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Department of Climate Change, Energy, the Environment and Water







Australian Collision Risk Framework

Review of current practice and species data

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Contributors

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Main cover photographs: Eliza Thompson, Elizabeth Stark.

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Acronyms

ACRF	Australian Collision Risk Framework for onshore and offshore wind farms
BBMP	Bird and Bat Management Plan
CLS	Collision Likelihood Score
CRA	Collision Risk Assessment
CRM	Collision Risk Model
DCCEEW	Australian Government Department of Climate Change, Energy, the Environment and Water
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
MNES	Matters of National Environmental Significance
OEI Act	Offshore Electricity Infrastructure Act 2021
RERI	Renewables Environmental Research Initiative

Definitions

Avoidance behaviour	The propensity for a volant species to avoid collision. In the context of the ACRF we refer specifically to the avoidance behaviour of birds and bats with wind turbine infrastructure, both static and the moving turbine blade. Avoidance behaviour can occur at a combination of scales; macro-avoidance is the avoidance of the entire facility footprint; meso-avoidance is the changing of flight paths within a facility to avoid individual turbines; micro avoidance is changed flight patterns to minimise risk when passing close to or within a turbine footprint (e.g. by flying higher or lower).
Collision Likelihood Score	A structured, **qualitative assessment** of collision likelihood risk using ranked criteria. CLS combines species activity, flight height, seasonal exposure, and collision history to generate transparent risk ratings. CLS is appropriate when data are insufficient for a CRM, during early project stages, or when collision risk is clearly very low or very high.
Collision Risk Assessment	A multi-step process that assesses the likelihood and consequence of wind turbine collisions for bird and bat species. The CRA is designed to identify species at risk, inform the mitigation hierarchy and to support regulatory approval of onshore and offshore wind farm developments.
Collision Risk Model	A **quantitative model** that uses numerical survey data to estimate the long-term average number of bird or bat collisions per year. CRM works best when flight activity (flights per area per time) can be measured or reliably modelled and should ideally include uncertainty (confidence intervals).
Daily activity	Timing and length of flight behaviour on a daily scale. Most species fall into one of three categories; nocturnal, diurnal, or crepuscular.
Exposure	Refers to the state where the target species could be involved in a turbine collision, i.e. “in harm’s way”. The number and duration of flights exposed to collision is directly related to

	the likelihood of collision.
Flight height distribution	The range of heights at which a particular species flies, usually used in reference to the rotor-swept area of a turbine.
Mitigation Hierarchy	A staged framework for managing environmental risks where avoidance of the risk is the primary objective, then minimisation, repair, then offsetting.
Propensity to evade collision	A species' ability to avoid turbine blades (or the wind farm in the case of macro avoidance) based on its behaviour and morphology
Rate and density of flights	Exposure to collision relates to a combination of the number of animals in flight, the number of flights made by those animals in a given time (flight rate) and the number of flight movements to cross through a given area of vertical space (flight density). Collision likelihood is directly related to the flux (flights through a given area in a given time), requiring an understanding of the rate and density of flights.
Risk category	A broad set of factors that contribute to an increase in the likelihood of a collision, e.g. exposure to turbine airspace, duration of exposure, ability to avoid.
Risk criteria	A specific type of data that provides information about the risk of collision. Criteria can be quantitative (e.g. flight height distribution) or qualitative (e.g. foraging strategy).
Risk metric	A specific value or score that can be calculated and entered into a CRM or CLS, e.g. proportion of flights at Rotor Swept Height (quantitative) or a score from 1-5 based on an estimate of frequency of flights at rotor swept height.
Rotor swept height	The vertical height space at which turbine blades rotate.
Seasonal patterns	Proportion of time a target species is likely to be present on proposed wind farm site across a year
Spatial use patterns	Proportion of time a target species is likely to be at a given location during its time on the wind farm site
Species morphology	The outward appearance of a species. For the purposes of collision risk assessment, we are specifically interested in size measures (length, wingspan etc), mass and flight speed.
Species manoeuvrability	The natural ability for a volant species to rapidly change flight trajectory, height, speed etc.
Turbine airspace	The column of vertical space spanning ground to maximum rotor swept height, and diameter equal to the rotor diameter, centred on the turbine tower. The likelihood of collision is much greater within rotor swept height; for that reason, some models ignore the area below minimum rotor swept height, others calculate it.

Executive Summary

The Australian Collision Risk Framework (ACRF) provides a standardised, transparent, and robust methodology for measuring, estimating, and managing the likelihood of bird and bat collisions at onshore and offshore wind farms. This report establishes the evidence base for the framework, addressing the need for consistent assessment of species listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

It is intended for proponents, regulators, and consultants to foster a clearer understanding of the evidence underpinning the ACRF, ensuring that the framework is interpreted correctly, applied appropriately, used defensibly in decision making, and relied upon to inform appropriate and effective mitigation strategies.

What's new

This work synthesises the current state of practice for collision risk assessment in Australia alongside a review of the Australian and international best-practice guidelines and models. This synthesis directly informs the guiding principles for the ACRF that draws from best practice while being mindful of the current processes and methods in use.

For the first time, it provides a standardised dataset of risk criteria for all EPBC-listed birds and bats, as well as migratory and marine species, to underpin site-specific risk assessments. This builds on recent work by Reid and Baker (2025) regional risk assessment to focus on site-scale metrics also. The data collated during this review will be made available via a species traits online tool for use in collision risk assessments. In this way we aim to move away from author-specific definitions of "likelihood" towards a structured approach that allows site assessments to be compared and combined for cumulative impact analysis.

Methods

The findings in this report are based on a comprehensive literature review of existing Australian and international regulatory frameworks, models and species data. To ensure international independence, the project engaged US-based experts to conduct a "rapid scan" of published collision risk models (CRM) and their technical requirements. Furthermore, the team reviewed current Australian practice by analysing EPBC Act referral documentation and approved Bird and Bat Adaptive Management Plans (BBMPs) for 182 wind farm projects. Finally, a set of functional species traits was developed and collated to inform future data collection and modelling.

Findings

Our review found that while many international frameworks offer useful elements, none currently address the diversity of species and environments required for the Australian context with sufficient precision. Key findings include:

Inconsistency in practice: Australian impact assessments currently use a variety of qualitative and quantitative approaches with no standard reporting of model inputs, making results difficult to reproduce or validate.

Modelling gaps: While quantitative models exist for diurnal birds, there is no currently accepted model for predicting annual collision rates for bats or flying foxes; these species are currently managed via qualitative assessment.

The importance of standardised collision criteria: Species traits (such as flight height, manoeuvrability, and activity patterns) are critical for assessing potential risk during initial site investigations and for designing optimal field surveys.

Pathways to assessment: The ACRF must support multiple pathways—qualitative assessments for rare species or data-poor environments, and quantitative models when robust flight activity data is available.

Predicting collision mortality remains technically challenging. Even well-established quantitative models are highly sensitive to uncertain inputs like flight speed and attempts to validate their predictive power have produced ambiguous results. Significant data gaps remain for nocturnal birds and all bat species. Additionally, many quantitative models are proprietary, which restricts their transparency and the ability for the industry to extend or improve them.

How to use this report

This report should be used as a reference for understanding the evidence base and rationale behind the ACRF.

Regulators and Proponents: Use the synthesis in **Table 1** to understand best-practice expectations across all project stages, from site characterisation to operation.

Consultants: Use the categorisation of models and functional traits to justify the selection of a specific assessment pathway (qualitative or quantitative) for a given site.

Survey Design: Reference the species trait analysis to ensure field programs are capturing the specific data (e.g., flight height distribution) required for robust modelling.

Research overview

The Australian Collision Risk Framework (ACRF) will guide users through the end-to-end process of measuring, estimating and managing the likelihood of collision for bird and bat species. It is designed for use during the project development phase.

The key purpose of the project is to provide a standardised, transparent and robust methodology by which the collision risk assessment of EPBC-listed species can be undertaken, provided and assessed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The ACRF will deliver on related objectives requiring a mix of desktop research, guidance development and decision support tools. **This document summarises the methodology and results of a literature review designed to address the project's research objectives and to form an evidence base for the methodology objectives**

ACRF research objectives

The research objectives of the ACRF project are to:

1. Determine the most accurate and precise method for predicting collision risk for EPBC-listed bird and bat species with onshore and offshore wind turbines in Australia.
2. Review and analyse international regulators' approaches to collision risk assessment for wind developments, identifying models, methodologies and data standards that can be adapted for use in the Australian context.
3. Assess the applicability and limitations of collision risk modelling (CRM) as a best practice for all EPBC-listed bird and bat species at risk of turbine collisions.
4. This will inform the methodology and guidance development objectives, to
5. Develop a standardised and transparent CRM approach suitable for consistent use by proponents and regulators in onshore and offshore wind development assessments under the EPBC Act.
6. Identify situations where CRM is not feasible and recommend alternative, standardised, and transparent collision risk assessment methods that align with best practice and EPBC Act requirements.
7. Define the minimum collision risk assessment information required by the department for robust EPBC assessments and develop a streamlined process for efficient and effective information submission by proponents.

Research methodology

We compiled a set of related literature synthesis tasks to rapidly scan existing peer-reviewed and 'grey' literature. The aim of this work was to address the project's research objectives by compiling and reviewing:

- Existing guidelines about predicting likelihood of collision from other Australian jurisdictions and overseas agencies.

- Peer-reviewed literature from international sources to collate the existing models and methods for collision risk assessment.

In addition, we have developed a set of functional traits relating to collision risk and collated this information for the bird and bat species listed under the EPBC Act. We have also reviewed other recent work in this area to inform the functional traits and risk characteristic groups developed (Reid and Baker 2025a; BirdLife International and BirdLife Australia 2025; Reid and Baker 2025b).

Summary of findings

Analysis of existing frameworks

Collision risk is established as an important component of any Environmental Impact Assessment for wind energy. As such, there exists a range of policy frameworks and guidance documents within Australia and in other international jurisdictions.

Documents were sourced from Australian states and international jurisdictions, including policy frameworks and best practice guidelines. All documents reviewed provide some useful information for developing a collision risk framework. Many provide high-level guidance for impact assessment more broadly, or address a specific aspect (collision risk or operational monitoring) with more specificity.

No existing framework addressed the same breadth of species diversity or range of development environments with the level of precision required of this project. However, there are best-practice elements from across different documents that are relevant to the ACRF. For instance, US Fish and Wildlife Service 2012 outlines a tiered monitoring approach, Bennun et al. 2021 is structured more heavily around the mitigation hierarchy and Aronson et al. 2014 focuses entirely on operational bat monitoring.

At a high level, the idea of adaptive management and/or mitigation hierarchy are embedded across all documents, highlighting the importance of using this as a clear basis for the ACRF. In addition to estimating collision likelihood the ACRF needs to provide resources to identify ways to avoid and mitigate that likelihood.

The full results of the review into existing frameworks are in section 'Literature review of existing frameworks and guidance'

Review of existing models

As evidenced by recent reviews, there are a range of quantitative avian CRMs in use and development worldwide. Cook et al 2025 identified 52 models, with only 23 having enough publicly available information to be reproducible. They found that inputs, data collection methods, and assumptions differ widely; and "*attempts to validate the predictive power of CRMs ... have produced results which are, at best, ambiguous*."

However, the depth of research into avian CRM provides us some consensus on the elements of a best-practice model for estimating avian collision.

The literature review to establish best practice in modelling built on the work in Cook et al. 2025 and included a review of the documentation that has been submitted for EPBC Act referral and assessment.

Full details of the review into collision risk models are given in section 'Review of international CRM/CRA'

State of practice in Australian Assessments

Our review of the literature and Australian site documentation found no existing CRM model specifically for bat species. Only qualitative and relative risk assessments exist, because acoustic monitoring cannot reliably count individual flights or provide coverage at rotor-swept height.

In addition, we found a variety of approaches to qualitative risk assessment in Australian impact assessments, with little to no agreed or published international best practice.

Where quantitative CRM is applied, there is no standard reporting of model inputs (so results are not reproducible), and there are a range of models in use, which are often out-of-date (e.g. early implementations of the 'Band' model which have been superseded).

This highlights the need for the ACRF to provide:

- **standardisation** of qualitative and quantitative methodologies,
- clear **decision guidance** on when a qualitative Collision Likelihood Score (CLS) or quantitative CRM is appropriate, and
- **consistent language** at all levels of qualitative and quantitative assessment.

This review is provided in detail in the section 'Current state of practice in Australia'. Full details of the review into collision risk models are given in section 'Review of international CRM/CRA'

Availability of species collision trait data

Various attempts have been made to quantify collision likelihood by using species traits in both Australia and overseas contexts. For example, BirdLife's recent development of the AviStep project in Australia develops a sensitivity index for collision of seabird species (BirdLife International and BirdLife Australia 2025). This sensitivity index is based around a series of species traits including flight heights, flight manoeuvrability, nocturnal activity and collision evidence.

Similarly, Reid and Baker 2025a and Reid and Baker 2025b outline an ecological risk assessment scoring system that details species' distributions, morphology (including wing dimensions and body mass), flight height and flight manoeuvrability to predict collision likelihood.

In addition to collision risk traits, those works also considered consequences of a collision relating to a species' conservation status and survival indicators (generation time - time for adults to produce offspring, adult survival). Both BirdLife International and BirdLife Australia 2025 and Reid and Baker 2025a/b are informative but more applicable to regional-scale modelling.

The ACRF builds on these methods and acknowledges their importance in the wind energy space.

It should be noted that our work collating species traits is not concerned with ranking species or predicting a certain collision risk value, but rather to be used as a standardised reference for:

- Assessing the potential for collision as part of an initial site investigation
- Designing an optimal data collection program to inform Impact Assessment
- Inputting into qualitative and quantitative collision likelihood models.

With this in mind, we present a set of functional traits that could inform collision likelihood and provide information to avoid and mitigate this risk.

This dataset is standardised for all listed species, as well as migratory and marine birds, insectivorous bats, and flying foxes. As such it can underpin a consistent approach to collision assessment despite the diversity of species covered. A full breakdown is provided in section 'Species trait analysis'

Literature review of existing frameworks and guidance

Key Research Questions:

1. What national and international regulatory frameworks exist for quantifying the likelihood of avian and bat mortality at wind energy facilities?
2. What non-regulatory guidance documents (e.g., from industry bodies, scientific groups, NGOs) are available for this purpose?
3. What are the common principles, methodologies, and components of these frameworks?
4. Which frameworks represent "best practice", evaluated against criteria of ease of use, applicability, flexibility, and robustness?

The review identified a select set of documents at sub-national, national and international jurisdictions. All documents considered wind energy impacts, including collision likelihood, but none focused specifically on collision likelihood.

Methodology

A set of best-practice documents was sourced via a Google search and direct review of key agency websites (e.g. Australian State Government environment agencies and highly regarded international bodies like the International Union for Conservation of Nature (IUCN)).

The second step of the review method involved systematically analysing each of the documents against the following themes:

- Purpose and focus (i.e. aim and/or objective of the document and the biodiversity scope)
- Guidance on undertaking an impact and/or risk assessment
- Monitoring requirements, including pre-construction (baseline), construction and post-construction monitoring
- Guidance on the use of collision risk modelling
- Methods to avoid, minimise or mitigate impacts
- Guidance on setting impact thresholds.

The third step was a qualitative assessment of the documents, looking at how detailed the guidance was (i.e., general or specific), whether it clearly explained how to measure or manage impacts to birds and bats (i.e., mortality), and whether the guidance could be applied broadly or adapted for use in Australia.

The first version of this review informed the identification of project stages within the ACRF, and a second version was compiled to inform developing ACRF stages. The information is arranged into:

1. **Early-stage studies:**
    - Macro-scale (site in region)
    - What species and what collision traits?
    - Initial site species collision likelihood and data gaps
    - Standardised central data repository of species traits (e.g. flight heights)
2. **Planning site investigations**

- Meso- (site) scale
- Decide on model pathway based on species traits
- Appraisal of existing data and ability to collate data in the time available and for the region
- Output is survey design and inferred collision pathways

3. **Initial collision likelihood modelling**
    - Interim modelling and data suitability for modelling
    - Focus on risk avoidance
    - Assessment of gaps and rebalancing data collection
4. **Final impact assessment post survey**
    - Report/data template and checklist to validate inputs
    - Output is model (qualitative or quantitative)
    - BBMP include validation and mitigation
5. **Post construction**
    - Validate and mitigate

Results

Table 1 provides a synthesis of the findings from the revised review against the tiered approach. Attachment 1 provides the full memorandum from 2rog including specific examples of methods and advice linking to specific sections from each reviewed document.

Table 1 - Synthesis of findings from framework review against project development stages

Criteria	Synthesis of material from reviewed frameworks
Early-stage studies	Across frameworks, early-stage planning emphasises risk avoidance through spatial screening and sensitivity mapping, using existing datasets and reconnaissance to identify species, habitats, and areas of concern. The focus is on strategic siting and scoping, informed by stakeholder consultation and cumulative impact assessment, before committing to fieldwork. All reviewed frameworks were unanimous that early identification of ecological constraints is the foundation of an efficient, minimum-impact assessment process.
Planning site investigations	The planning phase is about translating desktop insights into a structured survey design, defining which data are needed, why, and how they will inform risk models. Best practice requires alignment with seasonality and scaling survey effort to site sensitivity and species vulnerability. Engagement with regulators and experts is consistent across frameworks to refine objectives, select indicators, and plan data management. The aim is to ensure surveys are fit-for-purpose, representative, and capable of producing statistically valid, comparable data for modelling and decision-making.
Planning site	All frameworks require standardised, multi-season field surveys to establish a reliable

investigations	ecological baseline. These surveys combine species richness, abundance, and behavioural data (flight height, timing, activity rates, etc.) with environmental variables to parameterise collision models. Use of vantage point counts, acoustic detectors, radar, telemetry (etc.) is widely recommended, depending on target taxa and site context (and current best practice). Surveys must follow repeatable protocols, often using control sites (BACI), to support future comparison and validation of impact predictions. For example, US Fish and Wildlife Service 2012 states that baseline studies should assess the presence and behaviour of species of concern, and risks posed to them, via surveys of sufficient duration and intensity to capture annual/seasonal variations (multiple years may be required); the sensitivity of the site/species also influences monitoring duration/intensity. Survey protocols may include diurnal avian activity surveys, raptor nest searches, mist-netting, nocturnal surveys (etc.). As an additional example, the Victorian Framework states, in respect of bat species of concern, that up to 24 months of monitoring may be required where there is little known about bat activity at the site, or there are heightened risks associated with the site, or existing data indicates risks may be reduced.
Initial collision likelihood modelling	Risk assessment integrates site data with species and turbine parameters to estimate collision likelihood and exposure. Frameworks rely on collision risk models (e.g. Caneco et al. 2022), combining flight activity, avoidance rates, turbine characteristics etc. Assessments consider individual and population-level risks. The process is adaptive and central to shaping mitigation and project design.
Final assessment post survey	Final assessments synthesise all baseline and model outputs to produce validated collision and population impact estimates, benchmarked against defined thresholds or Acceptable Levels of Impact. Scenarios often include cumulative effects across multiple wind farms and long-term population viability modelling. This stage formalises whether risks are acceptable, what mitigations are required, and how adaptive monitoring will be structured.
Post construction	Post-construction monitoring validates predictions, quantifies realised impacts, and supports adaptive management. Two core monitoring types include carcass searches and acoustic or radar-based surveillance, corrected for detection biases. Results feed into iterative decision loops that adjust turbine operation (e.g. curtailment, deterrents) and evaluate mitigation effectiveness. Continuous data sharing and cumulative analyses are encouraged to improve regional evidence bases.

Review of international Collision Risk Models

Objective

To develop a comprehensive summary of existing models and associated data collection methodologies used for quantifying the likelihood of bird and bat collisions with wind turbines.

Key Research Questions:

1. What quantitative and qualitative models exist for predicting collision risk for birds and bats with both terrestrial and offshore wind turbines?
2. What are the specific data collection methodologies required to input into these models?
3. For each model, what are its specific input requirements, assumptions, limitations, and its applicability (e.g., to certain species groups, geographical regions, or project scales)?

Methodology

To ensure an international view and review independence, we engaged US-based ecological consulting firm Western EcoSystems Technology Inc. (WEST) to conduct a 'rapid scan' and synthesis of published work on CRM.

A recent review (Cook et al. 2025) provides an extensive list of collision risk models as at mid-2025. This was used as a starting point for model information gathering. In addition, WEST conducted an additional literature search and consulted with Senior and Principal Statisticians and Biologists (technical experts) to identify additional relevant literature for inclusion.

The following information was extracted from the literature and used by the authors of this report to categorise the types and applications of CRM: data collection methods; data needed to fit the model; standard operating procedures for data collection; biological characteristics used as model inputs; turbine specifications used as model inputs; model implementation approach; model requirements; model limitations; outputs; assumptions; and any additional relevant notes.

Results

Quantitative CRM is still an active area of research despite 40 years of development. The advent of technology like radar, telemetry, and GPS tagging to augment human observations has driven innovation in estimating the flight density and spatial extent of bird species (e.g. Goyert et al. 2024; van Melen et al. 2022; Brabant et al. 2015).

Many of the articles published to date describe the application of one of a few CRM approaches to a specific species, e.g. investigating the need for year-round surveying of kittiwakes in the German North Sea (Busch and Garthe 2018). Other papers describe regional and cumulative applications (Brabant et al. 2015).

Despite advances in data collection and estimation of input parameters, there are only a small number of theoretical approaches to estimating collision risk (Smales 2017).

Notable models and applications

A common approach (Band 2012) uses estimates of species density (birds / sqkm) with a model of turbine interaction based on the flight speed of the bird. The chance of colliding with the turbine is a geometric calculation considering the upwind/downwind flight speed and the rotor geometry. Because of the heavy reliance on bird flight speed at two stages, the model is overly sensitive to uncertainties in species flight speed data (Masden et al. 2021).

Despite known limitations, the "Band Model" has been the basis for a number of more recent CRM versions; most notably the `stochLAB` R package (Caneco et al. 2022) which extends the model with stochastic inputs and includes specific options (for example, the ability to model collision risk at different heights across the rotor swept area). The inputs are standardised but also specific (e.g. optimised for monthly surveys). The output is a range of predicted annual collisions for the site as a

whole. Other extensions of the "Band model" relate to innovative data capture, e.g. telemetry using MOTUS (Goyert et al. 2024).

A similar yet alternative approach used in Australia is the Biosis Collision Risk Model (Smales et al. 2013) which differs from Band in data capture; it uses direct measurements of flight rate (birds per area per time) which makes it less sensitive to bird flight speed estimates. The geometry of the calculation also differs from Band in that it includes the moving (rotor leading edge) and static (rotor and tower) components in the calculation, and it allows for bird interactions from any direction (not just up/down wind). This model has not been extended due to being proprietary, however an open-source extension (including stochastic inputs) is currently in preparation for publication (Stark et al. 2026).

Some specific applications are worth noting here. The US Fisheries and Wildlife Service developed a model that combines 'minutes of flight' inputs with Bayesian analysis using post construction data to generate a regional model for Golden Eagle (New et al. 2015). Although a specific application and more suited to regional-scale modelling it's an interesting alternative approach.

Recent research suggests individual (or agent) based models (IBMs) have some use in predicting collision risk and spatial utilisation from behavioural data (typically sourced from GPS data or similar) (van Melen et al. 2022; Wood et al. 2025). There are no commonly used IBMs, but this is an area of active research.

Finally, some of the impact assessment literature in Australia uses a Band-style model for the turbine interaction risk but modifies the inputs to include a direct flight flux and spatial utilisation model (e.g. Symbolix 2021). To our knowledge this is the only approach that currently exists to explicitly include spatial utilisation in the modelling pathway.

Notable exceptions

Despite the complexity and detailed technical nuance involved in quantifying annual collision rates for birds, the international and Australian literature has some significant limitations.

To date, most models are applied to diurnal, reasonably visible species, e.g. raptors, gulls, terns, geese etc. No model is currently accepted and in use for predicting the annual collision rate for any bat or flying fox and very little research has been published relating to nocturnal birds.

In addition, qualitative and semi-quantitative model frameworks exist to provide regional- and nation-scale assessment of susceptibility to collision, but we are not aware of any peer-reviewed approach that can be consistently applied at the site level.

Considering the scope of the ACRF these gaps in development are substantial and require the development of a consistent language for collision likelihood that can underpin qualitative and quantitative assessments, while keeping the door open for future innovations in data collection and individual-based models.

Current state of practice in Australia

Objective

To review referral and assessment documentation from EPBC Act assessed development to identify patterns, best practice and gaps in current practice for collision prediction.

Methods

Existing EPBC Act referral documentation and approved Bird and Bat Adaptive Management Plans (BBMPs) from operating wind farms were provided to Symbolix by DCCEEW for review. Symbolix also assessed Bird and Bat Management Plans available online and through direct enquiry to stakeholders.

Where necessary (and possible) we sought additional information on avian and bat impact assessment from State Government websites where the State managed documentation as part of a bilateral agreement or separately under State legislation.

Of the 182 developed or proposed wind farms identified in Australia, information available publicly online for 61 projects did not indicate whether collision risk assessments had been undertaken. An additional 22 projects included general risk assessments, but no publicly available details specific to collision risk were found (Figure 1).

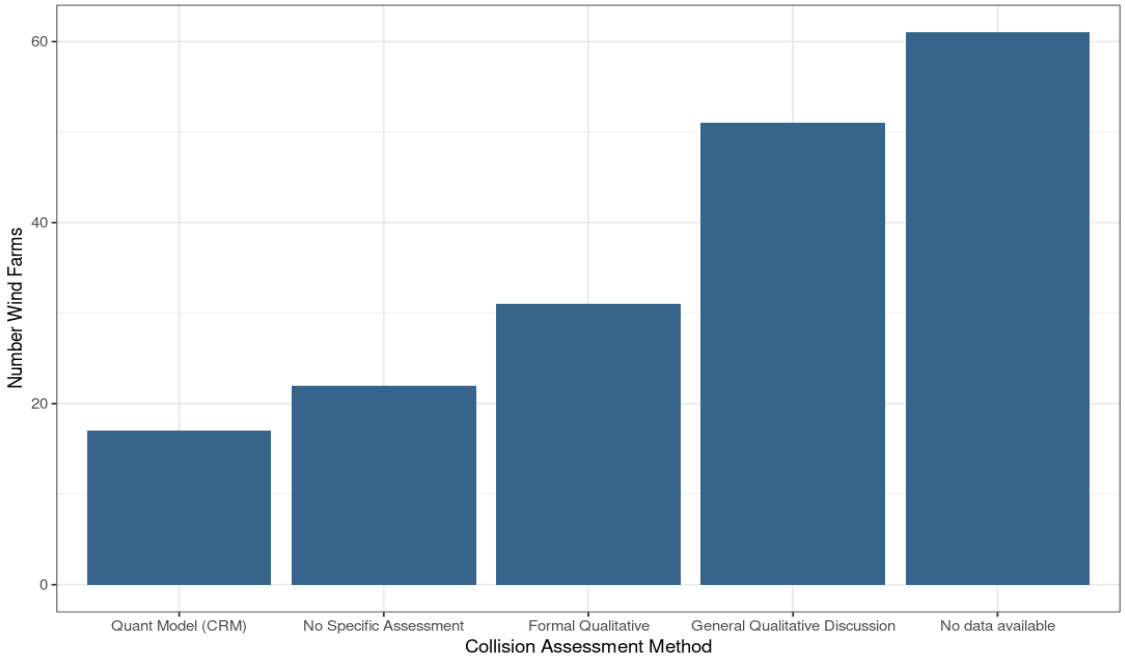


Figure 1 - Number of wind farm impact assessments (or Management Plans) with available documentation on collision risk assessment

General qualitative discussions most commonly identified species at higher likelihood of collision based on flights at rotor swept height. Other factors include habitat onsite, frequency of sightings or evidence of species onsite.

Formal qualitative risk assessment most often followed a format of a risk table and discussion of likelihood and consequence. Individual authors typically were consistent in definitions, but definitions of likelihood were not consistent between authors. Most commonly the likelihood of collision was assessed according to an expert assessment of probability (e.g. 50% chance of collision in one year is “likely” and more than 50% might be almost certain, or certain).

The lack of standardised definitions severely limits the ability to compare different sites or to combine sites in a cumulative assessment.

Of the sites with CRM, the models include Smales et al. 2013, Band et al., 2007 [1] and a modified spatial implementation of Band (e.g. Symbolix 2021). The level of detail on inputs varies between sites and is often incomplete. For the sites stating collision risk modelling (as opposed to a more qualitative approach) was done, the species covered included:

Australasian shelduck,
Australian magpie,
Australian raven,
Australian shoveler,
Australian wood duck,
black falcon,
black kite,
black swan,
black-shouldered kite,
brolga,
brown falcon,
cape barren goose,
common starling,
fairy martin,
fork-tailed swift,
galah,
great cormorant,
little black cormorant,
little eagle,
little raven,
masked lapwing,
nankeen kestrel,
peregrine falcon,
plumed whistling-duck,
spotted harrier,
straw-necked ibis,
superb parrot,
swamp harrier,
wedge-tailed eagle (including the Tasmanian wedge-tailed eagle ssp.),
welcome swallow,
whistling kite,
white-bellied sea-eagle
white-necked heron,
white-throated needletail,
woodswallow (dusky woodswallow),
yellow-billed spoonbill

However, we stress that for many of these there was incomplete information on the inputs and methodology used. For several older sites there is little information remaining in the public domain about the details of the pre-construction impact assessment

The lack of model standardisation, lack of standards for developing and reporting inputs and changing assessment requirements over time restrict the ability for historical site assessments to contribute to long-term understanding of species' collision risk. For example, even standardising the reporting of flight height distribution data would greatly increase the ability to augment height data on future assessments.

[1] *Notably a number of post 2020 documents referenced the older 2007 model, not the model versions that superseded that version, Band 2012 and following,*

Implications

ACRF cannot specify one approach - it needs to provide a framework around the risk classes and criteria and provide support so a proponent can justify why one approach was chosen over another. Most of the time a qualitative approach will be all that's possible due to the limitations of surveying very rare species, but that should consider all of:

Total risk exposure:

- site activity
- spatial use of the site (relative spatial risk)
- flight height profile (relative risk)
- temporal use of the site (seasonal / daily risk profile)
- ability to avoid collision given risk exposure:
    - morphometrics and flight / behavioural / avoidance expectations.

Of these, the first four directly impact the number of flights exposed to risk in any given year. They are more important than the final point (though it is necessary for a fully quantitative model). The final point will be relatively stable to changes in layout, or minor turbine changes. The total risk exposure provides the best assessment of the overall risk.

Species trait analysis

Objective

To create a repository of Australian terrestrial birds, seabirds and bats with available information on the biological and behavioural characteristics that influence their likelihood of collision with wind turbines, and by doing so identify any key data gaps.

Key Research Questions:

1. For bird and bat species, what published information exists regarding characteristics that influence collision risk (e.g., flight height, flight patterns, flocking behaviour, migration routes, sensory perception, habitat use)?
2. What is the source and context of this information?
3. Where do critical data gaps exist for specific taxa or risk-influencing characteristics?

Australian context

Within Australia, onshore wind farms have been established for almost 40 years. More recently, offshore wind farm feasibility licences have opened leading to rapidly expanding interest in offshore development (Briggs et al. 2021). While no offshore wind farms have been constructed to date, many are proposed and in the pre-construction phase. Given the large span of area current and future wind farm sites are likely to cover there is a high degree of overlap with diverse bird and bat species. Therefore, it is important that prospective onshore and offshore wind farms consider species collision likelihood in a standardised way.

There are 415 bird species (in the Aves class) and 12 bat species (in the Chiroptera order) listed federally under the EPBC Act, including migratory and marine flyover species.

These species vary considerably in all dimensions of ecology, including size, diet, and flight ability. As such, the susceptibility to collision also varies considerably. To fully grasp this collision likelihood variability, we undertook a literature review to collate data on species traits that may influence collision.

Scope of review

To understand the variation in species collision risk likelihood, we conducted a wide-scale literature review extracting a key set of biological and behavioural traits of birds and bats.

This literature review was a key step to set the foundation for our collision risk framework to understand why different species would be more or less susceptible to collision risk. We drew on information already contained within BirdLife International and BirdLife Australia 2025; Reid and Baker 2025a and 2025b to create a data repository of traits which will be made accessible through an online tool as part of the ACRF website.

Our review focuses on the individual collision likelihood of a species as opposed to the impacts of a collision (e.g. population impacts for threatened species). Instead, collision impacts are being undertaken within the related project *Decision support tool for collision mortality impacts* by the Arthur Rylah Institute.

It should also be noted that our trait-based framework provides an indicative risk as a conceptual model and should not be used in replacement of site-collected data or as a predictive tool. The data within the repository does not assign an overall risk score to each species but paves the way into how to go about assessing risk and how one would approach surveying and analysing species of concern.

The species trait literature review was a collaborative effort between Symbolix, Monash University and EcoAerial.

We also have crosschecked data compiled from the *Understanding bird and bat overland flight paths* project undertaken by Birdlife Australia, University of Queensland, University of Western Sydney and BatsLab.

Species traits

Drawing knowledge from both Australia and overseas, we collated a series of species traits that relate to specific risk categories. All these factors fall into one of three major categories (i.e., exposure, duration, or propensity) which can be thought of as failure gates (i.e. a species has to pass through each gate to collide with a turbine): *where* a species is likely to be that would influence collision (e.g. in the air), *when* collision is likely to occur (e.g. during the migration period) or *how* a species behaviour and morphology influences collision risk (e.g. manoeuvrability).

In other words (Figure 2):

- *Where* a species spends its time influences its exposure to risk
- *When* it flies influences the duration of that exposure
- *How* it behaves and flies influences its propensity to avoid the collision, when it is exposed.

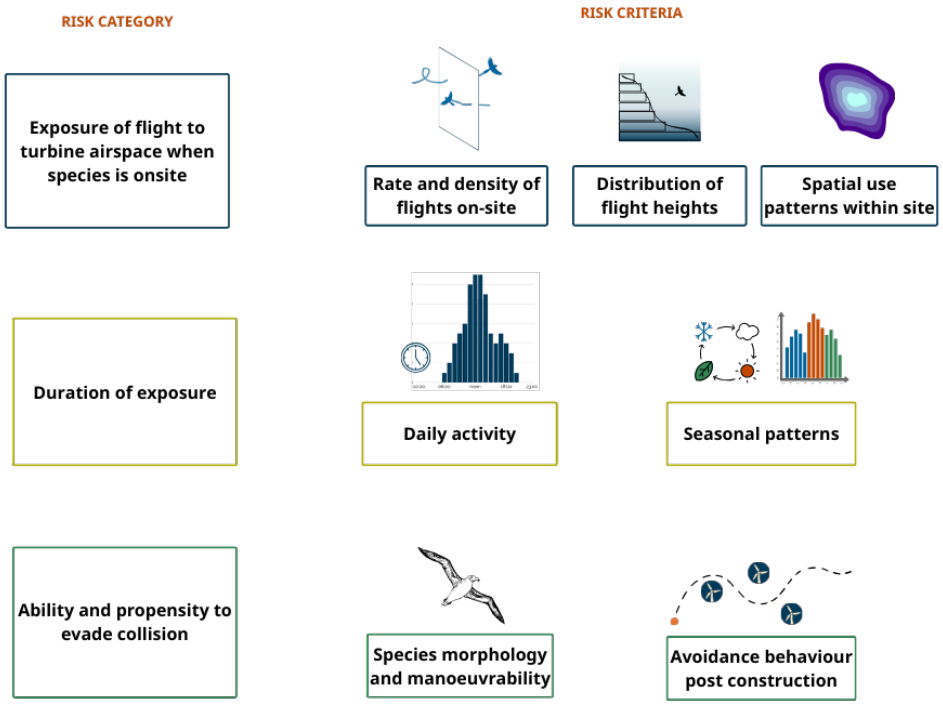


Figure 2 - Conceptual model of collision likelihood

Extracting data

A range of different data sources were used to collate species trait information including:

- DCCEEW Recovery Plans and Conservation Advice documents
- Handbook of Australian, New Zealand and Antarctic Birds (HANZAB)
- AVONET databases
- Species-specific scientific papers
- Grey literature, including state government websites and field guides.

Given a number of birds were subspecies, we used a two-tiered approach, where we sought data from the subspecies and then supplemented this with data at the species level.

There were also a number of species on the marine list where either one or a handful of individuals have ever been recorded in Australia (e.g. vagrants or unconfirmed observations). These were devoted less attention for the literature review given their low likelihood of appearing within Australia or surrounding waters.

Traits explored

We grouped traits into four main categories based on exposure within a wind farm. Multiple traits informed each grouping which in turn have a different influence on collision risk likelihood. The four main categories include:

- Spatial exposure
- Temporal exposure
- Flight behaviour
- Morphology

Spatial exposure

Flight height is considered one of the key determinants in collision risk likelihood (and often given high weighting) given that exposure within the rotor swept area increases the chance of collision (BirdLife International and BirdLife Australia 2025; Reid and Baker 2025b; Marques et al. 2014). Often, however, flight height profile data are not available in the literature. We were able to extract flight height data on less than 20% of the listed species, highlighting the need for site-collected data to assess risk as well as development of a flight height repository to better inform risk overall.

Without flight height data, spatial exposure can still be inferred from a number of traits including:

- **flight purpose**: purpose for flight, e.g. foraging, migration, hunting;
- **foraging location**: 3D foraging area, e.g. canopy, open-air, ground;
- **preferred habitat density**: preference for habitat categorised by density, e.g. semi-open, dense, open;
- **primary lifestyle**: where species spends most of its time in a vertical sense, e.g. aerial, terrestrial, aquatic;
- **habitat**: class of habitat preferred, e.g. desert, shrubland, woodland;
- **trophic level:** main diet of species from AVONET definitions, e.g. herbivore, carnivore;
- **trophic niche**: sub-level of species diet from AVONET definition, e.g. frugivore, invertivore;
- **nest location**: category of vegetation preferred for nesting, e.g. tree, ground, etc; and
- **nest height**: preferred height for nesting.

All these traits indicate where a species may occur within a site- vertically as well as horizontally. With such data, a proponent can begin to pull together a species profile of particular areas within a wind farm site that should be avoided for siting turbines (e.g. buffers) as well as which turbine types may be more of a risk in terms of rotor swept area and hub height.

Further, to summarise vertical spatial exposure, we allocated the same height groupings as in Reid and Baker 2025a for flight heights. These groups were applied to both bat and bird species using expert elicitation to proportionally assign species to three height levels around a turbine: below rotor swept area (below 30 m), within rotor swept area (30 - 350 m) or above rotor swept area (above 350 m).

Social behaviour

Social behaviour can also be linked to spatial exposure and associated risk likelihood. This is particularly relevant for certain resources that may be located across a site e.g. food and breeding areas. Species may also change social behaviour depending on time of year e.g. during migration, breeding periods or during cold weather. Social behaviour, especially flocking behaviours, have been linked to a higher number of collisions due to a reduction in awareness of surroundings (Drewitt and Langston 2008; Marques et al. 2014).

We used the following groups to categorise social behaviour:

- Flock - more than 10 individuals
- Small groups - less than or equal to 10 individuals
- Pairs - two individuals
- Solitary - one individual

Landform

Different species may use airspace depending on how the landscape is arranged in terms of topography. Limited data are available based on species landform preferences, but there is some evidence particularly for raptor species and the white-throated needletail (*Hirundapus caudacutus*) that prefer updraughts contained within ridgelines to gain altitude (Vignali et al. 2022) (Tarburton 2021).

This also coincides with preferences for wind farms to be sited on ridgelines to maximise wind energy generation. Other species may prefer different landforms, such as wet areas including wetlands, or more protected landforms like gullies. While, generally, wind turbines are unlikely to be directly sited in wetland or gullies, where species are likely to occur can inform how they may move through and/or around a wind farm site. Data were extracted from sources referencing topography and elevation data.

Temporal exposure

A bird's temporal exposure refers to how long it spends on site across two temporal scales: daily and seasonal or yearly. While some aspects are relatively well understood, e.g. if a species is migratory or nocturnal, the timing of where and when a species migrates remains difficult to ascertain specifically for many species, reinforcing that local records in relation to the proposed wind farm are imperative to understand risk.

Daily activity

The day-night cycle is a strong driver of species activity. Depending on a particular behaviour, e.g. foraging, commuting, breeding or migration, a species will be active at different times.

For many bat species, peak activity is throughout the night (but see *Pteropus natalis* that is active not only at night but also during part of the day). Birds, on the other hand, are more variable, with a range of species active during the day, dawn and dusk times (crepuscular) and at night.

These daily activity behaviours may also change throughout the year depending on migration and breeding. How the timing of behaviours influences collision risk is still unconfirmed but remains an important data source to know when surveying effort should be applied.

Besides natural behaviours, there may also be aspects of the wind farm site itself that can affect when and where a species flies depending on time of day e.g. turbine lighting may attract species to improve visibility and increase feeding opportunities throughout the night.

We use the following groups for daily activity:

- Nocturnal
- Crepuscular
- Diurnal

Seasonal activity

Beyond daily activity, species exposure differs throughout the year due to migration. Birds and bats migrate for a range of reasons, including breeding and resource acquisition. The distances covered, direction and timing of migration are highly species-specific and often weather dependent.

Species that migrate have been associated with higher collision risk likelihood (Aschwanden et al. 2018; Thaxter et al. 2017) given the large distances covered while migrating, leading to a higher potential of exposure to wind farm sites (i.e. the further a species flies the more likely they are to come into contact with one or more wind farms). We extracted data for species in relation to presence of migration, migration period, breeding period, non-breeding period and migratory distance to better understand seasonal activity.

We use the following groups to categorise seasonal activity:

- Migratory - species that move from one place to another based on different cues e.g. seasonal
- Partially migratory - species where some individuals migrate where others remain sedentary
- Sedentary - species that are resident to a certain area, present year round

Overall time flying

In addition to this, we extracted data from an index created by Reid and Baker 2025b on the amount of time across a year a bird species is flying. We have included this within the metadata for completeness but highlight data were not available for bats and ~50% of the bird species contained within our species list.

Weather conditions

Species may behave differently in different weather conditions. For example, bats are known to avoid rainy conditions not because of disorientation or inability to detect prey but due to increased foraging energy costs (Voigt et al. 2011). Additionally, species such as the white-throated needletail are known to move ahead of weather fronts which affects their timing of exposure to turbine collision. However, for most species we researched, available weather data related mainly to breeding timing and did not provide strong insights into collision risk.

Flight behaviour

Flight speed

Flight speed measures the rate at which species can cover particular distances over time. Flight speed is often hard to measure and can be highly variable depending on flight purpose (e.g. foraging, commuting) and flight stage (e.g. take-off, landing). With improving technology, e.g. biologgers and radar technology, flight speed data have become more widely available. Still, these datasets are often only from a small subset of individuals and still not available for all species.

Therefore, collating existing data on flight speeds remains difficult. Without flight speeds, flight behaviour can still be inferred from a number of traits including flight type and call frequency (in the case of some bats). Avoidance behaviours can also be informative, but data are largely unavailable.

Flight type

Flapping versus soaring flight can help infer the vertical space a species is likely to occupy. Soaring behaviours are usually associated with greater heights, as species take advantage of thermal updrafts to fly efficiently when migrating/commuting or foraging.

Avoidance behaviours

Avoidance behaviours refer to actions species use to evade entire wind farms (macro scale), individual turbines (meso scale) and turbine blades (micro scale). In quantitative modelling, avoidance rate is a highly influential parameter, but precise values remain scarce, with only a few species having available data on wind farm avoidance (Hull and Muir 2013).

Echolocation characteristics

Echolocation is a key sensory mechanism that allows particular bats to navigate, forage, and avoid obstacles when flying. Understanding the characteristics that contribute to echolocation including call frequency and call shape is important for assessing how bats perceive their surroundings and how they navigate through cluttered and open spaces.

Species morphology

Some aspects of morphology are important in determining how a species can physically move through the air. While these traits do not directly indicate the likelihood of collision risk, they are essential inputs for many quantitative collision risk models. Although many of these morphological values—such as body mass, wing length, wingspan, hand-wing index, and wing loading—are widely available, the data are not easily consolidated from a single source. To address this, we compiled these values into our species trait repository.

Evidence of collision

To integrate our risk traits, we compiled data on recorded species collisions at wind farms. We extracted data based on post-construction carcasses at operating wind farms at the family level to provide a consequence aspect to our data repository. This is important as some species considered at high risk may never collide, while others collide frequently. As such, evidence of collision provides the user with a valuable measure of realised risk, rather than only potential risk (likelihood).

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Attachments

1. `Attachment2_FrameworkReview_2rog.pdf` Detailed review of international frameworks

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WIND ENERGY ASSESSMENT – REVIEW OF BEST PRACTICE APPROACHES ALIGNED TO A TIERED APPROACH FOR COLLISION RISK ASSESSMENT

TO: Elizabeth Stark (Symbolix)	
FROM: Jeremy Shrubb, Dr Jeremy Simmonds (2rog Consulting)	
DATE: 15 October 2025	**PURPOSE:** Project deliverable

PREFACE

This memorandum contributes to the project to develop a standardised and transparent collision risk assessment framework for onshore and offshore Australian wind farms. It presents a synthesis of the previous review undertaken by 2rog Consulting (provided to Symbolix on 14 August 2025) of sub-national, national and international best-practice guidance and regulatory frameworks for quantifying wind energy facility impacts, including avian and bat mortality, against the proposed simplified tiered approach for collision risk assessment presented by Symbolix during the workshop of 9 September 2025.

METHOD

In the workshop of 9 September 2025, Symbolix presented the following basic tiered approach for collision risk assessment to project partners including the Commonwealth DCCEEW:

1. **Site characterisation**
    - Macro-scale (site in region)
    - What species and what collision traits?
    - Initial site species collision likelihood and data gaps
2. **Site investigation – planning**
    - Meso- (site) scale
    - Decide on model pathway based on species traits
    - Appraisal of existing data and ability to collate data in the time available and for the region
    - Output is survey design and inferred collision pathways
3. **Site investigation – data collection**
    - Works adaptively with risk (likelihood assessment)
    - Templated data collection
    - Standardised central data repository (e.g. flight heights)
4. **Site investigation – risk assessment**
    - Interim models
    - Focus on risk avoidance
    - Assessment of gaps and rebalancing data collection
5. **Final risk assessment (likelihood)**
    - Report/data template and checklist to validate inputs
    - Output is model (qualitative or quantitative)
    - BBAMP include validation and mitigation
6. **Construction and operation**
    - Validate and mitigate

This memorandum revises the previous review of guidance for wind energy impact assessment/management against the tiered approach. As part of this revision, this memorandum outlines specific examples, drawn from the best-practice guidance and regulatory frameworks, of methods for initial screening, impact avoidance, baseline survey minimum requirements and operational monitoring requirements (etc.). The findings of this revision are summarised in this memorandum (see Table 2 and Table 3). A spreadsheet containing detailed notes taken from the guidance documents accompanies this memorandum. Both the memorandum and spreadsheet contain page references to the guidance documents.

SUMMARY OF KEY FINDINGS

Table 2 provides a synthesis of the findings from the revised review against Symbolix's proposed tiered approach. Table 3 provides more comprehensive summaries against each of the criteria that comprise the tiered approach for each reviewed regulatory/guidance framework (see the accompanying spreadsheet for further detail).

The intention is that the information in this memorandum (and accompanying spreadsheet) will provide a pathway to locate useful information in the guidance/framework documents that will assist in drafting the Australian collision risk assessment framework. In particular, this memorandum should inform preparation of guidance documents on site characterisation/risk screening and site-based bird and bat survey data collection protocols, as well as other guidance documents that may be required on mitigations, adaptive management, ongoing monitoring, and collision risk modelling.

Table 2 Synthesis of findings from framework review against the basic tiered approach

Criteria	Synthesis of material from reviewed frameworks
Site characterisation	Across frameworks, early-stage planning emphasises risk avoidance through spatial screening and sensitivity mapping, using *existing* datasets and *reconnaissance* to identify species, habitats, and areas of concern. The focus is on strategic siting and scoping, informed by stakeholder consultation and cumulative impact assessment, before committing to fieldwork. All reviewed frameworks were unanimous that early identification of ecological constraints is the foundation of an efficient, minimum-impact assessment process.
Site investigation – planning	The planning phase is about translating desktop insights into a structured survey design, defining which data are needed, why, and how they will inform risk models. Best practice requires alignment with seasonality and scaling survey effort to site sensitivity and species vulnerability. Engagement with regulators and experts is consistent across frameworks to refine objectives, select indicators, and plan data management. The aim is to ensure surveys are fit-for-purpose, representative, and capable of producing statistically valid, comparable data for modelling and decision-making.
Site investigation – data collection	All frameworks require standardised, multi-season field surveys to establish a reliable ecological baseline. These surveys combine species richness, abundance, and behavioural data (flight height, timing, activity rates, etc.) with environmental variables to parameterise collision models. Use of vantage point counts, acoustic detectors, radar, telemetry (etc.) is widely recommended, depending on target taxa and site context (and current best practice). Surveys must follow repeatable protocols, often using control sites (BACI), to support future comparison and validation of impact predictions. For example, the US Framework states that baseline studies should assess the presence and behaviour of species of concern, and risks posed to them, via surveys of sufficient duration and intensity to capture annual/seasonal variations (multiple years may be required); the sensitivity of the site/species also influences monitoring duration/intensity. Survey protocols may include diurnal avian activity surveys, raptor nest searches, mist-netting, nocturnal surveys (etc.). As an additional example, the Victorian Framework states, in respect of bat species of concern, that up to 24 months of monitoring may be required where there is little known about bat activity at the site, or there are heightened risks associated with the site, or existing data indicates risks may be reduced.
Site investigation – risk assessment	Risk assessment integrates site data with species and turbine parameters to estimate collision likelihood and exposure. Frameworks rely on collision risk models (e.g. GenEst, StochLAB), combining flight activity, avoidance rates, turbine characteristics (etc.). Assessments consider individual and population-level risks. The process is adaptive and central to shaping mitigation and project design.
Final risk assessment (likelihood)	Final assessments synthesise all baseline and model outputs to produce validated collision and population impact estimates, benchmarked against defined thresholds or Acceptable Levels of Impact. Scenarios often include cumulative effects across multiple wind farms and long-term population viability modelling. This stage formalises whether risks are acceptable, what mitigations are required, and how adaptive monitoring will be structured.
Construction and operation	Post-construction monitoring validates predictions, quantifies realised impacts, and supports adaptive management. Two core monitoring types include carcass searches and acoustic or radar-based surveillance, corrected for detection biases. Results feed into iterative decision loops that adjust turbine

	operation (e.g. curtailment, deterrents) and evaluate mitigation effectiveness. Continuous data sharing and cumulative analyses are encouraged to improve regional evidence bases.

Table 3 Framework summaries according to the basic tiered approach

Frameworks	Site Characterisation	Site Investigation – Planning	Site Investigation – Data Collection	Site Investigation – Risk Assessment	Final Risk Assessment (Likelihood)	Construction and Operation
Victorian Framework The State of Victoria Department of Energy, Environment and Climate Action (Vic). 2025**. Handbook for the development of renewable energy in Victoria: Guidance to avoid, minimise, mitigate and compensate for impacts on threatened bird and bat species.**	Site characterisation establishes the ecological and spatial context for project design and risk assessment. It uses biodiversity mapping, imagery, and expert surveys to identify high-value habitats and nearby protected areas influencing species movements. Seasonal patterns, infrastructure elements, and cumulative impacts are assessed to inform site selection and layout to avoid or minimise collision risk. ***Reference: Section 6.1 (pp. 11-13).***	N/A	Baseline surveys combine desktop analysis with targeted field surveys for threatened bird and bat species, including acoustic, utilisation, and behavioural studies. Species-specific protocols (e.g. brolga wetland surveys, bat acoustic and trapping surveys) capture activity, flight height, and habitat use across seasons. Data are standardised, peer-reviewed, and linked to adaptive monitoring to refine site design, turbine placement and risk assessment. ***Reference: Section 6.1 (pp. 11-13), Appendix 2 (pp. 30-36), Appendix 3 (pp. 45-50).***	Risk assessment analyses site and species data to evaluate the likelihood and significance of impacts such as collision. It requires identifying uncertainties in species behaviour and population dynamics, addressing cumulative impacts, and defining mitigation measures to reduce or avoid collision-related impacts. ***Reference: Section 6.2 (pp. 14-16).***	The framework applies the mitigation hierarchy to confirm acceptable impact levels through avoidance, minimisation, mitigation, and compensation measures tailored to species and site context. Final risk assessments feed into Bat and Avifauna Management Plans (BAM Plans) that detail monitoring, adaptive management, and reporting to validate model assumptions and manage collision risk. ***Reference: Sections 6.3 and 6.4 (pp. 16-25), Section 7.2 (p. 26), Appendix 2 (pp. 37-43), Appendix 3 (pp. 51-53), Appendix 5 (pp. 62-65).***	Comprehensive post-construction monitoring validates predicted impacts, assesses mitigation effectiveness, and informs adaptive management. Standardised carcass searches, efficiency and persistence trials inform mortality data and statistical mortality estimation (e.g. GenEst). Continuous early-stage monitoring transitions to targeted long-term programs, with all data reported to regulators and shared to support cumulative impact assessment and adaptive learning. ***Reference: Sections 7 and 7.1 (p. 26), Appendix 4 (pp. 54-61).***
Queensland Framework Queensland Government Department of State Development, Infrastructure and Planning (Qld). 2025. **Planning Guideline. State Code 23: Wind farm development.**	N/A	The ecological assessment must be comprehensive, prepared by qualified experts, and follow the approved methodology. ***Reference: Section 4.2 (p. 13).***	Data collection involves multi-season desktop and field surveys to identify flora, fauna, and habitat linkages, using BACI designs for key species. Bird utilisation and bat activity surveys record abundance, flight height, and behaviour to support collision risk modelling, with additional species-specific studies for	Risk assessment links ecological findings to project layout and construction impacts, addressing both on-site and adjacent protected areas. Collision Risk Modelling is required for all threatened and high-flying species, integrating behavioural and turbine data to evaluate a range of scenarios and refine mitigation	Demonstrates how project design was modified to meet ecological standards and reduce collision risk. Bird and Bat Management Plans (BBMPs) outline species-specific mitigation, define triggers (e.g. shutdowns), integrate baseline data and modelling, establish operational mortality monitoring, and the use of emerging technologies. ***Reference: Section 4.2***	Operational monitoring includes two-season Bird Utilisation Surveys by qualified ecologists using BACI design to compare pre- and post-construction conditions. These assess ongoing site use by key species. ***Reference: Section 4.2 (p. 15), Appendix 2 (p. 41).***

Frameworks	Site Characterisation	Site Investigation – Planning	Site Investigation – Data Collection	Site Investigation – Risk Assessment	Final Risk Assessment (Likelihood)	Construction and Operation
			threatened or high-risk taxa. ***Reference: Section 4.2 (p. 13), Appendix 1 (pp. 38-39), Appendix 2 (pp. 40-42).***	strategies. ***Reference: Section 4.2 (pp. 13-14), Appendix 2 (p. 42).***	***(pp. 13-15), Appendix 2 (pp. 40-42).***	
Australian Offshore Framework Reid, K., Baker, G.B., Woehler, E. 2022. **Impacts on birds from offshore wind farms in Australia.** Department of Climate Change, Energy, the Environment and Water. Canberra.	Site characterisation identifies species presence and ecological context. It screens potential collision and displacement risks guiding survey design, proportionate baseline data collection and early mitigation planning for sensitive or high-risk species. ***Reference: Section 2.2 (pp. 22-23).***	Planning applies a coordinated, regional approach using radar, LiDAR, and camera systems to gather quantitative data for collision risk modelling. Sensitivity mapping and shared datasets support cumulative impact assessment, while multi-year, multi-scale studies are designed to identify bird taxa at risk from potential interactions to support site selection, behavioural analysis and evaluation of mitigations. ***Reference: Section 3 (pp. 33-34).***	Baseline data combine desktop reviews, site reconnaissance, and multi-method surveys (aerial, boat-based, radar, LiDAR, and tracking). These capture abundance, flight height, movement data (etc.) across full annual cycles. Cross-validation between technologies ensures species identification accuracy, producing comprehensive, comparable datasets for collision risk modelling. ***Reference: Section 2.3.1 (pp. 24-25), Section 2.3.2 (p. 26).***	Risk assessment applies a tiered CSIRO framework, progressing from qualitative to quantitative modelling to identify high-risk bird taxa. It integrates life-history and behavioural attributes to score collision and displacement susceptibility, using radar, tracking, camera data (etc.). The approach quantifies both mortality likelihood (macro to micro spatial scales) and population-level consequences. ***Reference: Section 1.1 (p. 7), Section 1.4 (pp. 12-15), Section 2.2 (p. 23), Section 2.3.2 (p. 25), Section 2.3.3 (pp. 26-27).***	Emphasises strategic siting to avoid high-density bird areas, supported by wildlife sensitivity mapping and large-scale distribution data. Collision risk modelling guides mitigation design, including turbine configuration, scheduling or automated curtailment during migrations (etc.); other measures may include visual or acoustic deterrents. Measures are refined through regular surveys and modelling to achieve acceptable collision risk levels. ***Reference: Section 2.4 (pp. 27-31).***	N/A
United States Framework U.S. Fish & Wildlife Service. 2012. **Land-based wind energy guidelines.**	Tier 1 involves a preliminary landscape-scale screening to identify ecologically sensitive areas and species of concern using existing spatial data and expert input. It directs development away from high-risk or legally constrained sites, assesses fragmentation risks, and determines whether	Tier 2 involves detailed site-specific characterisation using literature reviews, mapping, consultations, and expert field visits to verify species presence and habitat sensitivity. It informs collision risk understanding, identifies mitigation needs, and guides whether to proceed, adjust site design, or	Tier 3 introduces rigorous, quantitative field studies to document species distribution, abundance, and behaviour, addressing data gaps from earlier tiers. Studies use standardised, multi-season methods (e.g. acoustic monitoring, point counts, BACI design) to estimate exposure and refine risk	Risk is assessed through a weight-of-evidence approach combining site-specific exposure data with population and habitat context to estimate individual and population-level impacts. The framework also evaluates cumulative risks across projects, using shared datasets and expert consultation to compare	The tiered framework enables iterative, data-driven decision-making across project phases, refining risk understanding and guiding mitigation through adaptive management. Each tier supports go/no-go or modification decisions based on risk evidence. Best management practices address design, lighting, infrastructure placement, and decommissioning	Post-construction (Tier 4–5) studies validate predicted fatality rates through systematic carcass searches accounting for detection and scavenger biases. Monitoring spans at least one year across all seasons, with adaptive follow-up if impacts exceed predictions. Tier 5 studies investigate causes of higher-than-expected fatalities, test mitigation efficacy, and assess population-level effects using BACI or

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	further investigation or mitigation is required before progressing. ***Reference: Chapter 2 (pp. 12-13).***	advance to further investigation under Tier 3. ***Reference: Chapter 3 (pp. 14-18).***	predictions. Results inform site design, mitigation planning, and post-construction monitoring frameworks. ***Reference: Chapter 4 (pp. 19-33).***	relative risk and inform targeted mitigation design. ***Reference: Chapter 1 (p. 10).***	to minimise bird and bat collision and habitat risks throughout the project lifecycle. ***Reference: Chapter 1 (pp. 7-8), Chapter 7 (pp. 49-52).***	experimental designs. ***Reference: Chapter 5 (pp. 34-42), Chapter 6 (pp. 43-48).***
South Africa Bird Guideline Jenkins, A.R., van Rooyen, C.S., Smallie, J.J., Harrison, J.A., Diamond, J.A., Smit-Robinson, H.A., Ralston, S. 2015. **Birds and wind energy best-practice guidelines: best practice guidelines for assessing and monitoring the impact of wind-energy facilities on birds in southern Africa (3rd edition).**	Stage 1 scoping defines the study area, extending beyond the project footprint to encompass flight ranges and habitats of large birds of prey. It combines desktop review, short site visits, and stakeholder consultation to characterise habitats, identify key species and no-go areas, and estimate potential impacts to guide pre-construction monitoring design. ***Reference: 2.1 (pp. 15-18).***	Survey design prioritises threatened and impact-sensitive species, scaling effort to site sensitivity and using control sites for comparison. Scoping defines monitoring scope, mitigation options, and "no-go" areas. At least four surveys per annual cycle are recommended, with radar used for nocturnal or large-scale movements, ensuring data capture across varied conditions. ***Reference: Executive Summary (pp. 4-5), Section 2.1 (pp. 15-18).***	Stage 2 monitoring runs for at least 12 months to capture full seasonal variation, using BACI design with matched control sites. Surveys measure species richness, abundance, and flight behaviour through transects, point counts, vantage surveys, radar, and tracking. Data quantify flight activity within rotor-swept areas, identify nesting and wetland habitats, and establish baselines for impact prediction and mitigation design. ***Reference: Section 2.2 (pp. 19-36).***	Impact assessment compiles species occurrence, abundance, behaviour, and seasonality (etc.) to judge significance (including population and cumulative effects) and to guide layout, mitigation, or abandonment. Collision risk is indexed from vantage-point data or modelled (with assumptions stated), then validated post-construction to refine predictions. ***Reference: Section 2.2 (pp. 19-36).***	The framework applies a tiered, evidence-based process linking scoping, pre-construction, and post-construction stages. Final assessments integrate survey and modelling results to confirm mitigation adequacy, quantify realised impacts, and guide adaptive responses. All site data contribute to a central repository, enabling cumulative and landscape-scale avian risk evaluations. ***Reference: Executive Summary (pp. 4-5), Section 2 (p. 13).***	Construction and post-construction monitoring evaluate mitigation effectiveness, detect species disturbance, and quantify collision impacts. Programs include habitat mapping, abundance and movement surveys, and carcass searches adjusted for detection and scavenger bias. Monitoring begins at operation, continues for at least two years, and recurs at five-year intervals, with results informing adaptive management and updated mitigation measures. ***Reference: Section 2.3 (p. 37), Section 2.4 (pp. 38-47).***
South Africa Bat Guideline Aronson, J., Richardson, E., MacEwan, K., Jacobs, D., Marais, W., Taylor, P., Sowler, S., Hein, C., Richards, L. 2020. **South African good practice guidelines for operational monitoring for bats at wind energy facilities**	N/A	N/A	N/A	N/A	N/A	Operational monitoring combines acoustic surveys and carcass searches over at least two years (and periodically thereafter) to quantify bat fatalities and seasonal risk patterns. Standardised protocols use GenEst or Evidence of Absence models to correct biases and estimate fatalities per turbine or MW. Results trigger mitigation if thresholds are exceeded, with adaptive monitoring extended post-implementation to validate

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(2nd edition). South African Bat Assessment Association.						effectiveness. ***Reference: Section 1 (p. 3), Section 2 (pp. 4-11).***
European Commission European Commission (EC). 2020. **Guidance document on wind energy developments and EU nature legislation.** Publications Office of the European Union.	Early screening determines whether projects may significantly affect Natura 2000 sites, using existing data, expert judgement, and field checks. Strategic, spatial planning identifies low-risk areas and guides avoidance of sensitive habitats. Sensitivity mapping and ecosystem-based regional planning support early consultation and design adjustments to minimise ecological risks. ***Reference: 2.2.3.1 (pp. 22-23), Section 4 (pp. 44-51).***	Scoping defines baseline data needs through consultation among regulators, developers, and experts. Assessments cover all relevant habitats, species, and pathways, considering cumulative effects and whole lifecycle. Surveys may span 12–24 months to capture seasonal variation, with scope refined as information emerges. Data validity depends on recency. ***Reference: Section 3.2 (pp. 28-30).***	Baseline studies establish ecological context and population and habitat status. They combine desk-based reviews, reconnaissance visits, and targeted surveys to fill data gaps, ensuring comparability across project phases. For collision risk, standardised multi-method surveys (vantage point, acoustic, radar, thermal, tracking) are used for birds and bats, covering full annual cycles and relevant spatial scales (onshore and offshore). ***Reference: Section 3.3 (pp. 30-32), Section 5.3.1 (p. 63), Section 5.4.1 (pp. 73-74), Section 6.4.1 (pp. 101-102), Section 6.6.2.3 (pp. 123-124).***	Assesses the likelihood and significance of effects on Natura 2000 sites, considering magnitude, extent, duration, intensity, species vulnerability (etc.). Typical effects include habitat loss, disturbance, and collision risks or barrier effects. Cumulative impacts are evaluated. Uses evidence-based, precautionary, and proportionate methods with early coordination to define spatial and temporal scope. ***Reference: Section 3.1 (pp. 27-28), Section 3.4 (pp. 32-36).***	Applies a three-stage process: screening, detailed assessment of impacts on Natura 2000 sites, and, if unavoidable, compensatory measures. Uses precautionary principle: authorisation only when no reasonable scientific doubt of adverse effects. Integrates modelling (CRM, PVA, etc.) and empirical monitoring to evaluate collision and population risks. Mitigation hierarchy prioritises avoidance (siting, design), then minimisation (curtailment, deterrents). Thresholds and adaptive management link model outputs to observed data (e.g. GenEst estimates). ***Reference: Section 2.2.3 (pp. 19-21), Section 2.2.3.2 (pp. 23-24), Section 3.5 (pp. 36-39), Section 5 (pp. 54-57, 63-87), Section 6 (pp. 93-95, 101-107, 123-125).***	Monitoring ensures the scientific robustness of assessments and verifies mitigation effectiveness. Programmes must use standardised, statistically sound methods (preferably BACI) to detect significant effects and guide adaptive management. Continuous cycles of observation, evaluation, and adjustment maintain ecological safeguards. Multi-site data aggregation supports regional learning, while case studies (e.g. Spain, Germany, Netherlands) illustrate effective adaptive responses through curtailment, shutdowns, and cumulative-effects monitoring. ***Reference: Section 7 (pp. 126-133).***
IUCN Framework Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. 2021. **Mitigating biodiversity impacts associated with solar**	Emphasises early planning and landscape-scale screening to avoid high-risk sites. Site feasibility assessed using spatial and sensitivity mapping, stakeholder consultation, and biodiversity risk screening. Regional cumulative impacts	Field surveys validate desk-based assessments and address data gaps. Risk screening and sensitivity mapping define biodiversity sensitivities, produce a preliminary risk profile, and guide scoping of baseline surveys. Uses global and	Three survey types guide data collection: risk surveys (broad early assessments confirming biodiversity presence and avoidance opportunities), impact and mitigation surveys (targeted studies of priority species/habitats to assess	N/A	Applies the mitigation hierarchy through an iterative, adaptive process across all project phases (offshore and onshore). • Design phase: Use robust baseline data to	Monitoring must evaluate mitigation effectiveness and inform adaptive management. Indicators span: • Biodiversity state. • Impact pressures (mortality).

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and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.	addressed via strategic planning and population-level modelling. Early scoping defines project-specific objectives and efficient survey design, ensuring site selection and planning minimise biodiversity impacts. ***Reference: Section 2.4 (pp. 12-13), Section 3 (pp. 19-35), Section 8 (pp. 139-143).***	regional biodiversity databases and expert input. Environmental Impact Assessment follows these stages to predict impacts, refine mitigation and monitoring, and ensure stakeholder engagement. ***Reference: Section 2.4 (pp. 12-13), Section 3 (pp. 19-35).***	impacts and residuals), and baseline monitoring surveys (pre-impact benchmarks with repeatable design and control sites). Monitoring effort must match risk level; standardised regional monitoring and transparent data sharing are encouraged to support cumulative impact assessment and improve mitigation effectiveness. ***Reference: Section 8 (pp. 139-143).***		guide micro-siting, layout, etc. • Construction phase: Schedule to avoid sensitive periods; apply abatement and operational controls. • Operation phase: Implement shutdowns (scheduled/on-demand), curtailment (e.g. higher cut-in speeds for bats), and deterrents (visual/acoustic). ***Reference: Executive Summary, Section 2 (pp. 7-15), Section 5 (pp. 61-84), Section 6 (pp. 85-126).***	• Mitigation responses/thresholds. Onshore: conduct carcass searches, correct for biases. Use GenEst for standard estimation or Evidence of Absence for rare detections. Offshore: use vibration or thermal infrared sensors, as carcass recovery is impossible. Monitoring must yield defensible fatality estimates to assess compliance and adapt turbine operations accordingly. ***Reference: Section 8 (pp. 139-144).***
IFC Framework International Finance Corporation (IFC). 2023. **Post-construction bird and bat fatality monitoring for onshore wind energy facilities in emerging market countries. Good practice handbook and decision support tool.**	N/A	N/A	N/A	N/A	N/A	Implements post-construction fatality monitoring (PCFM) to quantify bird and bat mortality and guide adaptive management. Minimum 3-year monitoring with bias correction (searcher efficiency, carcass persistence, area searched). Use GenEst or Evidence of Absence for estimates. Results reviewed at least annually against thresholds; mitigation (e.g. shutdowns, curtailment, deterrents) adjusted as needed. Findings reported to regulators and stakeholders. ***Reference: Section 3 (pp. 14-39), Section 5 (pp. 62-71), Section 6 (pp. 72-87).***
Dutch Framework	N/A	N/A	N/A	Uses established collision risk modelling (historically the deterministic	Applies a three-stage modelling analysis: (1) collision mortality per farm (for	Uncertainties remain in species-specific avoidance rates, nocturnal activity, and flight-height

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IJntema, G.J., Heida, N., Leemans, J.J., Gymesi, A., Potiek, A. 2025. **Collision effects of North Sea wind turbines on bird species within the 'Kadar Ecologie & Cumulatie (KEC) 5.0."** Report 24-163. Waardenburg Ecology. Culemborg.				SNH CRM and stochastic sCRM). For each target species, the model estimates per-turbine collision risk and multiplies it by monthly transits across the wind farm, then sums across the year to derive annual collision estimates. ***Reference: Section 2.1 (pp. 11-22).***	migratory and local seabirds), (2) cumulative mortality across multiple wind farm scenarios, and (3) population-level effects tested against Acceptable Levels of Impact (ALI). Uses R Package StochLAB to estimate collision victims, and population models via R Package KEC4pop-models to project long-term demographic impacts. Analyses use ALIs over 40 years running 100,000 replicates of unimpacted versus impacted scenarios. ***Reference: Summary (pp. 6-7), Section 2 (pp. 9-25).***	distributions, which influence collision estimates. Future work should integrate GPS-logger data for better behavioural parameters, replace static densities with probabilistic flux models, and incorporate actual construction / decommissioning timelines rather than assuming continuous operation. Integrated population models are recommended to combine collision, habitat loss, and external pressures (e.g. climate change). ***Reference: Section 6.3 (pp. 66-69).***