiple sites to estimate regional statistics and explore state-wide patterns. We present a novel method to estimate per-turbine mortality rates using combined data from multiple sites. This method opens up the ability to investigate influences that extend beyond sites - e.g. seasonality and turbine size.

We compiled a substantial data, with a total of 5432 surveys over 14,746 hectares of carcass search data. The area covered in total in our dataset was 14,746.33 hectares, or 147 km 2 and a total 428 bats and 355 birds were found. That's approximately one carcass or feather-spot find per 6.9 turbine searches, or one find per 19 hectares.

## 1.1 Motivation for the study

There are few existing papers about which bird and bat species are most susceptible to collision in Australia.

In an appraisal of data from eight wind farms across south-east Australia, White-striped Freetail bats (*Austronomus australis*) were more frequently recorded in carcass records than other species (Smales 2012).

Similarly, one study at two wind farms in Tasmania found only 21% and 18% of bird species identified onsite were present in carcass monitoring data (Hull et al. 2013). The propensity of a species to collide is dependent on a number of factors, including flight height and behaviour. Raptors are commonly identified as an at-risk taxon group.

Although Australian bats are not migratory (unlike those seen at northern hemisphere sites), fatalities follow a seasonal pattern (Hull and Cawthen 2013). Not all bat species detected on site are found in mortality records, with high-flying open air foraging species found to be more at risk (Hull and Cawthen 2013).

## 1.2 Key results

The key findings for each study objective are summarised below.

### 1.2.1 Cumulative estimated mortality rates

We present a table in Section 4.6 of the estimated annual mortality per turbine for each species. This is limited to the species found at three or more sites, as we cannot reliably report combined results for species found at only one or two sites.

- Turbine size influences the mortality estimate, due to differing 'fall zones' for carcasses (Hull and Muir 2010). We estimated per turbine mortality for two size classes.
  - Small (SML) turbines have rotor diameter of less than or equal to 103m. Anything larger was classed as Large (LRG).
  - At time of writing there were 544 small class turbines and 220 large class turbines in Victoria (Appendix A).
- Between 7 and 10.8 bat mortalities occur per turbine per year in Western Victoria. The rate is not significantly different for different sizes (Section 4.5.1)
- For birds, significantly more mortalities occur at larger turbines. For small turbines, between 3.4 and 4.1 bird mortalities occur per turbine per year. For large turbines, the range varies between 5 and 6.7 per turbine per year.
- Our study suggests that mortalities are higher for White-striped Freetail Bats than any other bat or bird species. Between four to six White-striped Freetails are struck per turbine, and they were discovered at every site in the study. This implies that turbines in Western Victoria strike around as many White-striped Freetails as all birds combined.

### 1.2.2 Carcass loss to scavenge

- Wedge-tailed Eagles are lost to scavenge at a much slower rate than the other bird species studied. On average it takes 287 days for a a Wedge-tailed Eagle carcass to be scavenged (n = 37). We can be confident that some carcass evidence will remain for a long time period following collision.
  - We have no data on other very large carcasses (e.g. brolga) so cannot comment on whether the pattern extends to these species.
- For other bird carcasses, evidence was lost after an average of 5.68 days, with confidence interval [4.75, 6.79] days (n = 321).
- For bats, evidence was lost after an average of 2.69 days, with confidence interval [2.11, 3.43] days (n = 170).
- We found no significant difference between study sites in time to loss or searcher efficiency, so the above results can be used as reference values for similar sites and species.

### 1.2.3 Searcher efficiency

- Humans find 88% of all birds, n = 435, confidence interval [85%, 91%]
- Humans find 52% of all bats, n = 141, confidence interval [44%, 61%]
- Dogs find 84% of all carcasses regardless of type, n = 305, confidence interval [80%, 88%]
- We found no significant difference between study sites, so the above results can be used as reference values for similar sites, species and survey protocols.

### 1.2.4 Which species are most frequently represented in mortality data in Western Victoria?

- Approximately one carcass or feather-spot was found per 6.9 turbine searches, or one find per 19 hectares.
- A total of 13 species of bat and 40 species of bird were identified.
- 11 bats and 45 birds were unidentified.
- 35 species were found at only one or two sites.
- The two most common species found were the White-striped Freetail Bat (229 carcasses at 10 sites) and the Gould's Wattled Bat (77 carcasses at 8 sites).
- The most commonly found bird was the Australian Magpie (69 carcasses at 10 sites).

# 2 Introduction

Recent reviews have highlighted some of the variations and limitations in this site-specific data (Moloney and Smales 2019). Despite the challenges there remains an imperative to seek statistics that are applicable at the regional or state level to enable strategic forward planning.

Although there are site-specific variations in application, many wind farms in Victoria use similar carcass survey protocols. These protocols are summarised as:

- **Searcher efficiency trials** estimate success rate of a survey team at finding carcasses.
- **Scavenge rate trials** to estimate the time taken for all evidence of a carcass to be lost (mainly through scavenge) at a site.
- **Carcass searches** of the ground adjacent to turbines, out to a specified radius. All bird and bat carcasses (including feather spots and partial remains) are recorded and assumed to be due to turbine collisions. These searches are systematic and repeated at a known interval; surveys commonly occur monthly, and often a pulsed survey is also performed where a repeat search is carried out a few days later.
- **Estimates of total mortality** attributable to turbine collision. The data from each component survey is analysed and a statistical expansion algorithm is applied to estimate the overall number of mortalities.

In addition to these surveys, many sites implement management triggers that are based on the number of carcasses found (without expansion). Other surveys, such as Before-After-Control-Impact studies of bird utilisation are common. The scope of this work is constrained only to estimates of mortality due to turbine collisions.

## 2.1 Project aims

This study combined data from different sites to contribute insight to a number of landscape-scale questions. We discuss three key objectives in this report.

**1. Conduct an audit and analysis of scavenger and searcher efficiency rates to produce a set of references values for these metrics**

Considerable resources are spent generating searcher efficiency and scavenger rates for each site. Sourcing carcasses for these trials is not easy and limits the number of trials that can be reasonably conducted.

By combining and analysing the data across a number of sites we aim to:

- Generate reference values that can be used for validation of small trials or to replace field trials.
- Understand and document the natural variation in the rates and the factors that drive that variation. This information is vital for planning future carcass search programs.

**2. Analyse which species are most frequently represented in mortality data in Western**

**Victoria**

A recent study attempted to define wind farm ‘species of concern’ through a combination of flight heights, presence of the population within the general environments of wind farms, and the status and size of the Victorian population (Lumsden and Smales 2019). One limitation of that work was the inability to assess the direct likelihood of collision due to the size of the wind farm adjacent population. For example, the Orange-Bellied Parrot population suffers a large consequence from collision, but the limited size of the population makes collision very unlikely.

We can provide an external validation and extension of the work in Lumsden and Smales (2019) by directly interrogating collision data. Whereas that work provided an ecological view of the species present and at risk of collision, this study documents the presence/absence of species across a range of sites in western Victoria. The two sets of results provide different but complementary views of the likelihood of collision of particular species.

**3. Determine the cumulative estimated total mortality for the study area and per species/species group**

Most Victorian wind farms are required to survey and estimate the overall mortality rates for at least the first year or two of operation. That data is appropriate for site-by-site monitoring but does not offer much insight into landscape-scale patterns.

In this study we combine field data across multiple sites to construct a cumulative estimate for the combined “meta-site”.

We also consider the turbine and site factors that influence variation in the mortality rates.

## 2.2 Structure of this document

This document aims to provide a working compendium of statistics from last decade of wind farm mortality monitoring.

The document outlines

- Data processing and synthesis (Chapter 3.2)
- Analysis methodology (Chapter 3.4)
- Results (Chapter 4)
- Discussions and advice on future use (Chapter 5)

Where practical we rely on existing, peer reviewed methods that represent current best practice. The Monte-Carlo simulation method presented in Section 3.9 has been applied (by the authors) at a number of individual sites and presented at conferences, but this is described here in full for the first time.

As far as we are aware, the method of generating a meta-site to generate inputs to the simulation and estimate cumulative mortality is also novel (Section 3.8).

# 3 Methods

## 3.1 Study area

This study considered data from Victorian wind farms and included surveys from 2014 through to 2019.

We obtained field data from 10 operating sites. All sites were located to the west of Melbourne (Table 1 and Figure 1).

**Table 1: Wind farms in the study area by region**

| Region | Active wind farms | Included wind farms |
|---|---|---|
| Bendigo | 0 | 0 |
| Hume | 0 | 0 |
| Latrobe - Gippsland | 3 | 0 |
| North West | 6 | 2 |
| Shepparton | 0 | 0 |
| Warrnambool and South West | 11 | 5 |
| Geelong and Ballarat | 5 | 3 |

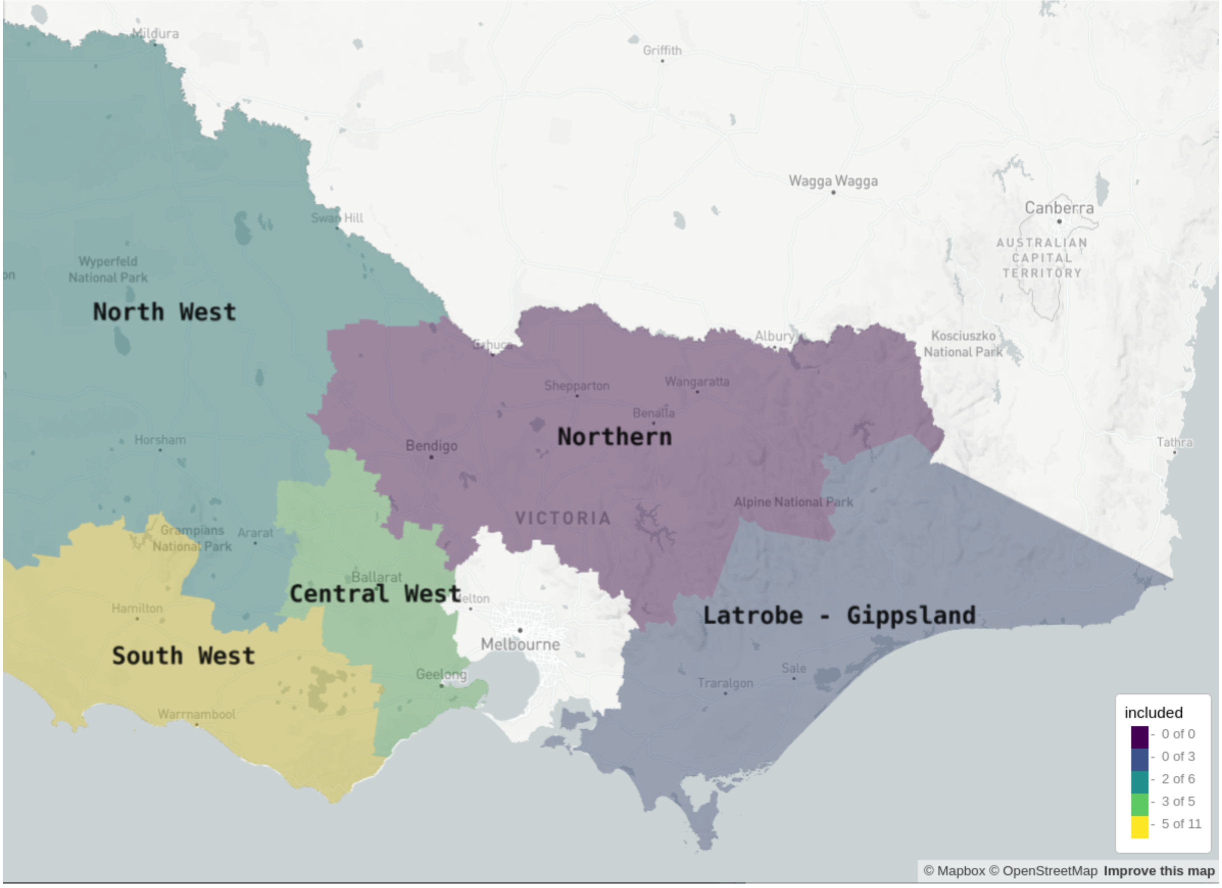


**Figure 1: Regions and wind farms in study**

## 3.2 Data preparation

Data was obtained from the contributing sites as a set of related datasets covering:

- Scavenger rate trials
- Searcher efficiency trials
- Carcass search protocols
- Carcass finds

In most cases we were able to source raw data (though the data-field names and conventions differed). In some cases, we had to reconstruct information based on the stated protocol in the site's Bird and Bat Management Plan (BAMP). We used the stated frequency, protocol and number of turbines to impute a survey data set to match the stated protocol. For example, if the protocol stated a site had monthly carcass searches at the same 15 turbines with a circular search area out to 100 metres, we synthesised survey data to match that.

In cases where the survey data set was imputed, we ensured the survey protocol matched the date of finds. However, more than one site did not record the turbine associated with the find and the use of formal survey IDs may have been inconsistent. This limited our choice of mortality estimator somewhat, as we discuss in section 3.9.

For each site, we pre-processed the data by standardising date formats, field names, etc. and performed typographical normalisation. We also requested and received further information from field teams providing the data to clarify uncertainties in the data and survey protocols.

The pre-processed data was uploaded to a NoSQL document database to allow for differing data schemas between sites.

We specified minimum datasets for each aspect of the survey protocol. Although most sites delivered more information, the minimum dataset represented the minimum fields required to combine data from multiple sites and undertake analysis on the combined set in a meaningful fashion.

We constructed the analysis datasets by merging the minimum dataset for each site.

## 3.3 Pre-processing data steps

The following sections outline the minimum data set standard and how we combined the site data for analysis.

### 3.3.1 Species data

Species data was an important part of all datasets but there was a large amount of variation in recording species details. Although in most cases species (or species group) was provided for carcass search finds, it was not uncommon for there to be less specificity in scavenger or searcher efficiency trials (e.g. ‘bird/bat’ or ‘large bird’ etc.).

To obtain reference names and taxon codes, we used the Victorian Biodiversity Atlas (VBA) (DELWP 2019). We re-coded misspelled or used alternative species names to match the reference set.

Where insufficient information was provided to identify a species (e.g. *Raven* rather than *Australian Raven* or *Little Raven*) we added a species collection (*Raven sp.*) to the species list and assigned a custom, unique taxon code. If a species could not be identified at all, we assigned it as *Unknown Bird* or *Unknown Bat*. For a list of all grouped taxa, see Appendix B.

### 3.3.2 Carcass loss to scavenge data

The following table summarises the minimum required dataset for estimating carcass loss due to scavenge

| **Variable** | **Description** |
|---|---|
| Site ID | Anonymised site identifier. |
| Study start date | We used this to define ‘season‘ categories of ’dry-hot’ (November - March) and ’wet-cold’ (April - September). Preliminary analysis showed the dual-season category produced a more balanced dataset and there were no significant differences for finer categories (e.g. four seasons or 12 months). |
| Taxon ID | Derived from look up of common or scientific name in the VBA. |
| Interval 1 | The last time (in days, fractions allowed) the carcass was assessed as having evidence remaining. |
| Interval 2 | The first time (in days) the carcass was assessed as not present. If evidence was still present at the end of the trial, Interval 2 was set to N/A. |

Some sites also collected data on the nearest turbine, the ground type/vegetation cover, and notes on the state of the carcass throughout the trial. This data was not consistent and absent at too many sites to be of use for this project.

The data is assembled in this way to accommodate what is known as ‘censoring.’ Often, we may only know the time period during which a scavenger took the carcass instead of a precise time. This could be a specific night, or maybe a few days. At other times, the carcass may remain within the test area at the end of the trial. We accommodate this by using a time interval method which enables good estimates of the time to loss of evidence (i.e. if a scavenger takes a carcass before a field officer has the opportunity to detect it) despite this apparent ambiguity. Note that data from sites that employed cameras (thus giving exact time of loss) can also be incorporated into this method.

### 3.3.3 Searcher efficiency data

Searcher efficiency is the proportion of carcasses found. We used the following dataset for this analysis:

| Variable | Description |
|---|---|
| Site ID | Anonymised site identifier. |
| Study date | We used this to define ‘season‘ categories of ’dry-hot’ (November - March) and ’wet-cold’ (April - September). Preliminary analysis showed the dual-season category produced a more balanced dataset and there were no significant differences for finer categories (e.g. four seasons or 12 months). |
| Taxon ID | Derived from look up of common or scientific name in the VBA. |
| Observer type | Human or Dog |
| Observer | Identifier for the individual observer. Not directly used in analysis. |
| Found | Was the carcass found? True/False |

Data on the ground type and distance from turbine tower was recorded by some sites but was not required in the analysis.

### 3.3.4 Carcass survey data

| Variable | Description |
|---|---|
| Site ID | Anonymised site identifier. |
| Survey date | As above |
| Turbine ID | Unique identifier for each turbine |
| Observer type | Human or Dog |
| Survey radius | Radial distance (from turbine) covered by the observer |
| Formal | Some observers used the survey data template to record dates and details of incidental finds. Only formal searches (and finds from these) were included in the analysis. |

Additional information was available for some but not all sites, including:

- Observer
- Start Time and Finish Time
- Ground cover type

However, these were not required for analysis and were often missing.

### 3.3.5 Carcass find data

| Variable | Description |
|---|---|
| Site ID | Anonymised site identifier. |
| Survey date | As above |
| Taxon ID | Derived from look up of common or scientific name in the VBA. |
| Turbine ID | Unique identifier for each turbine |
| Formal | Some observers used the survey data template to record dates and details of incidental finds. Only formal searches (and finds from these) were included in the analysis. |

We used a combination of date range, site ID and turbine ID to determine which carcasses belonged to which group of carcass searches.

### 3.3.6 Turbine classes

Our aim was to investigate state-wide patterns in mortality monitoring, which required combining data from multiple sites. Each site typically runs a single generator configuration. In the years of development of this industry these units have improved and expanded. These constantly updated units are individually identifiable, and tuned specifically to site and operational needs.

To generate landscape-scale patterns, we need to understand the impact of these generator models and how their differences affect what a field officer may discover during a carcass search. In particular, we need to account for the proportion of the carcasses that may fall outside the searched area. The area where a certain carcass might be found (the ‘fall zone’) is related to the morphometrics of the carcass and the size of the turbine (Hull and Muir 2010).

This approach means analysing whether site-to-site turbine size differences impact the mortality estimate. For example, is there a significant difference beween a swept diameter of 92 metres versus 94 metres?

We aimed to combine multiple sizes of turbines into a single mortality estimate while adequately incorporating turbine variability (in this case the swept area) into the statistical noise around the estimate of the mortality.

To allow for different fall zones, we grouped sites according to the size class of the turbines. The distribution of turbine sizes (weighted by the number of turbines in each size class) is shown in Table 2 (hub heights) and Table 3 (rotor diameter). This process was a data-based one, where statistical models were run. Where no significant differences were found in outcomes, specific generator configurations were grouped into super-classes.

**Table 2: Quantiles of the distribution of turbine hub heights (m) for all sites analysed**

| | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| Hub Height | 71.5 | 80 | 84 | 84 | 91.5 |

**Table 3: Quantiles of the distribution of turbine rotor diameter (m) for all sites analysed**

| | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| Rotor Diameter | 82 | 97 | 103 | 112 | 126 |

Different sets of classes were explored, starting with two hub height classes and four rotor-diameter classes.

For each species size class (Bat, Bird and Wedge-tailed Eagle) we computed the frequency of falls as a function of radial distance from the turbine using the algorithm from Hull and Muir (2010). These distributions of fall distances were compared using the two-sample Kolmogorov-Smirnov test and combined if the test found no significant difference in the two distributions.

This procedure resulted in two turbine size classes, both with nominal hub height 84:

- `small`:
  - Turbines with rotor-diameter less than or equal to 103 metres
  - Nominal rotor-diameter: 97 metres
- `large`:
  - Turbines with rotor-diameter larger than 103 metres
  - Nominal rotor-diameter: 112 metres

## 3.4 Analysis overview

The current 'gold standard' for collecting and analysing post-construction mortality data is specified in Huso, Dalthorp, and Korner-Nievergelt (2015), which reviews previous work and outlines best practices for accounting for imperfect detection.

In particular, the paper specifies methodologies to correct for carcasses landing outside the searched area, carcasses removed (via scavengers) prior to the search, and imperfect searcher efficiency. Although the paper also includes commentary on accounting for the decreasing detection probability with each search, we restricted our analysis to assuming a 'one-shot' detection probability.

Following Huso, Dalthorp, and Korner-Nievergelt (2015), we required statistical estimates for the proportion of:

- Carcasses removed (via scavengers) prior to the search
- Carcasses missed by searchers (imperfect searcher efficiency)
- Carcasses landing outside the searched area

We also needed an analysis to combine individual carcass surveys into a meta-site survey protocol so we could generate a cumulative mortality estimate.

## 3.5 Carcass loss to scavenge

We used the `survival` `R` package to generate Kaplan-Meier survival curves (Terry M. Therneau and Patricia M. Grambsch 2000). We also fit parameterised models to analyse:

- The most appropriate distribution to fit the time-to-loss curve
- Significant factors influencing time to scavenge

It was not feasible to develop scavenger decay rates for individual species aside from a couple of notable exceptions. Wedge-tailed Eagles were the subject of a specific scavenger study across a number of sites and had sufficient data to generate a specific decay/removal rate. Chickens and mice were included to test the assumption that they are adequate proxies for large birds and bats respectively.

### 3.5.1 Scavenge model parameters

The following size classes were included as parameters

- Bat
- Mouse (Bat Proxy)
- Bird - General
- Bird - Large
- Chicken (Large Bird Proxy)

- Wedge-tailed Eagle

Two seasons ("wet-cold" and "hot-dry") were also included as parameters. We tested four seasons initially, but resolved no significant difference between seasons. We updated the models to use two seasons, based around the drier summer months, and wetter, colder winters. We defined "wet-cold" as April-September inclusive, and "hot-dry" as October-March.

Model iteration using AICc and Tukey's pair-wise comparisons (Hothorn, Bretz, and Westfall (2008) & Tukey (1953)) allowed us to reduce the number of size classes to:

- Bat (including Mice)
- Bird - all sizes
- Wedge-tailed Eagle
- Chickens

Chickens are listed separately as our analysis showed them to be an invalid bird proxy because they have a significantly different scavenger loss profile to all the other classes. This is discussed in more detail in the Results section.

### 3.5.2 Distribution of carcass loss over time

Time to carcass loss is influenced by the parameters discussed above and the distribution of the loss curve we fit to the data (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.

For instance, an exponential curve assumes a constant rate of decay/removal. This is known as the loss (or hazard) function constant. In the exponential case, the probability of being scavenged in the next instant is independent of the amount of time the carcass has already lain in field.

One alternative loss function is the log-normal distribution. The log-normal has a loss function that is "humped," where it initially increases up to a maximum value and then tapers off to zero.

We tested the following distributions and used AICc (AIC with small sample correction) to distinguish between them:

- exponential
- log-normal
- log-logistic
- Weibull

We fit the four distributions to the empirical, censored data. There is an known interval (potentially open) during which each carcass was lost that is initialised for each trial at time = 0, and this empirical data resolves the hazard function. This allows objective choices to be made about the efficacy of the local scavengers.

## 3.6 Searcher efficiency

The searcher efficiency data came from documented trials where carcasses (often representing different size classes) were distributed across the study area. The searcher being tested then replicated a carcass search pattern and recorded discovered carcasses. This is a traditional binary trial where 'success' is finding the carcass and 'failure' is missing it.

Dalthorp et al. (2018) recommends repeated searcher efficiency trials to test the probability of finding a carcass on the first search as well as the conditional probability of finding it on subsequent searches (if missed on the first). The same paper proposes methods for estimating the joint probability of finding the carcass on the $n_{th}$ survey.

Historically the Australian practice has been to undertake a single replicate of each searcher efficiency trial, so we were only able to estimate the independent (non-conditional) probability.

None of the data analysed came from blind trials. These are not standard practice in Australia for a number of reasons. It can be difficult to source carcasses, so proxy species (e.g. mice) are often used. In more remote sites it is infeasible to have someone arrange carcasses prior to each survey.

We estimated searcher efficiency $p$ by fitting a binomial Generalised Linear Model (GLM). The optimal model was determined using AIC.

We fit separate models for humans and dogs, as it's logical they would respond differently to the covariates. In both cases we fit models of the form

$$logit(P_f) \sim season * size$$

where

- $P_f$ is the probability the carcass is found
- $season$ is one of `hot-dry` or `cold-wet`
- $size$ is one of `Bat`, `Bat Proxy (mouse)` `Bird` and `Bird - Large`

The initial round of modelling resolved no significant difference for humans between bird size classes, but both sizes of bird were significantly different from bats (using pair-wise comparisons per Hothorn, Bretz, and Westfall (2008) & Tukey (1953)). There were no significant effects on searcher efficiency for dogs based on size class. We therefore recoded the category levels to *Bird* and *Bat* for the final model fitting.

An explanatory season variable was not used in the analysis as it was not significant for humans or dogs.

## 3.7 Estimating carcasses landing outside the searched area

The radial extent covered by each survey was either explicitly included in the survey record or could be deduced from the relevant Managment Plan. All sites had square or round transects centred on the wind turbine tower.

We assumed that transect spacing was sufficient for full visibility in that area. We did not have data to carry out a distance correction to verify this assumption. In effect, we are assuming that the detectabilty studies reproduce the detection survey scenario and so implicitly accommodate the effective detection range of the (dog or human) observer.

We generated a fall-zone distribution for each of the combinations of species and turbine size listed in Appendix D (Figure 2). The percentage of the fall zone not covered by the survey area provides a correction for carcasses landing outside the searched area. 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 Hull and Muir (2010).

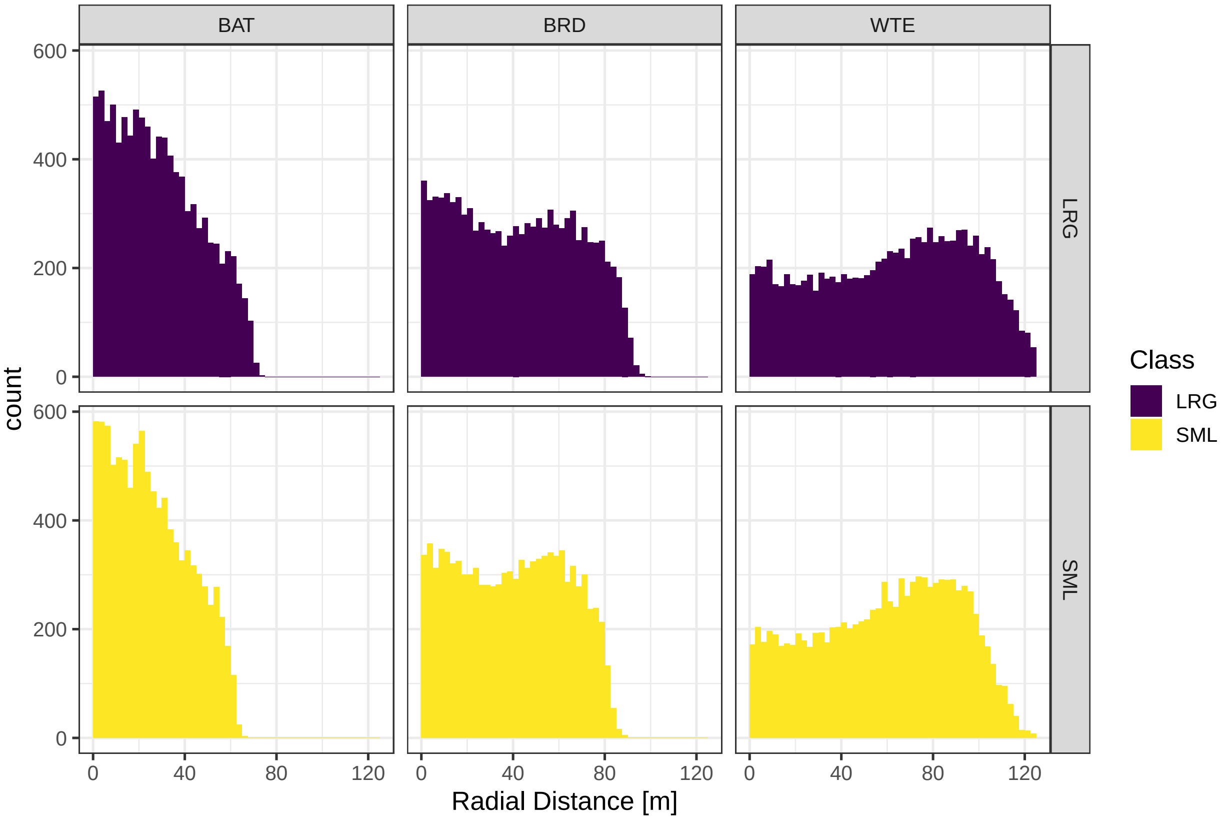


**Figure 2: Simulated (n=10,000) fall-zone distributions for different sizes of animal and turbine.**

## 3.8 'Meta-site' carcass survey

To create single mortality estimate that includes multiple sites, we assembled turbines (and survey protocols) into conceptual 'meta-sites'.

Alternatively, one could have reported on each site, then attempted to aggregate the disparate reports. However, developing meaningful aggregates would be difficult without becoming sidetracked with discussions about comparisons.

In addition, we established no significant differences between sites in searcher efficiency and can aggregate turbines into size classes.

To combine sites we undertook the following steps for each turbine size class:

- Standardised the turbine operating and survey dates. In effect, every operator and every survey began on Day 1.
  - Note: Because in this standardised time, some turbines might be physically in "warm-dry" while others are in "wet-cold". this effectively accommodates any small seasonal effects on detection, scavenge or collision as variance in the meta-estimate.
- We treat carcass search data for a site from different years as though it comes from replicate sites. So, a site that has carcass search data for two years becomes two replicate sites, that have operated for one year each. This assumes that years are independent of each other (with respect to mortality).

We now have a meta-survey protocol that covers all visited turbines from each size class. The protocol can be envisioned as a simple matrix of turbine by time; each turbine replicate occupies a row, and the number of columns represents a year.

This set-up treats each visited turbine (in a given turbine size class) as a replicate annual carcass survey, from which we can estimate the mortality per turbine per year.

## 3.9 Turbine collision mortality rate

### 3.9.1 Background

There are a number of current analytical and numerical methods suitable for estimating total mortality from carcass counts. Analytical methods include Huso (2011) and Korner-Nievergelt et al. (2011), while Dalthorp et al. (2018) presents an numerical package that extends the analytics estimates.

A number of earlier mortality estimators exist (e.g. Erikson, M. D., and K. (2000), Smallwood (2007)), but these are rarely used today because they produce biased results or exclude some inputs. Bernardino et al. (2013) provides a good overview of these limitations.

### 3.9.2 Standard approach

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

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

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

$$\hat{g}_{ij} \cong a_i r_{ij} p_{ij} \tag{2}$$

- $a_i$ 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 preceding sections outlined how we estimate $\hat{\mathbf{a}}$, $\hat{\mathbf{r}}$ and $\hat{\mathbf{p}}$. C is given by the field observation data.

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

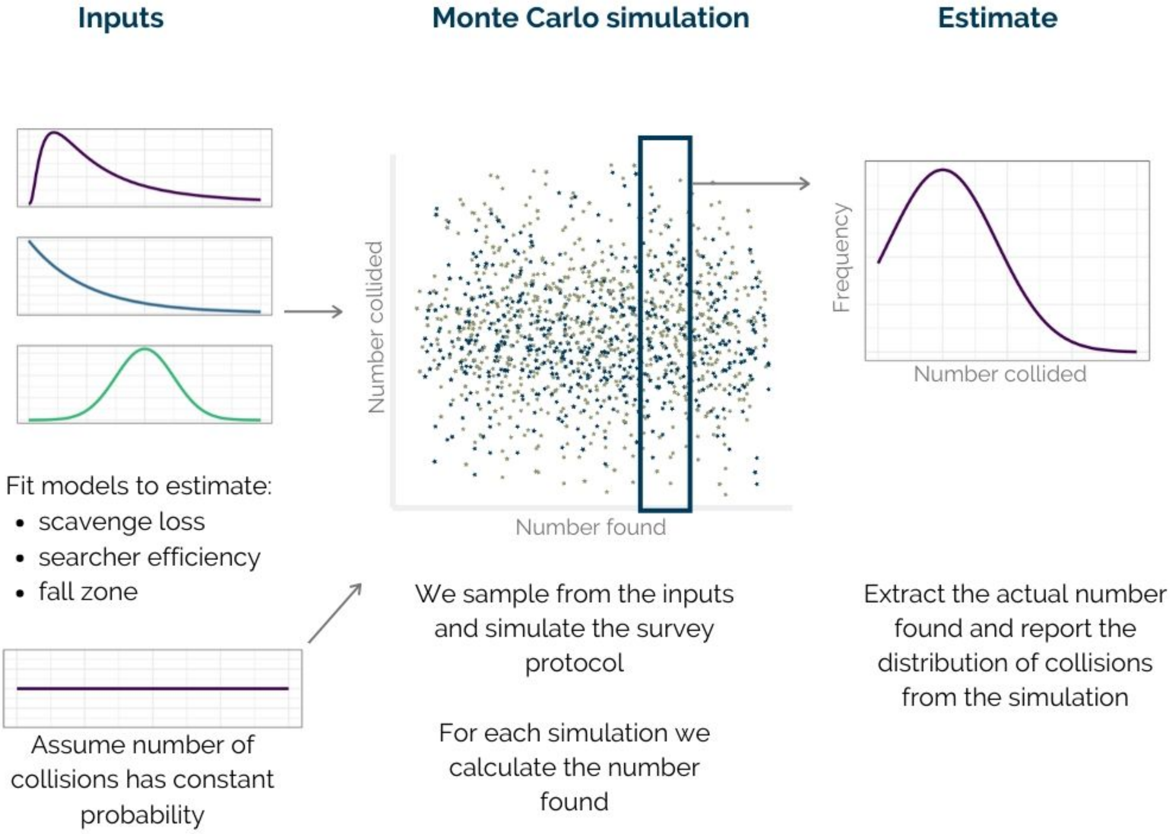
One limitation of analytical methods is estimating $r_{ij}$ when the time between surveys is not constant. In Australia, it is common for the time between searches to vary due to seasonal changes in effort or the use of a pulsed design in which the turbine is searched monthly with a return visit a few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

To allow for survey protocols with non-standard interval, the authors developed a Monte-Carlo simulation method. 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.

For the meta-site survey protocol in this study, we had a combination of pulsed searches, seasonal changes in effort, and differing protocols for different turbines. For this reason, we implemented the Monte-Carlo simulation method.

### 3.9.3 Estimating mortality using the Monte-Carlo method



Fit models to estimate:

- scavenge loss
- searcher efficiency
- fall zone

Assume number of collisions has constant probability

We sample from the inputs and simulate the survey protocol

For each simulation we calculate the number found

Extract the actual number found and report the distribution of collisions from the simulation

**Figure 3: Schematic showing the application of the Monte-Carlo method to simulate the phase space of possible collisions and subsequent carcass finds. The inputs are based on empirical distributions estimated from field trials.**

The Monte-Carlo simulator is an algorithmic approach to solving equations (1) and (2). The steps (Figure 3) are as follows

**Inputs**

- Number of simulations
- Turbine size class (or Site)
- Species class
- Start date and end date of the survey
- Start date of carcass 'arrivals'
  - 30 days before first survey (year 1)
  - Last date of previous year (subsequent years)
- Max and min number of annual carcasses - chosen to allow a broad selection of possible overall mortalities (e.g. 0 - 3000)

- A data list of the turbines and dates searched constructed from the survey data

**Monte-Carlo simulation**

For each iteration, simulate carcass collisions:

- select a number of annual carcass collisions at uniform random
- select the date and turbine they arrive at. We use a uniform distribution of dates and turbines

Simulate the survey protocol:

- For each actual survey date and turbine
    - Check if any simulated carcasses have arrived at that location prior to the survey
    - IF YES, determine if the carcass still remains (i.e. not scavenged), given the hazard decay function previously calculated
    - IF YES, determine if the carcass is detected by the observer, by sampling from the binomial distribution previously calculated
    - IF YES, mark as found
- After all surveys have been processed, record the number of carcasses arrived and the number found for that simulation and move to the next simulation round.

**Estimate**

The Monte-Carlo simulation generates a representative coverage of the phase space influencing the probability of detection.

To generate an estimate of mortality, we extract all simulations with the same number of discovered carcasses as the ‘real’ survey data under consideration.

The distribution of simulated carcass arrivals is a direct estimate of the mortality estimate. From it, we extract the median and confidence intervals.

Mortality was estimated for each site individually for validation and a visual check was performed to ensure that no site was dominating the meta-site estimate. We also generated meta-site estimates, with groups based on turbine size (section 3.3.6).

# 4 Results

## 4.1 Data summary

We define a carcass survey as **one survey visit to one turbine on one day for the purpose of counting carcasses**. The current data set contains 5432 such surveys.

The number of turbine carcass searches by observer type is summarised in Table 4.

**Table 4: Turbine searches by observer type**

| observer_type | no. obs | no. sites |
|---|---|---|
| Human | 2059 | 6 |
| Dog | 3373 | 7 |

### 4.1.1 Seasonal coverage

The carcass search data is distributed throughout the year (figure 4). There was increased survey activity over summer. This is indicative of the increased effort during times of bat activity required by many BBAMPs.

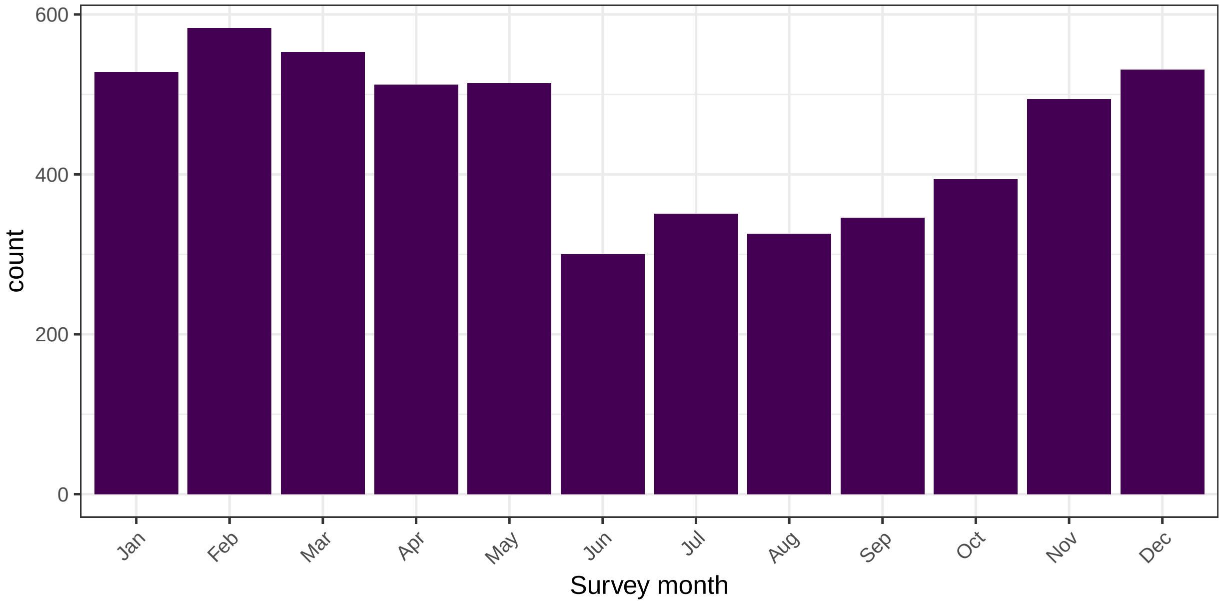


**Figure 4: Number of turbine searches per month**

## 4.2 Species finds - uncorrected

Even uncorrected carcass counts can provide some insight into the species involved in turbine collisions. These are also useful in understanding the efficiency of post-construction surveys (i.e. finds per unit time).

The area covered in total in our dataset was 14,746.33 hectares, or 147 km$^2$ and a total 428 bats and 355 birds were found. That's approximately one carcass or feather-spot find per 6.9 turbine searches, or one find per 19 hectares.

It's important to note that the 6 turbine searches out of 7 that find zero carcasses are still important data points for the purposes of estimating total mortality.

Although uncorrected carcass finds can be informative, to estimate mortality and cumulative impacts it's necessary to 'scale up' the carcass counts by taking into account scavenger and searcher efficiency.

### 4.2.1 Commonly documented species

The 25 most commonly found species (not accounting for scavenger rates or species detectability) are given in Table 5.

**Table 5: Twenty-five most documented species during carcass searches (at included sites)**

| Common name | No. found | No. sites |
|---|---|---|
| White-striped Freetail Bat | 229 | 10 |
| Gould's Wattled Bat | 77 | 8 |
| Australian Magpie | 69 | 10 |
| Unidentified Bird | 45 | 7 |
| Nankeen Kestrel | 41 | 8 |
| Raven sp. | 35 | 7 |
| Wedge-tailed Eagle | 33 | 7 |
| Eastern False Pipistrelle | 33 | 5 |
| European Skylark | 33 | 3 |
| Brown Falcon | 26 | 7 |
| Large Forest Bat | 16 | 6 |
| Lesser Long-eared Bat | 15 | <3 |
| Little Forest Bat | 13 | 6 |
| Unidentified Bat | 11 | 6 |
| Southern Freetail Bat | 10 | 4 |
| Southern Bent-wing Bat | 8 | <3 |
| European Goldfinch | 7 | 5 |
| Common Starling | 7 | 5 |
| Welcome Swallow | 6 | 4 |
| Chocolate Wattled Bat | 6 | 4 |
| Red-rumped Parrot | 5 | <3 |
| Grey-headed Flying-fox | 4 | <3 |
| House Sparrow | 4 | <3 |
| Magpie-lark | 4 | <3 |
| Southern Forest Bat | 4 | <3 |

The remaining species were found less frequently, with typically only one or two records each across all sites:

> *Sulphur-crested Cockatoo, Galah, Little Raven, Whistling Kite, Blue-winged Parrot, Finch sp., Cockatoo Sp., Stubble Quail, Pacific Black Duck, Barn Owl, Noisy Miner, Sacred Kingfisher, Australian Shelduck, Crimson Rosella, Unidentified Ducks, Gould's Long-eared Bat, Australian Wood Duck, Little Red Flying-fox, Long-billed Corella, Straw-necked Ibis, Australasian Swamphen, Australasian Pipit, Silvereye, Crested Pigeon, Common Bronzewing, Brown Goshawk, Little Corella, Peregrine Falcon, Black-shouldered Kite, Brown Songlark*

Even though these counts don't represent the total mortalities, it's interesting that the two of the three most commonly found species are (relatively small, relatively easily scavenged) bat species.

### 4.2.2 Species accumulation

We can review the number of species found for the first time as a function of the number of daily turbine searches completed. The chart below considers all of Victoria and plots the number of new species identified for each survey.

There are still new species of birds identified during new surveys, but given the number of species in Victoria (figure 5), that is not surprising.

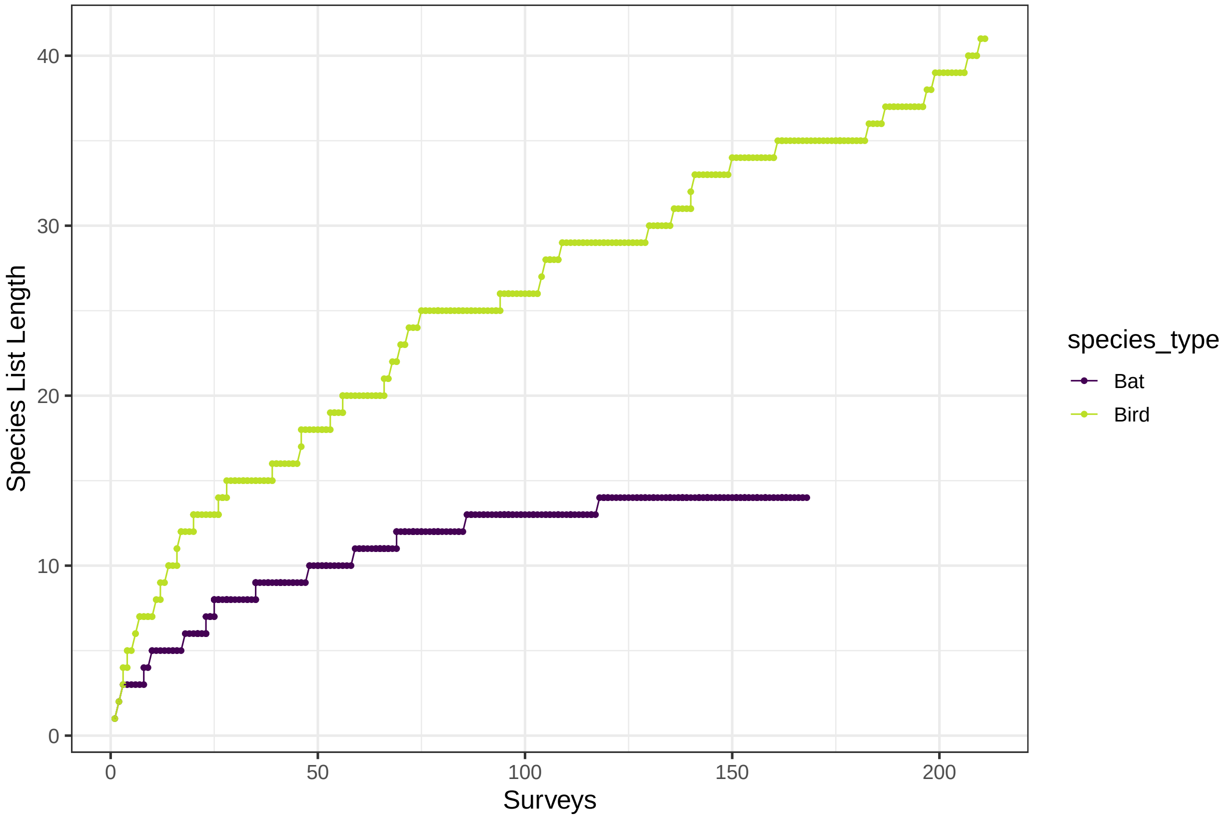


**Figure 5: New species accumulation curve for the carcass searches included in this study**

### 4.2.3 Field data - key results

- The study dataset included a total of 14,746 hectares of carcass search data
- Approximately one carcass or feather-spot was found per 6.9 turbine searches, or one find per 19 hectares.
- A total of 13 species of bat and 40 species of bird were identified.
- 11 bats and 45 birds were unidentified.
- 35 species were found at only one or two sites.

- The two most common species found were the White-striped Freetail Bat (229 carcasses at 10 sites) and the Gould's Wattled Bat (77 carcasses at 8 sites).
- The most commonly found bird was the Australian Magpie (69 carcasses at 10 sites).

## 4.3 Carcass loss to scavenge

As mentioned previously, there is a competition between the observers attempting to discover carcasses and the scavengers attempting to remove carcasses.

Many analysis techniques make implicit assumptions about this process. The most common one is that the probability of being scavenged is independent of the time that the carcass has lain on the ground. This is known as “constant hazard” and is modelled by fitting an exponential curve to the scavenger trial data. This is a good, safe assumption, and a reliable one to make when there is not enough evidence to make other, potentially more appropriate modelling assumptions. The risk is that this can lead to a bias depending upon the interaction of the *true* hazard rate and the surveying interval (Huso, Dalthorp, and Korner-Nievergelt (2015), Muir pers. comm).

Due to the collective nature of this study, there is enough data to generate insight into the time to scavenge and also the “shape” or rate of loss over time.

### 4.3.1 Scavenger loss curve shape

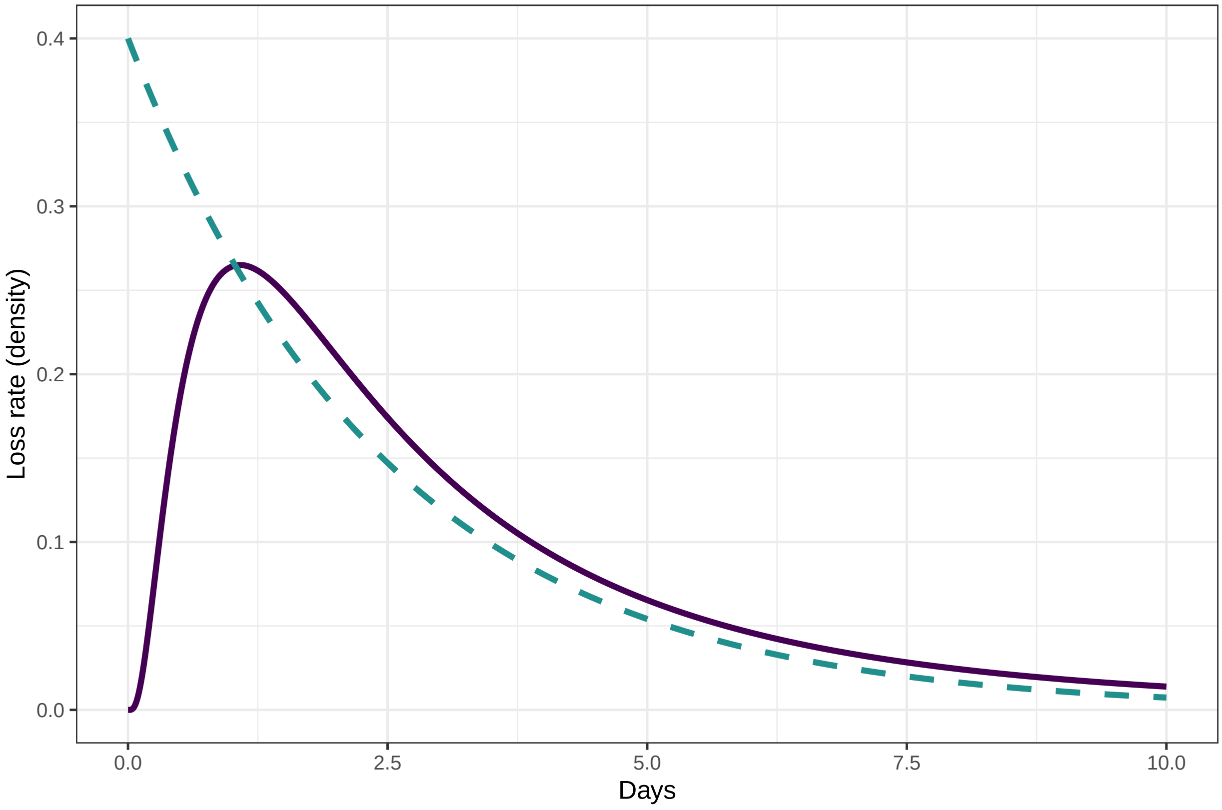


**Figure 6: Comparison of exponential (green/dashed) and log-normal curves (purple/solid) both with mean loss rate of 2.5 days.**

Fitting the following four potential shapes of the loss estimate showed the log-normal and log-logistic are the best fit for our dataset

- exponential (AICc 2339)
- log-normal (AICc 2244)
- log-logistic (AICc 2246)
- Weibull (AICc 2272)

This is in agreement with the recent work of Huso, Dalthorp, and Korner-Nievergelt (2015) who found the same for their sites.

Figure 6 demonstrates the impact of different shapes on the scavenger rate. The chart shows an exponential and log-normal hazard curve with the same mean (2.5 days) and scale (also 2.5 days). The exponential curve returns a higher probability of loss in the first couple of days (compared to log-normal). There is a crossing point after about one day. The long tail of the log-normal distribution suggests higher probability of loss than exponential after this time.

The time to scavenge predicted by a log-normal fit to the data is longer than the time to scavenge estimated by an exponential fit to the same data.

The differences between these two approaches are slight. However, they are real and can be detected with the large data set that this project offers.

### 4.3.2 Proxy species

The combined dataset contained two species proxies - Mice (for bats) and Chickens (for large birds). We compared the average time to scavenge and the shape of the loss curve to ascertain the performance of the proxy species.

Figure 7 compares the estimated loss time (plus 95% confidence interval) for proxies and other species groups.

The time to loss of Mice is slightly different to Bats ($p \sim 0.1$ using Tukey's contrast comparisons) (Figure 7 & 9) The shape of the loss function for mice mimics that of bats. This suggests that they are a reasonable proxy, though their use may lead to a slightly shorter estimate of time-to-scavenge.

In contrast, the time to loss for Chickens is significantly different to Birds ($p < 0.001$) (Figure 7 & 8). In fact, the time to loss for a Chicken carcass is not significantly different from that of a Mouse carcass ($p > 0.9$). We have thus excluded Chickens from the calculations of scavenge rate below and as inputs to the mortality estimate, but have allowed Mice.

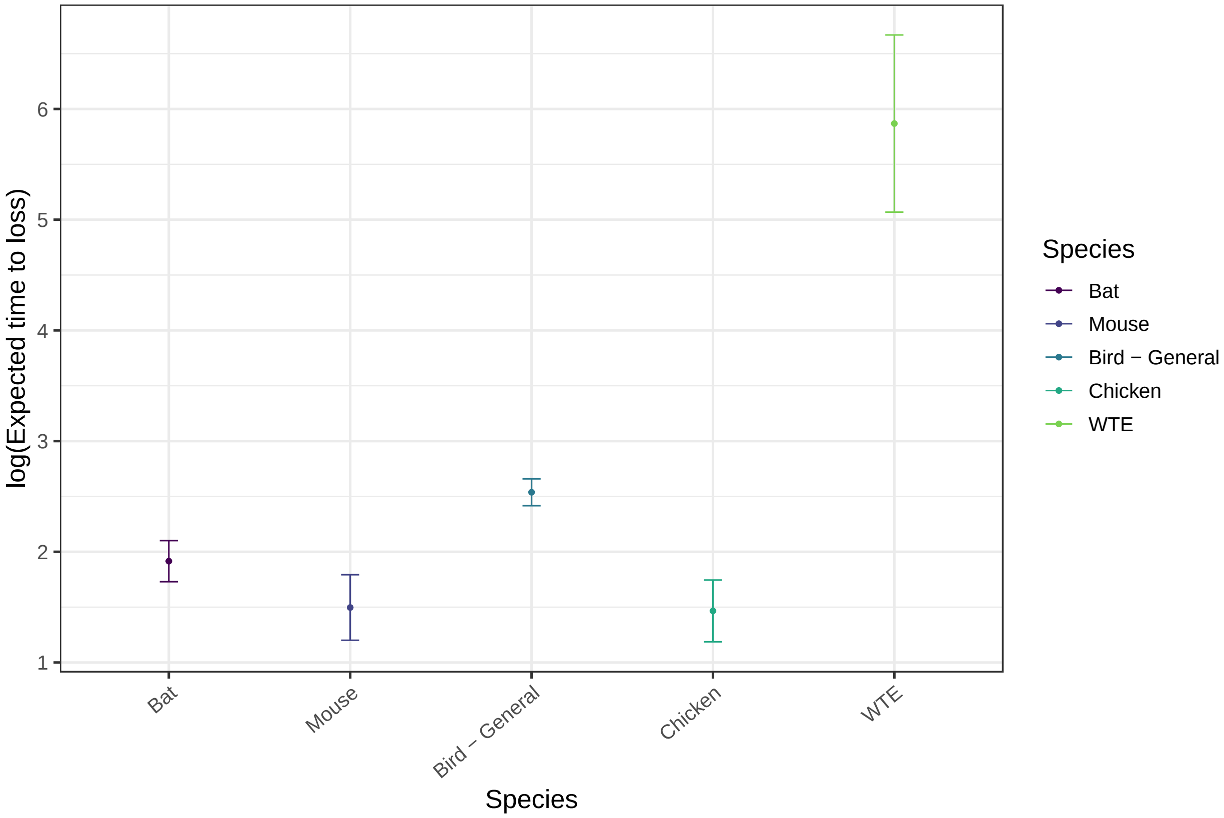


**Figure 7: Proxy species comparison - Average time to scavenge with 95% confidence interval**

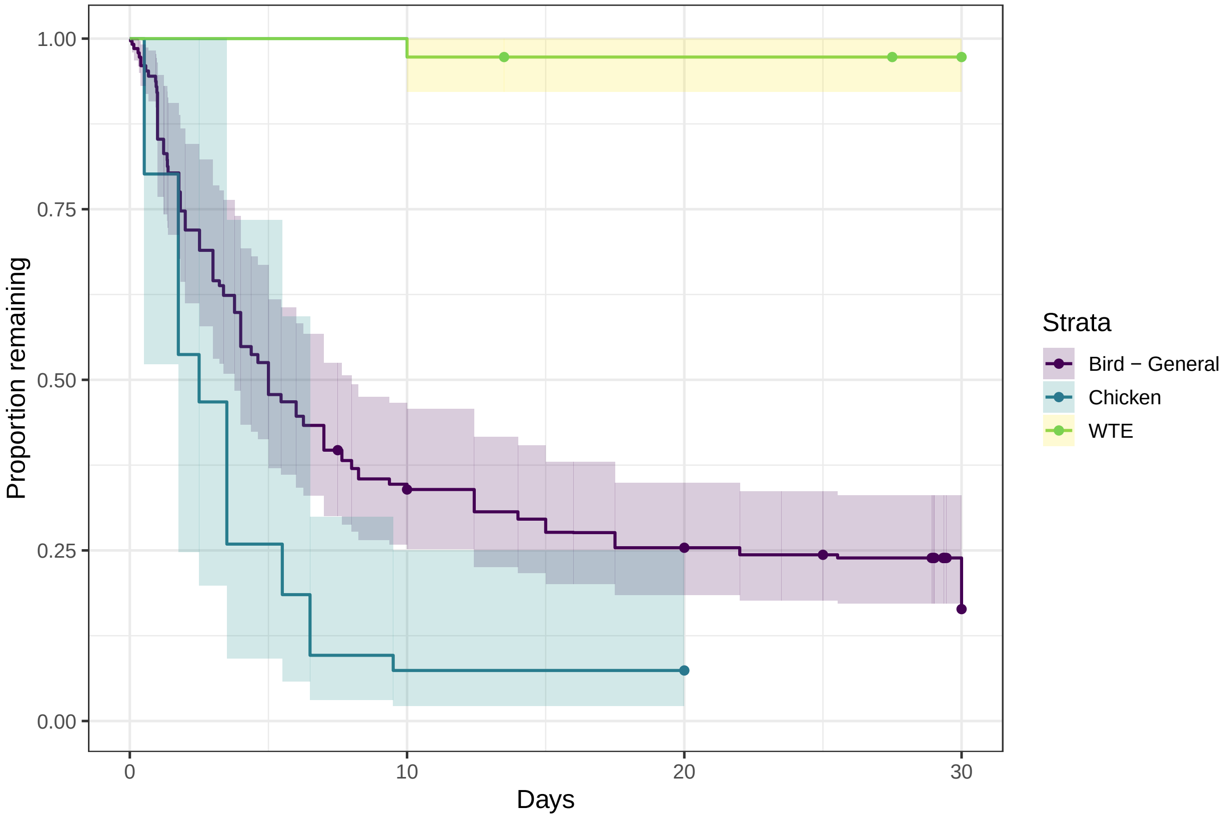


Figure 8: Hazard curve - bird proxy species comparison

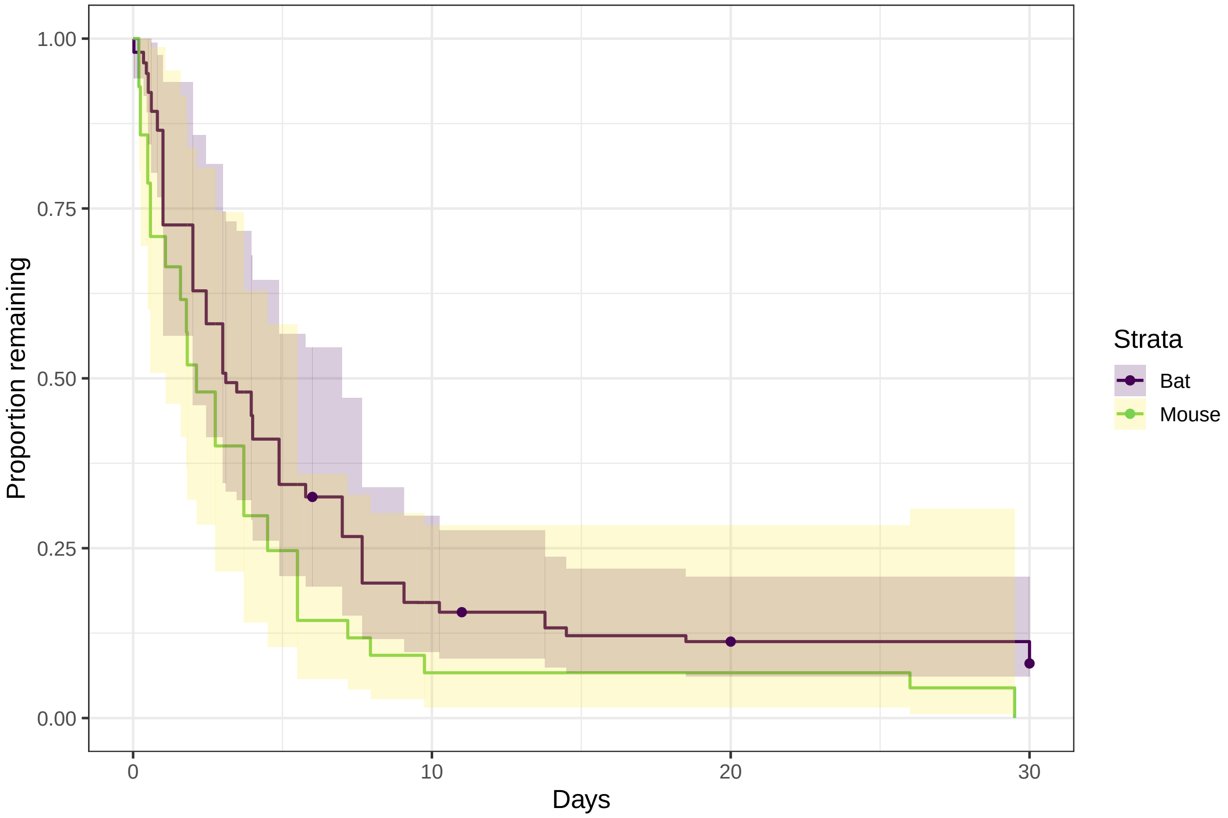


**Figure 9: Hazard curve - bat proxy species comparison**

### 4.3.3 Time to carcass loss

The final estimate of time to loss is summarised in Table 6. On average, bat carcasses are lost after a couple of days, and most birds within a week. Wedge-tailed Eagles are a notable exception, with evidence remaining in place for months.

**Table 6: Time to loss estimates for different carcass sizes. N is the number of trials, and the lower and upper bounds represent the 95% confidence interval**

| Archetype | n | Avg days to loss | lower bound | upper bound |
|---:|---|---|---|---|
| Bat | 170 | 2.7 | 2.1 | 3.4 |
| Bird - General | 321 | 5.7 | 4.8 | 6.8 |
| WTE | 37 | 287.3 | 130.1 | 634.5 |

### 4.3.4 Scavenge loss - Key results

- Wedge-tailed Eagles are lost to scavenge at a much slower rate than the other bird species studied. On average it takes 287 days for a a Wedge-tailed Eagle carcass to be scavenged (n = 37). We can be confident that some carcass evidence will remain for a long time period following collision.

  - We have no data on other very large carcasses (e.g. brolga) so cannot comment on whether the pattern extends to these species.

- For other bird carcasses, evidence was lost after an average of 5.68 days, with confidence interval [4.75, 6.79] days (n = 321).
- For bats, evidence was lost after an average of 2.69 days, with confidence interval [2.11, 3.43] days (n = 170).
- We found no significant difference between study sites in time to loss or searcher efficiency, so the above results can be used as reference values for similar sites and species.
- Mice have similar time to loss than bats, so are a reasonable choice as a proxy species for scavenger trials.
- Chickens are scavenged at a significantly faster rate than other bird species ($p < 0.001$), so are not a suitable proxy for large birds.
- We tested for seasonal differences based on a two-season year (‘cold-wet’ and ‘hot-dry’). We found no significant difference in the loss rates between seasons.
- This project was the first time a large enough set of data was pooled to robustly fit different distributions to the loss data. The authors have previously used the exponential distribution as a default (in the absence of better evidence). With pooled data we determined the best fit as a log-normal distribution. Time to scavenge estimated with a log-normal distribution results in a longer time than an exponential fit to the same data.

## 4.4 Searcher efficiency

### 4.4.1 Data summary

Table 7 shows the data coverage over each covariate for the searcher efficiency analysis.

**Table 7: Number of searcher efficiency trials by covariate.**

| Season | Size class | Dog | Human |
|---|---|---|---|
| hotdry | Bat | 82 | 53 |
| hotdry | Bird - General | 50 | 159 |
| hotdry | Large | 18 | 24 |
| wetcold | Bat | 86 | 88 |
| wetcold | Bird - General | 48 | 235 |
| wetcold | Large | 21 | 17 |

Appendix E lists the species used in the searcher efficiency trials. Species are often sourced from previously struck carcasses or from other research sources (e.g. House Mouse). Obtaining a representative sample of all sizes, morphologies and colours is limited to the samples available (within standard ethical practice).

After model fitting we were able to reduce the species covariates to two factors - Birds and Bats. We found no seasonal dependence in detection rates.

For human observers, we found a significant difference between the detection rates of birds and bats but no such difference for dogs (Table 8 and Figure 10).

**Table 8: Summary table of searcher efficiency (proportion found) by observer and species type**

| Observer type | Species type | Mean | Standard Error | No. found | No. trials |
|---|---|---|---|---|---|
| Human | Bird | 0.88 | 0.54 | 383 | 435 |
| Human | Bat | 0.52 | 0.54 | 74 | 141 |
| Dog | Bat/Bird | 0.84 | 0.54 | 257 | 305 |

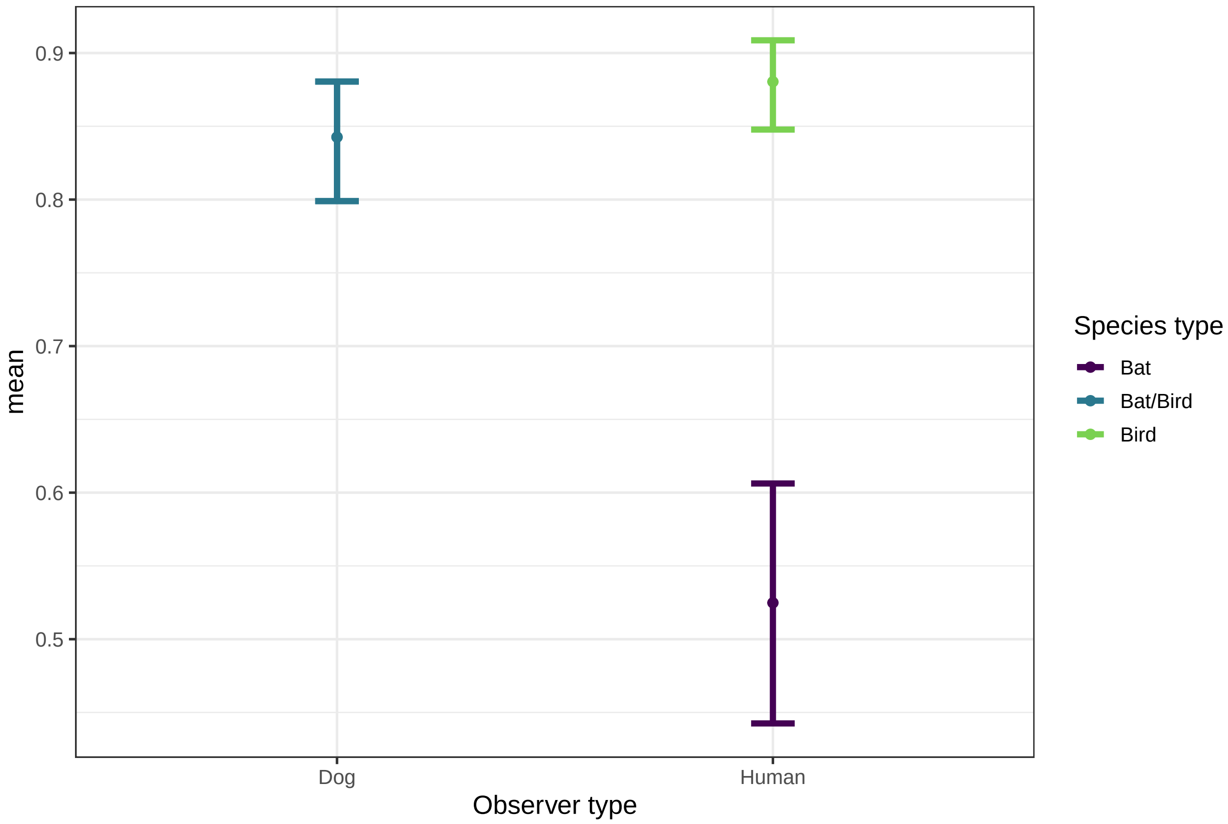


**Figure 10: Mean and 95% CI searcher efficiency by observer and species type**

The searcher efficiency of dogs compares favourably to humans when bats are the target species groups. There is no significant difference for birds. In interpreting this, we note that the species used tended to be larger for searcher trials with dogs.

The searcher efficiency rate for humans searching birds is valid, but we advise caution if used to estimate mortality of small bird species groups.

### 4.4.2 Searcher efficiency - Key results

- Searcher efficiency depends on the size and type of the carcass and whether human or canine observers are used.
- We found no significant difference in searcher efficiency in different seasons (cold-wet or hot-dry)
- We found no significant difference in the detection probability for different bird species (human). Dogs detected bats and birds with equal probability.
- Humans find 88% of all birds, n = 435, confidence interval [85%, 91%]
- Humans find 52% of all bats, n = 141, confidence interval [44%, 61%]
- Dogs find % of all carcasses regardless of type, n = , confidence interval [numeric(0)%,

numeric(0)%]

- We found no significant difference between study sites, so the above results can be used as reference values for similar sites, species and survey protocols.

## 4.5 Per-turbine mortality

The results for fall zones, time to loss and searcher efficiency were input into the mortality estimation.

We used 50,000 simulations to define the phase space of collisions and finds for each species type and turbine class. For each grouping, we filtered the simulation results to those with the correct number of carcass finds (for those sites in that period), as described above.

The histograms and tables below summarise the results.

### 4.5.1 Bats

Figure 11 and Table 9 summarise the estimated mortalities (and related variability) for Bat species.

The histograms for the turbine size classes substantially overlap, with small turbines showing a slightly higher expected mortality. Considering the amount of overlap in the distributions, it's reasonable to summarise this result as:

**Between 7 and 10.8 bat mortalities occur per turbine per year in Western Victoria**

The values in Table 9 provide more control to estimate based on turbine size. The data set modelled provides a good sample of the range of turbine sizes currently in use (or planned) in Victoria.

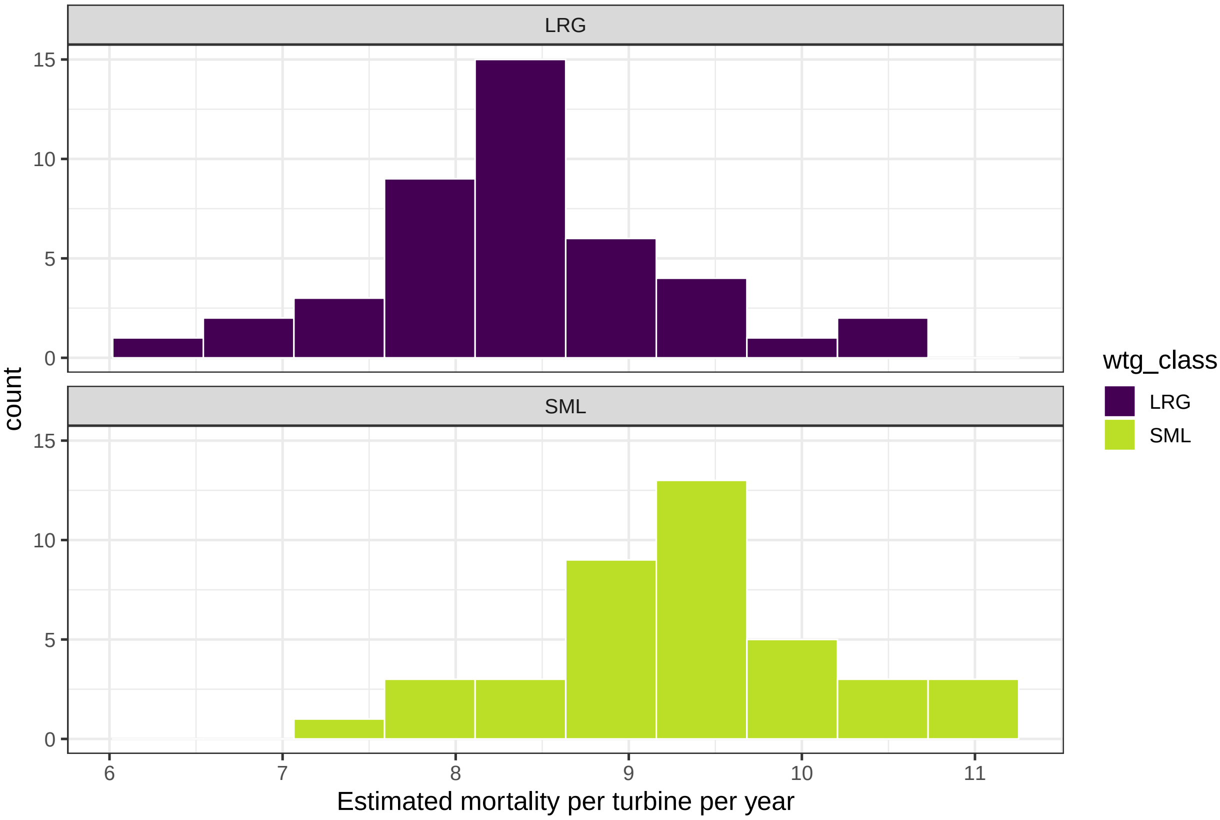


**Figure 11: Credible Distribution of Bat Mortalities per turbine year**

**Table 9: Statistical summary of bat mortalities (per turbine per year). Confidence interval bounds are the 5th and 95th percentile of the distribution.**

| wtg_class | No. found | Turbine years | Mean | Std.Dev. | CI lower | median | CI upper |
|---|---|---|---|---|---|---|---|
| SML | 334 | 151.30 | 9.27 | 0.84 | 7.97 | 9.25 | 10.78 |
| LRG | 94 | 49.57 | 8.36 | 0.87 | 7.03 | 8.39 | 10.12 |

### 4.5.2 Birds

For birds, we see a clear difference in the expected mortality losses for different turbine classes ( Figure 12 and Table 10 ). The larger the swept area, the larger the loss.

There are many possible contributors to this, including factors not explicitly modelled. Turbines with larger diameters, by necessity, are often higher above the ground level. This is an example of a latent variable, where we could imagine that the leading predictor of mortality is the highest point of the sweep. Although this was never measured, it is strongly correlated with rotor diameter.

For small turbines, between 3.4 and 4.1 bird mortalities occur per turbine per year. For large turbines, the range varies between 5 and 6.7 per turbine per year.

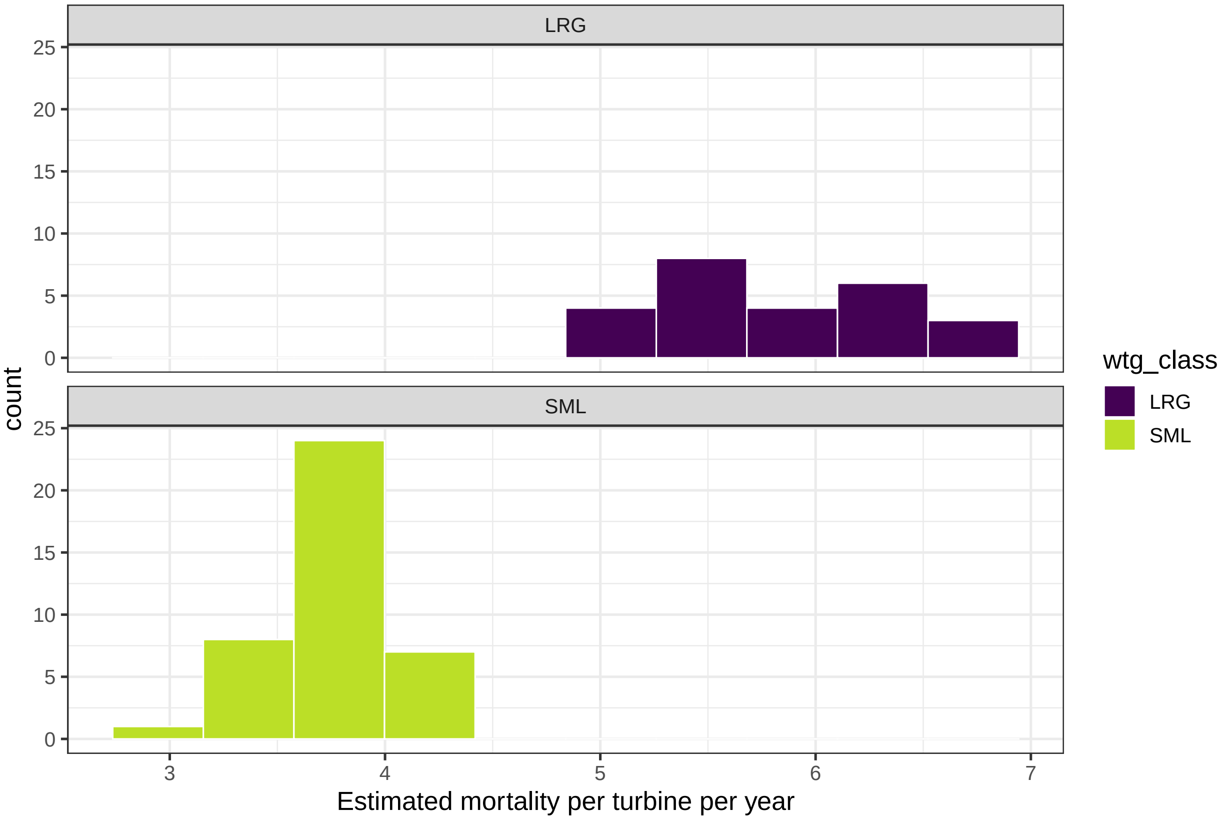


**Figure 12: Credible Distribution of Bird Mortalities per turbine year**

**Table 10: Statistical summary of bird mortalities (per turbine per year). Confidence interval bounds are the 5th and 95th percentile of the distribution.**

| wtg_class | No. found | Turbine years | Mean | Std.Dev. | CI lower | median | CI upper |
|---|---|---|---|---|---|---|---|
| SML | 203 | 151.30 | 3.77 | 0.23 | 3.44 | 3.78 | 4.06 |
| LRG | 119 | 49.57 | 5.83 | 0.57 | 4.98 | 5.73 | 6.70 |

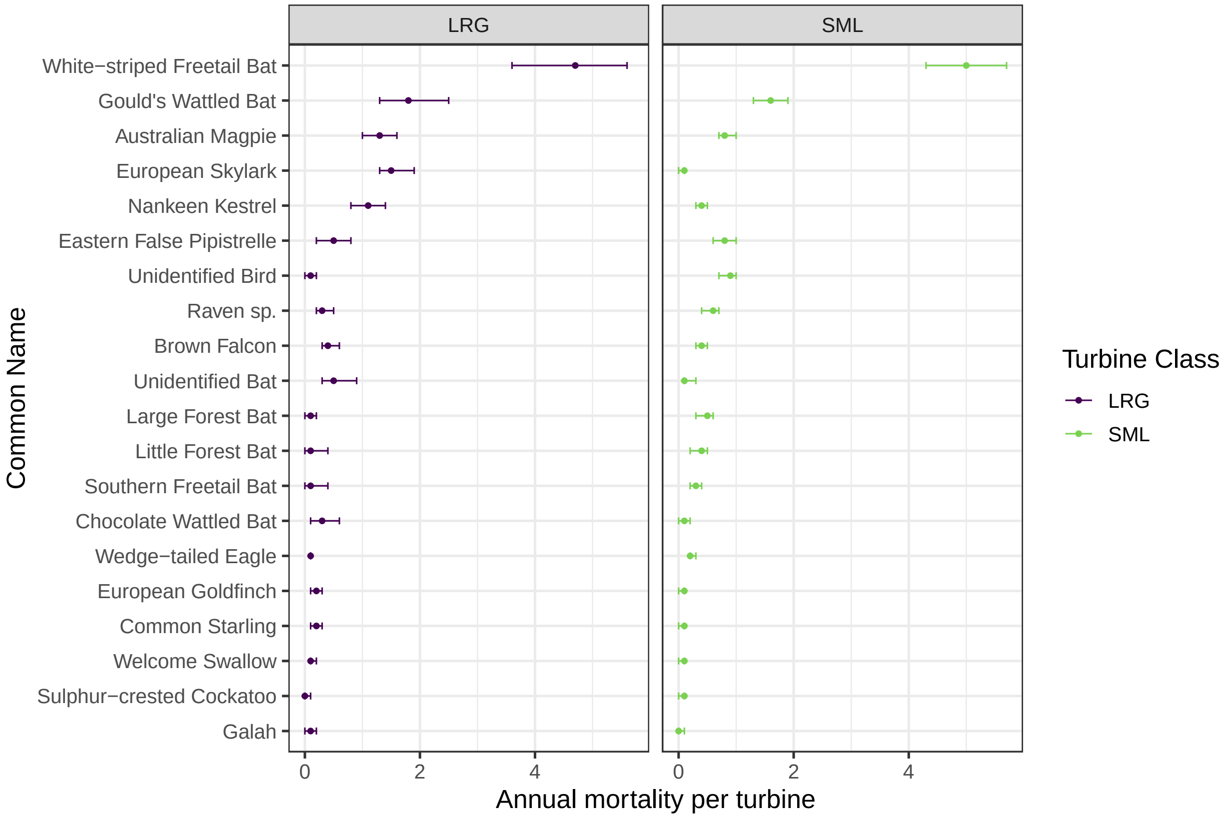
## 4.6 Mortality per species

**Table 11: Median, lower and upper confidence interval for the annual per turbine mortality by species. Results shown for each species with finds at more than two sites**

| common_name | N_found | N_sites | wtg_class | lowerCI | median | upperCI |
|---|---|---|---|---|---|---|
| Chocolate Wattled Bat | 3 | 1 | LRG | 0.1 | 0.3 | 0.6 |
| Chocolate Wattled Bat | 3 | 3 | SML | 0.0 | 0.1 | 0.2 |
| Eastern False Pipistrelle | 5 | 1 | LRG | 0.2 | 0.5 | 0.8 |
| Eastern False Pipistrelle | 28 | 4 | SML | 0.6 | 0.8 | 1.0 |
| Gould's Wattled Bat | 20 | 2 | LRG | 1.3 | 1.8 | 2.5 |
| Gould's Wattled Bat | 57 | 6 | SML | 1.3 | 1.6 | 1.9 |
| Large Forest Bat | 0 | 0 | LRG | 0.0 | 0.1 | 0.2 |
| Large Forest Bat | 16 | 6 | SML | 0.3 | 0.5 | 0.6 |
| Little Forest Bat | 1 | 1 | LRG | 0.0 | 0.1 | 0.4 |
| Little Forest Bat | 12 | 5 | SML | 0.2 | 0.4 | 0.5 |
| Southern Freetail Bat | 1 | 1 | LRG | 0.0 | 0.1 | 0.4 |
| Southern Freetail Bat | 9 | 3 | SML | 0.2 | 0.3 | 0.4 |
| Unidentified Bat | 6 | 3 | LRG | 0.3 | 0.5 | 0.9 |
| Unidentified Bat | 5 | 3 | SML | 0.1 | 0.1 | 0.3 |
| White-striped Freetail Bat | 52 | 4 | LRG | 3.6 | 4.7 | 5.6 |
| White-striped Freetail Bat | 177 | 6 | SML | 4.3 | 5.0 | 5.7 |
| Australian Magpie | 26 | 4 | LRG | 1.0 | 1.3 | 1.6 |
| Australian Magpie | 43 | 6 | SML | 0.7 | 0.8 | 1.0 |
| Brown Falcon | 8 | 3 | LRG | 0.3 | 0.4 | 0.6 |
| Brown Falcon | 18 | 4 | SML | 0.3 | 0.4 | 0.5 |
| Common Starling | 3 | 2 | LRG | 0.1 | 0.2 | 0.3 |
| Common Starling | 4 | 3 | SML | 0.0 | 0.1 | 0.1 |
| European Goldfinch | 3 | 1 | LRG | 0.1 | 0.2 | 0.3 |
| European Goldfinch | 4 | 4 | SML | 0.0 | 0.1 | 0.1 |
| European Skylark | 30 | 2 | LRG | 1.3 | 1.5 | 1.9 |
| European Skylark | 3 | 1 | SML | 0.0 | 0.1 | 0.1 |
| Galah | 1 | 1 | LRG | 0.0 | 0.1 | 0.2 |
| Galah | 2 | 2 | SML | 0.0 | 0.0 | 0.1 |
| Nankeen Kestrel | 22 | 4 | LRG | 0.8 | 1.1 | 1.4 |
| Nankeen Kestrel | 19 | 4 | SML | 0.3 | 0.4 | 0.5 |
| Raven sp. | 6 | 2 | LRG | 0.2 | 0.3 | 0.5 |
| Raven sp. | 29 | 5 | SML | 0.4 | 0.6 | 0.7 |
| Sulphur-crested Cockatoo | 0 | 0 | LRG | 0.0 | 0.0 | 0.1 |
| Sulphur-crested Cockatoo | 3 | 3 | SML | 0.0 | 0.1 | 0.1 |
| Unidentified Bird | 1 | 1 | LRG | 0.0 | 0.1 | 0.2 |

**Table 11: Median, lower and upper confidence interval for the annual per turbine mortality by species. Results shown for each species with finds at more than two sites *(continued)***

| common_name | N_found | N_sites | wtg_class | lowerCI | median | upperCI |
|---|---|---|---|---|---|---|
| Unidentified Bird | 44 | 6 | SML | 0.7 | 0.9 | 1.0 |
| Welcome Swallow | 2 | 1 | LRG | 0.1 | 0.1 | 0.2 |
| Welcome Swallow | 4 | 3 | SML | 0.0 | 0.1 | 0.1 |
| Wedge-tailed Eagle | 3 | 2 | LRG | 0.1 | 0.1 | 0.1 |
| Wedge-tailed Eagle | 30 | 5 | SML | 0.2 | 0.2 | 0.3 |



## 4.7 Species case study - White-striped Freetail Bat

White-striped Freetail Bats (WSFT) are the most commonly found species at Victorian wind farms (by an order of magnitude), so they are an obvious choice for a case study.

The annual per-turbine mortality estimates are summarised in Figure 13 and Table 12. As with the combined bat result, there is little difference between small and large turbines.

Between 3.8 and 6.2 WSFT Bat mortalities occur per turbine per year in Western Victoria.

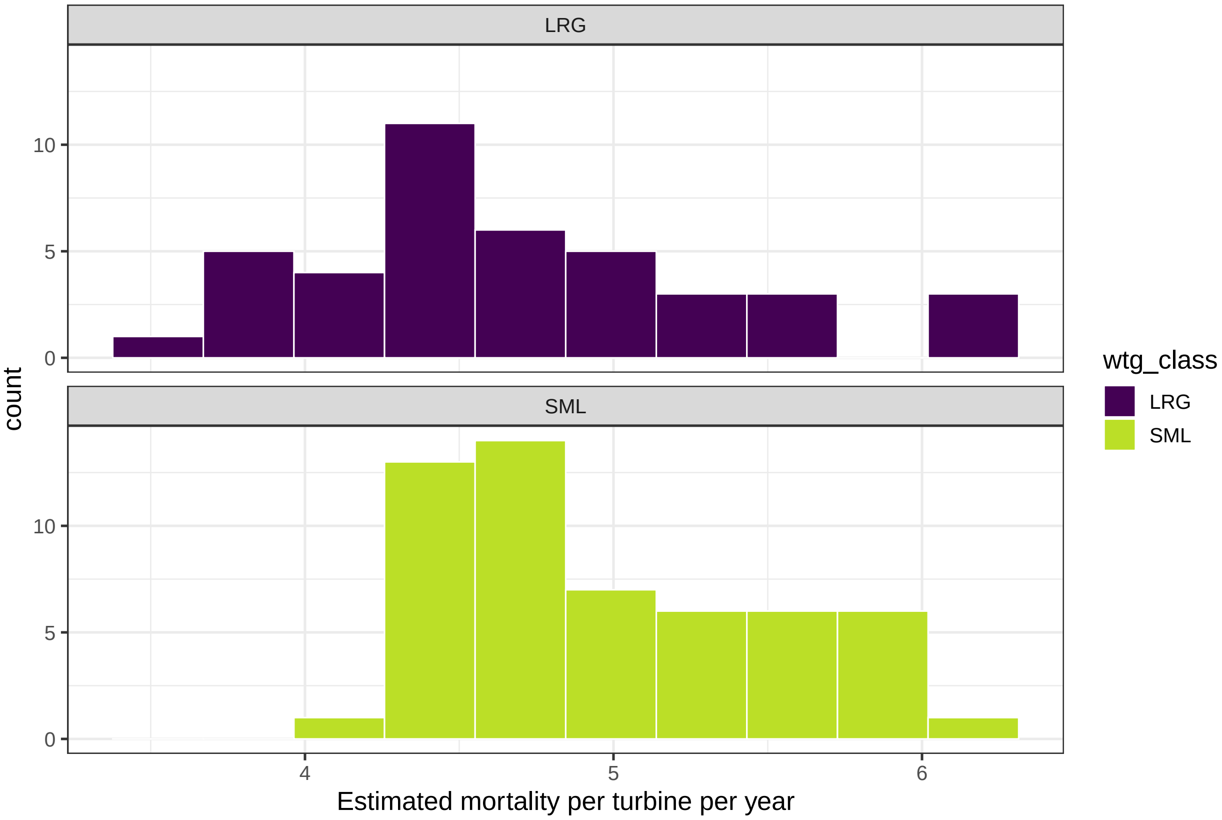


**Figure 13: Credible Distribution of WSFT mortalities per turbine year**

**Table 12: Statistical summary of WSFT mortalities (per turbine per year). Confidence interval bounds are the 5th and 95th percentile of the distribution.**

| wtg_class | No. found | Turbine years | Mean | Std.Dev. | CI lower | median | CI upper |
|---|---|---|---|---|---|---|---|
| SML | 177 | 151.30 | 4.97 | 0.51 | 4.32 | 4.82 | 5.79 |
| LRG | 52 | 49.57 | 4.68 | 0.67 | 3.77 | 4.50 | 6.21 |

### 4.7.1 Cumulative estimated mortality rates - Key results

- Turbine size influences the mortality estimate, due to differing ‘fall zones’ for carcasses (Hull and Muir 2010). We estimated per turbine mortality for two size classes.
    - Small (SML) turbines have rotor diameter of less than or equal to 103m. Anything larger was classed as Large (LRG).
    - At time of writing there were 317 small class turbines and 205 large class turbines in Victoria (Appendix A).
- Between 7 and 10.8 bat mortalities occur per turbine per year in Western Victoria. The rate is not significantly different for different sizes (Section 4.5.1)
- For birds, significantly more mortalities occur at larger turbines. For small turbines,

between 3.4 and 4.1 bird mortalities occur per turbine per year. For large turbines, the range varies between 5 and 6.7 per turbine per year.

- Our study suggests that mortalities are higher for White-striped Freetail Bats than any other bat or bird species. Between four to six White-striped Freetails are struck per turbine, and they were discovered at every site in the study. This implies that turbines in Western Victoria strike around as many White-striped Freetails as all birds combined.

# 5 Discussion - Towards Landscape Modelling

The results in the previous section represent the first attempt at generating multi-site, regional bird and bat mortality estimates from wind turbines.

For the first time, we can estimate the per-turbine mortality for individual species, and compare the incidence of collision for different species. We can also demonstrate the impact of different sized turbine on bird and bat mortality.

It's important to remember this estimate is based on a group of otherwise representative and random turbines of each size class. Individual turbines may average more or less than this value and the local species and population should be considered when applying this value to a particular site.

## 5.1 Some words of statistical caution

Whenever data is applied to generate a model prediction or estimate, assumptions are made.

Applied mathematicians, like ourselves, try explain as many of these assumptions as we can accommodate. We consider assumptions and explicitly encode and manage them in the modelling process. Commonly, these explicit assumptions are employed as modelling levers, something to be altered in the case of scenario and planning outcomes.

However, there remain implicit assumptions. These are often hidden, with no indication that they are there. As such, they can be traps for the unwary application of the statistic.

Let us take the current estimate of a per turbine annual mortality rate. It is a statistic, taken from data sources and combined in an unbiased fashion. It is a statistically unbiased, representative metric of one-year's worth of data at a representative wind turbine in Western Victoria.

But it is not infallible, and we advise caution in extending these findings without considering the likelihood of breaching a model assumption.

Wedge-tailed Eagles are a good example of why we advise some caution in using the meta-site mortality estimates. Wedge-tailed Eagles demonstrate a strong site-specific pattern in carcass finds (Table 13). Site A is clearly an outlier, with more than four times the number of carcass finds as the site with the next highest number. Inevitably, such a skew in the distribution of contributing sites will lead to potentially misleading interpretation of metrics.

This indicates that local geography is a driving factor in Wedge-tailed Eagle collisions, rather than turbine characteristics. The annual per-turbine statistic is a robust estimate of the current average, but it may not be broadly applicable to all sites, or state-wide projections.

**Table 13: Site carcass counts (observed) for Wedge-tailed Eagles**

| site_id | N |
|---|---|
| A | 20 |
| D | 4 |
| K | 2 |
| N | 4 |
| O | 1 |
| T | 1 |
| Y | 1 |

## 5.2 Generating future forecasts

For the reasons above, we have stopped short of providing 'whole of state' mortality estimates, or forecasting the cumulative impact over the 25 year lifetime of the current generation of sites.

Although such a state-wide estimate might be feasible for a broadly distributed species like Australian Magpies or White-Striped Freetail Bats, it relies on the assumption that the species exists and behaves the same at all sites.

In extending an annual estimate to 25 years, one is assuming that there are no correlations between years. Dry years are not associated in any way to subsequent dry years, or wet years. Long oscillations in weather (such as the Southern Oscillation Index), do not exist. These are just the obvious assumptions.

Further, a 25 year projection makes assumptions about population mechanics. It is assuming that the population behind the losses is infinite, and instantaneously re-stocked. It assumes that movement across the landscape is free.

## 5.3 What use is the data for policy and planning?

It is frustrating that, having provided the reader with the numbers required to generate cumulative long-range forecasts (for the first time), we now argue for caution.

There is considerable value in the results of this study, provided the scope and assumptions are managed. The per turbine mortality estimates serve as a naïve estimate for more detailed landscape models or population viability analysis. That is beyond the scope of this work, but this document aims to articulate enough methodology that future applications can use our results robustly.

The scavenger and searcher efficiency results can serve as proxies to reduce the need to replicate the same study at every site.

Ultimately, we provide this summary of post-construction mortality statistics at Victorian wind farms to assists planners and proponents to move beyond the initial phase of collating statistics.

We can now understand the broad patterns of collision risk, thanks to this concerted period of data collection. We hope this information can contribute to ecological studies and work focussed on key species and risks identified in this first stage of knowledge gathering.

# A Appendix - Wind Farms in Victoria

Data sourced from

- https://www.energy.vic.gov.au/renewable-energy/wind-energy/wind-projects
- https://en.wikipedia.org/wiki/List_of_wind_farms_in_Victoria

and direct enquiry.

**Table 14: Operating Wind Farms in Victoria at time of writing**

| Wind farm | Location | Year commissioned | No. turbines |
|---|---|---|---|
| Codrington | 25 km west of Port Fairy | 2001 | 14 |
| Toora | 8 km east of Foster | 2002 | 12 |
| Challicum Hills | 15 km east of Ararat | 2003 | 35 |
| Wonthaggi | 3 km from Wonthaggi | 2005 | 6 |
| Yambuk - Portland Wind Energy Project (Stage 1) | 20 km west of Port Fairy | 2007 | 20 |
| Waubra | 35 km north west of Ballarat | 2009 | 128 |
| Cape Bridgewater-Portland Wind Energy Project (Stage 2) | 20 km west of Portland | 2009 | 29 |
| Cape Nelson South – Portland Wind Energy Project (Stage 3) | 5 km south west of Portland | 2009 | 22 |
| Leonards Hill | 10 km south of Daylesford | 2011 | 2 |
| Mortons Lane | 25 km east of Hamilton | 2012 | 13 |
| Oaklands Hill | 45 km north east of Hamilton | 2012 | 32 |
| Macarthur | 16 km east of Macarthur | 2013 | 140 |
| Mount Mercer | 30 km south of Ballarat | 2014 | 64 |
| Chepstowe | 30 km west of Ballarat | 2015 | 3 |
| Cape Nelson North and Cape Sir William Grant – Portland Wind Energy Project (Stage 4) | Near Portland | 2015 | 23 |
| Bald Hills | 20 km south east of Inverloch | 2015 | 52 |
| Coonooer Bridge | 23 km north of St Arnaud | 2016 | 6 |
| Ararat | 10 km north east of Ararat | 2017 | 75 |

**Table 14: Operating Wind Farms in Victoria at time of writing *(continued)***

| Wind farm | Location | Year commissioned | No. turbines |
|---|---|---|---|
| Kiata | 10km south east of Nhill | 2017 | 9 |
| Maroona | 18 km south west of Ararat | 2018 | 2 |
| Yawong | 15 km north east of St Arnaud | 2018 | 2 |
| Salt Creek | 10 km north of Mortlake | 2018 | 15 |
| Yaloak South | 14 km south of Ballan | 2018 | 14 |
| Timboon West | 8 km north of Peterborough | 2018 | 2 |
| Mount Gellibrand | 25 km east of Colac | 2019 | 44 |

# B Appendix - Specially defined taxa

We augmented the reference species list with the following custom taxa to allow consistent species labelling across sites

| Taxon ID | Common Name | Scientific Name | Species Type | Taxon Type |
|---|---|---|---|---|
| 101 | Raven sp. | Corvus sp. | Bird | Passerine birds |
| 102 | Forest Bat sp. | Vespadelus sp. | Bat | Bats |
| 103 | Unidentified Bird | Unidentified Bird | Bird | Unknown |
| 104 | Unidentified Bat | Unidentified Bat | Bat | Unknown |
| 105 | House Mouse | Mus musculus | Bat | Bat proxy |
| 106 | Lorikeet sp. | Trichoglossus or Glossopsitta sp. | Bird | Other Non-passerine birds |
| 107 | Unidentified Quail | Quail sp. | Bird | Other Non-passerine birds |
| 108 | Finch sp. | Finch sp. | Bird | Passerine birds |
| 109 | Chicken | Gallus gallus domesticus | Bird | Non-passerine birds |
| 110 | Lapwing sp. (juv) | Vanellus sp. (juv) | Bird | Waders |
| 111 | Unidentified Bird - FS | Unidentified Bird | Bird | Unknown |
| 112 | Cockatoo Sp. | Cockatoo Sp. | Bird | Other Non-passerine birds |
| 113 | Unidentified Bird of Prey | Unidentified Bird of Prey | NA | Other Non-passerine birds |
| 114 | Domestic Pigeon | Columba livia | Bird | Other Non-passerine birds |

# C Appendix - Species used for scavenger rate trials

The following species made up the dataset analysed to provide scavenger rates. The original dataset also included 54 Chickens as proxies for large birds. These were excluded from analysis when shown to be removed at a significantly faster rate than other birds.

Mice were found to decay/be removed at a similar rate to bats so were kept in the analysis set as bat proxies.

| common_name | scavenge_type | N |
|---|---|---|
| Unidentified Bat | Bat | 72 |
| White-striped Freetail Bat | Bat | 45 |
| House Mouse | Bat | 45 |
| Gould's Wattled Bat | Bat | 5 |
| Grey-headed Flying-fox | Bat | 2 |
| Forest Bat sp. | Bat | 1 |
| Unidentified Bird | Bird - General | 119 |
| Australian Ringneck | Bird - General | 73 |
| Common Myna | Bird - General | 38 |
| Australian Magpie | Bird - General | 26 |
| Brown Falcon | Bird - General | 8 |
| Nankeen Kestrel | Bird - General | 7 |
| Domestic Pigeon | Bird - General | 7 |
| Raven sp. | Bird - General | 5 |
| Common Starling | Bird - General | 4 |
| Little Raven | Bird - General | 4 |
| Willie Wagtail | Bird - General | 3 |
| Australasian Grebe | Bird - General | 3 |
| Finch sp. | Bird - General | 3 |
| Sulphur-crested Cockatoo | Bird - General | 2 |
| Peregrine Falcon | Bird - General | 2 |
| Spotted Turtle-Dove | Bird - General | 2 |
| Welcome Swallow | Bird - General | 1 |
| Galah | Bird - General | 1 |
| Cockatoo Sp. | Bird - General | 1 |
| Little Corella | Bird - General | 1 |
| Pacific Black Duck | Bird - General | 1 |
| House Sparrow | Bird - General | 1 |
| Common Blackbird | Bird - General | 1 |
| Long-billed Corella | Bird - General | 1 |
| Little Eagle | Bird - General | 1 |

*(continued)*

| **common_name** | **scavenge_type** | **N** |
|---|---|---|
| Crested Pigeon | Bird - General | 1 |
| Silvereye | Bird - General | 1 |
| Laughing Kookaburra | Bird - General | 1 |
| White-throated Needletail | Bird - General | 1 |
| Barn Owl | Bird - General | 1 |
| New Holland Honeyeater | Bird - General | 1 |
| Wedge-tailed Eagle | WTE | 37 |
| Eurasian Coot | NA | 1 |
| Spotted Pardalote (coastal) | NA | 1 |

# D Appendix - Archetypes used for fall zone calculations

## D.1 Turbine archetypes

- Small: Hub height: 84m. Rotor diameter: 97m
- Large: Hub height: 84m. Rotor diameter: 112m

## D.2 Bird and bat archetypes

- All values in S.I. units.
- All values sourced from Hull and Muir (2010) except White-striped Freetail Bat - sourced from Bullen and McKenzie (2002) and Bullen and McKenzie (2008)

| **Species** | **Mean mass (kg)** | **S.D. mass** | **Min area (chest)** | **Max area (wing)** |
|---|---|---|---|---|
| Bat | 0.0140 | 0.002 | 0.0028 | 0.014 |
| Bird | 0.2800 | 0.020 | 0.0200 | 0.075 |
| Wedge-tailed Eagle | 4.2000 | 0.300 | 0.0700 | 0.600 |
| White-striped Freetail Bat | 0.0353 | 0.002 | 0.0040 | 0.026 |

# E Appendix - Species used in Searcher efficiency trials

**Table 16: List of species used in searcher efficiency trials**

| Common name | Species type | Dog | Human |
|---|---|---|---|
| Unidentified Bat | Bat | 64 | 91 |
| White-striped Freetail Bat | Bat | 76 | 27 |
| Gould's Wattled Bat | Bat | 8 | 4 |
| Forest Bat sp. | Bat | 3 | 1 |
| Large Forest Bat | Bat | 3 | 1 |
| Eastern False Pipistrelle | Bat | 2 | NA |
| Grey-headed Flying-fox | Bat | 6 | NA |
| House Mouse | Bat | NA | 17 |
| Lesser Long-eared Bat | Bat | 2 | NA |
| Southern Forest Bat | Bat | 4 | NA |
| Unidentified Bird | Bird | 47 | 316 |
| Common Myna | Bird | 6 | 42 |
| Australian Magpie | Bird | 14 | 14 |
| Wedge-tailed Eagle | Bird | 2 | 23 |
| Nankeen Kestrel | Bird | 9 | 10 |
| Raven sp. | Bird | 12 | 1 |
| Brown Falcon | Bird | 8 | 4 |
| House Sparrow | Bird | 2 | 3 |
| Little Corella | Bird | 1 | 2 |
| Silvereye | Bird | 1 | 2 |
| Southern Boobook | Bird | 1 | 2 |
| Spotted Turtle-Dove | Bird | 1 | 2 |
| Finch sp. | Bird | 1 | 1 |
| Galah | Bird | 1 | 1 |
| Tawny Frogmouth | Bird | 1 | 1 |
| Australasian Swamphen | Bird | NA | 1 |
| Australian Wood Duck | Bird | NA | 1 |
| Barn Owl | Bird | NA | 1 |
| Black Kite | Bird | 8 | NA |
| Black Swan | Bird | NA | 1 |
| Black-shouldered Kite | Bird | 2 | NA |
| Blue-winged Parrot | Bird | NA | 2 |
| Chicken | Bird | 8 | NA |
| Common Starling | Bird | 1 | NA |
| Crested Pigeon | Bird | 2 | NA |

**Table 16: List of species used in searcher efficiency trials *(continued)***

| Common name | Species type | Dog | Human |
|---|---|---|---|
| Domestic Pigeon | Bird | 2 | NA |
| Grey Goshawk | Bird | 2 | NA |
| Lapwing sp. (juv) | Bird | 4 | NA |
| New Holland Honeyeater | Bird | NA | 1 |
| Peregrine Falcon | Bird | NA | 2 |
| Rosella species | Bird | 1 | NA |
| Welcome Swallow | Bird | NA | 1 |
| White-throated Needletail | Bird | NA | 1 |

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